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

WATER RESOURCES OF THE ARROYO GRANDE - NIPOMO MESA AREA

SOUTHERN DISTRICT REPORT 2002

Gray Davis
Governor
State of California

Mary D. Nichols
Secretary for Resources
The Resources Agency

Thomas M. Hannigan
Director
Department of Water Resources

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

WATER RESOURCES OF THE ARROYO GRANDE - NIPOMO MESA AREA

SOUTHERN DISTRICT REPORT 2002

Copies of the report, either paper or CD, are available at the cost of production. Send requests to:

California Department of Water Resources
Southern District
770 Fairmont Avenue, Suite 102
Glendale, California 91203-1035

The report is also available online at:
http://wwwdpla.water.ca.gov/sd/

This Page Intentionally Blank

FOREWORD

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 within San Luis Obispo County. 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.

Mark Stuart, Acting Chief
Southern District
Department of Water Resources

TABLE OF CONTENTS

APPENDIXES

TABLES

FIGURES

PLATES
(At back of report)

ADDENDUM
(At back of report)

Division of Planning and Local Assistance

Naser J. Bateni . . . . Chief

Southern District

Mark Stuart . . . . Acting Chief
Charles R. White . . . . Chief[1]
Ahmad A. Hassan, Ph. D. . . . . Chief, Resources Assessment Branch[2]

This report was prepared by

Michael Maisner . . . . Engineer, Water Resources[3]
Evelyn Tompkins . . . . Senior Engineering Geologist

Contributions to Water Quality Chapter by

Harry Iwanaga . . . . Senior Engineering Geologist, Retired Annuitant

Program Manager for the study

Vern Knoop . . . . Senior Engineer, Water Resources

With assistance from

Linda Inouye . . . . Office Technician
Richard Lewy . . . . Engineering Geologist

Editing by

Phyllis J. Yates . . . . Research Writer

[1]Retired December 31, 2001

[2]Retired December 31, 1996

[3]Resigned February 19, 2002

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:

Doug Bird *Tony Boyd*
Glen Britton *Percy Garcia*
George Gibson *Paul Hilliard*
Craig Kesler *Dana Lilly*
Susan Litteral *Timothy Nanson*
Glen Priddy
San Luis Obispo County
Department of Public Works

John Mackenzie *Nancy Rollman*
Eric N. Wier
San Luis Obispo County
Department Of Planning and Building
Environmental Division

Bradford Seek
San Luis Obispo County Health Agency
Division of Environmental Health

Albert Ducusin *Avelino Lampitoc*
Shane Taylor *John Wallace*
City of Arroyo Grande

Jim Ashcraft *Dennis Delzeit*
Tina Grietens *Stuart Stewart*
City of Pismo Beach

Douglas Jones
Nipomo Community Services District

Philip Davis *Cindy J. Winter*
Oceano Community Services District

Roger Brett *Henrick Szopinski*
California Cities Water Company

Charles M. Baker
Rural Water Company, Inc.

Stewart Johnston
Santa Maria Water Conservation District

C. H. "Chuck" Ellison
South San Luis Obispo County Sanitation District,
Water Pollution Control Plant

Don Asquith
Envirocom, Inc.

Tim Cleath
Cleath & Associates

R. J. (Jim) Garing *Rusty Garing*
Garing, Taylor & Associates, Inc.

Barry Hecht
Balance Hydrologics, Inc.

John Jenks
Kennedy/Jenks Consultants

Richard C. Slade *Linda Smith*
Tim Warmon
Richard C. Slade & Associates LLC

John Synder
Koch California Ltd.

James O. Anderson *Gonzalo Garcia*
Tosco (Formerly Unocal 76 Products Company)

Charles Wells
Floyd V. Wells Drilling

Guadalupe Cooling Company

Santa Barbara County Public Works Department,
Water Resources Division

U. S. Geological Survey

California Department of Health Services

California Department of Finance

California Department of Conservation, Division of
Oil, Gas, and Geothermal Resources

This Page Intentionally Blank

EXECUTIVE SUMMARY

The objective of this study was to gain additional knowledge of the water resources within the Arroyo Grande - Nipomo Mesa area in San Luis Obispo County (Plate ES1). The Department of Water Resources conducted the study under an agreement with the San Luis Obispo County Flood Control and Water Conservation District to update the Department's 1979 report "Ground Water in the Arroyo Grande Area."[1]

San Luis Obispo County delineated the study area for the new investigation, setting the southern study area boundary at the Santa Barbara/San Luis Obispo County line. The study area encompasses 184 square miles (117,940 acres) within San Luis Obispo County and includes part of the watershed of Pismo Creek, the watersheds of Arroyo Grande and Nipomo Creeks, and that portion of the watershed of Santa Maria River within the county. It lies within the following hydrologic (watershed) areas and subareas:[2] Pismo Hydrologic Subarea (HSA) containing Pismo Creek watershed, Oceano HSA drained by Arroyo Grande Creek and its tributaries, Nipomo Mesa HSA containing Black Lake Canyon and Black Lake, and Guadalupe Hydrologic Area (HA) drained by Nipomo Creek and the Santa Maria River.

Underlying part of the study area is a portion of the Santa Maria Groundwater Basin, which extends into Santa Barbara County.[3] The basin consists of the main basin, Santa Maria, lying between the Pacific Ocean and Wilmar Avenue fault, and three subbasins-- Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley, which extend north and east of the Wilmar Avenue fault (Plate ES1).

The data assembled from various sources for this study are for the period of record through water year 2000 (October 1, 1999-September 30, 2000), except for water demand and supply data. The determination of water demand and supply and groundwater inflow and outflow was for the

---

[1]The agreement for the three-year study with San Luis Obispo County was executed in September 1993. The agreement stipulated that as soon as practical, after execution of the agreement, the Department commence work on the investigation. The Department began work in January 1996 and provided San Luis Obispo County with a draft report in April 1998, a second draft report in January 1999, and a final draft report in January 2000. Only the January 2000 report received widespread review and comment.

[2]Hydrologic Area and Hydrologic Subarea are the hierarchical nomenclature of watershed divisions in California. HSA is a subdivision of a HA. The hydrologic boundary for Nipomo Mesa HSA was field checked for this study.

[3]The results of this study are valid for the portion of the Santa Maria Groundwater Basin within San Luis Obispo County. No existing published investigations of the Santa Maria Basin analyzed the basin in its entirety within both San Luis Obispo and Santa Barbara Counties.

study period. The study period begins with water year 1975, the last year of data for the Department's 1979 investigation, and ends with water year 1995, the last year of the hydrologic base period. The hydrologic base period, which represents long-term average hydrologic conditions, was determined to be water years 1984 through 1995.

Because of the study area's size and differences in hydrologic and topographic characteristics and to provide applicable information for San Luis Obispo County, the Santa Maria Groundwater Basin and the portions of the study area outside the basin were divided and evaluated based on the hydrologic boundaries (Plate ES1). The divisions of the main Santa Maria Basin are: (1) the Tri-Cities Mesa - Arroyo Grande Plain portion that includes the lower Pismo Creek portion of the basin lying within Pismo HSA and the Tri-Cities Mesa, Arroyo Grande Plain, and Los Berros Creek portions of the basin lying within Oceano HSA; (2) the Nipomo Mesa portion of the basin, lying entirely within Nipomo Mesa HSA; and (3) the Santa Maria Valley portion of the basin, lying within Guadalupe HA.[4] The subbasins were evaluated within their respective hydrologic area or subarea: Arroyo Grande Valley Subbasin, lying within Oceano HSA; Pismo Creek Valley Subbasin, within Pismo HSA; and Nipomo Valley Subbasin, within Guadalupe HA. Those remaining portions of the study area outside the groundwater basin were also evaluated within their respective hydrologic area or subarea.

The knowledge of the water resources within the study area gained in this investigation is summarized below.

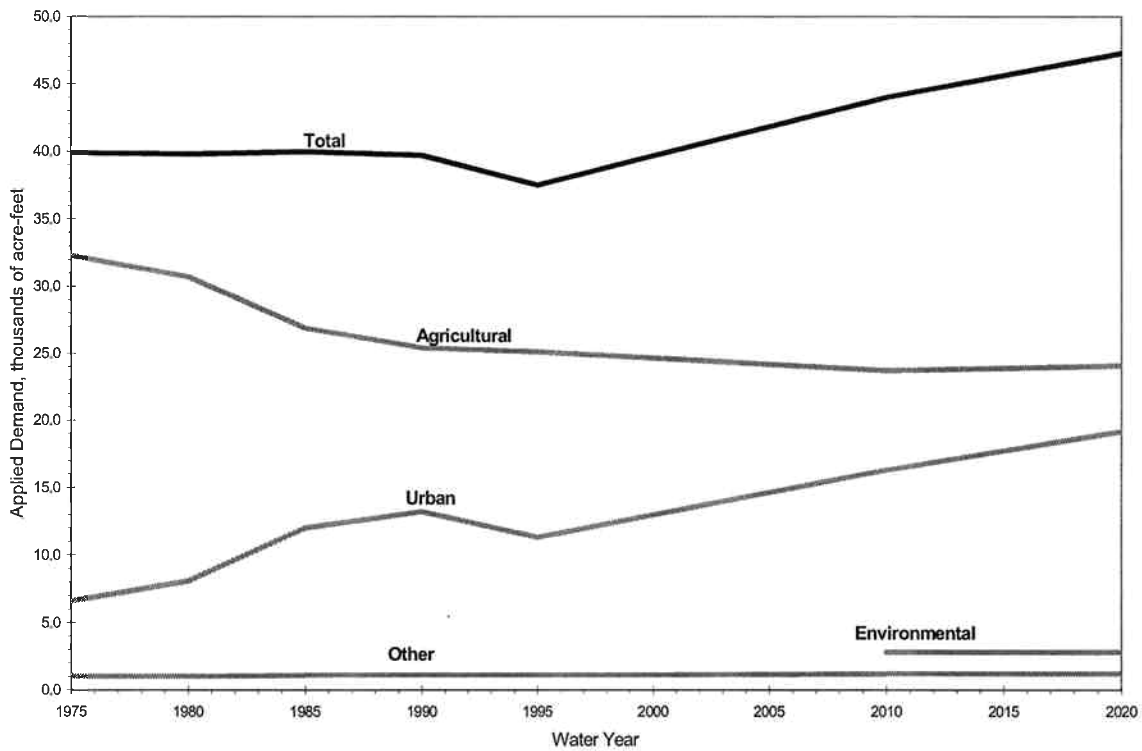
Water Demand

Within the study area, total applied water demand decreased by 2,400 acre-feet (AF) from 39,900 AF in 1975 to 37,500 AF in 1995 (Figure ES1). The decrease includes demand reduction achievable through implementing water conservation programs. Agricultural demand constituted the largest demand, accounting for about 70 percent, or 25,100 AF, of the 1995 total demand. Most of the rest of the demand was for urban uses, estimated to be 11,300 AF in 1995 for an estimated population of about 62,000. Conveyance losses, cooling, miscellaneous, and recreational demands used about 1,100 AF in 1995.

Year 2020 total applied water demand is projected to be 47,300 AF, an increase of about 9,800 AF more than 1995 amounts. The increase in total applied demand from 1995 to 2020 is attributable to increased urban and environmental demand. Year 2020 urban applied water demand is expected to increase to 19,200 AF for an estimated population of 98,740. Environmental demand, estimated at 2,800 AF, was identified for maintaining steelhead habitat on Arroyo Grande Creek for 2010 and 2020. Projections are that the demand for agriculture will decline to 24,100 AF by 2020, and will account for only about 50 percent of the total demand.

[4]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 ES2 - APPLIED WATER DEMAND WITHIN STUDY AREA



Conveyance losses, cooling, miscellaneous, and recreational demands were projected to increase to about 1,200 AF in 2020.

Total applied water demand overlying the main Santa Maria Groundwater Basin increased about 12 percent between 1975 and 1995 and by 2020 demand was projected to be 36,200AF, an increase of about 30 percent over the 1995 total demand of 27,500 AF.

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 recycled water.

Total water supply in the study area decreased by 2,500 AF, from 40,100 AF in 1975 to 37,600 AF in 1995, because of decreased groundwater extractions. Year 2020 water supply is expected to increase 9,700 AF over 1995 levels with the additional water supply coming from increased groundwater extractions, State Water Project deliveries, environmental releases from Lopez Reservoir, and recycled water. Supplies appear adequate to meet water demands through water year 2020.

Total groundwater supply (extractions) in the study area decreased by 4,600 AF, from 34,800 AF in 1975 to 30,200 AF in 1995, but year 2020 groundwater extractions are expected to increase 4,700 AF over 1995 levels.

Santa Maria Groundwater Basin

The Santa Maria Groundwater Basin underlies more than 280 square miles (181,790 acres) in the southwestern corner of San Luis Obispo County and the northwestern corner of Santa Barbara County. This study considered only the portion of the groundwater basin within San Luis Obispo County, about 61,220 acres (Plates ES1). Within the study area, the main Santa Maria Basin underlies about 49,910 acres; Arroyo Grande Valley Subbasin, 3,860 acres; Pismo Creek Valley Subbasin, 1,220 acres; and Nipomo Valley Subbasin, 6,230 acres. Both the surface area and the underlying permeable sediments form the basin.

The boundaries of the Santa Maria Basin were delineated based on mapped surface limits of Quaternary deposits and the Wilmar Avenue fault. The boundaries represent the surface expression of the basin and do not imply that the boundaries extend vertically downward in a third dimension. Arbitrary boundaries for the basin are eliminated by using mapped surface geologic contacts and faults.[5]

Within San Luis Obispo County, the main Santa Maria Basin is bounded on the north and east by the Wilmar Avenue fault, separating it from Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley Subbasins. The western boundary of the basin is 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.

The Arroyo Grande Valley Subbasin is bounded by the alluvial contact with older geologic units between Lopez Dam and the Wilmar Avenue fault. The Pismo Creek Valley Subbasin is bounded by the alluvial contact with older geologic units between the southern boundary of Edna Basin, where bedrock narrows the creek channel, and the Wilmar Avenue fault. The Nipomo Valley Subbasin is bounded on the north and east mainly by the contact of the older alluvium and Orcutt Formation with older geologic units and is separated from the main basin on the west by the Wilmar Avenue fault. The southern boundary of the subbasin, which is the watershed boundary for Nipomo Creek, is the study area boundary.

The potentially water-bearing sediments of the groundwater basin are underlain by bedrock. The bedrock base of the groundwater basin is vertically displaced across the Oceano, Santa Maria River, and Wilmar Avenue faults.

---

[5]Boundaries for the Santa Maria Basin in existing published studies are not based on mapped geologic contacts and faults and are arbitrary.

Groundwater occurs within the pore spaces in the semi-consolidated to unconsolidated sediments filling the basin to a maximum thickness of about 1,600 feet under the Santa Maria River. In the main groundwater basin, these deposits include the Squire Member of the Pismo Formation; the Careaga, Paso Robles, and Orcutt Formations; alluvium; and dune sands.[6] These sediments consist of discontinuous sedimentary layers or lenses of varying composition, texture, and thickness, ranging from clays to boulders.

The main groundwater basin is considered a composite aquifer system of unconfined conditions, with localized semi-confined to confined conditions and perched zones. Discontinuous clayey layers separate the multiple aquifer zones. The most productive and developed aquifers are in the alluvium and Paso Robles Formation. Aquifers in the Squire Member of the Pismo Formation and the Careaga Formation have, over time, become more important.

In Arroyo Grande Valley and Pismo Creek Valley Subbasins, groundwater occurs in the alluvium, ranging in thickness from negligible to a maximum of about 175 feet in Arroyo Grande Valley Subbasin. Groundwater is mainly unconfined. In some parts of the subbasins, the alluvium may be saturated only during rainfall.

In Nipomo Valley Subbasin, groundwater occurs in the older alluvium, which covers the floor of the valley up to about 90 feet thick, thinning to negligible thickness toward the eastern edges of the subbasin. Groundwater in the older alluvium is unconfined with local semi-perched conditions. The older alluvium stores a notable amount of groundwater and continues to supply some wells, although the older alluvium may be saturated only during rainfall at the eastern edges of the subbasin. The bedrock formations underlying the older alluvium have, over time, become a more important source of groundwater supply in Nipomo Valley Subbasin.

Both natural and incidental sources recharge groundwater in the main Santa Maria Basin. Stream infiltration, deep percolation of direct precipitation, and subsurface inflow are sources of natural recharge. Incidental recharge to the basin includes deep percolation of urban and agricultural return water, treated wastewater returns, and septic tank effluent.

Stream infiltration from Arroyo Grande Creek, regulated by Lopez Dam since 1969, and from unregulated Pismo Creek recharges the Tri-Cities Mesa - Arroyo Grande Plain portion of the main groundwater basin. Stream infiltration from Santa Maria River, regulated in part by Twitchell Dam since 1958, recharges the Santa Maria Valley portion of the main basin. The amount of recharge is related to the availability of streamflow.

Recharge to the groundwater basin by deep percolation of direct precipitation is intermittent, 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

[6]The Pismo and Careaga Formations are found only within their respective geologic depositional basins--the Pismo Formation within the Pismo Basin and the Careaga Formation within the Santa Maria Basin, separated in the study area by the Santa Maria River fault.

factors. Because no surface waters flow into Nipomo Mesa, deep percolation of direct precipitation is the major source of natural recharge.

Subsurface inflows from Arroyo Grande Valley and Pismo Creek Valley Subbasins and the adjoining San Luis Range recharge the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin. Arroyo Grande Plain is also recharged by subsurface inflow from the Nipomo Mesa portion of the basin. The Nipomo Mesa portion of the basin may be recharged by subsurface inflow from the adjoining Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown. In addition, Nipomo Mesa may be recharged by subsurface inflow from the Santa Maria Valley portion of the basin within San Luis Obispo County.[7] The Santa Maria Valley portion of the basin within the study area is recharged by subsurface inflow from the upstream part of the groundwater basin, outside the study area, and may also be recharged by subsurface inflow from the southern end of Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Groundwater is discharged from the main basin by extractions from wells, subsurface flow to the ocean, evapotranspiration losses, rising water, springflow, percolation into the underlying bedrock, and diffuse upward leakage at the Dune and Oso Flaco Lakes

In Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley Subbasins, groundwater is recharged by stream infiltration from surface flows in their respective creeks and tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, subsurface flows from the San Luis Range into Arroyo Grande Valley and Pismo Creek Valley Subbasins, subsurface flow from Edna Basin into Pismo Creek Valley Subbasin, and subsurface flow from Temattate Ridge into Nipomo Valley Subbasin. Discharge from the subbasins consists of surface and subsurface outflow to the main Santa Maria Groundwater Basin, evapotranspiration losses, and extractions from wells.

Groundwater elevation contours in the springs of 1975, 1985, 1995, and 2000 revealed that groundwater of the principal water body moved seaward to the Pacific Ocean in a generally westerly or west-northwesterly direction.[8] Coastal groundwater elevations were above mean sea level (msl) and subsurface outflow from the basin to the ocean was occurring, apparently precluding any sea water intrusion along the coast. Within the main groundwater basin,

---

[7]Subsurface flow from Santa Maria Valley into Nipomo Mesa will occur whenever the groundwater elevations beneath Nipomo Mesa are below those of Santa Maria Valley, altering the hydraulic gradient and direction of flow.

[8]Most of the wells are perforated continuously in multiple aquifers. Thus, groundwater elevations do not reflect a single aquifer, but represent the surface of the principal groundwater body. Perched groundwater levels were not considered. Locations of wells monitored for groundwater levels were from field descriptions of the locations as plotted on USGS 7.5-minute quadrangles and reference elevations were approximated using either the 7.5-minute quadrangles or digital aerial surveys at five- or two-foot contour intervals, where the surveys were available. In 2000, San Luis Obispo County located wells in their monitoring program using GPS (Global Positioning System). Unrectifiable problems with the GPS data resulted in erroneous well locations and elevations and thus could not be used in this study.

groundwater flows from northern Nipomo Mesa to Arroyo Grande Plain. Groundwater flows southwesterly in Arroyo Grande Valley and Nipomo Valley Subbasins.[9]

In spring 1995, enlargement of a pumping depression in the south-central part of Nipomo Mesa locally 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. With the significant recharge from the record rainfall of water year 1998, the magnitude of the depression lessened.

The magnitude of the depression is not well defined because wells with groundwater level data are limited and reference elevations for all wells were not surveyed. The dynamics of the groundwater system (transmitting properties of the aquifers and potential boundary conditions, such as the Santa Maria River fault) in this part of the basin likely affect development of pumping depressions, which have been documented on the mesa since 1965. In addition, pumpage is concentrated in this part of the mesa. Furthermore, the lateral extent of the depression will fluctuate depending on hydrologic conditions, amount of groundwater extractions in the area, and dynamics of the groundwater system, as the basin continuously seeks a new equilibrium. Subsurface flow from Santa Maria Valley into Nipomo Mesa will occur whenever groundwater elevations beneath the mesa are below those of the valley, altering the hydraulic gradient and direction of flow.

It is conjectural whether, in the future, sea water intrusion will threaten because of the pumping depressions in Nipomo Mesa. Sea water will intrude when the freshwater head is insufficient to counterbalance the greater density of sea water, even when the freshwater head is above msl.

Within the Santa Maria Basin, faults displace the water-bearing sediments, namely the Squire Member of the Pismo Formation and the Careaga and Paso Robles Formations. The Santa Maria River fault may affect groundwater flow in parts of the basin. Significant differences are found in groundwater elevations on opposite sides of the fault from near Highway 1 along the edge of Nipomo Mesa to about a mile east of Zenon Way (Plate ES1) and the fault appears to be a barrier or impediment to groundwater flow in the formations below the older dune sands. However, groundwater levels are in the older dune sands on the northerly side of the fault and groundwater may be able to cascade over the fault along this segment. Along other segments of the fault, determining the impact of the fault on groundwater flow with the available data was not possible.

With the available data, it could not be determined if the Oceano fault affects groundwater flow. Because the basin-fill deposits are the same on opposite sides of the fault and have similar hydraulic properties, the fault may have no impact.

The Wilmar Avenue fault does not affect groundwater flow in the alluvium from Arroyo Grande Valley and Pismo Creek Valley Subbasins to the main groundwater basin, but data were not available to determine whether the fault impacts subsurface flow from Nipomo Valley Subbasin

[9]Groundwater levels in wells in the Pismo Creek Valley Subbasin are not monitored by the county; therefore, no data were available to determine groundwater elevations.

into the main groundwater basin.

Groundwater levels in wells fluctuate over time representing the continuous adjustment of groundwater in storage to changes in recharge and discharge. Groundwater level measurements from wells over their period of record through 2000 were analyzed to determine their net changes over time.[10]

In the Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley portions of the main Santa Maria Basin and the Arroyo Grande Valley and Nipomo Valley Subbasins, the long-term fluctuations in water levels in wells reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term.

In some parts of the Nipomo Mesa portion of the basin (the part between the Santa Maria River fault and the Oceano fault and the part north of the Santa Maria River fault around El Campo Road-- Plate ES1), the volume of groundwater withdrawn has increased over time and is reflected in the declining trends in groundwater levels in some wells,[11] despite periods of 40 percent above average precipitation. In those parts of the basin, concentrated pumpage, the dynamics of the groundwater system, and sources of recharge influence groundwater level trends. The localized declines in groundwater levels reflect decreases in estimated amounts of groundwater in storage between 1975 and 1995. If declines in groundwater levels continue in the future and expand to additional parts of the basin, the groundwater resources of the basin could be threatened by sea water intrusion. However, in other parts of Nipomo Mesa, the long-term fluctuations in water levels in wells reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term.

Specific yield of the Santa Maria Basin, a measure of the ability of aquifers in the basin to supply groundwater, ranges from 3 to 21 percent, with a median value of 12 percent. Values varied the most in the Nipomo Mesa portion of the basin, ranging from 6 to 18 percent, and Arroyo Grande Valley Subbasin, ranging from 9 to 21 percent. The median specific yield value for wells north of the Santa Maria River fault was two percent lower than for the wells southerly of the Oceano fault. Storativity calculated from aquifer test analyses ranged from 0.001 to 0.0001.

Amounts of groundwater in storage in the basin, both above and below msl, were estimated for the water years 1975, 1985, 1995, and 2000 from the volume of saturated sediments in the groundwater basin and the specific yield of those saturated sediments ("specific yield method").[12] Figure ES2 shows the estimated amounts of groundwater in storage above msl. The amount in storage above msl is important, because of the need to protect this coastal basin from sea water intrusion.

---

[10]Groundwater level monitoring data were not available for Pismo Creek Valley Subbasin.

[11]Declining water levels in wells can lead to increased pumping costs, localized well interference, loss of production capacity, and possible quality degradation.

[12]Water level data were not available to estimate an amount of groundwater in storage in Pismo Creek Valley Subbasin.

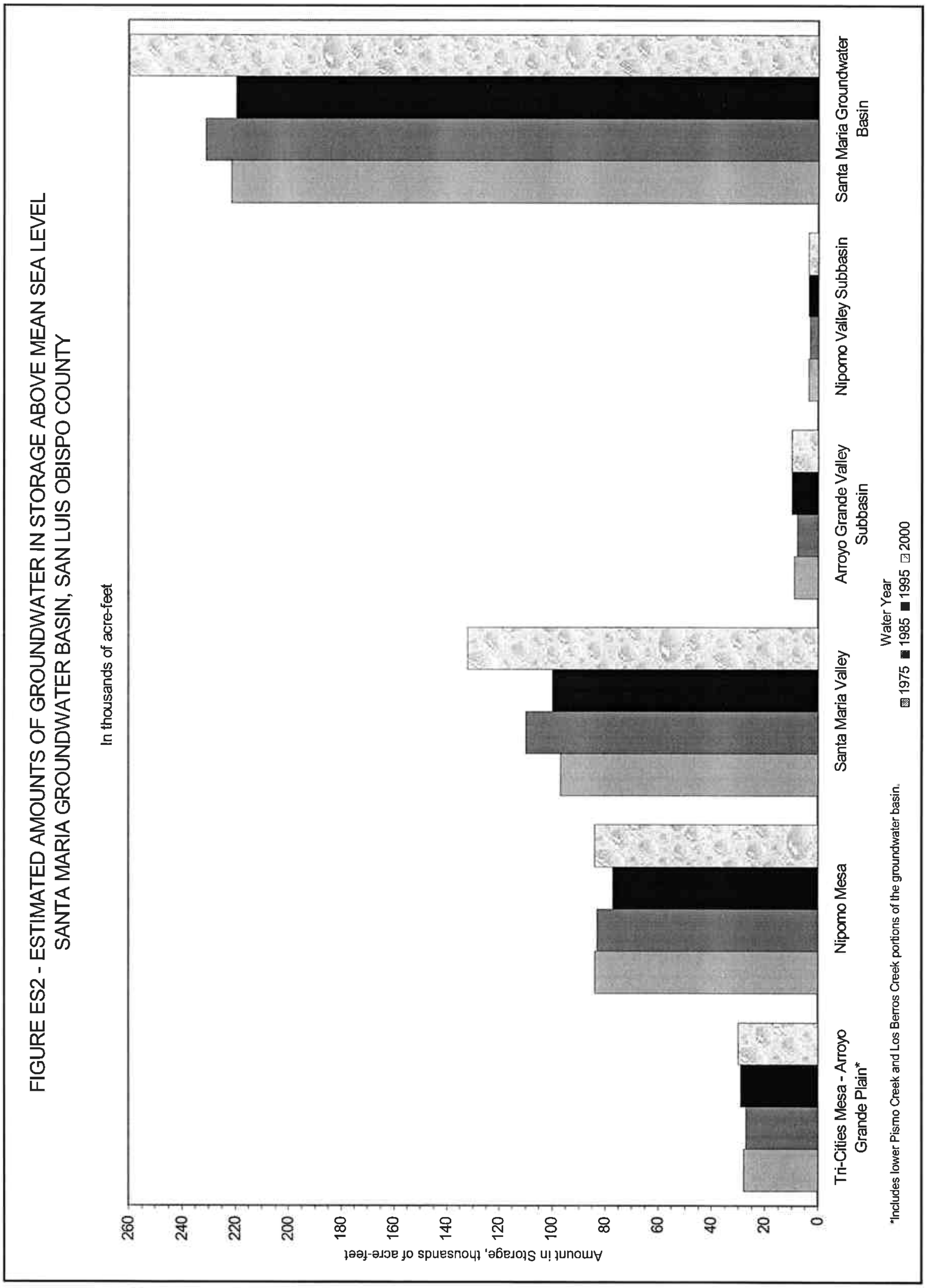


FIGURE ES2 - ESTIMATED AMOUNTS OF GROUNDWATER IN STORAGE ABOVE MEAN SEA LEVEL
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY

In the Santa Maria Groundwater Basin within San Luis Obispo County, the estimated amount of groundwater in storage in 1995, both above and below msl, was about 3.4 million AF, of which only about seven percent, or approximately 220,000 AF, was above msl. This amount is about 2,000 AF less than the amount in storage in 1975.

For the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin, the estimated amount of groundwater in storage above msl for 1975, 1985, and 1995 was almost the same, 27,000 to 29,000 AF. In this portion of the basin, the amount of groundwater in storage, between 1975 and 1985, declined 1,000 AF and between 1985 and 1995, increased 2,000 AF. The changes in storage coincide with hydrologic conditions, 1985 a dry year and 1995 a wet year.

In the Nipomo Mesa portion of the basin, the amount of groundwater in storage above msl in 1995 was estimated to be 77,000 AF. The 1995 amount above msl is about eight percent less (6,000 AF) than the amount in storage above msl in 1985. Because Nipomo Mesa's major source of recharge is deep percolation of precipitation, the loss in storage reflects variations in hydrologic conditions. The average rainfall during the period from water year 1985 through water year 1995 was about two inches less than the average rainfall during the period from water year 1975 through water year 1985. Also, the loss is primarily associated with those areas of pumping depressions and declining trends found in groundwater levels in some wells in parts of the mesa. As mentioned earlier, the magnitude of the depression in the south-central part of the mesa is not well defined because wells with groundwater level data are limited and reference elevations for all wells were not surveyed. The mesa also showed a small decline in storage above msl of 1,000 AF between 1975 and 1985.

In the Santa Maria Valley portion of the basin, the amount of groundwater in storage above msl in 1995 was estimated to be 100,000 AF. This amount is 3,000 AF more than the amount estimated to be in storage in 1975. In 1985, the valley was estimated to have 110,000 AF of groundwater in storage above msl, 13,000 AF more than in 1975, because of the 1983 wet year and substantial stream infiltration from the Santa Maria River that year and from Twitchell Reservoir releases in 1984. Stream infiltration from the Santa Maria River in the 1995 wet year was not yet fully reflected in groundwater elevations in the valley that year. Based on the trend in groundwater elevations, the amount in storage increased in the succeeding years as the recharge mound traveled away from the river. Part of the change in storage from 1985 to 1995 in Santa Maria Valley reflects movement of groundwater from the valley into Nipomo Mesa.

Arroyo Grande Valley Subbasin was estimated to have 8,000 to 10,000 AF of groundwater in storage in the alluvium and Nipomo Valley Subbasin, 3,100 to 3,700 AF of groundwater in storage in the older alluvium and Orcutt Formation. Both subbasins had losses in storage in the 1985 dry year and small gains in storage in the wet year 1995.

Because of the very wet year 1998, the estimated amount of groundwater in storage above msl in the basin in 2000 was 40,000 AF more than the 1995 amount and about 38,000 AF more than the 1975 amount. Estimated amounts above msl in the basin were: 30,000 AF in the Tri-Cities Mesa - Arroyo Grande portion of the basin, 84,000 AF in the Nipomo Mesa portion of the basin (this is the same amount as in 1975 despite the continued presence of the pumping depression in the south-central part on the mesa), 132,000 AF in the Santa Maria Valley portion of the basin, 10,000 AF in Arroyo Grande Valley Subbasin, and 3,700 AF in Nipomo Valley Subbasin.

In the Santa Maria Groundwater Basin, a dynamic balance exists between recharge and discharge, as the basin continuously seeks a new equilibrium. Changes in the amount of groundwater in storage are the response of the basin to variations in hydrologic conditions and recharge and discharge and to changes in land and water uses within the basin. To protect the basin from sea water intrusion, it is important that the amount of groundwater in storage in the basin be of sufficient quantity for the freshwater head to counterbalance the greater density of sea water and subsurface outflow to the ocean to occur.

Hydraulic conductivity and transmissivity quantify the rate at which groundwater flows. The highest hydraulic conductivity values, ranging from less than 100 up to about 7,000 gallons per day per foot squared, are generally found in the alluvium. Hydraulic conductivity for the Paso Robles Formation ranged from 1 to almost 3,000 gallons per day per foot squared. Lower conductivity values are generally found in the oldest formations--the Careaga Formation and the Squire Member of the Pismo Formation, ranging from 1 to about 300 gallons per day per foot squared. Also, lower values of conductivity tended to be found for the basin deposits north of the Santa Maria River fault underlying Nipomo Mesa.

Aquifer transmissivities of the basin were found to range over several orders of magnitude, from 100 to more than 400,000 gallons per day per foot. Transmissivity values of the alluvial aquifers in Santa Maria Valley were the highest, ranging from 200,000 to 400,000 gallons per day per foot. Transmissivity values of the Paso Robles Formation ranged from 100 to 160,000 gallons per day per foot, with the higher values found south of the Oceano fault, in both the Nipomo Mesa and Santa Maria Valley parts of the basin. Transmissivity of the Squire Member in the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin ranged from about 3,000 to 30,000 gallons per day per foot. The Careaga Formation had transmissivity values similar to those for the Paso Robles Formation. The lowest transmissivity values were typically found in the Nipomo Mesa part of the basin, north of the Santa Maria River fault, where values ranged from 100 to about 4,000 gallons per day per foot.

Amounts of subsurface flows out of, into and within the groundwater basin were estimated for water years 1975, 1985, and 1995 of the study period. Because hydraulic conductivity of the deposits ranges over several orders of magnitude, low, high, and geometric mean[13] subsurface flow amounts were estimated. Figure ES3 illustrates water year 1995 subsurface flow estimates.

The largest estimated amounts of subsurface outflow to the Pacific Ocean are from Santa Maria Valley, where the depth of the basin is greatest and the alluvium has high values of hydraulic conductivity. The estimated mean amount was about 6,000 AF in 1995 and also in 1975, and

[13] 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.

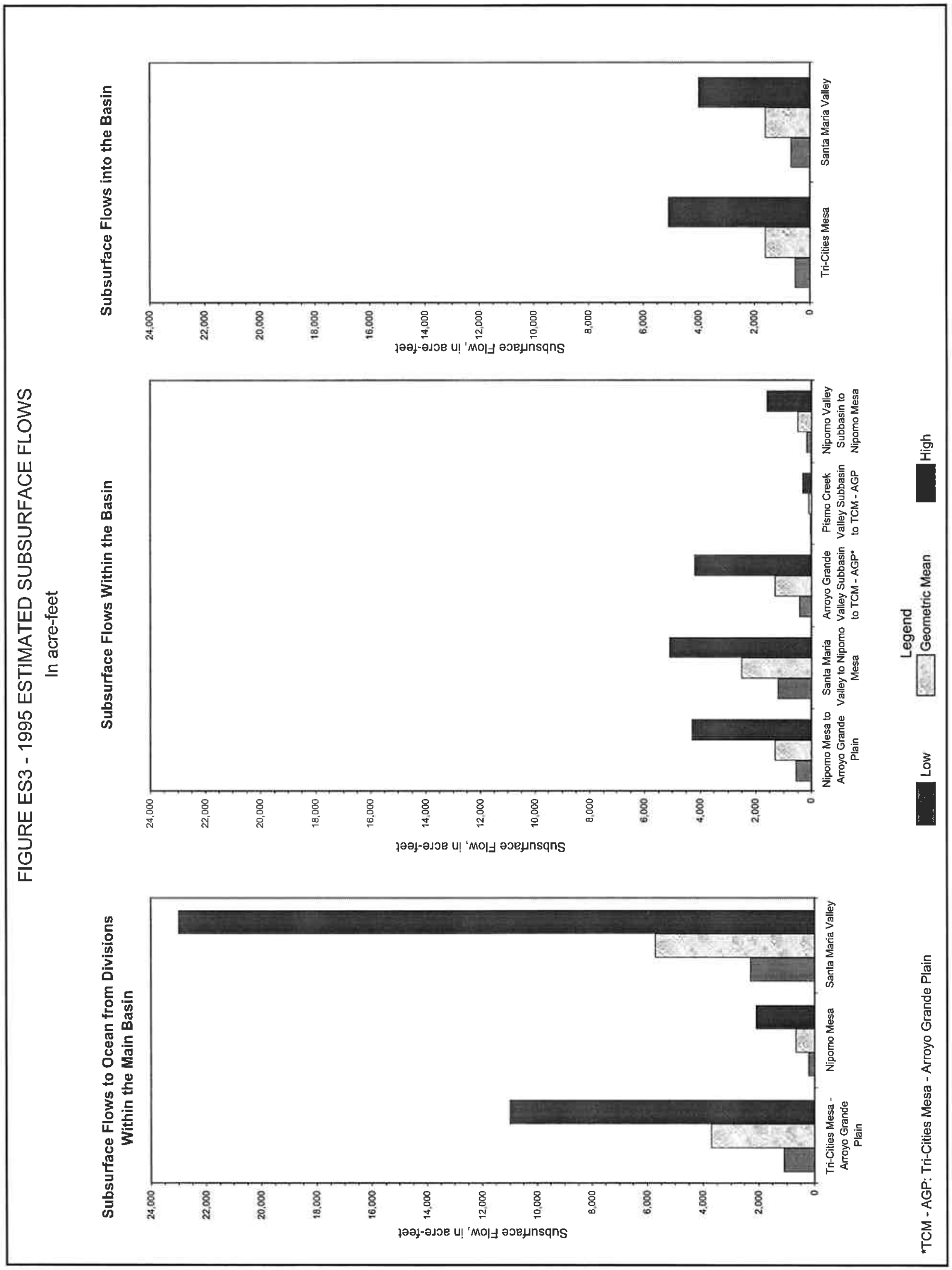


FIGURE ES3 - 1995 ESTIMATED SUBSURFACE FLOWS
In acre-feet

about 7,000 AF in 1985. Estimated amounts of subsurface outflow from Tri-Cities Mesa - Arroyo Grande Plain to the ocean were about half the outflow that occurs from Santa Maria Valley, with a mean amount of 3,700 AF in 1995 and about 3,000 AF in 1975 and 1985. The smallest estimated amounts of subsurface outflow to the ocean occur from Nipomo Mesa. The estimated mean amount was about 700 AF in 1995 and about 900 and 500 AF in 1975 and 1985, respectively.

Within the main groundwater basin, estimated amounts of subsurface flow from Nipomo Mesa to Arroyo Grande Plain ranged between 560 and 4,300 AF, with a mean amount of 1,300 AF in 1995 and also in 1975 and 1985. Estimated amounts of subsurface flow from Santa Maria Valley to Nipomo Mesa ranged between 1,200 to 5,100 AF, with a mean amount of 2,500 AF in 1995 and a mean amount of 1,200 AF in 1985.[14]

The mean amount of subsurface flow from Arroyo Grande Valley Subbasin to the main groundwater basin was estimated to be 1,300 AF in 1975 and 1995 and 1,100 AF in the dry year 1985. Based on very limited data, the mean amount of subsurface flow from Pismo Creek Valley Subbasin to the main groundwater basin was estimated to be 100 AF in 1995 and also in 1975 and 1985. If hydraulic continuity occurs across the Wilmar Avenue fault between Nipomo Valley Subbasin and Nipomo Mesa, the mean amount of subsurface flow into the mesa from the valley was estimated to be 500 AF in 1995 and also in 1975 and 1985.

Mean amounts of subsurface flow into the Tri-Cities Mesa part of the basin from bedrock were estimated to be 1,600 AF in 1995 and also in 1975 and 1985. Mean subsurface flows into Santa Maria Valley from upstream were estimated to be 1,600 AF in 1995 and 1,400 and 2,300 AF in 1975 and 1985, respectively.

Groundwater in Bedrock

The areas overlying bedrock are experiencing increasing development and associated utilization of groundwater. These areas, bordering the Santa Maria Groundwater Basin, consist primarily of the semi-consolidated to consolidated sandstone Pismo Formation in the northern part of the study area (generally north of the Wilmar Avenue fault and Tar Spring Creek and west of the Edna fault zone, Plate ES1) and the consolidated shale Monterey Formation and the volcanic tuff and lava Obispo Formation in the eastern part of the study area, including the area underlying the older alluvium in Nipomo Valley Subbasin (generally south of Tar Spring Creek and east of the Wilmar Avenue fault, Plate ES1).

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

[14]Subsurface flow will occur from the valley to the mesa depending on the lateral extent of the pumping depression in the mesa and groundwater elevations and hydraulic gradients.

encountered in both the Obispo and Monterey Formations.

Groundwater in bedrock is recharged mainly by intermittent deep percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and subsurface outflow to the adjoining Santa Maria 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. Estimates of hydraulic conductivity for the fractured tuff Obispo Formation were between 65 and 85 gallons per day per foot squared and for the Monterey Formation, 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 possibly about 270,000 AF. Specific yield values of the Obispo and Monterey Formations ranged from three to six percent, with a median value of four percent. The total groundwater storage capacity of the Monterey and Obispo Formations was estimated to be possibly about 360,000 AF.

Artificial Recharge

Artificial recharge (*in lieu* method) has been operating for more than 30 years in the study area. Surface water from Lopez Reservoir is supplied to agencies that would otherwise extract groundwater from the Tri-Cities Mesa -Arroyo Grande Plain part of the Santa Maria Basin.

Hydrogeologically, artificial recharge projects in the study area could be sustained. In Nipomo Mesa, a project (including *in lieu*) would be beneficial in alleviating declining trends in groundwater levels in some wells and associated loss in groundwater in storage that occurs in some parts of the mesa. The Nipomo Mesa portion of the basin has adequate space to store artificially recharged waters (only about 16 percent of its theoretical total storage capacity above msl is filled with groundwater). Potential development of this total storage capacity would be limited by the need to avoid groundwater leakage from the edges of the mesa. 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 groundwater quality data compiled from various sources for this study cover the period of record through 2000. Recent (1990 through 2000) groundwater quality data were available only from water agency wells (in the Tri-Cities Mesa[15] and Nipomo Mesa parts of the main Santa

[15]No recent quality data were available for the Arroyo Grande Plain and Los Berros Creek parts of the Tri-Cities Mesa - Arroyo Grande Plain portion of the main Santa Maria Basin; therefore this portion of the basin is referred to as Tri-Cities Mesa in this section.

Maria Groundwater Basin and in Nipomo Valley Subbasin) and the seven sea water intrusion monitoring wells sampled in 1996 for this study. Elsewhere in the basin, groundwater from wells was last sampled and analyzed in the late 1960s or 1970s, except for a few wells sampled in 1987. Groundwater in some parts of the basin has never been sampled.

The available groundwater quality data represent samples obtained from production wells, except for samples from the sea water intrusion monitoring wells. Thus, the water quality samples represent mixtures of groundwater from different aquifers. Only the sea water intrusion monitoring wells have piezometers at selected depths and represent depth-dependent samples.

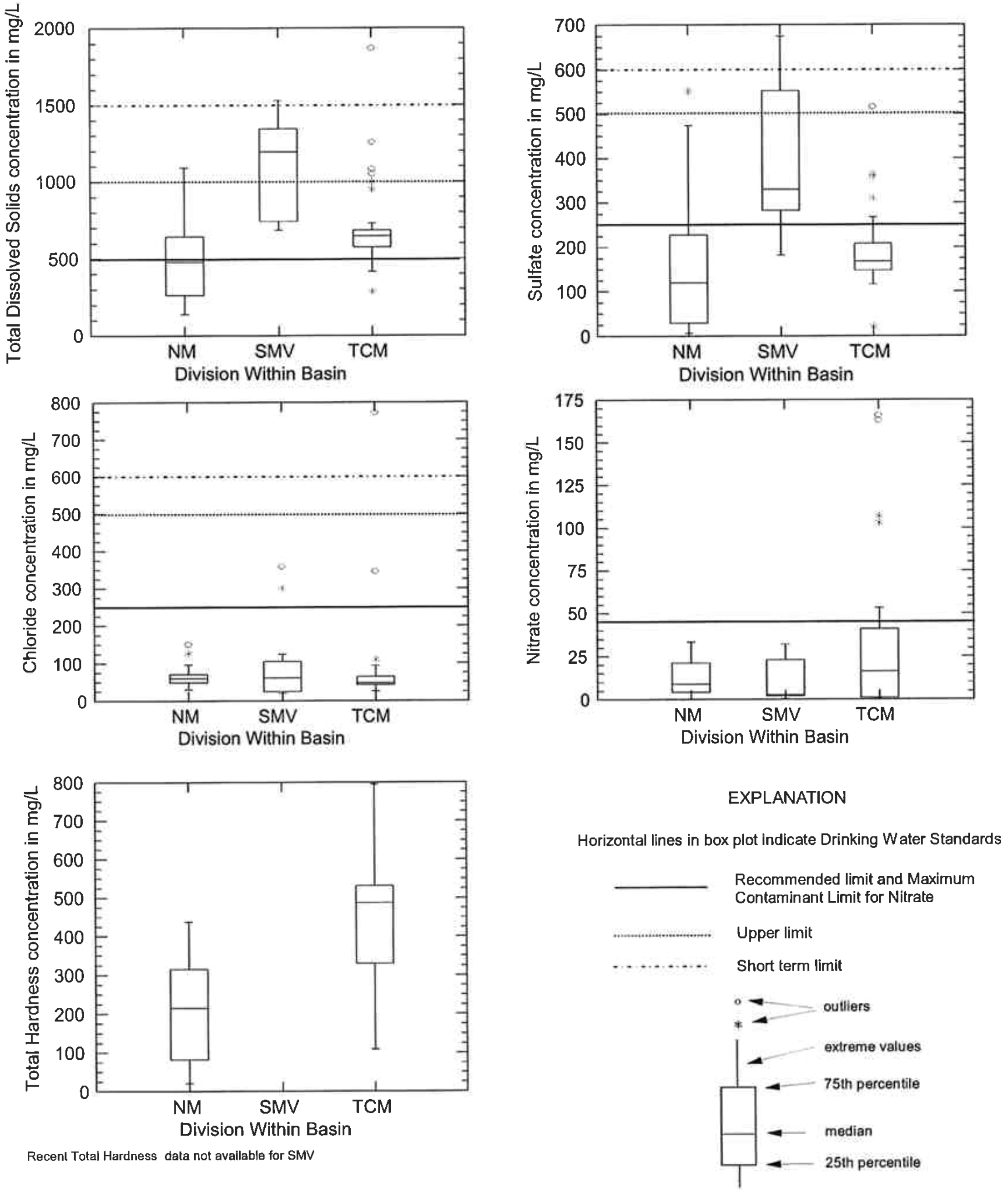
The chemical character of a water, the relative abundance of the major ions in a water, may be considered as a unique signature that often persists even after mixing with another water. Sampled groundwater in the Santa Maria Basin is often a mixed ion type, no one cation or anion dominates, reflecting the complex hydrogeological environment of the basin. However, some distinctions in chemical character of the groundwater exist between different parts of the basin. Groundwater in the Santa Maria Valley part of the basin is typically characterized as calcium-magnesium sulfate type. In the Tri-Cities Mesa part of the basin, groundwater can be dominated by the calcium cation and either the bicarbonate or sulfate anions. In the Nipomo Mesa part of the basin, many wells north of Black Lake Canyon extract groundwater with sodium as the dominant cation and chloride or bicarbonate as the dominant anion. In the Arroyo Grande Valley Subbasin, the chemical character of groundwater is either calcium-magnesium bicarbonate or calcium-magnesium sulfate. In Pismo Creek Valley Subbasin, the dominant ions of groundwater sampled historically were sodium and chloride-bicarbonate or sulfate-chloride. The chemical character of groundwater in Nipomo Valley Subbasin is mixed.

Boxplots, shown in Figure ES4, depict concentrations of Total Dissolved Solids, sulfate, chloride, nitrate, and total hardness found between 1990 and 2000 in sampled well waters in the main part of the basin. The figure shows that most sampled groundwater meets California Department of Health Services' Drinking Water Standards. The higher concentrations of TDS, sulfate, and chloride were found mainly in groundwater from the sea water intrusion monitoring wells and wells near faults. Groundwater is classified as moderate to very hard, although about one-third of the sampled wells in the Nipomo Mesa part of the basin extract groundwater classified as soft. In the Santa Maria Valley part of the basin, recently sampled groundwater was not analyzed for total hardness concentrations; however, historical data indicate most groundwater was very hard.

As can be seen on Figure ES4, groundwater with nitrate concentrations exceeding the maximum contaminant level is found in the Tri-Cities Mesa part of the basin. Those wells extracting groundwater exceeding the Maximum Contaminant Limit (MCL) have a top-perforated interval of less than 100 feet in depth.

Large portions of the basin lack recent nitrate data, particularly agricultural areas where historical data indicate nitrate concentrations in groundwater exceeded the MCL. The high nitrate concentrations had been attributed to ongoing agricultural activities.

FIGURE ES4 - BOX PLOTS OF TOTAL DISSOLVED SOLIDS, SULFATE, CHLORIDE, NITRATE, AND TOTAL HARDNESS CONCENTRATIONS IN WELL WATERS IN SANTA MARIA GROUNDWATER BASIN, 1990-2000 DATA



Division Within Basin
NM: Nipomo Mesa, 1990-2000 data from 35 wells (including 5 piezometers in 2 sea water intrusion monitoring wells)
SMV: Santa Maria Valley, 1992-1998 data from 4 wells (including 11 piezometers in 2 sea water intrusion monitoring wells)
TCM: Tri-Cities Mesa, 1995-2000 data from 25 wells (including 7 piezometers in 3 sea water intrusion monitoring wells)

Analyses of depth-dependent groundwater samples collected in March 1996 from the piezometers in the sea water intrusion monitoring wells show some vertical variability in groundwater quality. In the Tri-Cities Mesa part of the basin, a mineral gain with depth in the Paso Robles Formation was found, while little variation in quality with depth in the Squire Member of the Pismo Formation was found. In the Nipomo Mesa part of the basin, groundwater from the Paso Robles Formation shows a small mineral gain with depth and TDS concentrations could be lower in the Careaga Formation than in the Paso Robles Formation. In the Santa Maria Valley part of the basin, groundwater in the alluvium was as much as about 800 mg/L higher in TDS content than groundwater in the Paso Robles Formation. Also, the quality of groundwater in the Paso Robles Formation was generally about the same regardless of depth, except where it could be affected by downward percolation of poorer quality water from the alluvium or possibly oil field activity.

In the basin, sampled groundwater is typically classified as suitable to marginal under water quality guidelines for agricultural irrigation. However, historical data indicate that sampled groundwater in the Santa Maria Valley portion of the basin was classified as marginal to unsuitable for agricultural irrigation.

No recent quality data were available for Arroyo Grande Valley Subbasin, except for a partial analysis of a sample from one well in 1996. Historical groundwater quality data show a progressive deterioration of the groundwater quality in a downstream direction. Above Tar Spring Creek, the historical data show that concentrations of TDS, sulfate, and chloride in sampled groundwater met Drinking Water Standards and the water was classified as suitable under water quality guidelines for agricultural irrigation. Below Tar Spring Creek, TDS concentrations in extracted groundwater were typically more than 1,500 mg/L and sulfate concentrations were more than about 500 mg/L. The concentrations of these constituents also led the groundwater to be classified as marginal to unsuitable for agricultural irrigation. Most of the historical nitrate concentrations in groundwater met the MCL. Groundwater in the valley was classified as very hard.

No recent groundwater quality data were available for Pismo Creek Valley Subbasin. Historical data indicate that sulfate, chloride, and TDS concentrations generally did not meet Drinking Water Standards.

In Nipomo Valley Subbasin, TDS concentrations in groundwater extracted from the Obispo and Monterey Formations ranged between 750 and 1,300 mg/L; sulfate concentrations, between 200 and 340 mg/L; chloride concentrations, between 64 and 130 mg/L; and nitrate concentrations, between not detected and 3.5 mg/L. The groundwater is classified as very hard and as suitable to marginal under water quality guidelines for agricultural irrigation.

Because chloride concentrations in groundwater may indicate quality changes over time, this parameter was used to evaluate trends in the groundwater quality. Chloride concentrations in sampled groundwater in the main basin typically showed no significant trends of increasing concentrations over time. The generally stable chloride quality over time is indicative of a net outflow of groundwater to the ocean. Data were not available to show any reduction in the quality of groundwater in Nipomo Mesa from subsurface inflow of groundwater from Santa Maria Valley.

No evidence of sea water intrusion was found with the available data.

The use and reuse of groundwater for irrigation have been considered the major factors affecting quality of groundwater in parts of the basin. In addition, groundwater quality in wells may be affected by mineralized zones, residual saline deposits, or waters influenced by tidal action.

Surface water within the study area has not been sampled for quality since the 1960s and 1970s and this historical sampling was very infrequent. The quality of surface waters of the various creeks and the Santa Maria River varied, depending on the flow, with TDS concentrations measured at up to about 2,000 mg/L. Lopez Reservoir (not within the study area) is an important supply source within the study. Water from Lopez Reservoir is of high quality and meets Drinking Water Standards. TDS concentrations of the water range between 400 and 600 mg/L and the chemical character is calcium-magnesium bicarbonate.

Water Budget, Dependable Yield, and Overdraft

Water budgets, itemized accountings of all inflows and outflows occurring in hydrologic systems, were developed for this study to provide information for water supply planning within the main Santa Maria Groundwater Basin in San Luis Obispo County. The investigators had sufficient data to develop valid water budgets for each of the three portions into which the main groundwater basin was divided: Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa, and Santa Maria Valley (Plate ES1).

Using the general equation "*Inflow - Outflow = Surplus/Deficiency*," the components of groundwater inflow and outflow were determined for each year of the 1975 through 1995 study period and for future years 2010 and 2020. The future water budgets are based on projected land use changes and associated changes in water demands and on the base period 1984 through 1995, which represents long-term average hydrologic conditions.[16]

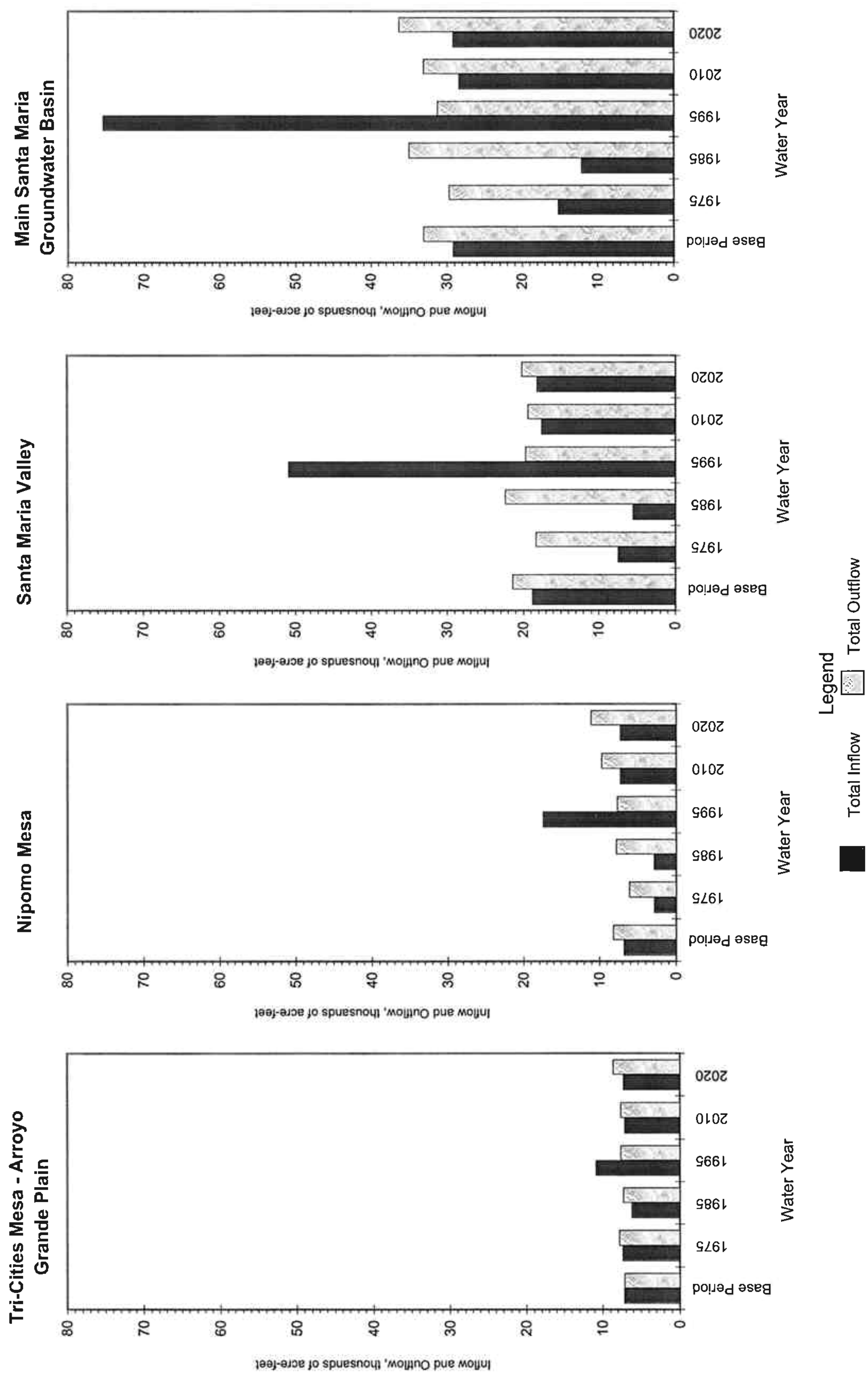
The surplus or deficiency for each year of the water budget is actually the amount of change in groundwater in storage that takes place. Thus, for this study, the water budgets show the amount of change in groundwater in storage in the Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa and Santa Maria Valley portions of the main groundwater basin.

Figure ES5 illustrates estimated inflow and outflow amounts for the divisions of the main basin

[16]Because of the wet water year 1998, the long-term mean for the period of record through water year 1995 is about 0.4 inch less than the long-term mean for the period of record through water year 2000 at precipitation station Nipomo 2NW.

FIGURE ES5 - INFLOW AND OUTFLOW WITHIN THE MAIN SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY

In thousands of acre-feet



and for the main basin as a whole for 1975; for 1985, a dry year; for 1995, a wet year; for the base period, 1984 through 1995; and for future years 2010 and 2020. The water budget for the main groundwater basin was arrived at by totaling the applicable components of the budgets for the three divisions of the basin.

Within the main Santa Maria Basin, total outflow (33,100 AF) exceeded total inflow (29,200 AF) by about 4,000 AF in the base period. Outflow is projected to exceed inflow by 4,700 AF in 2010 and by 7,100 AF in 2020.

In Tri-Cities Mesa - Arroyo Grande Plain, total inflows about equaled total outflows in the base period. Projected amounts show total outflow exceeding total inflow by 500 AF in 2010 and 1,300 AF in 2020.

Total outflow in Nipomo Mesa exceeded total inflow by 1,400 AF in the base period. Outflow is projected to exceed inflow in the future by 2,400 AF in 2010 and by 3,800 AF in 2020.

In Santa Maria Valley, total outflow exceeded total inflow by 2,600 AF in the base period. In the future, outflow is projected to exceed inflow by 1,800 AF in 2010 and by 2,000 AF in 2020.

In Tri-Cities Mesa - Arroyo Grande Plain, both the cumulative surplus/deficiency method and the "specific yield" method[17] estimated a gain of groundwater in storage of 1,000 to 6,000 AF between 1975 and 1995. In Nipomo Mesa, both methods estimated a loss of groundwater in storage of 7,000 to 11,000 AF between 1975 and 1995. In Santa Maria Valley, both methods estimated a gain of groundwater in storage of 3,000 to 5,400 AF between 1975 and 1995.

The projected deficiencies in the water budgets in 2010 and 2020 for Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa, and Santa Maria Valley (1,300, 3,800, and 2,000 AF in 2020, respectively) represent the potential losses in groundwater in storage if hydrologic base period conditions of this study occurred in those years with the projected land use and water demand changes. The projected deficiencies would amount to about one-tenth of a foot decline in groundwater levels in 2020 over the entire Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley portions of the basin and two-tenths of a foot decline in groundwater levels in 2020 over the entire Nipomo Mesa portion of the basin.

