GLENN A. BRITTON

STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 63-3

Sea-Water Intrusion:

PISMO-GUADALUPE AREA

FEBRUARY 1970

San Luis Obispo County Flood Control
and Water Conservation District

NORMAN B. LIVERMORE, JR.
Secretary for Resources
The Resources Agency

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

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Secretary for Resources	*Governor*	*Director*
The Resources Agency	State of California	Department of Water Resources

FOREWORD

This is a report on an investigation authorized under the California Water Code, Division 1, Chapter 2, Section 229. Purpose of this authorization is to "investigate conditions of the quality of all waters within the State, including saline waters, coastal and inland, as related to all sources of pollution of whatever nature...."

This report is one of a series designed to determine the extent and nature of salt water intrusion into coastal aquifers. It grew out of a request from the San Luis Obispo County Flood Control and Water Conservation District to study the causes and to suggest possible corrective measures for saline water produced by certain wells within the coastal portions of the county.

For their assistance in this investigation, grateful acknowledgment is made to the San Luis Obispo County Flood Control and Water Conservation District, Union Oil Company of California, United States Geological Survey, other agencies of the Federal Government and the State of California, and cities, counties, public water districts, private companies, and individuals.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
December 9, 1969

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ABSTRACT

Several wells in the shallow aquifers near the ocean in the Pismo-Guadalupe area of San Luis Obispo County have been found to be producing water containing increasing concentrations of chlorides; sea-water intrusion was suspected. However, investigation disclosed that the sources were the natural salinity of the geologic environment, salt concentration by evapotranspiration, and downward percolation of sea water entering tidal channels at times of extremely high tide. Although evidence of sea-water intrusion was found in three deepe confined aquifers, there is no immediate danger to the water supply. The report concludes that, with contin pumping, ocean water can be drawn into the major aquifers, and it recommends that local agencies maintain th piezometers that were constructed for this study and monitor coastal aquifers with them.

CHAPTER I. INTRODUCTION

The intrusion of sea water is an ever-present threat to those coastal ground water basins that are used to supply fresh water. Already, 19 basins in Southern California have been found to be subject to the encroachment of salt water. This can lead to the loss of not only the fresh water they contain but also the potential storage and transmission capabilities of the basins themselves.

One of the coastal basins in which such intrusion has been suspected is that underlying the Pismo-Guadalupe Area, which is the coastal reach of Arroyo Grande Valley in San Luis Obispo County and Santa Maria Valley in San Luis Obispo and Santa Barbara Counties (Figure 1). A cooperative monitoring program maintained by the Department of Water Resources and the San Luis Obispo County Flood Control and Water Conservation District has showed that several wells in the basin have been producing water that contains increasing concentrations of chloride. Sea-water intrusion was suspected as the cause.

Because ground water is the chief supply of water for the valley, which is noted for its truck crops, an investigation was undertaken in 1964. Control of sea-water intrusion requires both knowledge of the complex ground water regimen and time to implement control measures.

Objective and Scope of Investigation

The objective of this program was to determine the extent and rate of sea-water intrusion. Specifically, this involved three tasks: one, to establish a minimum sea-water intrusion monitoring system; second, to determine the geologic, hydrologic, and native water quality environment; and third, to determine the present status of sea-water intrusion and evaluate the potential for and likely nature of further salt water encroachment.

The scope of the investigation encompassed comprehensive and integrated analyses of geologic, hydrologic, and water quality data, together with a general evaluation of present and projected net water use and probable offshore reservoir conditions.

Conduct of Investigation

The investigation began in July 1964 and by May 1966 a progress report had been completed. The report provided both a cursory review of well data and samplings from the monitoring piezometers in the Arroyo Grande Plain, which is a portion of the study area.

Additional monitoring piezometers were constructed at Oso Flaco Lake in 1966 and the Guadalupe Oil Field in 1967, both of which are also in the study area. Water level and water sampling programs were conducted in the fall of 1967. By 1969, when data obtained both from field work and from available reports and files had been analyzed, preparation of this bulletin was completed.

Although all basic data are not included in this bulletin, they are available in the files of the

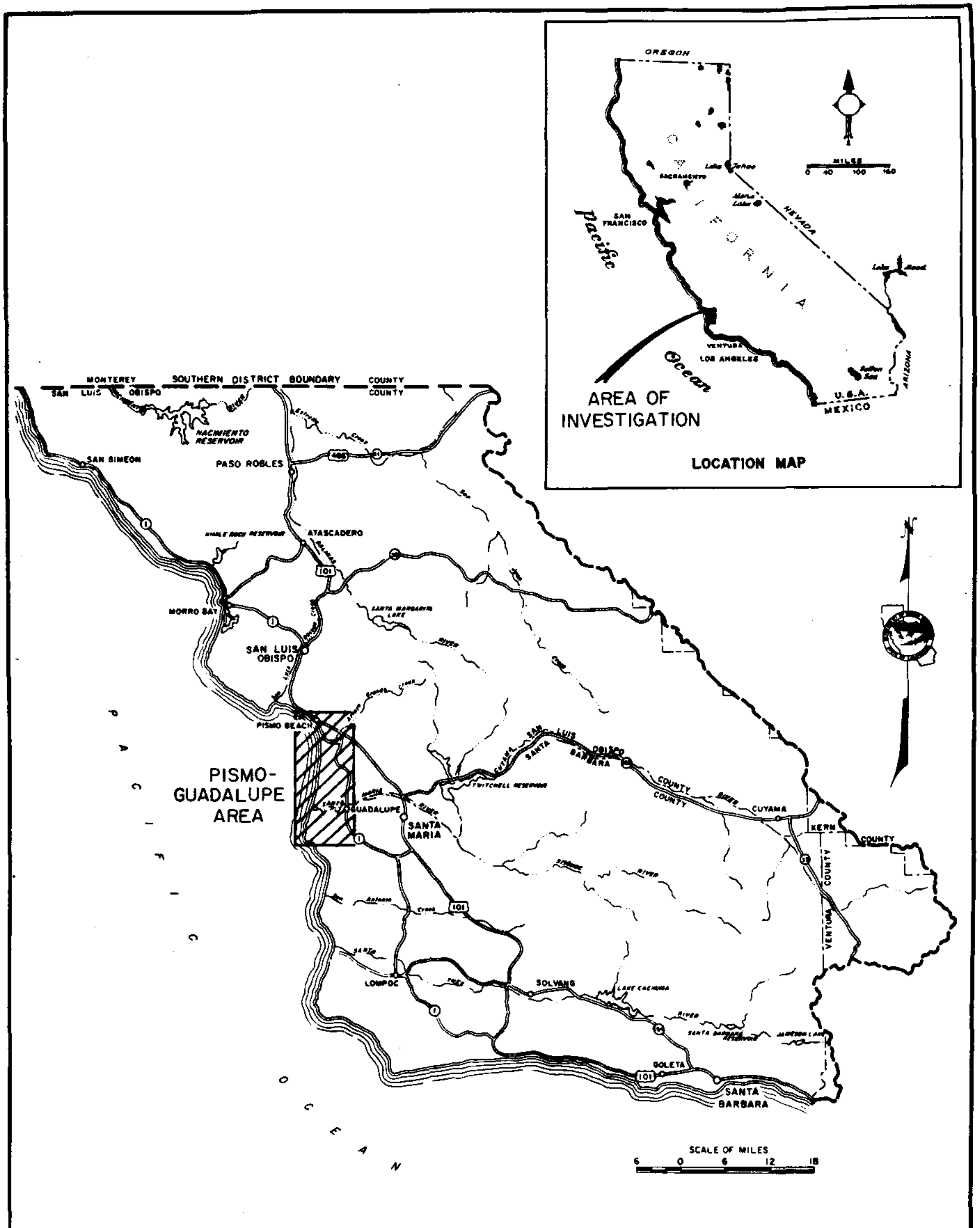

Figure 1 - VICINITY MAP

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

Department, Southern District. These data are currently being placed in a form to permit rapid retrieval through use of an EDP system.

A list of reports relative to the study area is given in Appendix A. Detailed geologic exploration mapping in the area is currently being conducted by C. A. Hall of the University of California at Los Angeles. Findings from his study, which has not yet been published in a report, have been of considerable assistance to this investigation.

Definitions of terms used in the report are given in Appendix B.

Area of Investigation

The study area is a rectangle of approximately 40,000 acres which occupies the coastal zone of San Luis Obispo and Santa Barbara Counties. The area is about 20 miles long and 3 miles wide. (See Figure 2.)

It consists of several flat alluviated coastal plains, interrupted by hills, mesas, sand dunes, and terraces, and is drained by several waterways.

Rainfall averages about 15 inches, and fog is common throughout the year.

Coastal Plains

The coastal plain is divided into two portions: the Santa Maria Plain on the south and its northern counterpart, the Arroyo Grande and Pismo Plains.

The Santa Maria Plain, which extends about 20 miles inland, reaches its maximum width of 5 miles near the community of Guadalupe. The plain has a westward gradient which averages about 20 feet per mile.

The Arroyo Grande Plain is about 5 square miles in area. It was formed by erosion and deposition of Arroyo Grande Creek. The plain attains its maximum width of about 2 miles just south of Oceano, and has an average westward gradient of about 30 feet per mile.

The Pismo Plain is about 2 square miles in area. It was formed from sediments deposited by Pismo Creek.

Hills, Mesas, Sand Dunes, and Terraces

The Casmalia Hills help form the southernmost drainage divide in the Santa Maria Valley. The main features near the crest are steep ravines and sharp ridges, which are the result of anticlinally folded Miocene and Pliocene sediments that are fairly resistant. On the northern flanks are rolling hills and moderate to deep gullies, which are the results of erosion on what are chiefly unconsolidated sediments of upper Pliocene and Pleistocene age.

The San Luis Hills make up the northernmost drainage divide. They can be divided into two portions: one, which lies west of Pismo Creek, rapidly attains elevations up to 1,000 feet, with steep ravines and sharp ridges being the result; and a second, which is east of Pismo Creek, rises to about 700 feet, but more gently.

Three physiographic features of importance within the area of investigation are the Orcutt, Nipomo, and Tri-Cities Mesas, or uplands, and their associated sand dunes.

Orcutt Mesa is predominately covered by older sand dunes and is the result of downcutting by the Santa Maria River.

That portion of Nipomo Mesa that is within the area of investigation may be divided into two parts: a western portion that is overlain by Recent sand dunes and an eastern half that is covered by older sand dunes. The

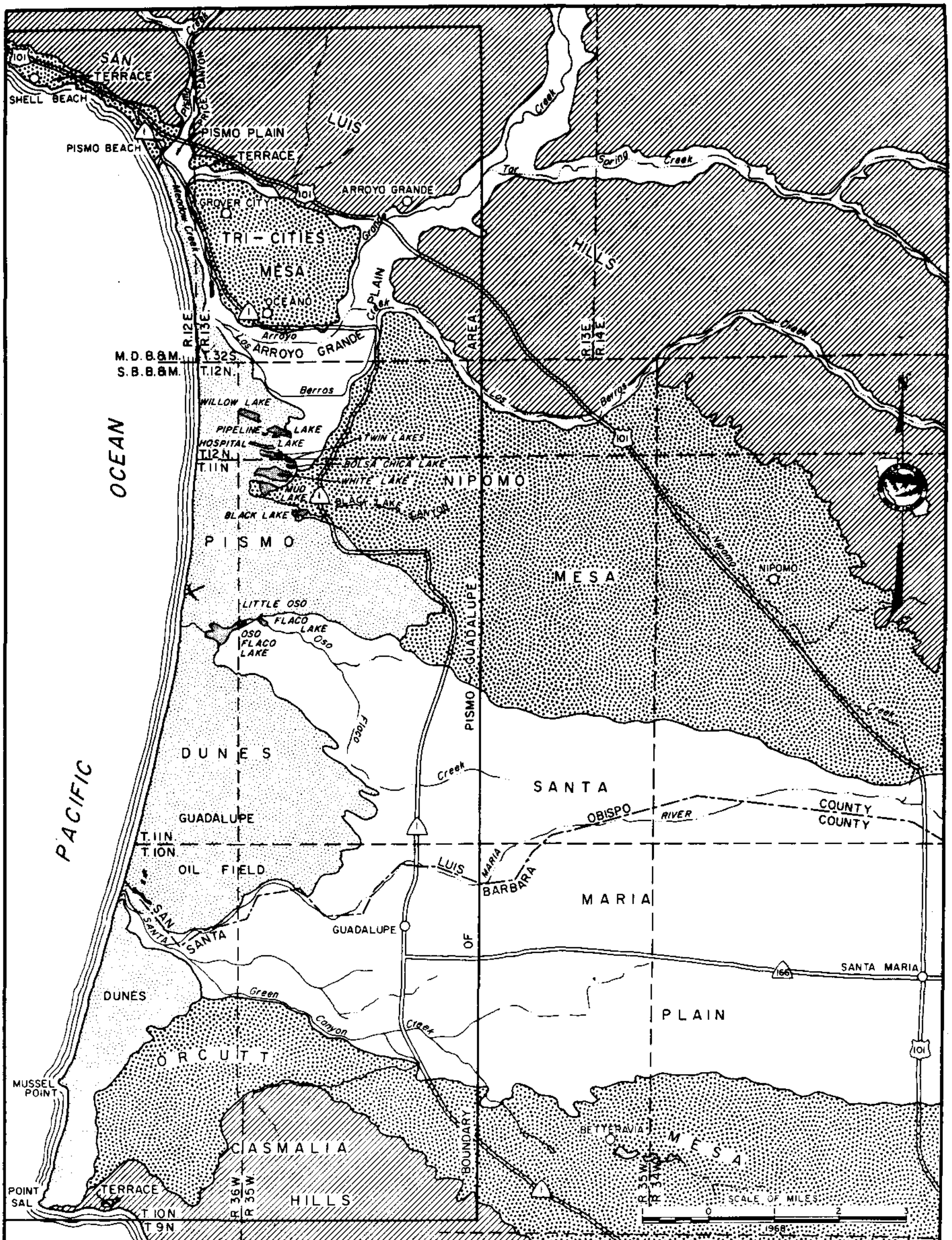

Figure 2. PHYSIOGRAPHIC FEATURES

Recent sand dunes along the coast have been termed the Pismo Dunes. They extend both north and south beyond Nipomo Mesa.

The Tri-Cities Mesa covers approximately 4 square miles. It is a remnant of the deposition that was laid down, historically, by Pismo and Arroyo Grande Creeks. Older sand dunes now cover the area.

Marine terraces are found at two points. One prominent terrace extends from Pismo Beach north through Shell Beach and beyond the study area. The other terrace, which is much smaller, is in the extreme southern end of the study area.

Drainage Systems and Waterways

The Santa Maria River formerly flowed out to sea near the present Oso Flaco Lake, following the general pattern of Oso Flaco Creek. This channel is blocked from the ocean by sand dunes which, in turn, form Oso Flaco Lake. The present Santa Maria River discharges to the west of Guadalupe. The direct connection between the river and the ocean usually occurs only during the winter, at times of peak runoff. In summer, a buildup of sand blocks the outlet.

In the Tri-Cities Mesa are two major drainage channels: the Pismo and Arroyo Grande Creeks.

Marshland, accompanied by a series of fresh water lakes, ponds, and sloughs, is found in the western part of Nipomo Mesa from Pismo Beach to Black Lake. Other marshland within the study area is found at Oso Flaco and Little Oso Flaco Lakes, in the southwestern part of the Guadalupe Oil Field, and about 1.5 miles southeast of where the Santa Maria River discharges to the ocean.

Offshore Topography

The 1967 bathymetric map that was prepared by the U.S. Coast and Geodetic Survey shows the offshore topography in the study area to be smooth. The slope is so gentle that at approximately 20 miles offshore, the depths range from 1,100 to 1,400 feet below sea level with no indications of submarine canyons or of seaward extensions of present stream valleys. Such relatively flat offshore extensions of alluvial formations have a potential for storing large quantities of fresh water.

CHAPTER II. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The principal findings, conclusions and recommendations of this investigation are as follows:

Findings

1. Fresh ground waters containing 20 to 70 ppm chloride predominate at the coast in a series of multiple confined aquifers formed in Recent alluvium, the lower Pleistocene Paso Robles Formation, and the upper Pliocene Careaga Sand.