In Tri-Cities Mesa - Arroyo Grande Plain, the projected increase in urban extractions is the major factor contributing to projected deficiencies in 2010 and 2020. Reductions in subsurface outflow to the ocean will likely offset future negative imbalances between inflow and outflow and loss of groundwater in storage. In addition, recharge enhancement of Arroyo Grande Creek could increase stream infiltration amounts and potentially offset future deficiencies. However, if in the future, subsurface outflow to the ocean is not of sufficient quantity for the freshwater head to counterbalance the greater density of sea water, sea water intrusion of the groundwater basin

[17]Method used to estimate groundwater in storage, discussed in section on Santa Maria Groundwater Basin.

could occur.

In Nipomo Mesa, the projected increase in urban extractions is the major factor contributing to projected deficiencies in 2010 and 2020. Reductions in subsurface outflows to the ocean and to Tri-Cities Mesa - Arroyo Grande Plain and increased subsurface inflow from Santa Maria Valley will likely offset the future negative imbalances between inflow and outflow and reduce the amount of loss in groundwater in storage. Subsurface outflow to the ocean was only 600 AF in the base period and reductions in this outflow would need to be small because of the concern regarding sea water intrusion.

In Santa Maria Valley, the projected deficiencies are not the result of future increased extractions (extractions were projected to increase only 200 AF between 1995 and 2020). Projected subsurface outflows in 2010 and 2020 are substantial (6,200 AF to the ocean and 2,300 AF to Nipomo Mesa) from this portion of the basin. Potential future deficiencies will likely be offset by reduced subsurface outflow to the ocean, which accounts for about 30 percent of the total outflow in the future. However, if in the future, subsurface outflow to Nipomo Mesa increases above the projected amount, water budgets for this portion of the basin could show larger deficits (loss of groundwater in storage). The same concern regarding sea water intrusion applies. In addition, restoration and maintenance of the storage capacity of Twitchell Reservoir could improve future recharge amounts from the Santa Maria River to the groundwater basin.

The dependable yield of a groundwater basin is the average quantity of water that can be withdrawn from the basin over a period of time (during which water supply conditions approximate average conditions) without resulting in adverse effects, such as sea water intrusion, subsidence, permanently lowered groundwater levels, or degradation of water quality. Dependable yield is determined for a specified set of conditions and any changes in those conditions require a new calculation.

For this study, estimates of dependable yield for each division of the main groundwater basin were determined from the hydrologic equation for the 1984 through 1995 base period and for the 1975 through 1995 study period. Because subsurface flows to the ocean could be reduced and subsurface flows between portions of the basin increased or decreased, the dependable yield is given as a range. Thus, the dependable yield is estimated to range between 4,000 and 5,600 AF for the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin, between 4,800 and 6,000 AF for the Nipomo Mesa portion of the basin, and between 11,100 and 13,000 AF for the Santa Maria Valley portion of the basin. These estimates of dependable yield for each portion of the main groundwater basin are more meaningful if they are considered as a unified whole because the estimates are directly affected by the amounts and nature of the subsurface flows occurring between portions of the basin. Thus, the dependable yield for the main Santa Maria Basin within San Luis Obispo County ranges between 19,900 and 24,600 AF.

Overdraft is defined as the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which the water supply conditions approximate average conditions. Droughts or periods of less than normal rainfall do not cause overdraft. Basically, overdraft means that extractions exceed the dependable yield of the basin.

This study refrains from finding that the Santa Maria Groundwater Basin within San Luis Obispo County is currently in overdraft because of consistent subsurface outflow to the ocean and no evidence of sea water intrusion. The periodic recovery of the basin provides sufficient recharge to preclude long-term adverse conditions. The basin was estimated to have about 38,000 AF more groundwater in storage in water year 2000 than in 1975. In the Nipomo Mesa portion of the basin, the amount of groundwater in storage in 2000 was estimated to be the same as in 1975, despite the continued presence of the pumping depression in the south-central part of the mesa. Pumping depressions and declines in groundwater levels in some wells in some parts of the Nipomo Mesa portion of the basin do not imply that a condition of overdraft exists in the entire groundwater basin, but are more likely indicative of the dynamics of the groundwater system and sources of recharge in the mesa. Other recent investigations also found that the basin is not in a condition of overdraft.

The projected deficiencies in the water budgets in water years 2010 and 2020 for the three portions of the main Santa Maria Basin do not necessarily imply overdraft conditions in those years. Projected extractions are within the range of dependable yield estimates, with the exception of Nipomo Mesa in 2020. Because the basin continuously seeks a new equilibrium, reductions in subsurface outflow to the ocean and changes in subsurface flow between portions of the basin will likely compensate for deficiencies (loss of groundwater in storage). Such changes in subsurface flows as the basin seeks a new equilibrium will not likely result in overdraft provided that sea water intrusion and other adverse effects are avoided. However, because of the potential for adverse effects, increasing amounts of subsurface flow from the Santa Maria Valley portion of the basin into the Nipomo Mesa portion of the basin to meet projected water demands should not be used as a long-term solution to water supply needs in Nipomo Mesa. The projected deficiencies in the water budgets do indicate the need for continued planning, improved data, periodic reevaluation of the water budgets, artificial recharge programs, and expanded use of recycled water.

The groundwater basin is an area of dynamic growth, subject to constantly changing conditions, which affect water supply, use, and disposal. Human activities that can modify water supply conditions and consequently water budgets include items such as: extent of extractions, transfers of water use, increases in impermeable areas, 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 groundwater basin, protracted dry or wet periods will significantly affect future water budgets. Therefore, it needs to be recognized that any water budgets and dependable yield values will be superseded in the future as conditions change.

Recommendations

On the basis of the information gained in this investigation, it is recommended that San Luis

Obispo County consider the following:

- Continue the groundwater level monitoring program and expand the program to include key wells in Pismo Creek Valley Subbasin, the eastern part of Nipomo Mesa (bounded by Summit Station Road, Hetrick Avenue, the Santa Maria River fault, Highway 101, and Joshua Road), and the areas overlying bedrock, and also expand the coverage of the south-central part of Nipomo Mesa;
- Undertake a comprehensive water quality assessment of the water resources in the study area and develop a water quality monitoring program with the information provided by the comprehensive assessment;
- Annually monitor both groundwater levels and quality in the 23 piezometers within the seven wells along the coast for sea water intrusion;
- Install a precipitation station on the Nipomo Mesa near Highway 1 and Willow Road to gain needed precipitation data for this area;
- Undertake infiltration and soil moisture studies to more accurately determine the amount of deep percolation of precipitation and stream infiltration that occurs within the study area;
- Undertake studies to more precisely determine the location of the Santa Maria River fault and its impact and the impacts of the Oceano fault and the Wilmar Avenue fault on groundwater flow within the basin;
- Reconcile the reference elevations for the groundwater level monitoring wells;
- Expand the monitoring of streamflow with needed gages at the confluence with the Pacific Ocean on Pismo and Arroyo Grande Creeks and at Guadalupe on the Santa Maria River;
- Investigate the feasibility of an artificial recharge program using supplemental water in the study area; and
- Expand the use of recycled water as a source of supply within the study area.

This Page Intentionally Blank

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 mentioned that groundwater extractions had resulted in declining water levels in all parts of the study area.[2]

Therefore, the San Luis Obispo County Flood Control and Water Conservation District and the Department have entered into an agreement to update the 1979 report, expanding the area of study within San Luis Obispo County.[3] San Luis Obispo County delineated the study area for the new investigation setting the southern boundary at the Santa Barbara/San Luis Obispo County line. This is a report on the findings made in the new study.

Objective and Scope

The objective of this investigation is to gain more knowledge about the water resources within the Arroyo Grande - Nipomo Mesa area.

This investigation expands the 1979 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 (Figure 1).

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.

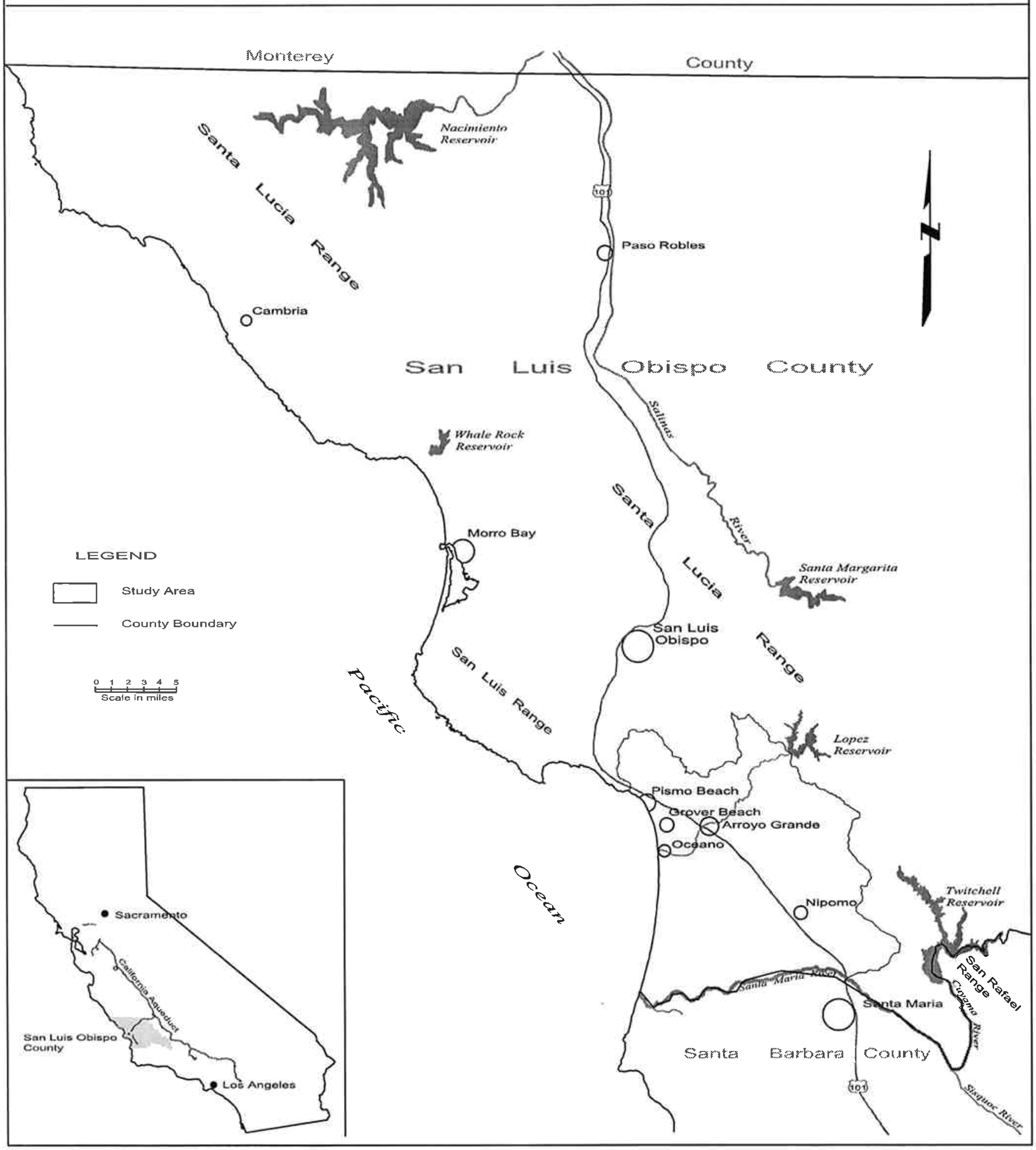
---

[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.

[3] The agreement for the three-year study with San Luis Obispo County was executed in September 1993. The agreement stipulated that as soon as practical, after execution of the agreement, the Department commence work on the investigation. The Department began work in January 1996 and provided San Luis Obispo County with a draft report in April 1998, a second draft report in January 1999, and a final draft report in January 2000. Only the January 2000 report received widespread review and comment.

FIGURE 1 - LOCATION OF STUDY AREA



- Prepare a geologic map of the study area.
- Collect and review well drillers' reports and other subsurface geologic information.
- Construct geologic cross sections.
- Determine groundwater basin characteristics, including water levels, storage capacity, water in storage, safe yield, transmissivity, and natural and artificial replenishment.
- Determine quantity and quality of water available--groundwater, surface water, and recycled 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 demand.
- Examine factors influencing water demand.

The data assembled for this study are for the period of record through water year 2000,[4] except for water demand and supply data. The determination of water demand and supply and groundwater inflow and outflow was for the study period. Because this study is an update of the Department's 1979 investigation, the starting year of the study period, 1975, is taken from the last year of data for that report. The ending year of the study period, water year 1995, is the last year of the hydrologic base period.[5] The hydrologic base period for this study, which represents long-term average hydrologic conditions, is water years 1984 through 1995.

Data Availability

To fulfill the tasks given above, information had to be acquired from numerous sources-- those agencies and individuals listed on the acknowledgment page and the Department's own files. Information obtained includes: geologic and hydrologic reports; population, water supply and demand, land use, water delivery, precipitation, streamflow, groundwater extraction, groundwater level, pump test, and surface water and groundwater quality data; wastewater treatment plant production, disposal, and reuse data; well completion reports and geophysical logs, and oil well lithologic and geophysical logs.[6] Reports and other documents reviewed for this study are listed in Appendix A.

The available data were in either paper or electronic format. Much of the collected data was initially on paper media and had to be entered into an electronic format for analysis in this study. Electronic information received recently does not always match with previously received data.

---

[4] A water year is October 1 of one year through September 30 of the next year. It is usually designated by the second year.

[5] An explanation of how the base period was determined is in Appendix B.

[6] Discussion of well completion reports, locations, and reference elevations is in Appendix C.

Inconsistencies in the data required rectification of the suspect data before inclusion in this study's databases.

Analyses for this project relied on the collected available data. Data gaps are discussed in more detail in the appropriate sections of the report.

Area of Investigation

The study area occupies 184 square miles (117,940 acres) of the southwestern coastal portion of San Luis Obispo County, between the City of San Luis Obispo and the City of Santa Maria in Santa Barbara County (Figure 1). It is bounded on the north and east by the Santa Lucia, San Luis, 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. The terrain of the study area 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 study area encompasses a portion of the watershed of Pismo Creek, the watersheds of Arroyo Grande and Nipomo Creeks, and that portion of the watershed of Santa Maria River within San Luis Obispo County. It lies within the following hydrologic (watershed) areas and subareas: the Pismo, Oceano, and Nipomo Mesa Hydrologic Subareas (HSA), and Guadalupe HA (Plate 1).[7] 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 the Santa Maria River and Nipomo Creek.

Underlying about 50 percent, or 61,220 acres, of the study area is a portion of the Santa Maria Groundwater Basin, which extends into Santa Barbara County (Plate 1).[8] Within the study area, the basin includes the main basin, Santa Maria, and three subbasins-- Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley.

Because of the study area's size and differences in hydrologic and topographic characteristics and to provide applicable information for San Luis Obispo County, the Santa Maria Groundwater Basin and the portions of the study area outside the basin were divided and evaluated based on the hydrologic boundaries (Plate 1). The divisions of the main Santa Maria Basin are: (1) the Tri-Cities Mesa - Arroyo Grande Plain portion that includes the lower Pismo Creek portion of the basin lying within Pismo HSA and the Tri-Cities Mesa, Arroyo Grande Plain, and Los Berros

[7]Hydrologic Area and Hydrologic Subarea are the hierarchical nomenclature of watershed divisions in California. HSA is a subdivision of a HA. The hydrologic boundary for Nipomo Mesa HSA was field checked for this study.

[8]The results of this study are valid for the portion of the Santa Maria Groundwater Basin within San Luis Obispo County. No existing published investigations of the Santa Maria Basin analyzed the basin in its entirety within both San Luis Obispo and Santa Barbara Counties.

TABLE 1
SURFACE AREAS OF HYDROLOGIC AREAS AND SUBAREAS

Hydrologic Area or Subarea *Division Within Groundwater Basin*	Amount Within Study Area: Acres	Amount Within Study Area: Square Miles	Amount Within Main Groundwater Basin: Acres	Amount Within Main Groundwater Basin: Square Miles	Amount Within Groundwater Subbasin: Acres	Amount Within Groundwater Subbasin: Square Miles
Pismo HSA	8,920	13.9				
*Pismo Creek**			*320*	*0.5*	*1,220*	
Pismo Creek Valley Subbasin						*1.9*
Oceano HSA	52,880	82.6				
*Tri-Cities Mesa - Arroyo Grande Plain***			*10,450*	*16.3*		
Arroyo Grande Valley Subbasin					*3,860*	*6.0*
Nipomo Mesa HSA	17,580	27.5				
Nipomo Mesa			*17,580*	*27.5*		
Guadalupe HA	38,560	60.2				
Santa Maria Valley			*21,560*	*33.7*		
Nipomo Valley Subbasin					*6,230*	*9.7*
Study Area Total	117,940	184.3				
Groundwater Basin Total			*49,910*	*78.0*	*11,310*	*17.7*

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.
* Shown separately from Tri-Cities Mesa - Arroyo Grande Plain to provide surface area amounts.
** Includes the Los Berros Creek portion of the groundwater basin.

Creek portions of the basin lying within Oceano HSA; (2) the Nipomo Mesa portion of the basin, lying entirely within Nipomo Mesa HSA; and (3) the Santa Maria Valley portion of the basin, lying within Guadalupe HA. The subbasins were evaluated within their respective hydrologic area or subarea: Arroyo Grande Valley Subbasin, lying within Oceano HSA; Pismo Creek Valley Subbasin, within Pismo HSA; and Nipomo Valley Subbasin, within Guadalupe HA. Those remaining portions of the study area outside the groundwater basin were also evaluated within their respective hydrologic area or subarea. Table 1 gives the surface acreage of the hydrologic areas and subareas and the divisions of the groundwater basin within the study area.

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. These communities receive all or a portion of their water supply from the Santa Maria Groundwater Basin. Lopez Reservoir (not within the study area) is an important source of water supply within the study area. In August 1997, the Coastal Branch of the State Water Project began bringing water to several of the communities. Plate 1 shows its general alignment.

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 Arroyo Grande-Nipomo Mesa study area lies within a west-northwest-trending region of the southern central coastal area of California that forms a structural and geomorphic transition between the adjoining north-northwest-trending Coast Ranges Geomorphic Province to the northeast and the west-trending Transverse Ranges Geomorphic Province to the south (Figure 2). Nitchman (1988) and Namson and Davis (1990) have described this area as an active fold and thrust belt.

This region developed as the result of two temporally distinct tectonic regimes that operated during Cenozoic[1] time: (1) a late Oligocene to late Miocene phase characterized by right lateral strike-slip faulting, with concurrent subsidence of fault-bounded blocks forming marine depositional basins (Hall, 1978a, 1981; Blake et al., 1978; Stanley and Surdam, 1984), followed by late Miocene to early Pliocene continued strike-slip faulting, but with shortening between faults forming large-scale folds (Hall, 1978a, 1981; Stanley and Surdam, 1984); and (2) late Pliocene to Holocene north-northeast crustal shortening accommodated by displacement along a new generation of parallel west-northwest-striking reverse and thrust faults and local folding, and by uplift, subsidence, or tilting of intervening crustal blocks (Nitchman, 1988; Clark et al., 1994; Vittori et al., 1994; Lettis et al., 1994).[2]

Three geologic depositional basins--Pismo, Santa Maria, and Huasna Basins--created by these tectonic regimes underlie the study area (Figure 2). These basins contain thick, mostly marine sedimentary Tertiary deposits that unconformably lie on a basement of Jurassic (?)-Cretaceous Complex.

The triangularly shaped Santa Maria 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 portion of the basin within San Luis Obispo County.

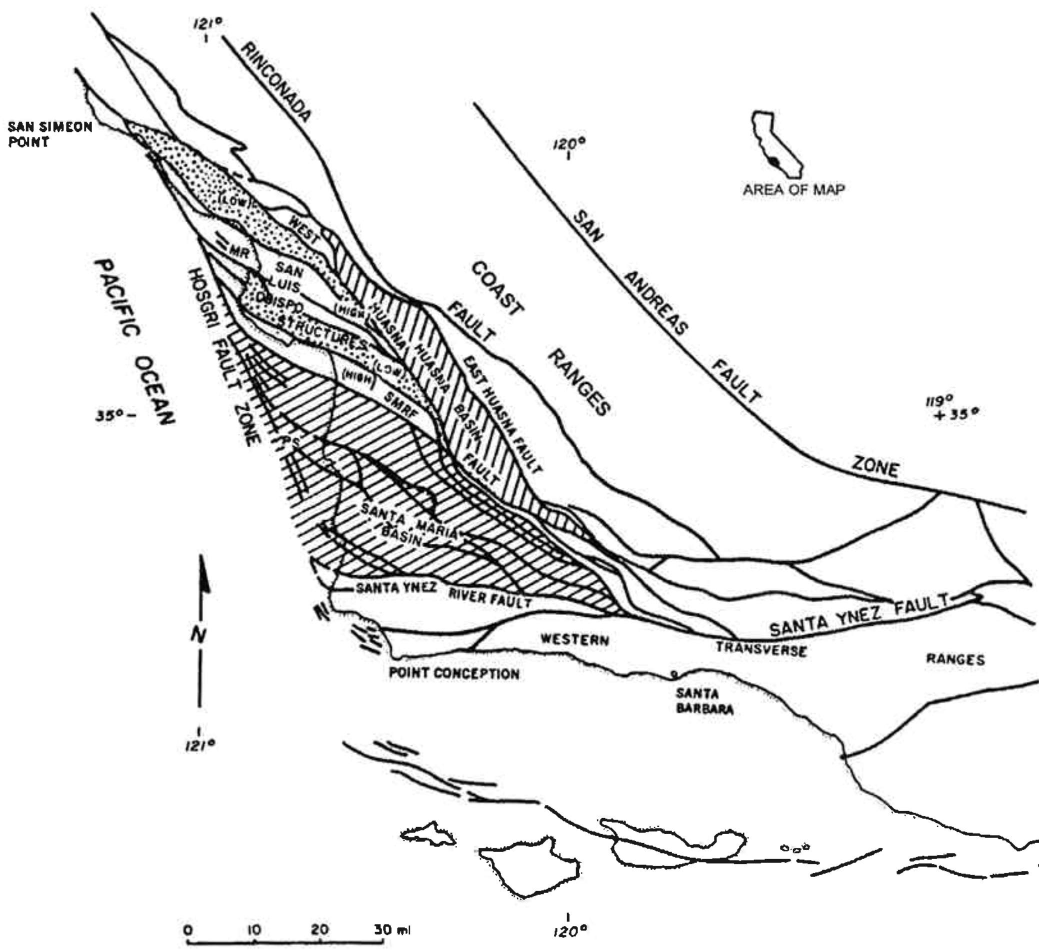
---

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

[2]Luyendyk et al., 1980 and Hornafius, 1985 have alternatively explained basin development by localized extension resulting from Miocene and Pliocene clockwise rotation of the Transverse Ranges.

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

FIGURE 2 - 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).

The Pismo 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 (Hall, 1981; Heasler and Surdam, 1984; Stanley and Surdam, 1984). The basin extends west offshore to the Hosgri fault zone (Heasler and Surdam, 1984; Kablanow and Surdam, 1984; Clark et al., 1994). The study area overlies the southern portion of the basin.

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

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 (Plate 2) depicts the geographic extent of the different exposed sediments and rocks. Three cross-sections (Plates 3-5) were constructed for this study from water well and oil well lithologs and electric logs (locations shown on Plate 2). Figure 3 presents a stratigraphic column of the Jurassic through Pleistocene formations found in each of the three geologic basins.

Basement Complex

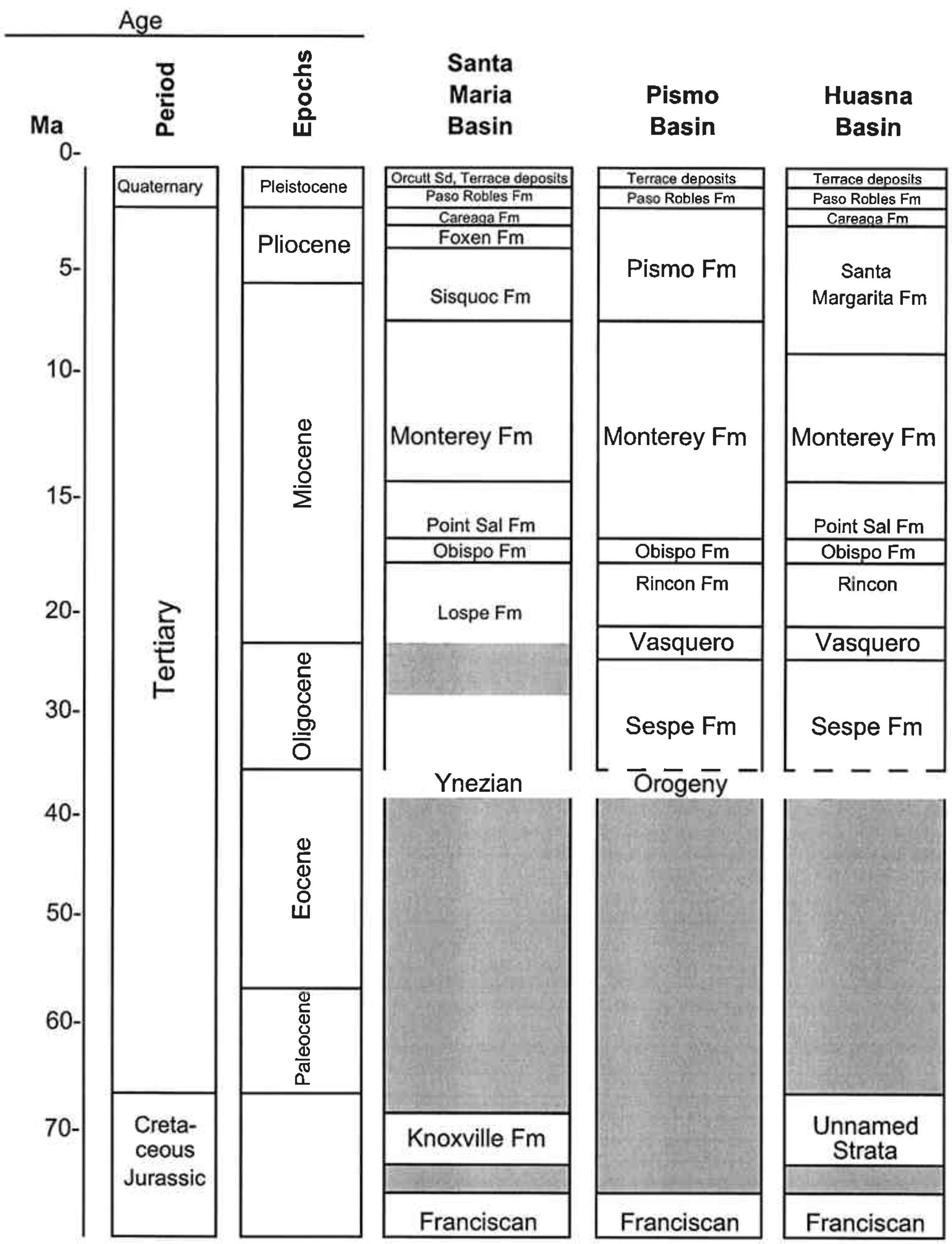
The oldest rocks found in the study area are those referred to as basement complex. These rocks include the Jurassic (?) Franciscan and Knoxville Formations and unnamed Cretaceous strata. The basement complex unconformably underlies the younger Tertiary and Quaternary deposits. Outcrops are found along an area between the West Huasna and Edna faults near Lopez Reservoir, along Los Berros Creek, and in the southern end of the Nipomo Valley near the junction of Highways 101 and 166. These rocks are grouped with Tertiary formations and shown as "TuKJf" on Plate 2.

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 and Corbato, 1967; Hall, 1973; Hanson, et al., 1994).

Volcanic Rocks

Early Miocene volcanic and pyroclastic rocks in the study area comprise: (1) tuff, altered tuff,

FIGURE 3 - 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) 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 near Picacho Hill and the northern and eastern highlands that flank the Nipomo Valley.

The Obispo Formation is an important source of water supply in the study area. 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 well completion reports,[5] the Obispo Formation is described as either volcanic sandstone, volcanic shale--often black or gray--or volcanic rock, hard or soft, 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 Basins are largely filled with thick accumulations of mostly marine consolidated to unconsolidated sedimentary rocks of Cenozoic age.

The Oligocene through middle 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.

The consolidated Miocene Monterey Formation is an important water supply source in the study area. 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 beds. The formation is commonly fractured and sheared. On the lithologs of well completion reports, the Monterey Formation is described as hard or soft Monterey shale or shale, usually fractured, with some clay.

Santa Margarita Formation. This late Miocene-Pliocene marine formation is found in the

[4]Montmorillonite clays are characterized by swelling in water and extreme colloidal behavior.
[5]Before 1991, these reports were called "Water Well Drillers Report."

Huasna Basin. The formation is a distinctive white-weathering massive bedded, poorly to moderately consolidated, coarse-grained arkosic sandstone and siltstone, with some siliceous claystone and diatomite (Hall and Corbato, 1967).

Pismo Formation. The Pismo Formation of the Pismo 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; Stanley and Surdam, 1984; Nitchman, 1988; Hanson et al., 1994). The formation is made up of three depositional sequences of relatively conformable successions of genetically related strata bound by unconformities (Stanley and Surdam, 1984). Hall and Surdam (1967) divided the formation into five members: late Miocene-early Pliocene Miguelito--interbedded diatomaceous claystone and siltstone; late Miocene-early Pliocene Edna--bituminous and nonbituminous sandstone and minor conglomerate beds; late Pliocene Gragg--sandstone and conglomerate; late Pliocene Bellview--sandstone and mudstone; and late Pliocene Squire--sandstone and interbeds of silts and clays (Hall, 1973). Hall (1973) reported a maximum of 550 feet of the Squire Member in the Pismo Basin.

In the study area, extensive exposures of the Pismo Formation occur north of the Wilmar Avenue fault (Plate 2). The Squire Member also occurs at depth between the Santa Maria River fault and the Wilmar Avenue fault in the Pismo Basin (Plates 3-5). The Squire Member is about 550 feet thick under Tri-Cities Mesa and thins to about 50 feet southeasterly along the block between the Santa Maria River and Wilmar Avenue faults.

Plate 2 shows the Squire Member of the Pismo Formation as mapped by Hall (1973). However, Nitchman (1988) remapped part of the surface geology of the eastern San Luis Range. Nitchman differs in his separation of the Squire and Edna Members. He interprets the Squire Member to have been deposited as a thin veneer (up to about 100 feet thick) across the entire San Luis Range from Pismo Beach to Edna Valley, resulting in limited outcrops of the member as opposed to the extensively mapped exposure of Hall. Hall's 1973 Map Sheet 24 includes the statement: "No clear lithologic distinction between Edna and Squire Members in this area." This statement is included on Plate 2 of this study. Water well drillers' lithologic descriptions for wells drilled in the area mapped as the Edna Member by Hall (1973) are frequently similar to those of wells drilled in the area mapped as the Squire Member, making differentiation of the members inaccurate with these data alone. It is beyond the scope of this study to determine the exact extent of the Squire Member.

The Pismo Formation and in particular, the Squire Member, is an important source of groundwater in the study area. As described on the lithologs of well completion reports, the Squire Member generally consists of coarse- to fine-grained gray to blue to greenish sand with some gravel, interbedded by discontinuous beds 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.

Careaga Formation. The late Pliocene shallow-water marine Careaga Formation of the Santa Maria Basin within the study area is typically described on the lithologs of well completion 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 about 150 feet thick south of the Santa Maria River fault under Nipomo Mesa (Plate 5) and progressively thickens to about 700 feet toward the southwest part of the study area, along the Santa Maria River (Plate 4).

Paso Robles Formation. The Pliocene-Pleistocene (?) Paso Robles Formation[6] was deposited 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 well completion reports, the formation typically consists of unconsolidated to poorly consolidated to sometimes cemented beds or lenses 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. The shale gravel is usually porcelaneous pebbles from the Monterey Formation. The nearshore marine deposits can be fossiliferous near the base of the formation.

In the Santa Maria Basin, the Paso Robles Formation lies conformably upon the Careaga Formation; where the Careaga Formation is absent, the formation lies unconformably upon undifferentiated Tertiary rocks or basement complex. In the Pismo Basin, the Paso Robles Formation lies unconformably upon rocks of late Pliocene age or upon many of the older rock units in the area (Hall, 1973).

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 characteristic, but discontinuous, 50- to 100-foot beds of clay and freshwater limestone; where these were absent, they used conglomerate as the base, but considered the base not well controlled; and, where there was neither clay nor conglomerate, 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

[6]The type region of the Paso Robles Formation is in the Salinas Valley. The usage of the formation name has been extended to nonmarine rocks of the same general stratigraphic position in the Santa Maria Basin by Woodring and Bramlette (1950) and to rocks in the Arroyo Grande 15' Quadrangle by Hall (1973).

Worts (1951), California Department of Water Resources (1958, 1970), Cleath & Associates (1996a), and Hanson et al. (1994).

Thickness of the formation within the study area varies considerably between the Pismo Basin and the Santa Maria Basin and within the basins themselves. In the Pismo Basin, the formation ranges from about 40 feet near Pismo Creek to about 250 feet near Arroyo Grande Creek and the Santa Maria River fault (Plate 3). In the Santa Maria Basin, the formation progressively thickens from about 200 feet along the northwestern margin of the basin (Plate 5) to about 700 feet at the Santa Maria River (Plate 4).

Individual beds 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." 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 beds within the Paso Robles Formation along the coast and inland. The coastal cross-section A-A′ (Plate 3) prepared for this study includes the correlations from the 1970 investigation.

Orcutt Formation. Worts (1951) reported that the late Pleistocene, essentially nonmarine, Orcutt Formation may be present beneath the Santa Maria Valley within the study area, where the lower member of the alluvium is missing. Based on the lithologs of the well completion 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. Where exposed, the thickness of the formation is about 100 feet (Hall, 1978b).

Older Alluvium and Terrace Deposits. Middle to late Pleistocene older alluvium is found on the floor of Nipomo Valley, lying unconformably upon undifferentiated Tertiary rocks, Miocene Obispo pyroclastics, or basement complex. The older alluvium 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.

Middle 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 one 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[7] 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 Basin, the alluvium overlies the Paso Robles Formation on the Arroyo Grande Plain, and it overlies older sedimentary or basement complex along Arroyo Grande Valley and Pismo Creek and their tributaries. 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 thickness of the alluvium normally ranged between 75 and 100 feet, with a maximum thickness of about 175 feet just 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 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 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.

[7] 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).

Clay beds within the alluvium were found to range in thickness from one foot to 30 feet in the Arroyo Grande Plain and from one foot to 170 feet (as reported on the litholog of well completion reports) in the Santa Maria Plain. As with the Paso Robles Formation, the individual beds 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 beds within the alluvium along the coast and inland. The coastal cross-section prepared for this study as cross-section A-A′ (Plate 3) includes the correlations from the 1970 investigation.

Dune Sand. Both late Pleistocene and Holocene eolian-deposited dune sand is within the study area (Plate 2). 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 Mesa triangular lobe of older dune sands is more than four 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. Lithologs of water wells indicate that the dune sands may contain perching layers of clay.

The older dunes have a maximum thickness of about 60 feet on the Tri-Cities Mesa and about 300 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

As mentioned at the beginning of the chapter, the region within which the study area lies is structurally and geomorphically distinct from surrounding areas in southern central coastal California. 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[8] San Luis/Pismo and Santa Maria Valley structural blocks, and a series of faults.

Synclines

The Santa Maria Valley syncline is an asymmetrical fold that developed within the northern part of the Santa Maria Basin. The syncline is evident only from subsurface data. The northern limb of the syncline, which lies within the study area, is a gentle subsurface fold and is bounded by the Santa Maria River fault. The axial trace of the syncline lies about six miles south of the county line, not along the middle of Santa Maria Valley. The Santa Maria syncline and its margins are cut by numerous faults of middle and late Cenozoic age.

The Pismo syncline is the dominant structural element of the San Luis Range. Field evidence gathered by Nitchman (1988) indicates that the syncline is an open, doubly plunging syncline composed of numerous small folds and subparallel axial traces. The syncline is bounded on the northeast and southwest 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 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; subsidiary folds are along the limbs of the larger fold (Hall and Corbato, 1967). The syncline 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 4 and Plate 2). The structural blocks were defined on the basis of 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 block is bordered on the southwest by a diffuse zone of late Quaternary west-northwest-trending, northeast-dipping reverse faults (Wilmar Avenue and Oceano faults) and monoclines that separate it from the subsiding Santa Maria Valley structural block. The northeast side of the block is bounded by the west-northwest-trending, southwest-dipping

[8]Post Miocene structures

FIGURE 4 - MAP OF STRUCTURAL BLOCKS IN THE SOUTH-CENTRAL CALIFORNIA COAST REGION

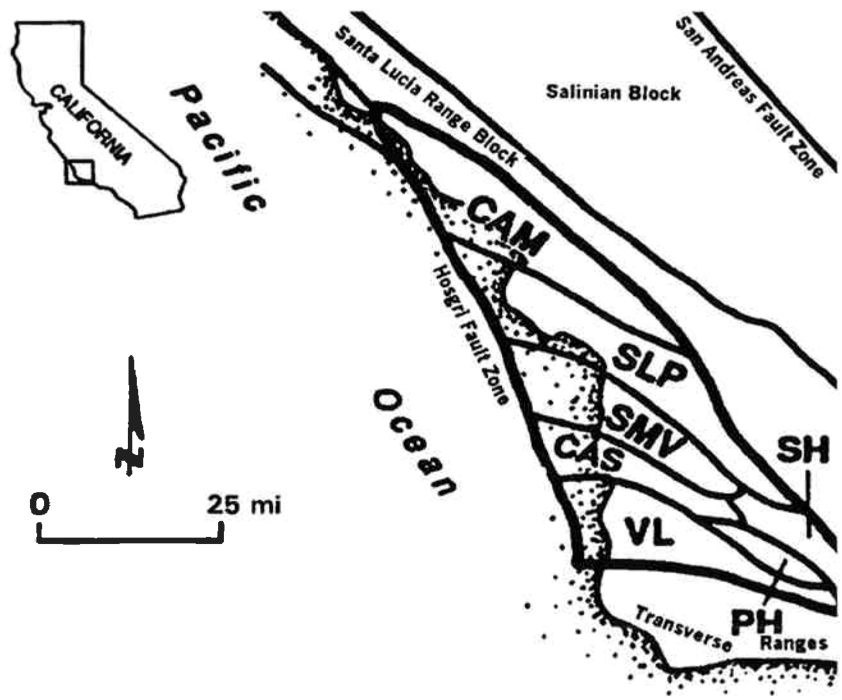


Figure simplified from Lettis, et al., 1994. Abbreviations are: CAM = Cambria block, SLP = San Luis/Pismo block, SMV = Santa Maria Valley block, CAS = Casmalia block, VL = Vandenberg/Lompoc block, PH = Purisima Hills block, SH = Solomon Hills block.

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 middle 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 4.

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 2.

Santa Maria River Fault. Hall (1978a, 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) the northward truncation of late Miocene and early Pliocene diatomaceous mudstone and siltstone associated with the Santa Maria Basin, (3) an up to the northeast vertical offset of Franciscan basement, and (4) other stratigraphic contrasts evident from subsurface data.[9] The fault appears to have played a major role in the formation of the Santa Maria Basin (Hall, 1978a, 1981, 1982). Hall (1982) mapped the subsurface location of the fault. The fault is shown at the surface only near Suey Ranch in Santa Barbara County by Dibblee (1994). The youngest fault activity along this fault may have occurred as recently as late Quaternary (Buchanan-Banks, et al., 1978; Hall, 1978a; and U. S. Geological Survey, 1981).

The fault trends west-northwest across the study area, extending offshore near Oceano and merging with the offshore north-striking Hosgri fault zone. At the coast, the location of the fault is constrained by its intersection with the Madonna Construction Company's Oceano 1 oil well at a depth of 1,000 feet (cross-section A-A′, Plate 3). Between Highway 1 and about one mile east of Zenon Way, the fault is constrained by water wells showing significant differences in water levels (Chapter V). To the southeast, from near the head of Black Lake Canyon to near Division Street, Hanson, et al. (1994) postulated a zone of subsurface steps or warps in the top of the bedrock, rather than a single fault. From the coast to its exposure at Suey Ranch, the fault is constrained by significant lithologic differences on opposite sides of the fault. Pismo Basin stratigraphy is displayed northeast of the fault and Santa Maria Basin stratigraphy is displayed southwest of the fault (discussed earlier in this chapter).

Cross-section A-A′ (Plate 3) shows the Santa Maria River fault coinciding with the Oceano fault at the coast and about 90 feet of vertical offset of the base of the Squire Member/Pismo Formation and the base of the Careaga Formation. The section also shows the juxtaposition of Franciscan basement rocks against the Careaga Formation and undifferentiated Tertiary sediments of the Santa Maria Basin. It is not known how much, if any, of the offset across the faults may be attributed to activity of the Santa Maria River fault. Cross-section B-B′ (Plate 4) shows vertical offset of about 250 feet of the base of the Squire Member/Pismo Formation and

[9] 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.

the base of the Careaga Formation and Franciscan Complex (?) juxtaposed to the Careaga Formation. Cross-section C-C′ (Plate 5) shows vertical offset of about 180 feet of the base of the Squire Member/Pismo Formation and the base of the Careaga Formation and the juxtaposition of the Knoxville Formation (?) to the Careaga Formation.

West Huasna Fault Zone. This major northwest-trending fault zone transects the northeastern edge of the study area, crossing the Arroyo Grande Valley approximately a mile downstream from Lopez Dam and bounding Pismo and Huasna 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 Edna fault zone forms the northern boundary of the Pismo syncline (Hall, 1973). Nitchman (1988) defined it as a high-angle right strike-slip fault that juxtaposes Miocene and Pliocene strata against Franciscan basement rocks. Lettis et al. (1994) interpreted the fault as a zone of high-angle, down-to-the-southwest normal faulting. The Edna fault is considered by Lettis and Hall (1994) to be the southwestern part of the Los Osos fault zone. Hall (1973) stated that the Edna fault cuts late Pliocene and Pleistocene strata. Detailed bedrock mapping and trenching conducted by Lettis et al. (1994) confirmed that the Edna fault has had no late Quaternary movement.

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 is exposed only at a sea cliff in Pismo Beach and extends at least to Arroyo Grande. 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). The fault extends offshore, veering slightly to the west for at least three miles (Nitchman, 1988; Pacific Gas and Electric Company, 1988; Lettis et al., 1994).

Cross-section A-A′ (Plate 3) intersects the western segment of the fault, and cross-section B-B′ (Plate 4) intersects the eastern segment.

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 subtle geomorphic and geologic features, including a straight segment of Nipomo Creek. Cross-section C-C′ (Plate 5) illustrates the juxtaposition of the Miocene Monterey Formation with the Paso Robles Formation and Squire Member/Pismo Formation across this postulated extension of the Wilmar Avenue fault.

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 offsets the base of the Careaga Formation about 200 feet (Plate 4) and about 250 feet (Plate 5) across the fault under central Nipomo Mesa. The vertical separation of the upper contact of the Franciscan Complex is about 500 feet across the fault. 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 that can be attributed solely to activity of the Oceano fault is not known.

This Page Intentionally Blank

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 and Lopez Reservoir, State Water Project, and recycled water provide the area's supply. Water demand/supply totals may not sum because of rounding.

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

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. Groundwater extractions for the large water purveyors are measured by flowmeters and both quantity and quality data are reported to various regulatory agencies. Groundwater extractions for small public and private water purveyors are usually not measured or metered and, more importantly, both quantity and quality data are not reported to any regulatory agency.

Applied Water Demand

Table 2 depicts applied water demand in the study area for 1975 through 2020 for urban, agricultural, and other (includes environmental) categories. Applied water is that water delivered to the intake of a water system or farm headgate. Total applied water demand decreased by 2,400 acre-feet (AF), from 39,900 AF in 1975 to 37,500 AF in 1995, because of decreased agricultural demand. Year 2020 total applied water demand is projected to increase about 9,800 AF over 1995 levels, with the additional amount attributable to increased urban demand of about 8,000 AF and environmental demand of 2,800 AF. Agricultural demand constituted the largest demand in the study area, accounting for about 80 percent of the total in 1975 and declining to about 70 percent of the total in 1995. From 1995 to 2020, agricultural demand is projected to decrease by 1,000 AF and by 2020 will account for about 50 percent of the total applied demand. Average annual decreases of about 115 AF for applied water demand were realized in the 21-year period 1975 through 1995 and an average annual increase of about 400 AF of applied water demand is expected between 1995 and 2020.

Total applied water demand overlying the main Santa Maria Groundwater Basin increased about 12 percent between 1975 and 1995 and by 2020 demand was projected to be 36,200AF, an increase of about 30 percent over the 1995 total demand of 27,500 AF (Table 2).

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

Water Demand Within Study Area/ *Overlying the Main Santa Maria Groundwater Basin*	1975	1980	1985	1990	1995	2010	2020
Urban	6.6	8.1	12.0	13.2	11.3	16.3	19.2
Groundwater Basin	*6.4*	*7.9*	*11.5*	*12.6*	*10.9*	*15.8*	*18.5*
Agricultural	32.3	30.7	26.9	25.4	25.1	23.7	24.1
Groundwater Basin	*17.2*	*18.2*	*19.2*	*17.4*	*15.5*	*14.6*	*15.1*
Other**	1.0	1.0	1.1	1.1	1.1	4.0	4.0
*Groundwater Basin****	*1.0*	*1.0*	*1.1*	*1.1*	*1.1*	*2.6*	*2.6*
Study Area Total	39.9	39.8	40.0	39.7	37.5	44.0	47.3
Groundwater Basin Total	*24.6*	*27.1*	*31.8*	*31.1*	*27.5*	*32.9*	*36.2*

*All values rounded to the nearest 100 acre-feet.
**Values for 2010 and 2020 include 2,800 AF of applied environmental demand.
***Values for 2010 and 2020 include 1,400 AF of applied environmental demand.

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

Hydrologic Area/Subarea *Division Within Main Santa Maria Groundwater Basin*	1975	1980	1985	1990	1995	2010	2020
Pismo/Oceano HSA	32,910	33,500	39,150	44,800	47,090	60,440	67,810
*Tri-Cities Mesa - Arroyo Grande Plain***	*31,260*	*31,840*	*37,190*	*41,570*	*44,730*	*57,420*	*64,420*
Nipomo Mesa HSA							
*Nipomo Mesa****	*5,530*	*6,490*	*7,580*	*9,660*	*10,400*	*17,900*	*22,960*
Guadalupe HA	2,460	2,600	3,150	3,700	4,030	5,590	6,760
Santa Maria Valley	*2,340*	*2,560*	*2,990*	*3,560*	*3,830*	*5,310*	*6,420*
Study Area Total	41,190	43,040	50,280	57,680	62,060	84,880	98,740
Groundwater Basin Total	*39,130*	*40,890*	*47,760*	*54,790*	*58,960*	*80,640*	*93,790*

Note: All values rounded to the nearest 10 persons.
*All values from DOF Special Projections for DWR, May 1996.
**Division includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
***This portion of the main groundwater basin lies entirely within the HSA.

Trends in population and land use affect the applied water demands within the study area.

Population and Land Use

The population is concentrated in small communities. Small family homesteads are also distributed throughout the study area. Table 3 depicts population for 1975 through 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 over 1995 levels by 2020, with a total population in 2020 of more than 98,000. Population overlying the main groundwater basin increased by almost 20,000 between 1975 and 1995 and is expected to increase by almost 35,000 by 2020, with a 2020 population of almost 94,000.

Land use in the study area was surveyed by the Department in 1977, 1985, and 1995, and the resultant maps were digitized using AutoCAD. A geographic information system (GIS) was used to determine the spatial distribution 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.

The detailed land use acreages obtained from the GIS were divided into their respective hydrologic areas and subareas. These acreages were then divided as being either within the main groundwater basin, within the groundwater subbasins, or outside the main groundwater basin and subbasins. Finally, the detailed land use acreages were aggregated into agricultural, native, and urban classifications as depicted in Table 4.

Urban Applied Demand

Urban applied water demand[1] for each hydrologic area and hydrologic subarea in the study area for 1975 through 2020 is shown in Table 5. Population figures for each hydrologic area and 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.

Population increased by about 21,000 persons between 1975 and 1995 resulting in an increase of 4,700 AF in total urban applied water demand, from the 6,600 AF to 11,300 AF, 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 37,000 persons, or 59 percent, in the same period. Urban applied water demand overlying the main groundwater basin increased by 4,500 AF between 1975 and 1995 and is expected to increase by 7,600 AF over 1995 levels by 2020.

Agricultural Applied Demand

Agricultural applied water demand by hydrologic area and hydrologic subarea for 1975 through

[1]Urban applied water demand includes demand for golf course irrigation.

TABLE 4
LAND USE ACREAGE WITHIN STUDY AREA
In Acres*

Hydrologic Area/Subarea	Land Use Category	Within Main Groundwater Basin 1975	1985	1995	Within Subbasins 1975	1985	1995	Within Watershed Outside Main Groundwater Basin and Subbasins 1975	1985	1995	Total Within Hydrologic Area/Subbarea 1975	1985	1995
Pismo		Pismo Creek			Pismo Creek Valley Subbasin			Remaining Area			Subtotal		
	Agriculture **	0	20	0	10	30	0	10	0	0	20	50	0
	Urban	220	240	270	80	140	180	270	510	570	570	890	1,020
	Native	100	60	50	1,130	1,050	1,040	7,100	6,870	6,810	8,330	7,980	7,900
	Total	320	320	320	1,220	1,220	1,220	7,380	7,380	7,380	8,920	8,920	8,920
Oceano		Tri-Cities Mesa - Arroyo Grande Plain***			Arroyo Grande Valley			Remaining Area			Subtotal		
	Agriculture **	3,060	2,760	2,590	1,620	1,900	1,920	1,580	1,810	1,200	6,260	6,470	5,710
	Urban	3,220	3,730	4,070	270	370	380	1,790	2,220	3,160	5,280	6,320	7,610
	Native	4,170	3,960	3,790	1,970	1,590	1,560	35,200	34,540	34,210	41,340	40,090	39,560
	Total	10,450	10,450	10,450	3,860	3,860	3,860	38,570	38,570	38,570	52,880	52,880	52,880
Nipomo Mesa		Nipomo Mesa									Subtotal		
	Agriculture **	1,420	1,430	1,220							1,420	1,430	1,220
	Urban	1,230	2,530	4,670							1,230	2,530	4,670
	Native	14,930	13,620	11,690							14,930	13,620	11,690
	Total	17,580	17,580	17,580							17,580	17,580	17,580
Guadalupe		Santa Maria Valley			Nipomo Valley			Remaining Area			Subtotal		
	Agriculture **	6,630	9,540	9,330	2,890	3,460	3,330	3,280	3,480	3,440	12,800	16,480	16,100
	Urban	500	1,150	1,560	280	310	490	0	50	120	780	1,510	2,170
	Native	14,430	10,870	10,670	3,060	2,460	2,410	7,490	7,240	7,210	24,980	20,570	20,290
	Total	21,560	21,560	21,560	6,230	6,230	6,230	10,770	10,770	10,770	38,560	38,560	38,560
						Study Area Totals							
	Agriculture **	11,110	13,750	13,140	4,520	5,390	5,250	4,870	5,290	4,640	20,500	24,430	23,030
	Urban	5,170	7,650	10,570	630	820	1,050	2,060	2,780	3,850	7,860	11,250	15,470
	Native	33,630	28,510	26,200	6,160	5,100	5,010	49,790	48,650	48,230	89,580	82,260	79,440
	Total	49,910	49,910	49,910	11,310	11,310	11,310	56,720	56,720	56,720	117,940	117,940	117,940

*All values rounded to the nearest 10 acres
**Includes irrigated and nonirrigated lands
***Includes Los Berros Creek portion of the main groundwater basin.

TABLE 5
URBAN APPLIED WATER DEMAND *
Thousands of acre-feet

Hydrologic Area/Subarea *Division Within Main Santa Maria Groundwater Basin*	1975	1980	1985	1990	1995	2010	2020
Pismo/Oceano HSA	4.8	5.7	8.5	8.7	7.7	10.4	11.7
*Tri-Cities Mesa - Arroyo Grande Plain***	*4.6*	*5.5*	*8.1*	*8.1*	*7.3*	*9.9*	*11.1*
Nipomo Mesa HSA							
*Nipomo Mesa****	*1.5*	*2.1*	*3.0*	*3.9*	*3.1*	*5.2*	*6.6*
Guadalupe HA	0.3	0.3	0.5	0.6	0.5	0.7	0.9
Santa Maria Valley	*0.3*	*0.3*	*0.4*	*0.6*	*0.5*	*0.7*	*0.8*
Study Area Total	6.6	8.1	12.0	13.2	11.3	16.3	19.2
Groundwater Basin Total	*6.4*	*7.9*	*11.5*	*12.6*	*10.9*	*15.8*	*18.5*

Note: All values rounded to the nearest 100 acre-feet.
*Demand values derived by multiplying population by per capita water use.
**Division includes lower Pismo Creek and Los Berros Creek portions of the main groundwater basin.
***This portion of the main groundwater basin lies entirely within the HSA.

2020 is shown in Table 6. Unit applied water for each crop category is determined by dividing evapotranspiration of applied water 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 7,200 AF from the 32,300 AF in 1975 to 25,100 AF in 1995. Year 2020 agricultural applied water demand is expected to decrease 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.

Agricultural applied water demand overlying the main groundwater basin decreased 1,700 AF between 1975 and 1995 and is expected to decrease by another 400 AF by 2020. The agricultural demand overlying the main groundwater basin is relatively constant compared with demand in the entire study area. This suggests that most of the changes in agricultural crop type and water use are occurring outside the main groundwater basin.

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

Environmental Applied Demand

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

TABLE 6
AGRICULTURAL APPLIED WATER DEMAND
Thousands of acre-feet

Hydrologic Area/Subarea *Division Within Main Santa Maria Groundwater Basin*	1975	1980	1985	1990	1995	2010	2020
Pismo/Oceano HSA*	10.5	10.6	9.0	9.4	9.6	9.0	8.8
*Tri-Cities Mesa - Arroyo Grande Plain***	*4.7*	*4.2*	*3.7*	*3.3*	*3.0*	*2.8*	*2.8*
Nipomo Mesa HSA							
*Nipomo Mesa****	*1.4*	*1.7*	*2.0*	*1.9*	*1.6*	*1.6*	*1.6*
Guadalupe HA	20.4	18.4	15.9	14.1	13.9	13.1	13.7
Santa Maria Valley	*11.1*	*12.3*	*13.5*	*12.2*	*10.9*	*10.1*	*10.7*
Study Area Total	32.3	30.7	26.9	25.4	25.1	23.7	24.1
Groundwater Basin Total	*17.2*	*18.2*	*19.2*	*17.4*	*15.5*	*14.5*	*15.1*

Note: All values rounded to the nearest 100 acre-feet.
*The irrigated cropped acres in Pismo HSA for 1975 was 11.4; 1985, 26.6; and 1995, 0.0. Demand associated with these acreages amounted to less than 100 AF; therefore, the demand was combined for the two HSAs.
**Division includes lower Pismo Creek and Los Berros Creek portions of the main groundwater basin.
***This portion of the main groundwater basin lies entirely within the HSA.

the study is completed, the county is conducting an interim supplemental release program of 2,800 acre-feet per year (AFY) from Lopez Dam for maintaining steelhead habitat. The supplemental 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.

This environmental applied demand is included in Pismo/Oceano HSA's other applied water demand values for 2010 and 2020 in Table 7. The stretch of Arroyo Grande Creek overlying the main groundwater basin is about half of the length of the creek from Lopez Dam to its confluence with the Pacific Ocean. Therefore, the 2010 and 2020 environmental demands shown in Table 7 for Tri-Cities Mesa and Arroyo Grand Plain are half of the county's proposed release of 2,800 AFY.

Several Sensitive Resource Areas (SRA) are 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 for local waterfowl. The Oso Flaco Lake SRA serves as a local wetland complex providing habitat for

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

Hydrologic Area/Subarea *Division Within Main Santa Maria Groundwater Basin*	1975	1980	1985	1990	1995	2010	2020
Pismo/Oceano HSA**	0.05	0.05	0.09	0.09	0.09	2.92	2.94
*Tri-Cities Mesa - Arroyo Grande Plain****	*0.05*	*0.05*	*0.09*	*0.09*	*0.09*	*1.52*	*1.54*
Nipomo Mesa HSA							
Nipomo Mesa+	*0.95*	*0.95*	*0.96*	*0.96*	*0.97*	*0.97*	*0.98*
Guadalupe HA	0.03	0.04	0.04	0.05	0.06	0.07	0.08
Santa Maria Valley	*0.03*	*0.04*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*
Study Area Total	1.03	1.04	1.09	1.10	1.12	3.96	4.00
Groundwater Basin Total	*1.03*	*1.04*	*1.09*	*1.10*	*1.12*	*2.56*	*2.60*

Note: All values rounded to the nearest 10 acre-feet.
*Values for 2010 and 2020 are estimated based on historical trends.
**Values for 2010 and 2020 include 2,800 AF of applied environmental demand.
***Values for 2010 and 2020 include 1,400 AF of applied environmental demand - half of the release is attributable to the area overlying the main groundwater basin. Division includes lower Pismo Creek and Los Berros Creek portions of the main groundwater basin.
+This portion of the main groundwater basin lies entirely within the HSA.

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 (one to three miles) upstream of the ocean. The Santa Maria River and its tributaries also support the threatened California red-legged frog. Habitat for the red-legged frog and the endangered Pismo clarkia plant is found in the Arroyo Grande Creek 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,[2] and environmental water demands. Table 7 lists other applied water demands by hydrologic area or subarea for 1975 through 2020. Water demand for this category increased by 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 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 values for the other applied water demand category for the main groundwater basin differ only by the 1,400 AF reduction for steelhead releases. All other components remain the same.

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 the calculations for this study.

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, p. 69) reviewed the hydrologic impacts of eucalyptus on Nipomo Mesa and 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."

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 recycled water.

Water supply for each hydrologic area and hydrologic subarea in the study area for 1975 through 2020 is shown in Table 8. Total water supply in the study area decreased by 2,500 AF, from 40,100 AF in 1975 to 37,600 AF in 1995, because of decreased groundwater extractions. Year 2020 water supply is projected to increase 9,700 AF over 1995 levels with the additional water supply coming from increased groundwater extractions, State Water Project deliveries, environmental releases from Lopez Reservoir, and recycled water. Supplies appear adequate to meet water demands through water year 2020.

The total water supply overlying the main groundwater basin increased by 2,800 AF from 1975 to 1995. Year 2020 water supply is projected to increase 8,700 AF over 1995 levels with the

[2]Recreational demand does not include demand for golf course irrigation water. That demand is included in the urban demand category.

TABLE 8
STUDY AREA WATER SUPPLIES
Thousands of acre-feet

Hydrologic Area/Subarea *Division Within Main Santa Maria Groundwater Basin*	Supply Source	1975	1980	1985	1990	1995	2010	2020
Pismo/Oceano HSA	Groundwater	10.1	10.3	9.1	8.6	10.0	10.1	11.0
	Surface*	5.3	6.1	8.5	9.6	7.4	12.2	12.4
*Tri-Cities Mesa - Arroyo Grande Plain***	*Groundwater*	*4.6*	*4.2*	*4.3*	*3.2*	*3.8*	*4.4*	*5.4*
	*Surface****	*4.8*	*5.6*	*7.6*	*8.3*	*6.6*	*9.8*	*10.1*
Nipomo Mesa HSA								
Nipomo Mesa+	*Groundwater*	*4.0*	*4.7*	*5.9*	*6.7*	*5.7*	*7.8*	*9.2*
Guadalupe HA	Groundwater	20.7	18.7	16.4	14.8	14.5	13.9	14.7
Santa Maria Valley	*Groundwater*	*11.4*	*12.6*	*13.9*	*12.9*	*11.5*	*10.9*	*11.6*
Study Area Total	Groundwater	34.8	33.7	31.4	30.1	30.2	31.8	34.9
	Surface*	5.3	6.1	8.5	9.6	7.4	12.2	12.4
	Total	40.1	39.8	39.9	39.7	37.6	44.0	47.3
Groundwater Basin	*Groundwater*	*20.0*	*21.5*	*24.1*	*22.8*	*21.0*	*23.1*	*26.2*
	*Surface****	*4.8*	*5.6*	*7.6*	*8.3*	*6.6*	*9.8*	*10.1*
	Total	*24.8*	*27.1*	*31.7*	*31.1*	*27.6*	*32.9*	*36.3*

Note: All values rounded to the nearest 100 acre-feet. Water demand/supply totals may not sum because of rounding.

*Values for 1975 through 1995 include Lopez Reservoir deliveries to urban agencies and downstream releases for agriculture (Table 10). Values for 2010 and 2020 include State Water Project deliveries of 1,350 AF and 1,590 AF, respectively and Lopez Reservoir deliveries and releases of 8,000 AF for urban and agricultural demands and environmental releases of 2,800 AF.

**Division includes lower Pismo Creek and Los Berros Creek portions of the main groundwater basin.

***Values for 1975 through 1995 include Lopez Reservoir deliveries to urban agencies and downstream releases for agriculture. Values for 2010 and 2020 include State Water Project deliveries of 1,350 AF and 1,590 AF, respectively and Lopez Reservoir deliveries and releases of 8,000 AF for urban and agricultural demands and environmental releases of 1,400 AF.

+This portion of the main groundwater basin lies entirely within the HSA.

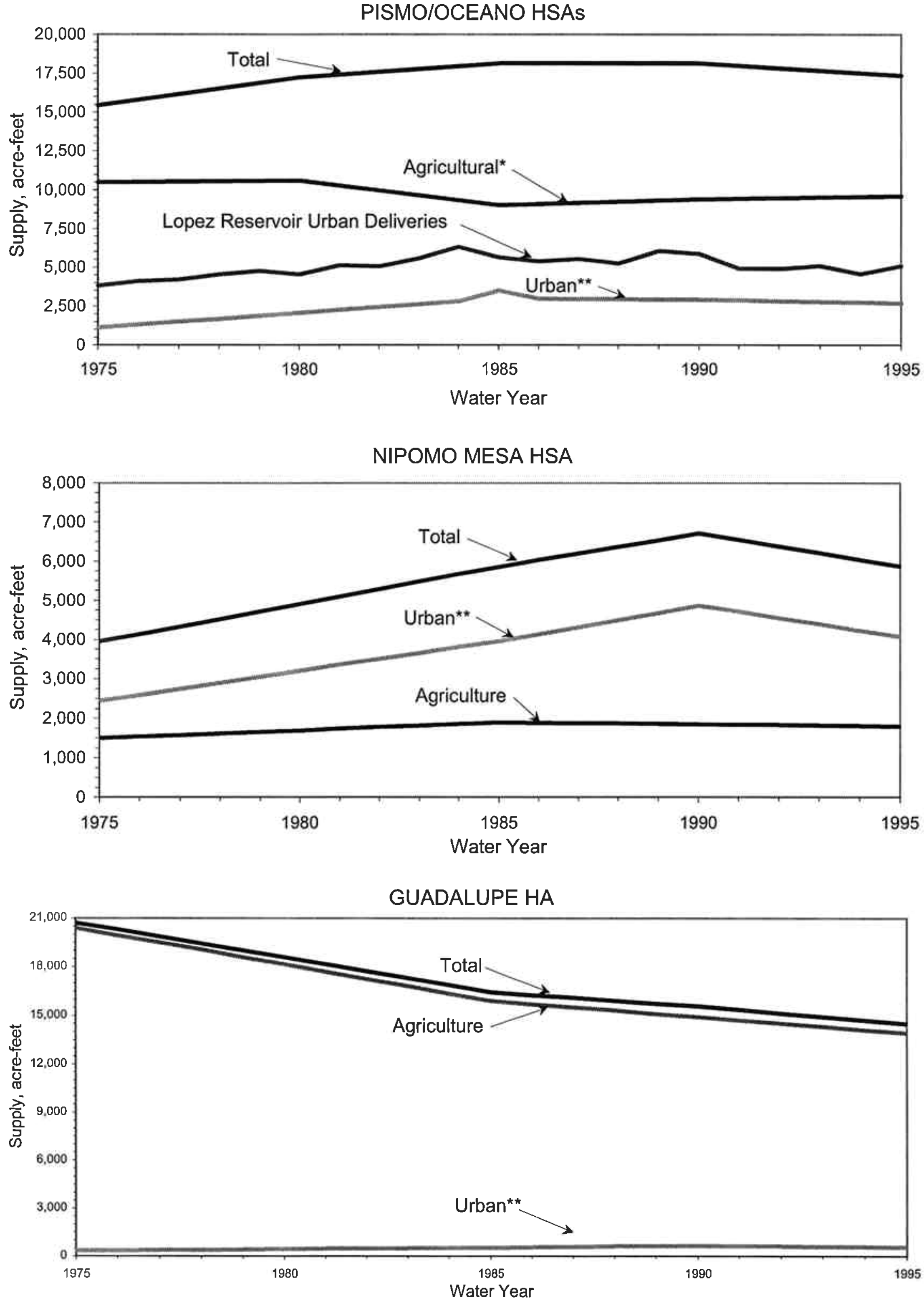
additional water supply coming from those sources mentioned above for the study area.

Figure 5 shows the relative changes in amounts of urban and agricultural water supplies and Lopez Reservoir deliveries between 1975 and 1995.

Groundwater

As Table 8 shows, groundwater is the largest single source of water supply in the study area. Total groundwater extractions within the study area decreased by 4,600 AF from 34,800 AF in 1975 to 30,200 AF in 1995, but year 2020 groundwater extractions are expected to increase

FIGURE 5 - 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).

4,700 AF over 1995 levels. Figure 6 shows the amounts of groundwater extractions in water year 1995 within the study area.

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 2,100 AF from 5,300 AF in 1975 to 7,400 AF in 1995, and year 2020 surface water supply is expected to increase 5,000 AF over 1995 levels. State Water Project deliveries were estimated to be 1,350 AF in 2010, 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 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; about 192,000 AF were delivered to municipal and agricultural interests between 1969 and 1995. 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 water years 1969 through 1995 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

TABLE 9
LOPEZ RESERVOIR ENTITLEMENTS
In acre-feet

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

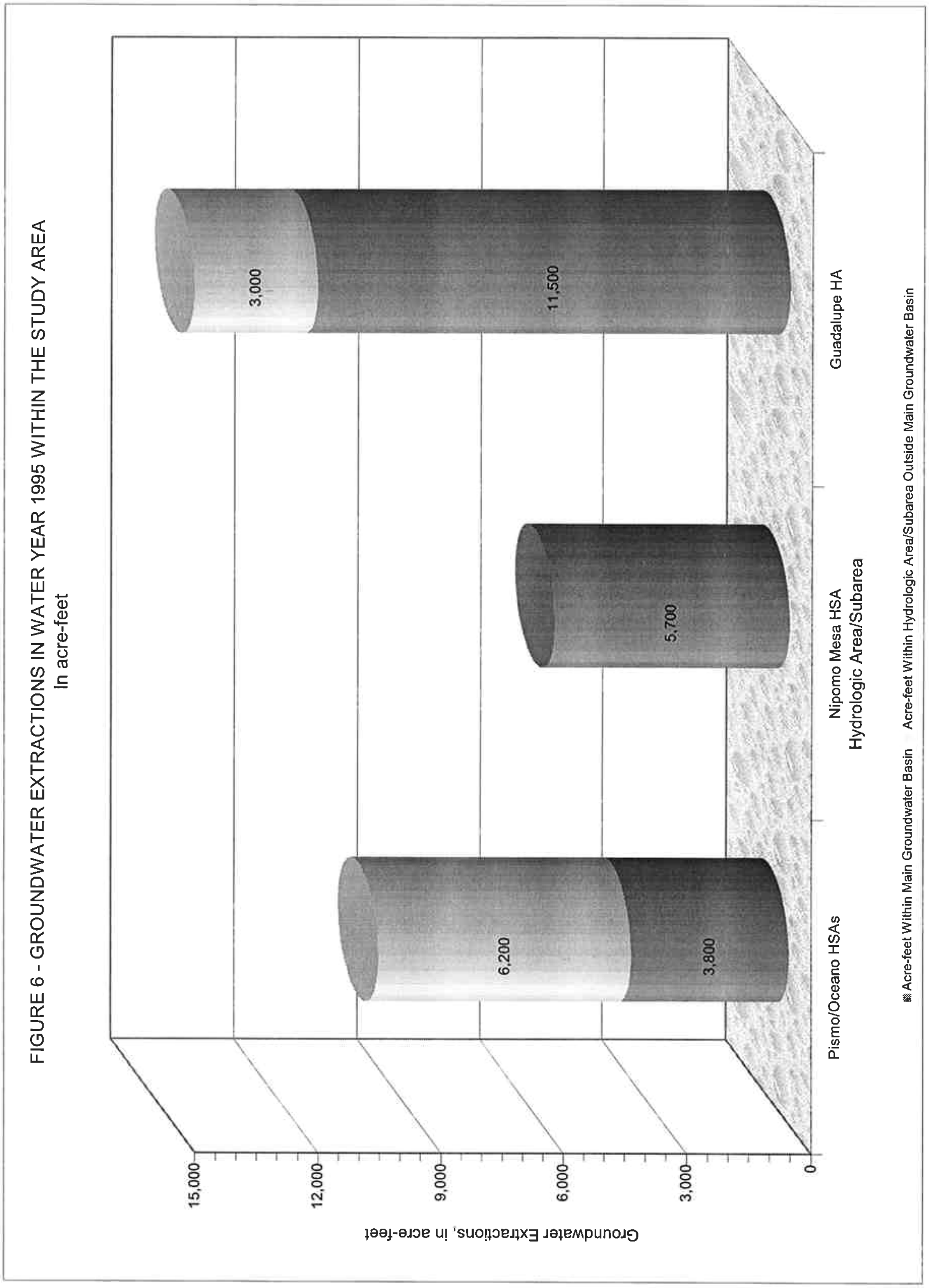


FIGURE 6 - GROUNDWATER EXTRACTIONS IN WATER YEAR 1995 WITHIN THE STUDY AREA
In acre-feet

TABLE 10
LOPEZ RESERVOIR WATER DELIVERIES TO CONTRACTORS,* 1969 through 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

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 December 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. Plate 1 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 up to 400 AF of its entitlement, according to a spokesperson for the District.

Recycled Water

Recycled 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.

Present Facilities. Plate 6 depicts the locations of existing and proposed wastewater treatment plants (WWTPs) in the study area. Average yearly effluent[3] from each of the plants for 1990 through 1995 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, Southland, and Cypress Ridge WWTPs, 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 AFY. 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 AFY, and disposes of its effluent through the ocean outfall. The Tosco (formerly Unocal) WWTP, which began operation in 1954, produces about 650 AFY of effluent; this is disposed of through a company-owned and

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	1,130	3,030	50	210	470	4,890
1991	1,190	2,980	50	200	560	4,980
1992	1,130	2,840	60	240	660	4,930
1993	1,240	2,890	70	250	660	5,110
1994	1,050	2,900	90	290	560	4,890
1995	1,130	2,920	80	330	660	5,120

Note: All values rounded to the nearest 10 acre-feet.
*Formerly Unocal. Only refinery discharge water is treated prior to ocean disposal. No sewage is treated.

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

operated ocean outfall.

The Black Lake Golf Course WWTP when it began operation in 1986 had an operating capacity of 112 AFY. Expansion of the plant, doubling its capacity to 224 AFY, 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 recycled almost 80 AF of treated wastewater from the 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 AFY (Table 13).

The Southland WWTP, which began operation in 1985, had an operating capacity of 403 AFY. Initial expansion of the plant in 1999 increased its capacity to about 670 AFY with additional expansion, completed in 2000, increasing the plant's capacity to about 1,050 AFY (Ibid.). Disposal of effluent is through several aerated lagoons and eventually infiltration to the groundwater basin. In 1995, about 330 AFY of recycled water from the Southland WWTP was estimated to incidentally percolate to the groundwater basin. After both expansions of the plant, the incidental percolation was estimated to be about 1,000 AFY, with the remainder evaporating (Table 13).

The Cypress Ridge Development constructed a wastewater treatment plant with a capacity of 123 AFY. The plant is similar to the plant at Black Lake Golf Course with recycled water used to meet a portion of the development's golf course water demand. Incidental infiltration to the groundwater basin from golf course irrigation is estimated to be six AFY at build out (Table 13).

TABLE 13
INCIDENTAL GROUNDWATER RECHARGE OF RECYCLED WATER
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
2010	950	20	1,000	6	30	1,756
2020	950	20	1,000	6	30	1,756

Note: All values estimated to the nearest acre-foot.
N/A: not applicable
*South SLO County is a potential recharge amount.
**Incidental recharge from recycled water for irrigation.

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 potential 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 L. Wallace & Associates (1996). They found that further research of the market for recycled water use in the area was needed and a progress report was published in 2001. The study showed that the market for secondary effluent quality recycled water accounted for only one percent of the current water demand within the District service area. Thus, a tertiary upgrade to the existing WWTP would be required to allow unrestricted use of treated wastewater.

The progress report also indicated that the tertiary quality recycled water market would expand if concentrations of chloride and Total Dissolved Solids were reduced. It was estimated that the combined tertiary recycled water market could exceed 2,600 AFY (more than 40 percent of the current water demand within the service area), with an additional 1,000 AFY of demand potentially realized in the Nipomo area.

In the above-mentioned 2001 report, four alternatives (10 sub-alternatives) were considered for providing recycled water within the district service area and to specific potential demands outside the area. The alternatives are: (1) direct landscape irrigation using 130 to 595 AFY of tertiary recycled water or 76 AFY of secondary-23[4] recycled water; (2) groundwater recharge of 950 AFY of demineralized tertiary recycled water in Tri-Cities Mesa, plus landscape irrigation; (3) direct crop irrigation in Tri-Cities Mesa and stream augmentation of Arroyo Grande Creek using 950 AFY of demineralized tertiary recycled water; and (4) direct industrial reuse for cooling at the Tosco refinery of 950 AFY of demineralized tertiary recycled water (Tosco has expressed no interest in using the recycled water). The cost of the alternatives ranges from $2,200/AF for direct landscape irrigation using secondary-23 recycled water to $8,500/AF for direct landscape irrigation using tertiary recycled water within the entire service area. The costs were found to be up to tenfold the cost of potable water in the area and prohibitive. If any of these alternatives is adopted, up to about 950 AFY of recycled water could incidentally recharge the groundwater basin in the future (Table 13).

The baseline environmental assessment and constraint analysis and supplemental environmental impact report for the Woodlands Specific Plan depicts the construction of a wastewater treatment plant similar to the plant at Black Lake Golf Course. The plant will have a capacity of 350 AFY and produce tertiary quality recycled water 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

[4]Number refers to most probable number count of total coliform bacteria in 100 milliliters.

irrigation is estimated to be 30 AFY for Woodlands at build out (Table 13).

Recycled water is being increasingly used for various beneficial purposes throughout California, the U.S., and the world. The State of California has a goal of 1,000,000 AF of recycled water use by year 2020. In 1995 within the study area, about 4,700 AF of wastewater treatment plant effluent was disposed of through ocean outfall discharge. This water could be treated to suitable standards and beneficially used in various ways.

IV. HYDROLOGY

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

Many of the precipitation and stream gaging stations used for analysis in the study area do not have a long-term record, a continuous record, or both. Data for some of the gaging stations were missing for a number of days, months, or years. Measurements at some stations were discontinued, leaving data gaps.

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. Data for water years 1996 through 2000 were also arranged into a water year format and are included in Appendix B, but they were not used in the hydrologic analysis for the base period. 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. Plate 7 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.

---

[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.

TABLE 14
PRECIPITATION STATIONS

Data Point Number	Gage Number	Station Name	Long-Term Average Precipitation to 1995, Inches
1	1.0	California State Polytechnic University	22.00
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, San Luis Obispo	19.98
7	55.0	Union Oil Company, Avila Beach	17.61
8	85.0	County Yard, Arroyo Grande	15.98
9	87.0	Police Department, Arroyo Grande	15.17
10	100.0	Ranchita Ranch	22.24
11	126.0	Police Department, Pismo Beach	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, San Luis Obispo	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, Oceano	15.84
20	175.1	Penny Ranch	19.00
21	177.1	Corporate Yard, Arroyo Grande	15.41
22	178.1	Lopez Dam, Lopez Reservoir	20.04
23	178.2	Tar Spring, USGS	15.58
24	179.1	Water Treatment Plant, Lopez Ter. Res.	16.84
25	193.0	Wastewater Plant, Lopez Lake	21.78
26	194.0	Wastewater Plant, Oceano	16.90
27	195.1	Police Department, Arroyo Grande	14.63
28	200.0	M. Bolding - Printz Road	18.17
29	205.0	County Yard, Arroyo Grande	14.47
30	205.2	Holzingers Cow Camp	18.28
31	BET387	Betteravia Union Sugar Company	13.42
32	PUR352	Puritan Ice Company	12.38
33	SMC380	Santa Maria City	13.41
34	SMH400	Santa Maria State Hwy. Maintenance Yard	13.59
35	UBA410	Union Oil Battles Plant, Santa Maria	12.74
36	UGO407	Union Oil Company, Guadalupe	13.71

Plate 8 shows lines of equal mean annual precipitation in and around the study area for water years 1870 through 1995. The isohyets were constructed using only those stations shown on Plate 8. 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 through water year 2000 for stations California State Polytechnic University at San Luis Obispo, Nipomo 2NW, and City of Santa Maria are shown in Figures 7-9, respectively. Because of the wet water year 1998, the long-term mean for the period of record through water year 2000 increased about 0.2 to 0.4 inch from the long-term mean for the period of record through water year 1995 at these stations. Similar increases were also seen at other stations (Appendix B).

Figure 10 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 are consistent. The station is located near the geometric center of the study area in Nipomo Valley and has a long-term continuous record.

From the data for the Nipomo 2NW station, water years 1984 through 1995 were selected as the base hydrologic period for this study. (See Appendix B for a detailed determination of the base hydrologic period.)

Precipitation data for Nipomo Mesa are lacking and installation of a station near Highway 1 and Willow Road could prove useful.

Surface Water

Watercourses contributing to the water supply are depicted in Plate 9. 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 Plate 9, 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

---

[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).

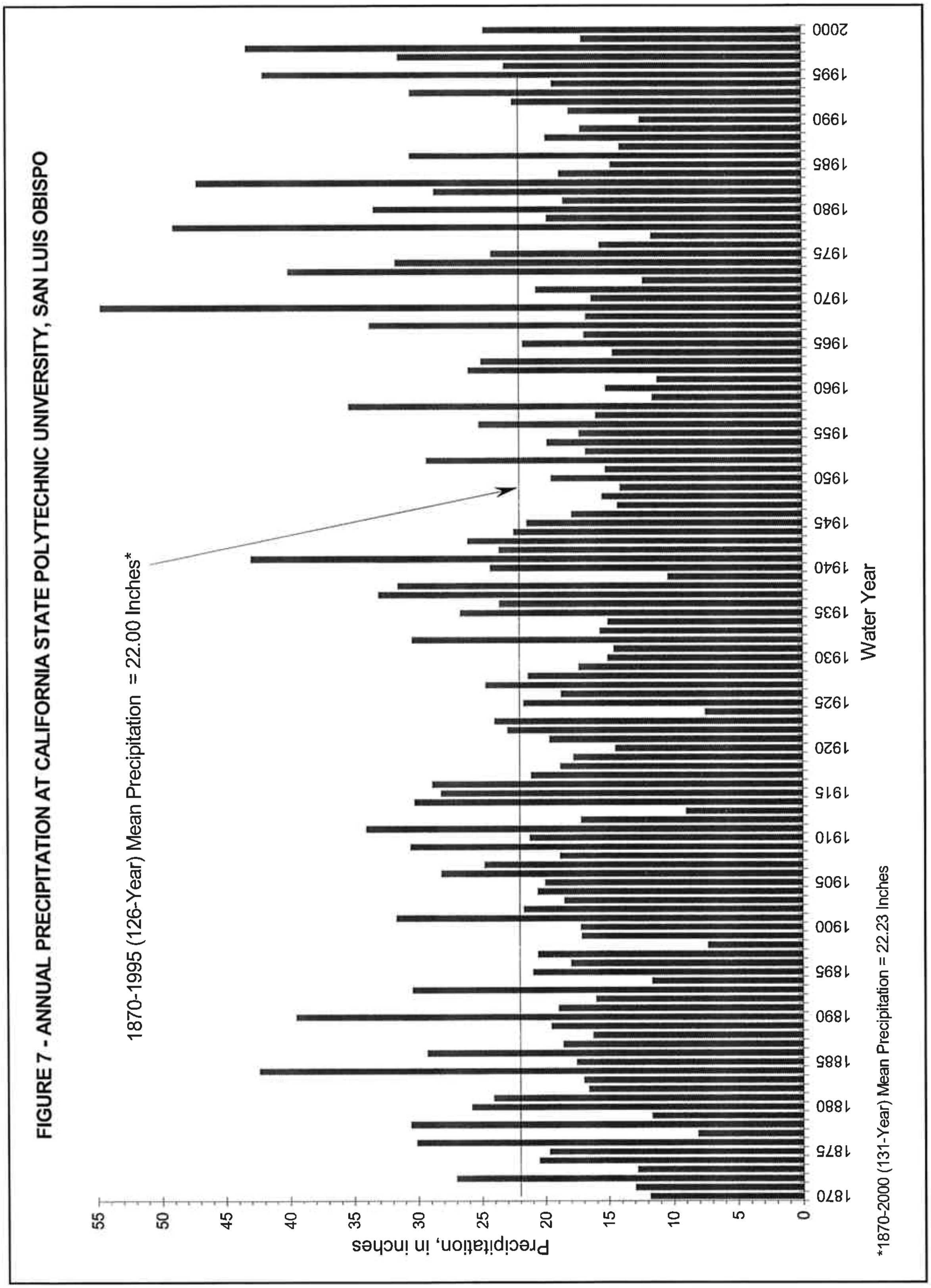


FIGURE 7 - ANNUAL PRECIPITATION AT CALIFORNIA STATE POLYTECHNIC UNIVERSITY, SAN LUIS OBISPO

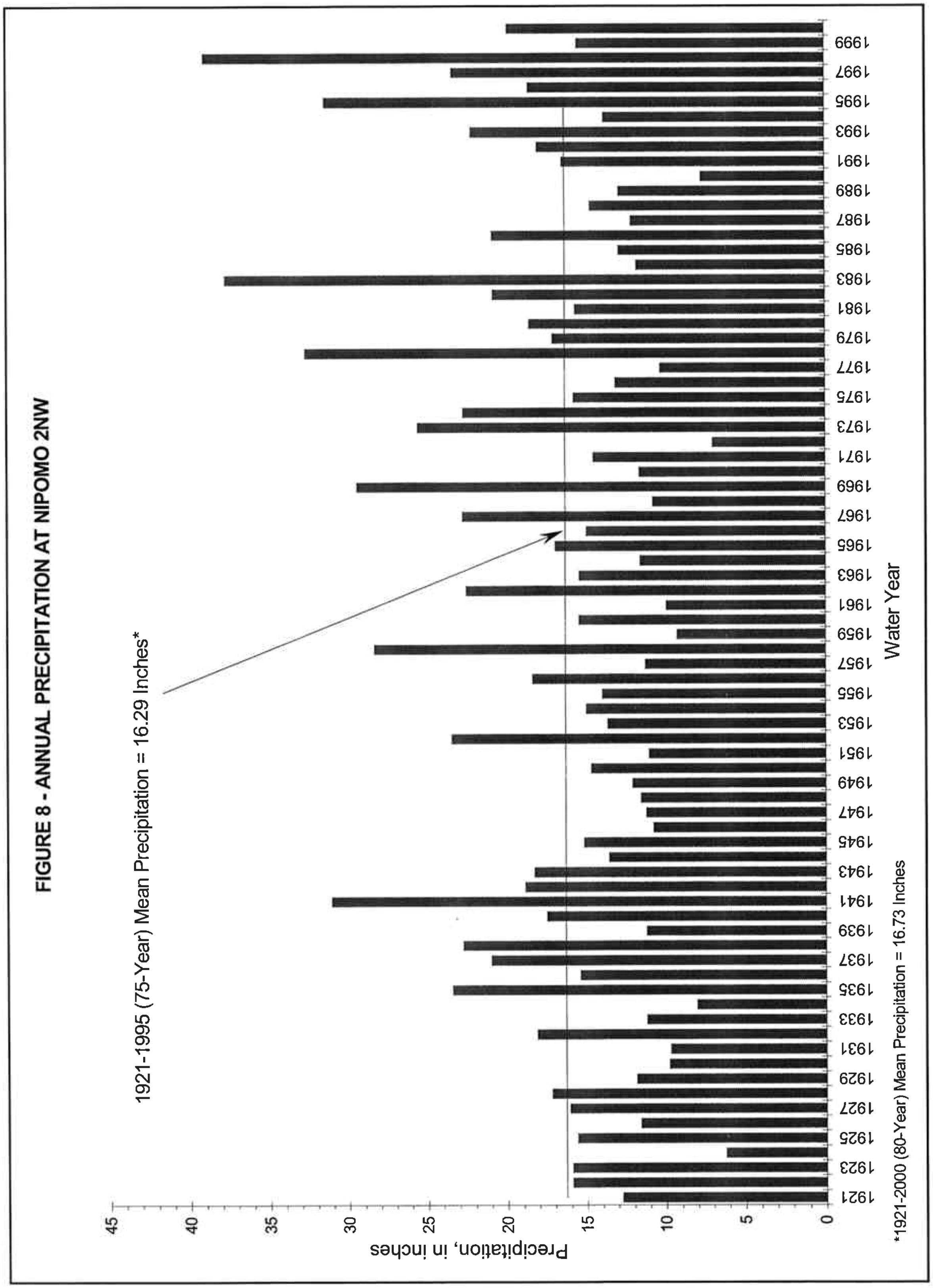


FIGURE 8 - ANNUAL PRECIPITATION AT NIPOMO 2NW

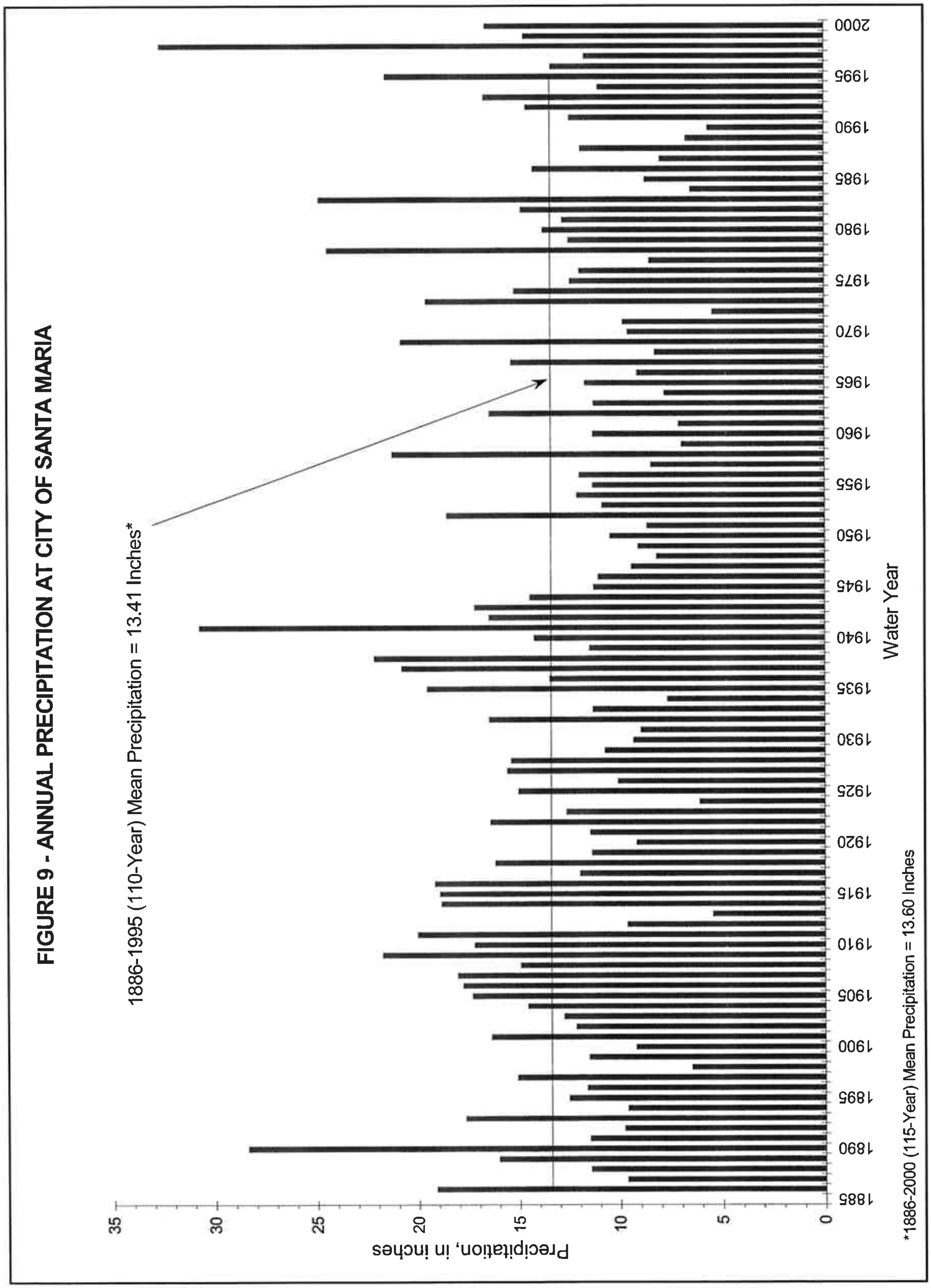
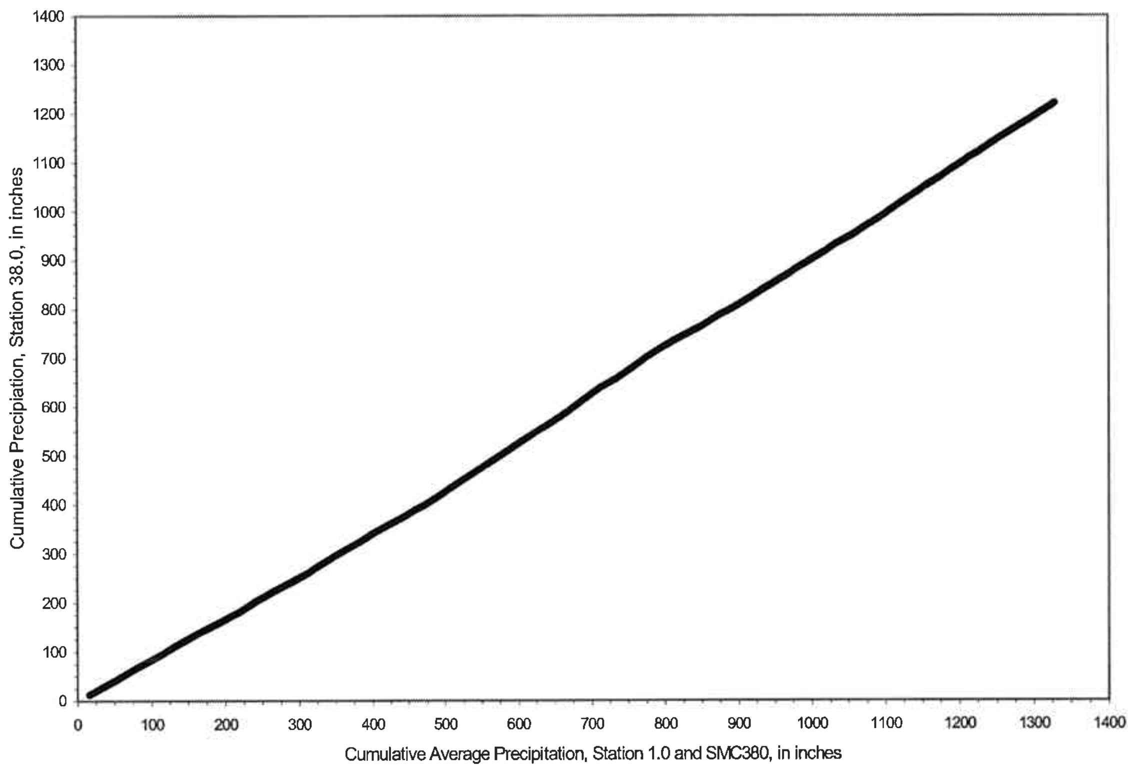


FIGURE 9 - ANNUAL PRECIPITATION AT CITY OF SANTA MARIA

FIGURE 10 - 1921 THROUGH 1995 ANNUAL PRECIPITATION DOUBLE MASS ANALYSIS



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 through 1995), the estimated average annual runoff ranged from 140 to 200 AF.

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, regulated by Lopez Dam since 1969, is one of the main watercourses within the study area and measures about 13 miles from the dam to its mouth at the Pacific

Ocean. Lopez Dam regulates surface releases to maximize groundwater recharge of the Santa Maria Groundwater Basin and provide flood control. The portion of the creek between the dam and the City of Arroyo Grande supports extensive agricultural activities.

As reported in Bulletin No. 1,[4] estimated mean seasonal runoff for water years 1895 through 1947 was 23,900 AF (Appendix E). Stream gaging data for Arroyo Grande Creek at Arroyo Grande, covering water years 1940 through 1995, are also shown in Appendix E. Analysis of this record indicates that the average annual runoff was 12,727 AF for 1940 through 1995 and 5,851 AF for the 1984 through 1995 base period, including all tributaries and excluding deliveries from Lopez Reservoir. These amounts are considerably lower than the mean seasonal runoff reported in Bulletin No. 1; however, the difference is attributable to impoundment of runoff at Lopez Reservoir.

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.

Los Berros Creek, another tributary of 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 to 2000 is available. The base period runoff for the entire watershed was between 800 and 1,100 AF each year.

Historically, the bluffs at the edges of Nipomo Mesa experienced relatively small amounts of runoff. With increased development, larger amounts of precipitation are draining to the adjacent Arroyo Grande Plain and Santa Maria Valley portions of the study area. However, runoff amounts reaching these adjacent areas are still small and are not quantified in this report.

Black Lake Canyon occupies about one square mile in the west-central part of Nipomo Mesa. It is about one-quarter mile wide and the watershed attains a maximum elevation of about 400 feet

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

above msl along its four-mile length. Because of its unique flora and fauna, San Luis Obispo County designated the canyon as a Sensitive Resource Area.

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 nine 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; estimates of average annual base period runoff amount to 800-925 AF.

The Santa Maria River, regulated in part by Twitchell Dam since 1958, 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 through 1947, as reported in Bulletin No. 1, is shown in Appendix E. The mean seasonal runoff for this period amounted to about 90,900 AF.

Appendix E contains stream gaging data for the Sisquoc River near Garey from water years 1942 to 2000, Cuyama River below Twitchell Dam from water years 1959 through 1983, and Santa Maria River near Guadalupe from water years 1941 through 1987. Analysis of the records of the Santa Maria River near Guadalupe gage indicates that the average annual runoff for 1941 through 1987 was about 21,700 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.

Although not located within the study area, the U. S. Bureau of Reclamation completed Twitchell Reservoir on the Cuyama River in 1958 as a flood control and water conservation reservoir. Twitchell Dam regulates surface releases to the Santa Maria River system to maximize groundwater recharge of the Santa Maria Groundwater Basin and provide flood control.

Continuous streamflow data on Pismo Creek and the Santa Maria River at Guadalupe are lacking. Recording data at these locations would provide a more accurate and continuous record for determining hydrologic information. Also, installation of stream gages at the confluence with the Pacific Ocean at Arroyo Grande Creek and at Santa Maria River would be useful.

This Page Intentionally Blank

V. HYDROGEOLOGY

Geologic conditions and processes and the local climate control virtually all aspects of the occurrence and movement of groundwater. Fundamentally, lithology and structure of the rocks and sediments determine the existence and character of openings in which groundwater occurs. Geologic processes, including faulting, folding, volcanism, and weathering, significantly affect groundwater occurrence and movement. The ability of different rocks and sediments to store, transmit, and adequately supply large-scale water 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 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 uplands 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 Santa Maria Groundwater Basin underlies more than 280 square miles (181,790 acres) in the southwestern corner of San Luis Obispo County and the northwestern corner of Santa Barbara County. The groundwater basin formed within the geologic depositional Pismo and Santa Maria Basins separated by the Santa Maria River fault (described in Chapter II) and the present limits of the groundwater basin were established in mid-Pleistocene time. This study considered only the portion of the basin within San Luis Obispo County, about 61,220 acres. About 120,570 acres, or 66 percent of the area overlying Santa Maria Basin, is located in Santa Barbara County.

Within the study area, the Santa Maria Basin consists of the main basin, Santa Maria, and three subbasins, Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley. The main basin underlies about 49,910 acres and the subbasins underlie a total of 11,310 acres. Both the surface area and the underlying permeable sediments form the basin. In San Luis Obispo County, the main Santa Maria Basin underlies the coastal plains of Santa Maria River and Arroyo Grande and Pismo Creeks interposed by Tri-Cities and Nipomo Mesas.

Groundwater Basin Boundaries

The boundaries of the Santa Maria Basin, as defined in this study, are shown in Plate 10. The boundaries were delineated based on mapped surface limits of Quaternary deposits and the Wilmar Avenue fault (Hall and Corbato, 1967, map scale 1:48,000; Hall, 1973, map scale 1:48,000; Hall, 1978b, map scale 1:24,00; Dibblee, 1989 and 1994, map scales 1:24,000; and Hanson et al., 1994, map scale 1:24,000). The boundaries represent the surface expression of the basin and do not imply that the boundaries extend vertically downward in a third dimension.[1] Arbitrary boundaries for the basin are eliminated by using mapped surface geologic contacts and faults.[2]

Santa Maria Basin. Within San Luis Obispo County, the main basin is bounded on the north and east by the Wilmar Avenue fault, separating it from Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley Subbasins. The western boundary of the groundwater basin is 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.

As mentioned in Chapter I, the main groundwater basin was divided and evaluated based on the hydrologic boundaries,[3] because of the need to provide applicable information for San Luis Obispo County. The divisions of the main basin are: (1) the Tri-Cities Mesa - Arroyo Grande Plain portion, that includes the lower Pismo Creek portion of the basin lying within Pismo HSA and the Tri-Cities Mesa, Arroyo Grande Plain, and Los Berros Creek portions of the basin lying within Oceano HSA;[4] (2) the Nipomo Mesa portion of the basin, lying entirely within Nipomo Mesa HSA; and (3) the Santa Maria Valley portion of the basin, lying within Guadalupe HA.

Arroyo Grande Valley Subbasin. The Arroyo Grande Valley Subbasin lies within the Oceano HSA in the San Luis Range at the northwestern edge of the main Santa Maria Basin. The subbasin is the alluvial-filled Arroyo Grande Valley, drained by Arroyo Grande Creek and its tributaries from below Lopez Dam to its southern boundary at the Wilmar Avenue fault, which separates it from the main basin. It underlies about 3,860 acres. The boundaries coincide with the alluvial contact with older sedimentary rocks and basement complex between Lopez Dam and the Wilmar Avenue fault.

---

[1]Mapping of the basin boundary in three dimensions would require extensive subsurface investigation and is beyond the scope of this study.

[2]Boundaries for the Santa Maria Basin in existing published studies are not based on mapped geologic contacts and faults and are arbitrary.

[3]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.

[4]Some discussions providing more detailed information may specifically address the lower Pismo Creek, Los Berros Creek, Tri-Cities Mesa, or Arroyo Grande Plain portions of this division of the basin.

Pismo Creek Valley Subbasin. The Pismo Creek Valley Subbasin lies within the Pismo HSA in the San Luis Range at the northern edge of the main groundwater basin. The subbasin is the alluvial-filled valley of Price Canyon, which is drained by Pismo Creek and its tributaries. It underlies about 1,220 acres. The boundaries of the subbasin coincide with the alluvial contact with older sedimentary rocks and the Obispo Formation. The northern boundary of the subbasin coincides with the southern boundary of Edna Basin, where bedrock narrows the creek channel, and the southern boundary of the subbasin is along the Wilmar Avenue fault.

Nipomo Valley Subbasin. The Nipomo Valley Subbasin underlies about 6,230 acres within the Guadalupe HA. This 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. The subbasin is bounded mainly by the contact of the older alluvium and Orcutt Formation with older geologic units and is separated from the main basin on the west by the Wilmar Avenue fault. The southern boundary of the subbasin, which is the watershed boundary for Nipomo Creek, is the study area boundary.

Base of Groundwater Basin

The potentially water-bearing basin-fill sediments are underlain by bedrock. Elevation contours of the bedrock surface that forms the base of the groundwater basin are shown in Plate 11. The base contours were developed from interpretation of available water and oil well lithologs and electric logs, and previously published cross-sections and base contour maps. The base of the main groundwater basin 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. The base contours reflect vertical displacement of the bedrock across the Oceano and Santa Maria River faults.

The base of the alluvial sediments in Arroyo Grande Valley Subbasin rises from about msl at Wilmar Avenue fault to almost 350 feet above msl at Lopez Dam.

In Pismo Creek Valley Subbasin near Wilmar Avenue fault, the base of the alluvial sediments ranges from about 40 feet below msl to msl. Data for the rest of the subbasin are unavailable.

In Nipomo Valley Subbasin, the base of the older alluvial sediments ranges from less than 200 feet above msl near Highway 166 to between 275 and 300 feet above msl east of Thompson Avenue. The bedrock is vertically displaced across the Wilmar Avenue fault (Plate 5).

Occurrence of Groundwater

Groundwater occurs within the pore spaces in the sedimentary deposits filling the basin. In the main basin, these deposits include the Squire Member of the Pismo Formation; the Careaga, Paso Robles, and Orcutt Formations; alluvium; and dune sands. They sequentially fill the basin to a maximum thickness of about 1,600 feet from oldest to youngest. The Pismo and Careaga 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.

Santa Maria Basin. The main Santa Maria Basin is considered a composite aquifer system of unconfined conditions, with localized semi-confined to confined conditions and perched zones.[5] Discontinuous clayey layers separate the multiple aquifer zones (see Plates 3-5). Confinement may be restricted to the deeper aquifer zones (Cleath & Associates, 1996a).

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 flowing. Today, flowing wells may occur only adjacent to the coast.

Holocene alluvium through upper Pliocene sediments constitute the principal groundwater reservoir of the basin. The most productive and developed aquifers are in the alluvium and 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. Aquifers in the Squire Member of the Pismo Formation and the Careaga Formation have, over time, become more important. Wells typically produce from either the Careaga Formation or the Squire Member in combination with the Paso Robles Formation

Both the recent dune sands and parts of the older dune sands are largely unsaturated, but are important for rapidly infiltrating recharge waters to the saturated zone. The recent dune sands are not known to be tapped by wells. The older dune sands are penetrated by wells that produce primarily from the underlying formations.

Perched Groundwater Zones. Localized zones of saturation may exist above the main water table. This situation occurs where clay lenses within the vadose zone intercept downward percolating water and cause some of it to accumulate above the lenses. The upper surface of the groundwater in these cases is called a perched water table.

Local zones of perched groundwater occur within the older dune sands on the mesa, but not continuously across the mesa. The Morro Group (1990) found that the ponds at the upper end of Black Lake Canyon are perched groundwater. The dune lakes, south of Oceano, and Oso Flaco and Little Oso Flaco Lakes are surface water bodies hydraulically connected to perched

[5] 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).

groundwater. Also, minor bodies of perched and semi-perched groundwater are present locally in the coastal alluvial deposits.

Some wells produce small quantities of groundwater from these perched zones, but they are typically not dependable sources of supply, and are greatly affected by variable hydrologic conditions. Because perched groundwater is not a dependable source of supply, it is not considered for water supply planning purposes in this report.

Arroyo Grande Valley Subbasin. Groundwater occurs in the alluvium. Thickness of the alluvium averages about 100 feet. Maximum thickness of the alluvium is about 175 feet just above the confluence of Tar Spring and Arroyo Grande Creeks (Goss and Reed, 1969, p. 72). Groundwater is mainly unconfined. In some parts of the subbasin, the alluvium may be saturated only during rainfall.

Pismo Creek Valley Subbasin. Groundwater occurs in the alluvium. Thickness of the alluvium ranges from negligible to about 60 feet near the southern boundary. Groundwater is unconfined. In some parts of the subbasin, the alluvium may be saturated only during rainfall.

Nipomo Valley Subbasin. Groundwater occurs in the older alluvium, which covers the floor of the valley up to about 90 feet thick, thinning to negligible thickness toward the eastern edges of the subbasin. Groundwater in the older alluvium is unconfined with local semi-perched conditions. The older alluvium stores a notable amount of groundwater and continues to supply some wells, although the older alluvium may be saturated only during rainfall at the eastern edges of the subbasin. The bedrock formations underlying the older alluvium have, over time, become a more important source of groundwater supply in the subbasin. These formations are discussed later in this chapter, under the section "Groundwater in Bedrock."

Well Yields and Depths. The yields and depths of wells for the different groundwater basin deposits are summarized from the well completion reports and presented in Table 15.

By means of "schematic box plots" (Tukey, 1977), Figure 11 depicts well yields, as reported on available well completion reports. 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, plotted individually as outliers.[6] Extreme and outlier values play important roles in providing information on a data set.

The highest yields are generally from wells producing from the alluvium and the Paso Robles Formation in Tri-Cities Mesa and Santa Maria Valley. Yields of wells in Nipomo Mesa are shown separately for wells north of the Santa Maria River fault and for those south of the fault.

---

[6]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	Division Within Basin	Well Depths, in feet		Well Yields, in gallons per minute	
		Median	Range	Median	Range
Alluvium	Arroyo Grande Plain	100	25 - 155	60	10 - 1,700
	Los Berros Creek	80	60 - 100	70	25 - 250
	Santa Maria Valley	175	91 - 222	50	20 - 2,300
	Arroyo Grande Valley Subbasin	95	38 - 155	60	13-500
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	Tri-Cities Mesa	460	300 - 600	1,070	150 - 2,000
Squire Member	Tri-Cities Mesa	480	295 - 607	270	90 - 1000

*The smaller well yields are typically from residential wells.
**Dry holes are encountered northeast of the Santa Maria River fault (northeast of Pomeroy Road).

The figure shows the large difference in well yields found on opposite sides of the Santa Maria River fault. For wells on the north side of the fault, the median yield is 10 gallons per minute and for wells on the south side of the fault, the median yield is 210 gallons per minute.

Data are limited for Pismo Creek Valley Subbasin, with only two well completion reports listing well yields. Those yields were 25 and 30 gallons per minute.

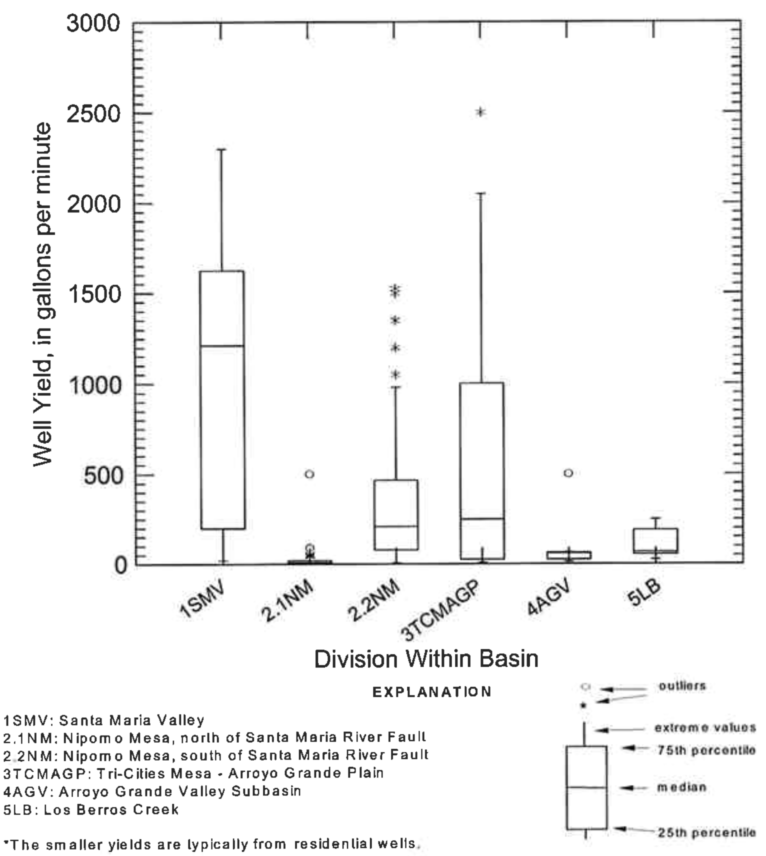
In Nipomo Valley Subbasin, a few older wells are perforated only in the older alluvium, are less than 80 feet deep, and have yields of 20 to 30 gallons per minute.

Recharge and Discharge

Santa Maria Basin. Groundwater in the main Santa Maria Basin is recharged from both natural and incidental sources. Stream infiltration, deep percolation of direct precipitation, and subsurface inflow are sources of natural recharge.

Stream infiltration from Arroyo Grande Creek, regulated by Lopez Dam since 1969, recharges the Tri-Cities Mesa - Arroyo Grande Plain portion of the main groundwater basin. Lawrance, Fisk & McFarland, Inc. (1985c) reported that the Tri-Cities Mesa part of the groundwater basin recharges rapidly during wet years and depletes rapidly during dry periods and that whenever

FIGURE 11 - YIELD OF WELLS IN SANTA MARIA GROUNDWATER BASIN*



natural water supply is sufficient for Lopez Reservoir to fill, the supply has also been sufficient to recharge Tri-Cities Mesa.

Stream infiltration from Pismo Creek, which is unregulated, recharges the northern part of the Tri-Cities Mesa - Arroyo Grande Plain portion of the main Santa Maria Basin.

The Santa Maria River, regulated in part by Twitchell Dam since 1958, recharges the Santa Maria Valley portion of the main groundwater basin. 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 Santa Maria Valley to be affected.

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

Recharge to the groundwater basin by deep percolation of direct precipitation is intermittent, 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. Because no surface waters flow into Nipomo Mesa, deep percolation of direct precipitation is the major source of natural recharge for the mesa. Interdunal depressions trap runoff in the mesa, thereby enhancing infiltration and percolation of rainfall.

Subsurface inflows also recharge the main groundwater basin. The Tri-Cities Mesa - Arroyo Grande Plain portion of the basin is recharged by subsurface inflows from Arroyo Grande Valley and Pismo Creek Valley Subbasins. In addition, Tri-Cities Mesa is recharged by subsurface inflow from the adjoining San Luis Range, and Arroyo Grande Plain is recharged by subsurface inflow from the Nipomo Mesa portion of the basin. The Nipomo Mesa portion of the main basin may be recharged by subsurface inflow from the adjoining Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown (discussed under *Faults* in the next section). Nipomo Mesa can also be recharged by subsurface inflow from the Santa Maria Valley portion of the basin within San Luis Obispo County (discussed in the next section).[7] The Santa Maria Valley portion of the main basin within the study area is recharged by subsurface inflow from the upstream part of the groundwater basin, outside the study area, and may also be recharged by subsurface inflow from the southern end of Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Deep percolation of urban and agricultural return water, treated wastewater returns, and septic tank effluent are sources of incidental recharge to the groundwater basin.

Groundwater discharges from the basin as subsurface outflow to the Pacific Ocean. Discharge also consists of evapotranspiration losses, rising water, springflow, and percolation into the underlying bedrock. At the Dune Lakes and Oso Flaco Lakes, groundwater discharges as diffuse upward leakage. Extractions from wells for beneficial consumptive uses are a significant source of discharge from the basin.

Arroyo Grande Valley Subbasin. Groundwater is recharged by stream infiltration from surface flows in Arroyo Grande Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from the San Luis Range. Discharge from the subbasin consists of surface and subsurface outflow to the main Santa Maria Basin, evapotranspiration losses, and extractions from wells.

Pismo Creek Valley Subbasin. Groundwater is recharged by stream infiltration from surface

[7]Subsurface inflows from Santa Maria Valley into Nipomo Mesa will occur whenever the groundwater elevations beneath Nipomo Mesa are below those of Santa Maria Valley, altering the hydraulic gradient and direction of flow.

flows in Pismo Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from Edna Basin and the San Luis Range. Discharge from the subbasin consists of surface and subsurface outflows to the main Santa Maria Basin, evapotranspiration losses, and extractions from a few small wells.

Nipomo Valley Subbasin. Groundwater is recharged by stream infiltration from surface flows in Nipomo Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from Temattate Ridge. Groundwater is discharged from the subbasin by well extractions, evapotranspiration, and subsurface outflows to the main Santa Maria Basin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Groundwater Elevations and Movement

Contour maps of elevations of the groundwater surface in a basin show not only the elevation to which the basin is filled, but also the direction in which the water is moving and the slope producing the movement. The contours connect points of equal hydraulic head or equal altitude of the water surface. The direction of groundwater movement is perpendicular to the contours. The rate of movement is proportional to the hydraulic gradient and the permeability of the deposits. Contour maps of groundwater elevations show areal conditions as of a specific date. By comparing maps for different times, any changes in direction of groundwater movement or storage that may have occurred during the interval between maps can be determined.

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. The natural flow patterns become distorted in areas of large-scale groundwater development.

For this study, groundwater elevation contour maps were prepared for three specific times, the springs of 1975, 1985, and 1995 (Plates 12-14).[8] Groundwater level measurement records were compiled from monitoring programs conducted by San Luis Obispo County; Santa Maria Water Conservation District; USGS; Santa Barbara County Public Works Department, Water Resources Division; and the Department. In addition, fragmentary records from well owners, well drillers, and others were included. Static (nonpumping) depth to water measurements from wells throughout the study area were used. The depths to water were subtracted from the reference elevation of the well (generally one-half foot to one foot above the land surface) to obtain the groundwater elevation, then plotted on a map and contoured.

[8]Insufficient groundwater level measurements were available to construct a groundwater elevation contour map for spring 1984, the beginning water year of the hydrologic base period; therefore, a map was constructed for spring 1985.

At the request of San Luis Obispo County, a spring 2000 groundwater elevation contour map was prepared and is Plate A1 in the Addendum attached at the back of this report.

Several important points need to be noted. Most of the wells are perforated continuously in multiple aquifers.[9] Thus, the contours do not reflect the groundwater elevation of a single aquifer, but represent the surface of the principal groundwater body. Perched groundwater levels were not used in making the maps. Well locations and reference elevations are from field descriptions of the locations as plotted on USGS 7.5-minute quadrangles.[10] Reference elevations were approximated using either the 7.5-minute quadrangles or, where available, digital aerial surveys at five- or two-foot contour intervals. The seawater intrusion wells along the coast and a few other wells in the study area have surveyed reference elevations. Also, monitored wells are not distributed evenly throughout the study area, creating data gaps. Contour lines were interpolated in these areas. Data gaps increased over time as fewer wells were monitored.

The springs of 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 receiving about 80 percent of the long-term average[11] and Nipomo Mesa and Santa Maria Valley receiving about 90 percent of the long-term average. Water year 1985 was a dry year, with Tri-Cities Mesa - Arroyo Grande Plain receiving 55 percent of the long-term average; Nipomo Mesa, 77 percent; and Santa Maria Valley, 64 percent. Water year 1995 was a wet year, with Tri-Cities Mesa - Arroyo Grande Plain receiving 181 percent of the long-term average; Nipomo Mesa, 191 percent; and Santa Maria Valley, 194 percent.

The shape of the groundwater elevation contours on Plates 12-14 shows that groundwater of the principal water body moves seaward to the Pacific Ocean in a generally westerly or west-northwesterly direction. The plates also show that coastal groundwater elevations were above msl and outflow from the basin to the ocean was occurring, apparently precluding any sea water intrusion along the coast.

Faults. Faults can impede groundwater flow, serve as conduits for flow, or not affect 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 the Santa Maria Basin.

The Santa Maria River fault may affect groundwater flow in parts of the basin.

In Arroyo Grande Plain, the elevation contours are shown crossing the Santa Maria River fault, because with the available data, it is not possible to determine if the fault is a groundwater flow barrier or impediment along this segment. Wells drilled in Arroyo Grande Plain are shallow,

---

[9] Well completion reports are not available for many of the wells that are monitored for depth to groundwater. Some wells have information only on the total depth of the well and not the perforated intervals.

[10] In 2000, San Luis Obispo County located the wells in their monitoring program using GPS (Global Positioning System). Unrectifiable problems with the GPS data resulted in erroneous well locations and elevations and thus could not be used in this study.

[11] Long-term averages for precipitation stations represent period of record through water year 2000 for the station.

producing from the alluvium. No wells are monitored on the southwest side of the fault. The fault may be a barrier to flow in the older formations, but flow may occur across the fault in the alluvium. Displacement across the fault is not as great at the coast as it is along the segment of the fault east of Highway 1 to about a mile east of Zenon Way.

From east of Highway 1 to about a mile east of Zenon Way, significant differences are found in groundwater elevations on opposite sides of the Santa Maria River fault. The fault appears to be a barrier or impediment to groundwater flow in the formations below the older dune sands; however, groundwater levels are in the older dune sands on the north side of the fault and groundwater may be able to cascade over the fault along this segment.

Groundwater elevations are similar on opposite sides of the Santa Maria River fault along the segment near the head of Black Lake Canyon (north of Willow Road to about a mile east of Zenon Way). Along this segment of the fault and to the southeast, faulting has been postulated as bedrock steps (Hanson, et al., 1994), rather than a single fault (Plate 5 of this report). Data are not available to determine what impact the nature of the faulting has on hydraulic continuity across the fault and thus the contours are not extended across the fault.

From south of Willow Road to Joshua Street, water level measurements are not available in wells on the northerly side of the Santa Maria River fault, except for a few level measurements for wells near Joshua Street. The contours are dashed on the plates. As mentioned above, hydraulic continuity across the fault is unknown.

Previous studies did not show the Oceano fault affecting groundwater flow. With the data available for this study, it could not be determined if the fault affects groundwater flow. Because the basin-fill deposits are the same on opposite sides of the fault (Santa Maria Depositional Basin) and have similar hydraulic properties, the fault may have no impact.

The Wilmar Avenue fault does not affect groundwater flow in the alluvium from the Arroyo Grande Valley and Pismo Creek Valley Subbasins to the main basin. Data are not available to determine whether the fault impacts flow from Nipomo Valley Subbasin to the main basin.

Studies are needed to determine more precisely the location of the Santa Maria River fault and its impact and that of the Oceano fault on groundwater flow within the main basin. In addition, the impact of the Wilmar Avenue fault on groundwater flow needs to be assessed.

Spring 1975 Groundwater Elevation Contours. Groundwater elevations in spring 1975, shown on Plate 12, ranged from about 10 to 20 feet above msl along the coast to 350 feet above msl in Arroyo Grande Valley Subbasin, just below Lopez Dam and to 400 feet above msl in Nipomo Valley Subbasin. Groundwater elevations in Tri-Cities Mesa - Arroyo Grande Plain are largely affected by stream infiltration from Arroyo Grande Creek and elevations in Santa Maria Valley by stream infiltration from the Santa Maria River.

A gradient of about 50 feet per mile was nearly uniform as groundwater moved southwesterly down Arroyo Grande Valley Subbasin. The gradient distinctly steepened south of Highway 101, as groundwater flowed out into the main basin. 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 5 to 10 feet per mile as groundwater moved westerly toward the ocean under Tri-Cities Mesa-Arroyo Grande Plain.

Groundwater conditions in 1975 in Nipomo Mesa indicate that groundwater, south of the Santa Maria River fault, moved in a west-northwesterly direction across the mesa to the ocean at a gradient generally between five and 10 feet per mile. In northern Nipomo Mesa, east of Highway 1 and north of the Santa Maria River fault, groundwater elevations indicate flow from the mesa into the Arroyo Grande Plain. Also, small pumping depressions were present south of Black Lake Canyon, along Willow Road, and near Division Street.

Near Zenon Way north of the Santa Maria River fault, the contours show a small pumping depression, based on a level measurement from one well. This well has always had low groundwater elevations. No well completion report is available for this well, but a nearby well with a report shows that sediments in this part of the basin are low-yielding, largely clays and shales. The groundwater elevation in this well dropped about 15 feet between spring 1975 and spring 1995. Cleath & Associates (1994) also reported the existence of lower groundwater elevations in this part of the basin.

In Santa Maria Valley, the general direction of groundwater flow was westerly and west-northwesterly from near Highway 101 to the ocean. The gradient was steep near Highway 101, at about 25 feet per mile, then flattened markedly to about 2.5 feet per mile across the center of the valley, and increased slightly to about six feet per mile from near Highway 1 to the ocean.

As indicated by the contours on Plate 12, groundwater flowed southwesterly in Nipomo Valley Subbasin. Groundwater elevations in the subbasin ranged from about 250 to 400 feet above msl. A groundwater high occurs roughly along the watershed divide between Los Berros Creek and Nipomo Valley; the high differentiates groundwater moving toward the alluvial aquifer of Los Berros Creek from groundwater flowing into Nipomo Valley (Cleath & Associates, 1995).