2. Shallow coastal ground waters (less than 100 feet deep) in Recent tidal and fluvial deposits and upper Paso Robles beds north of Arroyo Grande Creek contain 100 to 1,630 ppm chloride. Historic water levels in these aquifers preclude sea-water intrusion. Sources of the chloride are:

   (a) The natural salinity of the geologic environment (former tidal marshes and sloughs),

   (b) Salt concentration by evapotranspiration,

   (c) Downward percolation of sea water entering tidal channels at times of extremely high tides.

3. The slight seaward gain in chloride (125 ppm) in unconfined ground water of marine terrace deposits north of Pismo Creek and a basal, south-sloping salt water wedge in the Careaga Sand are natural sea-water intrusion conditions. A possible sea-water intrusion condition is also noted in the B zone of the Paso Robles Formation. There are few wells in these aquifers.

4. Inland ground waters contain 30 to 190 ppm chloride. Concentrations greater than 100 ppm are indicative of man-related degradation. The chief sources of degradation are:

   (a) Recycling of excess irrigation water,

   (b) Deep percolation of domestic sewage.

5. Structural and stratigraphic conditions, the gentle seaward dip of the ocean floor, and high historic artesian water levels indicate a large offshore storage of fresh ground water.

6. Although water levels at the coast are now above sea level, the hydraulic potential for sea-water encroachment exists in the Paso Robles and Careaga aquifers.

7. Water levels in the southern part of the Arroyo Grande Hydrologic Subunit and in the Santa Maria Hydrologic Subunit exhibited a persistent decline from 1951-68, indicative of over-pumping. Water levels in the northern part of the Arroyo Grande Hydrologic Subunit fluctuated with rainfall, but they showed little if any net decline.

8. Projected net water demands for the northern part of the Arroyo Grande Hydrologic Subunit during 1970-90 will be largely offset by the supplemental yield of Lopez Reservoir. Increasing net water demands for the southern part of the Arroyo Grande Subunit and the Santa Maria Hydrologic Subunit will necessitate increased over-pumping of ground water supplies.

Conclusions

1. Sea-water intrusion is not an immediate problem onshore at present.

2. Intrusion is probably advancing landward from different salt water forebays at different rates in each confined aquifer.

3. Projected net water demands during 1970-90, even with local supplemental supplies, favor a slight increase in the rate of salt water encroachment in the southern part of the Arroyo Grande and Santa Maria Hydrologic Subunits.

4. The onshore arrival of intrusion is dependent chiefly on the extent of fresh ground water offshore and the rate of salt water encroachment. Intrusion will likely reach the coast first in shallow aquifers which crop out near shore and are subject to heavy pumping.

5. Based on limited data, there is evidence of an essentially unused body of fresh ground water in the lower Paso Robles Formation, the Careaga Sand, and the upper Pismo Formation (central San Luis Hills).

RECOMMENDATIONS

1. The Department and San Luis Obispo County should implement the following recommendations relating to the establishment of and measurement and sampling of a grid of wells which will detect sea water intrusion, the establishment of water well standards, and the determination of extent and location of offshore aquifers.

2. Maintenance and observation of the Department's piezometers and other wells which may be selected to establish a well grid to assist in the detection of sea-water intrusion should be reassigned to local water agencies and funded at the local level.

3. Annual sampling and testing of a grid of wells during early October, and semiannual observation of a grid of wells in April and October are suggested as minimum frequencies to detect sea-water intrusion.

4. An annual report evaluating the status of sea-water intrusion based on the well measurement and sampling program should be prepared and distributed by the Department.

5. If extensive development of the deep aquifers occurs in the future, piezometers for well measurement and chloride sampling will be needed to detect sea-water intrusion.

6. An offshore geophysical survey (such as a sparker survey) should be undertaken to evaluate the location, extent, and outcrop areas of aquifers and to estimate the potential offshore freshwater storage capacity. This could be conducted as a cooperative effort by interested agencies as funds are made available.

7. To help prevent movement of degraded water from one aquifer to another, standards for both the construction and destruction of water wells should be established pursuant to procedures set forth in existing State law.

CHAPTER III. GEOLOGY

Before the rate and extent of sea-water intrusion can be known, a competent understanding of the geologic framework in which ground water is stored and moves must be developed.

Geologic History

In the study area, the record of geologic events before the Miocene Epoch is obscure and indefinite. No doubt there were times of deformation, deposition, and erosion. However, there is no direct evidence, at present, as to what events took place. It is known that Franciscan rocks were rather extensive during the later part of Jurassic time. Toward the end of this period, the area was covered by the sea when the shales, sandstones, and conglomerates of the Knoxville Formation were deposited.

In early Miocene, nonmarine sediments were deposited in the region. Following this, the sea invaded the area for the first known time during the Tertiary. Miocene marine sediments of sandstones, shales, siltstones, claystones, and mudstones were laid down. Simultaneously, Miocene volcanic rocks were introduced with some deformation taking place.

The sea continued to occupy the region until the end of the Pliocene. During early and middle Pliocene, marine sediments of sandstones, shales, siltstones, claystones, and mudstones were deposited. Deformation was minor, but continual, throughout the Pliocene. The Pismo Formation was deposited during this epoch.

During upper Pliocene time the sea advanced farther inland, and the Careaga Sand was deposited.

In lower Pleistocene time the Paso Robles Formation was laid down. Generally it is considered to be of continental origin. However, in the study area, it is locally of lagoonal or brackish-water origin because it was deposited in synclinal troughs that were still submerged at or near the coastline. Minor warping accompanied the deposition of both the Careaga Sand and the Paso Robles Formation.

In middle Pleistocene time, major deformation and intense folding took place. It was at this time that the present limits of the ground water basin were established. Even the Jurassic sediments and igneous rocks were further uplifted, accentuating the shape and limitations of the basin. At this time, there was partial removal of the Paso Robles Formation in the Arroyo Grande and Nipomo Mesa areas. In the southern part of the study area, the Careaga Sand and Paso Robles Formation were bent upward by the Casmalia Hills. Concurrently, they were depressed into the adjacent syncline that was immediately north of these highlands, and they were cut by faults.

After the intense folding and major deformation of the middle Pleistocene, conditions became more stable. This period of quiescence continued into the upper Pleistocene. The Orcutt Formation was deposited by the ancestral streams. In the study area, there are local beds that are interfingered within the Orcutt Formation. This is probably due to a lagoonal or brackish-water environment.

Minor faulting and folding took place after the deposition of the Orcutt Formation, but prior to the forming of the fluvial and marine terrace deposits. This was the last deformation that was to affect the formation of the Santa Maria Valley Ground Water Basin.

The extent and elevation of the marine terraces within the study area indicate that there must have been times of extended uplift in the upper Pleistocene. It is assumed that the ancestral rivers and streams were approximately in the same positions as they are today.

At the end of the Pleistocene, during the Wisconsin glacial age, sea level was considerably lowered. This caused the rivers and streams to further entrench their streambeds.

After the retreat of Wisconsin glaciation, the last glacial period, the sea level rose, causing Recent alluvial and channel deposits to backfill the coastal valleys.

More recent events are the erosion of offshore projecting headlands and the transporting of sand to protected areas by waves and longshore currents. The prevailing wind is from the northwest, and this has transported the sand inland. This process is still going on. It is believed that the ancestral Arroyo Grande Creek discharged at a point farther south than it does now. However, as the dune sands progressed landward, they forced the creek north to its present location.

Stratigraphy

For this study, the geologic formations of the Pismo Beach-Guadalupe Area have been divided into three series. First are the formations of the younger, unconsolidated water-bearing series which range in age from lower Pleistocene through Recent times. The second is the group that is categorized as an older, unconsolidated to cemented water-bearing series. Figure 3 shows the generalized stratigraphic and hydrogeologic relationships of these two water-bearing series. The third group is designated as a consolidated, essentially nonwater-bearing series, the members of which range from Jurassic to upper Pliocene. Plate 1 shows the areal distribution of all these series.

For this report, high permeability is rated as more than 500 gallons per day per square foot, moderate permeability is 100 to 500, and low permeability is less than 100 gallons per day per square foot.

Younger Water-Bearing Series

Included in the younger water-bearing series are the formations of Recent, upper Pleistocene, and lower Pleistocene age.

Recent Formations. The thickness of the younger sand dunes ranges from a few feet to 190 feet (Sections A-A' through D-D' on Plates 2A and 2B). On rare occasions, local semiperched or perched water zones may be found in them.

For this study, the river channel deposits are considered along with the alluvium and are shown as one unit, Recent alluvium, on Plate 1. The water-bearing properties of these deposits are important in that they transmit seepage losses downward. Generally, these deposits are above the water table.

In general, the alluvial deposits are limited to the stream valleys and

AGE	FORMATION (Maximum thickness in feet)	AQUIFER (Maximum thickness in feet)	MAXIMUM DEPTH to base of formation in feet	GENERALIZED LITHOLOGY AND AREAL EXTENT	HYDROGEOLOGIC FEATURES Water-bearing properties, use, maximum well yields, and specific capacity (sc)
RECENT	Dune sand–Qs (190)	—	190	Fine to medium sand. Unconsolidated. Extensive dune belt along coast.	High permeability. Largely unsaturated. Unconfined. Transmits precipitation to Qal. Not tapped by wells.
	Alluvium–Qal Santa Maria River (250)	Semiperched in Upper Member (120)		Discontinuous, fine to medium silty sand in sandy silt and clay confining cap. Unconsolidated.	Low to moderate permeability. Unconfined to semiconfined. Generally untapped by wells.
		Lower Member (150)	250	Fine to coarse sand, gravel and locally cobbles with sandy silt and clay. Unconsolidated.	High permeability. Confined to semiconfined. Principal aquifer of Santa Maria Plain. Tapped by large irrigation wells commonly multiperforated in upper Qpr. 1720 gpm. SC 46 gpm/ft.
	Alluvium – Qal Pismo Creek (80)	Upper Zone (40)	40	Fine to medium sand and gravel with sandy silt and clay. Unconsolidated. Limited to Price Canyon and Pismo Plain.	Moderate permeability. Unconfined. Tapped by a few small wells.
		Lower Zone (20)	80	Medium to coarse sand and gravel with silt. Unconsolidated. Limited to Price Canyon and buried 2,300-foot-wide channel extending southwest to coast.	High permeability. Semiconfined. Principal aquifer in Price Canyon and Pismo Plain. Tapped by a few irrigation wells. 500 gpm (estimated).
	Alluvium – Qal Arroyo Grande Creek (130)	Upper Zone (50)	50	Fine to coarse sand and gravel with sandy silt and clay. Grades to sandy silt and clay south and east of streambed. Unconsolidated.	Moderate to high permeability. Unconfined. Tapped by domestic wells near coast. 70 gpm. SC 14 gpm/ft.
		Lower Zone (80)	130	Medium to coarse sand, gravel, and locally cobbles with sandy silt and clay. Unconsolidated.	High permeability. Confined to semiconfined (upstream). Principal aquifer of Arroyo Grande Plain. Tapped by large irrigation wells. 1700 gpm. SC 50 gpm/ft.
	Alluvium – Qal Los Berros Creek (100)	Undifferentiated (100)	100	Fine to coarse sand and gravel with sandy silt and clay. Unconsolidated.	Moderate to high permeability. Unconfined to semiconfined. Tapped by a few domestic wells.
UPPER PLEISTOCENE	Terrace Deposits –Qt (50)	—	50	Fine to coarse sand with gravel and sandy to gravelly silt. Unconsolidated. Limited to coastal terrace northwest of the City of Pismo Beach.	Low to moderate permeability. Largely unsaturated. Unconfined. Tapped by a few domestic wells in the City of Pismo Beach.
	Older Dune Sand –Qso			Fine to medium sand. Unconsolidated. Limited to mesas.	Moderate permeability. Largely unsaturated. Unconfined. Transmits precipitation and locally return irrigation water and sewage to underlying Qpr. Tapped by sand points and domestic wells near Black Lake Slough on Nipomo Mesa.
	Tri-Cities Mesa (40)	—	40		
	Nipomo Mesa (150)	—	150		
	Orcutt Mesa (120)	—	120		
	Orcutt Sand–Qo (200)	—	> 275	Fine to medium sand, silt and clay underlain by fine to coarse sand and gravel with silt and clay. Unconsolidated. Identified only beneath Orcutt Mesa. Undifferentiated from upper Qpr beneath Nipomo Mesa and north Santa Maria Plain.	Low to moderate permeability. Unconfined. Tapped by a few wells in study area. Important aquifer inland where formation is coarse-grained.
LOWER PLEISTOCENE	Paso Robles Formation–Qpr (780)	A to E Zones	850	Fine to coarse sand and gravel, silty to clayey sand and gravel, and fine to medium silty sand. Unconsolidated. Two to five aquifers designated from top to bottom as the A to E Zones. Aquifers separated by silt and clay confining beds near coast, merged inland.	Moderate to high permeability. Confined at coast and below alluvial plains. Confined to unconfined beneath mesas and along flanks of foothills. Major aquifer system. Tapped by large municipal, industrial and irrigation wells, as well as numerous domestic wells 2,500 gpm. SC 89 gpm/ft.
PLIOCENE	Careaga Sand –Tpc (740)	Undifferentiated	1,600	Fine to coarse sand with gravel, fine to medium sand, and silty sand. Unconsolidated to well cemented, calcareous. Two to three aquifers, undifferentiated. Aquifers separated by relatively continuous silt and clay confining beds.	Low to moderate permeability. Confined. Tapped by a few deep wells multiperforated in overlying aquifers. Potentially an important water supply.
	Pismo Formation –Tpp fresh water-bearing sandstone members (600)	Undifferentiated	600	Fine to coarse sand with interbeds of hard calcareous sandstone. Unconsolidated. Upper portion believed equivalent to Careaga Sand. Limited to the San Luis Hills.	Low to moderate permeability. Unconfined. Tapped by a few domestic wells. Potentially an important water supply.

Figure 3 – **GENERALIZED STRATIGRAPHIC COLUMN OF WATER-BEARING FORMATIONS**

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

alluvial plains. Throughout the study area, the alluvium lies unconformably on the Paso Robles Formation or other older beds. The alluvium, in turn, is overlain locally by the Recent river channel deposits or dune sands.

The alluvium in the Santa Maria Plain consists of an upper and a lower member. In the eastern part of the Santa Maria Valley (outside the study area), the upper and lower members are similar in lithology. Wells that are perforated in the eastern portion of the Santa Maria Valley have high yields.

However, the upper member becomes finer grained to the west, with the result that the permeability decreases. Essentially unused semiperched water is found within the upper member. In some places, the tighter sediments form a cap and confine the water to the underlying deposits (Sections C-C' and D-D', Plate 2B).

The lower member of the alluvium, the principal aquifer of the Santa Maria Plain, yields water readily to wells. It is tapped by large irrigation wells that are commonly multiperforated in the upper Paso Robles Formation. Thickness of the lower member ranges from 0 to 150 feet (Sections A-A' through D-D', Plates 2A and 2B). Within the lower member are found a series of interrelated confined to semiconfined aquifers that range in thickness from 5 to 65 feet (Section C-C', Plate 2B). Within the Santa Maria Plain, the northern extent of the lower member and its associated aquifers is found in the vicinity of Oso Flaco Lake Road (Plate 1 and Section C-C', Plate 2B).

In the Pismo Creek area, the alluvium is divided into an upper and a lower zone. The lower zone is the principal aquifer in Price Canyon and the Pismo Plain.

In the Arroyo Grande Creek area, the alluvium is also divided into an upper and lower zone. The zones are separated by fine-grained silty sediments. The aquifer in the upper zone follows the pattern of the present Arroyo Grande stream channel and swings north to well 32S/13E-30N1-3, but probably not much beyond (Section A-A', Plate 2A). Estimated permeability, based on the specific capacity, is 840 gallons per day per square foot. The southern boundary may be under the Pismo Dunes.

There is some continuity upstream between shallow and deep aquifers. The deep aquifer follows the general pattern of Arroyo Grande Creek from east to west until the aquifer reaches the southwest quarter of Section 32 in Township 32 South, Range 13 East. This is its northern limit, from here it projects southeasterly. This deeper aquifer is the principal aquifer of the Arroyo Grande Plain. Estimated permeability is 2,300 to 3,000 gallons per day per square foot.

The aquifers in the Los Berros Creek area are undifferentiated.

Upper Pleistocene Formations. The only terrace deposits that outcrop in the study area are marine formed. (Plate 1). Thickness ranged from 0 to 50 feet.