The county does not monitor groundwater levels in wells in the Pismo Creek Valley Subbasin. No data were available to determine groundwater elevations in this subbasin in 1975. Wells in this part of the basin need to be included in the county's monitoring program. The selection of wells to be included is beyond the scope of this study.

Spring 1985 Groundwater Elevation Contours. Plate 13 shows spring 1985 groundwater elevation contours. Groundwater conditions were generally similar to those in spring 1975, although water year 1985 was a dry year. The hydraulic gradient in Tri-Cities Mesa-Arroyo Grande Plain flattened slightly compared to that in 1975. In Nipomo Mesa, the hydraulic gradient in the center of the mesa markedly flattened compared to that in 1975, about 2.5 feet per mile. The local depressions in Nipomo Mesa were in the same locations, but were slightly larger than those of 1975. The depression near Division Street extended slightly into Santa Maria Valley and groundwater was flowing from the valley into the mesa. In Santa Maria Valley, groundwater elevations were slightly higher than 1975 elevations and the hydraulic gradient was about seven feet per mile across the valley. The higher elevations and thus increased groundwater in storage were the result of the substantial stream infiltration from the Santa Maria River in the 1983 wet year, when flows were about 700 percent of normal, and from Twitchell Reservoir releases in 1984.

Groundwater elevations were slightly lower than those in 1975 in Arroyo Grande Valley and Nipomo Valley Subbasins, reflecting the dry year.

In Pismo Creek Valley Subbasin, a static water level measurement was reported on one well completion report for a well drilled in spring 1985. This level resulted in a groundwater elevation of 20 feet above msl about one-half mile north of Highway 101.

Spring 1995 Groundwater Elevation Contours. Plate 14 shows spring 1995 groundwater elevation contours. The contours generally indicate 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. In the Willow Road area, groundwater elevations were below msl. 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 (only within San Luis Obispo County) was moving into the mesa. Cleath & Associates (1996a, p. 18) also reported the existence of the depression.

Groundwater in Santa Maria Valley near the county line flowed in a westerly direction, unaffected by the depression. 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 did not yet reflect recharge from the 1995 wet year (almost double the long-term mean precipitation).

Several points need to be mentioned about the depression in the south-central part of Nipomo Mesa shown in Plate 14. The magnitude of the depression is not well defined because wells with groundwater level data are limited (more thorough coverage of groundwater level monitoring is needed in this part of Nipomo Mesa[12]) and reference elevations for all the wells were not surveyed. The dynamics of the groundwater system (transmitting properties of the aquifers and potential boundary conditions, such as the Santa Maria River fault) in this part of the basin likely affect development of pumping depressions. Depressions have been documented on the mesa since 1965 (California Department of Water Resources, 1979). In addition, pumpage is concentrated in this part of the mesa. 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.

[12]It is beyond the scope of this study to select specific wells to be monitored.

Furthermore, the lateral extent of the depression will fluctuate depending on hydrologic conditions, amount of groundwater extractions in the area, and dynamics of the groundwater system, as the basin continuously seeks a new equilibrium. Subsurface flow from Santa Maria Valley into Nipomo Mesa will occur whenever groundwater elevations beneath the mesa are below those of the valley, altering the hydraulic gradient and direction of flow. Because of the 1998 wet year, the extent of the depression was reduced as levels in some wells rose and even continued rising in 1999 (discussed in the next section; also, see Plate A1 in the addendum).

Groundwater elevations in spring 1995 indicate that coastal groundwater elevations appeared to be above msl and outflow to the ocean was occurring. It is conjectural whether, in the future, sea water intrusion will threaten because of the pumping depressions in Nipomo Mesa. Sea water will intrude when the freshwater head is insufficient to counterbalance the greater density of sea water, even when the freshwater head is above msl.

Water Level Fluctuations and Trends

Groundwater levels in wells fluctuate over time representing the continuous adjustment of groundwater in storage to changes in recharge and discharge. The many processes that cause levels to fluctuate include pumpage, recharge from direct precipitation and streamflow, infiltration of applied water, and subsurface inflows and outflows. Hydrographs plotted from periodic water level measurements illustrate the nature of the fluctuations, both annual and long term. Observed trends in water levels are one of the most reliable means of evaluating the status of a groundwater basin.

For this study, hydrographs of water levels in selected wells were constructed and net changes in their groundwater levels were determined over time. The wells were selected on the basis of length of record, completeness of record, and geographic distribution. Wells discussed in this report are identified by their State Well Numbers.

Historical annual spring static water level measurements through water year 2000[13] were used (levels are usually highest in the spring). Some wells in Santa Maria Valley, within San Luis Obispo County, have spring groundwater level measurement records for more than 60 years, 1938 through 2000. Other wells in the basin have records for about 40 years (1959 through 2000) to shorter lengths of time (1985 through 2000). The water level measurements were converted to elevations using the reference point elevation for the well.

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. Some measurements are likely suspect because of

[13]The analysis of trends in groundwater elevations was revised from the draft report to include period of record through water year 1998 (wettest year on record), and again revised to period of record through water year 2000 at the request of San Luis Obispo County in April 2001.

errors made during the measuring process or database entry process. Gaps are found in the data. The frequency of measurement varied between the wells and over time at a given well.

Because rainfall serves as an index of available recharge for groundwater, the cumulative departure from the long-term average rainfall is also plotted on the hydrographs. Rainfall varies from year to year, tending to recur in discernible cycles of a period of relatively wet years followed by a period of several relatively dry years. These cycles are shown by the curve of cumulative departure from the long-term average rainfall. Positively sloping lines on the cumulative departure curve indicate wet years or wet periods and negatively sloping lines indicate dry years or dry periods.

Three precipitation stations with long-term records were used for different parts of the groundwater basin. The Bates Plumbing station in Arroyo Grande, with precipitation records from 1956 to 2000, was used with wells in Tri-Cities Mesa - Arroyo Grande Plain and Arroyo Grande Valley Subbasin; Nipomo 2NW station, with precipitation records from 1921 to 2000, was used with wells in Nipomo Mesa, Los Berros Creek, and Nipomo Valley Subbasin; and Santa Maria station, with precipitation records from 1886 to 2000, was used with wells in Santa Maria Valley. Since the 1930s (when the earliest water level measurements were made in the study area), there have been three wet periods of above average precipitation: water years 1937 through 1944, 1978 through 1983, and 1992 through 1998; and two dry periods of below average precipitation: water years 1945 through 1977 and 1984 through 1991. The long dry period of 1945 through 1977 is punctuated with a few wet years (1952, 1958, and 1969) and the dry period of 1984 through 1991 is punctuated with the 1986 wet year.

The behavior of the groundwater levels in the selected wells is compared to the rainfall trends and to other factors as appropriate. Although no precise correlation between groundwater elevations and rainfall exists, the graphs should generally show elevations rising during times of excess recharge and elevations declining during times of below average recharge. When precipitation and other sources of recharge are inadequate to compensate for discharges over the long term, water levels may show an overall decline over time.

The amplitude of groundwater elevation fluctuation at a particular point resulting from a given volume of recharge to or discharge from the basin is determined by the dynamics of the groundwater system (transmitting properties of the aquifers and potential boundary conditions) in the zone of fluctuation at that point. This may account for some of the differences in the degree of fluctuations on the hydrographs shown in the following figures. These differences could also be caused, in part, by uneven distribution of precipitation in the area, local differences in the infiltration rate, location of wells with respect to areas of natural discharge, use of the well, and depth to the water table below land surface.

The hydrographs in this report are grouped by the divisions of the main basin, with Nipomo Mesa subdivided into four parts-- northern, central, western, and southeastern. Hydrographs are also presented for Arroyo Grande Valley and Nipomo Valley Subbasins, but groundwater level monitoring data are not available to prepare any hydrographs for the Pismo Creek Valley Subbasin. A summary of net changes in water levels during each of the periods of above and below average precipitation is also given on each figure.

Tri-Cities Mesa - Arroyo Grande Plain. Hydrographs of wells in Tri-Cities Mesa - Arroyo Grande Plain are shown on Figures 12 and 13. Figure 12 includes well 32S/13E-29J02, perforated in the Paso Robles Formation and wells 32S/13E-31H07 and 32S/13E-33K03, perforated in the alluvium. Figure 13 illustrates hydrographs of deeper wells, 32S/13E-29E07, 32S/13E-29G15, and 32S/13E-32D11, perforated in the Squire Member of the Pismo Formation.

On Figure 12, the hydrographs for wells 29J02 and 33K03 closely follow the rainfall trends. Well 31H07 is nearer to Arroyo Grande Creek and the response of groundwater elevations to changes in rainfall is subdued. Levels could be influenced by the location of the well near the creek, its use, its shallower depth to water (5 to 12 feet), or different characteristics of the aquifer in this part of the basin. Levels in these wells declined during the dry cycles and rose during the wet cycles. The highest water level of record for wells 29J02 and 33K03 occurred in the wet year 1983 and for well 31H07 in the wet year 1998. The figure also shows that over the long term, levels have generally been stable.

Groundwater level fluctuations in the deeper wells shown in Figure 13 do not follow rainfall trends as closely as the shallower wells in Figure 12. Lack of measurements in some years affects the apparent pattern of fluctuations. The aquifer properties of these deeper wells are different, affecting their response to recharge and discharge events. Also wells 29E07 and 29G15 show almost no annual variability since the early 1990s, suggesting changed well use such as increased production. During the dry cycle of 1984 to 1991, wells 29E07 and 29G15 had levels that dropped below msl and well 32D11 dropped to a foot above msl. Levels recovered during the following wet cycle. All three wells show a decline in levels over their period of record, between about 4 and 11 feet, an indication that discharge may be exceeding recharge of the Squire Member aquifers in this part of the basin.

Los Berros Creek. Figure 14 presents hydrographs of wells 12N/35W-34C03 and 12N/35W-35K02, perforated in the alluvial aquifer of Los Berros Creek. Groundwater levels in the wells generally follow rainfall trends. The lowest water levels in these wells occurred in the dry year 1990. Well 34C03 had a net rise in levels of about four feet over its period of record and well 35K02, about seven feet. Based on the long-term trends in levels in these wells, it appears that recharge and discharge are generally in balance over time in this part of the basin.

Northern Nipomo Mesa. Figure 15 presents hydrographs of wells perforated in the Paso Robles Formation. Wells 12N/35W-32G01 and 12N/35W-33L01 are on the south side of the Santa Maria River fault. Wells 12N/35W-33E01, 11N/35W-03B01, and 11N/35W-02G02 are on the north side of the Santa Maria River fault. The figure clearly shows the large differences in groundwater elevations found on opposing sides of the fault, about 90 to 125 feet of difference.

FIGURE 12 - TREND IN GROUNDWATER ELEVATIONS, TRI-CITIES MESA - ARROYO GRANDE PLAIN SHALLOW WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91	1992-98	1998	2000
32S/13E-29J02	-8.3	3.2	-16.4	7.1	1.5	-3.2
32S/13E-31H07	0.1	1.0	-1.8	4.1	5.0	2.8[1965-99]
32S/13E-33K03	-18.0	6.2	-1.8	8.4	5.0	-3.6

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

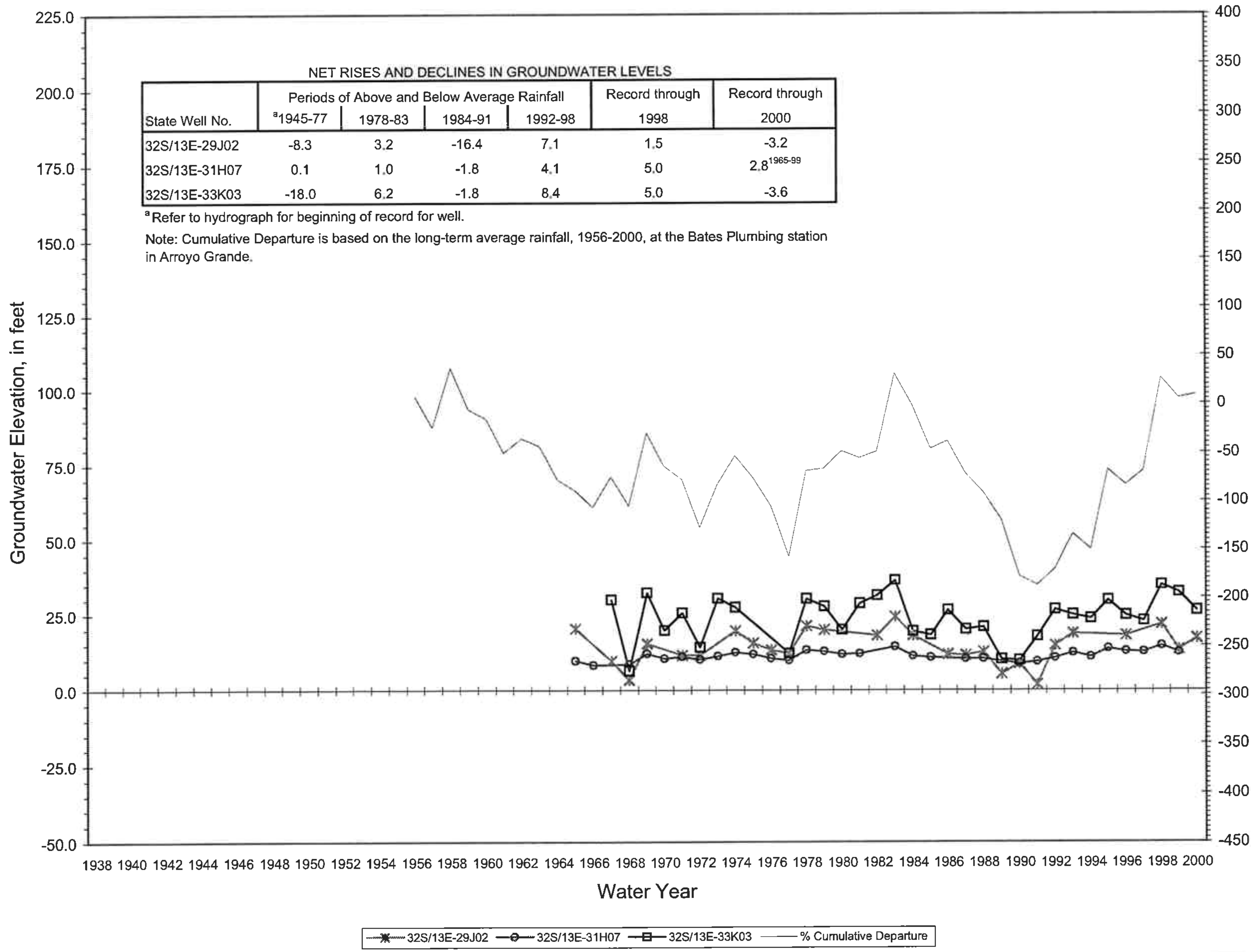


FIGURE 13 - TREND IN GROUNDWATER ELEVATIONS, TRI-CITIES MESA - ARROYO GRANDE PLAIN DEEP WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall 1978-83[a]	1984-91	1992-98	Record through 1998	Record through 2000
32S/13E-29E07	3.3	-10.3[1986-91]	2.0[1992-97]	-3.8[1979-97]	-3.8[1979-99]
32S/13E-29G15		-5.5	[b]	-10.4[1983-97]	-11.1
32S/13E-32D11	8.6	-7.9	5.8	4.0	-4.2

[a] Refer to hydrograph for beginning of record for well.

[b] Well only measured in 1997.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

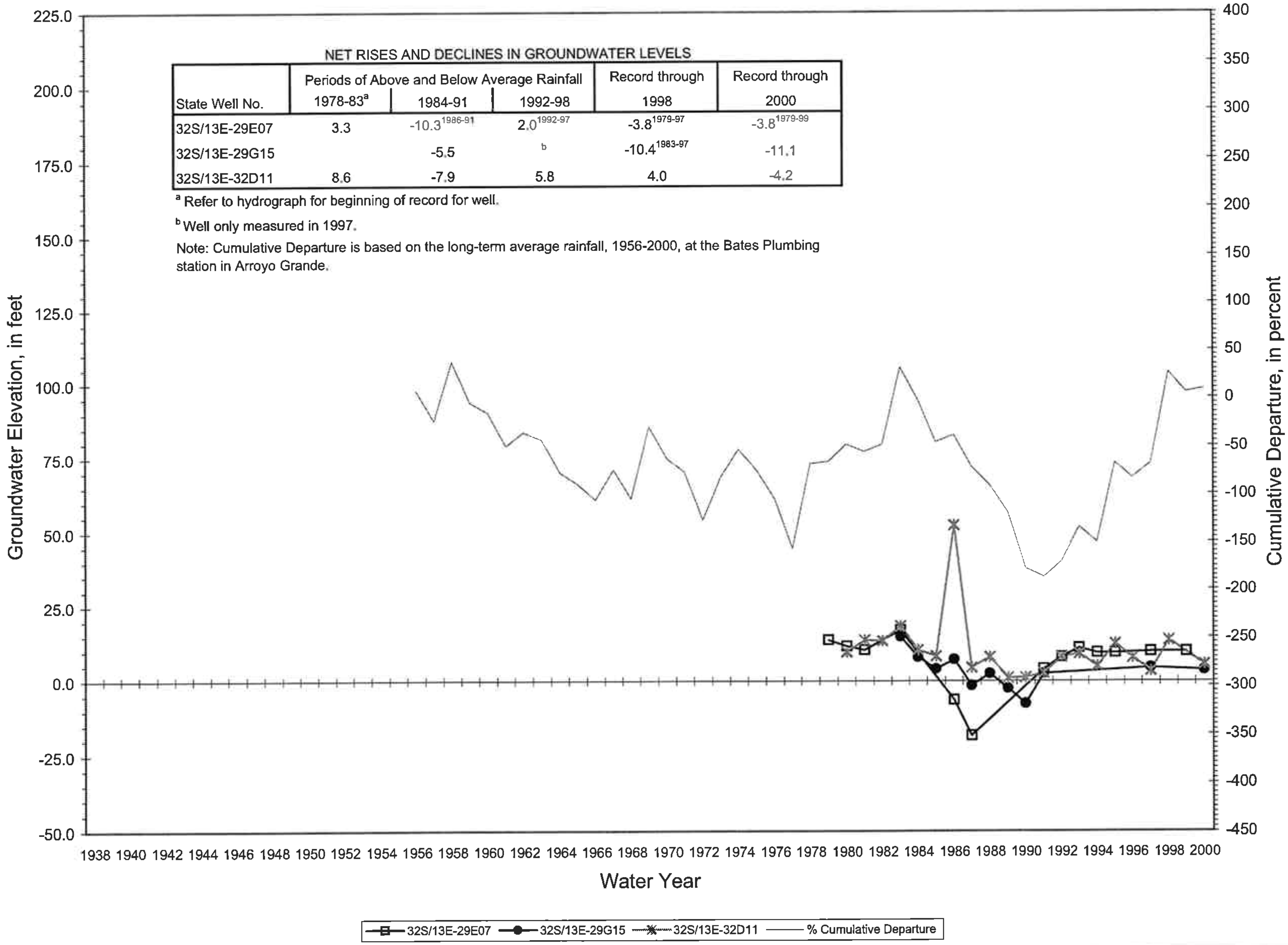
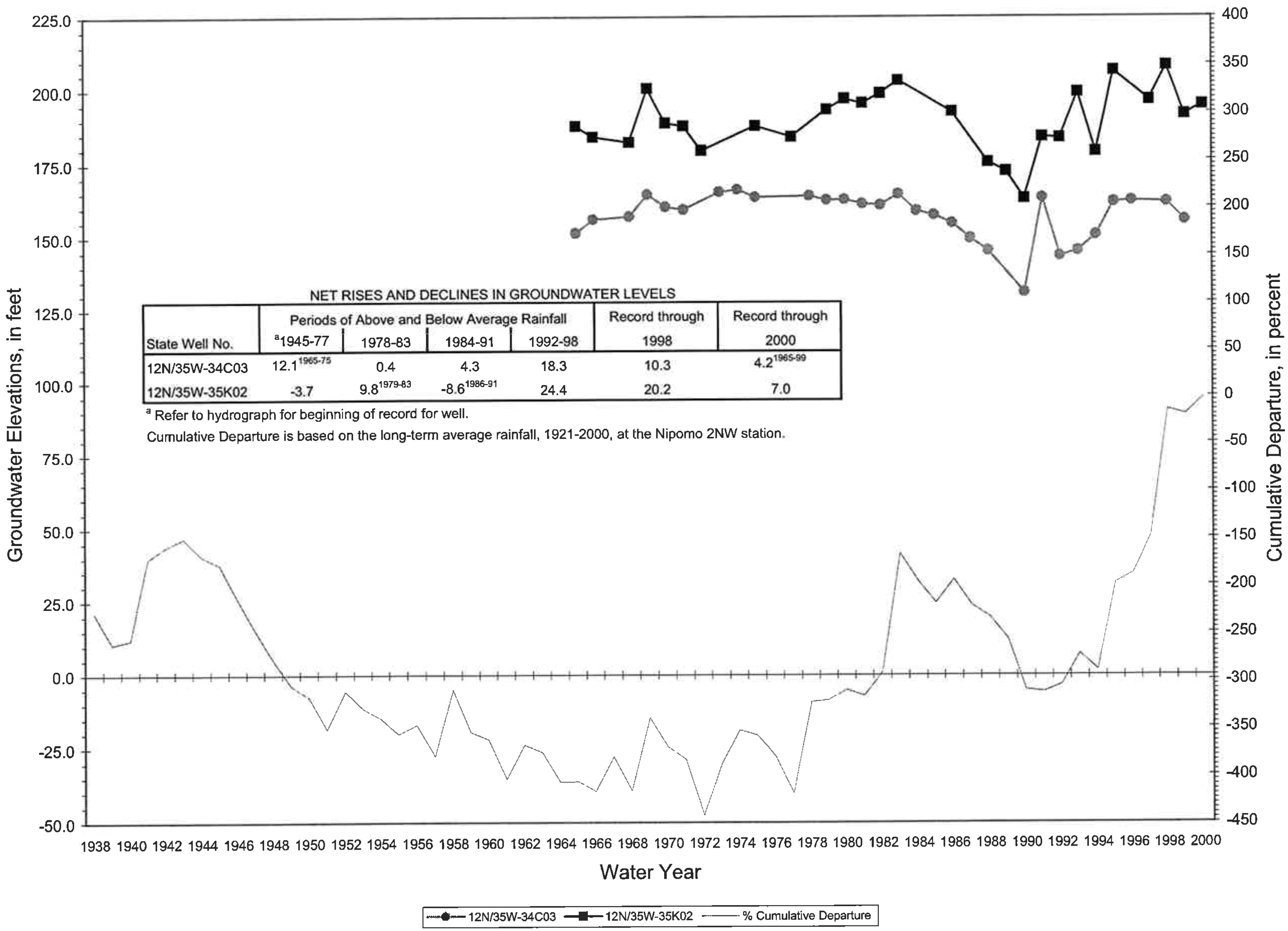


FIGURE 14 - TREND IN GROUNDWATER ELEVATIONS, LOS BERROS CREEK WELLS



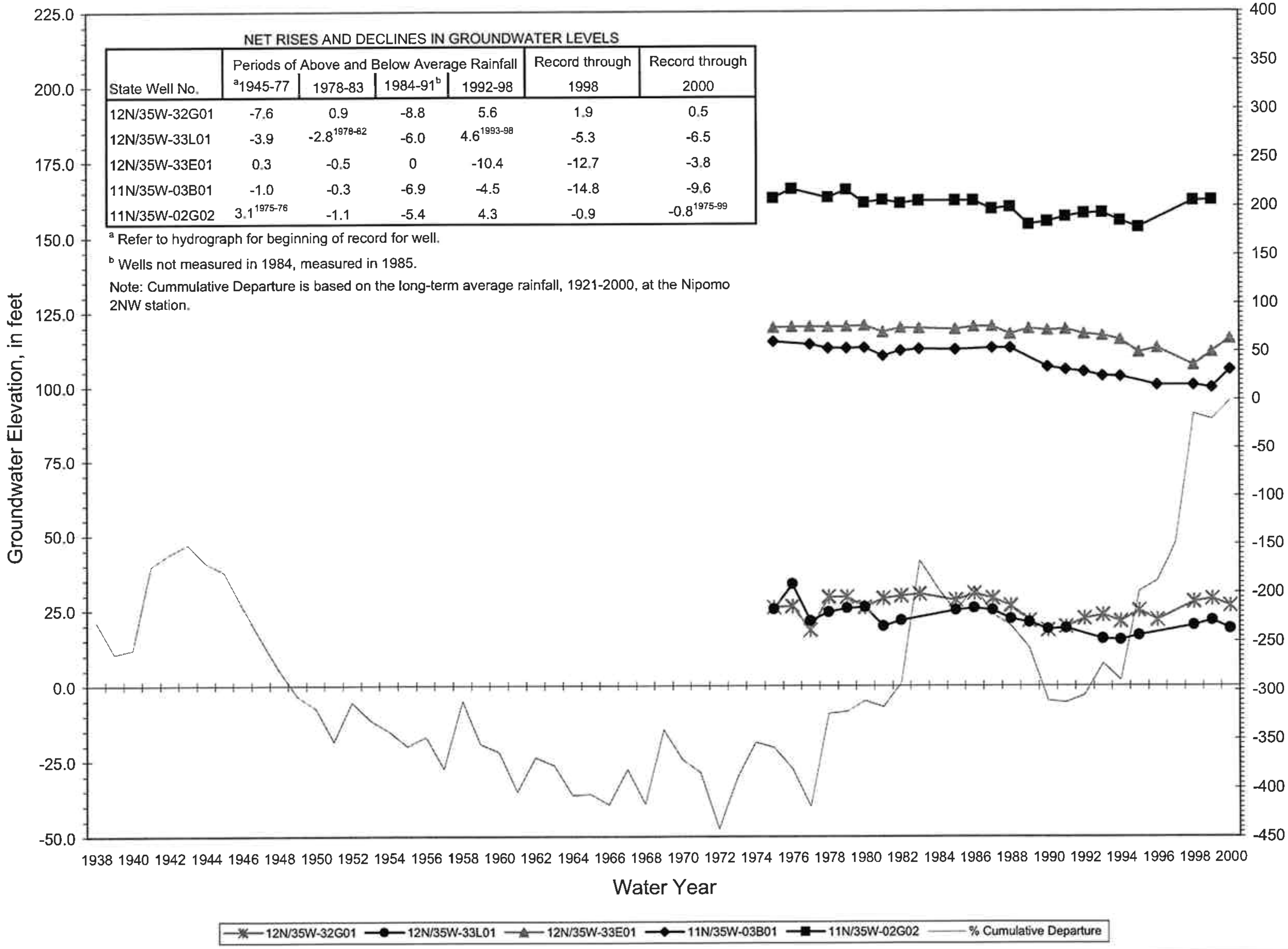
NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91	1992-98	1998	2000
12N/35W-34C03	12.1 [1965-75]	0.4	4.3	18.3	10.3	4.2 [1965-99]
12N/35W-35K02	-3.7	9.8 [1979-83]	-8.6 [1986-91]	24.4	20.2	7.0

[a] Refer to hydrograph for beginning of record for well.

Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

FIGURE 15 - TREND IN GROUNDWATER ELEVATIONS, NORTHERN NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91[b]	1992-98	Record through 1998	Record through 2000
12N/35W-32G01	-7.6	0.9	-8.8	5.6	1.9	0.5
12N/35W-33L01	-3.9	-2.8[1978-82]	-6.0	4.6[1993-98]	-5.3	-6.5
12N/35W-33E01	0.3	-0.5	0	-10.4	-12.7	-3.8
11N/35W-03B01	-1.0	-0.3	-6.9	-4.5	-14.8	-9.6
11N/35W-02G02	3.1[1975-76]	-1.1	-5.4	4.3	-0.9	-0.8[1975-99]

[a] Refer to hydrograph for beginning of record for well.

[b] Wells not measured in 1984, measured in 1985.

Note: Cummulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

Levels in wells on the north side of the Santa Maria River fault, 33E01, 03B01, and 02G02, show almost no variability and no correlation with trends in rainfall. The levels in these wells have steadily declined over time, despite cycles of greater rainfall. Well 33E01 had a record low level in 1998, the wettest rainfall year on record. Over the period of record, the decline ranged from about 10 feet in well 03B01 to about one foot in well 02G02.

Wells 32G01 and 33L01 on the south side of the fault show a subdued correlation to trends in rainfall. Groundwater levels in well 33L01 declined about six feet over its period of record. This well is within the depression by Halcyon Road shown on Plate14. Levels in well 32G01 had a net rise of a half-foot over its period of record, an amount that may be attributable to water level measuring practices.

In northern Nipomo Mesa, wells on both sides of the Santa Maria River fault are showing small long-term declines in water levels. In this part of the basin, the volume of groundwater withdrawn for use may be slightly exceeding recharge, resulting in small declines in the amount of groundwater in storage.

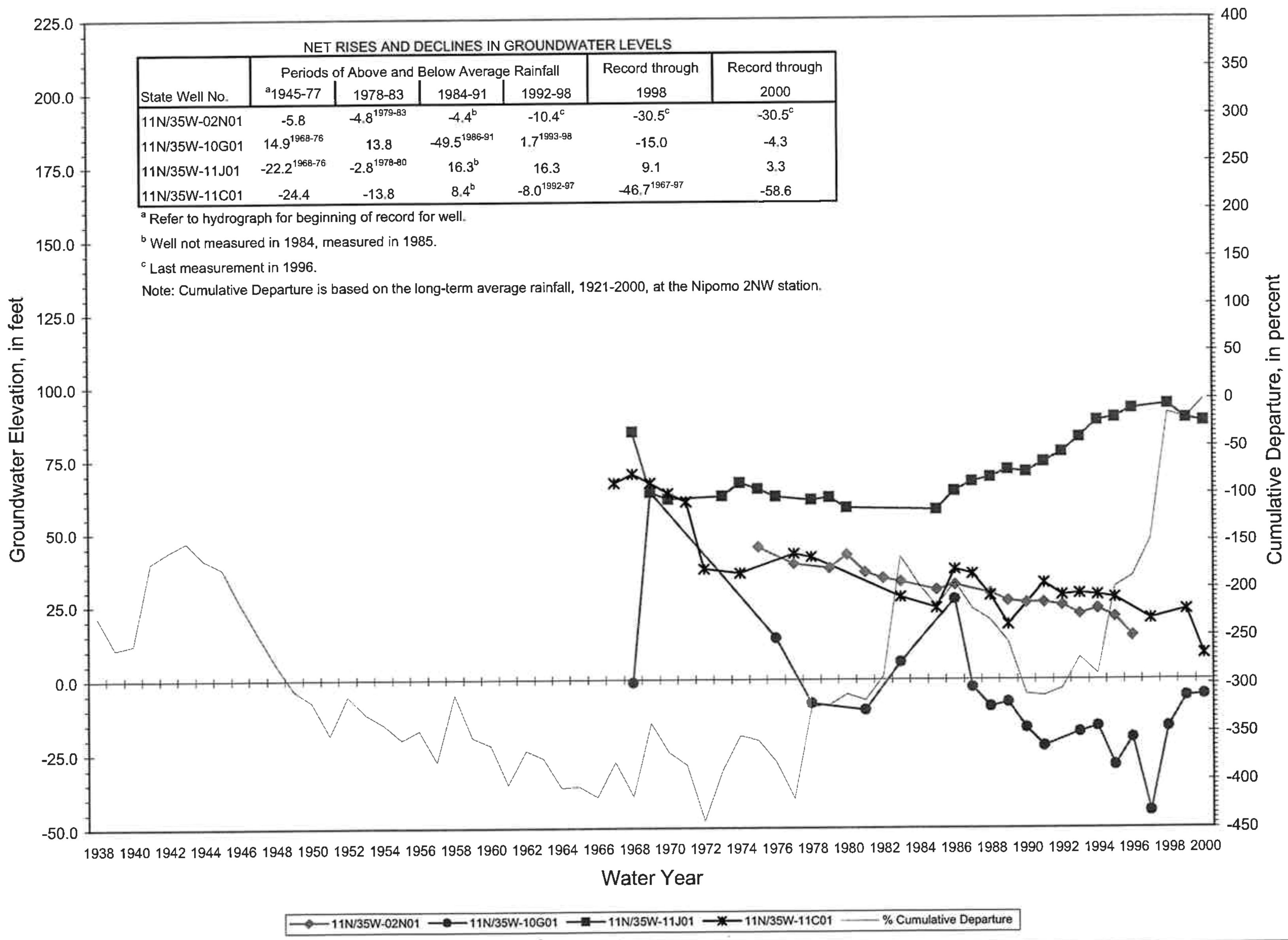
Central Nipomo Mesa. Hydrographs of four wells perforated in the Paso Robles Formation are shown on Figure 16. Wells 11N/35W-02N01, 11N/35W-10G01, and 11N/35W-11J01 are on the south side of the Santa Maria River fault and well 11N/35W-11C01 is on the north side of the fault. As mentioned earlier, groundwater elevations are similar on opposite sides of the fault along the segment near the head of Black Lake Canyon (north of Willow Road to about a mile east of Zenon Way).

Well 02N01 is near the head of Black Lake Canyon and at the edge of the depression shown on Plate 14. The levels in this well do not follow rainfall trends, showing no response to wet years. The levels have declined almost steadily over time, about one foot per year over the period of record. Monitoring of this well stopped in 1996.

Well 10G01 is in the center of the depression shown on Plate 14. Prior to 1985, this well had been used for irrigation, and measurements of water levels were sporadic. In 1985, the pump was removed, contributing to the rise in levels in 1986. The well is now used for observation only. The fluctuations of levels in this well may be affected by the extractions of nearby wells. The greatest rise in levels in response to recharge from rainfall occurred in the wet year 1969, when the groundwater level rose 65 feet. Levels declined 72 feet between 1969 and 1978, dropping below msl. Between 1986 and 1991, levels declined about 50 feet, but recovered and rose about 12 feet by 2000. The spring levels have been continuously below msl since 1987. The average decline over the period of record is about 0.13 foot per year.

Groundwater levels in well 11J01 do not show a correlation with rainfall. Levels rose about three feet over its period of record, even rising during the dry period 1984 through 1991, when rainfall was 32 percent below normal. The use of this well may have changed around 1985. Prior to 1985, the well was used for stock and irrigation. Since that time, the well appears to be

FIGURE 16 - TREND IN GROUNDWATER ELEVATIONS, CENTRAL NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91	1992-98	1998	2000
11N/35W-02N01	-5.8	-4.8[1979-83]	-4.4[b]	-10.4[c]	-30.5[c]	-30.5[c]
11N/35W-10G01	14.9[1968-76]	13.8	-49.5[1986-91]	1.7[1993-98]	-15.0	-4.3
11N/35W-11J01	-22.2[1968-76]	-2.8[1978-80]	16.3[b]	16.3	9.1	3.3
11N/35W-11C01	-24.4	-13.8	8.4[b]	-8.0[1992-97]	-46.7[1967-97]	-58.6

[a] Refer to hydrograph for beginning of record for well.

[b] Well not measured in 1984, measured in 1985.

[c] Last measurement in 1996.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

used just for domestic water and groundwater levels have steadily risen. This well is unaffected by the depression shown on Plate 14. Also, a nearby well had levels that rose 37 feet between 1988 and 1996. Wells with level measurements in the immediate area, just south of the Santa Maria River fault, indicate a balance between recharge and discharge.

Well 11C01, located on the north side of Santa Maria River fault and near the head of Black Lake Canyon, is monitored but not in use. The groundwater levels dropped too low and the well sanded up. In 1972, the water level in this well declined 23 feet in a year in which precipitation was about 40 percent of normal. Fluctuations of levels in this well do not appear to correlate well with rainfall, some years with high rainfall do not result in a corresponding rise in groundwater levels. Levels have declined almost 60 feet over the period of record; however, the initial groundwater level measurements may have been perched levels, which are common near the head of the canyon.

In wells such as 02N01, 10G01, and 11C01, the long-term declines in groundwater levels reflect a lack of balance between recharge and discharge and the loss of groundwater storage that is occurring in this part of the mesa.

Western Nipomo Mesa. The wells with hydrographs shown on Figure 17 are located south of the Oceano fault. Well 11N/35W-05L01 is on the north side of Black Lake Canyon and well 11N/35W-05R01 is on the south side of the canyon. Both wells are perforated in the Paso Robles Formation. Well 11N/35W-09K04 is south of Willow Road and east of Highway 1. A well completion report is not available for this well, but it is also likely perforated in the Paso Robles Formation.

The hydrographs show that water levels in these wells vary from year to year generally in close correlation with trends in rainfall. The greater variability of levels in well 09K04 may be attributable to its use, the presence of other wells nearby, applied water use in the area, variability in rainfall distribution, or differences in hydraulic properties of the water-bearing sediments.

Wells 05L01 and 05R01 are at the edge of a small depression near the lower end of Black Lake Canyon, shown on Plate 14. The hydrographs of these wells show that over the long term, levels have generally been stable, with a small decline of about one foot over their periods of record. That amount of decline may be attributable to water level measuring practices and it appears recharge is balancing discharge over time.

Southeastern Nipomo Mesa. Figure 18 presents hydrographs of wells located in southeastern Nipomo Mesa. Wells 11N/34W-19Q01, 11N/35W-13E02, 11N/35W-24D01, and 11N/35W-24L02 are perforated in the Paso Robles Formation and are located between the Oceano fault and the Santa Maria River fault. Well 11N/34W-27E01 is perforated in the Squire Member of the Pismo Formation and is located between the Santa Maria River fault and the Wilmar Avenue fault, at the edge of the boundary for Nipomo Mesa HSA.

FIGURE 17 - TREND IN GROUNDWATER ELEVATIONS, WESTERN NIPOMO MESA WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
11N/35W-05L01	-13.4	12.3	-1.3	11.1	0.9	-0.6
11N/35W-05R01	-14.4	5.1	-5.3[b]	$-4.3^{1992-97}$	$-13.1^{1975-97}$	-1.1
11N/35W-09K04	-16.1	-2.8	23.6[b]	19.3	2.4	-0.3

[a] Refer to hydrograph for beginning of record for well.

[b] Well not measured in 1984, measured in 1985.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

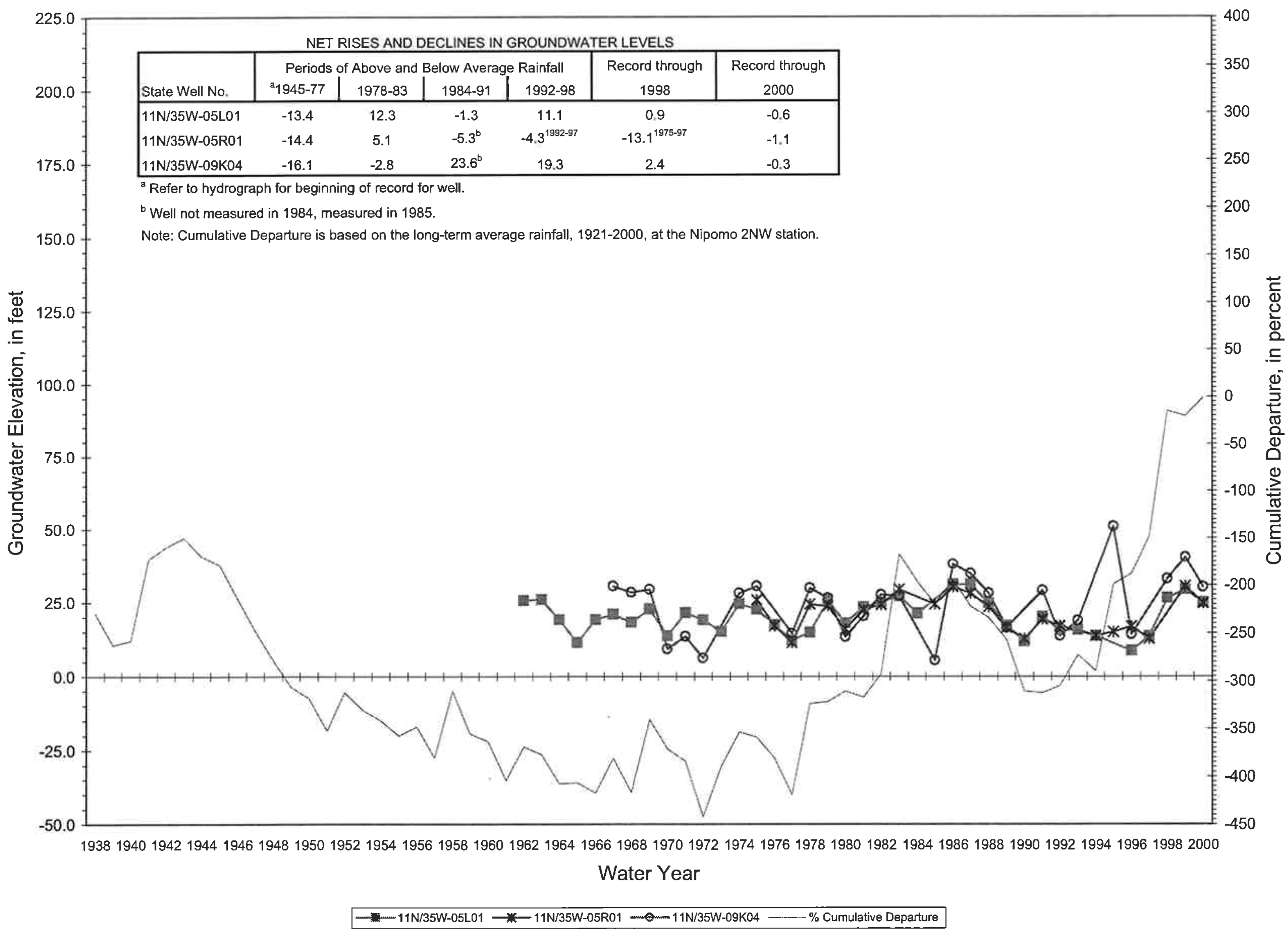
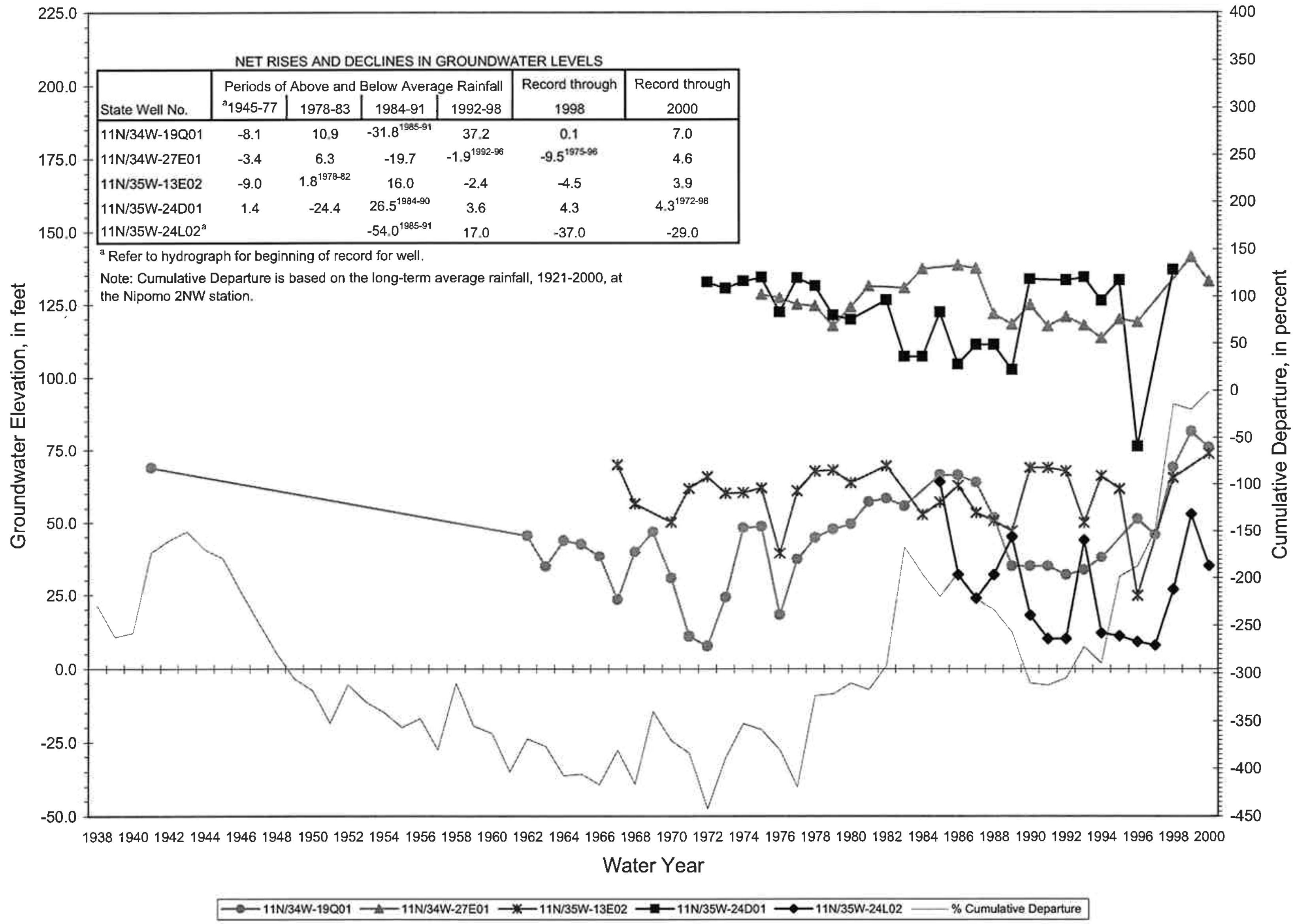


FIGURE 18 - TREND IN GROUNDWATER ELEVATIONS, SOUTHEASTERN NIPOMO MESA WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
11N/34W-19Q01	-8.1	10.9	$-31.8^{1985-91}$	37.2	0.1	7.0
11N/34W-27E01	-3.4	6.3	-19.7	$-1.9^{1992-96}$	$-9.5^{1975-96}$	4.6
11N/35W-13E02	-9.0	$1.8^{1978-82}$	16.0	-2.4	-4.5	3.9
11N/35W-24D01	1.4	-24.4	$26.5^{1984-90}$	3.6	4.3	$4.3^{1972-98}$
11N/35W-24L02[a]			$-54.0^{1985-91}$	17.0	-37.0	-29.0

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

Fluctuations in groundwater levels in well 19Q01 generally follow trends in rainfall. The static water level reported on the well completion report at the time the well was drilled in 1941 is included on the hydrograph. Since 1998, water levels have been higher than the 1941 level. The water level rose 23 feet in the 1998 wet year and continued to rise another 12.5 feet in 1999. Although this well is on the mesa, it is about 2 miles northwest of the Santa Maria River and may also be recharged from infiltration from the river.

Water level fluctuations in well 13E02 do not generally follow rainfall trends. A net rise in water levels occurred in the dry period of 1984 through 1991 and a small net decline in water levels occurred in the wet period of 1992 through 1998. Other factors may be influencing the levels in this well, such as the use of the well, the presence of other wells nearby, applied water use in the area, variability in rainfall distribution, or differences in hydraulic properties of the water-bearing sediments. Over its period of record, levels in this well rose about four feet.

Groundwater elevations in well 24D01 represent perched water conditions. The well is within the depression shown on Plate 14, but its water levels are not being affected as are levels of the principal groundwater body. Well 24D01 had a net rise of about four feet in levels over its period of record. Fluctuations in water levels in this well do not correlate with rainfall. This well had a net decline in water levels during the wet period of 1978 through 1983 and a net rise in water levels during the dry period of 1984 through 1991. The low groundwater elevation in 1996 may not be a static level, but no comment was noted in the county's database.

Well 24L02, a water agency production well, is within the depression shown on Plate 14 and levels are being affected by extractions that exceed recharge in this area. Water level response to wet years is affected by production from the well. Over its period of record (1985 to 2000), water levels have declined about 30 feet, or about two feet per year.

Groundwater elevations in well 27E01 are not perched levels, but are representative of groundwater elevations on the north side of this segment of the Santa Maria River fault. The hydrograph of this well is included on Figure 18 to illustrate the possible differences in groundwater elevations found on opposing sides of the fault along this segment. Levels in this well generally follow rainfall trends. Over its period of record, levels rose about five feet.

Summary Comments on Nipomo Mesa Groundwater Elevation Trends. Nipomo Mesa has seen increasing development along with associated increased demands on groundwater supplies (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 wells[14] in parts of the basin (the part between the Santa Maria River fault and the Oceano fault and the part north of the Santa Maria River fault around El Campo Road), despite periods of 40 percent above average precipitation. In those parts of the basin, concentrated pumpage, the dynamics of the

[14]Declining water levels in wells can lead to increased pumping costs, localized well interference, loss of production capacity, and possible quality degradation.

groundwater system (transmitting properties of the aquifers and potential boundary conditions, such as the Santa Maria River fault), and sources of recharge influence groundwater level trends. If declines in groundwater levels continue in the future and expand to additional parts of the basin, the groundwater resources of the basin could be threatened by sea water intrusion. The localized declines in groundwater levels reflect decreases in estimated amounts of groundwater in storage between 1975 and 1995, discussed in the next section.

However, in other parts of the basin in Nipomo Mesa, the long-term fluctuations in water levels in wells reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term.

The eastern edge of the mesa, bounded by Summit Station Road, Hetrick Avenue, the Santa Maria River fault, Highway 101, and Joshua Road lacks water level monitoring data. Wells in this part of the basin need to be included in the county's monitoring program. It is beyond the scope of this study to select specific wells to be monitored.

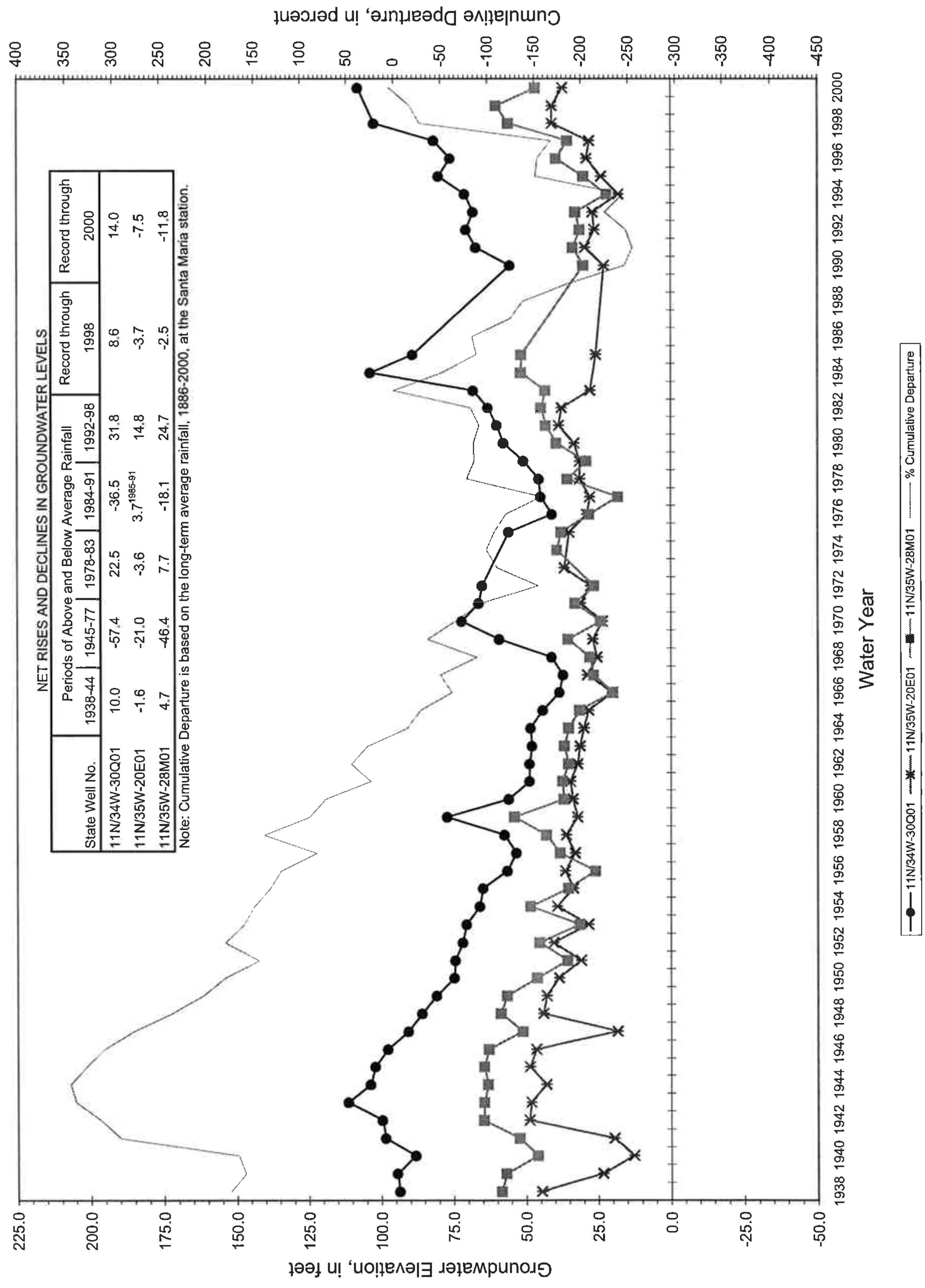
Santa Maria Valley. Figure 19 presents hydrographs of three wells in Santa Maria Valley within the study area and a summary of net changes in water levels during each of the wet and dry periods. Well 11N/34W-30Q01 is perforated in the alluvium adjacent to the river channel in the eastern part of the valley. Well 11N/35W-20E01 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. Well 11N/35W-28M01, perforated in the Paso Robles Formation, is in about the center of the valley approximately 2 miles north of the river channel, near Highway 1.

In 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 stage of the river. 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 19 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 generally clear correlation of water level fluctuations with trends in rainfall.

During the 1945 through 1977 dry cycle, a substantial decline in groundwater levels from the highs of the early 1940s occurred. Declines in water levels in these wells ranged from 0.6 foot per year in well 20E01 to 1.7 feet per year in well 30Q01. The net declines were the result of drier than normal climatic conditions and increased pumpage. Some recovery of groundwater levels occurred in wells 30Q01 and 28M01 during the 1978 through 1983 wet period. Levels again declined during the 1984 through 1991 dry period, with declines ranging from 1.1 to 4.5 feet per year. Levels rose during the 1992 through 1998 wet cycle, and it can be seen that by

FIGURE 19 - TREND IN GROUNDWATER ELEVATIONS, SANTA MARIA VALLEY WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall 1938-44	1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
11N/34W-30Q01	10.0	-57.4	22.5	-36.5	31.8	8.6	14.0
11N/35W-20E01	-1.6	-21.0	-3.6	3.7[1985-91]	14.8	-3.7	-7.5
11N/35W-28M01	4.7	-46.4	7.7	-18.1	24.7	-2.5	-11.8

Note: Cumulative Departure is based on the long-term average rainfall, 1886-2000, at the Santa Maria station.

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 water levels in Santa Maria Valley. The long-term changes of water levels in these wells appear to reflect hydrologic variations and indicate that recharge is balancing discharge in the valley.

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

Arroyo Grande Valley Subbasin. Hydrographs of two wells located in Arroyo Grande Valley Subbasin are shown on Figure 21. Wells 32S/13E-23F01 and 32S/13E-12Q03 are perforated in alluvium. Levels in these wells show the stabilizing effect of the releases from Lopez Reservoir since 1969, particularly during dry periods. During the 1984 through 1991 dry period, both wells had net rises in levels, while wells in Tri-Cities Mesa - Arroyo Grande Plain showed net declines (Figure 12). From 1998 to 2000, the levels in these wells have dropped; well 23F01 declined 30 feet since the high elevations of 1998.

Nipomo Valley Subbasin. Figure 22 shows hydrographs of three wells perforated in the Monterey Formation, because groundwater levels in wells perforated only in the older alluvium are not monitored by the county in Nipomo Valley Subbasin. The graphs show the greater cyclic fluctuation in fractured bedrock wells than in wells perforated in unconsolidated sediments of the main groundwater basin. The wells generally show rising levels during wet periods and falling levels during dry periods. Over the period of record, wells 11N/34W-09P01 and 11N/34W-05K01 had a rise in levels, while well 11N/34W-17B04 showed a small decline of about 1.5 feet.

Summary Comments on Hydrographs. The hydrographs in Figures 12 through 22 show that long-term trends in groundwater levels, with the exception of some parts of the basin in Nipomo Mesa, reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term. Further, it can be seen that trends are not manifested in the entire basin simultaneously because of its size and variations in sources of groundwater recharge or discharge and other mechanisms operating locally.

Groundwater Storage

Porosity and Specific Yield. Two important hydraulic properties of an aquifer that are related to its storage function are porosity and specific yield (storativity). Porosity is the ratio of voids in a rock or sediment to the total volume of material and is an index of how much groundwater can be stored in a saturated material. Porosity is usually expressed as a percentage and can be classified as either primary or secondary. Primary porosity represents the original openings present when the sediment or rock was formed (Fetter, 1988). Secondary porosity consists of openings formed through fracturing or weathering of a rock or sediment after it was formed (Ibid.).

FIGURE 20 - DIAGRAMMATIC SECTION SHOWING GROUNDWATER LEVEL PROFILES ALONG THE SANTA MARIA RIVER

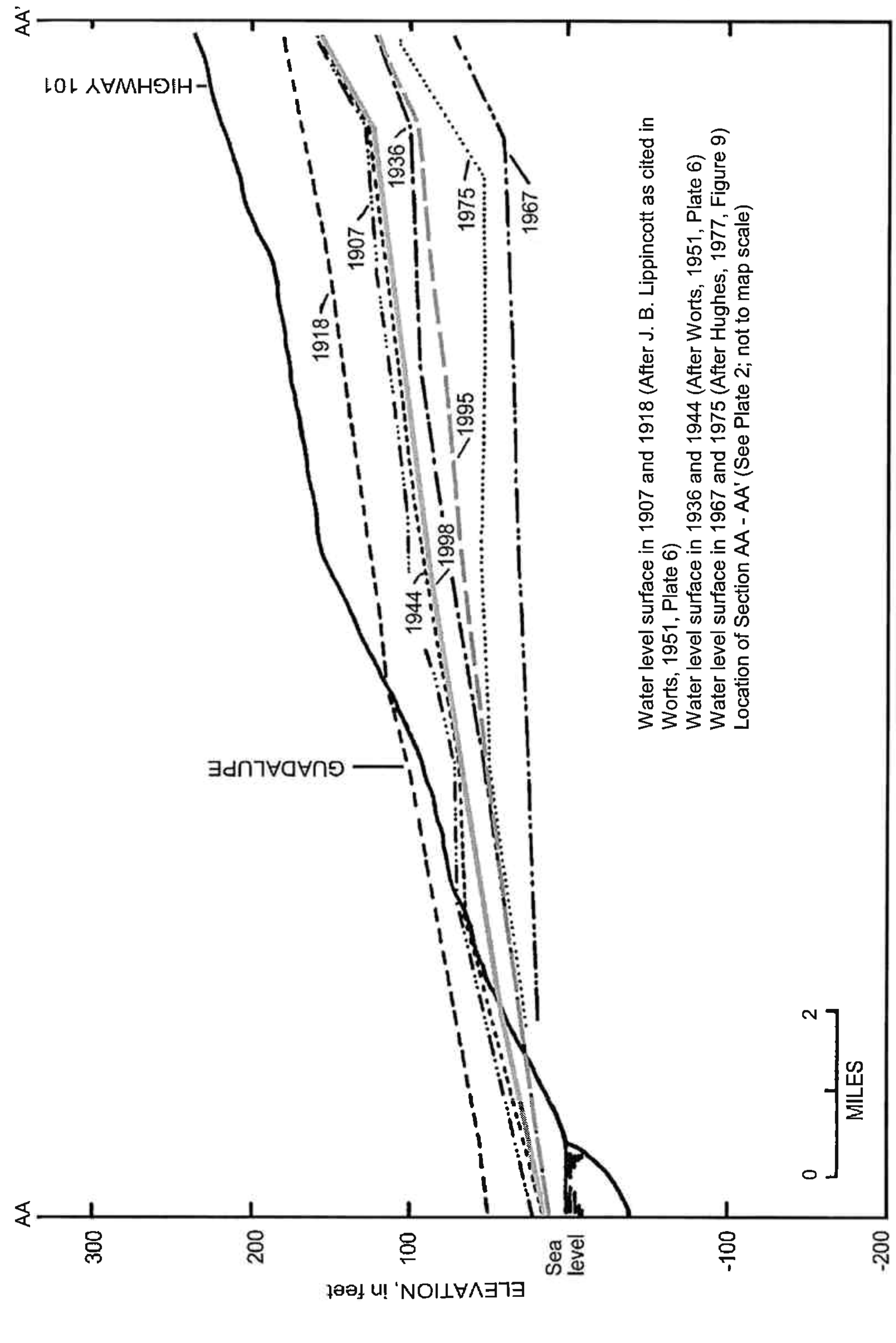
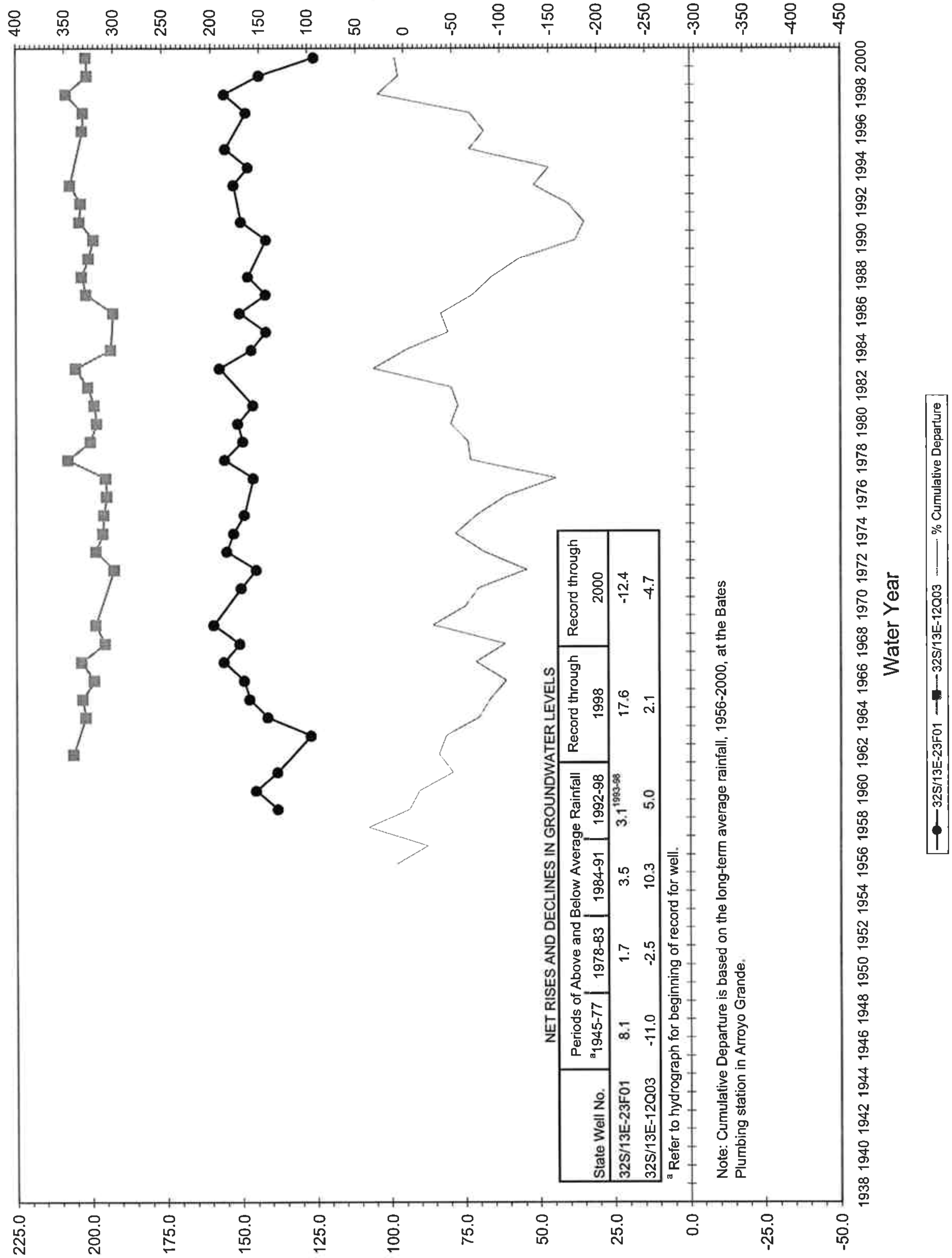


FIGURE 21 - TREND IN GROUNDWATER ELEVATIONS, ARROYO GRANDE VALLEY SUBBASIN WELLS



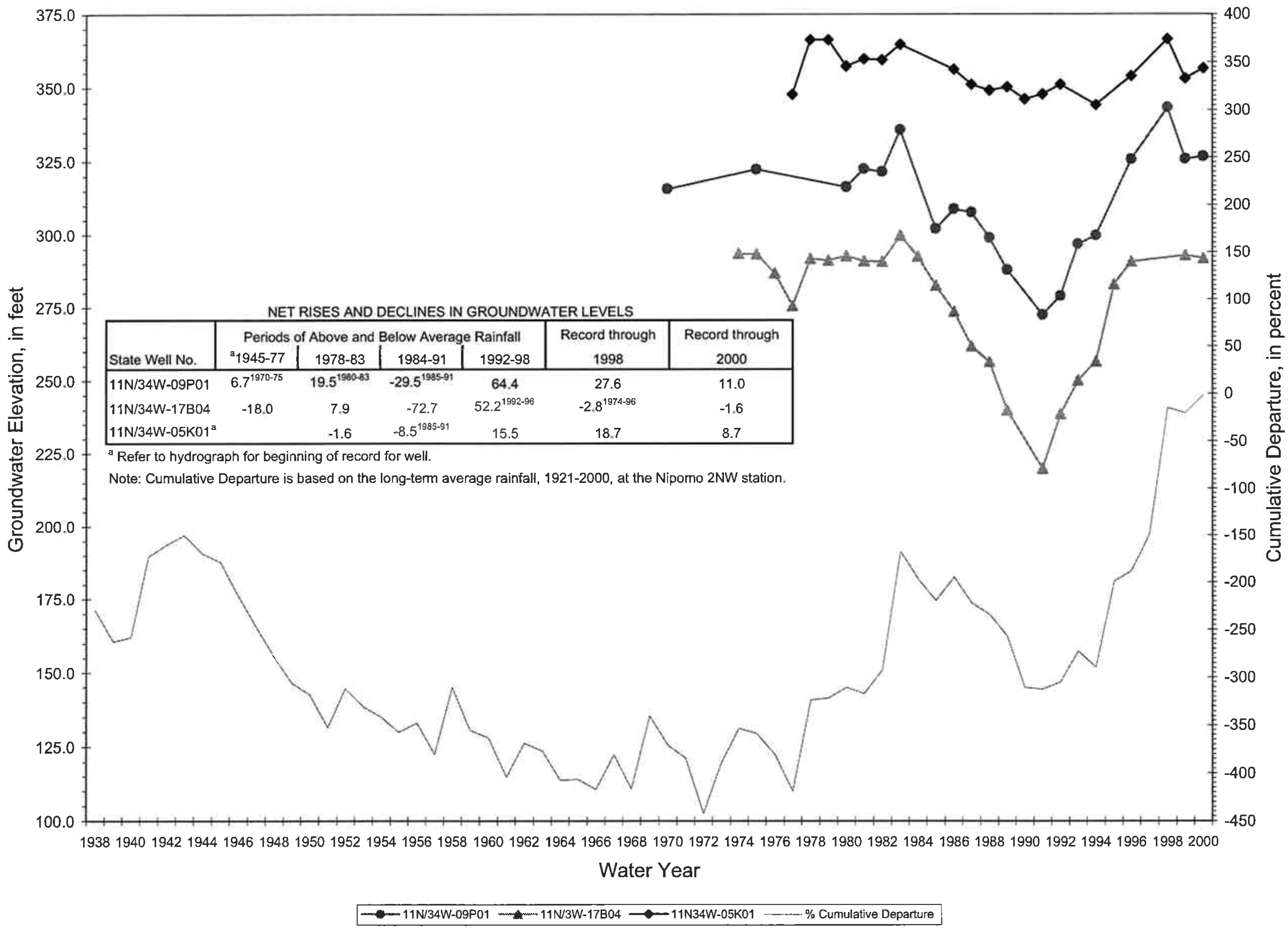
NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91	1992-98	1998	2000
32S/13E-23F01	8.1	1.7	3.5	3.1 [1993-98]	17.6	-12.4
32S/13E-12Q03	-11.0	-2.5	10.3	5.0	2.1	-4.7

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

FIGURE 22 - TREND IN GROUNDWATER ELEVATIONS, NIPOMO VALLEY SUBBASIN WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through 1998	Record through 2000
	[a]1945-77	1978-83	1984-91	1992-98		
11N/34W-09P01	6.7[1970-75]	19.5[1980-83]	-29.5[1985-91]	64.4	27.6	11.0
11N/34W-17B04	-18.0	7.9	-72.7	52.2[1992-96]	-2.8[1974-96]	-1.6
11N/34W-05K01[a]		-1.6	-8.5[1985-91]	15.5	18.7	8.7

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

However, only a part of the water in a saturated material will drain freely from rocks or sediments due to gravity. Specific yield describes the portion of the saturated pore space that could actually be available for extraction 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 retention increases with decreasing grain size.

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 to about 30 percent (Heath, 1983).

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} (Heath, 1983). 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 California Department of Public Works, Division of Water Resources (1934) and modified for the Paso Robles Formation by the Department (California Department of Water Resources, 1958) were used (Appendix C). Values were assigned to the types of materials penetrated as listed on lithologs of selected well completion 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.

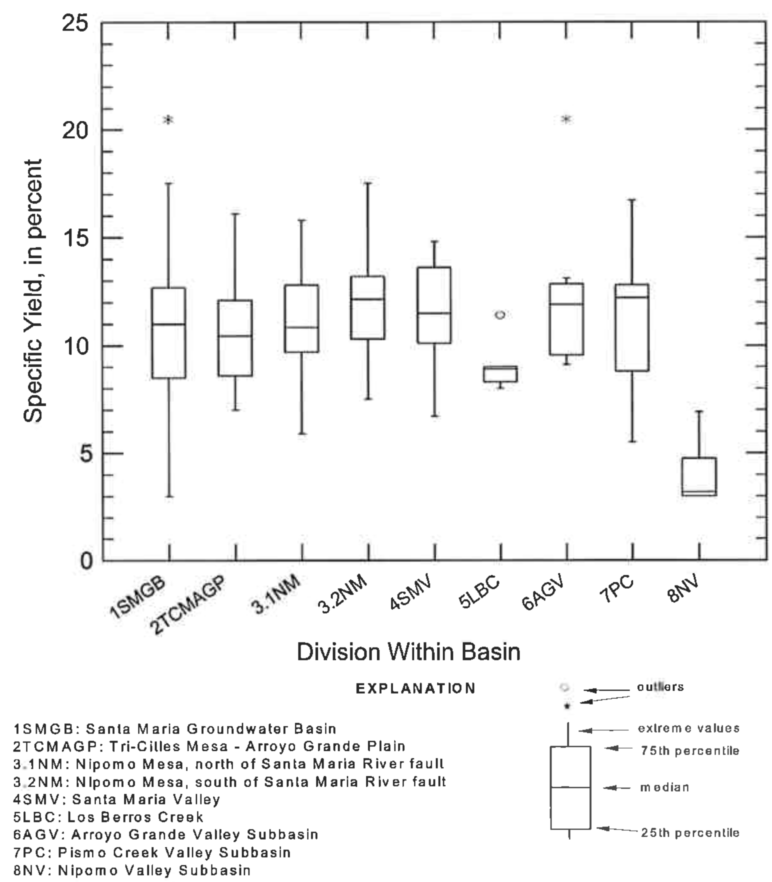
Table 16 presents the representative average weighted specific yield values determined for the

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

		Average Weighted Specific Yield	
Division Within Basin/Basin	N*	Median Value	Range of Values
Oceano HSA**			
Tri-Cities Mesa - Arroyo Grande Plain	22	11	7-16
Los Berros Creek	5	9	8-11
Arroyo Grande Valley Subbasin	8	12	9-21
Pismo Creek Valley Subbasin	5	11	6-17
Nipomo Mesa HSA**			
Nipomo Mesa	44	12	6-18
Guadalupe HA**			
Santa Maria Valley	14	12	7-15
Nipomo Valley Subbasin	7	3	3-5
Santa Maria Groundwater Basin	113	12	3-21

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

FIGURE 23 - SPECIFIC YIELD VALUES, SANTA MARIA GROUNDWATER BASIN



Santa Maria Groundwater Basin and for divisions within the basin. Overall, the estimated median values found in the different portions of the main basin are similar. Nipomo Mesa and Arroyo Grande Valley Subbasin had the largest variation in specific yield values, ranging by 12 percent. Most of the wells on the mesa with the lower values are found north of the Santa Maria River fault. The median specific yield value for wells north of the fault is two percent lower than for wells south of the Oceano fault and about one-half percent lower than for wells between the Santa Maria River and Oceano faults.

Figure 23 illustrates the values given in Table 16 by means of "schematic box plots." On the figure, Nipomo Mesa was divided into two parts, north of Santa Maria River fault and south of the fault, to show the difference found in specific yield values for the basin sediments on each side of the fault.

The areal average weighted specific yield values estimated in this study for Nipomo Mesa and Santa Maria Valley are two to three 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.

Storativity calculated from aquifer test analyses ranged from 0.001 to 0.0001, representative of semi-confined to confined conditions.

Table 17 shows the average weighted specific yield values estimated for the individual basin-fill deposits and formations. The alluvium and older dune sands were found to have the highest specific yield values and the older alluvium in Nipomo Valley Subbasin had the lowest specific yield values as a result of the high clay content of the deposit. The specific yield values for the Paso Robles Formation differed on opposite sides of the Santa Maria River fault, the median

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

Deposit/Formation	Division Within Basin	N*	Average Weighted Specific Yield	
			Median Value	Range of Values
Holocene Alluvium	Arroyo Grande Plain	15	12	8-22
	Santa Maria Valley	11	13	9-23
	Arroyo Grande Valley Subbasin	8	12	9-21
	Pismo Creek Valley Subbasin	5	12	6-17
Older Dune Sand	Tri-Cities Mesa	10	13	5-22
	Nipomo Mesa	66	17	5-26
Older Alluvium	Nipomo Valley Subbasin	15	3	3-7
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, Pismo Formation	Tri-Cities Mesa	18	10	6-16
	Nipomo Mesa	13	7	3-19

* N is the number of selected wells used.

value was two percent lower for the formation on the northeast side of the fault. The Careaga Formation was found to have specific yield values similar to the older dune sand in some wells.

Total Storage Capacity. The total volume of water that could theoretically be held in underground storage in the basin (not what is actually in storage at a given time) is quantified as total storage capacity. It is determined by multiplying the area overlying the basin by the total thickness and the average weighted specific yield ("specific yield method"). Total groundwater storage capacity takes into account only the theoretical physical capacity of the basin and not the many factors that can limit the ultimate development potential of the basin, such as quality, subsurface outflow, economic, environmental, or institutional limitations. However, estimates of total storage capacity can be useful for planning purposes.

Table 18 gives the total storage capacity estimates for the basin as a whole and for the divisions within the basin.[15] These estimates assume the basin-fill deposits can be saturated to within about 20 feet of ground surface. Estimated total storage capacity is given for both above msl and

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

Division Within Basin/Basin	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⁺	10,770	11.0	52,000⁺⁺	360,000⁺⁺	412,000
Arroyo Grande Valley Subbasin	3,860	12.3	14,000⁺⁺	0	14,000
Pismo Creek Valley Subbasin	1,220	11.2	2,000⁺⁺	--	2,000
Nipomo Mesa HSA***					
Nipomo Mesa	17,580	11.7	490,000⁺⁺	720,000⁺⁺	1,210,000
Guadalupe HA***					
Santa Maria Valley	21,560	11.6	218,000⁺⁺	2,100,000⁺⁺	2,318,000
Nipomo Valley Subbasin	6,230	3.8	8,000⁺⁺	0	8,000
Santa Maria Groundwater Basin	61,220		784,000	3,180,000	3,964,000

*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 groundwater basin.
⁺Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
⁺⁺Values rounded to two significant figures.

[15] Basin boundaries are shown on Plate 10.

below msl. A few points need to be mentioned. Because this method of estimating total storage capacity uses simplifying assumptions that may introduce errors of a few percent, the estimates in Table 18 were rounded to two significant figures. 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 estimated total storage capacity of the basin within San Luis Obispo County, both above and below msl, is about 4 million AF, of which about 20 percent is above msl. About half the total storage capacity of the groundwater basin, most of it below msl, is within Santa Maria Valley.

Of the estimated total storage capacity of Santa Maria Valley, only about 10 percent, or 218,000 AF, is above msl. Nipomo Mesa has the largest estimated total storage capacity for groundwater above msl, about one-half million AF, or about 40 percent of its total capacity. In Tri-Cities Mesa - Arroyo Grande Plain, about 15 percent, or 52,000 AF, of the estimated total storage capacity is above msl.

While the theoretical total storage capacity above msl for Nipomo Mesa is large, any development potential of this capacity would be limited by the need to avoid groundwater leakage from the edges of the mesa.

Estimated total storage capacity of the subbasins is small compared to that of the main basin, 24,000 AF, of which about 60 percent is in Arroyo Grande Valley Subbasin.

Groundwater in Storage. 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 ("specific yield method").[16] The upper limit of saturation was determined from the groundwater elevation contour maps, Plates 12-14. Table 19 presents the estimated amounts in storage for the basin as a whole and for divisions within the basin, for both above and below msl.[17] The amount in storage above msl is important, because of the physical limitation placed on this coastal basin

[16]Amounts in storage were also estimated for spring 2000 for Santa Maria Groundwater Basin and are given in Table A1 in the addendum attached at the back of this report.

[17]Differences in amounts of groundwater in storage in this report from the January 2000 final draft report are because of changes in basin boundaries, base of the potentially water-bearing sediments, reference elevations of wells, groundwater elevation contours, and average weighted specific yield values (more well completion reports were available for this report).

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

Division Within the Basin/Basin	Surface Area, in acres	Average Weighted Specific Yield,[a] in percent	Water Year	Amount of Groundwater in Storage (Available Storage Capacity)			Change in Storage, Above MSL[b]	
				Above MSL[b]	Below MSL[b]	Total	Between Years	Amount
Oceano HSA[c]								
Tri-Cities Mesa - Arroyo Grande Plain[d]	10,770	11.0	1975	28,000[e]	360,000[e]	388,000	1975 and 1985	-1,000
			1985	27,000[e]	360,000[e]	387,000	1985 and 1995	2,000
			1995	29,000[e]	360,000[e]	389,000	1975 and 1995	1,000
Arroyo Grande Valley Subbasin	3,860	12.7	1975	9,000[e]	0	9,000	1975 and 1985	-1,000
			1985	8,000[e]	0	8,000	1985 and 1995	2,000
			1995	10,000[e]	0	10,000	1975 and 1995	1,000
Pismo Creek Valley Subbasin[f]	1,220			--	--	--		--
Nipomo Mesa HSA[c]	17,580	11.0	1975	84,000[e]	720,000[e]	804,000	1975 and 1985	-1,000
Nipomo Mesa			1985	83,000[e]	720,000[e]	803,000	1985 and 1995	-6,000
			1995	77,000[e]	720,000[e,g]	797,000	1975 and 1995	-7,000
Guadalupe HA[c]	21,560	11.1	1975	97,000[e]	2,100,000[e]	2,197,000	1975 and 1985	13,000
Santa Maria Valley			1985	110,000[e]	2,100,000[e]	2,210,000	1985 and 1995	-10,000
			1995	100,000[e]	2,100,000[e]	2,200,000	1975 and 1995	3,000
Nipomo Valley Subbasin	6,230	3.8	1975	3,600[e]	0	3,600	1975 and 1985	-500
			1985	3,100[e]	0	3,100	1985 and 1995	600
			1995	3,700[e]	0	3,700	1975 and 1995	100
Santa Maria Groundwater Basin	61,220		1975	221,600	3,180,000	3,401,600	1975 and 1985	9,500
			1985	231,100	3,180,000	3,411,100	1985 and 1995	-11,400
			1995	219,700	3,180,000	3,399,700	1975 and 1995	-1,900

[a] Specific yield values used for calculating amount of groundwater in storage were determined for only the saturated thickness of the basin.
[b] MSL is mean sea level.
[c] Hydrologic area or subarea overlying groundwater basin.
[d] Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
[e] Values rounded to two significant figures.
[f] Water level data were not available to determine amount in storage for the subbasin.
[g] A small amount of groundwater in storage was lost from below MSL because of the depression. It is not shown because of rounding to significant figures.

by the need to protect the basin from sea water intrusion. The table also presents the amount of change in storage above msl that took place between the three water years. 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 portion 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, within the San Luis Obispo County portion of the Santa Maria Groundwater Basin, the estimated amount of groundwater in storage, both above and below msl, was about 3.4 million AF, of which only about seven percent, or approximately 220,000 AF, was above msl. This amount is about 2,000 AF less than the amount in storage in 1975.

For Tri-Cities Mesa - Arroyo Grande Plain, the estimated amount of groundwater in storage, both above and below msl, for the three springs was nearly the same, 387,000 to 389,000 AF, of which 27,000 to 29,000 AF, or about six percent, were above msl. In this portion of the basin, the amount of groundwater in storage, between 1975 and 1985, declined 1,000 AF and between 1985 and 1995, increased 2,000 AF. The changes in storage coincide with hydrologic conditions, 1985 a dry year and 1995 a wet year, and also reflect stream infiltration.

In Nipomo Mesa, the amount of groundwater in storage in 1995, both above and below msl, was estimated to be about 800,000 AF, of which 77,000 AF, or about 10 percent, were above msl. The 1995 amount above msl is about eight percent less (6,000 AF) than the amount in storage above msl in 1985. Because Nipomo Mesa's major source of recharge is deep percolation of precipitation, the loss in storage reflects variations in hydrologic conditions. The average rainfall during the period from water year 1985 through water year 1995 was about two inches less than the average rainfall during the period from water year 1975 through water year 1985. Also, the loss is primarily associated with those areas of pumping depressions shown on Plate 14 and declining trends found in groundwater levels in some wells in parts of the mesa. As mentioned earlier, the magnitude of the depression in the south-central part of the mesa is not well defined because wells with groundwater level data are limited and reference elevations for all the wells were not surveyed. The mesa also showed a small decline in storage above msl of 1,000 AF between 1975 and 1985.

Santa Maria Valley was estimated to have 2.2 million AF of groundwater in storage in 1995, both above and below msl, of which 100,000 AF, or about five percent, were above msl. This amount is 3,000 AF more than the estimated amount in storage in spring 1975. In 1985, the valley was estimated to have 110,000 AF of groundwater in storage above msl, 13,000 AF more than 1975, because of the 1983 wet year and substantial stream infiltration from the Santa Maria River that year and from Twitchell Reservoir releases in 1984. Stream infiltration from the Santa

Maria River in the 1995 wet year was not yet fully reflected in groundwater elevations in the valley that year. Based on the trend in groundwater elevations, the amount in storage increased in the succeeding years as the recharge mound traveled away from the river. Part of the change in storage from 1985 to 1995 in Santa Maria Valley reflects movement of groundwater from the valley into Nipomo Mesa (shown by the pumping depression on Plate 14).

Arroyo Grande Valley Subbasin was estimated to have 8,000 to 10,000 AF of groundwater in storage. The subbasin had a loss in storage in the 1985 dry year and a small gain in storage in the wet year 1995.

Water level data were not available to estimate an amount of groundwater in storage in Pismo Creek Valley Subbasin.

Nipomo Valley Subbasin was estimated to have 3,100 to 3,700 AF of groundwater in storage in the older alluvium and Orcutt Formation. The subbasin had a loss in storage in the 1985 dry year and a small gain in storage in the wet year 1995.

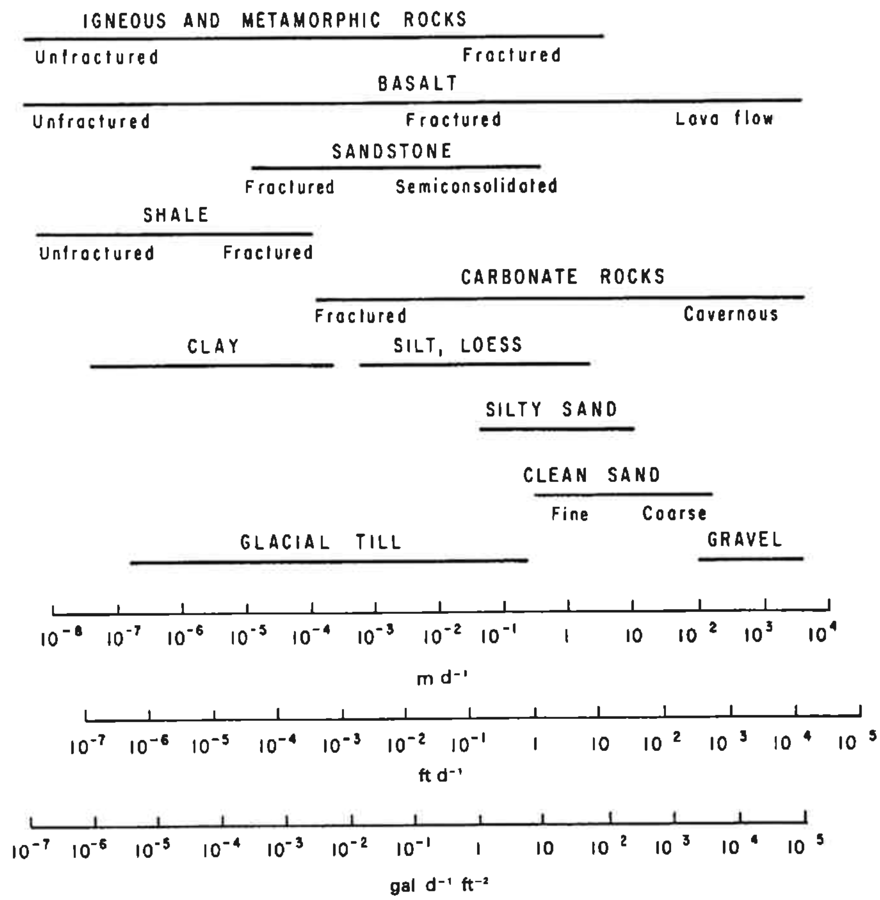
Because of the very wet year 1998, the estimated amount of groundwater in storage above msl in the basin in 2000 was 40,000 AF more than the 1995 amount and about 38,000 AF more than the 1975 amount. Estimated amounts above msl in the basin were: 30,000 AF in the Tri-Cities Mesa - Arroyo Grande portion of the basin, 84,000 AF in the Nipomo Mesa portion of the basin (this is the same amount as in 1975 despite the continued presence of the pumping depression in the south-central part on the mesa, Plate A1 in the Addendum), 132,000 AF in the Santa Maria Valley portion of the basin, 10,000 AF in Arroyo Grande Valley Subbasin, and 3,700 AF in Nipomo Valley Subbasin. (See Table A1 in the Addendum.)

In the Santa Maria Groundwater Basin, a dynamic balance exists between recharge and discharge, as the basin continuously seeks a new equilibrium. Changes in the amount of groundwater in storage are the response of the basin to variations in hydrologic conditions and recharge and discharge and to changes in land and water uses within the basin. Recharge to the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin is augmented by stream infiltration from Lopez Reservoir releases and to the Santa Maria Valley portion of the basin by stream infiltration from Twitchell Reservoir releases. Because Nipomo Mesa's only major source of recharge is deep percolation of precipitation, this part of the basin is more susceptible to prolonged dry periods and increasing demands on its groundwater supplies. To protect the basin from sea water intrusion, it is important that the amount of groundwater in storage in the basin be of sufficient quantity for the freshwater head to counterbalance the greater density of sea water and subsurface outflow to the ocean to occur.

Hydraulic Conductivity and Transmissivity

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

FIGURE 24 - HYDRAULIC CONDUCTIVITY OF SELECTED ROCKS



From: Heath, R. C., 1983

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 24 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, but is most commonly greater 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 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 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 well completion reports. The three methods are described in Appendix C.

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 division within the basin. The highest hydraulic conductivity values are generally found in the alluvium. Lower conductivity values are generally found in the oldest formations--the Careaga Formation and the Squire Member of the Pismo Formation. Also, lower values of conductivity tended to be found in the basin deposits north of the Santa Maria River fault underlying Nipomo Mesa.

Aquifer transmissivities of the basin were found to range over several orders of magnitude, from 100 to more than 400,000 gallons per day per foot. Transmissivity values of the alluvial aquifers in Santa Maria Valley were the highest, ranging from 200,000 to 400,000 gallons per day per foot. In Arroyo Grande Valley, values of the alluvial aquifers were as high as 100,000 gallons per day per foot. Transmissivity values of the Paso Robles Formation ranged from 100 to 160,000 gallons per day per foot. The higher values for the formation were found south of the Oceano fault, in both Nipomo Mesa and Santa Maria Valley parts of the basin. Values for the Paso Robles Formation in Tri-Cities - Arroyo Grande Plain ranged from 20,000 to 130,000 gallons per day per foot. Transmissivity of the Squire Member in Tri-Cities Mesa - Arroyo Grande Plain ranged from about 3,000 to 30,000 gallons per day per foot. The Careaga Formation had transmissivity values similar to those for the Paso Robles Formation. The lowest transmissivity values are typically found in the Nipomo Mesa part of the basin, north of the Santa Maria River fault, where values ranged from 100 to about 4,000 gallons per day per foot.

Subsurface Flows

Within the basin, groundwater flows from recharge areas to discharge areas. Groundwater flows

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

Deposit/Formation	Division Within Basin	Hydraulic Conductivity* Aquifer Test	Pump Efficiency	Lithologic Correlation
Alluvium	Arroyo Grande Plain		700-2,000	40-4,200
	Arroyo Grande Valley Subbasin	2,000	9-90	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	1,500**	55-1,000	
Older Alluvium	Nipomo Valley Subbasin		115-255	<1-20
Paso Robles Formation	Tri-Cities Mesa - Arroyo Grande Plain	370-900	120-2,700	5-2,900
	Nipomo Mesa	22-540	1-375	5-800
	Santa Maria Valley	65***	10-1,035	20-2,000
Paso Robles and Careaga Formations	Nipomo Mesa	10-50	15-90	
Paso Robles Fm and Squire Member	Tri-Cities Mesa	50-130	130-450	
	Nipomo Mesa		1-45	
Careaga Formation	Nipomo Mesa			<1-235⁺⁺
	Santa Maria Valley	75⁺		<1-320⁺⁺
Squire Member	Tri-Cities Mesa	30-40	20-110⁺⁺	3-325⁺⁺
	Nipomo Mesa		1-10⁺⁺	<1-200⁺⁺

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

**Worts (1951) determined the hydraulic conductivity based on recovery tests.

***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.

from the main basin to the Pacific Ocean. Within the main basin, groundwater flows from Nipomo Mesa to Arroyo Grande Plain and, depending on groundwater elevations and hydraulic gradients in Nipomo Mesa, groundwater may flow from Santa Maria Valley in San Luis Obispo County to Nipomo Mesa. Also, groundwater flows from Arroyo Grande Valley and Pismo Creek Valley Subbasins to the Tri-Cities Mesa - Arroyo Grande Plain portion of the main basin and possibly from Nipomo Valley Subbasin to the Nipomo Mesa portion of the main basin. As mentioned earlier, hydraulic connection across the Wilmar Avenue fault in Nipomo Valley is not known. Groundwater may also flow into the basin from the surrounding bedrock and, in Santa Maria Valley, from the upstream portion of the basin, outside the study area[18]. Amounts of subsurface flows were estimated for water years 1975, 1985, and 1995 of the study period.

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 through which the subsurface flow occurs, the hydraulic conductivity of the deposits, and the hydraulic gradient. Because of the high degree of variability of hydraulic conductivity of the deposits, estimated low, high, and geometric mean[19] values of hydraulic conductivity for deposits along the cross-section were used to calculate subsurface flow amounts. Hydraulic gradients were computed for 1975, 1985, and 1995 from Plates 12-14. The estimated quantities of subsurface flows thus derived for this study are presented in Table 21.

Subsurface Outflows to the Ocean. Geologic cross-section A-A′ (Plate 3) was used to determine the area through which the subsurface outflow to the ocean takes place. The total saturated cross-sectional area was about 50 million square feet. The estimated mean amount of outflow from the basin to the ocean was about 10,000 AF each year.

The largest estimated amounts of outflow to the ocean are from Santa Maria Valley, where the depth of the basin is greatest and the alluvium has a high hydraulic conductivity. Estimated amounts ranged from a low amount of 1,800 AF in 1975 and 1995 to a high amount of 23,000 AF in 1985, with estimated mean amounts of about 6,000 AF in 1975 and 1995 and about 7,000 AF in 1985. About two-thirds of the estimated amount of outflow from the valley to the ocean occurs through the alluvium. The slightly higher estimated outflow from Santa Maria Valley in 1985 was the result of an increased hydraulic gradient from higher groundwater elevations (a greater amount of groundwater was in storage because of substantial stream infiltration from the Santa Maria River in the 1983 wet water year and from Twitchell Reservoir releases in 1984).

[18]The Santa Maria Valley portion of the main basin may also be recharged by some subsurface inflow from the southern end of Nipomo Valley Subbasin, but data are insufficient to estimate amounts and hydraulic connection across the Wilmar Avenue fault is not known.

[19]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	Division Within the Basin/Basin	Water Year	Estimated Amounts: Low Amount	High Amount	Geometric Mean Amount
Outflows to the Ocean	Tri-Cities Mesa - Arroyo Grande Plain*	1975	1,000	10,000	3,200
	Nipomo Mesa		270	2,700	880
	Santa Maria Valley		1,800	18,000	5,700
	Groundwater Basin Total		3,070	30,700	9,780
	Tri-Cities Mesa - Arroyo Grande Plain*	1985	900	9,000	2,800
	Nipomo Mesa		150	1,500	470
	Santa Maria Valley		2,300	23,000	7,300
	Groundwater Basin Total		3,350	33,500	10,570
	Tri-Cities Mesa - Arroyo Grande Plain*	1995	1,100	11,000	3,700
	Nipomo Mesa		210	2,100	670
	Santa Maria Valley		1,800	18,000	5,700
	Groundwater Basin Total		3,110	31,000	10,070
Flows Within the Basin	Nipomo Mesa to Arroyo Grande Plain	1975, 1985, 1995	560	4,300	1,300
	Santa Maria Valley to Nipomo Mesa**	1985	570	2,500	1,200
		1995	1,200	5,100	2,500
	Arroyo Grande Valley Subbasin to Tri-Cities Mesa - Arroyo Grande Plain*	1975 & 1995	420	4,200	1,300
		1985	340	3,400	1,100
	Pismo Creek Valley Subbasin to Tri-Cities Mesa - Arroyo Grande Plain*	1975, 1985, 1995	30	320	100
	Nipomo Valley Subbasin to Nipomo Mesa	1975, 1985, 1995	160	1,600	500
Flows Into the Basin	Inflow from bedrock to Tri-Cities Mesa	1975, 1985, 1995	520	5,100	1,600
	Inflow from upstream (outside study area) to Santa Maria Valley	1975	580	3,500	1,400
		1985	940	5,600	2,300
		1995	670	4,000	1,600

*Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
**Subsurface flow from Santa Maria Valley to Nipomo Mesa will occur depending on groundwater elevations and hydraulic gradients.

Estimated amounts of outflow from Tri-Cities Mesa - Arroyo Grande Plain to the ocean were about half the outflow that occurs from Santa Maria Valley. Estimated amounts ranged from a low amount of 900 AF in 1985 to a high amount of 11,000 AF in 1995, with estimated mean amounts of about 3,000 AF in 1975 and 1985 and about 4,000 AF in 1995. About 40 percent of the outflow occurs through the alluvium of Arroyo Grande and Pismo Creeks.

The smallest estimated amounts of outflow to the ocean occur from Nipomo Mesa. Estimated amounts ranged from a low amount of 150 AF in 1985 to a high amount of 2,700 AF in 1975, with estimated mean amounts of about 900 and 500 AF in 1975 and 1985, respectively, and about 700 AF in 1995.

Subsurface Flows within the Basin. To determine subsurface flow from Nipomo Mesa to Arroyo Grande Plain, a north-south cross-sectional area, cutting the edge of the mesa bordering the plain, was used to define the area through which the flow occurs. The total saturated cross-sectional area was about 3.75 million square feet. Because the hydraulic gradient was the same for all three years, the estimated flow amounts were the same, with a mean amount of 1,300 AF.

To determine subsurface flow from Santa Maria Valley to Nipomo Mesa in 1995, an east-west cross-section area cutting the basin near the southern edge of the depression shown on Plate 14 was used to define the area through which the flow takes place. The total saturated cross-sectional area was about 10.8 million square feet. The mean estimated amount of subsurface flow in 1995 was 2,500 AF, with a range of 1,200 to 5,100 AF. The saturated cross-sectional area for flow in 1985 was about 2.2 million square feet and the mean amount of subsurface flow was estimated to be 1,200 AF. Cleath & Associates (1996a) had estimated an average of 3,300 AFY of groundwater to flow from the valley to the mesa between 1977 and 1992, which is within the 1995 range estimated in this study. Subsurface flow will occur from the valley to the mesa depending on the lateral extent of the pumping depression in the mesa and groundwater elevations and hydraulic gradients.

To determine subsurface flow from the subbasins to the main basin, cross-sectional areas along the Wilmar Avenue fault were used to define the area through which flow takes place. The total saturated cross-sectional area for Arroyo Grande Valley Subbasin was about 200,000 square feet. The mean amount of subsurface flow was estimated to be about 1,300 AF in 1975 and 1995 and 1,100 AF in the dry year 1985. The total saturated cross-sectional area for Pismo Creek Valley Subbasin was about 100,000 square feet. Based on limited data, the mean amount of subsurface flow is estimated to be 100 AF each of the three years. The total saturated cross-sectional area for Nipomo Valley Subbasin was about 1 million square feet. If hydraulic continuity occurs across the Wilmar Avenue fault between Nipomo Valley Subbasin and Nipomo Mesa, the mean subsurface flow amount into the mesa from the valley was estimated to be 500 AF each of the three years.

Subsurface Flows into the Basin. To determine subsurface flows into the basin from the bedrock and from upstream in Santa Maria Valley outside the study area, two saturated cross-sectional areas were used. These are the edge of the basin along the San Luis Range, which is about 3 million square feet, and across the Santa Maria River east of Highway 101 in Santa Maria Valley along the study area boundary, which is about 125,000 square feet. Mean subsurface flows into the Tri-Cities Mesa part of the basin from bedrock were estimated to be 1,600 AF each of the three years. Mean subsurface flows into Santa Maria Valley from upstream were estimated to be 1,400 and 1,600 AF in 1975 and 1995, respectively. The estimated mean flow into Santa Maria Valley in 1985, about 2,300 AF, was greater because of an increased hydraulic gradient from higher groundwater elevations.

Groundwater in Bedrock

Evaluating groundwater conditions in the bedrock of the study area is challenging because of the complex geology and limited data available. These rocks are significant for their role as sources of local groundwater supply and as natural recharge for the groundwater basin. The areas overlying bedrock are also seeing increasing development and associated utilization of groundwater. Given the typically limited capacity of bedrock to store and transmit groundwater, documenting what is known is important.

The occurrence and movement of groundwater in bedrock 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. Fracturing, weathering, and solution after the rock formed produce secondary openings. 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.

The bedrock aquifers within the study area consist primarily of the semi-consolidated sandstone Pismo Formation, the consolidated shale Monterey Formation, and the volcanic tuff and lava Obispo Formation.[20] The Pismo Formation is found in the area north of the Wilmar Avenue fault and Tar Spring Creek and west of the Edna fault zone. The Monterey and Obispo Formations are mainly found south of the northern alluvial contact of Tar Spring Creek and east of the Wilmar Avenue fault, including the area underlying the older alluvium in Nipomo Valley Subbasin. The main groundwater development in the subbasin is in the Obispo and Monterey Formations. (See Plate 2 for location of these formations.)

Pismo Formation

Within the area northwest of Arroyo Grande Valley and Tar Spring Creek, the Pismo Syncline is

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

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 in fractures. Available well completion reports do not indicate groundwater being extracted from the shallow alluvial fill that blankets the floors of the canyons.

A review of well completion reports of wells drilled in this area provides some information on depths of the wells and the yields obtained. Wells were drilled to depths of 1,040 feet, but most are not deeper than 500 feet and half are less than 300 feet. Yields typically ranged from 10 to 100 gallons per minute, with half the wells yielding less than 30 gallons per minute. A few well completion reports of wells less than 100 feet deep indicated yields as only very little.

Movement of the groundwater locally follows the topography, ultimately moving west-southwesterly into the adjoining Santa Maria Groundwater Basin.

Groundwater is recharged mainly by intermittent deep percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and subsurface outflow to the adjoining 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.[21]

The hydraulic conductivity of sandstone is one to four orders of magnitude lower than the values for unconsolidated sand (Figure 24). 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).

Transmissivity values for a few wells with pumping test data ranged from 240 to about 2,400 gallons per day per foot and hydraulic conductivity values ranged from one 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 this 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 one gallon to about 1,000 gallons per day per foot squared.

Two reports reviewed for this study evaluated the Pismo Formation. A 1988 report by RRM Design Group gave information on an investigation of the potential groundwater supply for a

[21]The values estimated in this bedrock area are similar to those found for the Squire Member within the Tri-Cities Mesa part of the groundwater basin.

154-acre parcel north of Highway 101 and west of Oak Park Boulevard. A 1999 report by Firma included information from a water supply study by Cleath & Associates (1998b) of the deep aquifer of the Pismo Formation in an area of about 86 acres north of Highway 101 and between Oak Park Boulevard and Corbit Canyon Road (Village Glen).

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:

> "[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, p. 33) also stated that Cleath & Associates had estimated aquifer storage for the site at "more than 50,000 acre feet of water."

Based on test hole information in the Village Glen area, Cleath & Associates (1998b) identified a deep aquifer in the Pismo Formation, lying below ground surface at a depth of about 600 feet and with a maximum thickness of about 300 feet. The aquifer was described as composed of olive brown, loose, clean, fine-grained sand and was estimated to have a transmissivity of 620 gallons per day per foot and hydraulic conductivity of three gallons per day per foot squared. Groundwater in storage in the deep aquifer at the site was estimated to be 19,000 to 50,000 AF, based on average aquifer thickness. It was noted that the aquifer has restricted ability to transmit water and to release water from storage (Cleath & Associates, 1998b).

Using the median specific yield value of 10 percent and a thickness of 300 feet for the Pismo Formation, the total groundwater storage capacity for the area northwest of Arroyo Grande Valley and Tar Spring Creek was estimated to be possibly about 270,000 AF.

Monterey and Obispo Formations

In the area south of Tar Spring Creek and east of the Wilmar Avenue fault, groundwater is found in the Monterey and Obispo Formations. The water-bearing characteristics of fractured rock and volcanic rock are varied and more complex than are those of the members 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 well completion reports sometimes indicated layers of soft shale. Soft shale may not retain significant fracture openings below about 100 feet (Davis, 1988). Possible closure of fractures below 100 feet is important for availability of groundwater. However, Isherwood (1981) determined that, if Monterey shale is brittle with large amounts of silica, it could 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 densities. Fracturing, which increases both porosity and hydraulic conductivity, is a major geologic control on the flux of groundwater in both the tuffs and lavas.

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 Los Berros Canyon 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 the total volume of the Obispo Formation yielded groundwater readily.

Groundwater is recharged mainly by intermittent deep percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and possibly subsurface outflow to the adjoining Santa Maria Groundwater Basin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Available well completion reports of wells provide some information on the occurrence of groundwater in the Monterey and Obispo Formations.

Underlying the alluvium of Tar Spring Creek, 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 the wells having a yield of less than 50 gallons per minute. Groundwater movement locally follows topography and ultimately is westward.

Wells in Nipomo Valley Subbasin and the adjacent highlands extract groundwater from either the Obispo or Monterey Formation. Based on available well completion reports, wells drilled into the Obispo Formation ranged in depth from 130 to 875 feet, with half the wells greater than 400 feet. Yields ranged from 5 to 750 gallons per minute, with half the wells yielding less than about 60 gallons per minute. About one-third of the boreholes drilled into the Obispo Formation 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."

Depth to water ranged from land surface to about 300 feet, with many wells showing evidence of confining pressures in both formations. Figure 22, presented earlier in this report, shows water level hydrographs of wells perforated in the Monterey Formation in Nipomo Valley Subbasin.

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 24 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.

On the basis of 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 (hydraulic conductivity of about 65 gallons per day per foot squared). 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 perforated in bedrock in Nipomo Valley Subbasin, 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 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 three to five percent and for the Obispo Formation from three to six percent, with median values of four percent for both formations. The total groundwater storage capacity of the two formations 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. The method used and area selected, therefore, should be those that best fit local conditions.

Artificial recharge (*in lieu* method) has been operating for more than 30 years in the study area. Surface water from Lopez Reservoir is supplied to agencies that would otherwise extract groundwater from the Tri-Cities Mesa -Arroyo Grande Plain part of the Santa Maria Basin.

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 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 AFY 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 of the Pismo 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 can be avoided.

LFM (1985b) estimated that when groundwater in storage in the Tri-Cities Mesa - Arroyo Grande Plain portion 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 the basin in Tri-Cities Mesa - Arroyo Grande Plain, so that storage capacity for additional groundwater in this part of the basin 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 AFY 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 AFY 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 declining trends in groundwater levels in some wells and associated loss in groundwater in storage that occurs in some parts of the mesa. The Nipomo Mesa portion of the basin has adequate space to store artificially recharged waters (only about 16 percent of its theoretical total storage capacity above msl is filled with groundwater). Potential development of this total storage capacity would be limited by the need to avoid groundwater leakage from the edges of the mesa. 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.

This Page Intentionally Blank

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

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 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 greater than 45 milligrams per liter (mg/L) as nitrate (Keeney, 1986). Other potential health effects include birth defects, cancer, and nervous system impairments (Ibid.).

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 Wolfe (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.

---

[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	mg/L	<500	1,000	1,500	--	--
Specific Conductance	micro-mhos/cm	900	1,600	2,200	--	--
Sulfate	mg/L	<250	500	600	--	--
Chloride	mg/L	<250	500	600	--	--
Nitrate	mg/L	--	--	--	45	--
Department of Water Resources classification of relative hardness. Hardness as $CaCO_3$						
Soft	mg/L		--	--	--	<100
Moderate	mg/L		--	--	--	100-200
Very hard	mg/L		--	--	--	>200

*From: California Administrative Code, 1989, California Domestic Water Quality and Monitoring Regulations: Sections 64435 (a), 64444.5, and 64473 (a), Chapter 15, Title 22.
**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 groundwater, 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 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

To evaluate groundwater quality in this study, mineral quality data for the study area were compiled from various sources, including the Department's own files, State Water Resources Control Board, California Department of Health Services, USGS, and local agencies. Sampling and analyses of groundwater were not conducted in this study (these activities were not within the scope of study). The decision to sample the seven sea water intrusion monitoring wells was made after work began on the study. These wells were sampled in March 1996.

The compiled database contains mineral analyses of groundwater from 403 wells sampled between 1927 and 2000 within the study area. Of these wells, about 50 percent were sampled only once. Analyses for some well waters are only partial (just one or two constituents). The cation-anion balances were checked for all complete analyses. Analyses that did not exhibit a cation-anion balance were omitted from the compiled database.

Groundwater sampling in the study area has not been uniform temporally or spatially and the extent of recent available data varies greatly. Municipal system wells in the Tri-Cities Mesa[3] and Nipomo Mesa parts of the groundwater basin have been sampled at regular intervals and water

[3]No recent quality data were available for the Arroyo Grande Plain and Los Berros Creek parts of the Tri-Cities Mesa - Arroyo Grande Plain portion of the main Santa Maria Basin.

quality data are available for these wells for the period of record through 2000. In Nipomo Valley Subbasin, a few wells were sampled once or twice in the 1990s and one well was sampled in 2000. Elsewhere in the basin, groundwater from wells was last sampled and analyzed in the late 1960s or 1970s, except for a few wells sampled in 1987. Groundwater in some parts of the basin has never been sampled.

The available groundwater quality data represent samples obtained from production wells, except for samples from the sea water intrusion monitoring wells. Production wells generally have long screened intervals, perforating multiple aquifers. Each aquifer may contain water of distinctly different quality, and each aquifer may yield water to the production well at different or variable rates. Thus, the water quality samples represent mixtures of groundwater from different aquifers. Only the sea water intrusion monitoring wells have piezometers at selected depths and yield depth-dependent samples.

Because of the available database for this study, the evaluation of groundwater quality in the study area is limited to graphical techniques and summary statistical analysis, including Stiff and trilinear diagrams, boxplots, and chemical hydrographs.

Stiff diagrams were constructed and are presented on a map of the study area (Plate 15). Stiff diagrams illustrate the relative abundance of the major mineral ions in water samples. The shapes of the diagrams indicate dominant cations and anions characterizing the water and the width of the diagram is an approximation of the total ionic content. The character of a water may be considered as a unique signature that often persists even after mixing with another water. Spatial relationships and patterns of differences and similarities in groundwater composition within the study area may be perceived from the plate. The Stiff diagrams are based on analyses of groundwater sampled between 1990 and 2000, except for some 1980s analyses in parts of the basin lacking more recent data. In these parts of the basin, the Stiff diagrams are shown in gray on the plate.

Because of the complexity of the basin, a trilinear diagram was prepared as another means of representing the chemical character of groundwater (Figure 25). Analyses from 79 wells were plotted on the diagram. The wells were sampled between 1990 and 2000, except four wells sampled in the 1980s. A trilinear diagram shows the relative contribution of major cations and anions, on a charge-equivalent basis, to the total ionic content of the groundwater. Cations are shown in the left triangle and anions in the right triangle; the central diamond integrates the data. This diagram is useful for comparing large number of groundwater analyses throughout the basin, and it points out arrays of data and singularities. It can also be helpful for showing the effects of mixing two waters from different sources.

Plate 15 shows the areal distribution of groundwater quality, but does not show variations in chemical quality with depth. To evaluate vertical variability in groundwater quality, Stiff diagrams were constructed and plotted on the coastal cross-section A-A' (Plate 16). The diagrams were constructed from the analyses of depth-dependent groundwater samples collected in March 1996 from the piezometers of seven sea water intrusion monitoring wells.

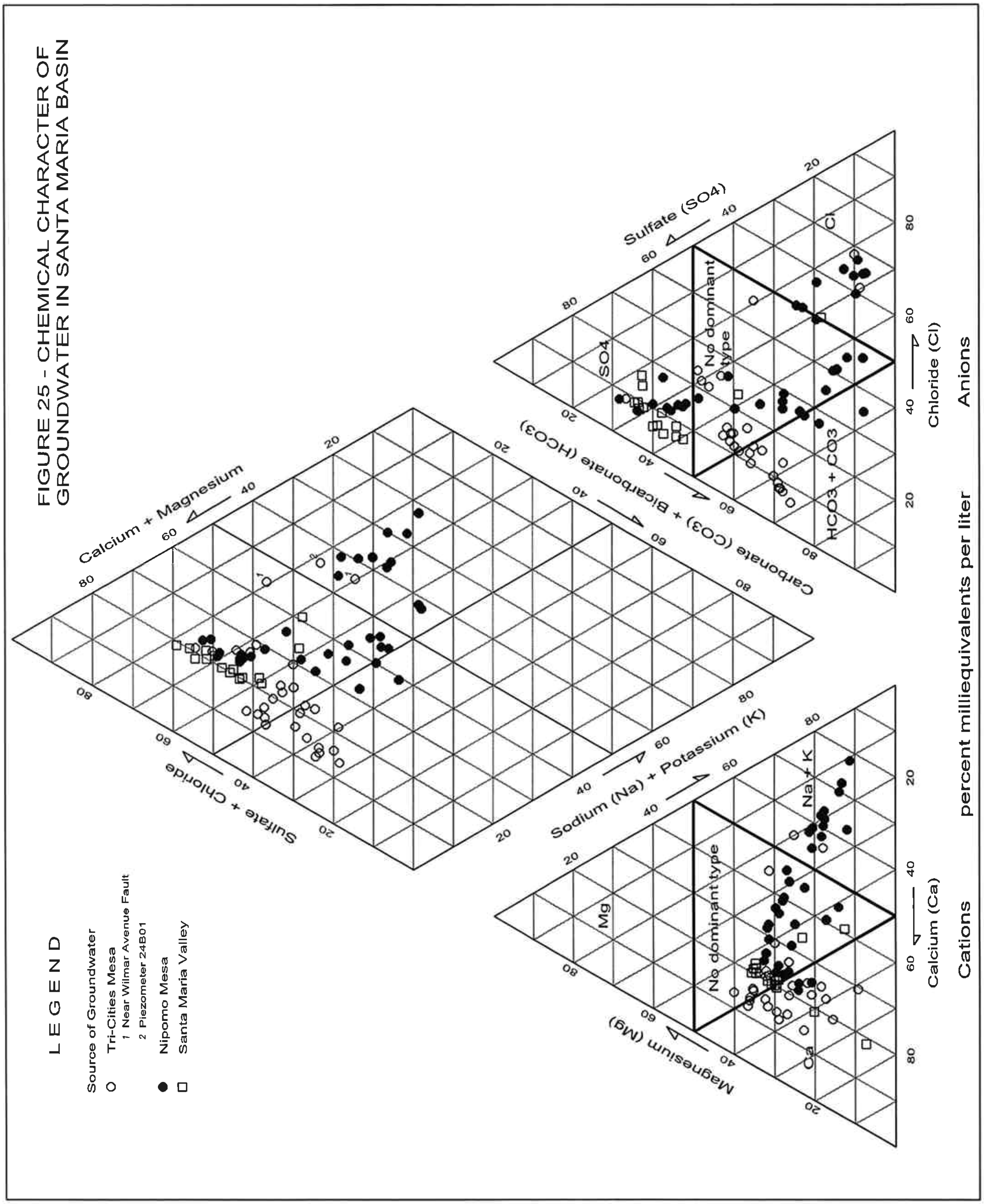


FIGURE 25 - CHEMICAL CHARACTER OF GROUNDWATER IN SANTA MARIA BASIN

Boxplots were constructed to depict graphically the statistical descriptors of the recent data (1990 through 2000) for quality constituents--TDS, sulfate, chloride, nitrate, and total hardness (Figure 26). These plots display the main aspects of the data--the middle 50 percent of the data values, between the values in the upper and lower 25 percent quartiles; the whiskers indicate the range of values outside an interval of the interquartile range; and values outside the whisker range are plotted individually as outliers and extremes. Outlier and extreme values play important roles in providing information on a data set. These values may represent unusual hydrogeologic conditions or degradation from human activities. The variability of the selected constituents, as well as differences in quality between divisions within the groundwater basin, can be observed from these boxplots.

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 increase in chloride concentration 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 groundwater 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 were evaluated and statistically tested to see if any trend existed. Three hydrographs are given as figures accompanying the text for that part of the groundwater basin.

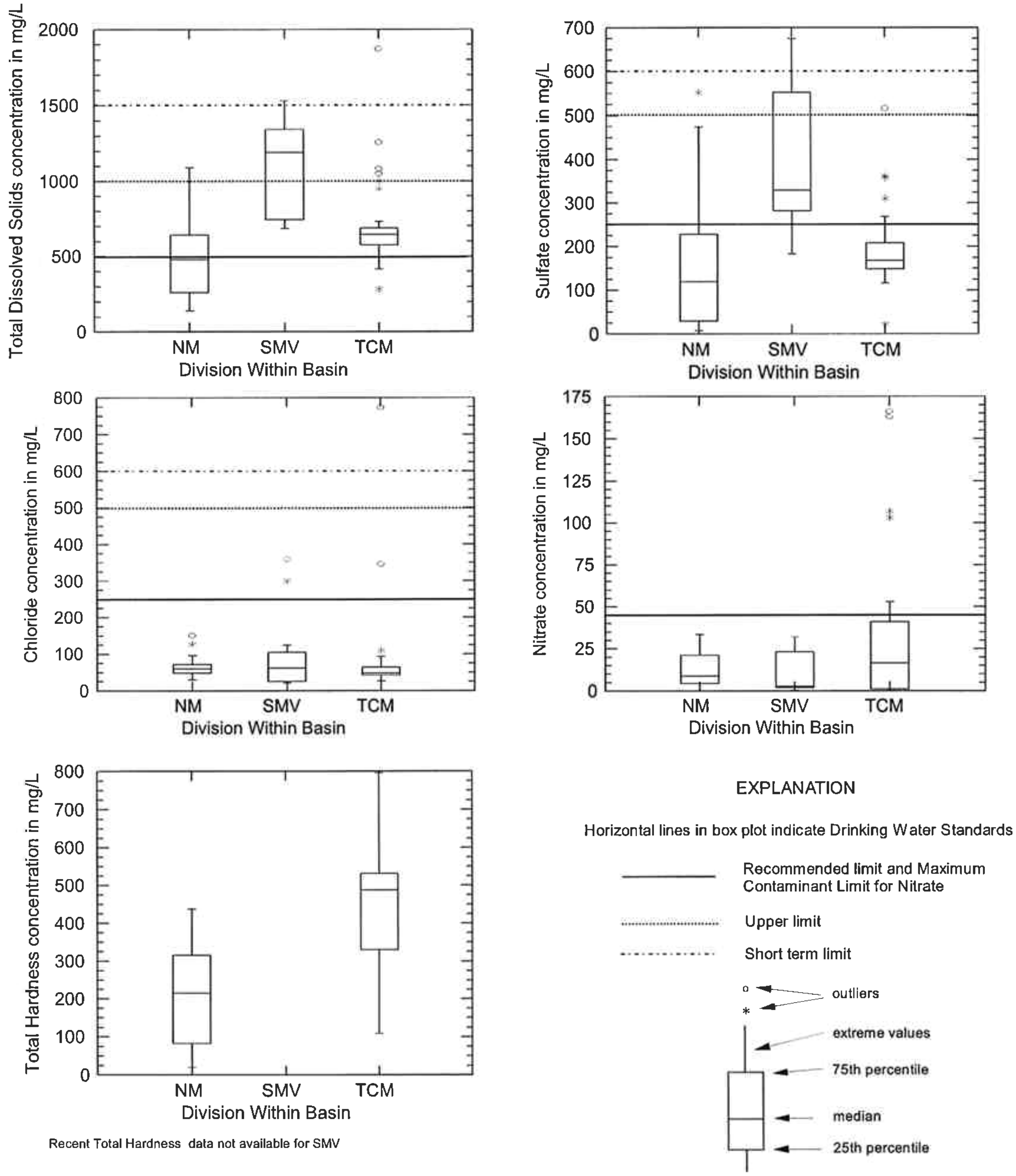
Care must be taken in interpreting any apparent trends in groundwater quality from the graphs and in extrapolating from data from a few wells to an entire basin. A basin will not change uniformly in quality. The geologic fabric and chemical composition, character, and hydraulic properties of groundwater are highly variable from place to place. Groundwater quality tends to change at "points." Any changes in quality over time are essentially specific to the wells represented in the graphs.

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

Tri-Cities Mesa - Arroyo Grande Plain

Tri-Cities Mesa. In the Tri-Cities Mesa part of the basin, mineral quality constituents in groundwater from 115 wells were analyzed from samples obtained between 1952 and 2000. Of those wells, 25 were sampled between 1995 and 2000, including seven piezometers in three sea water intrusion monitoring wells. Most of these wells with recent data are water agency wells and are sampled recurrently. Sampled wells ranged from 36 to 610 feet in depth and extracted groundwater from either the alluvium or the Paso Robles Formation only, from both those deposits, from the Squire Member of the Pismo Formation, or from the Squire Member in

FIGURE 26 - BOX PLOTS OF TOTAL DISSOLVED SOLIDS, SULFATE, CHLORIDE, NITRATE, AND TOTAL HARDNESS CONCENTRATIONS IN WELL WATERS IN SANTA MARIA GROUNDWATER BASIN, 1990-2000 DATA



Division Within Basin
NM: Nipomo Mesa, 1990-2000 data from 35 wells (including 5 piezometers in 2 sea water intrusion monitoring wells)
SMV: Santa Maria Valley, 1992-1998 data from 4 wells (including 11 piezometers in 2 sea water intrusion monitoring wells)
TCM: Tri-Cities Mesa, 1995-2000 data from 25 wells (including 7 piezometers in 3 sea water intrusion monitoring wells)

combination with the Paso Robles Formation.