Whenever they rest on consolidated rock, the terrace deposits yield small quantities of water to wells. Otherwise, they mainly serve to transmit water to the underlying sediments or directly to the ocean whenever there is free drainage.

The older dune sands are found in three localities within the area of investigation (Plate 1 and Section B-B', Plate 2A).

The characteristics of the older dune sands are similar to those of the younger dune sands. There are some local semiperched or perched water zones in these sands.

The Orcutt Sand is a slightly deformed terrace deposit (Plate 1). It lies unconformably on the Paso Robles Formation or locally upon older rocks. The thickness ranges from 0 to approximately 200 feet within the study area.

The Orcutt Sand is mainly of fluvial origin; however, in the coastal area it may be, in part, of marine origin. Within the study area, it is not considered a major water producer. However, it serves to transmit water to underlying formations.

Lower Pleistocene Formations. The Paso Robles Formation makes up the lower Pleistocene deposits within the study area. It lies unconformably upon the Careaga Sand or older rocks. The formation may be described as consisting of locally lenticular beds or lenses; no one rock type occurs throughout. The thickness varies considerably within the study area (Sections C-C' and D-D', Plate 2B). The formation is considered at least partially of marine origin. Permeability ranges from 500 to 1,700 gallons per day per square foot, based on pumping test analyses.

In the Santa Maria Plain are five zones (A-E). The upper ones are separated by clays. The lower zones are separated from the upper zones by a rather thick clay layer that is continuous along the coast, but may not extend inland (Sections C-C' and D-D', Plate 2B).

In the area around Arroyo Grande Plain and Tri-Cities Mesa, the Paso Robles Formation retains the zones. Here, however, the aquifers begin to merge, become thinner, and finally some of them disappear (Sections A-A' and B-B', Plate 2A).

The upper zones are tapped by large municipal, industrial, and irrigation wells along with many domestic wells. Well number 32S/3E-29E2 has a maximum flow of 2,500 gallons per minute with a specific capacity of 89 (gallons per minute per foot of drawdown). The estimated permeability for this well is 1,500 gallons per day per square foot.

The lower zones are considered part of this major aquifer system except along the flanks of the basin. They are confined, have a moderate to high permeability, and are tapped by a few deep industrial and irrigation wells. These wells are multiperforated within the zones of the Paso Robles Formation, along with the Careaga Sand. Flows through well number 11N/35-7R1 range as high as 1,500 gallons per minute with a specific capacity of 26 (gallons per minute per foot of drawdown).

Older Water-Bearing Series

The upper Pliocene Careaga Sand and lower to upper Pliocene Pismo Formation are predominately of marine origin.

The thickness of the Careaga Sand varies within the Pismo-Guadalupe area. Maximum thickness is approximately 740 feet (Section D-D', Plate 2B). In general, the thickness increases from south to north and west to east in the Santa Maria Plain (Sections C-C' and D-D', Plate 2B). North of Pismo Dunes and Nipomo Mesa, the thickness decreases to the north and east as the sand approaches the San Luis Hills (Sections A-A' and B-B', Plate 2A).

Since no wells are perforated exclusively in the Careaga Sand, no definitive information is available as to formation permeability or well yield. However, based on the Department's exploratory drilling, these aquifers might be a potentially important water supply.

The sandstone members of the Pismo Formation are the only units that are considered within this report. The thickness of the sandstone ranges from about 70 feet to about 600 feet.

Because of its large areal extent and moderate permeabilities, this formation could be a good future source of water.

Nonwater-Bearing Series

The consolidated, essentially non-water-bearing series is made up of igneous, sedimentary, and metamorphic rocks that range in age from Jurassic to upper Pliocene. For this report, they are categorized into five groups: the undifferentiated Pliocene sediments, the undifferentiated Miocene sediments, the Miocene volcanics, the Knoxville Formation, and the Franciscan Formation (Plate 1). These rocks underlie and flank the water-bearing deposits within the study area.

In general, this series of rocks yield small quantities of fresh water from fractures and joints at shallow depths in the hill and mountainous areas. However, with depth, the water becomes brackish to saline. In high rainfall areas, such as the Casmalia Hills, springs are common during the winter.

Geologic Structure

The formation of the Santa Maria Valley area has been influenced by activity in the California Coast Ranges and Transverse Ranges. As a result, the major geologic structure which underlies and forms the valley itself is an asymmetric syncline which is bordered by the Casmalia Hills on the south and the San Luis Hills on the north. Most geologic structures of the Pismo Beach-Guadalupe area have a general west-northwestward trend, which is parallel to the trend of the Santa Maria Basin (Plate 1).

Folds

The Santa Maria Valley Syncline is evident only by subsurface data. The southern limb has a very steep gradient as it approaches the Casmalia Hills, but the northern one has a much more gradual rise as it approaches the San Luis Hills (Sections A-A' and C-C', Plates 2A and 2B).

The entire basin is limited by this major syncline and by the bordering highlands in the north and south.

Faults

The only fault that appears to impede the movement of ground water in the study area is that mapped by Hall (1967). It trends slightly west of northwest in the San Luis Hills (Plate 1). Where this fault cuts across the water-bearing members of the Pismo Formation, it may directly affect this potential source of ground water. This structural feature could either enchance or impede the movement of ground water; it could also affect recharge to this portion of the basin.

Between wells 32S/13E-31La and 32S/13E-31F2-4 is a vertical displacement of almost 100 feet at the base of the Careaga Sand, with the north side moved up in relation to the south side. (Section A-A', Plate 2A). Subsurface data show it; there is no surface evidence of a fault. Displacement becomes greater with depth.

Along with this, in Section 33, Township 12 North, Range 35 West, the water level in well -33R1 is deep in relation to the levels in -33J1 and in others immediately to the north. (See Plate 3).

Considerably more evidence will be needed, however, before the presence and location of a fault can be established and its relation to the movement of the ground water determined.

CHAPTER IV. HYDROLOGY

Essential to a determination of the extent of sea-water intrusion is a knowledge of the hydrologic environment. To gain this knowledge requires information on where ground water occurs, where and how recharge and discharge take place, where and in what direction ground water is moving, and what fluctuation is taking place in the level of water in wells within the basin.

Ground Water Occurrence

As has been pointed out earlier, the Recent alluvium deposits and the Plio-Pleistocene sediments constitute the principal ground water reservoir of the study area. Water contained in the alluvium and upper portion of the Paso Robles Formation is extensively developed for beneficial uses. The few known wells which tap the Careaga Sand, four on Nipomo Mesa and one on Tri-Cities Mesa, also derive water from the Paso Robles Formation.

Minor bodies of semiperched water are present locally in coastal alluvial deposits, in the older dune sands of Nipomo Mesa and Tri-Cities Mesa, in coastal terrace deposits north of Pismo Creek, and in the Recent sands of the Pismo Dunes. These aquifers supply small quantities of water to shallow domestic wells.

Recharge and Discharge

Over portions of the Pismo-Guadalupe area, particularly the alluvial valleys, the principal water body is effectively confined by overlying deposits of clay and silt. Recharge from the ground surface in substantial amounts can occur only beyond these confining deposits.

As indicated by 1967 water level contours shown on Plate 3, replenishment in the coastal margin is derived chiefly by underflow from inland reaches of Pismo, Arroyo Grande, and Santa Maria Valleys. Limited recharge of semiperched waters and the upper part of the principal body takes place in permeable reaches of the major stream channels. The principal recharge on the mesas and San Luis Hills is from percolation of rainfall and return of excess irrigation water.

Discharge of ground water from the principal body is primarily by withdrawals from wells and offshore subsurface outflow. Only a very small amount of the total discharge may be attributed to evapotranspiration.

Ground Water Movement

Plate 3 shows contours representing the surface of the principal water body in the Pismo-Guadalupe area in the fall of 1967. Within the area of confined water, the contours are drawn on the pressure surface of the uppermost member of the principal water body; elsewhere, on the water table. The map also shows the aquifer (or aquifers) tapped by the wells for which measurements were obtained. Water levels at wells in the San Luis Hills were not measured during the fall of 1967. Water level records in this area are available for the early 1950's, and the more current of the measurements available are shown on Plate 3.

Although water levels in wells perforated in semiperched ground water bodies were not used in the construction of the water level contour map, the water level altitudes in these wells are also shown in Plate 3 so they can be compared with the pressure level in the principal water body.

The shape of the 1967 contours shows that ground water of the principal water body moves seaward in a generally westerly direction. Local sources of recharge to the principal body are indicated by contours which show the southward movement of water down Pismo Creek, the southwestward movement of water down Arroyo Grande Creek, and the northwestward movement of water down Los Berros Creek.

Since 1945, heavy withdrawal of ground water has produced a large cone of depression in the area north of Oceano. Although the cone has not been enlarged, it has been modified primarily by a change in pumping pattern in the area.

As of the fall of 1967, three smaller pumping depressions were noted in the area north of Oceano. The largest of these was centered in the northwestern quarter of Section 29, Township 32 South, Range 13 East, where the piezometric surface was 5 feet below sea level. All three depressions are related to the heavy withdrawal of ground water from the principal water body for municipal purposes. During the same period, well measurements seaward of these depressions indicate that water levels were above sea level and a seaward gradient prevailed in this and other portions of the study area.

In addition, three relatively shallow cones of depression were also noted in the fall of 1967 as shown on Plate 3. These depressions are attributed to heavy pumping for irrigation of crops and are centered in the western half of Section 29, Township 12 North, Range 35 West, and the south half of Sections 9 and 20, Township 11 North, Range 35 West. It should be noted that during 1966-67 above normal rainfall and runoff occurred and dewatering activity was in progress at Lopez Dam.

Water Level Fluctuations

Water level data in the Pismo Hydrologic Subarea are sparse; historic data are practically nonexistent. The one exception is well 32S/12E-13R1, which has infrequent measurements from 1954 to 1962. The hydrograph for this well is given in Figure 4 and its location is shown in Plate 3.

In contrast to the Pismo Subarea, numerous water level data are available for the Arroyo Grande Subunit. Figure 4 gives fluctuations of water levels in nine selected wells in the northern part of the subunit; Plate 3 shows their locations.

These hydrographs and miscellaneous other measurements for wells penetrating the principal waterbody indicate that little decline has occurred. Although the overall water trend in the northern part of the Arroyo Grande Subunit is one of stability, a marked seasonal decline occurs during the spring, summer, and autumn when pumping is heavy, followed by a rise in the winter when pumping is reduced.

The hydrograph of well 11N/35W-7R1, which is in the southern part of the Arroyo Grande Subunit, shows an average water level decline of nearly 2 feet per year (Figure 4). Its location is shown on Plate 3.

The overall water level trend in the Santa Maria Hydrologic Subunit is one of steady decline. Long-term hydrographs for six wells are shown in Figure 5 and their locations on Plate 3. These hydrographs and other measurements for wells penetrating the principal water body show that the rate and total amount of decline depend largely on the geographic location of the well in

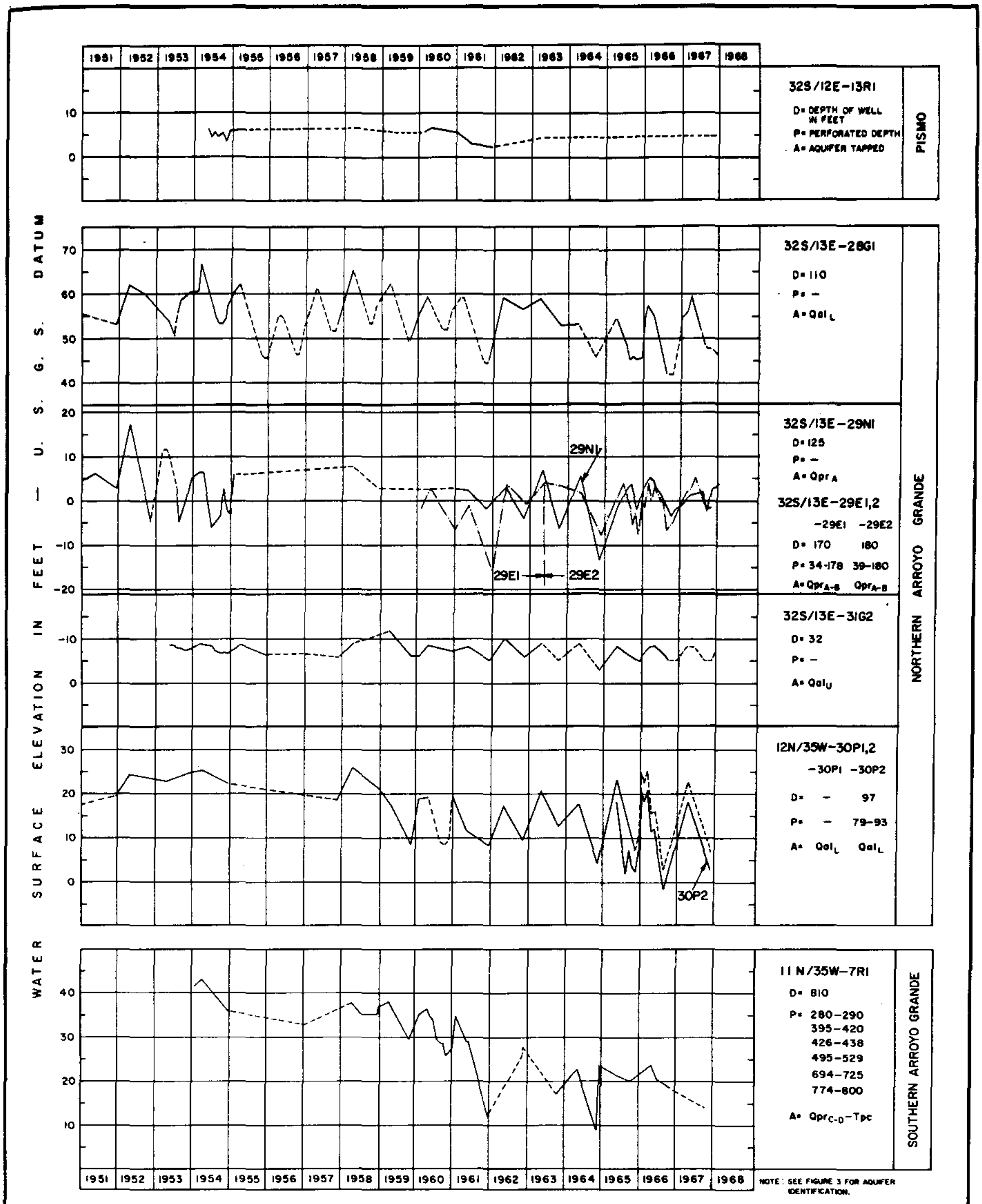

Figure 4. HYDROGRAPHS OF WATER LEVEL IN WELLS - PISMO SUBAREA AND ARROYO GRANDE HYDROLOGIC SUBUNIT

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

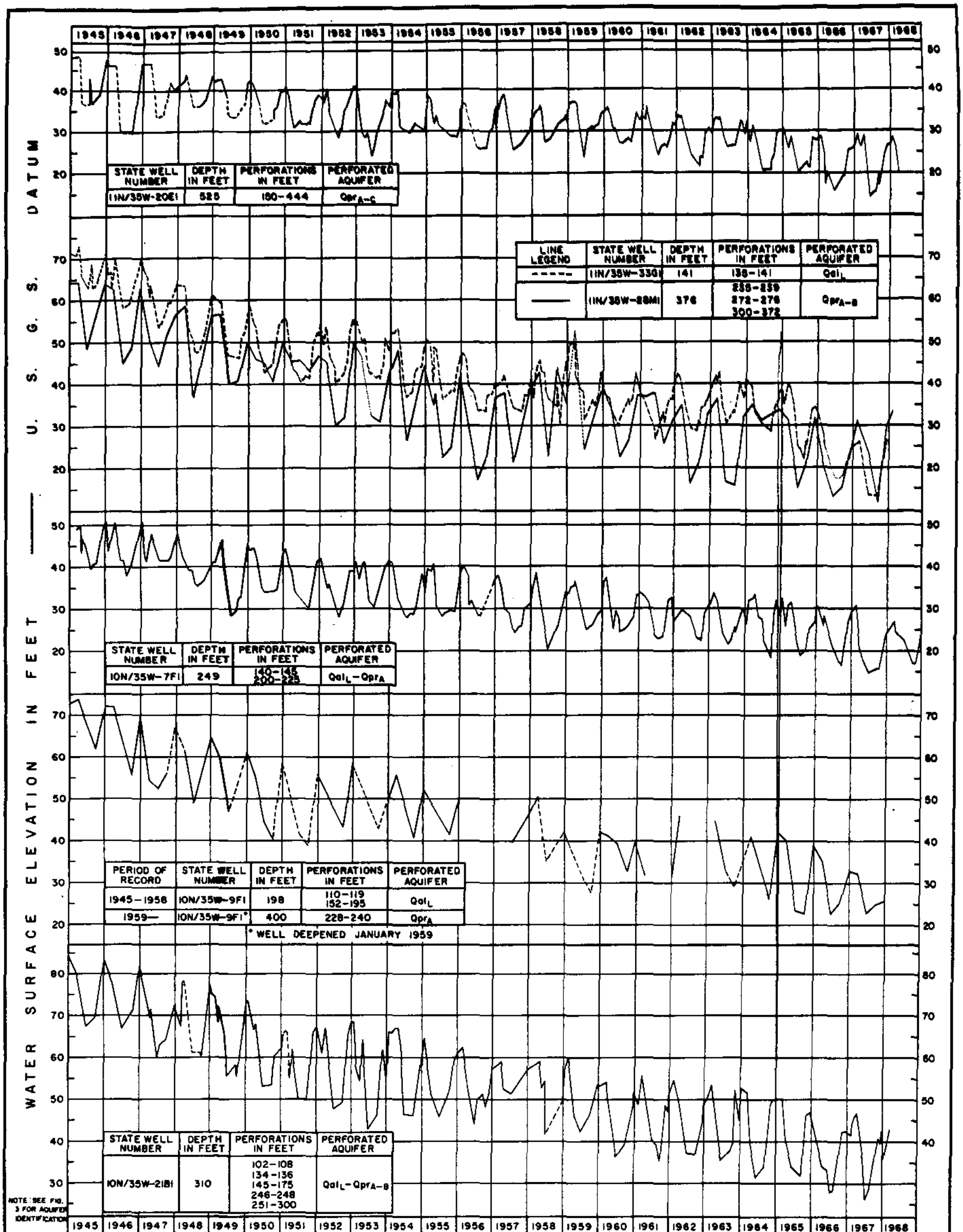

Figure 5. HYDROGRAPHS OF WATER LEVEL IN WELLS - SANTA MARIA HYDROLOGIC SUBUNIT

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

relation to the concentrated area of pumping in the eastern part of the study area.