Stiff diagrams in Plate 15 show that the dominant cation is calcium and the dominant anions are bicarbonate and sulfate, except for groundwater near the Wilmar Avenue fault. Wells near the fault (18P01 and 19B01) extract groundwater from the Squire Member and are sodium chloride in character. Well 32D11 and piezometer 24B03 are perforated in the Squire Member and wells 30K19 and 19Q02 are perforated in both the Squire Member and the Paso Robles Formation. The other wells with diagrams are perforated in the Paso Robles Formation.

Figure 25 plots the recent data from 25 wells, including seven piezometers in three sea water intrusion monitoring wells. The trilinear diagram shows the similarity of character of most groundwater found in this part of the basin, as well as the different character of groundwater found near the Wilmar Avenue fault.

Plate 16 illustrates vertical variability in groundwater quality in seven piezometers in three sea water intrusion monitoring wells, 32S/12E-24B, 32S/13E-30F, and 32S/13E-30N, in the Tri-Cities Mesa part of the basin. Piezometer 30N02 shows a mineral gain with depth in the Paso Robles Formation. This increase of about 400 mg/L in TDS content may result from the finer grained facies of the aquifer in this part of the basin. The Stiff diagrams show little variation in quality with depth of those piezometers in the Squire Member of the Pismo Formation. Groundwater from piezometer 24B01 in the alluvium of Pismo Creek shows a distinctly different quality and character than the groundwater from the other piezometers. This situation was found to be the result of solution of residual marine and evaporative salts indigenous to the geologic environment in this part of the basin (California Department of Water Resources, 1970).

Boxplots of 1995 to 2000 analyses of groundwater for quality parameters– TDS, sulfate, chloride, nitrate, and total hardness– for Tri-Cities Mesa are shown in Figure 26 along with boxplots of recent data for Nipomo Mesa and Santa Maria Valley. The analyses are from 25 wells, including seven piezometers in three sea water intrusion monitoring wells.

The boxplot for TDS shows that most wells extracted groundwater with concentrations between about 500 and 700 mg/L, meeting the upper limit Drinking Water Standard. The TDS concentrations above 1,000 mg/L were found in two of the sea water intrusion monitoring wells, one well near the Wilmar Avenue fault and in a tributary of Pismo Creek, and two wells about 150 feet deep near Arroyo Grande Creek. Most of the wells extract groundwater with sulfate and chloride concentrations below 250 mg/L, the recommended Drinking Water Standard for both constituents. Six of the analyses for nitrate concentrations in water from wells exceeded the MCL. The wells have a top-perforated interval of less than 100 feet in depth. Most of the groundwater is classified as very hard, although a few wells in the northern part of the mesa produce groundwater classified as moderate.

Groundwater quality in wells in proximity to the Wilmar Avenue fault and along the coast may be affected by mineralization from the fault zone, old saline deposits, or possibly local sea water intrusion in the shallower deposits.

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

Historically, concentrations of TDS in groundwater were as high as 3,640 mg/L; sulfate, 644 mg/L; and chloride, 1,626 mg/L. The wells with these high concentrations typically were along low marshy coastal areas, in the drainage of Pismo Creek, and in the southern part of the mesa near Arroyo Grande Creek. The concentrations were attributed to tidal inflows in lagoons near the shallow wells (California Department of Water Resources, 1970).

To determine if groundwater quality has changed over time, a chloride hydrograph of data from eight wells sampled recurrently was constructed and the data were regressed over time (Figure 27). Of those wells, only well 32S/13E-19Q02 had a statistically significant increase in chloride concentrations over time. This well extracts groundwater from the Paso Robles Formation and the Squire Member of the Pismo Formation. Chloride concentrations rose about 35 mg/L over 25 years. Well 32S/13E-29E01 had a statistically significant downward trend in chloride concentrations over time. This well extracts groundwater from the Paso Robles Formation. Chloride concentrations in groundwater extracted by the other wells show no significant trends over time. The generally stable chloride quality over time is indicative of a net outflow of groundwater to the ocean.

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

No recent quality data were available for the Arroyo Grande Plain and Los Berros Creek parts of the basin. Given the data limitations, no trend analysis or box plots were developed for this part of the basin. Mineral constituents in groundwater from 41 wells were analyzed from samples taken between 1950 and 1987. Of those wells, about three-fourths were sampled only once. Sampled wells are 38 to 396 feet deep, with most in the 90- to 100-foot range.

The chemical character of groundwater in the Arroyo Grande Plain part of the basin was typically either calcium-magnesium sulfate or calcium-magnesium sulfate-bicarbonate. Plate 15 shows diagrams for two 1987 analyses from well samples collected in Los Berros Creek. The dominant cations were calcium or sodium and the dominant anions were sulfate or chloride.

Historical data show that only 10 percent of the sampled wells produced groundwater with TDS concentrations of less than 500 mg/L and about half the wells produced groundwater with sulfate concentrations of less than 250 mg/L. About 15 percent of the sampled wells produced groundwater with concentrations of TDS greater than 1,500 mg/L and sulfate greater than 500 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 met the recommended Drinking Water Standard. About 40 percent of the wells produced groundwater

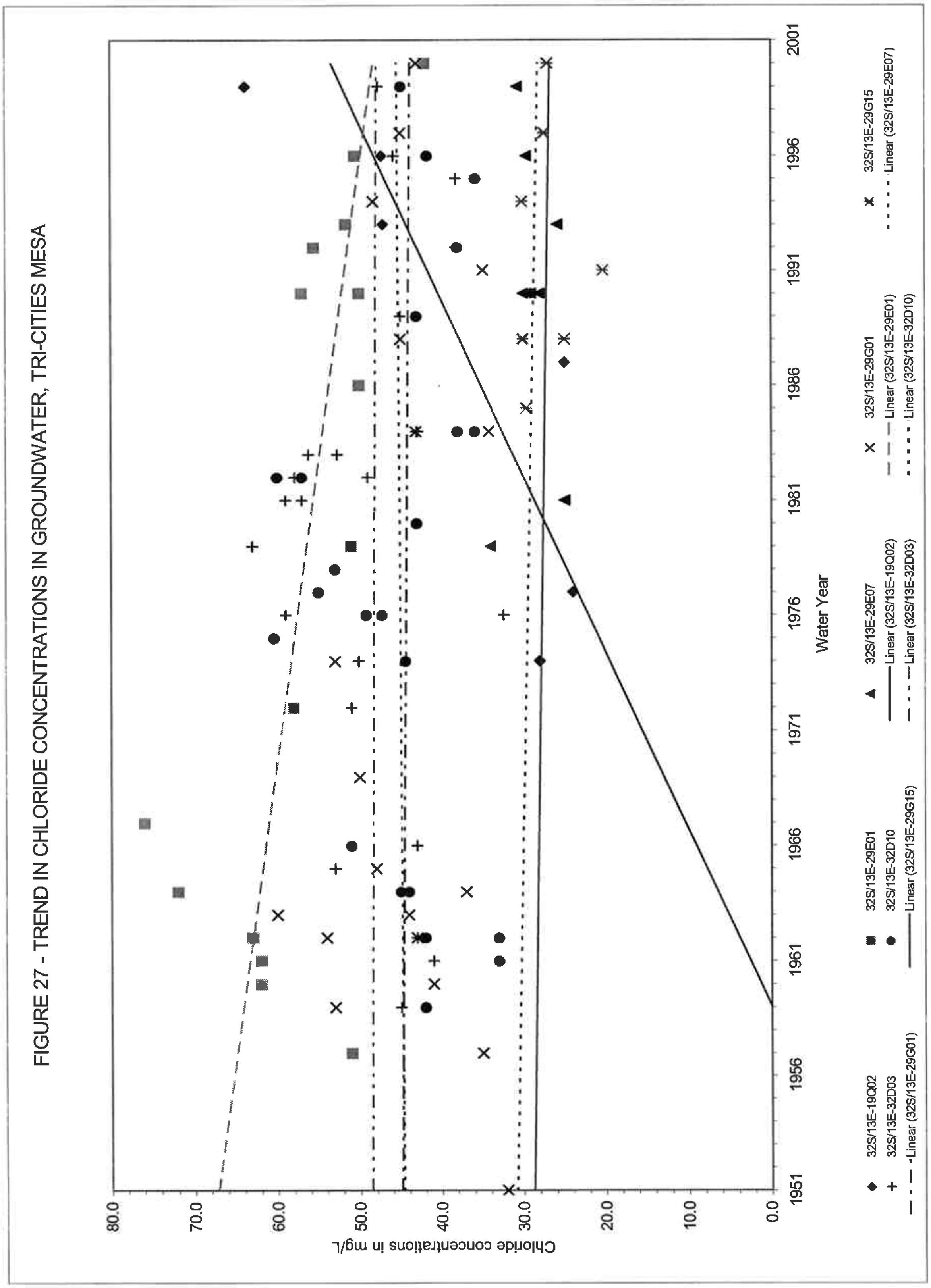


FIGURE 27 - TREND IN CHLORIDE CONCENTRATIONS IN GROUNDWATER, TRI-CITIES MESA

with concentrations of nitrate that exceeded the MCL. Groundwater quality was likely impaired by return irrigation water. The data indicate that most of the sampled groundwater was very hard.

Some wells produced groundwater classified as marginal under water quality guidelines for agricultural irrigation.

Nipomo Mesa

In the Nipomo Mesa part of the basin, mineral quality constituents in groundwater from 101 wells were analyzed from samples taken between 1953 and 2000. Of those wells, 35 have recent data from 1990 through 2000, including two sea water intrusion monitoring wells with five piezometers. Most of these wells with recent data are water agency wells and are sampled recurrently. Sampled wells range in depth from 24 to 810 feet, with well depth typically increasing toward the west and south. South of the Santa Maria River fault, wells extract groundwater from the Paso Robles Formation, with the deeper wells extracting from the Careaga Formation as well. North of the Santa Maria River fault, wells extract groundwater from the Paso Robles Formation and the Squire Member of the Pismo Formation, but none of these wells has been sampled recently.

The Stiff diagrams in Plate 15 illustrate the varied chemical character and generally lower TDS concentrations found in groundwater in Nipomo Mesa. Well 14E01 and wells south of Mesa Road (shown in Plate 15) in Nipomo Mesa extract groundwater from both the Paso Robles and Careaga Formations, except for well 24L01. This well is screened over 520 feet and represents quality from the older dune sand and the Paso Robles and Careaga Formations. Piezometer 36L02 is perforated in the Careaga Formation. The other wells with diagrams in the mesa extract groundwater from the Paso Robles Formation. North of Black Lake Canyon, many wells extract groundwater with sodium as the dominant cation and chloride or bicarbonate as the dominant anion. South of the canyon, no one cation in extracted groundwater typically dominates, but some wells extract groundwater with sulfate as the dominant anion.

Figure 25 clearly shows the diversity of chemical character of groundwater extracted from the mesa. The diagram plots the recent data from 35 wells. The diverse character reflects the complex hydrogeological environment of this part of the basin.

Vertical variability in groundwater quality in Nipomo Mesa is shown in Plate 16 with Stiff diagrams for five piezometers in two sea water intrusion monitoring wells, 12N/36W-36L and 11N/36W-12C. The chemical character of groundwater from piezometers 36L01, 12C01, and 12C02 in the Paso Robles Formation is the same, calcium-magnesium-sodium sulfate. Groundwater from piezometer 12C02 shows a small mineral gain with depth, an increase of about 130 mg/L in TDS concentration. Groundwater from piezometers 36L02 and 12C03 in the Careaga Formation has a lower mineral content than the groundwater in the overlying Paso Robles Formation, a decrease of about 100 to 300 mg/L in TDS concentration. TDS concentrations can be lower in the Careaga Formation than in the Paso Robles Formation. The formation is composed largely of quartz sand, rather than reworked Monterey shale as in the Paso Robles Formation, and is therefore less soluble, tending to decrease TDS concentrations. The major cation in the groundwater from these two piezometers may be either sodium or calcium with secondary cations and the dominant anion is bicarbonate with either sulfate or chloride as a secondary anion.

Boxplots of 1990 to 2000 analyses of groundwater for quality parameters– TDS, sulfate, chloride, nitrate, and total hardness– for Nipomo Mesa are shown in Figure 26. The analyses are from 35 wells, including five piezometers in two sea water intrusion monitoring wells. 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 deeper wells and in the western and southern parts of the mesa. Chloride concentrations in extracted groundwater are low, less than about 130 mg/L. Nitrate concentrations in groundwater from these wells met the MCL. About one-third 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.

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

To determine if groundwater quality has changed over time, a chloride hydrograph of data from five wells sampled recurrently was constructed and the data were regressed over time (Figure 28). Of those wells, only well 11N/35W-24J01 had a statistically significant decline in chloride concentrations over time. This well extracts groundwater from the Paso Robles Formation. Chloride concentrations declined about 30 mg/L over about 20 years. Wells 11N/35W-10G04 and 11N/34W-19L03 had statistically significant increases in chloride concentrations over time, rising about 7 mg/L in about 13 years in well 10G04 and about 18 mg/L in about 30 years in well 19L03. Well 10G04 extracts groundwater from the Paso Robles Formation and is within the area of the pumping depression shown in Plate 14. Well 19L03 extracts groundwater from the Paso Robles and Careaga Formations. Chloride concentrations in groundwater extracted by the other wells show no significant trends over time.

Although wells 11N/35W-24L01 and 11N/35W-24L02 showed no increasing trend in chloride concentrations, well 24L02 and another well, 11N/35W-24L03, have shown increases in sulfate and TDS concentrations over their period of record. These wells are within the depression shown in Plate 14 and the increases in concentrations of these two constituents may reflect groundwater inflow from Santa Maria Valley. Data are not available to show any reduction in the quality of groundwater in the mesa from the depression (Plate 14) and subsurface inflow of groundwater from Santa Maria Valley.

Santa Maria Valley

Within the study area, the Santa Maria Valley is largely an agricultural area, with thousands of

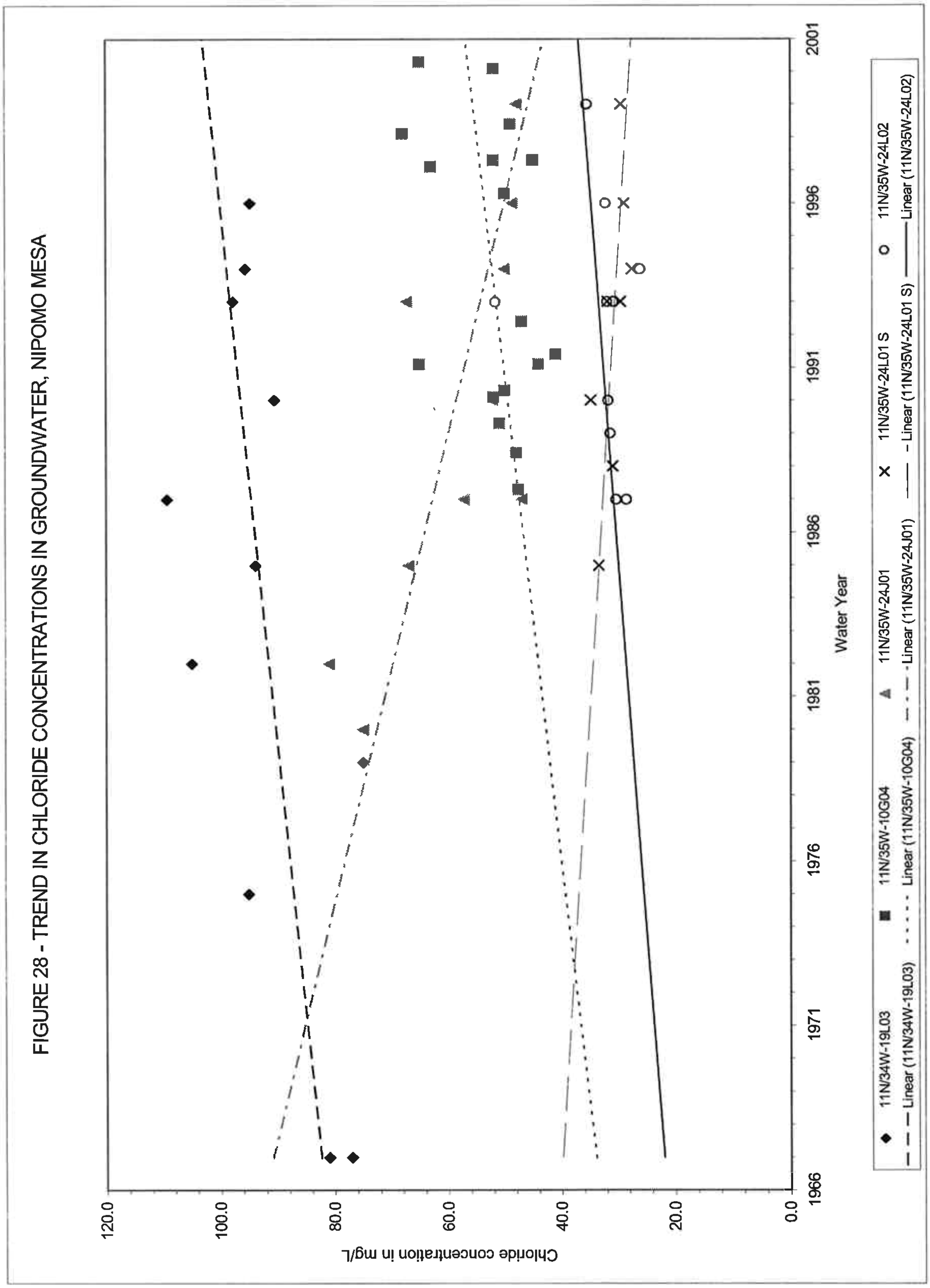


FIGURE 28 - TREND IN CHLORIDE CONCENTRATIONS IN GROUNDWATER, NIPOMO MESA

acres under irrigation.

In the Santa Maria Valley part of the basin, mineral quality constituents in groundwater from 74 wells were analyzed from samples taken between 1927 and 1998. Only four wells have recent analyses (1992 through 1998)– these were the two sea water intrusion monitoring wells with recent data for 11 piezometers and two wells with partial analyses. Other than the sea water intrusion monitoring wells, a complete mineral analysis of groundwater was last performed on a sample from only one well in 1987. Data were available for one sample collected in 1985 and one in 1981. The lack of recent data is clearly seen in Plate 15. Sampled wells ranged from less than 50 feet to greater than 600 feet in depth and are perforated in alluvium or the Paso Robles Formation or in both deposits.

Most groundwater in the valley may be characterized as a calcium-magnesium sulfate type (Plate 15). 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 trilinear diagram in Figure 25 shows the dominant calcium-magnesium sulfate type of groundwater. Because the only recent complete analyses available were from the 11 piezometers in the two sea water intrusion monitoring wells, the data from the four wells sampled in the 1980s were included in the diagram.

Plate 16 illustrates vertical variability in groundwater quality for 11 piezometers in two sea water intrusion monitoring wells in the alluvium and the Paso Robles Formation in Santa Maria Valley, 11N/36W-35J and 10N/36W-02Q. The Stiff diagrams show the large mineral decrease in groundwater in the Paso Robles Formation from groundwater in the alluvium, as much as about an 800 mg/L decrease in TDS content. The quality of groundwater in the Paso Robles Formation is generally about the same regardless of depth, except for piezometer 35J03. The groundwater in this piezometer may be affected by downward percolation of poorer quality water from the alluvium or possibly oil field activity.

Boxplots of the recent data shown in Figure 26 illustrate the high concentrations of TDS and sulfate found in the four wells described at the beginning of this section. The concentrations did not meet recommended Drinking Water Standards. Except for one shallow piezometer and one well near Highway 101, chloride concentrations met the recommended Drinking Water Standard and nitrate concentrations met the MCL. The groundwater extracted from these wells was not analyzed for total hardness concentrations.

The use and reuse of groundwater for irrigation have been considered the major factors 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.

Historical data show that concentrations of TDS and sulfate in groundwater from about three-fourths of the sampled wells met the upper limits for drinking water. The groundwater was classified as marginal to unsuitable under water quality guidelines for agricultural irrigation. About 25 percent of sampled wells extracted groundwater with nitrate concentrations that exceeded the MCL; concentrations were as high as 240 mg/L. The higher concentrations tended to be found in the shallower wells. Chloride concentrations in groundwater were generally less than 250 mg/L. Most of the groundwater was classified as very hard.

To determine if groundwater quality has changed over time, a chloride hydrograph of data from eight piezometers in two sea water intrusion monitoring wells sampled recurrently was constructed and the data were regressed over time (Figure 29). Except for the shallowest alluvial piezometer, 10N/36W-2Q07, chloride concentrations have been stable over time. The generally stable chloride quality over time is indicative of a net outflow of groundwater to the ocean. The increase in chloride concentrations in this piezometer is discussed in the section on sea water intrusion in this chapter.

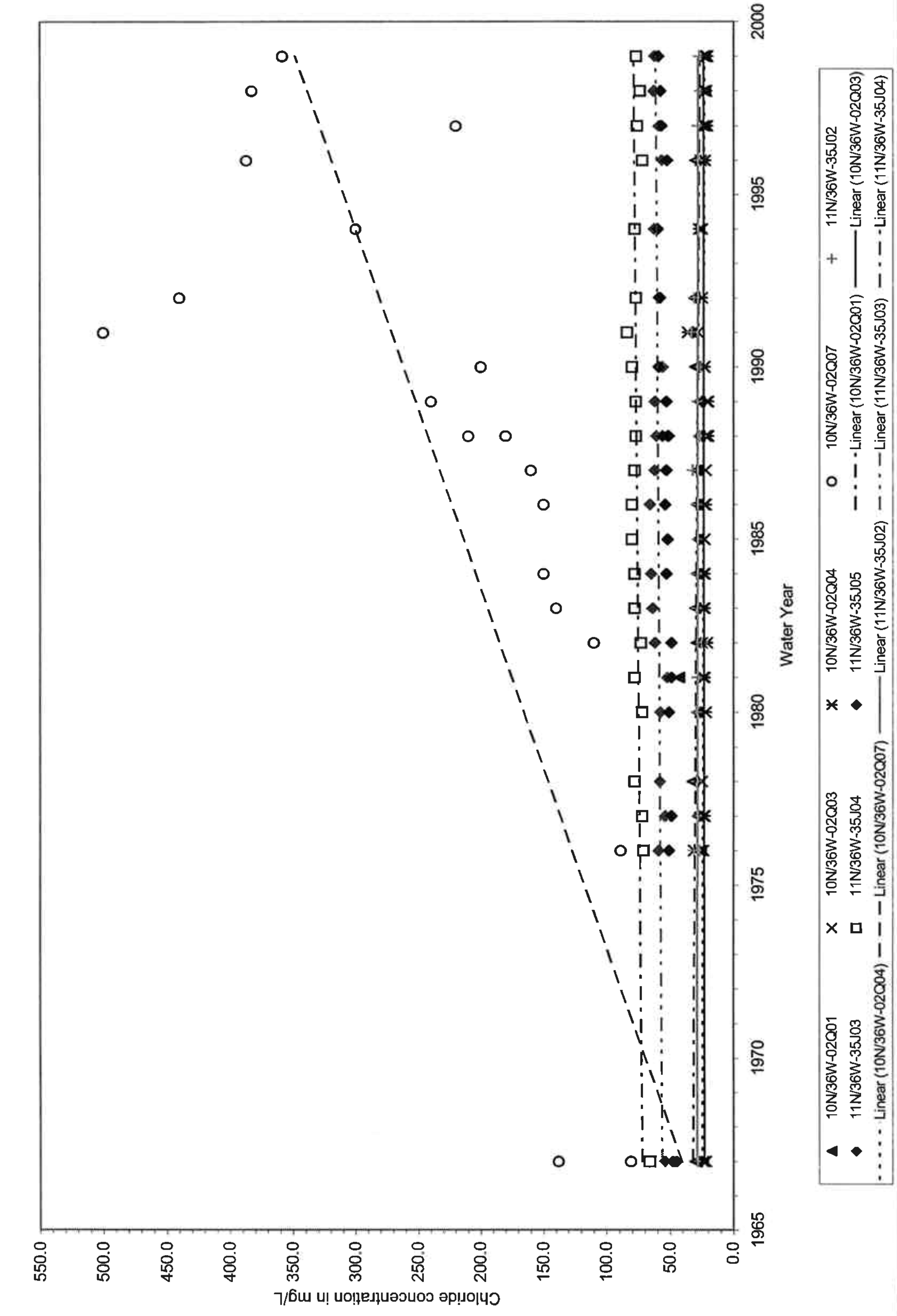
Arroyo Grande Valley Subbasin

No recent quality data were available for Arroyo Grande Valley Subbasin, except for a partial analysis of a sample from one well in 1996. Given the data limitations, no trend analysis or box plots were developed for this part of the basin. Mineral quality constituents in groundwater from 21 wells were analyzed from samples collected between 1954 and 1987. Of those wells, 13 were sampled only once.

The Stiff diagrams of 1980s analyses in Plate 15 show the progressive deterioration of the groundwater quality in a downstream direction. The chemical character of groundwater in the valley is calcium-magnesium bicarbonate in the upstream section above the confluence with Tar Spring Creek and calcium-magnesium sulfate in the downstream section below Tar Spring Creek. This downstream section overlies a zone of multiple faults that is probably highly mineralized and may impact the quality of the groundwater. Irrigation return water also may impact the quality. Sampled wells in the valley are 60 to 150 feet deep.

The historical data show that, except for concentrations of TDS and sulfate in water from one well, concentrations of TDS, sulfate, and chloride in groundwater in the upstream section met Drinking Water Standards and the water was classified as suitable under water quality guidelines for agricultural irrigation. In the downstream section, TDS concentrations in extracted groundwater were typically more than 1,500 mg/L and exceeded the short-term Drinking Water Standard. Likewise, the sulfate concentrations were more than about 500 mg/L and exceeded the upper limit of the standard. The concentrations of these constituents also led to the groundwater being classified as marginal to unsuitable under water quality guidelines for agricultural irrigation. Chloride concentrations ranged between 17 and 136 mg/L and met the recommended Drinking Water Standard. Nitrate concentrations in groundwater met the MCL, except in water from two wells. Concentrations in these wells, sampled only one time, were 68 and 102 mg/L. Groundwater in the valley was classified as very hard.

FIGURE 29 - TREND IN CHLORIDE CONCENTRATIONS IN GROUNDWATER, SANTA MARIA VALLEY



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 was magnesium-calcium-sodium bicarbonate in character and had a TDS concentration of 630 mg/L.

Pismo Creek Valley Subbasin

No recent groundwater quality data were available for Pismo Creek Valley Subbasin. The historical data consist of analyses from seven wells sampled in the 1950s and 1960s. Given the data limitations, no trend analysis or box plots were developed for this part of the basin. The data indicate that groundwater quality in Pismo Creek Valley Subbasin generally did not meet Drinking Water Standards for sulfate, chloride, and TDS. Concentrations of sulfate ranged from 740 to 1 mg/L; chloride, from 766 to 49 mg/L; and TDS, from 2,390 to 790 mg/L. Nitrate concentrations in two wells exceeded the MCL. The dominant ions were 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 30 to 102 feet.

Nipomo Valley Subbasin

In Nipomo Valley Subbasin, mineral quality constituents in groundwater from 22 wells were analyzed from samples taken between 1962 and 2000. Of those wells, only six were sampled between 1992 and 2000. Sampled wells are between 40 and 400 feet deep. Groundwater is extracted mainly from the Obispo and Monterey Formations.

The chemical character of the groundwater, as shown by Stiff diagrams for wells in Nipomo Valley Subbasin in Plate 15, is mixed, no one cation or anion dominates.

TDS concentrations in groundwater sampled recently ranged between 750 and 1,300 mg/L; sulfate concentrations, between 200 and 340 mg/L; chloride concentrations, between 64 and 130 mg/L; and nitrate concentrations, between not detected and 3.5 mg/L. Like most of the groundwater in the study area, the groundwater is classified as very hard. Historical data show that groundwater in two wells had nitrate concentrations that exceeded the MCL.

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

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, possibly affecting 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 Subbasin. 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 can continue to contribute nitrate and other minerals to groundwater as rainwater and irrigation return infiltrate to 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 the South San Luis Obispo County Sanitation District WWTP's ocean outfall, wastewater from this part of the groundwater basin has largely been removed as an ongoing source of nitrate.

Nipomo Community Services District operates the Black Lake Golf Course and Southland WWTPs. Wastewater from the Black Lake Golf Course WWTP discharges to an aerated lagoon and ultimately is used to irrigate portions of the adjacent golf course. Sampled well water near the Black Lake Golf Course WWTP had low nitrate concentrations. The Southland WWTP, located southwest of Nipomo, 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 incidentally recharges the groundwater basin. Semi-annual sampling, between January 1995 and July 2000, of groundwater from Southland WWTP Monitoring Well Number 1 showed variable nitrate concentrations, ranging between not detected and 301 mg/L, with a median concentration of 30 mg/L (data provided by Doug Jones of Nipomo Community Services District).[4] The nitrate concentration in the well water was 4.4 mg/L in July 2000.

Grover Beach has continued to use the local groundwater, which is high in nitrate, by reducing

[4]Because of the variability in nitrate concentrations, the median value of 30 mg/L was used for Plate 17.

the nitrate concentrations to acceptable levels. In 1989, the city constructed a 2.3-million-gallon per day ion exchange plant. 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 1990 and 2000 are plotted in Plate 17. It graphically shows three ranges of nitrate concentrations in groundwater from sampled wells. As can be seen on the plate, groundwater with nitrate concentrations exceeding the MCL is found mainly in the Tri-Cities Mesa part of the basin.

The plate also shows the lack of recent data for large portions of the study area, particularly for agricultural areas (Santa Maria Valley and Arroyo Grande Plain and Valley). Historically, groundwater in these agricultural areas exceeded the MCL. The high nitrate concentrations had been attributed to the ongoing agricultural activities.

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 portion of the basin. 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.

The influence from the use of fertilizers will likely continue to be the major factor determining nitrate concentrations in groundwater. Because nitrate concentrations may exceed the California Department of Health Services's MCL in some areas, it would be useful to routinely test for nitrate content in groundwater supplies for domestic use.

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 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.[5] The 1996 water quality data, plus historical data, for these wells are listed in Table 23. The piezometers are identified by State Well Numbers and their piezometer depths are given. Their locations are shown in Plate 18. 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-24B01, show high concentrations of chloride. However, samples from this depth have historically shown high concentrations of sodium chloride. This situation was found to be the result of solution of residual marine and evaporative salts indigenous to the geologic environment in this part of the basin (California Department of Water Resources, 1970). Samples from piezometers 32S/12E-24B02 and 32S/12E-24B03 show no sign of sea water intrusion. In addition, the four other piezometers in this part of the basin--32S/13E-30F02 and 30F03 and 32S/13E-30N02 and 30N03--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-36L01 and 36L02 nor by the three piezometers 11N/36W-12C01, 12C02, and 12C03, which are on the beach west of Nipomo Mesa.

In 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-02Q07, has shown high chloride

[5]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	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	NO_3 mg/L	B mg/L	Fl mg/L	Total Hardness mg/L	Perforated interval (feet)
32S/12E-24B01 M	660117	8.2	1,700	95	83	406	20.0	440	175	652	1.0	0.07	0.3	579	48-65
32S/12E-24B01 M	760609	8.2	1,706	94	95	400	16.2	474	159	667	0.4	0.12	0.5	625	48-65
32S/12E-24B01 M	960326	7.8	1,870	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	0.12	--	--	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	305	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	379	197	41	0.2	0.13	--	--	305 - 372
32S/13E-30N02 M	660121	7.5	1,069	148	63	71	5.0	232	483	54	0.0	0.12	0.5	629	175 - 255
32S/13E-30N02 M	760607	7.9	1,093	150	60	62	4.7	248	484	48	0.0	0.13	0.7	624	175 - 255
32S/13E-30N02 M	960327	8.1	1,050	145	60	71	5.5	243	516	50	0.9	0.23	--	--	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	150	161	70	106.8	0.13	--	--	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	233	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	390	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	207	474	38	1.8	0.25	--	--	280 - 290

TDS: Total Dissolved Solids, Ca: Calcium, Mg: Magnesium, Na: Sodium, K: Potassium, HCO_3: Bicarbonate, SO_4: Sulfate, Cl: Chloride, NO_3: Nitrate, B: Boron, Fl: Fluoride

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	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	NO_3 mg/L	B mg/L	Fl mg/L	Total Hardness mg/L	Perforated interval (feet)
11N/36W-12C02 S	760608	7.7	1,015	129	52	90	4.6	184	488	48	1.4	0.16	0.5	536	450 - 460
11N/36W-12C02 S	960326	8.1	1,090	150	52	80	5.2	246	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	317	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	261	362	27	2.2	0.20	--	--	527 - 615
11N/36W-35J03 S	670928	7.8	1,031	132	55	89	4.0	239	462	54	10.8	0.18	0.6	556	247 - 490
11N/36W-35J03 S	770726	--	1,130	150	58	87	3.5	250	490	54	--	0.10	--	610	247 - 490
11N/36W-35J03 S	871028	7.7	1,200	170	70	85	3.9	279	580	61	15.5	0.21	0.4	--	247 - 490
11N/36W-35J03 S	960327	7.4	1,230	179	64	88	4.0	291	556	57	26.3	0.28	--	--	247 - 490
11N/36W-35J03 S	981117	7.38	1,198	165	74	86	3.9	278	550	62	31.3	0.23	0.4	--	247 - 490
11N/36W-35J04 S	670928	7.5	1,177	159	67	90	4.0	265	530	66	11.5	0.14	0.7	673	175 - 228
11N/36W-35J04 S	770726	--	1,460	190	73	86	4.3	300	600	72	--	0.20	--	780	175 - 228
11N/36W-35J04 S	871028	7.5	1,490	220	86	90	0.3	346	740	77	12.8	0.23	0.4	--	175 - 228
11N/36W-35J04 S	960327	7.4	1,500	343	21	96	4.4	358	665	72	22.7	0.33	--	--	175 - 228
11N/36W-35J04 S	981117	7.3	1,470	202	93	93	4.4	344	664	77	27.3	0.25	0.4	--	175 - 228
11N/36W-35J05 S	670928	7.4	1,029	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	1,100	170	66	75	3.6	305	520	52	5.3	0.19	0.5	--	74 - 138
11N/36W-35J05 S	960327	7.4	1,210	--	69	82	3.8	316	554	53	8.9	0.27	--	--	74 - 138
11N/36W-35J05 S	981117	7.3	1,216	163	75	78	4.1	293	555	59	11.4	0.21	0.5	--	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	261	352	30	2.1	0.19	--	--	567 - 671
10N/36W-02Q01 S	981116	7.4	716	91	46	50	3.2	229	287	23	2.0	0.15	0.2	--	567 - 671

TDS: Total Dissolved Solids, Ca: Calcium, Mg: Magnesium, Na: Sodium, K: Potassium, HCO_3: Bicarbonate, SO_4: Sulfate, Cl: Chloride, NO_3: Nitrate, B: Boron, Fl: Fluoride

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	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	NO_3 mg/L	B mg/L	Fl mg/L	Total Hardness mg/L	Perforated interval (feet)
10N/36W-02Q02 S	670929	7.9	726	90	41	67	4.0	254	294	24	1.3	0.11	0.4	393	467 - 535
10N/36W-02Q02 S	770726	--	780	99	44	59	3.2	260	300	24	--	0.10	--	430	467 - 535
10N/36W-02Q02 S	960327	8.0	758	102	49	56	3.1	273	278	27	2.0	0.19	--	--	467 - 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	262	286	26	1.9	0.20	--	--	397 - 444
10N/36W-02Q03 S	981116	7.4	727	92	49	50	3.0	243	297	22	2.0	0.14	0.2	--	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	98	46	49	2.7	255	312	23	2.8	0.19	--	--	291 - 378
10N/36W-02Q04 S	981116	7.5	685	88	47	49	2.5	222	277	21	2.7	0.14	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	1,200	178	71	83	3.9	261	534	85	7.0	0.27	--	--	185 - 246
10N/36W-02Q06 S	670929	7.8	1,000	139	54	82	3.0	250	439	61	3.5	0.18	0.6	569	130 - 170
10N/36W-02Q06 S	760521	7.9	813	119	52	61	2.6	258	355	42	4.4	0.08	0.6	511	130 - 170
10N/36W-02Q06 S	960327	7.2	1,530	286	58	101	4.4	297	675	124	1.2	0.32	--	--	130 - 170
10N/36W-02Q07 S	670929	7.4	747	103	44	74	4.0	319	214	81	11.0	0.14	0.5	438	19 - 47
10N/36W-02Q07 S	760604	8.2	683	89	40	66	3.5	278	170	89	10.0	0.06	0.7	387	19 - 47
10N/36W-02Q07 S	871028	7.5	839	130	49	91	5.7	322	120	210	--	0.15	0.3	--	19 - 47
10N/36W-02Q07 S	960327	7.2	1,310	195	32	190	11.5	415	190	387	0.3	0.40	--	--	19 - 47
10N/36W-02Q07 S	981116	7.4	1,186	158	73	153	5.6	397	182	358	0.4	0.52	0.4	--	19 - 47

TDS: Total Dissolved Solids, Ca: Calcium, Mg: Magnesium, Na: Sodium, K: Potassium, HCO_3: Bicarbonate, SO_4: Sulfate, Cl: Chloride, NO_3: Nitrate, B: Boron, Fl: Fluoride

concentrations, and in 1991, it showed a marked increase. This increase has diminished, but the concentration remains higher than its historical values, which may be an indication of sea water intrusion into the shallow aquifer. However, because of the shallow depth, this high chloride concentration may result from tidal action and percolation of poor quality surface waters rather than sea water intrusion. The piezometer 10N/36W-02Q06 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-35J02, 35J03, 35J04, and 35J05 also showed no sign of sea water intrusion.

To protect the quality of the groundwater, a regular yearly sea water intrusion monitoring program would help, with particular attention paid to piezometer 10N/36W-02Q06. A monitoring program, with sampling and analyses of major ions and boron, bromide, iodine, deuterium, and oxygen -16 and -18, would record any trends indicating changes that 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 pronounced. Typically, the quality varies inversely to the rate of discharge, with waters of lower TDS concentration 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 Reservoir, bank seepage, and nonpoint discharges, including uncontrolled runoff from agricultural and urban areas not related to stormflows.

Surface water within the study area has not been sampled for quality since the 1960s and 1970s and this historical sampling was 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 generally between 500 and 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 (California 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.

Lopez Reservoir (not within the study area) is an important supply source within the study. Concentrations of mineral constituents in water from Lopez Reservoir, before treatment, meet 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.

Future Needs

The lack of recent and adequate water quality data throughout the study area is evident in this study. Groundwater in parts of the basin and surface water, except for Lopez Reservoir water, have not been sampled and analyzed since the late 1960s or 1970s. Moreover, vertically discrete groundwater samples were available only for the sea water intrusion monitoring wells. A basinwide study of groundwater quality, characterizing spatial conditions, both areally and with depth, and surface water quality has never been conducted.

Given the importance of the resource, there is need for the county to undertake a comprehensive water quality assessment of the water resources in the study area that includes sampling for an array of quality constituents (inorganic constituents, physical measurements, isotopes, and selected organic constituents) with spatially distributed sample locations (areally and with depth) throughout the basin and be unbiased with respect to known or suspected local problem areas. Such an effort will provide the information necessary to design an effective monitoring program. It is beyond the scope of this study to design the needed assessment or monitoring plan.

This Page Intentionally Blank

VII. WATER BUDGET

An important component of this study is an itemized accounting (water budget) of all inflows, outflows, and changes in the amount of groundwater in storage to provide information for water supply planning within the main Santa Maria Groundwater Basin in San Luis Obispo County. For this accounting, the investigators had sufficient data to develop valid water budgets, weighing the amounts of groundwater inflow against the amounts of groundwater outflow, for each of the three portions into which the main groundwater basin was divided: Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa, and Santa Maria Valley (Plate 19).

Using the general equation "*Inflow - Outflow = Surplus/Deficiency*," the components of groundwater inflow and outflow were determined for each year of the 1975 through 1995 study period and for future years 2010 and 2020. The future water budgets are based on projected land use changes and associated changes in water demands and on the base period 1984 through 1995, which represents long-term average hydrologic conditions.[1]

The surplus or deficiency for each year of a water budget is actually the amount of change in groundwater in storage that takes place. Thus, for this study, the water budgets show the amount of change in groundwater in storage in the three portions of the main groundwater basin.

Table 24 presents the water budget for the main Santa Maria Groundwater Basin and Tables 25 through 27 present the water budgets for Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa, and Santa Maria Valley, respectively. The water budget for the main basin was arrived at by totaling the applicable components of the budgets for the three portions of the basin.

As can be seen in Table 24, the base period total inflow for the main groundwater basin was 29,200 AF and total outflow, 33,100 AF. The outflow therefore exceeded inflow by 3,900 AF. In 1995, a wet year, inflow was greater than outflow by 44,200 AF. Outflow is projected to exceed inflow by 4,700 AF in 2010 and by 7,100 AF in 2020.

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 groundwater inflow and groundwater outflow.

---

[1]Because of the wet water year 1998, the long-term mean for the period of record through water year 1995 is about 0.4 inch less than the long-term mean for the period of record through water year 2000 at precipitation station Nipomo 2NW.

TABLE 24

MAIN SANTA MARIA GROUNDWATER BASIN WATER BUDGET

(Thousands of acre-feet)

Components	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	2010*	2020*	Base Period**
Inflow																								
Deep Percolation of Precipitation ***	2.7	0.9	0.0	30.7	2.9	3.1	2.7	19.4	34.7	0.9	0.9	19.3	1.0	1.2	1.0	0.0	2.5	3.0	21.0	1.0	29.2	5.5	5.2	6.8
Urban Return Water	0.6	0.6	0.6	0.7	0.7	0.7	0.8	1.0	1.0	1.1	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.2	1.2	1.9	2.5	1.3
Agricultural Return Water	3.5	4.2	4.2	4.3	4.3	3.9	4.2	4.1	4.1	4.0	3.8	3.7	3.6	3.4	3.3	3.1	2.9	3.1	3.0	3.0	2.9	2.3	2.8	3.3
Other Return Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stream Infiltration	3.5	0.7	0.5	30.1	30.7	36.5	4.2	9.3	36.8	39.1	0.5	15.6	0.4	1.0	0.5	0.4	12.9	9.2	25.7	7.8	36.7	12.5	12.5	12.5
Incidental Recharge of Recycled Wate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	1.1	1.1	0.2
Subsurface Flow into the Main Groundwater Basin	4.9	4.7	4.7	5.8	5.8	5.8	5.6	5.8	5.8	5.6	5.6	5.8	4.7	4.7	4.7	4.7	5.1	5.1	5.1	4.9	5.1	5.1	5.1	5.1
Total Inflow	15.2	11.1	10.0	71.6	44.4	50.0	17.5	39.6	82.4	50.7	12.1	45.8	11.1	11.8	11.1	9.9	25.1	22.0	56.4	18.2	75.4	28.4	29.2	29.2
Outflow																								
Urban Groundwater Extractions	2.6	2.7	2.9	3.1	3.3	3.4	3.9	4.4	4.9	5.4	5.9	6.1	6.3	6.3	6.6	6.8	6.6	6.5	6.2	6.1	5.9	9.3	11.9	6.2
Agricultural Groundwater Extractions	16.2	16.5	16.6	16.9	17.1	17.3	17.4	17.3	17.4	17.4	17.4	16.9	16.5	16.0	15.6	15.1	14.8	14.7	14.4	14.3	14.0	12.6	13.2	15.7
Other Groundwater Extractions	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Subsurface Outflow to the Ocean	9.8	9.0	9.0	12.6	12.6	12.6	12.1	12.1	12.6	11.3	10.6	11.7	9.0	9.0	9.0	9.0	10.1	10.1	10.1	9.0	10.1	10.0	10.0	10.0
Total Outflow	29.7	29.3	29.6	33.7	34.1	34.4	34.5	34.9	36.0	35.2	35.0	35.8	32.9	32.4	32.3	32.1	32.7	32.5	31.9	30.6	31.2	33.1	36.3	33.1
Surplus/Deficiency (Inflow Minus Outflow)	-14.5	-18.2	-19.6	37.9	10.3	15.6	-17.0	4.7	46.4	15.5	-22.9	10.0	-21.8	-20.6	-21.2	-22.2	-7.6	-10.5	24.5	-12.4	44.2	-4.7	-7.1	-3.9
Cumulative Surplus/Deficiency		-32.7	-52.3	-14.4	-4.1	11.5	-5.5	-0.8	45.6	61.1	38.2	48.2	26.4	5.8	-15.4	-37.6	-45.2	-55.7	-31.2	-43.6	0.6			

Note: All values rounded to the nearest 100 acre-feet.

*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.

**Base period is water year 1984 through water year 1995. Base period values are the average of values for years 1984 through 1995.

***All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, variations in soil moisture at the beginning and end of the rainy season, and variations in other related characteristics, the amount reaching groundwater is unknown.

TABLE 25

TRI-CITIES MESA - ARROYO GRANDE PLAIN WATER BUDGET

(Thousands of acre-feet)

Components	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	2010*	2020*	Base Period**
Inflow* **																								
Deep Percolation of Precipitation[1]	1.3	0.6	0.0	4.2	1.4	1.5	1.3	2.7	4.9	0.6	0.6	2.7	0.6	0.7	0.6	0.0	1.3	1.5	2.9	0.6	4.1	1.1	1.1	1.4
Urban Return[2]	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1.0	0.5
Agricultural Return[2]	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.3
Other Return[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stream Infiltration[3]	0.8	0.6	0.5	1.9	1.0	1.5	0.9	1.1	2.4	1.3	0.5	1.0	0.4	0.3	0.5	0.4	0.7	0.8	1.2	0.3	1.6	0.8	0.8	0.8
Subsurface Inflow from Nipomo Mesa[4]	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Subsurface Inflow from Pismo Creek Valley Subbasin[4]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subsurface Inflow from Arroyo Grande Valley Subbasin[5]	1.3	1.1	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.1	1.1	1.3	1.1	1.1	1.1	1.1	1.3	1.3	1.3	1.1	1.3	1.2	1.2	1.2
Subsurface Inflow from Bedrock to Tri-Cities Mesa[4]	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Total Inflow	7.4	6.3	5.6	11.4	7.7	8.3	7.3	9.1	12.6	7.0	6.2	9.0	6.0	5.9	6.0	5.2	7.0	7.4	9.2	5.8	10.8	7.1	7.3	7.2
Outflow* **																								
Urban Groundwater Extractions[2]	0.8	0.8	0.9	0.9	1.0	1.0	1.3	1.6	1.9	2.2	2.5	2.5	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	3.4	4.4	2.3
Agricultural Groundwater Extractions[2]	3.7	3.6	3.5	3.5	3.4	3.3	3.0	2.7	2.5	2.2	1.9	1.7	1.5	1.4	1.2	1.0	1.1	1.2	1.3	1.4	1.5	0.9	0.9	1.5
Other Groundwater Extractions[2]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subsurface Outflow to Ocean[5]	3.2	2.8	2.8	3.7	3.7	3.7	3.2	3.2	3.7	2.8	2.8	3.7	2.8	2.8	2.8	2.8	3.7	3.7	3.7	2.8	3.7	3.2	3.2	3.2
Total Outflow	7.8	7.3	7.3	8.2	8.2	8.1	7.6	7.6	8.2	7.3	7.3	8.0	6.8	6.6	6.4	6.2	7.2	7.3	7.4	6.6	7.6	7.6	8.6	7.1
Surplus/Deficiency (Inflow Minus Outflow)	-0.4	-1.0	-1.7	3.2	-0.5	0.2	-0.3	1.5	4.4	-0.3	-1.1	1.0	-0.8	-0.7	-0.4	-1.0	-0.2	0.1	1.8	-0.8	3.2	-0.5	-1.3	0.1
Cumulative Surplus/Deficiency		-1.4	-3.1	0.1	-0.4	-0.2	-0.5	1.0	5.4	5.1	4.0	5.0	4.2	3.5	3.1	2.1	1.9	2.0	3.8	3.0	6.2			

Note: All values rounded to the nearest 100 acre-feet.

*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.

**Base period is water year 1984 through water year 1995. Base period values are the average of values for years 1984 through 1995.

***See text for more detailed explanation of determination of estimated amounts of the components of inflow and outflow.

[1]All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, variations in soil moisture at the beginning and end of the rainy season, and variations in other related characteristics, the amount reaching groundwater is unknown.

Values of deep percolation of precipitation were calculated for land use survey years 1977, 1985, and 1995; values for intervening years were determined by weighting the calculated values by the amount of precipitation that year.

[2]Values calculated for 1975, 1980, 1985, 1990, and 1995; values for intervening years are straight-lined projections.

[3]Estimated for each year of the budget from gaged streamflow records of Arroyo Grande Creek at Arroyo Grande and from detailed analysis of previous studies by other investigators.

[4]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V. Those values were the same; therefore, values for intervening years are the same amount.

[5]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V; for intervening years used either the 1975, 1985, or 1995 value depending on hydrologic conditions.

TABLE 26

NIPOMO MESA WATER BUDGET

(Thousands of acre-feet)

Components	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	2010*	2020*	Base Period**
Inflow* **																								
Deep Percolation of Precipitation[1]	0.6	0.2	0.0	13.8	0.6	0.7	0.6	8.8	15.9	0.2	0.2	8.8	0.2	0.2	0.2	0.0	0.6	0.6	9.4	0.2	13.3	2.1	1.8	2.8
Urban Return[2]	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.6	1.0	1.3	0.7
Agricultural Return[2]	0.2	0.8	0.8	0.8	0.8	0.3	0.7	0.6	0.6	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Other Return[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recharge of Recycled Water[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	1.1	1.1	0.2
Subsurface Inflow from Santa Maria Valley[3]	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.3	2.3	2.3
Subsurface Inflow from Nipomo Valley Subbasin[4]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total Inflow	2.8	3.0	2.8	16.7	3.5	3.1	3.4	11.6	18.7	2.9	2.9	12.9	4.4	4.4	4.5	4.4	4.9	4.9	13.7	4.4	17.5	7.3	7.3	6.8
Outflow* **																								
Urban Groundwater Extractions[2]	1.5	1.6	1.7	1.9	2.0	2.1	2.3	2.5	2.6	2.8	3.0	3.2	3.4	3.5	3.7	3.9	3.7	3.6	3.4	3.3	3.1	5.2	6.6	3.4
Agricultural Groundwater Extractions[2]	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.6	1.9
Other Groundwater Extractions[2]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Subsurface Outflow to Tri-Cities Mesa - Arroyo Grande Plain[4]	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Subsurface Outflow to Ocean[5]	0.9	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.5	0.7	0.5	0.5	0.5	0.5	0.7	0.7	0.7	0.5	0.7	0.6	0.6	0.6
Total Outflow	6.1	5.9	6.0	6.7	6.8	7.0	7.3	7.5	7.7	7.5	7.8	8.2	8.2	8.2	8.4	8.6	8.5	8.4	8.1	7.8	7.7	9.7	11.1	8.2
Surplus/Deficiency (Inflow Minus Outflow)	-3.3	-2.9	-3.2	10.0	-3.3	-3.9	-3.9	4.1	11.0	-4.6	-4.9	4.7	-3.8	-3.8	-3.9	-4.2	-3.6	-3.5	5.6	-3.4	9.8	-2.4	-3.8	-1.4
Cumulative Surplus/Deficiency		-6.2	-9.4	0.6	-2.7	-6.6	-10.5	-6.4	4.6	0.0	-4.9	-0.2	-4.0	-7.8	-11.7	-15.9	-19.5	-23.0	-17.4	-20.8	-11.0			

Note: All values rounded to the nearest 100 acre-feet.

*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.

***See text for more detailed explanation of determination of estimated amounts of the components of inflow and outflow.

**Base period is water year 1984 through water year 1995. Base period values are the average of values for years 1984 through 1995.

[1]All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, variations in soil moisture at the beginning and end of the rainy season, and variations in other related characteristics, the amount reaching groundwater is unknown.

Values of deep percolation of precipitation were calculated for land use survey years 1977, 1985, and 1995; values for intervening years were determined by weighting the calculated values by the amount of precipitation that year.

[2]Values calculated for 1975, 1980, 1985, 1990, and 1995; values for intervening years are straight-lined projections.

[3]Estimated 1985 and 1995 geometric mean values from Table 21, Chapter V; used 1985 value for 1975-85 and 1995 value for 1986-95.

[4]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V. Those values were the same; therefore, values for intervening years are the same amount.

[5]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V; for intervening years used either the 1975, 1985, or 1995 value depending on hydrologic conditions.

TABLE 27
SANTA MARIA VALLEY WATER BUDGET
(Thousands of acre-feet)

Components	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	2010*	2020*	Base Period**
Inflow* **																								
Deep Percolation of Precipitation[1]	0.8	0.1	0.0	12.7	0.9	0.9	0.8	7.9	13.9	0.1	0.1	7.8	0.2	0.3	0.2	0.0	0.6	0.9	8.7	0.2	11.8	2.3	2.3	2.6
Urban Return[2]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Agricultural Return[2]	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9	2.8	2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.3	1.8	2.3	2.7
Other Return[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stream Infiltration[3]	2.7	0.1	0.0	28.2	29.7	35.0	3.3	8.2	34.4	37.8	0.0	14.6	0.0	0.7	0.0	0.0	12.2	8.4	24.5	7.5	35.1	11.7	11.7	11.7
Subsurface Inflow from Outside Study Area[4]	1.4	1.4	1.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7
Total Inflow	7.5	4.3	4.1	46.0	35.7	41.1	9.3	21.4	53.6	43.3	5.5	27.7	4.5	5.3	4.4	4.1	17.0	13.5	37.3	11.8	50.9	17.6	18.2	18.8
Outflow* **																								
Urban Groundwater Extractions[2]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.7	0.9	0.5
Agricultural Groundwater Extractions[2]	11.1	11.4	11.6	11.8	12.1	12.3	12.6	12.8	13.0	13.3	13.5	13.2	13.0	12.7	12.5	12.2	11.9	11.7	11.4	11.2	10.9	10.1	10.7	12.3
Other Groundwater Extractions[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subsurface Outflow to Nipomo Mesa[5]	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.3	2.3	2.3
Subsurface Outflow to Ocean[6]	5.7	5.7	5.7	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.3	7.3	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	6.2	6.2	6.2
Total Outflow	18.3	18.6	18.8	21.3	21.6	21.8	22.1	22.3	22.6	22.9	22.4	23.4	21.7	21.4	21.3	21.1	20.8	20.6	20.2	20.0	19.7	19.4	20.2	21.4
Surplus/Deficiency (Inflow Minus Outflow)	-10.8	-14.3	-14.7	24.7	14.1	19.3	-12.8	-0.9	31.0	20.4	-16.9	4.3	-17.2	-16.1	-16.9	-17.0	-3.8	-7.1	17.1	-8.2	31.2	-1.8	-2.0	-2.6
Cumulative Surplus/Deficiency		-25.1	-39.8	-15.1	-1.0	18.3	5.5	4.6	35.6	56.0	39.1	43.4	26.2	10.1	-6.8	-23.8	-27.6	-34.7	-17.6	-25.8	5.4			

Note: All values rounded to the nearest 100 acre-feet.

*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.

**Base period is water year 1984 through water year 1995. Base period values are the average of values for years 1984 through 1995.

***See text for more detailed explanation of determination of estimated amounts of the components of inflow and outflow.

[1]All or a portion of this amount of water is available for deep percolation; however, because of antecedent groundwater conditions, variations in storm intensities, variations in soil moisture at the beginning and end of the rainy season, and variations in other related characteristics, the amount reaching groundwater is unknown.

Values of deep percolation of precipitation were calculated for land use survey years 1977, 1985, and 1995; values for intervening years were determined by weighting the calculated values by the amount of precipitation that year.

[2]Values calculated for 1975, 1980, 1985, 1990, and 1995; values for intervening years are straight-lined projections.

[3]Estimated for each year of the budget from gaged streamflow records of Santa Maria River at Guadalupe, Sisquoc River near Garey, and Cuyama River below Twitchell Dam and from detailed analysis of previous studies by other investigators.

[4]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V; for intervening years used either 1975, 1985, or 1995 value depending on rainfall and streamflow conditions.

[5]Estimated 1985 and 1995 geometric mean values from Table 21, Chapter V; used 1985 value for 1975-85 and 1995 value for 1986-95.

[6]Estimated 1975, 1985, and 1995 geometric mean values from Table 21, Chapter V; for intervening years used either 1975, 1985, or 1995 value depending on hydrologic conditions except for years 1978-84. For those years used 8,000 AF because of high creek infiltration from Twitchell Reservoir releases (based on Worts's 1918 estimate).

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 of Precipitation	Unknown

*From: Peters, 1981.

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 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 large in some cases, the estimated amounts in the water budgets are not all simultaneously overestimating or underestimating their actual values.

Inflow Components

Groundwater flows into the main Santa Maria Basin through deep percolation of precipitation; urban, agricultural, and other returns; stream infiltration; incidental recharge of recycled water; and subsurface flows of groundwater between portions within and from outside the main basin.

Deep Percolation of Precipitation

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

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 through 1995 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 are 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 AF.

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 annually and on areas of native vegetation when 17 inches of precipitation have fallen annually. In the Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley portions of the main groundwater basin, any amount of rainfall above 30 inches annually was not considered to contribute to deep percolation of precipitation regardless of the land use classification. 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 of the Blaney study are not the same as those in the Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley portions of the main groundwater basin, it was assumed that they are sufficiently similar for the estimates to be reasonably valid.

Because the Nipomo Mesa portion of the basin has unique soil characteristics and topographic features, any amount of annual rainfall, including amounts greater than 30 inches, is considered to contribute to deep percolation of precipitation. As mentioned in Chapter IV, at the edges of the bluffs of Nipomo Mesa, a small amount of runoff is draining to adjacent areas, however, the amounts are quite small and have not been quantified in this report.

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, variations in soil moisture at the beginning and end of the rainy season, and variations in other related characteristics. Thus, rigid use of the method would be subject to some error.

For the water budgets, values of deep percolation of precipitation were calculated for 1977, 1985, and 1995;[2] values for intervening years were determined by weighting the calculated values by the amount of rainfall that year. The base period and future years (2010 and 2020) values are the average of the values for 1984 through 1995.

Because of differences in soils, percolation rates and climatic conditions, potential deep percolation as a percentage of precipitation varied widely for the three portions of the main groundwater basin. In Tri-Cities Mesa - Arroyo Grande Plain, deep percolation as a percentage of precipitation ranged from 0 (in dry years) to 14.5 (in wet years) percent over the study period with a base period amount of about nine percent. Deep percolation as a percentage of precipitation in Nipomo Mesa ranged from 0 (in dry years) to 29 (in wet years) percent over the study period with a base period value of almost 12 percent. In Santa Maria Valley, deep percolation as a percentage of precipitation ranged from 0 (in dry years) to 40 (in wet years) percent over the study period with a base period amount of almost 16 percent. As would be expected, deep percolation as a percentage of precipitation in water years classified as dry is low or nonexistent and high in water years classified as wet. The base period amount always falls between these two extreme values.

The base period estimate of potential deep percolation of precipitation was greatest (2,800 AF, 40 percent of total inflow) in Nipomo Mesa, which covers a surface area of almost 17,600 acres (Table 26). The lowest estimate of base period deep percolation of precipitation was 1,400 AF, 19 percent of total inflow, in Tri-Cities Mesa - Arroyo Grande Plain, which covers a surface area of almost 10,800 acres (Table 25). The estimate of base period deep percolation of precipitation for Santa Maria Valley was 2,600 AF, 15 percent of total inflow, with a surface area of almost 21,600 acres (Table 27).

Deep percolation of precipitation follows rainfall trends, with significant amounts of deep percolation occurring only in wet years, such as 1995 (Tables 24-27). Hydrographs of groundwater levels presented in Chapter V, showed corresponding rises in levels, and thus amount of groundwater in storage, in response to deep percolation of precipitation in wet years, except in some wells in parts of the Nipomo Mesa portion of the groundwater basin. In wet years, deep percolation of precipitation accounted for 30 to 40 percent of total inflow in Tri-Cities Mesa - Arroyo Grande Plain; 70 to 80 percent of total inflow in Nipomo Mesa; and 20 to 30 percent of total inflow in Santa Maria Valley.

---

[2]Years of land use surveys conducted by the Department.

In some dry years, no deep percolation of rainfall occurred (Tables 24-27). Most of the lack of or decrease in rainfall recharge in dry years is compensated for by decreases in subsurface outflows and amounts of groundwater in storage.

Because of projected land use changes in 2010 and 2020 (increased development and reduction in pervious area), deep percolation of precipitation was estimated to decrease in future years from the base period estimates in each of the three portions of the main groundwater basin (Tables 25-27). In Tri-Cities Mesa - Arroyo Grande Plain, deep percolation of precipitation is projected to be 300 AF less in 2010 and 2020 than in the base period; in Nipomo Mesa, 700 AF less in 2010 and 1,000 AF less in 2020 than in the base period; and in Santa Maria Valley, 300 AF less in 2010 and 2020 than in the base period.

Soil moisture and infiltration studies are needed to more accurately determine the amount of deep percolation of precipitation occurring within the groundwater basin.

Urban 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.[3] It was calculated as urban applied water less water not consumed by evapotranspiration or system losses. For the main groundwater basin as a whole, urban return water amounted to 1,300 AF during the base period (Table 24). Of this amount, 500 AF was returned in Tri-Cities Mesa - Arroyo Grande Plain, 700 AF in Nipomo Mesa, and 100 AF in Santa Maria Valley (Tables 25-27). These values were rounded to the nearest 100 AF.

Urban return water was projected to increase in year 2020 from the 1995 estimates in Tri-Cities Mesa - Arroyo Grande Plain by 500 AF, or about 200 percent, in Nipomo Mesa by 700 AF, or about 220 percent, and in Santa Maria Valley by 100 AF, or 200 percent.

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 to crops during the growing season.

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 acreage, soil types, average climatological conditions, and existing irrigation management practices. The totals reported in the tables were rounded to the nearest 100 AF.

[3]Includes return from golf course irrigation.

Base period agricultural returns were 3,300 AF for the main groundwater basin (Table 24). Of this amount, 300 AF was returned in Tri-Cities Mesa - Arroyo Grande Plain, 300 AF in Nipomo Mesa, and 2,700 AF in Santa Maria Valley (Tables 25-27). By year 2020, agricultural return water was projected to decrease in Tri-Cities Mesa - Arroyo Grande Plain by 100 AF or about 33 percent from the 1995 estimate; remain the same, 300 AF, in Nipomo Mesa (less than 100 AF of change, thus it is not reflected in the future amounts); and fluctuate downward 500 AF between 1995 and 2010 and then return to the 1995 amount of 2,300 AF in Santa Maria Valley.

Other Return Water

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.[4] For the main groundwater basin as a whole, the category of other return water was less than 100 AF and thus appears as zero in the tables.

Stream Infiltration

Surface flows in Pismo and Arroyo Grande Creeks and their tributaries contribute the stream infiltration in the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin. Lopez Dam regulates flows on Arroyo Grande Creek. Surface flows in the Santa Maria River contribute to stream infiltration in the Santa Maria Valley portion of the basin. Twitchell Dam regulates some of the flows on the Santa Maria River. Surface flows in Black Lake Canyon may contribute to the underlying groundwater resources in the Nipomo Mesa portion of the basin; however, they were not quantified in this study (less than 100 AF). It is believed that much, if not all, water that percolates toward the underlying groundwater basin in Black Lake Canyon is captured and retained as perched water.

Stream infiltration is dependent on the permeability of the streambed material and the flow regimen of the streams. For this study, the amounts of stream infiltration were estimated for each year of the budget from gaged streamflow records of Arroyo Grande Creek at Arroyo Grande, Santa Maria River at Guadalupe, Sisquoc River near Garey, and Cuyama River below Twitchell Dam. Furthermore, the estimates of stream infiltration for Arroyo Grande Creek were made after a thorough analysis of the data and the following studies: California Department of Public Works, Division of Water Resources, 1921, 1945, and 1955; Arroyo Grande Soil Conservation District and San Luis Obispo County Flood Control and Water Conservation District, 1955; California Department of Water Resources, 1958; Hoover & Associates, Inc., 1985a and 1985b; and Lawrance, Fisk, & McFarland, 1985a, 1985b, and 1985c. The estimates of stream infiltration for Santa Maria River were made after a thorough analysis of the data and the following studies: U. S. Department of Agriculture, 1942 and 1951; Thomasson, 1951; Worts, 1951, U. S. Bureau of Reclamation, 1952 and 1955; Miller and Evenson, 1966; Hughes, 1977;

[4]Cooling water from the Tosco facility is discharged to an ocean outfall.

Lipinski, 1985; and Luhdorff & Scalmanini, 1997.

In addition, the amounts of stream infiltration were determined independently of the deep percolation of precipitation on urban, agricultural and native vegetation land use areas. The base period and 2010 and 2020 stream infiltration values are the average of the 1984 through 1995 values. Stream infiltration values were rounded to the nearest 100 AF.

For the base period, 12,500 AF of streamflow was estimated to infiltrate in the main groundwater basin, with 800 AF (about 10 percent of total inflow) infiltrating in Tri-Cities Mesa - Arroyo Grande Plain and 11,700 AF (about 60 percent of total inflow) infiltrating in Santa Maria Valley (Tables 24, 25, and 27). In wet years, stream infiltration was two to three times greater than the base period amount in both Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley. In dry years, stream infiltration was about 300 to 500 AF (about 10 percent of total inflow) in Tri-Cities Mesa - Arroyo Grande Plain mainly as the result of releases from Lopez Reservoir. In Santa Maria Valley, stream infiltration was zero AF in some dry years, but could be a significant amount if water were available in storage in Twitchell Reservoir for release, as occurred in 1984.

Because of the lack of stream gages on Arroyo Grande Creek at its confluence with the Pacific Ocean and since 1987 on Santa Maria River at Guadalupe, the range of error in estimating streamflow could be 10 to 200 percent (Table 28). If stream infiltration amounts are higher than those estimated in the water budgets, the projected deficiencies in the budgets in 2010 and 2020 could be offset in Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley.

Stream infiltration studies are needed to more accurately determine the amount of infiltration to the groundwater basin from Arroyo Grande and Pismo Creeks and Santa Maria River.

Recycled Water

For the main groundwater basin, the incidental recharge of recycled water[5] amounted to 200 AF in the base period and was projected to amount to 1,100 AF in 2010 and 2020.

There is no incidental recharge of recycled water in the Tri-Cities Mesa - Arroyo Grande Plain portion of the groundwater basin at present. Treated wastewater generated in the area 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 expands its plant capabilities and incidentally recharges recycled water to the Tri-Cities Mesa - Arroyo Grande Plain portion of the groundwater basin, the total inflow of the water budget could increase by up to 950 AF in 2010 and 2020.

[5]All wastewater treatment plants in the main groundwater basin produce effluent that meets secondary standards.

The only portion of the main groundwater basin in which recycled water was incidentally recharged was Nipomo Mesa (Table 26). The amount incidentally recharged is that reported for Nipomo Community Services District's Black Lake and Southland WWTPs (Table 13 in Chapter III). The year 2010 and 2020 values reflect planned expansion of those two plants and the Cypress Ridge project, and construction of a future plant at the Woodlands project.

There is no incidental recharge of recycled water in the Santa Maria Valley at present and none is planned in the future.

A small proportion of the rural population within the main groundwater basin 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 recycled water were rounded to the nearest acre-foot.

Subsurface Inflows

Subsurface inflows occur from the subbasins to the main basin, from the bedrock into the basin, from one portion to another within the main basin, and from outside the study area into the Santa Maria Valley portion of the basin.

The subsurface inflow estimates in the water budgets are the geometric mean values given for years 1975, 1985, and 1995 in Table 21, Chapter V. The methodology for calculating subsurface flows is discussed in Chapter V.

The 1975, 1985, and 1995 values were applied to those years of the budget. Values for intervening years were derived by applying either the 1975, 1985, or 1995 value based on the amount of rainfall for that year (further explanation is provided on Tables 25-27). The base period and future years (2010 and 2020) values are the average of the values for 1984 through 1995. In Tables 24-27, the subsurface flow values were rounded to the nearest 100 AF.

Subsurface flow into the main groundwater basin within San Luis Obispo County was 5,100 AF during the base period (Table 24). Of this amount, 2,900 AF (40 percent of total inflow) is subsurface flow into the Tri-Cities - Arroyo Grande Plain portion of the main basin from Pismo Creek Valley and Arroyo Grande Valley Subbasins and bedrock (Table 25), 500 AF of subsurface flow from Nipomo Valley Subbasin into the Nipomo Mesa portion of the main basin (about seven percent of total inflow, Table 26), and 1,700 AF of subsurface flow from outside the study area into the Santa Maria Valley portion of the main basin (about nine percent of total inflow, Table 27).

Subsurface flow also occurs between portions of the main groundwater basin. Table 25 shows 1,300 AF of inflow to Tri-Cities Mesa - Arroyo Grande Plain from Nipomo Mesa for all years of the budget (about 20 percent of total inflow in the base period). Table 26 shows 2,300 AF of inflow to Nipomo Mesa from Santa Maria Valley during the base period and future years (about 35 percent of total inflow in the base period).

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 portion of the main groundwater basin to another. The largest outflow component for the main groundwater basin is groundwater extractions, with agricultural extractions accounting for about 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.[6] 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 AF.

As shown in Table 24, urban groundwater extractions amounted to 6,200 AF, about 20 percent of total outflow, in the base period for the main groundwater basin. Of this amount, 2,300 AF, about 30 percent of the outflow, were extracted in Tri-Cities Mesa - Arroyo Grande Plain; 3,400 AF, about 40 percent of the outflow, in Nipomo Mesa; and 500 AF, only two percent of the outflow in Santa Maria Valley (Tables 25-27).

Between 1995 and 2020, urban extractions are projected to increase by 2,100 AF or more than 190 percent, in Tri-Cities Mesa - Arroyo Grande Plain; to increase by 3,500 AF, or about 215 percent, in Nipomo Mesa; and to increase by 400 AF, or 180 percent, in the Santa Maria Valley.

Groundwater extracted for urban use accounts for the major portion of extractions in Tri-Cities Mesa - Arroyo Grande Plain and Nipomo Mesa. Beginning in 1985, urban extractions exceeded agricultural extractions in Tri-Cities Mesa - Arroyo Grande Plain and are projected to exceed them by 3,500 AF in 2020. In Nipomo Mesa, urban extractions were about the same amount as agricultural extractions in 1975, exceeding them by ever increasing amounts since then, and are projected to exceed them by 5,000 AF in 2020. The increasing urban extractions in some parts of Nipomo Mesa have created extensive pumping depressions (discussed in Chapter V). In Santa Maria Valley, urban groundwater extractions are a very small component of total extractions and are projected to remain so through 2020.

---

[6]Urban groundwater extractions include extractions for golf course irrigation.

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 acreage, evapotranspiration of applied water values, unit applied water rates, and irrigation efficiencies. In the tables, they were rounded to the nearest 100 AF.

In the base period, agricultural groundwater extractions from the main groundwater basin were 15,700 AF, accounting for about 50 percent of the total outflow (Table 24). Of this amount, 1,500 AF, about 20 percent of the total outflow, were extracted from Tri-Cities Mesa - Arroyo Grande Plain; 1,900 AF, about 25 percent of the total outflow, from Nipomo Mesa; and 12,300 AF, about 55 percent of the total outflow, from Santa Maria Valley (Tables 25-27).

In Tri-Cities Mesa - Arroyo Grande Plain, agricultural extractions are projected to decline 600 AF, or about 60 percent, between 1995 and 2020, while remaining the same in Nipomo Mesa and declining slightly, 200 AF, in Santa Maria Valley.

Other Extractions

The values given for groundwater extractions for the other uses are those determined for water demand for that category and consist of extractions for cooling, recreation,[7] and miscellaneous uses, such as ice or concrete production. Land use acreage 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 main groundwater basin was 1,200 AF, which consists of 100 AF in Tri-Cities Mesa - Arroyo Grande Plain and in Santa Maria Valley, and 1,000 AF in Nipomo Mesa (Tables 24-27). Other extractions in 2010 and 2020 are projected to be the base period amounts.

Subsurface Outflows

Subsurface outflows were not only to the ocean, which affects the water budget for the main groundwater basin as a whole, but were also from one portion of the main basin to another, which affect the water budgets of only those portions involved.

The subsurface outflow estimates in the water budgets are the geometric mean values given for years 1975, 1985, and 1995 in Table 21, Chapter V. The methodology for calculating subsurface flows is discussed in Chapter V.

The 1975, 1985, and 1995 values were applied to those years of the budget. Values for

---

[7]Recreational extractions do not include extractions for golf course irrigation water, which are included in urban extractions.

intervening years were derived by applying either the 1975, 1985, or 1995 values based on the amount of rainfall for that year (further explanation is provided on Tables 25-27). The base period and future years (2010 and 2020) values are the average of the values for 1984 through 1995. In Tables 24-27, the subsurface flow values were rounded to the nearest 100 AF.

During the base period, 10,000 AF were estimated to flow in the subsurface from the main groundwater basin to the ocean (Table 24). Of this amount, 3,200 AF, 45 percent of total outflow, were from the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin (Table 25); 600 AF, less than 10 percent of total outflow, from the Nipomo Mesa portion of the basin (Table 26); and 6,200 AF, about 30 percent of total outflow, from the Santa Maria Valley portion of the basin (Table 27).

Although some of this outflow to the ocean could be captured, there is a risk in doing so. Subsurface outflow to the ocean must be of sufficient quantity for the freshwater head to counterbalance the greater density of sea water to prevent sea water intrusion.

Because of differences in the groundwater elevations, gradients, and direction of flow, water flows in the subsurface from one portion within the main groundwater basin to another, as is discussed in Chapter V. Table 26 shows base period subsurface outflow from Nipomo Mesa to Tri-Cities Mesa - Arroyo Grande Plain as 1,300 AF, about 15 percent of total outflow. Table 27 shows base period subsurface outflow to Nipomo Mesa from Santa Maria Valley amounted to 2,300 AF, about 10 percent of total outflow.

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 the main Santa Maria Groundwater Basin 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 21 years was determined for each portion of the main groundwater basin. 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."[8] The comparison is a means of checking the probable amount of error in the budget (Peters, 1981). The cumulative surplus/deficiency estimates for the three portions of the basin are given in Tables 25-27.

[8]Specific yield method is discussed in Chapter V and was used to estimate groundwater in storage and total storage capacity.

Figures 30-32 show the comparison between the water budget cumulative values and the "specific yield method" values for each portion of the main basin; it can be seen that there is some discrepancy between the two methods. In the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin, the cumulative water budget method estimated a surplus of 6,000 AF of groundwater in storage between 1975 and 1995 and the "specific yield method" estimated a surplus of 1,000 AF (Figure 30). In the Nipomo Mesa portion of the basin, the cumulative water budget method estimated a loss of 11,000 AF of groundwater in storage between 1975 and 1995 and the "specific yield method" estimated a loss of 7,000 AF (Figure 31). In the Santa Maria Valley portion of the basin, the cumulative water budget method estimated a surplus of 5,400 AF of groundwater in storage between 1975 and 1995 and the "specific yield method" estimated a surplus of 3,000 AF (Figure 32).

The differences between the results of the two methods are believed reasonable, considering the available data. 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.

An analysis of the water budgets revealed the following:

- Stream infiltration and deep percolation of precipitation are the major sources of inflow to the main Santa Maria Groundwater Basin. Inflow from these sources was significantly larger in wet years. Groundwater storage space must be available for recharge from a series of wet years to be effective; otherwise, the inflow is simply rejected and contributes to surface and subsurface outflow to the ocean.

- In dry years, urban, agricultural, and other returns help offset the lack of recharge from natural sources. In Nipomo Mesa and Santa Maria Valley, urban, agricultural, and other returns result from extractions of groundwater; in Tri-Cities Mesa - Arroyo Grande Plain, returns are also from use of surface water.

- The largest source of outflow from the main basin was agricultural extractions, followed by subsurface flow to the ocean. In the base period, about 80 percent of the agricultural extractions from the main basin are from Santa Maria Valley. Urban extractions are the major extractions in the Nipomo Mesa and Tri-Cities Mesa - Arroyo Grande Plain portions of the basin.

- In the base period, total outflows were estimated to exceed total inflows in the main basin by about 10 percent. In Tri-Cities Mesa - Arroyo Grande Plain, total inflow about equaled total outflow in the base period, while in Nipomo Mesa and Santa Maria Valley total outflow exceeded total inflow in the base period by 17 and 11 percent, respectively.

  In wet years, inflows were estimated to exceed outflows by greater than 200 percent in Nipomo Mesa and Santa Maria Valley (as much as 11,000 and 31,000 AF, respectively)

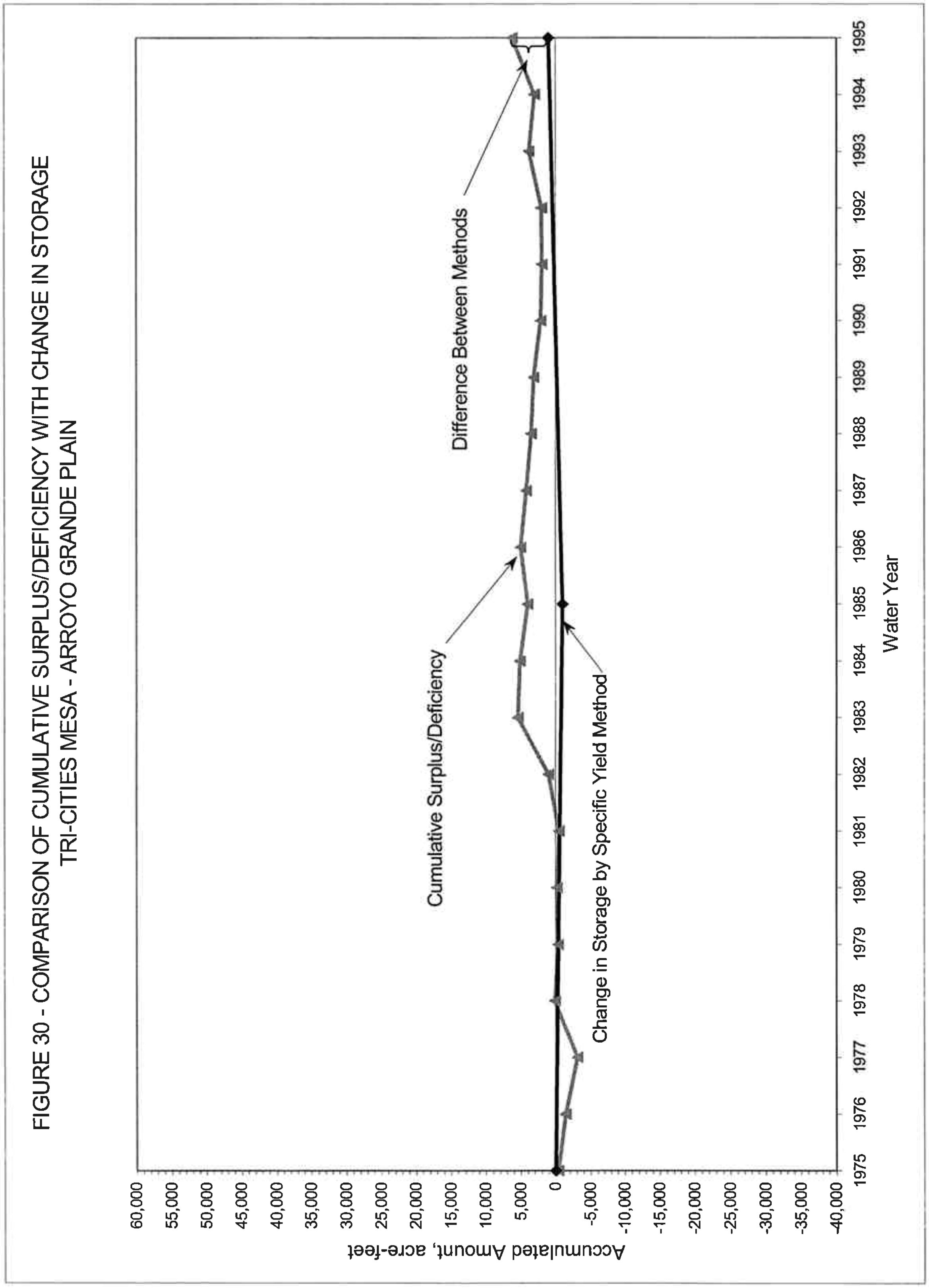
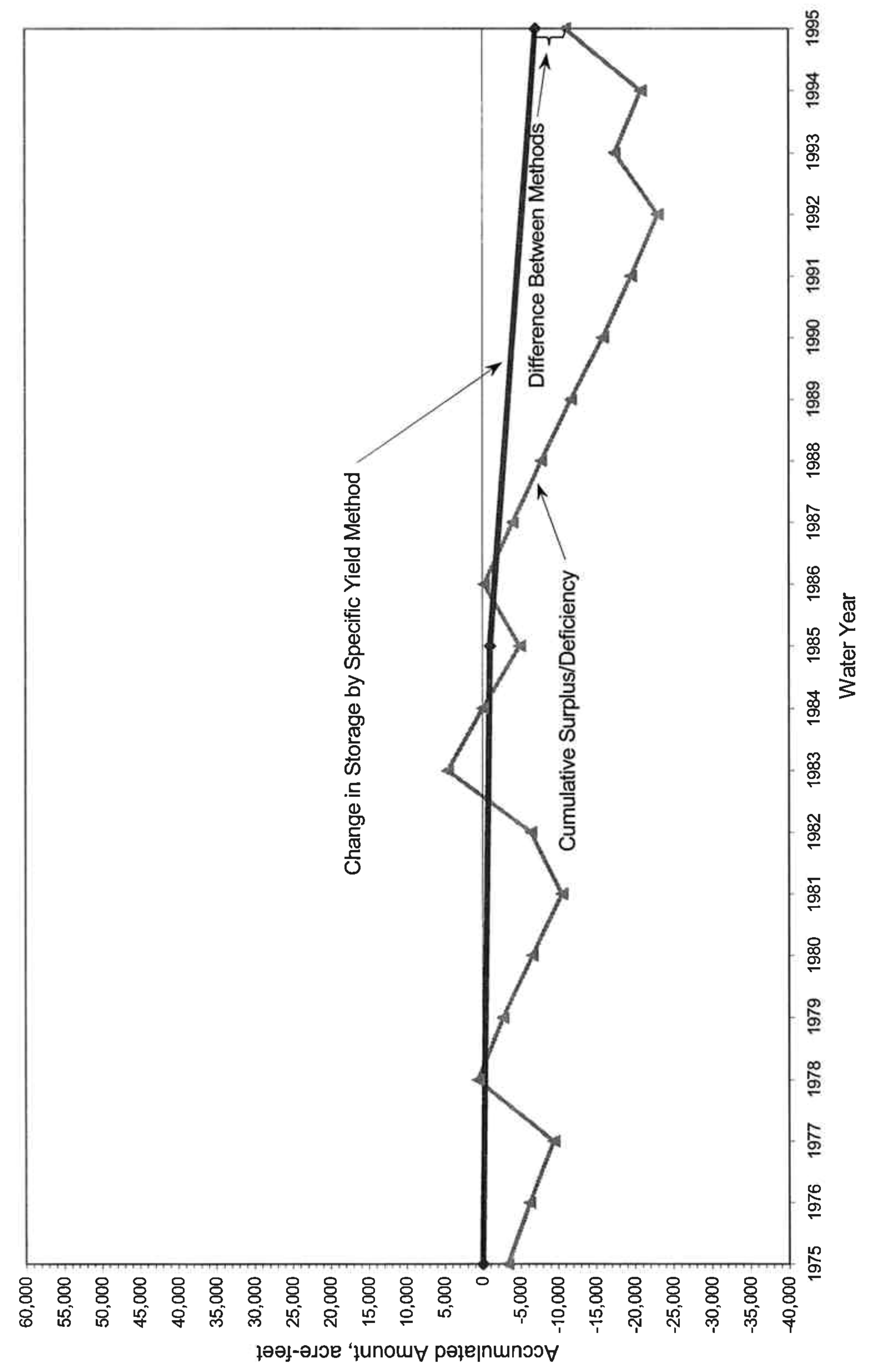


FIGURE 30 - COMPARISON OF CUMULATIVE SURPLUS/DEFICIENCY WITH CHANGE IN STORAGE
TRI-CITIES MESA - ARROYO GRANDE PLAIN
Accumulated Amount, acre-feet
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
Water Year
Difference Between Methods
Cumulative Surplus/Deficiency
Change in Storage by Specific Yield Method

FIGURE 31 - COMPARISON OF CUMULATIVE SURPLUS/DEFICIENCY WITH CHANGE IN STORAGE
NIPOMO MESA



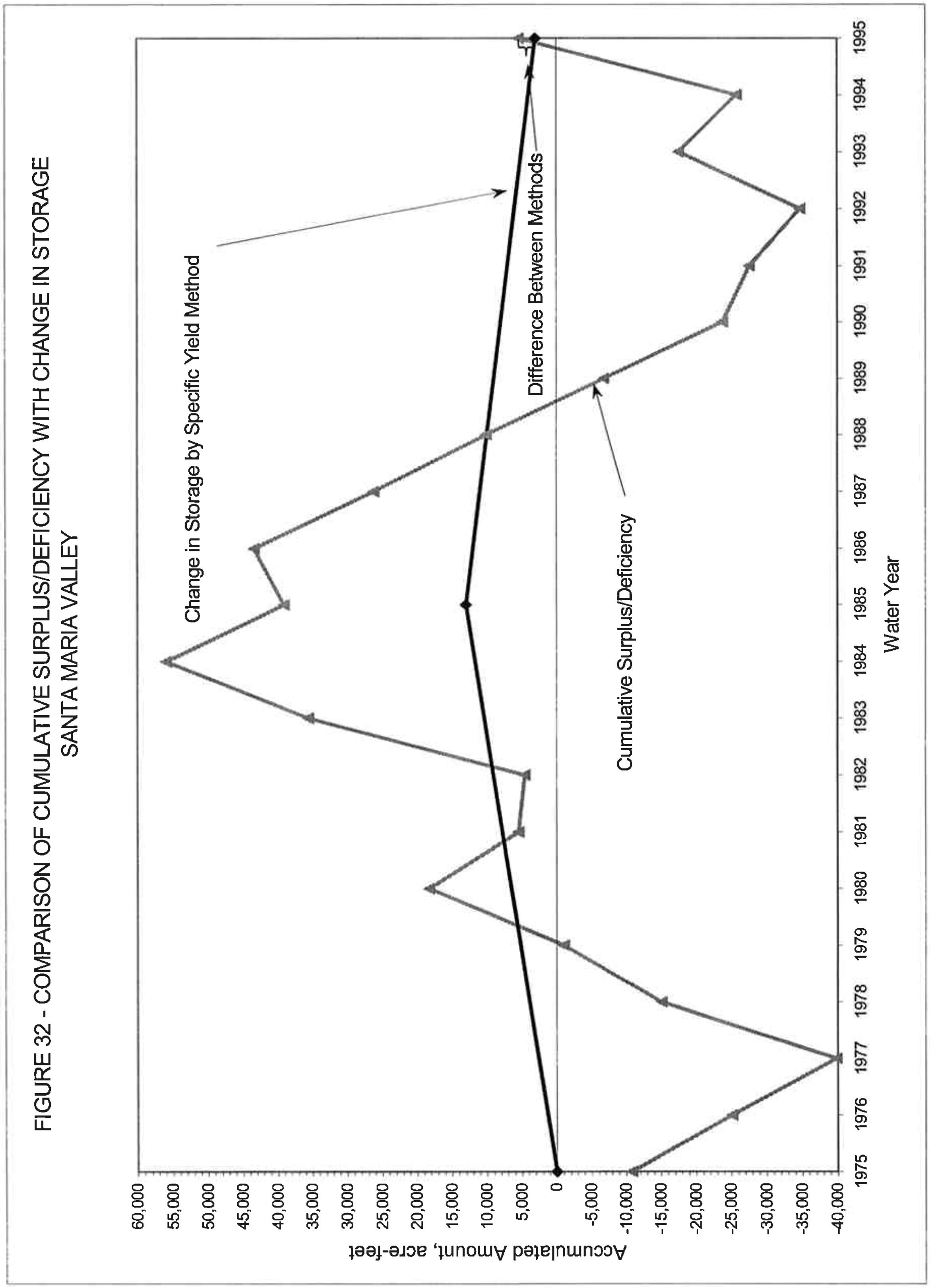


FIGURE 32 - COMPARISON OF CUMULATIVE SURPLUS/DEFICIENCY WITH CHANGE IN STORAGE
SANTA MARIA VALLEY
Change in Storage by Specific Yield Method
Difference Between Methods
Cumulative Surplus/Deficiency
Accumulated Amount, acre-feet
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
Water Year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

and up to about 150 percent in Tri-Cities Mesa - Arroyo Grande Plain (up to about 4,000 AF). The gains in groundwater in storage help to offset succeeding dry year deficiencies.

In dry years, total outflows exceeded total inflows. In Tri-Cities Mesa - Arroyo Grande Plain, losses in groundwater in storage were relatively small, less than 2,000 AF, because of estimated subsurface inflow and stream infiltration from Lopez Reservoir releases. Dry year deficiencies in Nipomo Mesa were estimated to be up to about 5,000 AF and are lessened by subsurface inflow from Santa Maria Valley. In Santa Maria Valley, dry year deficiencies were estimated to be as high as about 17,000 AF, although conservation releases from Twitchell Reservoir can offset reduced inflows in dry years (as occurred in 1984, which had estimated total inflow exceeding total outflow).

- The 2010 and 2020 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 through water year 1995. The surpluses/deficiencies represent the possible amount of change of groundwater in storage that could take place, if the hydrologic base period conditions of this study prevailed that year.

  The projected deficiencies in the 2010 and 2020 water budgets for Tri-Cities Mesa - Arroyo Grande Plain, Nipomo Mesa, and Santa Maria Valley (1,300, 3,800, and 2,000 AF in 2020, respectively) represent the potential losses in groundwater in storage if hydrologic base period conditions occurred in those years. The projected deficiencies would amount to about one-tenth of a foot decline in groundwater levels in 2020 over the entire Tri-Cities Mesa - Arroyo Grande Plain and Santa Maria Valley portions of the basin and two-tenths of a foot decline in groundwater levels in 2020 over the entire Nipomo Mesa portion of the basin.

- In Tri-Cities Mesa - Arroyo Grande Plain, the projected increase in urban extractions (190 percent from 1995 to 2020), which will account for about 50 percent of the outflow, is the major factor contributing to the projected deficiencies. Reductions in subsurface outflow to the ocean, which accounts for about 35 percent of total outflow, will likely offset future negative imbalances between inflow and outflow and loss of groundwater in storage. Also, recharge enhancement of Arroyo Grande Creek could increase stream infiltration amounts and potentially offset future deficiencies. However, if in the future, subsurface outflow to the ocean is not of sufficient quantity for the freshwater head to counterbalance the greater density of sea water, sea water intrusion of the groundwater basin could occur.

- In Nipomo Mesa, the projected increase in urban extractions (about 215 percent from 1995 to 2020), which will account for 60 percent of the outflow, is the major factor contributing to projected deficiencies. Reductions in subsurface outflows to the ocean and to Tri-Cities Mesa - Arroyo Grande Plain and increased subsurface inflow from Santa Maria Valley will likely offset future negative imbalances between inflow and outflow, reducing the projected amount of loss in groundwater in storage. Subsurface outflow to the ocean was only 600 AF in the base period (seven percent of total outflow) and reductions in this outflow would need to be small because of the concern regarding sea water intrusion, as mentioned above.

- In Santa Maria Valley, the projected deficiencies are not the result of future increased extractions (extractions were projected to increase only 200 AF between 1995 and 2020). Projected subsurface outflows are substantial (6,200 AF to the ocean and 2,300 AF to Nipomo Mesa) from this portion of the basin. Potential future deficiencies will likely be offset by reduced subsurface outflow to the ocean, which accounts for about 30 percent of the total outflow in the future. However, if in the future, subsurface outflow to Nipomo Mesa increases above the projected amount of 2,300 AF, water budgets for this portion of the basin could show larger deficits (loss of groundwater in storage). The same concern regarding sea water intrusion, as mentioned above, applies.

  Also, estimated stream infiltration over the base period was low because of five years with little or no stream infiltration (estimated stream infiltration over the study period was 1,700 AF more than in the base period). Silt accumulation in Twitchell Reservoir has significantly reduced its storage capacity and effectiveness in augmenting groundwater recharge. Restoration and maintenance of the storage capacity of the reservoir could improve future recharge amounts from the Santa Maria River to the groundwater basin.

Dependable Yield and Overdraft

Dependable Yield. The dependable yield of a groundwater basin is the average quantity of water that can be withdrawn from the basin over a period of time (during which water supply conditions approximate average conditions) without resulting in adverse effects, such as sea water intrusion, subsidence, permanently lowered groundwater levels, or degradation of water quality. Dependable yield is determined for a specified set of conditions and any changes in those conditions require a new calculation.

For this study, the estimates of dependable yield are based on the hydrologic equation for the 1984 through 1995 base period and for the 1975 through 1995 study period and were determined by two methods: the dependable yield may be equal to the average annual inflow minus the natural outflow, or it may be equal to the average annual extractions plus or minus the change in the amount of groundwater in storage.[9] The estimates of dependable yield for each portion of the main basin are given in Table 29.

---

[9]The methodology used and the accuracy of the assumptions for the components of the hydrologic equation were discussed earlier in this chapter.

TABLE 29
ESTIMATES OF DEPENDABLE YIELD, MAIN SANTA MARIA GROUNDWATER BASIN
In acre-feet

Division Within Main Groundwater Basin	Average Annual Inflow Minus Natural Outflow		Average Annual Extractions Plus Change in Storage	
	Base Period*	Study Period**	Base Period*	Study Period**
Tri-Cities Mesa - Arroyo Grande Plain	4,000	4,400	4,100	4,200
Nipomo Mesa	4,900	5,000	4,700	4,800
Santa Maria Valley	10,300	12,900	11,900	12,800

*The base period is water years 1984 through 1995.
**The study period is water years 1975 through 1995.

Because subsurface flows to the ocean could be reduced and subsurface flows between the portions of the basin increased or decreased, the dependable yield values in Table 29 can be conservatively increased. Thus, the dependable yield for each portion of the main basin is given as a range.[10] The dependable yield is estimated to range between 4,000 and 5,600 AF for the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin, between 4,800 and 6,000 AF for the Nipomo Mesa portion of the basin, and between 11,100 and 13,000 AF for the Santa Maria Valley portion of the basin.

These estimates of dependable yield for each portion of the main groundwater basin are more meaningful if they are considered as a unified whole because the estimates are directly affected by the amounts and nature of the subsurface flows occurring between portions of the basin. Thus, the dependable yield for the main Santa Maria Basin within San Luis Obispo County ranges between 19,900 and 24,600 AF.

During the course of this study, it became apparent that better data are needed to determine stream infiltration, deep percolation of precipitation, and groundwater extractions. Information is also needed that would assist in understanding the role of the Santa Maria River, Oceano, and Wilmar Avenue faults on subsurface flows. The resulting improvement in the estimated amounts of the items of water supply and use will, in turn, improve the estimates of dependable yield.

Overdraft. This report defines overdraft as the condition of a groundwater basin or subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which the water supply conditions approximate average conditions (California Department of Water Resources, Draft 2002). Droughts or periods of less than normal rainfall do not cause overdraft. Basically, overdraft means that extractions exceed the dependable yield of the basin.

[10]The lower value of dependable yield is the average of the two base period values given in Table 29 (rounded).

This study refrains from finding that the Santa Maria Groundwater Basin within San Luis Obispo County is currently in overdraft because of consistent subsurface outflow to the ocean and no evidence of sea water intrusion. The periodic recovery of the basin provides sufficient recharge to preclude long-term adverse conditions. The basin was estimated to have about 38,000 AF more groundwater in storage in water year 2000 than in 1975. In the Nipomo Mesa portion of the basin, the amount of groundwater in storage in 2000 was estimated to be the same as in 1975, despite the continued presence of the pumping depression in the south-central part of the mesa. Pumping depressions and declines in groundwater levels in some wells in some parts of the Nipomo Mesa portion of the basin do not imply that a condition of overdraft exists in the entire groundwater basin, but are more likely indicative of the dynamics of the groundwater system and sources of recharge in the mesa. Other recent investigations also found that the basin is not in a condition of overdraft (The Morro Group, 1990; Cleath, 1996a; Luhdorff & Scalmanini, Consulting Engineers, 1997; and Environmental Science Associates, 1998 and 2001).

The projected deficiencies in the water budgets in water years 2010 and 2020 for the three portions of the main Santa Maria Basin do not necessarily imply overdraft conditions in those years. Projected extractions are within the range of dependable yield estimates, with the exception of Nipomo Mesa in 2020. Because the basin continuously seeks a new equilibrium, reductions in subsurface outflow to the ocean and changes in subsurface flow between portions of the basin will likely compensate for projected deficiencies (loss of groundwater in storage). Such changes in subsurface flows as the basin seeks a new equilibrium will not likely result in overdraft provided that sea water intrusion and other adverse effects are avoided. However, because of the potential for adverse effects, increasing amounts of subsurface flow from the Santa Maria Valley portion of the basin into the Nipomo Mesa portion of the basin to meet projected water demands should not be used as a long-term solution to water supply needs in Nipomo Mesa. The projected deficiencies in the water budgets do indicate the need for continued planning, improved data (mentioned above in this chapter and in other chapters of this report), periodic reevaluation of the water budgets, artificial recharge programs, and expanded use of recycled water.

The groundwater basin is an area of dynamic growth, subject to constantly changing conditions, which affect water supply, use, and disposal. Human activities that can modify water supply conditions and consequently water budgets include items such as: extent of extractions, transfers of water use, increases in impermeable areas, 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 groundwater basin, protracted dry or wet periods will significantly affect future water supply conditions. Therefore, it needs to be recognized that any water budgets and dependable yield values will be superseded in the future as conditions change.

This Page Intentionally Blank

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.

Dependable 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 subsidence, sea water intrusion, permanently lowered groundwater levels, or degradation of quality. If water management in the basin changes, the perennial yield of the basin may change.

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 permeable materials capable of furnishing a significant supply of groundwater to wells or storing a significant amount of water. A groundwater basin is delineated by reasonably well-defined boundaries in a lateral and vertical direction. It is three-dimensional and includes both the surface extent and all of the subsurface water-yielding material; however, the surface boundaries of the basin should not be construed to imply that those boundaries extend vertically downward in a third dimension.

Groundwater subbasin A subbasin is a subdivision of a groundwater basin that is delineated using geologic and hydrogeologic conditions, such as faults or zones of low permeability, or consideration of institutional boundaries for purposes of collecting and analyzing data.

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 subbasin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years, during which the water supply conditions approximate average conditions (Department of Water Resources, Bulletin 118 Update, Draft 2002).

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.

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.

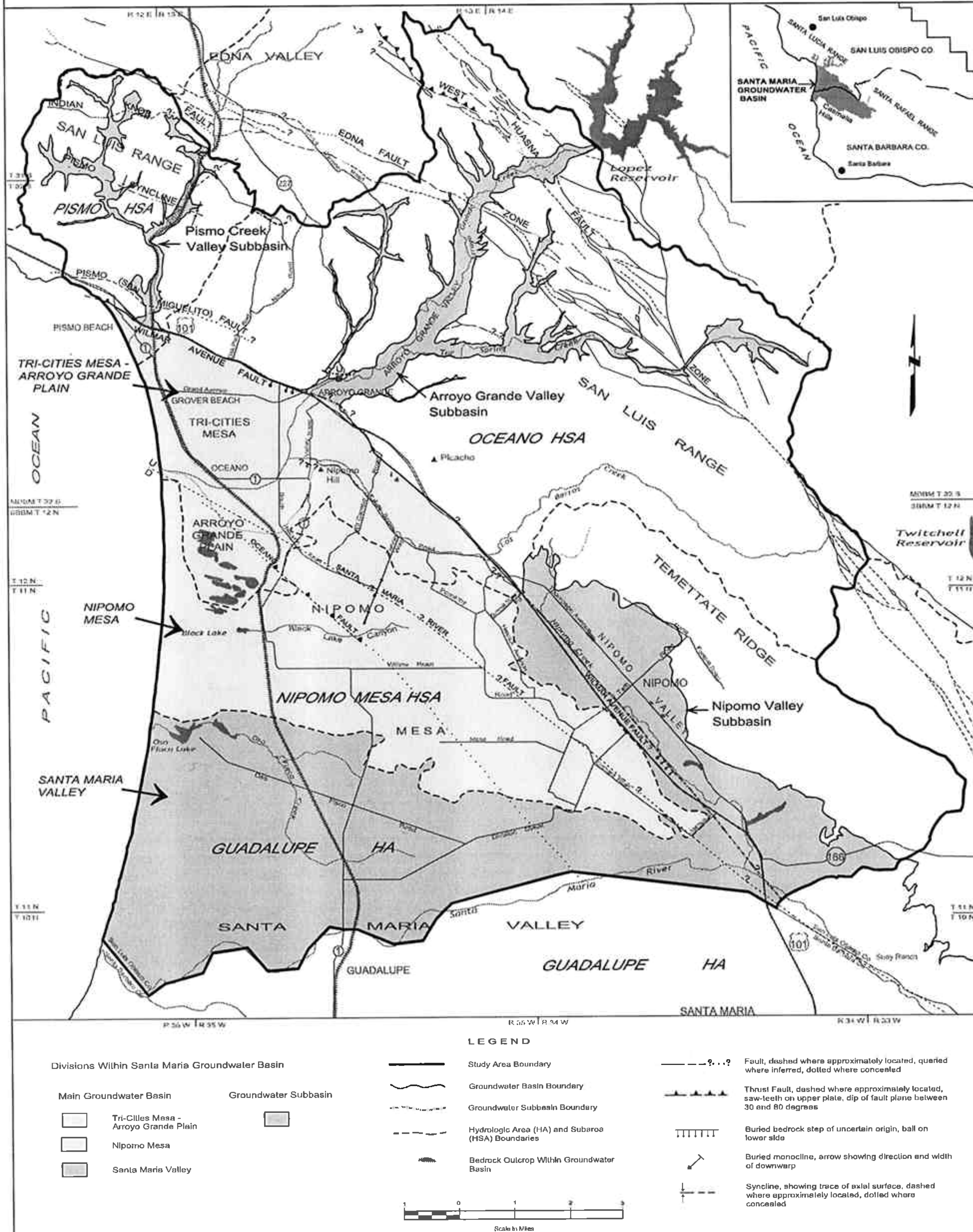
Water conservation Reduction in applied water resulting from more efficient use of water such as implementation of urban best management practices or agricultural efficient water management practices. The extent to which these actions actually create a savings in water supply depends on how they affect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

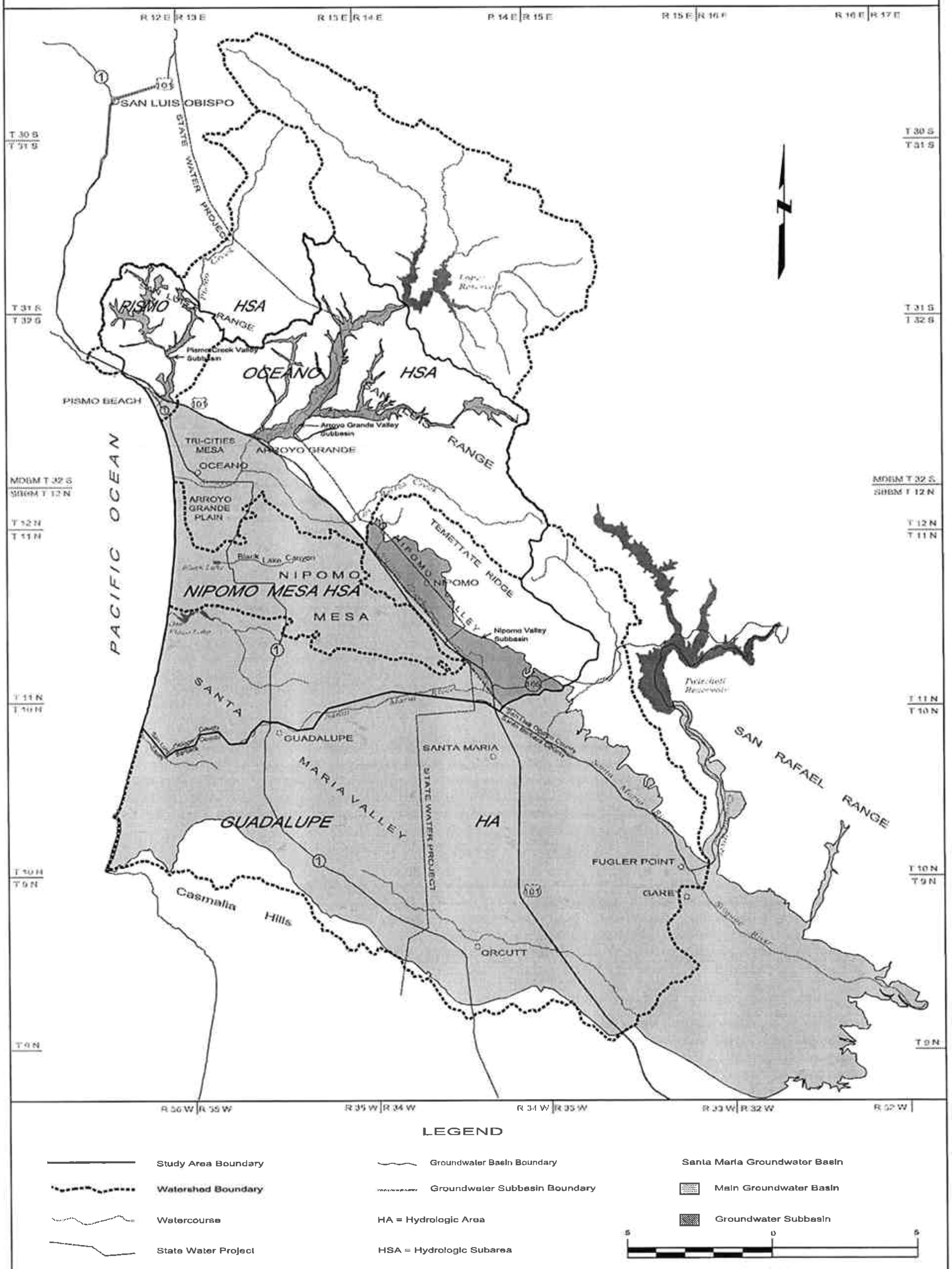
Zone of aeration A subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity, and containing air or gases generally under atmospheric pressure.

PLATE ES1 - ARROYO GRANDE - NIPOMO MESA STUDY AREA



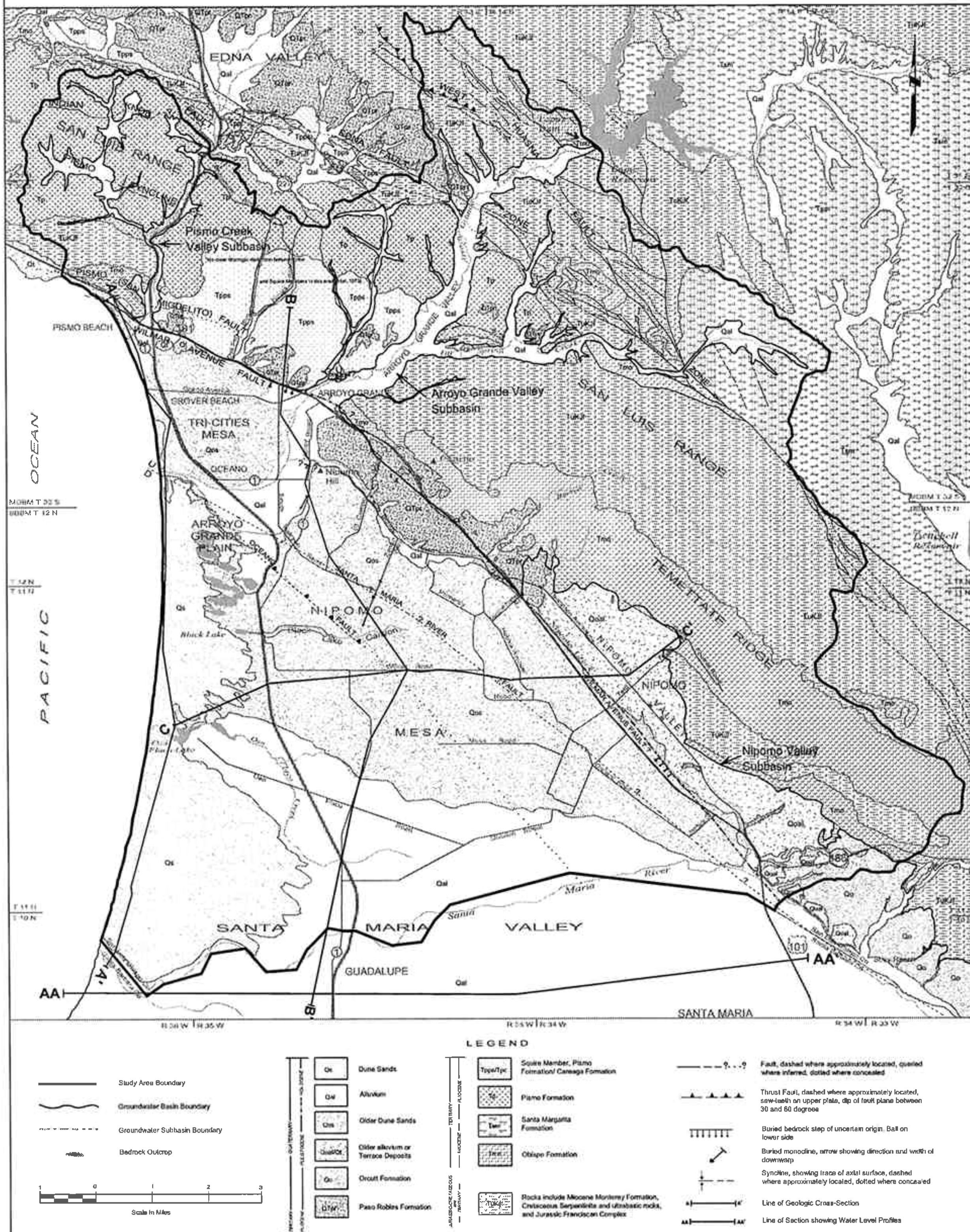
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 1 - STUDY AREA AND WATERSHEDS

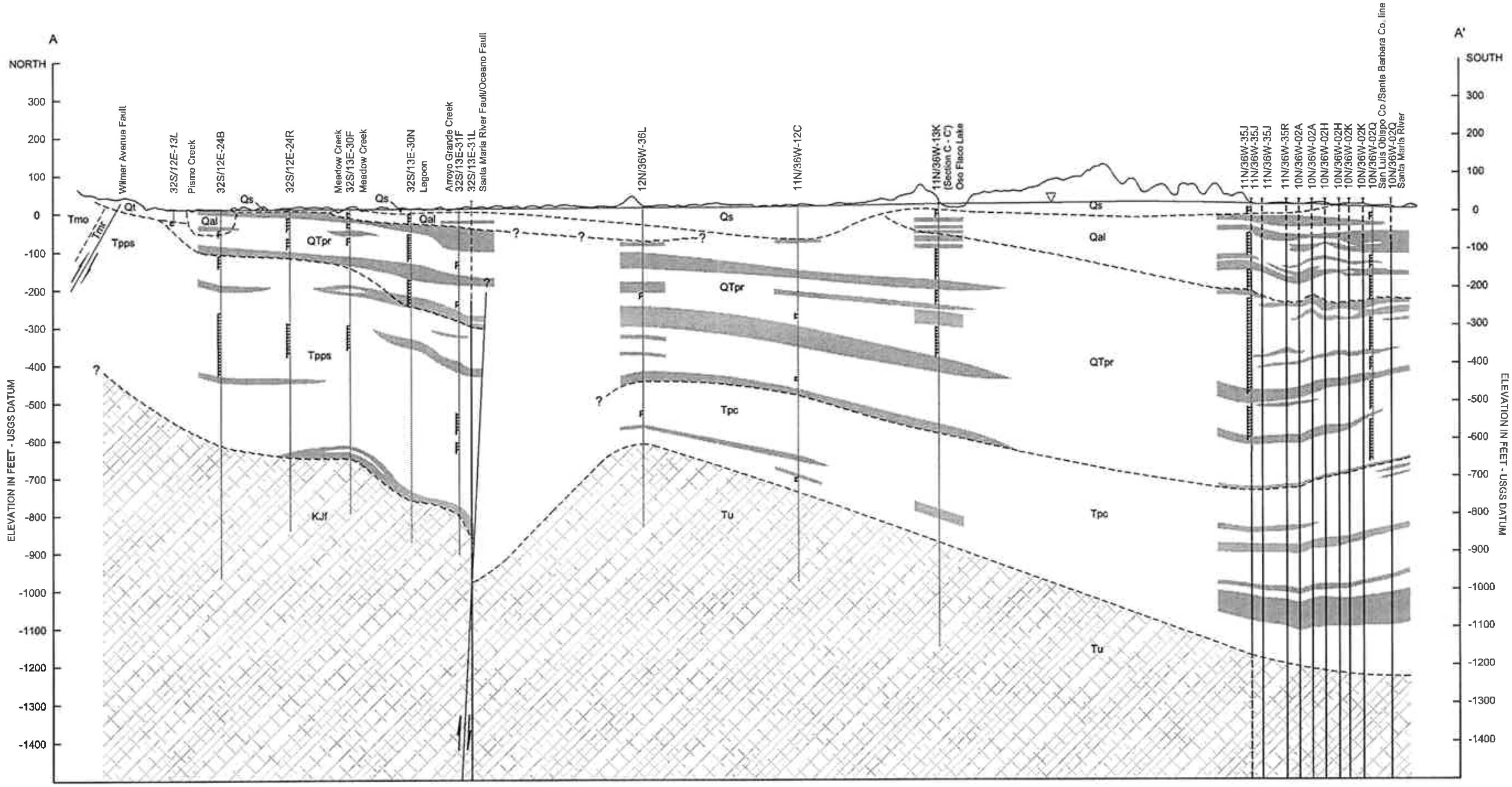


Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 2 - GENERALIZED GEOLOGY OF THE ARROYO GRANDE - NIPOMO MESA AREA



Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002



EXPLANATION

Formation and Symbol

Qs	Dune Sand
Qal	Alluvial Deposits
Qt	Terrace Deposits
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tmo	Obispo Formation
Tmr	Rincon Formation
Tu	Undifferentiated Tertiary Deposits
KJf	Franciscan Complex

12N/36W-36L — Water well with electric and geologic log

32S/12E-13L — Water well with geologic log

10N/36W-02G — Oil well with electric log, dashed above record

Hydrogeologic Unit

- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

- Perforated interval
- Fault, arrows indicate relative vertical movement
- Unconformity
- Contact
- 1995 Groundwater Elevation

Note: References include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

WATER RESOURCES OF THE

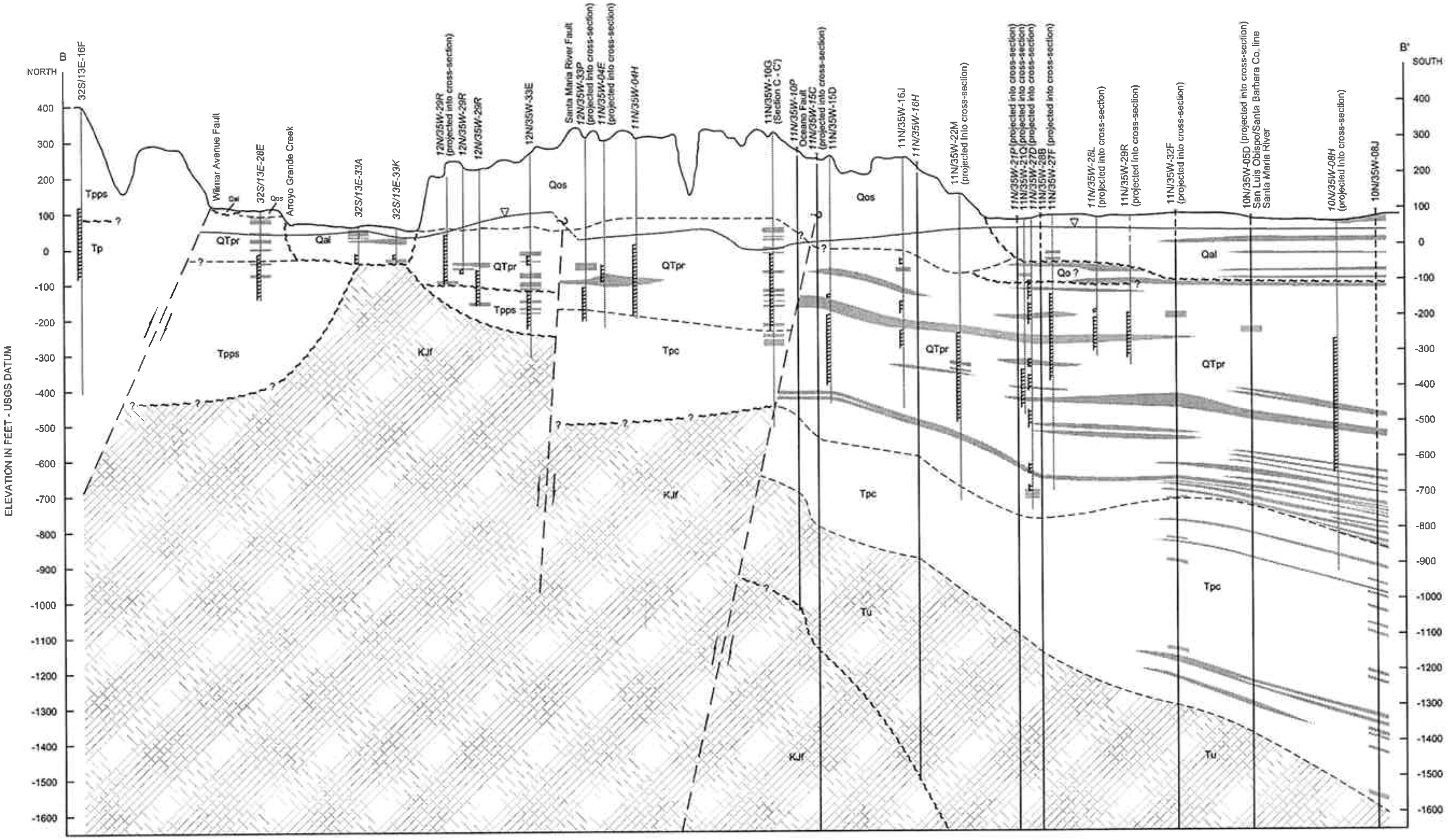
ARROYO GRANDE - NIPOMO MESA AREA

◇◇◇

PLATE 3

GEOLOGIC SECTION A - A'

Department of Water Resources, Southern District, 2002



EXPLANATION

Formation and Symbol

Qal	Alluvial Deposits
Qos	Older Dune Sand
Qo	Orcutt Formation
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tp	Pismo Formation
Tu	Undifferentiated Tertiary Deposits
KJf	Franciscan Complex