Hydrographs for 1963-67, as shown in Figure 6, illustrate the head relationship between semiperched and confined ground waters at inland and coastal wells of the Santa Maria Hydrologic Subunit.

The following are considered significant:

1. Piezometric head at inland confined aquifers are considerably depressed due to heavy pumping for irrigation: The head of confined ground waters ranges from 8 feet above semiperched water table at coastal wells to 40 feet below the semiperched water table in inland wells.

2. Inland ground waters, both semiperched and confined, show larger fluctuations between summer and winter than do the coastal aquifers, as the result of heavy summer pumping.

3. Relative decline of confined ground waters for the period 1963-67 is considerably greater at inland wells than at coastal wells.

4. From 1963 to 1967, fluctuations of the semiperched water table at all wells remained essentially stable because pumping was minor.

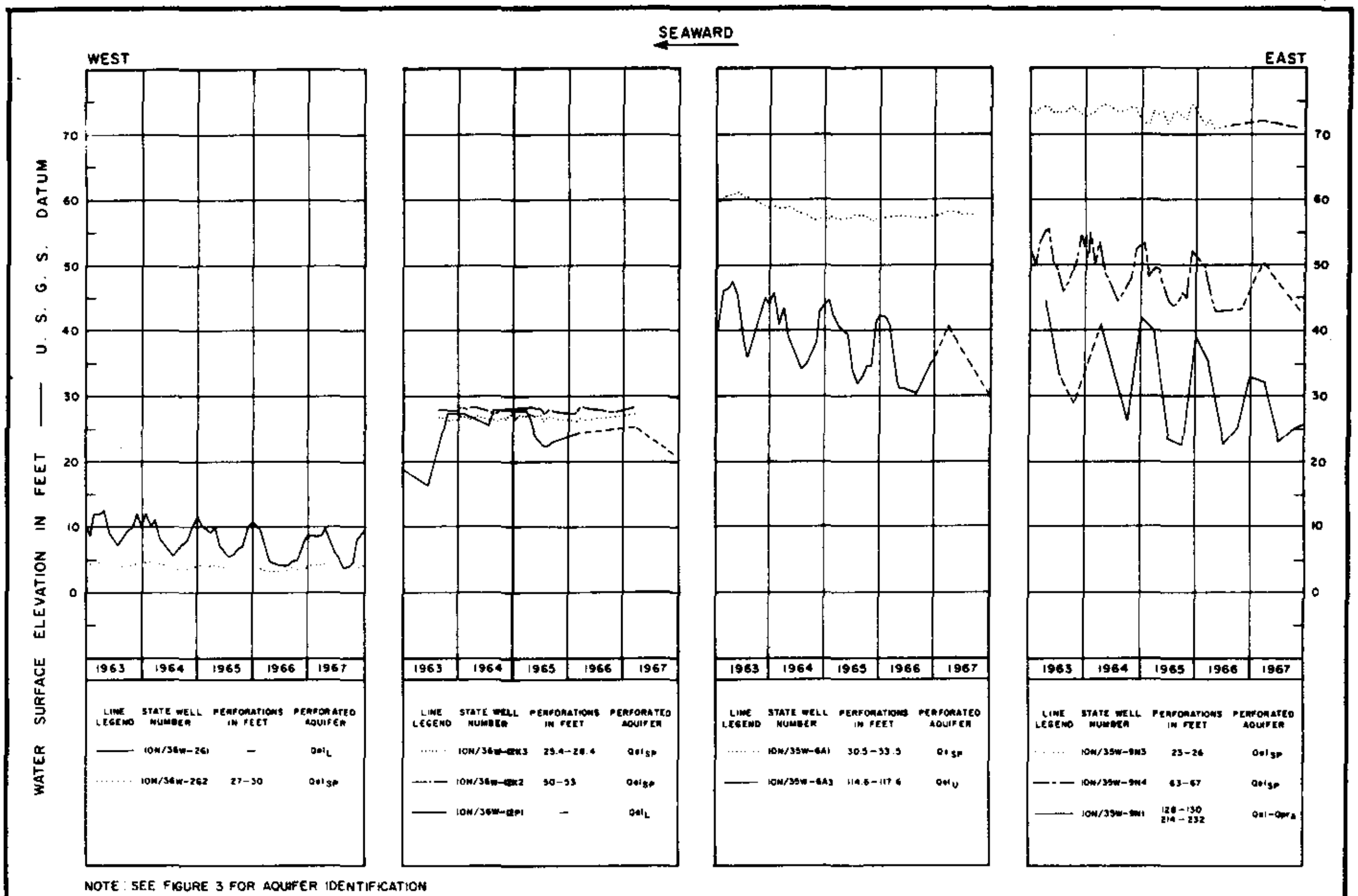

Figure 6. HEAD RELATIONSHIP BETWEEN SEMIPERCHED AND CONFINED GROUND WATERS - SANTA MARIA HYDROLOGIC SUBUNIT

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

5. Except for local landward movement of ground water toward pumping depressions, the general movement in the Santa Maria Hydrologic Subunit is seaward.

Monthly fluctuations of water levels of 32 DWR-constructed piezometers at eight coastal sites (sites POO-1 through 5, OFO-1, GO-1 and 2) are shown in Figure 7 for May 1967 to August 1968. Construction data for these observation wells are given in Table 1.

The hydrographs show that the seasonal rise and fall of water levels closely parallel the fluctuations of water at wells previously discussed (Figures 4, 5, and 6). However, these coastal piezometers, being somewhat farther from areas of concentrated pumping, show smaller annual fluctuations.

In addition, water levels at piezometers which penetrate the lower portions of the principal water body (i.e., the Careaga Sand and lower Paso Robles Formation) generally exhibit higher head. This head relationship is probably due to the fact that the upper portion of the principal water body is more heavily drawn upon.

TABLE 1

OBSERVATION WELLS AND PIEZOMETERS

Field number	State well number	Depth of hole, in feet	Length of casing,* in feet	Depth of perforations, in feet	Formation tapped	Aquifer
POO-1A	32S/12E-24B3	964	435	270-435	Careaga sand	--
POO-1B	32S/12E-24B2	964	145	120-145	Paso Robles	B zone
POO-1C	32S/12E-24B1	964	65	48-65	Alluvium	Lower zone
POO-2A	32S/12E-24R3	848	390	300-390	Careaga sand	--
POO-2B	32S/12E-24R2	848	100	75-100	Paso Robles	A zone
POO-2C	32S/12E-24R1	848	60	30-60	Paso Robles	A zone
POO-3A	32S/13E-30F3	802	372	305-372	Careaga sand	--
POO-3B	32S/13E-30F2	802	100	75-100	Paso Robles	A zone
POO-3C	32S/13E-30F1	802	55	15-30 40-55	Paso Robles	Seimperched-A zone
POO-4A	32S/13E-30N2	873	255	175-255	Paso Robles	B zone
POO-4B	32S/13E-30N3	873	135	60-135	Paso Robles	A zone
POO-4C	32S/13E-30N1	873	40	15-40	Alluvium	Upper zone
POO-5A	32S/13E-31F4	906	565	480-565	Careaga sand	--
POO-5B	32S/13E-31F3	906	260	240-260	Paso Robles	B zone
POO-5C	32S/13E-31F2	906	152	132-152	Paso Robles	A zone
OFO-1A	11N/36W-13K6	1,165	400	320-400	Paso Robles	C zone
OFO-1B	11N/36W-13K5	1,165	270	230-270	Paso Robles	B zone
OFO-1C	11N/36W-13K4	215	203	120-203	Paso Robles	A zone
OFO-1D	11N/36W-13K3	215	90	70-90	Alluvium	Seimperched
OFO-1E	11N/36W-13K2	215	45	30-45	Alluvium	Semiperched
GO-1A	10N/36W-2Q1	671	671	568-671	Paso Robles	E zone
GO-1B	10N/36W-2Q2	671	535	467-535	Paso Robles	D zone
GO-1C	10N/36W-2Q3	448	444	397-444	Paso Robles	C zone
GO-1D	10N/36W-2Q4	448	378	291-378	Paso Robles	B zone
GO-1E	10N/36W-2Q5	448	246	185-246	Alluvium	Lower member
GO-1F	10N/36W-2Q6	448	176	130-176	Alluvium	Lower member
GO-1G	10N/36W-2Q7	47	47	19-47	Alluvium	Semiperched
GO-2A	11N/36W-35J2	629	615	527-615	Paso Robles	D zone
GO-2B	11N/36W-35J3	629	495	247-495	Paso Robles	B - C zone
GO-2C	11N/36W-35J4	629	228	175-228	Alluvium	Lower member
GO-2D	11N/36W-35J5	138	138	74-138	Alluvium	Lower member
GO-2E	11N/36W-35J6	37	37	14-37	Recent sand dune	--

*Diameter of casing for wells is 2 inches, except for POO-3C and POO-4C which are 1 inch.

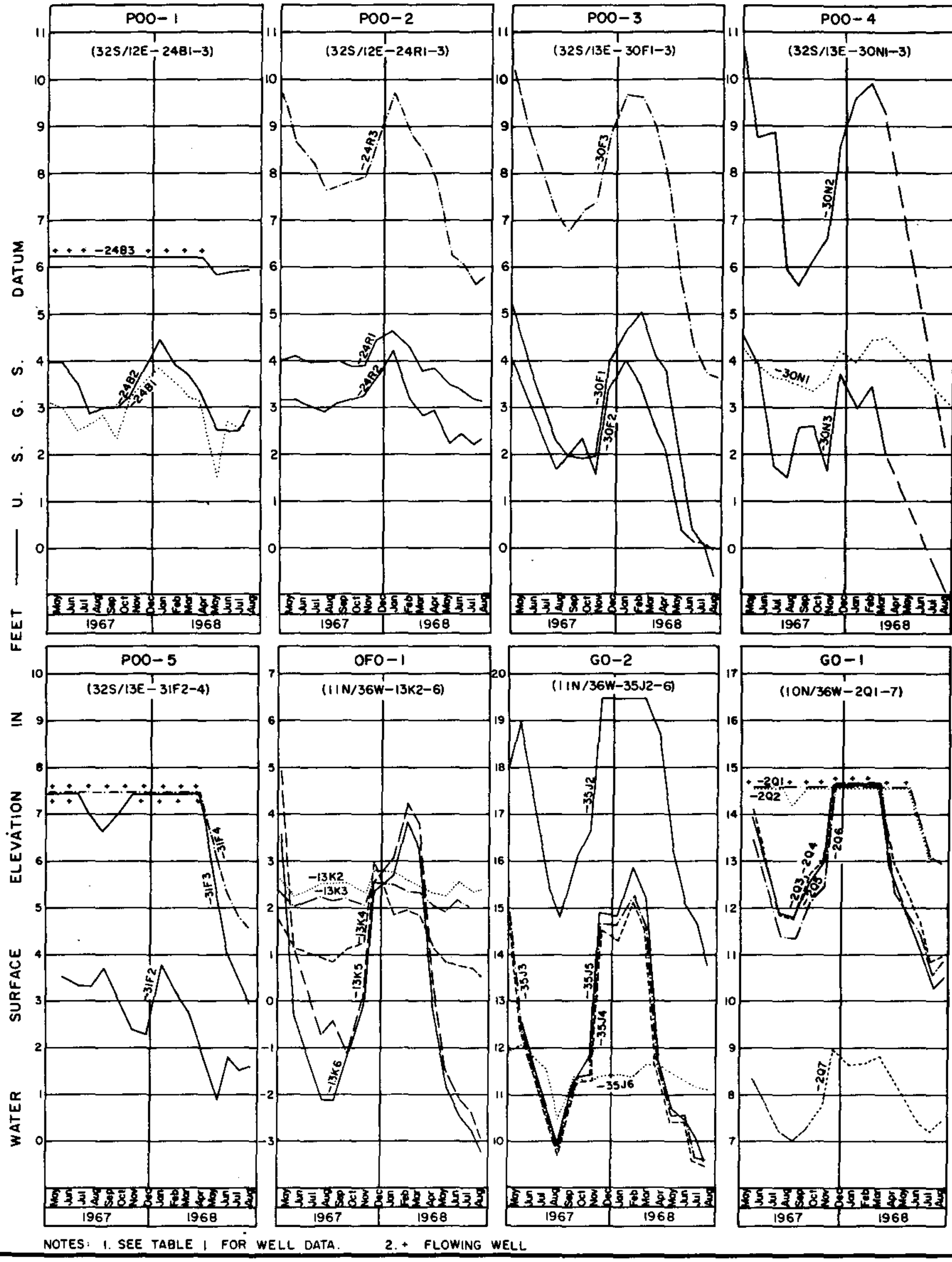

Figure 7. HYDROGRAPHS OF WATER LEVEL IN OBSERVATION WELLS

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CHAPTER V. WATER QUALITY

This chapter reports on the findings of the study that was made into the quality of surface and ground waters. The findings are reported by hydrologic subunits.

In the analyses, emphasis was put upon chloride content because it is generally considered the indicator of seawater intrusion. However, the waters were also analyzed for total dissolved solids (TDS), total hardness, sulfate, and nitrate. Criteria for classifying the waters for domestic and municipal uses and for agricultural uses are given in Appendix C.

The Pismo-Guadalupe area has a relative abundance of small perennial streams and marshes, lakes and lagoons. The standing bodies are due principally to the damming effects of a coastal dune ridge. The waters are tapped locally for minor domestic, stock, and agricultural uses and have limited potential for future development.

As has been pointed out earlier, ground water is supplied primarily from a principal reservoir and, to a lesser amount, from a number of semi-perched water bodies.

The variation in quality of the different ground waters results principally from the differences in their modes of recharge, the quality of the recharge water, and the chemical composition of the geologic environment, and from their susceptibility to degradation from evapotranspiration, residual salt deposits, return irrigation water, sewage, and downward percolation of sea water entering tidal channels at times of extremely high tides.

Pismo Hydrologic Subarea

Very little of the Pismo Subarea is in the study area; it occupies the northernmost part of the area.

Surface Water

Surface waters include perennial flow and storm runoff in Pismo Creek and mixed stream and tidal water in a coastal lagoon. Selected water quality data are listed in Table 2. Electrical conductivity (EC) and chloride measurements for water in the lagoon are listed in Table 3.

Under historic conditions, ground water levels are generally higher than the lagoon surface, preventing significant recharge from that source.

Ground Water

Comparative chemical data for the several ground water bodies are listed in Table 4.

Pronounced changes in quality are associated with water flowing through the Recent alluvium, progressing downstream from a canyon to a former tidal flat environment. Graphic comparison of these differences and trends is shown by the Stiff diagrams plotted in Figure 8.

The pattern of each diagram reflects the equivalent parts per million (epm) concentration of the major cations (increasing left from 0) and the major anions (increasing right from 0).

TABLE 2

CHEMICAL QUALITY OF PISMO CREEK AND LAGOON

1961 - 1967

Source	Location	Flow	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
				In parts per million				
Pismo Creek	SPRR* and Hwy 101 bridges	Perennial	$MgCaHCO_3$	770-920	530-610	90-140	130-150	3-11
		Storm runoff	$MgCaHCO_3$	200-260	120-130	30	20-40	1-4
Lagoon	Cypress St. bridge**	Tidal lagoon	NaCl	4310	1,180	1,960	380	3

*Southern Pacific Railroad.
**One mile inland from ocean.

TABLE 3

ELECTRICAL CONDUCTIVITY AND CHLORIDE TRAVERSE
OF PISMO CREEK LAGOON

October 1967

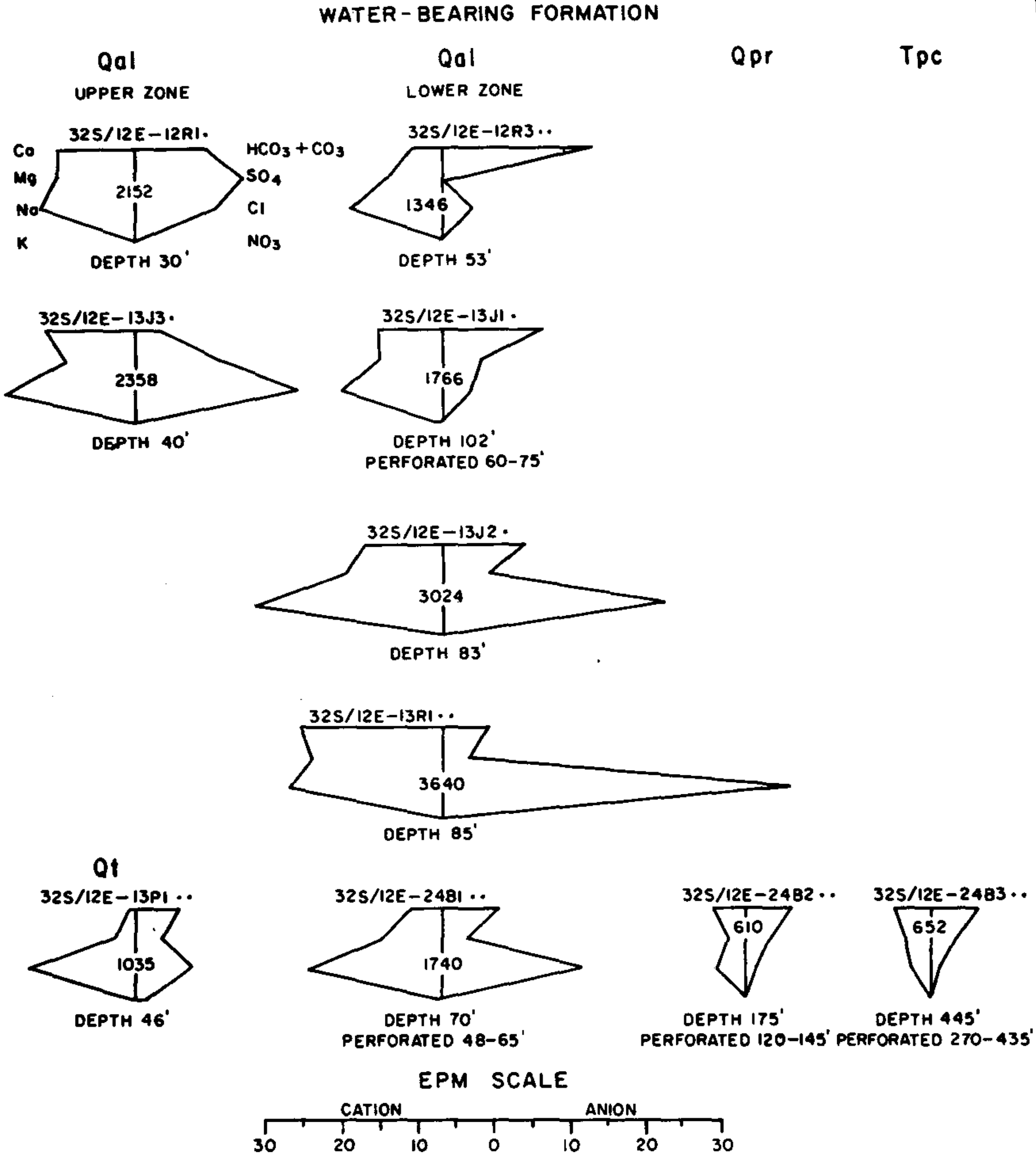
Location	Distance from ocean in feet	E C in micromhos/cm	Cl in ppm
Beach	400	8,000	2,190
Cypress St.	1,300	7,160	1,960
Lagoon head	2,000	3,200	760

TABLE 4

CHEMICAL QUALITY OF GROUND WATERS
PISMO HYDROLOGIC SUBAREA

1961 - 1967

Water-bearing formation	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
			In parts per million			
Recent alluvium upper zone	$NaMgSO_4HCO_3$ NaCaCl	2,000-2,360	570-1,100	285-770	540-680	0-48
lower zone	$NaHCO_3$ $NaMgHCO_3Cl$ NaCl	1,270-1,470 1,450-1,930 1,630-4,570	500-560 740-930 580-1,760	140-210 280-530 650-1,840	0-60 200-250 220-340	0-23 0-5 0-10
Pleistocene terrace deposits	$NaClHCO_3$ NaCl	760-1,160	60-330	160-330	120-180	55-100
Paso Robles Formation	$CaNaHCO_3$	540-610	330-380	40-60	140-150	0-2
Careaga Sand	$CaNaHCO_3$ $CaMgHCO_3$	570-670	330-410	40-80	150-160	0-3



NOTE:

TOTAL DISSOLVED SOLIDS IN PPM SHOWN INSIDE STIFF DIAGRAMS.

• SAMPLE COLLECTED JUNE-JULY 1964.

•• SAMPLE COLLECTED SEPTEMBER-OCTOBER 1967.

WELLS LISTED VERTICALLY IN DOWNSTREAM ORDER; LOCATION SHOWN ON PLATE 4.

WELLS LISTED ACROSS ARE ADJACENT OR EQUIDISTANT FROM THE OCEAN.

SEE FIGURE 3 FOR AQUIFER IDENTIFICATION.

Figure 8. STIFF DIAGRAMS OF GROUND WATERS—PISMO HYDROLOGIC SUBAREA

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

Chemical character is given by shape, and TDS (shown inside each diagram) is indicated by size.

The upstream water in the lower zone of the alluvium is similar chemically to that in flanking sandstone of the Pismo Formation.

Downstream from Section 12, Township 32 South, Range 12 East, ground water of the lower zone gains in dissolved mineral matter, particularly sodium and chloride. A dark gray color, hydrogen sulfide odor, and stable sulfate (contrasting with increasing TDS) indicate the activity of sulfate-reducing bacteria common to tidal flat environment.

The comparatively high chloride in the terrace deposits will be discussed in the next chapter.

Chemical data for ground water in the Paso Robles Formation is available only for piezometer POO-1B (well 32S/12E-24B2), April 1965 to September 1967. Chloride decreased during January 1966 to September 1967. Minor chemical changes and reducing chloride are unrelated to piezometric fluctuations and probably reflect latent flushing of drilling mud filtrate.

Chemical analyses of ground water in the Careaga Sand are limited to piezometer POO-1A (well 32S/12E-24B3). Decreases in TDS and chloride since April 1965 are probably due to gradual flushing of drilling mud filtrate.

As shown in geologic section A-A' on Plate 2A, a wedge of salt water rising in elevation from south to north (toward an outcrop on the ocean floor) is present in the basal Careaga Sand. This formation has an undersea outcrop west of the northern end of the section. Although this salty water is intercepted by the bottom 20-foot perforated section of the piezometer, this water is clearly not being withdrawn during sampling. The 2-inch piezometer yields artesian flow up to 15 gallons per minute, principally from overlying, more permeable, fresh water beds.

Approximate values for TDS and chloride in the salt water zone can be determined from electric logs and empirical relationships between EC, TDS, and chloride of local waters. Concentrations are as follows:

Site	Depth in feet	TDS in ppm	Cl in ppm
POO-1	425	4,200	1,900
	690	6,800	3,450
POO-2	630	5,850	2,900

Arroyo Grande Hydrologic Subunit

The Arroyo Grande Subunit occupies most of the middle of the study area. It covers both the Tri-Cities and Nipomo Mesas.

Surface Water

Surface waters in Arroyo Grande Hydrologic Subunit include perennial flow and storm runoff of three creeks, shallow perennial lakes and marshes, a tidal estuary and lagoons, and irrigation return water in drainage ditches. The chemical quality of the creeks is compared in Table 5 and of the lakes and ditches in Table 6.

The extent that Arroyo Grande Creek undergoes tidal mixing in the coastal estuary is uncertain, but sea water may reach the estuary head about 2,400 feet inland during low stream flow. Immediately to the south, tidal action reportedly extends 3,000 feet inland to flooded sand pits which connect by a drainage ditch with the creek channel.

Meadow Creek, a small perennial stream originating at Pismo Lake, flows inland

TABLE 5

CHEMICAL QUALITY OF ARROYO GRANDE, LOS BERROS, AND MEADOW CREEKS

Creek	Location	Flow	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
				In parts per million				
Arroyo Grande	USGS gage and Highway 101 bridge	Perennial	$CaMgHCO_3$	720-830	540-580	30-50	220-240	0-5
		Storm runoff	$CaMgHCO_3$	490	370	20	130	3
	Highway 1 bridge	Ephemeral	$MgCaHCO_3$	700	590	40	130	14
	SPRR bridge*	Slight runoff	$CaMgHCO_3$	490-680	350-480	20-40	130-180	3-7
	0.7 mile from ocean (in estuary)	Ephemeral	$CaMgHCO_3$	710	510	30	190	8
Los Berros	Valley Road bridge	Slight runoff	$CaMgSO_4$	1,790	1,110	120	690	9
Meadow	Highway 101 bridge	Slight runoff	$NaMgHCO_3Cl$	970	390	260	70	0
	SPRR bridge*	Sump	NaCl	2,810	700	1,010	10	4
	Le Sage Golf Course west of P00-3	Lake	NaCl	1,940	660	630	370	16
		Perennial	NaCl	1,810	690	560	310	9
	Pier St. bridge**	Lagoon	$NaMgHCO_3Cl$	1,040	550	210	230	6
			NaCl	7,630	1,680	3,460	740	0

*Southern Pacific Railroad.
**One-third mile from ocean.

of a coastal dune ridge, through marshes and lagoons, to its junction with Arroyo Grande Creek near the ocean. This drainage occupies a former tidal slough filled with dune sand and fluvial sediments containing residual marine evaporite and sands. Accordingly, surface and shallow contributing ground waters of Meadow Creek are chemically similar to fresh water degraded by incipient sea-water intrusion. These waters are poorer in quality than inland ground waters and, locally, are causing slight degradation of shallow ground waters where levels are depressed by pumping.

Downstream to the lagoons, TDS and chlorides decrease, and in the interconnected lagoons of Pismo Beach State Park, the quality fluctuates. This is shown by the variation in quality of two samples collected at Pier Street Bridge in Table 5.

Ten shallow lakes maintained chiefly by ground water seepage are contained in sand dunes at the edge of Nipomo Mesa. The chemical quality of these waters indicates two sources of supply: (1) unconfined ground water of excellent quality underlying Nipomo Mesa and (2) poor quality semiperched ground water of the lower Arroyo Grande Plain. Chemical data are given in Table 6.

Unconfined ground water beneath Nipomo Mesa intercepts ground surface in Black Lake Canyon, forming a shallow slough which feeds Black Lake and Mudd Lake to

TABLE 6

CHEMICAL QUALITY OF IRRIGATION RETURN WATER AND SAND DUNE LAKES 1961-1967

Source	Location	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
			In parts per million				
Irrigation ditch s/o Arroyo Grande Creek	0.7 mile from ocean	$CaMgSO_4$	1920	1210	180	690	88
Irrigation ditch	12N/35W-31K	$CaMgHCO_3SO_4$	1380	830	160	330	20
Celery Lake	North shore	$CaMgSO_4$	2330	1280	220	1000	6
Big Twin Lake	East shore	$NaMgHCO_3$	1860	890	350	210	2
White Lake	North shore	$NaClSO_4$	2210-2400	510-870	490-680	150-330	3-37
	South shore	$MgNaSO_4Cl$	1910	920	280	660	37
Mud Lake	South shore	NaCl	1970	610	650	80	3
Black Lake	South shore	NaCl	540-740	100-170	190-300	10	3
Black Lake Canyon Slough	Hwy 1	NaCl	340	50	120	10	5

the west and White Lake to the north. Data in Table 6 show a progressive downstream increase in TDS.

Ground Water

Table 7 lists the range in concentration of selected constituents for predominant water types in the various aquifers of the Arroyo Grande Hydrologic Subunit.

Figure 9 presents the nitrate concentration.

In the upper zone of the Recent alluvium underlying Arroyo Grande Creek, recharge is from irrigation return water and sewage.

Water in the lower zone gains in mineral content downstream to Highway 101. From there, it passes out of flanking Tertiary rocks containing brackish water (to the east) into Pleistocene deposits containing fresh water and it shows a decrease in TDS. This freshening (500 ppm decrease in TDS) is attributed primarily to recharge from underlying and flanking aquifers (Nipomo Mesa) of the Paso Robles Formation and Careaga Sand. In contrast, chloride is relatively uniform.

Nitrate exceeds 45 ppm at 7 to 15 wells sampled in the lower zone. Abrupt lateral changes, the lack of any consistent areal trend, and the relatively wide concentration range for a narrow, confined ground water body suggest that high nitrate is not present in the aquifer but is added externally by fertilizing procedures. The addition of

TABLE 7
CHEMICAL QUALITY OF GROUND WATERS
Arroyo Grande Hydrologic Subunit
1961–1967

Water-bearing formation	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
		In parts per million				
Recent alluvium						
Arroyo Grande Creek						
Upper zone	$CaMgSO_4HCO_3$) $MgCaHCO_3SO_4$)	940-1600	590-1110	60-270	290-640	2-143
(coastal)	NaCl	2500-2872	600-720	960-1100	340-410	1-4
Lower zone	$CaMgSO_4$) $CaMgSO_4HCO_3$) $MgSO_4HCO_3$)	1330-1930	890-1290	70-160	430-820	0-138
Los Berros Creek	$CaMgHCO_3$	730-790	470-520	70	180-200	3-18
	$CaMgSO_4HCO_3$	1040-1710	620-1100	100-170	400-550	25-80
Paso Robles Formation						
Western area*						
Semiperched	$NaClNO_3$	240-540	90-190	80-90	10-90	90-140
	$CaMgSO_4HCO_3$	490-870	270-490	50-100	110-210	34-150
	NaCaCl	1900-1960	840	540-580	380-440	26-31
A zone	$NaCaClNO_3$	410-590	90-280	50-130	40-110	66-163
	$CaMgHCO_3SO_4$	510-1010	330-620	40-110	100-394	0-115
	$CaMgHCO_3$	460-720	280-520	30-140	80-190	0-32
	$MgCaHCO_3$					
	NaCl	1677-2410	630	600-870	90-160	0-8
B zone	$NaClNO_3$	200-340	50-100	50-70	0-40	54-115
	$CaMgHCO_3$	430-770	290-490	30-80	80-180	0-44
	$CaMgSO_4$	1020-1160	610-650	50	480-550	0-2
Paso Robles Formation						
Eastern area*						
Semiperched	$NaNO_3Cl$	230-620	70-180	30-110	10-20	103-195
A and B zones	NaCl	160-270	30-60	40-100	0-20	0-52
C, D and E zones	$CaMgHCO_3$	470	280	50	90	20
	$CaMgSO_4HCO_3$	380-720	300-580	50-80	100-230	0-10
	$CaMgSO_4$	550-990	300-580	40-50	200-460	0-3
Careaga Sand	$CaMgHCO_3$	550-690	230-490	30-70	150-190	0-2
	$CaMgSO_4$	950-1010	600-620	40-50	360-390	0-2
Pismo Formation	NaCl	200-470	30-270	50-180	10- 80	0-6
	$NaHCO_3$	240-1150	100-450	60-130	0-20	0

*For convenience, Paso Robles Formation is divided into an eastern and western area at approximately Highway 1.