12N/36W-36L — Water well with electric and geologic log

32S/12E-13L — Water well with geologic log

10N/36W-02G — Oil well with electric log, dashed above record

11N/35W-10P — Oil well with geologic log, dashed above record

Hydrogeologic Unit

- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

Perforated Interval

Fault, arrows indicate relative vertical movement

Unconformity

Contact

1995 Groundwater Elevation

Note: References Include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

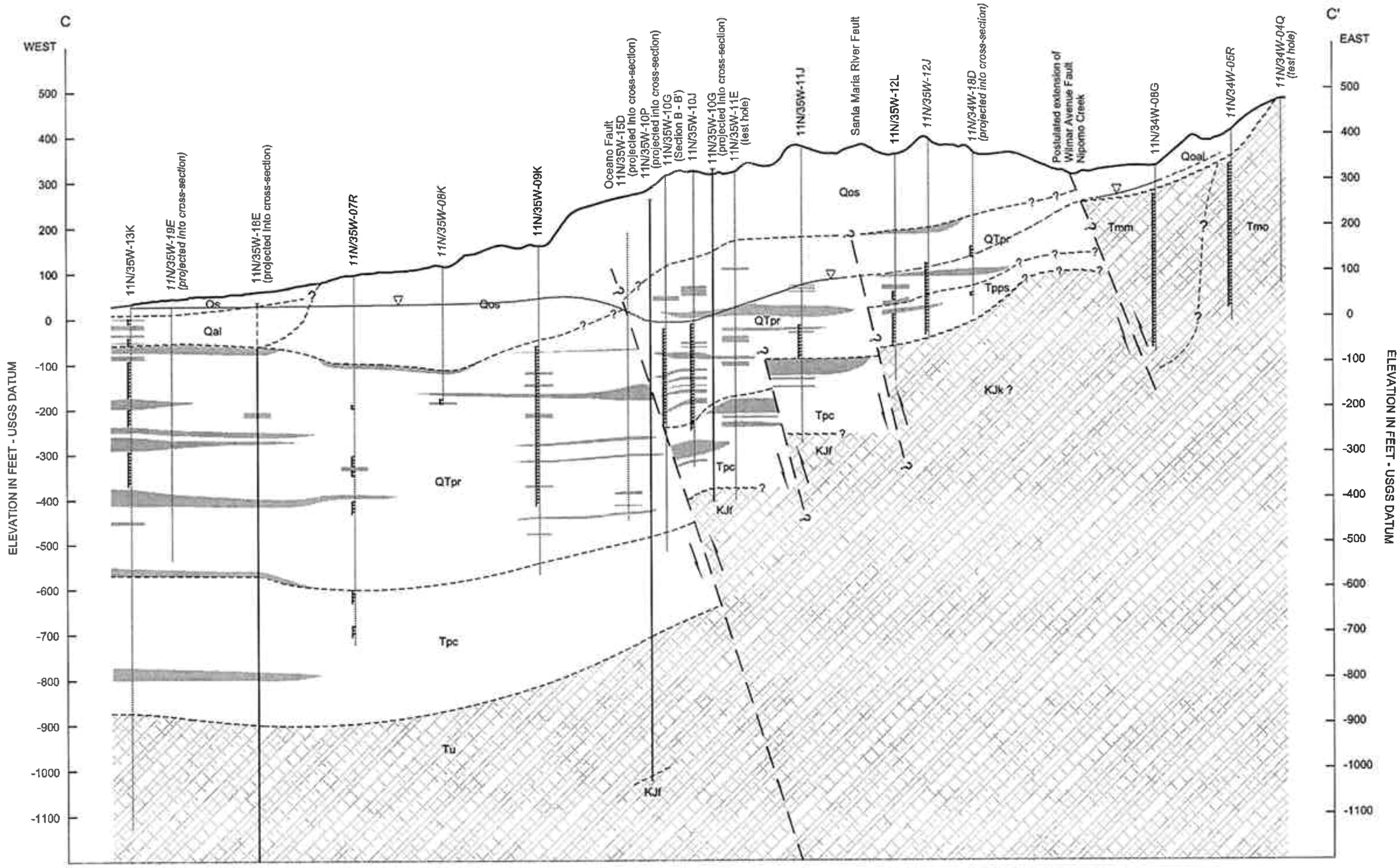
WATER RESOURCES OF THE ARROYO GRANDE - NIPOMO MESA AREA

◇◇◇

PLATE 4

GEOLOGIC SECTION B - B'

Department of Water Resources, Southern District, 2002



EXPLANATION

Formation and Symbol
- Qs — Dune Sand
- Qal — Alluvial Deposits
- Qos — Older Dune Sand
- Qoal — Older Alluvial Deposits
- QTpr — Paso Robles Formation
- Tpc — Careaga Formation
- Tpps — Squire Member, Pismo Formation
- Tmm — Monterey Formation
- Tmo — Obispo Formation
- Tu — Undifferentiated Tertiary Deposits
- KJk — Knoxville Formation
- KJf — Franciscan Complex

- 12N/36W-36L — Water well with electric and geologic log
- 32S/12E-13L — Water well with geologic log
- 10N/36W-02G — Oil well with electric log, dashed above record
- 11N/35W-10P — Oil well with geologic log, dashed above record

Hydrogeologic Unit
- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

- Perforated Interval
- Fault, arrows indicate relative vertical movement
- Unconformity
- Contact
- 1995 Groundwater Elevation

Note: References include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

WATER RESOURCES OF THE

ARROYO GRANDE - NIPOMO MESA AREA

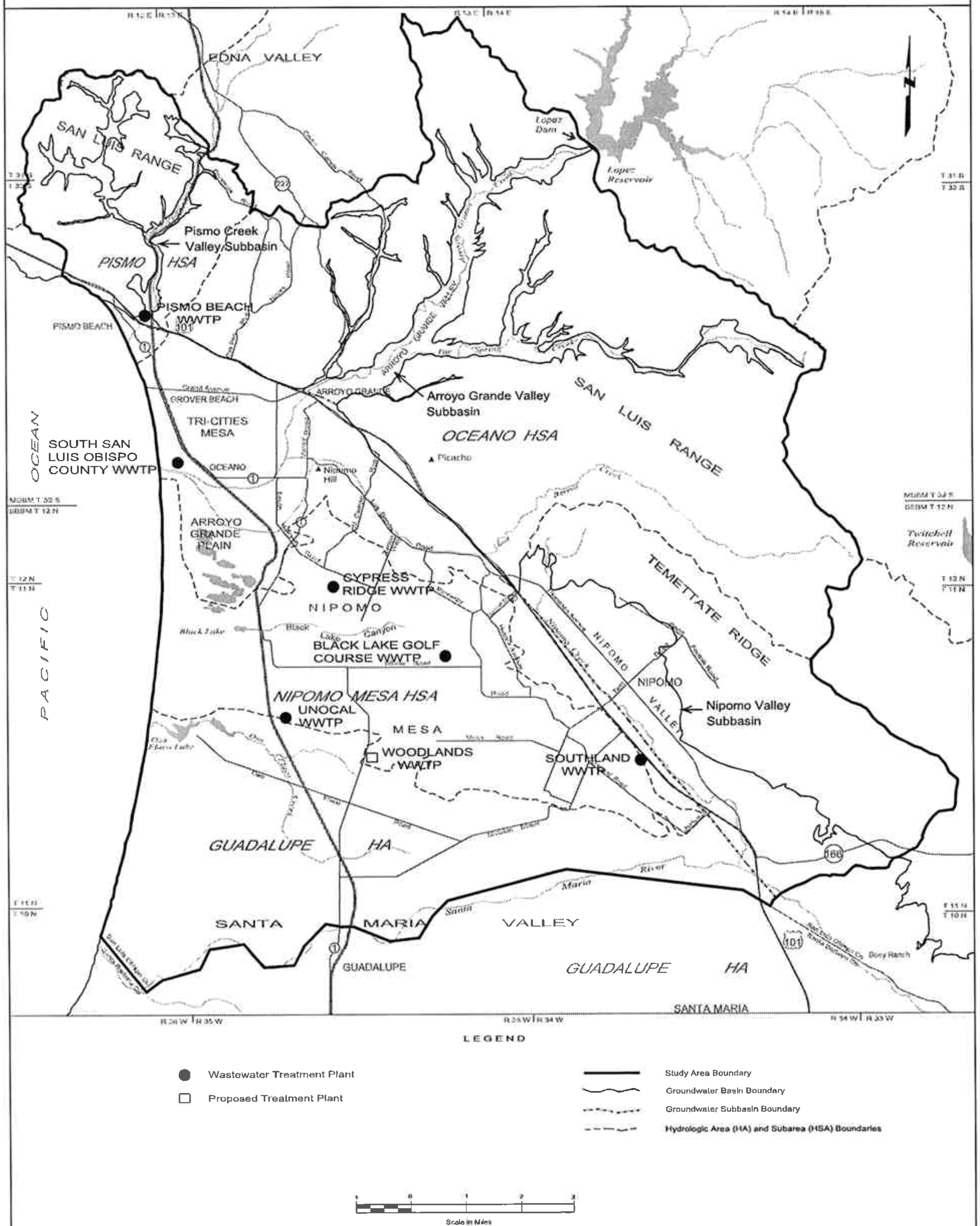
◇◇◇

PLATE 5

GEOLOGIC SECTION C - C'

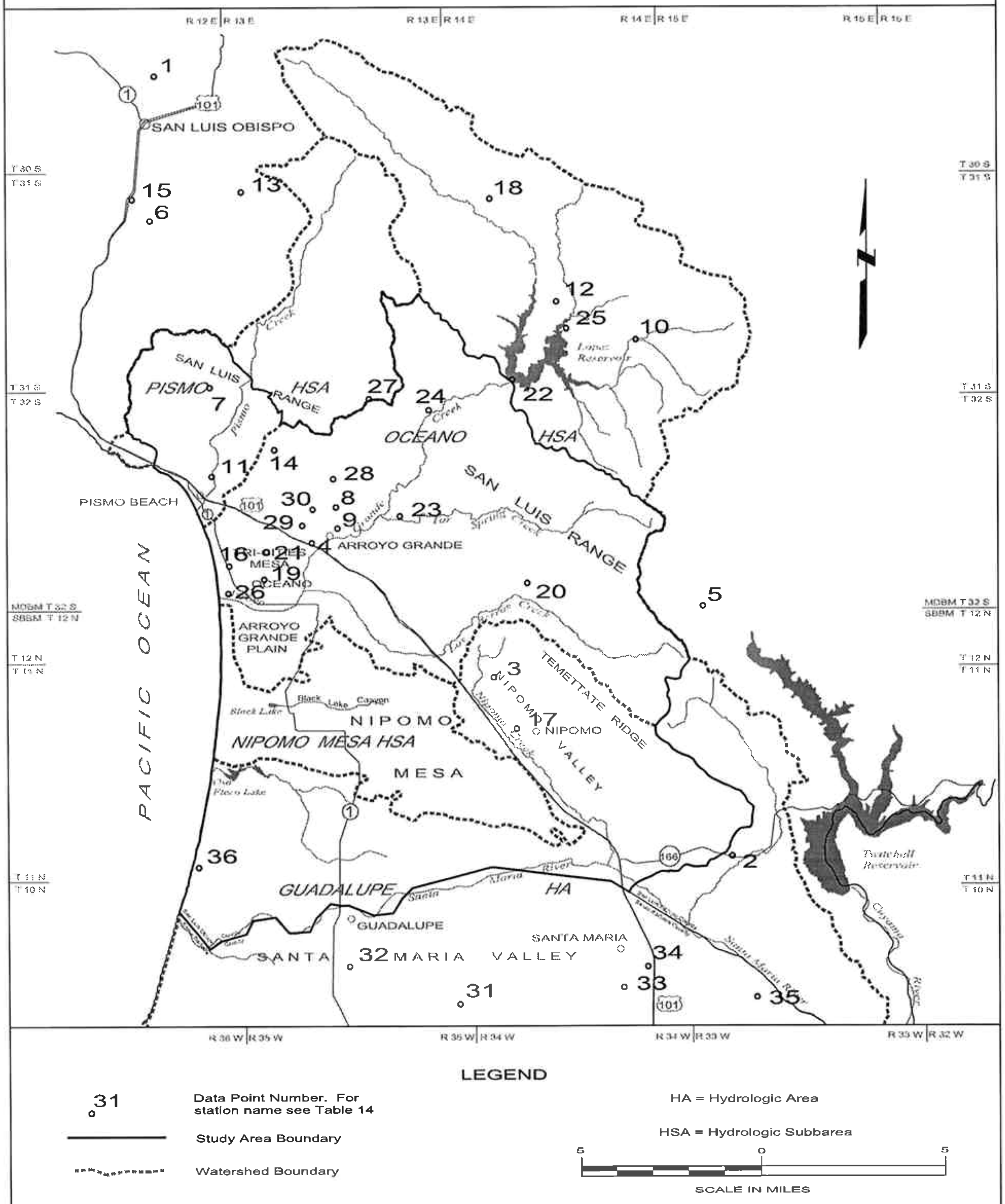
Department of Water Resources, Southern District, 2002

PLATE 6 - WASTEWATER TREATMENT PLANT LOCATIONS



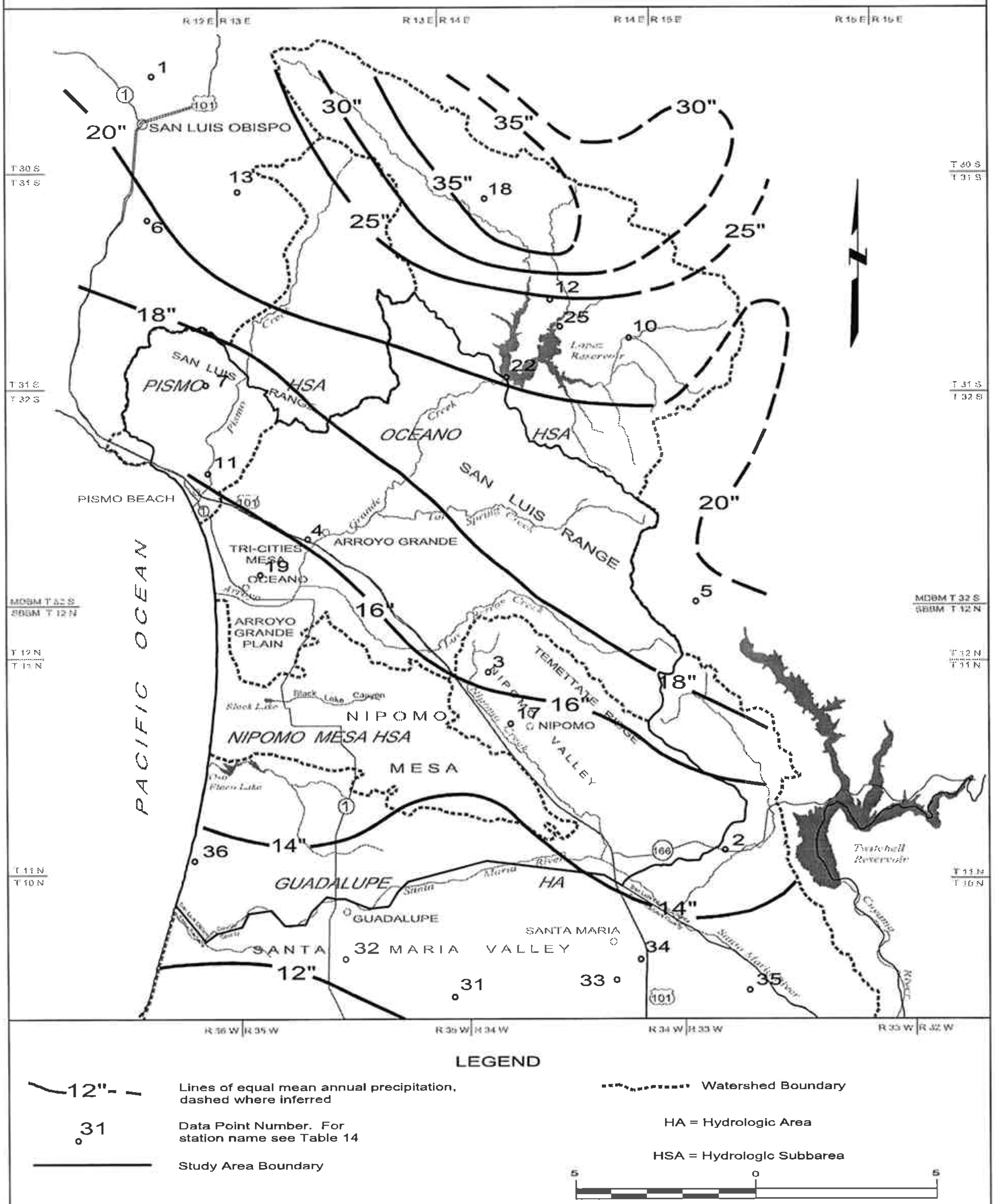
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 7 - PRECIPITATION STATION LOCATIONS



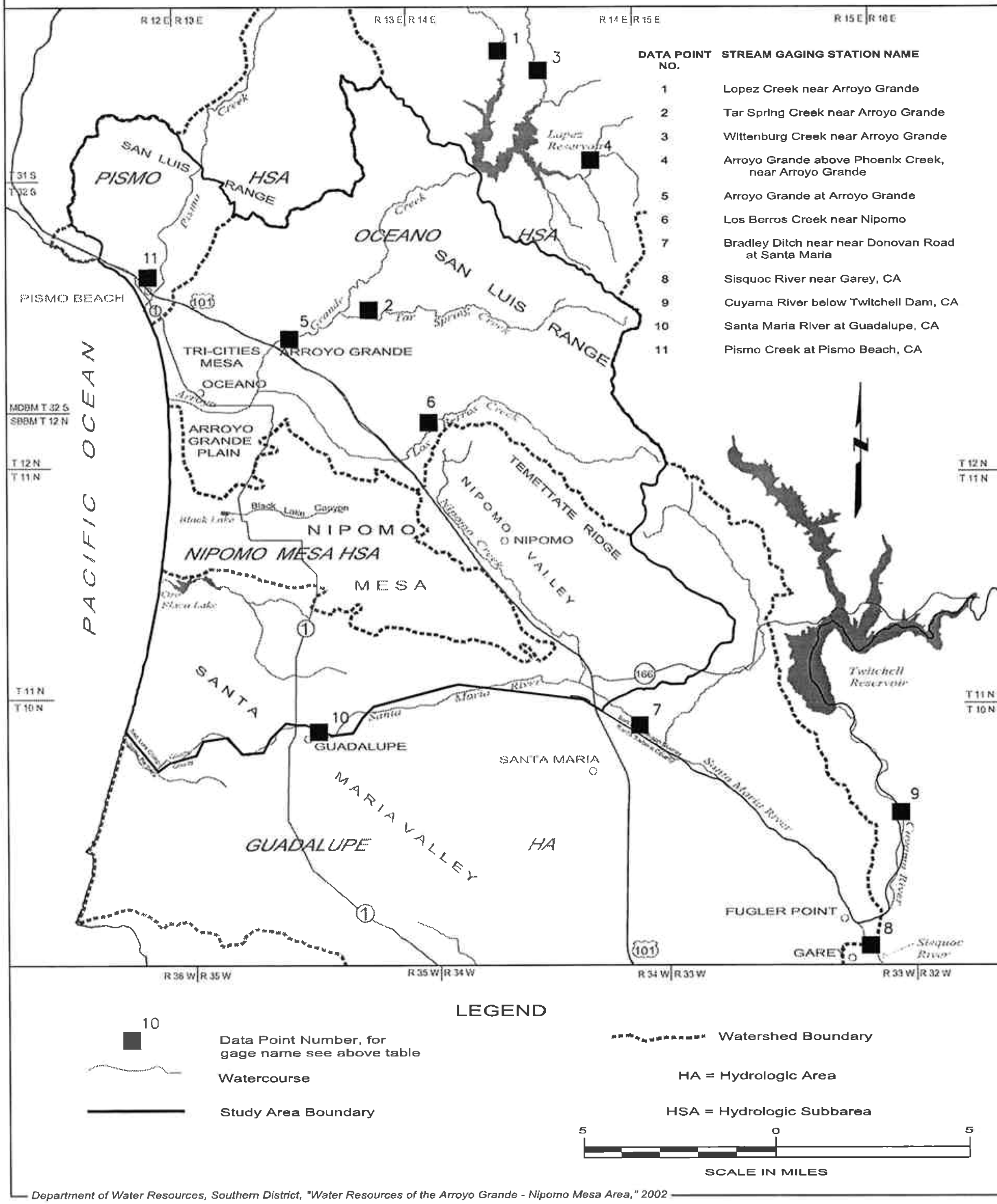
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 8 - LINES OF EQUAL MEAN ANNUAL PRECIPITATION, 1870 THROUGH 1995



Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

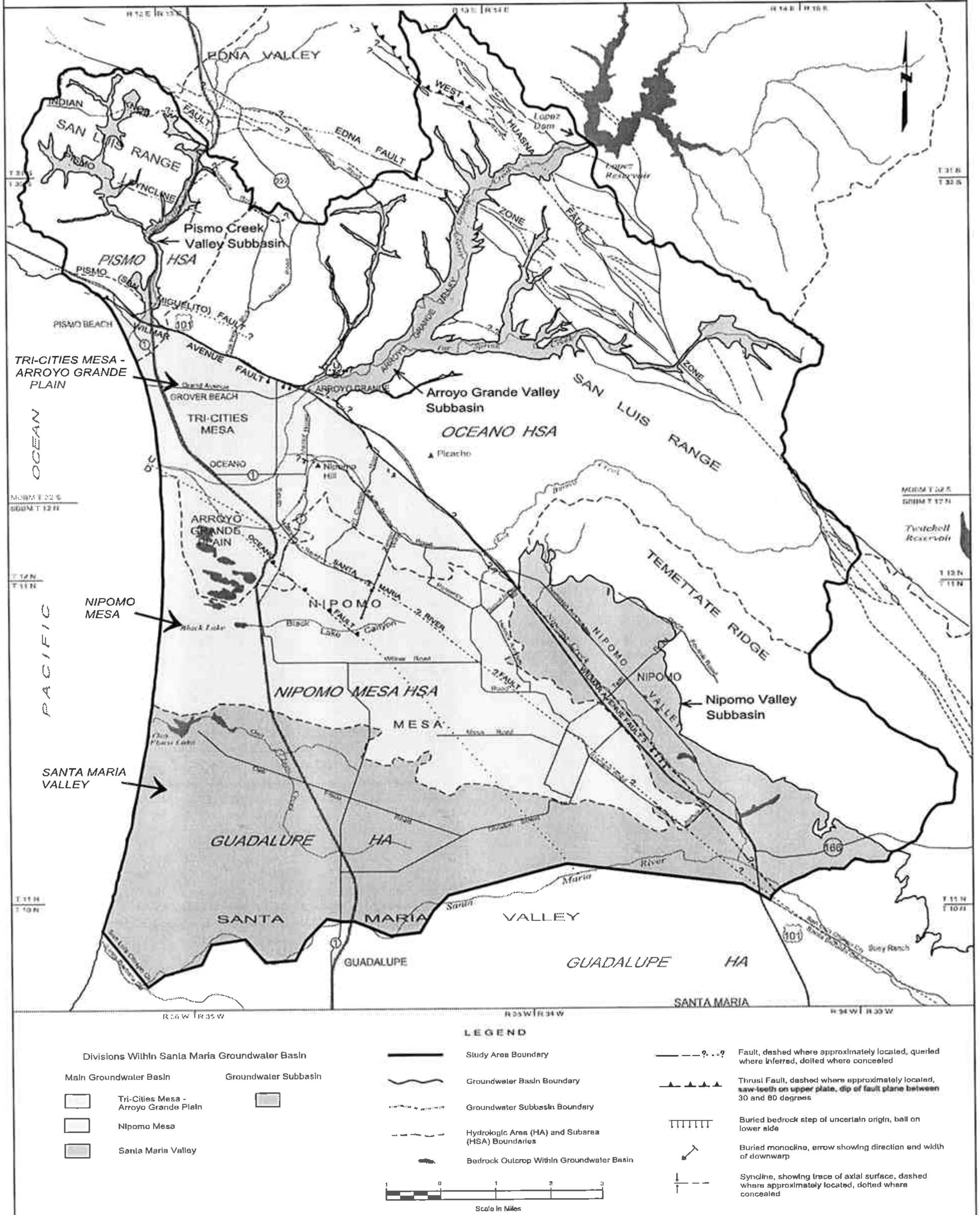
PLATE 9 - STREAM GAGE LOCATIONS



DATA POINT NO.	STREAM GAGING STATION NAME
1	Lopez Creek near Arroyo Grande
2	Tar Spring Creek near Arroyo Grande
3	Wittenburg Creek near Arroyo Grande
4	Arroyo Grande above Phoenix Creek, near Arroyo Grande
5	Arroyo Grande at Arroyo Grande
6	Los Berros Creek near Nipomo
7	Bradley Ditch near near Donovan Road at Santa Maria
8	Sisquoc River near Garey, CA
9	Cuyama River below Twitchell Dam, CA
10	Santa Maria River at Guadalupe, CA
11	Pismo Creek at Pismo Beach, CA

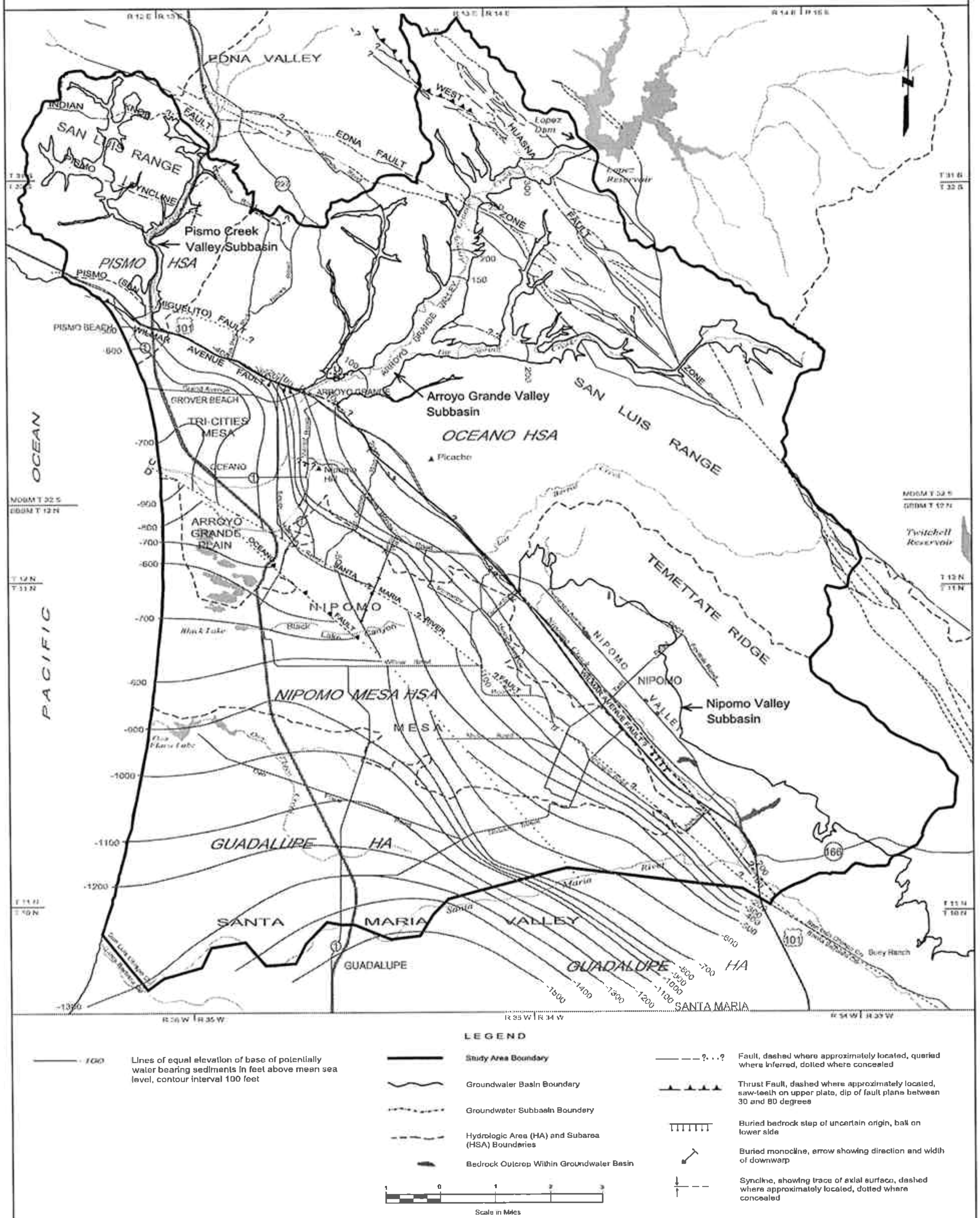
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 10 - SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY



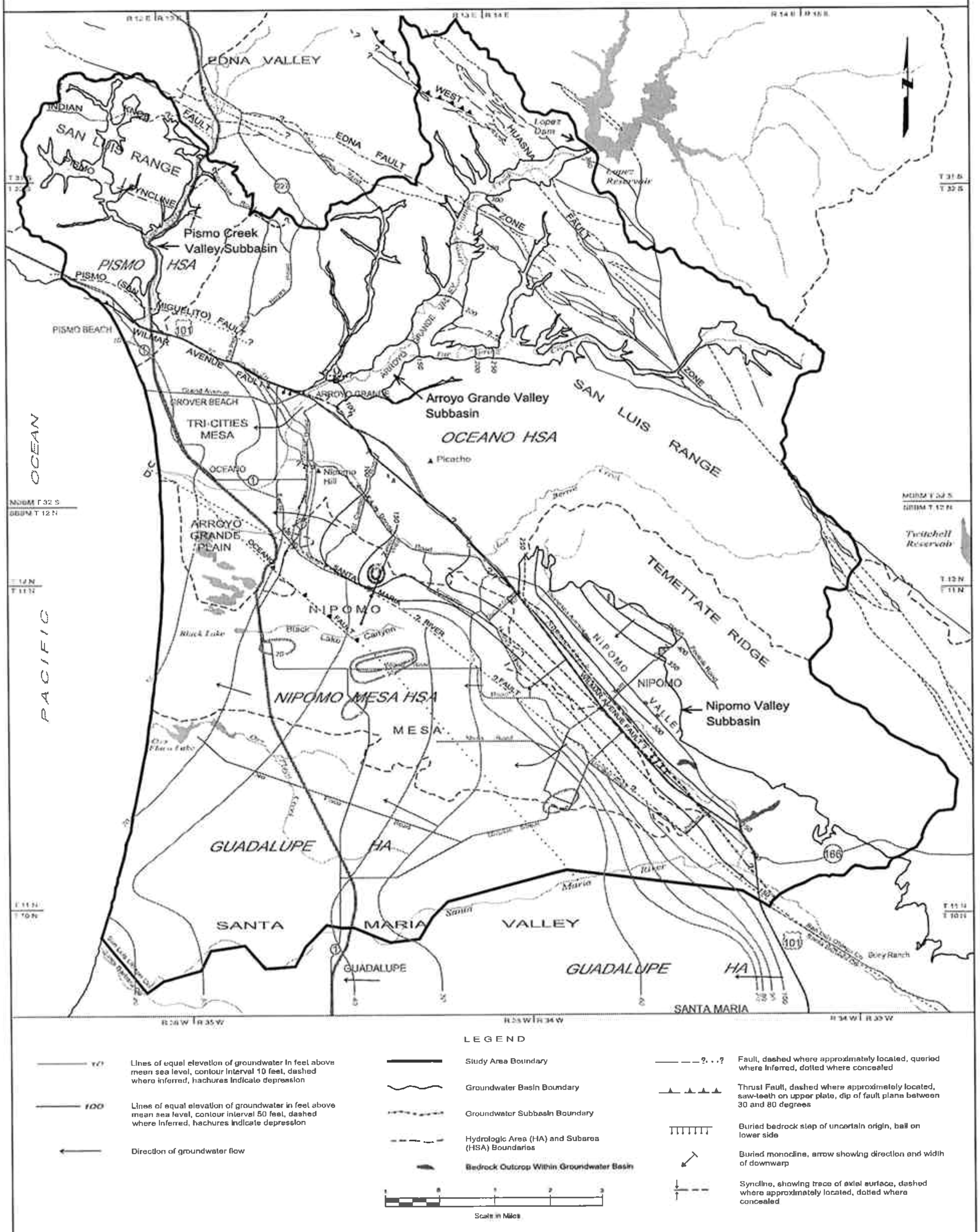
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 11 - BASE OF POTENTIALLY WATER-BEARING SEDIMENTS



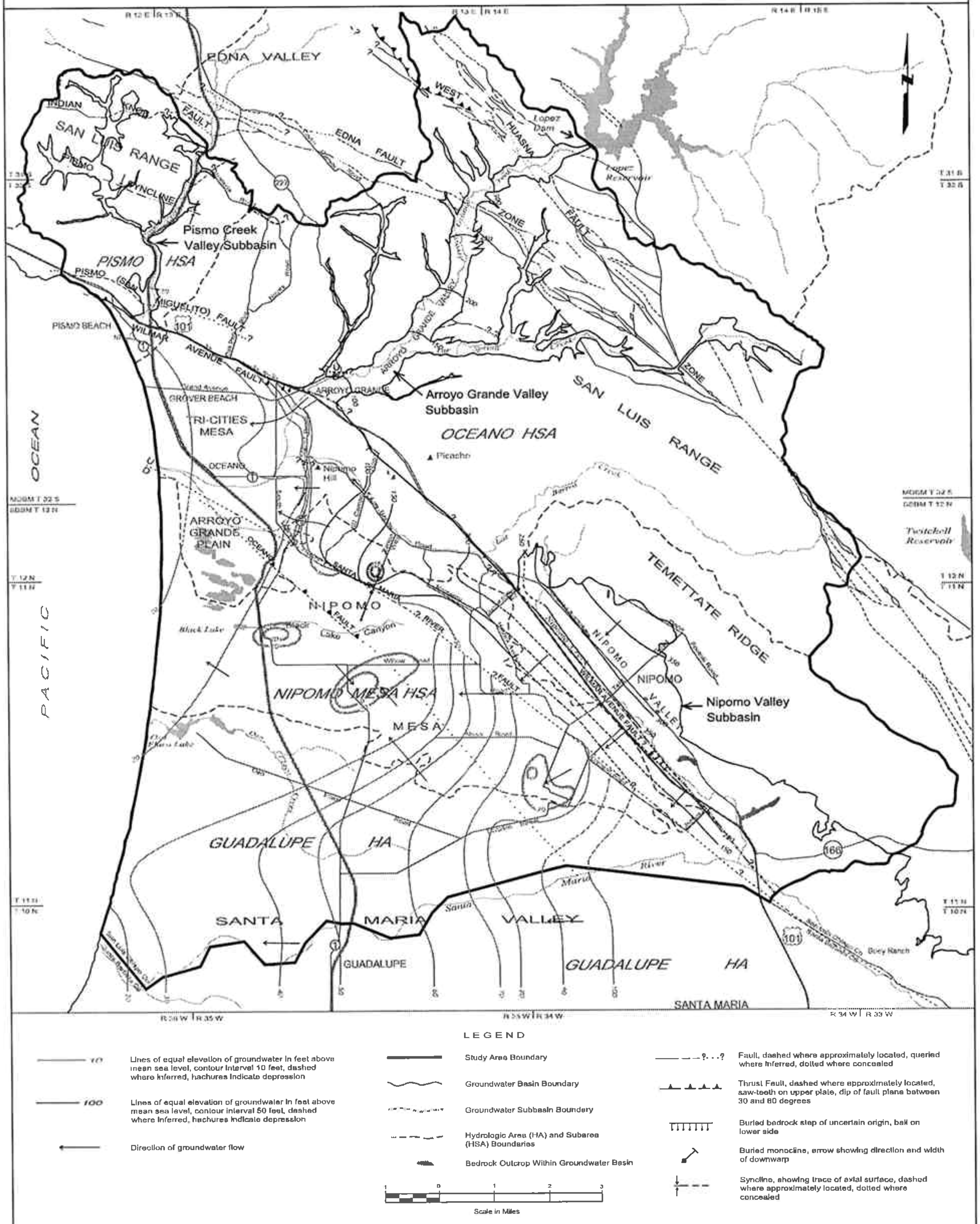
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 12 - SPRING 1975 GROUNDWATER ELEVATION CONTOURS



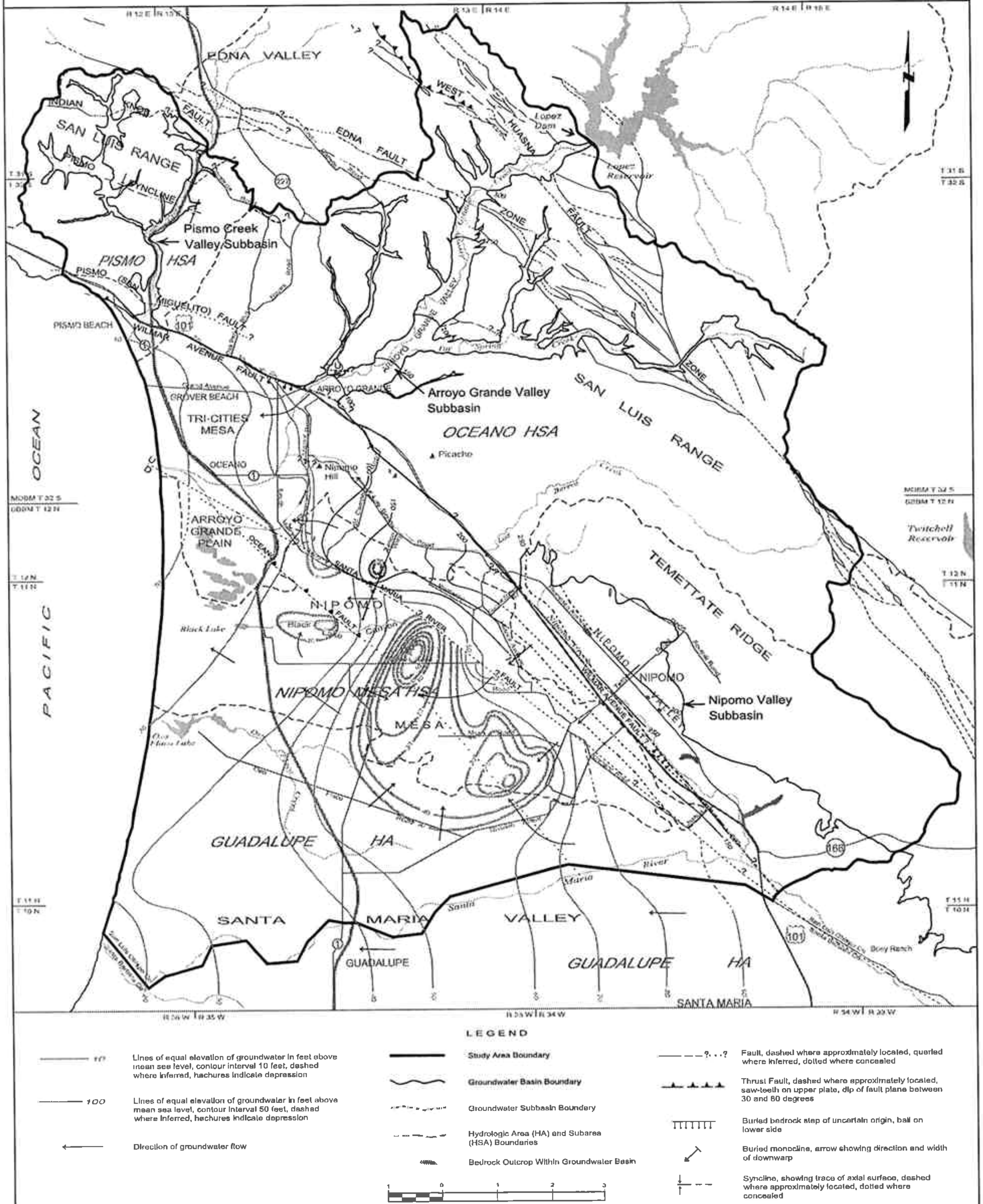
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 13 - SPRING 1985 GROUNDWATER ELEVATION CONTOURS



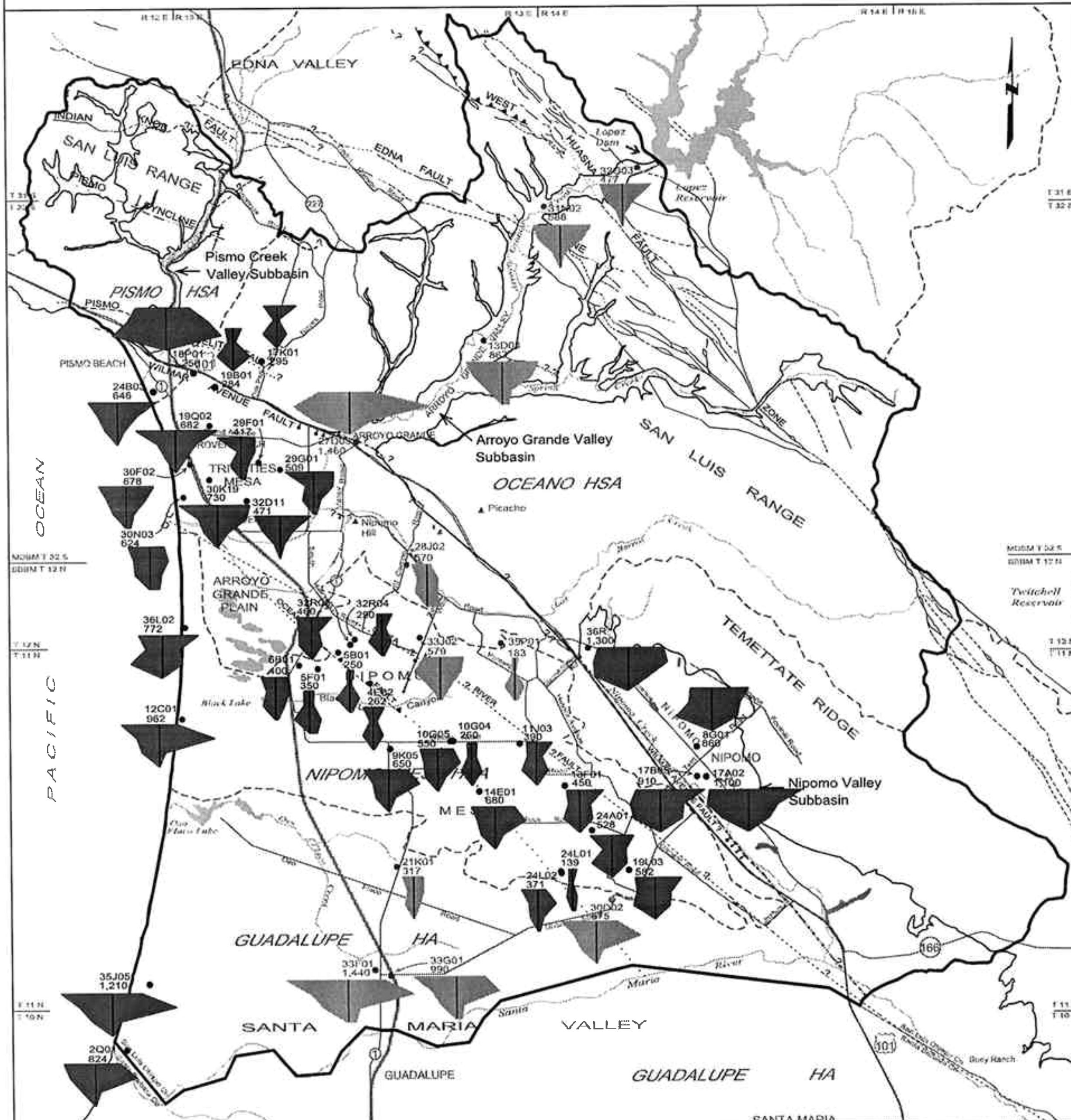
Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 14 - SPRING 1995 GROUNDWATER ELEVATION CONTOURS



Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 15 - AREAL REPRESENTATION OF WATER QUALITY FROM WELLS



LEGEND

Key to Stiff Diagrams

10J02 State Well Number
510 TDS concentration in mg/L

Cations: Calcium, Magnesium, Sodium, Potassium
Anions: Bicarbonate, Sulfate, Chloride, Nitrate

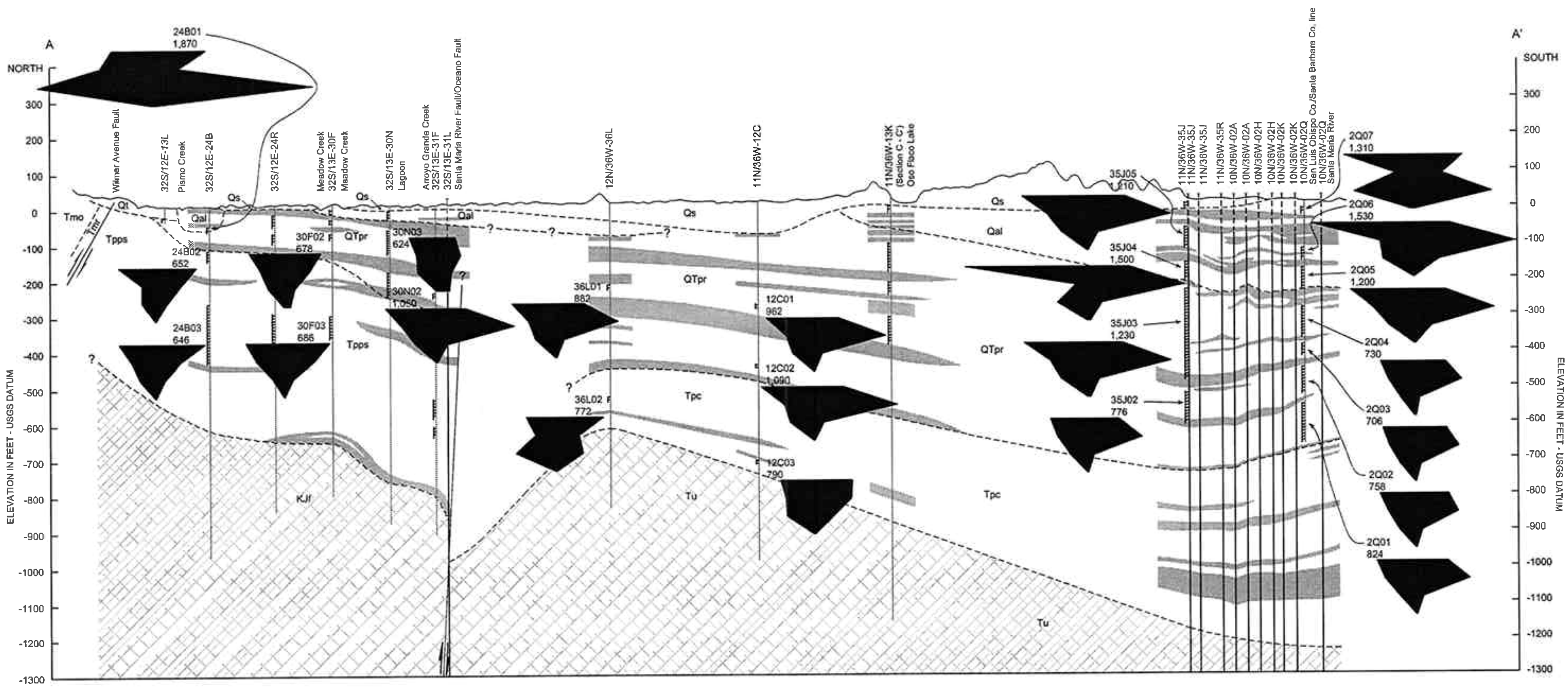
Cations 4 2 0 2 4 Anions
Concentrations in milliequivalents per liter

Note: Diagrams in blue represent data from 1992 to 2000. Diagrams in gray represent data from the 1980s. The shape of the Stiff diagram indicates chemical composition. Differences in diagram configuration reflect differences in chemical composition. The size of the diagram is an indication of Total Dissolved Solids content.

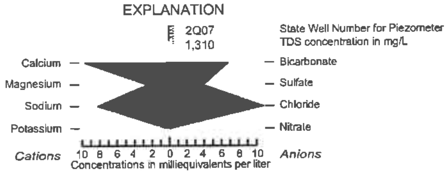
- Study Area Boundary
- Groundwater Basin Boundary
- Groundwater Subbasin Boundary
- Hydrologic Area (HA) and Subarea (HSA) Boundaries
- Bedrock Outcrop Within Groundwater Basin
- Fault, dashed where approximately located, queried where inferred, dotted where concealed
- Thrust Fault, dashed where approximately located, saw-teeth on upper plate, dip of fault plane between 30 and 80 degrees
- Buried bedrock step of uncertain origin, ball on lower side
- Buried monocline, arrow showing direction and width of downwarp
- Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed

1 0 1 2 3
Scale in Miles

Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002



EXPLANATION



Groundwater sampled in March 1996. The shape of the Stiff diagram indicates the chemical composition. Differences in diagram configuration reflect differences in chemical composition. The size of the diagram is an indication of Total Dissolved Solids concentration.

Formation and Symbol

Qs	Dune Sand
Qal	Alluvial Deposits
Qt	Terrace Deposits
QTpr	Paso Robles Formation
Tpc	Careaga Formation
Tpps	Squire Member, Pismo Formation
Tmo	Obispo Formation
Tmr	Rincon Formation
Tu	Undifferentiated Tertiary Deposits
KJf	Franciscan Complex

12N/36W-36L	Water well with electric and geologic log
32S/12E-13L	Water well with geologic log
10N/36W-02G	Oil well with electric log, dashed above record

Hydrogeologic Unit

- Unconsolidated to weakly cemented clayey silt to silty clay with minor sand and gravel
- Unconsolidated to weakly cemented sand, gravel, silt, sandstone with minor clay and silty clay
- Bedrock

- Perforated interval
- Fault, arrows indicate relative vertical movement
- Unconformity
- Contact

Note: References include: Department of Water Resources, 1970; Buchanan-Banks et al., 1978; Hall, 1981; Nitchman, 1988; Hanson et al., 1994; Lettis et al., 1994.

Location of geologic section shown on Plate 2

Vertical scale 20 times horizontal scale

Horizontal scale in feet

4000 0 4000

WATER RESOURCES OF THE

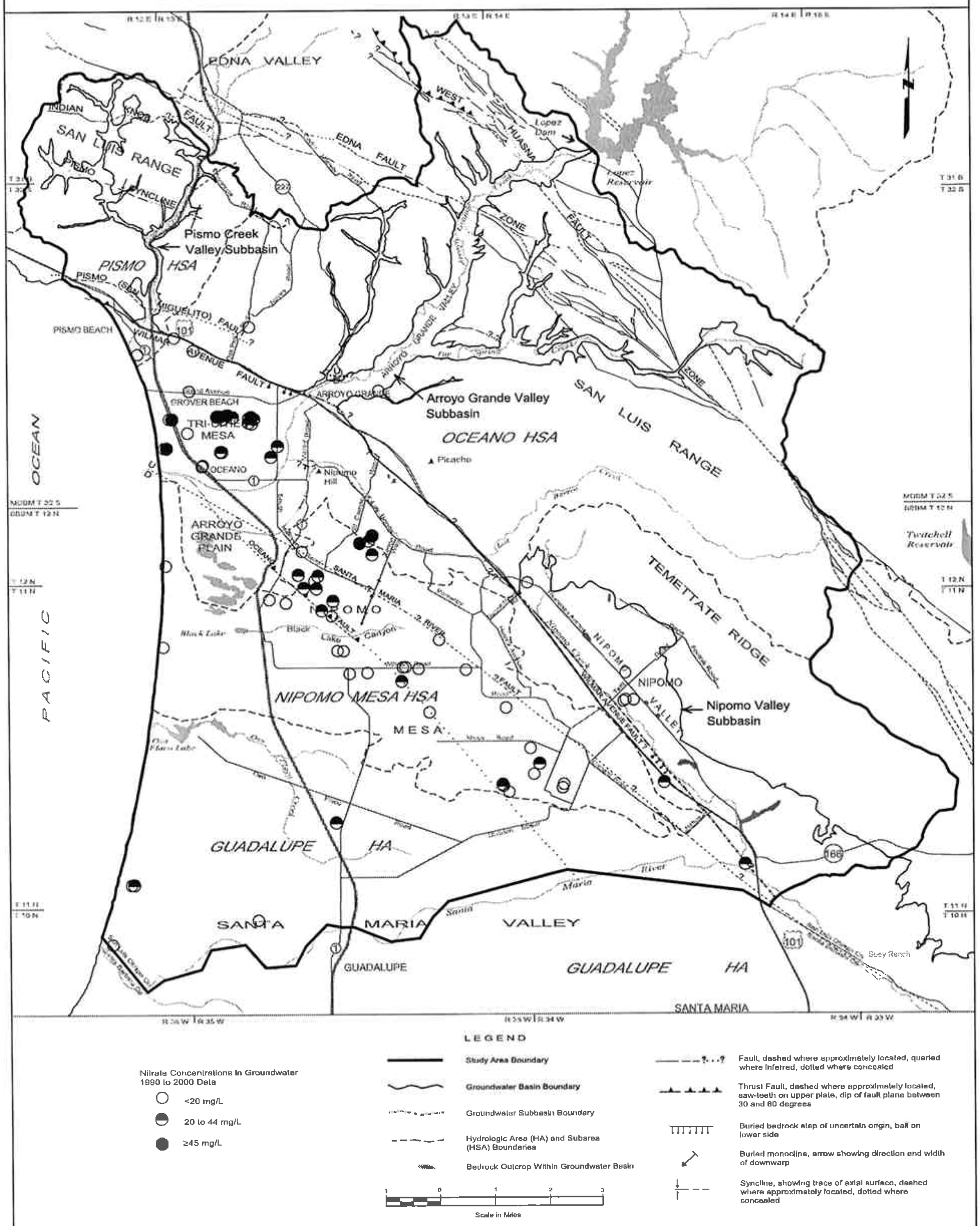
ARROYO GRANDE - NIPOMO MESA AREA

◇◇◇

PLATE 16 - VERTICAL VARIATION IN GROUNDWATER QUALITY

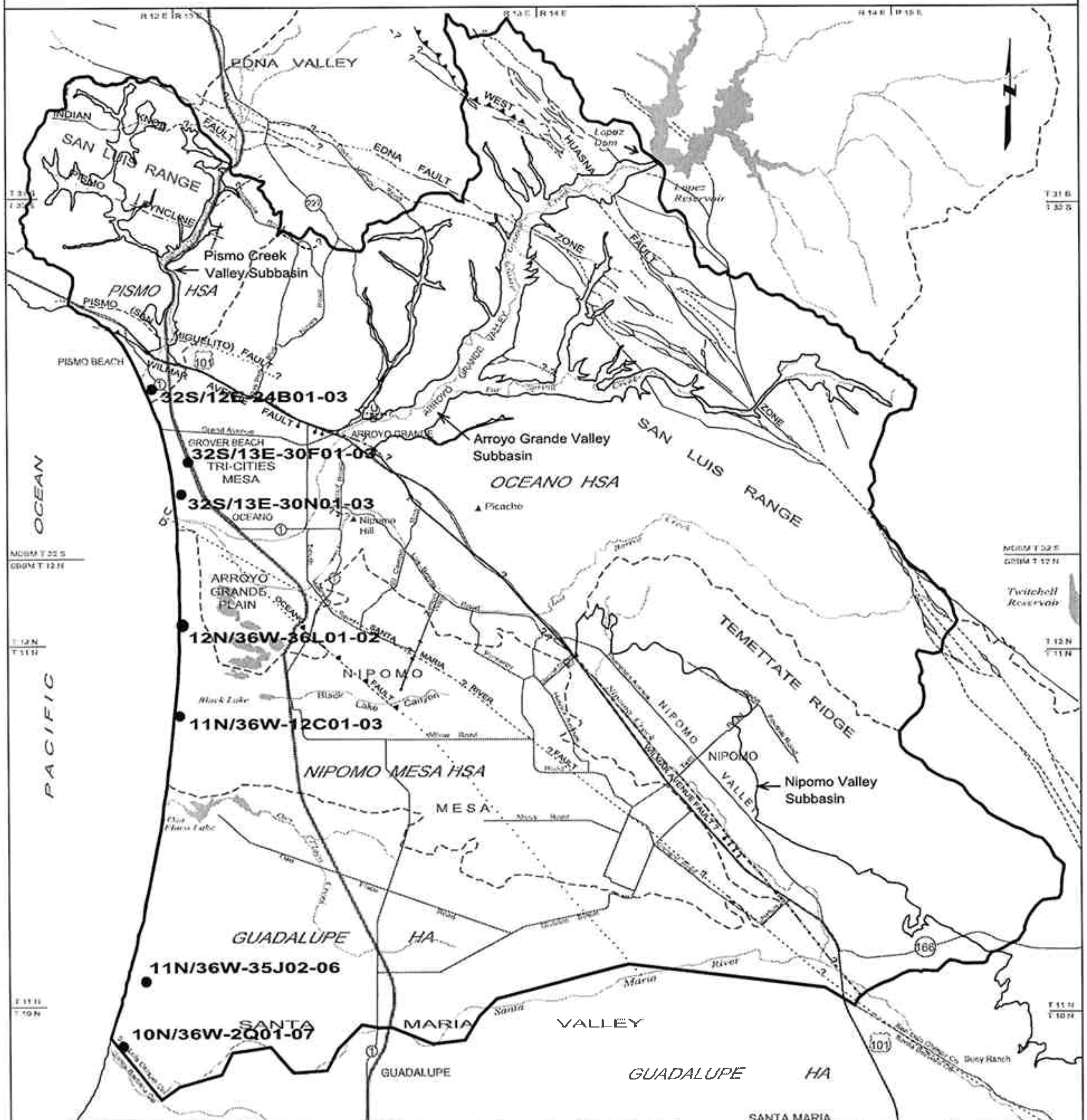
Department of Water Resources, Southern District, 2002

PLATE 17 - NITRATE CONCENTRATIONS IN GROUNDWATER



Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 18 - SEA WATER INTRUSION MONITORING WELLS



Note: Each sea water intrusion monitoring well contains two or more piezometers

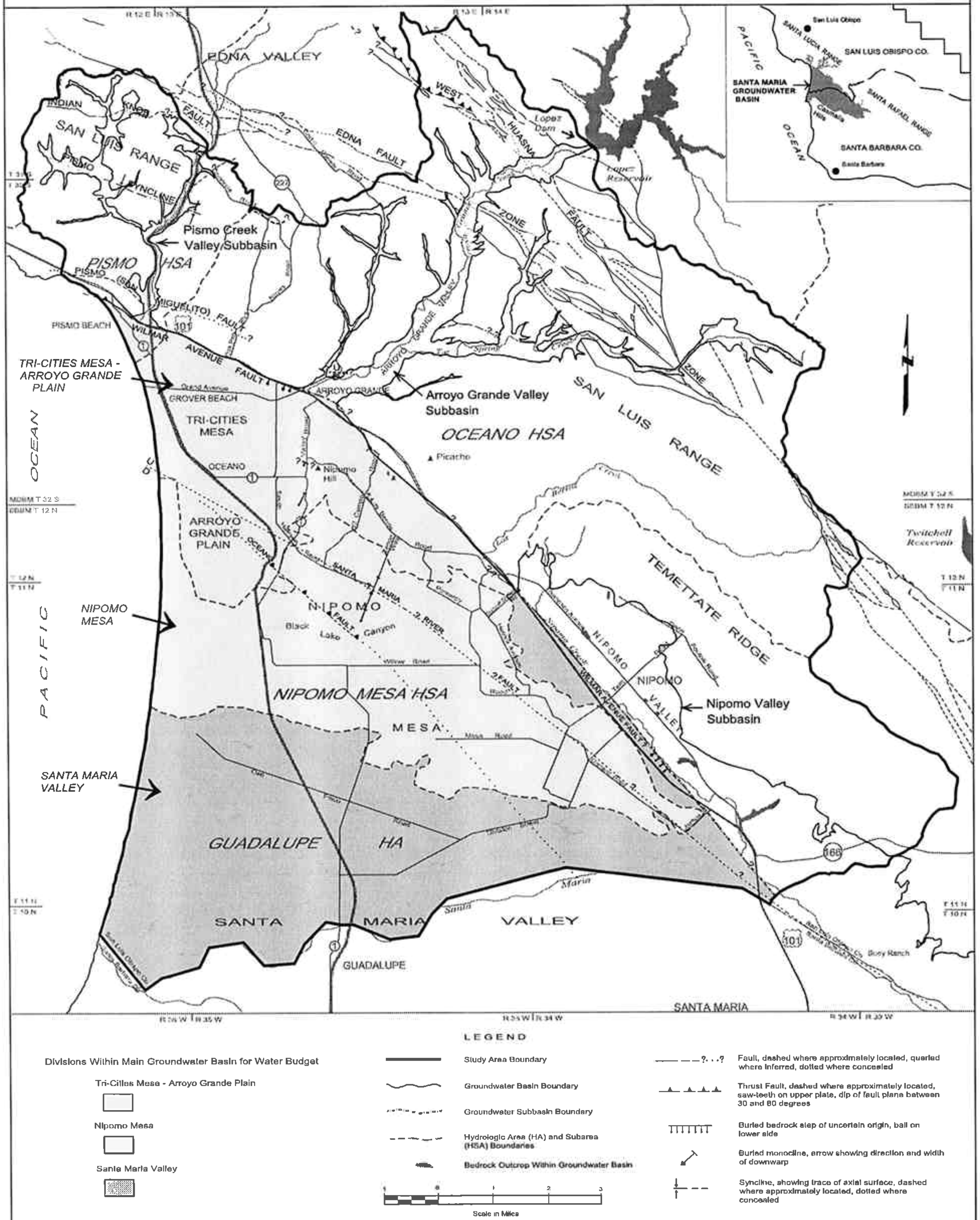
LEGEND

- Study Area Boundary
- Groundwater Basin Boundary
- Groundwater Subbasin Boundary
- Hydrologic Area (HA) and Subarea (HSA) Boundaries
- Bedrock Outcrop Within Groundwater Basin
- 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 80 degrees
- Buried bedrock step of uncertain origin, ball on lower side
- Buried monocline, arrow showing direction and width of downwarp
- Syncline, showing trace of axial surface, dashed where approximately located, dotted where concealed

Scale in Miles

Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002

PLATE 19 - DIVISIONS WITHIN MAIN SANTA MARIA GROUNDWATER BASIN FOR WATER BUDGET



Department of Water Resources, Southern District, "Water Resources of the Arroyo Grande - Nipomo Mesa Area," 2002