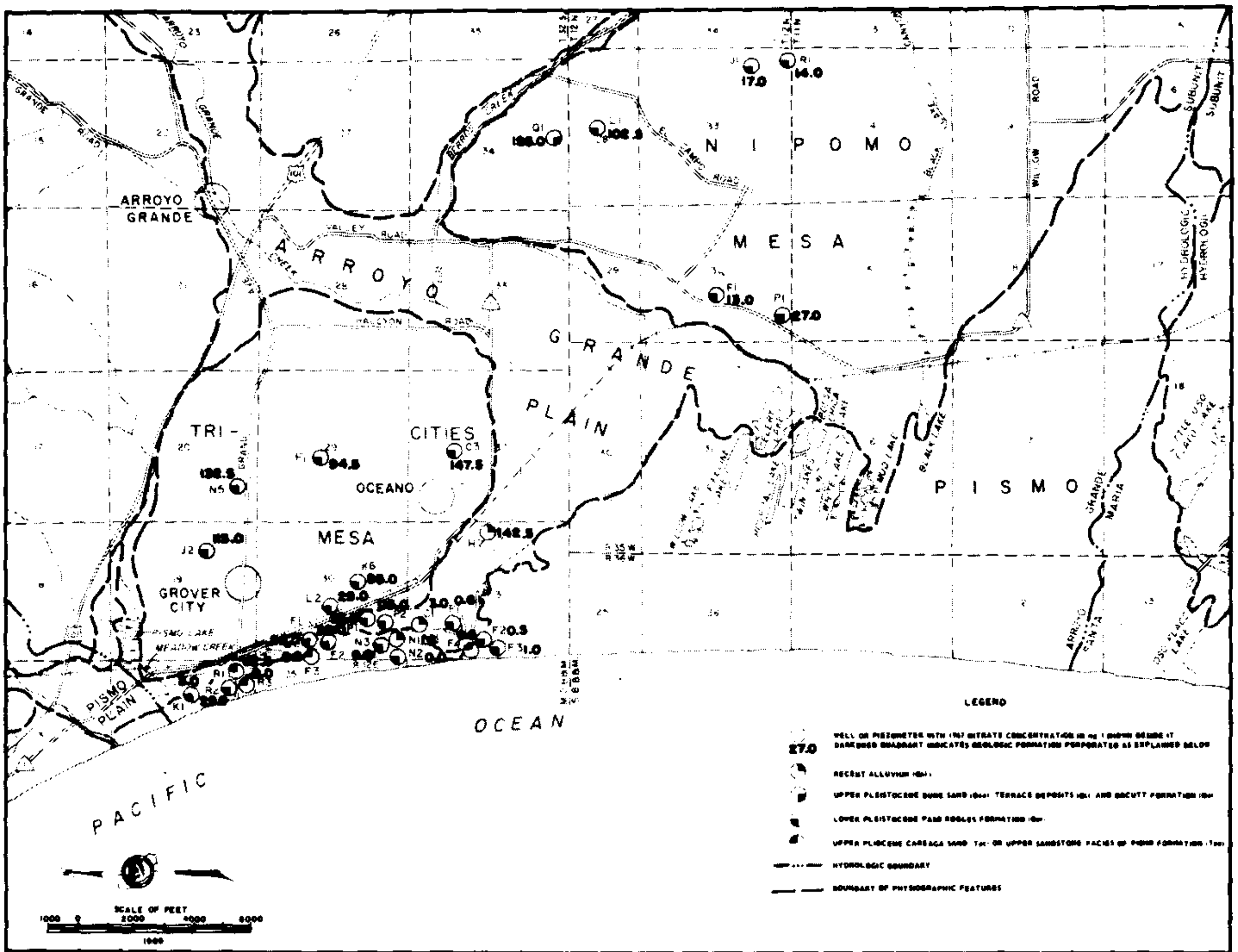


Figure 9 -NITRATE CONCENTRATIONS OF GROUND WATER-1967, ARROYO GRANDE HYDROLOGIC SUBUNIT

liquid fertilizer from a pressure tank to the well discharge near the pump is commonly practiced. Occasionally when the pump is shut off, liquid fertilizer is allowed to enter the well casing.

Water underlying Los Berros Creek gains in dissolved mineral matter and changes in chemical character as it passes downstream through a narrows cut in Franciscan and Tertiary rocks.

Chemical analyses of ground water in fine-grained alluvium of Meadow Creek south of the Pismo Hydrologic Subarea are unavailable. However, ground water in the Pismo Hydrologic Subarea and surface water of Pismo Lake, Meadow Creek and La Sage Lake are similar. Data for the surface waters and degraded ground water of the underlying Paso Robles Formation indicate that the shallow Recent deposits contain sodium chloride or sodium-calcium chloride ground water. TDS and chloride probably exceed 1,700 and 600 ppm, respectively.

Isolated bodies of semiperched ground water occur in shallow Paso Robles Formation beds beneath Tri-Cities Mesa where the A zone is capped by silt and clay. Recharge consists of vertical percolation of rainfall and, in developed areas, return irrigation water and sewage. Accordingly, the chemical quality is diverse. As shown in Figure 10, ion concentrations in such areas drop abruptly with increased recharge from rainfall (well 32S/13E-32A1 in spring of 1958 and well 32S/13E-32H1 in fall of 1961) and rise as percolated rainwater is dissipated or replaced by return irrigation water.

In the western area, A zone water that is calcium-magnesium bicarbonate in character (subject to sodium-chloride degradation) extends south from a northern recharge area to beyond site P00-2. From site P00-3 south and east, the water is calcium-magnesium bicarbonate-sulfate in character, grading to a magnesium-calcium bicarbonate type in the southwest corner of Section 32, Township 32 South, Range 3 East. Recharge is partially underflow west and north from Arroyo Grande alluvium, but the lower mineral content and high nitrate burden of A zone water indicate a substantial amount of vertical recharge from rainfall and return irrigation water.

Nitrate commonly ranges from 45 to 175 ppm east of Highway 1 to approximately the middle of Section 29, Township 32 South, Range 13 East (where the A zone grades to fine-grained sediments). Concentrations decrease progressively south to Sections 31 and 32 and probably are less than 30 ppm beneath Arroyo Grande Plain.

Recharge of B zone water is primarily underflow from the north and east, with a change in the character of the water from sodium to calcium-magnesium. The predominance of calcium and magnesium over sodium is mainly due to solution of existing evaporite minerals: calcite ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$), and magnesium sulfate. This is supported by the increase of sulfate and bicarbonate ions in the same water. At the coast, chemical character changes and dissolved minerals increase from north to south, reaching peak levels at P00-5. This coincides with and probably results from a coarse to fine-grained facies change of the aquifer.

The water that underlies Tri-Cities Mesa (Section 19) north of the pumping depression is low in dissolved minerals and chemically similar to overlying zone A water recharged by percolation of rainfall and return applied water.

Based on water quality monitoring at wells 32S/13E-28E1, -29G1, and -29G2, chemical quality of B zone water in the pumping depression has been essentially stable since 1950. This area is geologically most susceptible to vertical degradation. However, nitrate has increased at each well from initial values of less than 15 ppm to 44 ppm. This and the transient change in anion character from bicarbonate to bicarbonate-sulfate at wells -29G1 and -29G2 indicate recharge from overlying A zone water.

The abrupt drop in TDS (about 1,150 ppm) between B zone well -28E1 and lower alluvial well -27D3, the different chemical character of B zone and alluvial waters, and the steepening of the hydraulic gradient between the aquifers all substantiate the conclusion that underflow west from Arroyo Grande alluvium to the municipal pumping depression is constricted by a coarse to fine-grained facies change of the Paso Robles Formation.

Ground water in the eastern area of the Paso Robles Formation underlying Nipomo Mesa and the eastern fringe of Arroyo Grande Plain is fairly uniform

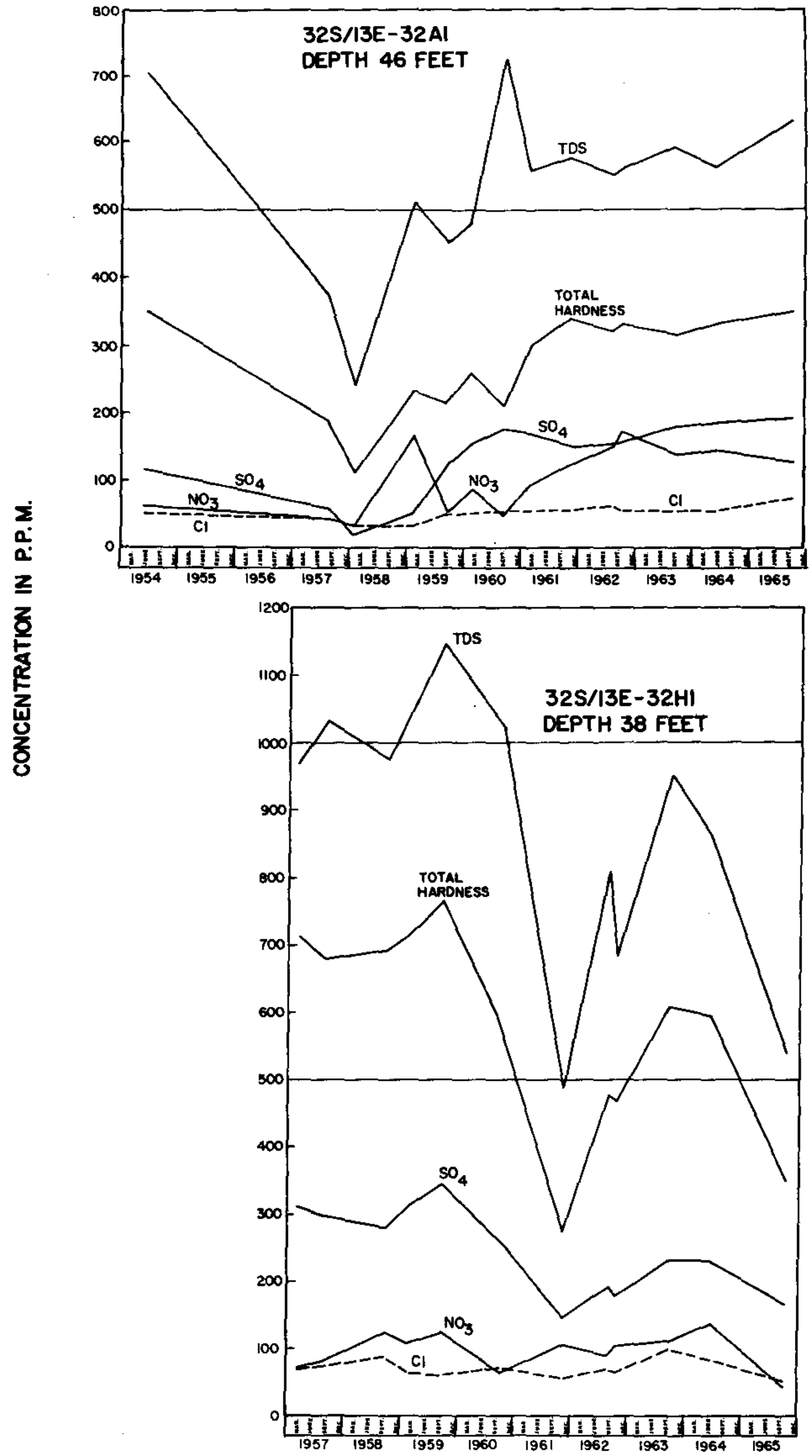


Figure 10- FLUCTUATION IN CHEMICAL QUALITY OF SEMIPERCHED GROUND WATER—TRI-CITIES MESA

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in chemical quality areally, as may be seen in Figure 11.

Unconfined water (A and B zones) underlying Nipomo Mesa is recharged principally by percolation of rainfall. Where recharge is in part by percolating sewage or agricultural waste water, the anion character is changed from chloride alone to nitrate-chloride.

Only at well 12N/35W-29R1 does nitrate increase to 50 ppm.

Judging from the limited historic recharge of return applied water and longterm monitoring of one Nipomo Mesa well (11N/35W-9P1) since October 1953, the quality of this water has remained essentially stable. However,

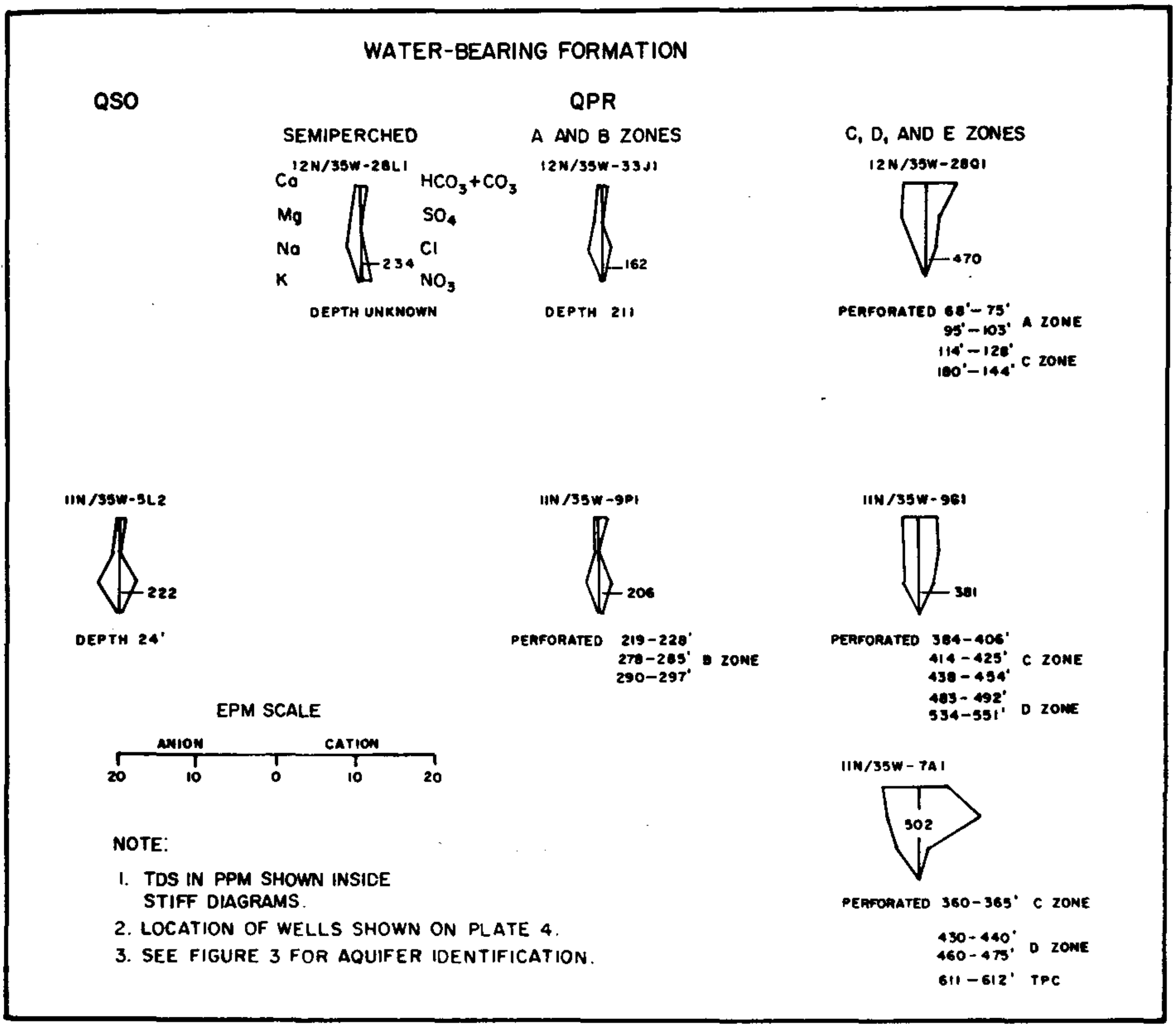

Figure 11- STIFF DIAGRAMS OF GROUND WATERS – NIPOMO MESA

it is readily subject to degradation from percolating waste waters.

The change from sand to clay in the Paso Robles Formation causes perching of percolating waters at the north limit of Nipomo Mesa. This semiperched water is tapped by wells 32S/13E-34Q1 and 12N/35W-28L1, and at both is degraded by return applied water. The wells are peripheral to an irrigated field. In addition to being near an irrigated field well 32S/13E-34Q1, which yields the highest nitrate-laden water of the study area is near a cesspool.

Available data on confined ground water (C, D, and E zones) underlying Nipomo Mesa indicate that the anion character grades from bicarbonate to sulfate. The bicarbonate water appears to: (1) overlie the sulfate water, (2) be limited to the C zone, and (3) mix locally with chloride water (wells 12N/35W-32F1 and -33B2) or be replaced by it (well -32N1) where the confining layer is discontinuous and vertical recharge is significant. A lateral bicarbonate to sulfate transition with a corresponding increase in TDS, total hardness, and sulfate is evident from south and west (downdip) toward wells 11N/35W-7A1,-7R1, and -17D1.

The chloride and nitrate increase slightly where confined and unconfined water mix naturally or artificially as a result of flow between perforations in wells taking both zones. The sulfate water is extracted from deeper wells (including several partially perforated in the Careaga Sand).

The quality of the confined waters has remained stable and, except where the confining cap is broken, it is not subject to degradation from percolating wastes. Data for one well 11N/35W-7A1, show no appreciable chemical changes between October 1953 and July 1967.

From P00-1 (in Pismo Hydrologic Subarea) south to P00-3, water in the upper Careaga Sand is calcium-magnesium bicarbonate in chemical character. The native chloride concentration is probably 30 to 50 ppm. Higher initial values at each site, ranging to 70 ppm and decreasing with time, are attributed to gradual flushing of drilling mud filtrate. Total hardness decreases from north to south and sulfate increases from north to south.

At P00-5, chemical character is altered to calcium-magnesium sulfate, the standard type of the Santa Maria Hydrologic Subunit. Chemical differences and the higher piezometric level at P00-5 indicate poorer quality water at the site is flowing west from Nipomo Mesa.

As noted previously, in the bottom of the formation is a wedge of salty water. It pinches out between P00-2 and P00-3. Its inland boundary is undeterminable, but probably does not extend past Highway 1. Beyond the salt water wedge, electric logs indicate the basal Careaga contains poor quality water or is fine grained.

At present, the salt water wedge is essentially stable or in equilibrium with long-term average recharge and upward and offshore discharge. If this native state is upset by pumping, the salty water can be expected to move upward, south, and inland toward extraction centers. This, however, does not preclude the use of Careaga water because the rate of advance would be slight, (assuming the aquifer is not overdeveloped) and it could be regulated by controlled pumping. Limited development and regulated pumping are both feasible because increased design, construction, and drilling costs will be required for Careaga wells.

In the Pismo Formation and shallow alluvium of minor stream beds of the San Luis Hills (Between Pismo and Arroyo Grande Creeks), there is a natural mineral gain and a sodium chloride to sodium bicarbonate change between wells drilled less than 200 feet and oil wells that are 900 to 1,000 feet deep.

Santa Maria Hydrologic Subunit

The Santa Maria Subunit takes in the southern half of the study area.

Surface Water

Surface waters in the coastal Santa Maria Plain include perennial flow and storm runoff of the Santa Maria River and two small creeks, shallow perennial lakes and marshes, and return irrigation water in drainage ditches. Table 8 compares the quality of those surface waters that have been analyzed for chemical constitutents.

The Santa Maria River, from near its origin at the confluence of the Sisquoc and Cuyama Rivers (east of the study area) to within 3 miles of the ocean, sustains surface flow only during winter storms. Most of the tributary flow is regulated by impoundment and controlled release at Twitchell Dam, constructed on the Cuyama River in 1958. Hence, present storm flow is supplied principally by the Sisquoc River. Perennial flow occurs in a 3-mile stretch between the Guadalupe Sewage Treatment Plant and the ocean and is supplied by an undetermined blend of primary treated sewage effluent and semiperched water.

Runoff reaching the study area varies in quality with the rate of flow. The greater the flow rate the better the quality. At low flow, water in the river is equivalent to or better in

TABLE 8

CHEMICAL QUALITY OF SURFACE WATERS IN THE SANTA MARIA BASIN

1961 - 1967

Source and location	Flow	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
			In parts per million				
Santa Maria River Highway 1 bridge	Storm runoff	$CaMgHCO_3$	250	160	10	80	2
	Slight runoff	$CaMgSO_4$	1,600	930	90	680	0
Effluent from Guadalupe Plant to Santa Maria River	.035 MGD average	$Ca(NaMg)SO_4$	2020-2320	1040-1170	240-320	850-900	5-9
Green Canyon Creek Highway 1 bridge	Storm runoff	$NaMgCaSO_4Cl$	720	250	120	210	2
Oso Flaco Lake	--	$Ca(NaMg)SO_4$	1100-1480	630-930	100-130	430-670	0-11
Little Oso Flaco Lake	--	$Ca(NaMg)SO_4$	1120	620	80	410	2

quality than the semiperched ground water.

Oso Flaco Lake, Little Oso Flaco Lake, and the perennial flow of Oso Flaco Creek are sustained by seepage of semiperched ground water from Recent alluvium.

Ground Water

Confined ground water in the aquifers in the Santa Maria Hydrologic Subunit, beneath the valley floor, differs between aquifers in mineral concentration. Underflow from the inland basin is the main source of recharge.

Figure 12 illustrates the vertical, seaward, and lateral changes in chemical quality of water held in different aquifers at three sites. Seaward decreases in mineral concentration (above the C zone) are compared left to right by data for inland site 10N/35W-9N and seaward sites 11N/36W-35J and 10N/36W-2Q. Lateral decreases in mineral concentration approaching Orcutt Mesa are compared left to right by data for coastal sites 11N/36W-35J and 10N/36W-2Q. Vertical improvement in chemical quality of confined ground waters is evident at each site, but only the data for 10N/36W-2Q show the natural mineral gain in the lower Paso Robles Formation.

The range of concentration of selected chemical constituents for each aquifer or formation is given in Table 9.

TABLE 9

CHEMICAL QUALITY OF GROUND WATERS
SANTA MARIA HYDROLOGIC SUBUNIT
1961 - 1967

Water-bearing formation	Chemical character	TDS	Total hardness	Cl	SO_4	NO_3
		In parts per million				
Recent alluvium						
Upper member	$NaHCO_3$	380-6,840	190-2,950	60-450	100-3,710	0-16
	$CaMgSO_4$ and mixtures					
Lower member*	$CaMgSO_4$	900-2,710	530-1,460	50-180	340-1,380	4-87
Orcutt Formation	$CaMgNaSO_4HCO_3$	640-900	350-504	40-290	240-320	0-16
	$CaNaMgSO_4Cl$					
	$CaMgSO_4ClHCO_3$					
Paso Robles Formation**	$CaMgSO_4$	510-1,090	170-600	20-60	190-580	1-13
	$CaMgNaSO_4HCO_3$					

*Includes mixed water from A zone of Paso Robles Formation.
**Data for degraded water of A zone unavailable.

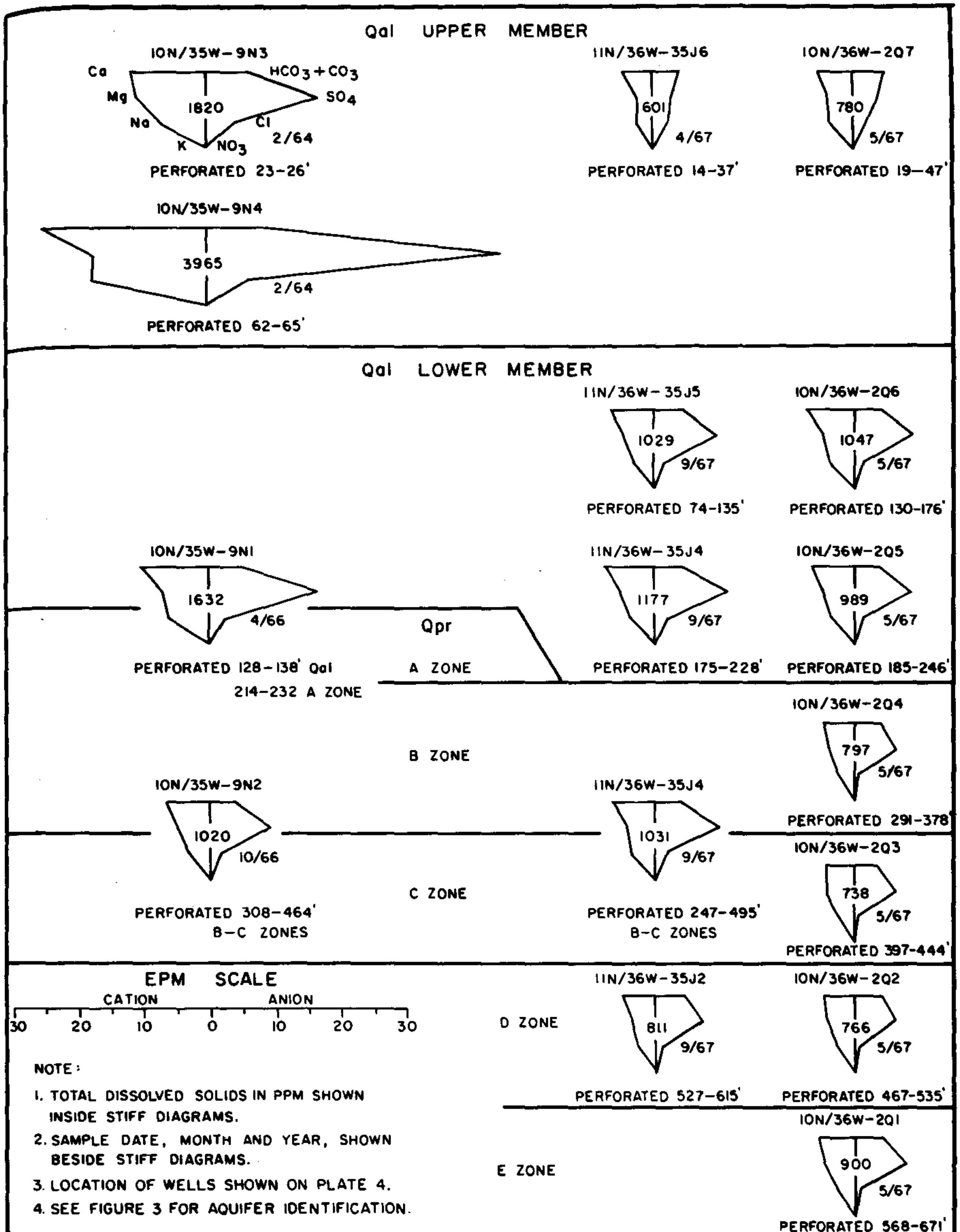

Figure 12. STIFF DIAGRAMS OF GROUND WATERS—SANTA MARIA HYDROLOGIC SUBUNIT

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Of the semiperched water in Recent dune sands and upper alluvium, the best occurs in predominantly sandy deposits near Nipomo Mesa and beneath the coastal dunes where recharge is primarily from rainfall and where degradation from return irrigation is negligible. This water contains 380 to 750 ppm TDS. Chlorides range from 60 to 140 ppm, with local increases to 290 ppm near the coast (piezometer 10N/36W-2G2). Sulfate is less than 300 ppm and nitrate, 16 ppm.

At USGS multiple piezometer installations 10N/35W-6A1-3 and 10N/36W-12K2-3 and DWR site OFO-1, salinity decreases with depth in upper alluvial deposits. At USGS multiple piezometer site 10N/35W-9N3 and -9N4, the reverse is true.

In the lower member of the Recent alluvium, ground water of near native quality at the coast contains 900 to 1,190 ppm TDS and 50 to 80 ppm chloride. Nitrate is less than 15 ppm. Total hardness is 530 to 670 ppm and sulfate is 340 to 530 ppm. Although now beneath nonirrigable sand dunes, this and offshore water (probably of better quality) would flow landward if the present seaward hydraulic gradient should be reversed.

Chemical analyses inland of the coast do not give a true measure of water quality in the lower member. Virtually all wells sampled for complete analyses are also perforated in either the A zone of the Paso Robles Formation or, at the south limit of the valley floor, in the Orcutt Formation.

Current data for wells yielding mixed water give a TDS range of 1,240 to 2,710 ppm and a chloride range of 80 to 180 ppm.

TDS increases from west to east and generally from north to south, reaching peak levels at well 10N/35W-16M1. Nitrate is commonly below 25 ppm, but at well 10N/35W-21C1 (depth and perforations unknown) has ranged between 35 and 87 ppm. Total hardness is 650 to 1,460 ppm and sulfate is 480 to 1,380 ppm.

Ground water in the Orcutt Formation, south of the Santa Maria Plain, varies in chemical character, but is fairly uniform in concentration of dissolved minerals.

Monitoring for chloride at a well just east of the study area indicates that upstream waste discharge of sewage, return irrigation water, or sugar refining waste water is causing degradation downstream. Chloride increased from 85 ppm in June 1948 to 287 ppm in June 1965. Conversely, chloride decreases of 109 ppm during 1944-48 and 102 ppm during 1965-67 were likely caused by increased recharge from higher rainfall. These changing chloride concentrations indicate that the Orcutt Formation over a broad area transmits seepage readily, although lenticular silt and clay strata may inhibit recharge locally.

Confined ground water in the Paso Robles Formation is relatively uniform in chemical quality although vertical and lateral changes take place. Among the four aquifers designated from top to bottom the B to E zones, TDS at coastal piezometers increases downward 100 to 300 ppm. Progressing northeast toward Nipomo Mesa, concentrations decrease by 300 to 500 ppm. Recharge from Orcutt Mesa is indicated by a 300 ppm north to south decrease in TDS between piezometer sites GO-1 and GO-2.

Historic increases of 150 ppm TDS at inland well 10N/35W-9N2 (B zone) since 1957 are attributed to slight degradation from recycling processes and seaward encroachment of affected water.

Stable mineral concentrations at wells 11N/35W-18M1 (A zone), -19E2 (A-D zones), and -28L1 (B zone) since 1953 indicate the zone of influence, except in the A zone, is essentially east of Highway 1. Degraded ground water in the A zone, underlying the lower member of the Recent alluvium, may extend to the coast, but the degree of degradation cannot be determined from existing data. Because of this uncertainty, those seeking the best available water should perforate aquifers below a depth of 300 feet.

Chemical analyses of confined ground water in the Careaga Sand are unavailable. Judging from both comparative data for Paso Robles and Careaga aquifers tapped by piezometers (POO) to the north and the natural gain downward in mineral content within the Paso Robles Formation, Careaga water should be slightly higher in TDS but similar chemically to that in the Paso Robles E zone.

However, the Careaga Sand is composed largely of quartz sand, rather than reworked Monterey shale, and is therefore less soluble. This would tend to decrease TDS. On the other hand, greater calcareous cementation of the Careaga Sand may cause a gain in hardness and bicarbonate. Sulfate reduction present in the Pismo Formation (San Luis Hills) may persist south in the Careaga Sand; this would bring a loss in that ion, but a proportionate increase in bicarbonate and possibly an H_2S odor. The large reservoir of untapped water in the Careaga Sand merits development, either by itself or in conjunction with overlying zones.

CHAPTER VI. SOURCES OF SALT WATER DEGRADATION

As was pointed out earlier, this investigation was undertaken when an abnormal increase in chloride concentrations was detected in shallow coastal aquifers between the City of Pismo Beach and Arroyo Grande Creek (Plate 4). Increasing chloride is often a sign of sea-water intrusion.

The study revealed that, although a small amount of sea-water intrusion is taking place in two of the little used aquifers in the northern part of the study area, the chloride in the aquifers south of Pismo Beach comes from other sources.

Accordingly, the study was directed to determining what these other sources might be and what the possibility is for sea-water intrusion in the future.

Experience has shown that sea-water intrusion occurs only when the hydraulic head of the fresh water in an aquifer is less than the hydraulic head of salt water. Once this condition is established, landward flow prevails. Salt water advances inland as a wedge-shaped body along the bottom of an aquifer; normally seaward flow of fresh water continues above the salt water wedge. Accordingly, the salinity of ground water increases downward within an intruded aquifer.

Encroachment of the salt water wedge is identified by a rapid and pronounced gain in chloride, normally a lesser gain in sulfate, a negligible gain in bicarbonate, and no gain in nitrate. (Relative increases in the cations are influenced by base exchange.)

Seasonal fluctuations in fresh water levels affect the advance of the wedge and the salinity of water extracted from wells. Rising water levels (winter and spring) retard or repulse the wedge. Falling water levels (summer and fall) accelerate onshore flow of salt water. Accordingly, pumped water (generally a blend of fresh and salt water) gains in salinity with declining water levels and reduces in salinity with rising levels.

In the study area, available comparative data show that chlorides increase upward within or between aquifers; this indicates a surface source.

Further, there is no correlation between maximum chlorides and minimum water levels. In aquifers having the highest chloride content, the water surface elevation is above the minimal level required for sea-water intrusion. Conversely, chlorides are within the native range in deeper aquifers hydraulically subject to intrusion.

Finally, associated changes in other chemical constituents and the spring peaking in chloride are not indicative of sea-water degradation.

In light of these facts, the causes for abnormal concentrations and local increases in chloride were analyzed for each affected aquifer. Description is given by descending stratigraphic order which corresponds with decreasing chloride degradation.

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Recent Alluvium--Pismo Creek

Prior to construction of piezometers at well 32S/12E-24B1 (POO-1) in April 1965, the downstream sodium-chloride gain (to well 32S/12E-13R1) in ground water of Recent alluvium was assumed to be caused by sea-water intrusion (Figure 8). Proximity to the San Luis Hills also suggested recharge from saline connates.

These assumptions are unsupported by hydrogeochemical data--both historic and those recently acquired. Historic water levels and chloride concentrations for suspected wells and piezometer 32S/12E-24B1 are compared in Figure 13. The data show that an essentially stable, positive water level has persisted since 1954; therefore, a seaward hydraulic gradient has been sustained in the lower alluvial zone. Water levels have not been low enough to permit sea-water intrusion. Chloride concentrations decrease between well 32S/12E-13R1 and the piezometer, located seaward of the well. This basic evidence clearly precludes sea-water intrusion, pointing instead to a landward source.

If upward movement of saline connates or salty water present in the basal Careaga Sand were taking place, the lower alluvial zone would contain higher chloride water. Also these sources would cause an upstream chloride gain toward Price Canyon where Recent alluvium lies directly upon Pliocene beds. Neither of these conditions is met; at well -13R1 (which yields the high chloride water), the lower alluvial zone is underlain by fresh water-bearing deposits. Furthermore, ground waters extracted from 900- to 1,100-foot depths by oil wells upstream in Price Canyon are low in chloride. Chloride concentrations in three waste discharges (Signal Main, Signal Rock, and Hyla sumps) were less than 150 ppm in October 1967.

Therefore, the water was analyzed for trace elements in an effort to determine its source. Application of trace elements for determining the source of chloride is illustrated by the data of Bradford at University of California, Riverside, plotted in Figure 14. The significant feature is the seaward trend in concentration of the most abundant elements in chloride-degraded ground water relative to the concentration of those elements in sea water. Downstream trace element trends are reversed or inconsistent with those which would develop from intrusion, particularly: (1) the seaward decrease in boron, strontium and probably barium; (2) the seaward increase in manganese; and (3) the lack of seaward dilution in molybdenum. Similar trends for molybdenum and manganese are given by USGS data, which also show no seaward gain in aluminum. These conditions substantiate that sea water is not the source of chloride.

From a study of trace element concentrations in surface and ground waters of California, oil field brines, deep-seated springs, and sea water, Silvey (1967) found enrichment of germanium in waters of deep origin (more than 500 ppb for springs and an average of 14 ppb for brines) and undetectable amounts in ground water, sea water, and all but two of 65 stream waters. A Department study (1967) of trace elements in thermal springs of Long Valley, California, confirms the association of germanium with deep sources. The undetectable germanium content (less than 0.3 ppb) in ground waters of the Pismo Hydrologic Subarea, therefore, precludes saline connates as a chloride source.

When the data failed to support the assumptions, the explanation for the chloride degradation of this water was sought elsewhere. Local residents report that the alluvial soil is rich in "alkali salts" and that "alkali salt water" (sodium chloride taste) was encountered by the first city wells constructed in Recent alluvium prior to

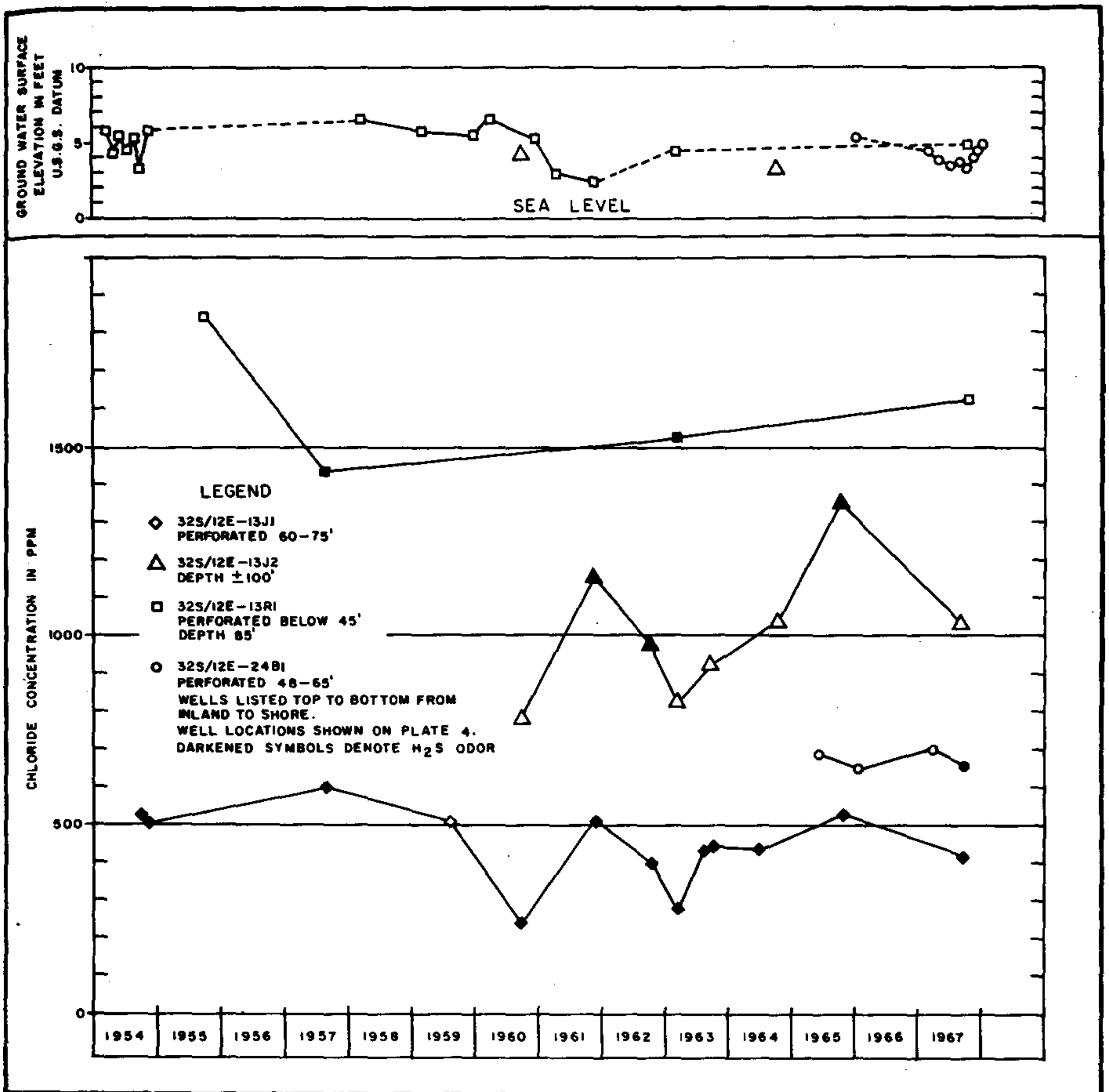

Figure 13. CHLORIDE AND WATER LEVEL TRENDS IN THE LOWER ALLUVIAL ZONE — PISMO HYDROLOGIC SUBAREA

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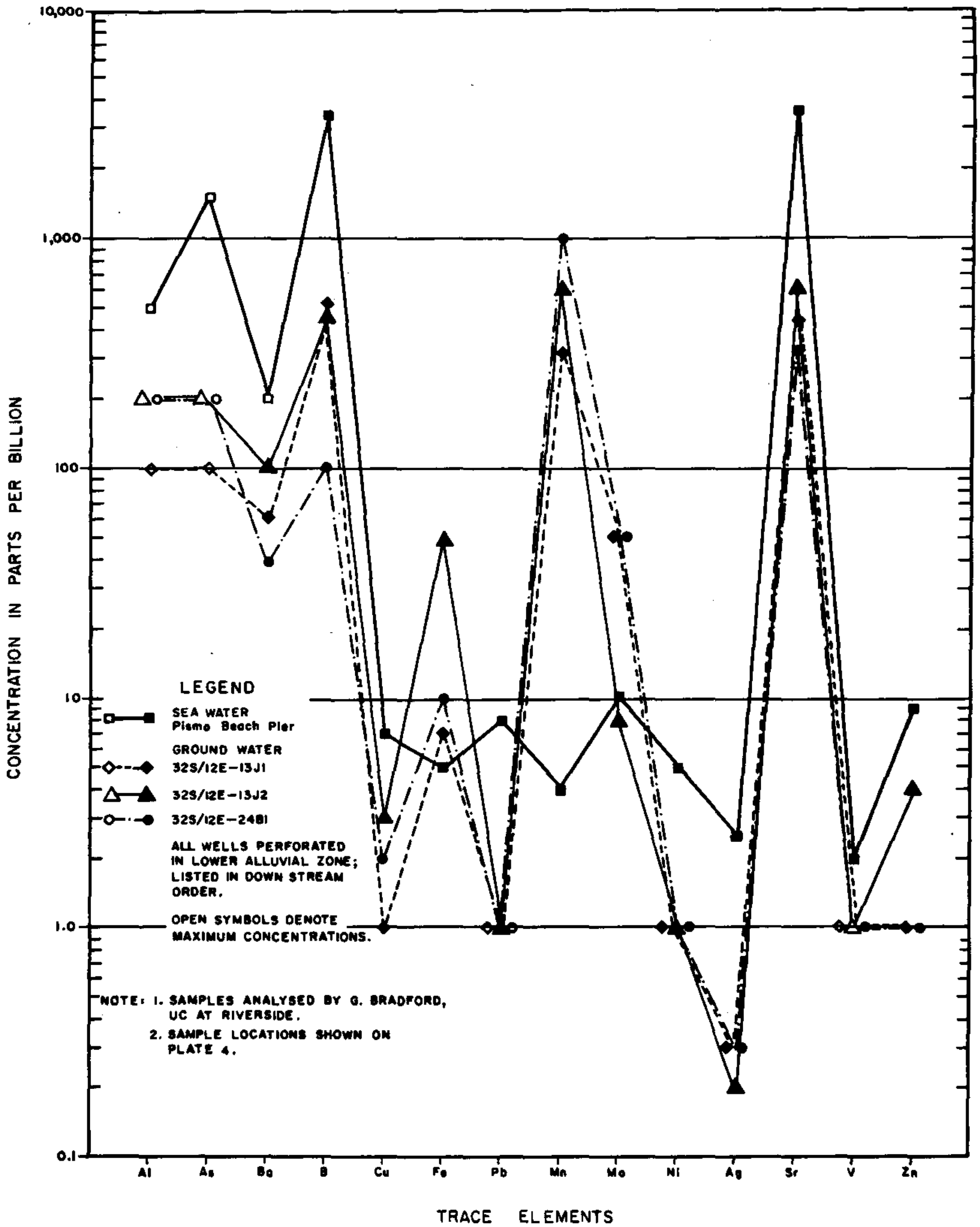

Figure 14. TRACE ELEMENTS IN SEA WATER AND CHLORIDE DEGRADED GROUND WATER — PISMO HYDROLOGIC SUBAREA

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1930. Figure 12 shows that, except for freshening after heavier rainfall in 1958 and 1962 (wells 32S/12E-13J1 and -13J2) and except for the samples collected after brief pumping (well -13R1), chloride concentrations have not changed appreciably.

Data show a focus of increasing chloride toward well -13R1, which is nearest to Pismo Lake, a chloride-enriching, sulfate-reducing environment (Table 5). In wells near -13R1 which tap the upper and lower alluvial zones, chlorides increase toward ground surface. These conditions all point to natural degradation from solution of residual marine and evaporite salts indigenous to the geologic environment.

Seasonal chloride fluctuations at wells 32S/12E-13J1 and -13J2 indicate that the sodium chloride in solution is diluted with the increased underflow that results from higher rainfall in the watershed tributary to Price Canyon.

Chloride gain with pumping time at well -13J2 is attributed to either of the following: (1) increasing vertical recharge of unconfined water as the water level is lowered by pumping or (2) increasing lateral recharge. The well is situated at the eastern edge of ground water moving downstream from Price Canyon (Plate 4). With increased pumping (well -13J2 replaced well -13R1 for irrigation supply), a greater portion of the water it yields may be supplied by flow originating from the east. In short, pumping could have drawn high chloride water north and west into the cone of depression surrounding the well, but not into the main stream of underflow from Price Canyon, which is tapped by upstream well -13J2 and coastal piezometer -24B1.

Recent Alluvium--Arroyo Grande Creek

Well 32S/13E-31C1, located about 30 feet from a lagoon of Meadow Creek (Plate 4) and constructed in the upper alluvial (unconfined) zone, yields high chloride water which has been cited locally as evidence of sea-water intrusion. Data pertinent to this assumption are given in Table 10.

TABLE 10

DATA FROM WELL 32S/13E-31C1

Sample date	Sounded well, depth in feet	Pumping time, in minutes	Water level, elevation, in feet*	Cl, in ppm
1- 7-63	--	thief sample	--	523
4-14-65	56.4	60	4.40	960
1-22-66	--	60	3.37	1,008
10- 4-64	39.0	90	3.25	1,101

*Based on approximate RP elevation of 9 feet extrapolated from surveyed RP and water table elevation of piezometer 32S/13E-30N1.

Water levels at the well have exceeded the minimum elevation necessary for sea-water intrusion. Further, chlorides at piezometer 32S/13E-30N1 (P00-4), located slightly seaward of this well and about 100 feet from the lagoon, have not exceeded 132 ppm since June 1965. Increasing chloride with decreasing depth at the well indicates a surface source. Relative chloride concentrations for the well and piezometer show a focus of degradation toward the lagoon.

One of two tide gates separating the lagoons from the tidal channel of Arroyo Grande Creek has leaked since their installation in 1957. The bottom elevation of the gate is 4.3 feet above sea level. During high tides, salt water flows into the lagoons to at least 550 feet upstream of well -31C1. (See Table 5, sample at Pier St. Bridge.) This is the obvious source of chloride water tapped by the well.

Recent Alluvium--Santa Maria River

In the Santa Maria Hydrologic Subunit, high mineral concentrations are found in the top of the confined system, which is the lower member of the Recent alluvium, and in that aquifer, they decrease seaward from younger to older water. Mineralization diminishes downward through multiple aquifers of the underlying Paso Robles Formation and is evident only in the A and B zones. The recycling of applied water in the basin forebay east of the study area is the source of this degradation.

Sampling programs dating back to 1941 (in a few cases to 1927) show that degradation from recycling has been slight to moderate at most wells, that the process is continuing even though chloride tends to stabilize, and that the zone of influence is advancing seaward. Ultimately, this water may reach coastal monitoring sites and, if so, it would cause a slow gain in chloride but probably not above 200 ppm. Plate 4 shows the present extent of 100 ppm chloride front.

Such degradation of coastal waters can be easily distinguished from sea-water intrusion by accompanying increases in chloride, sulfate, and TDS. Figure 15 shows the arrival of degraded water at well 10N/35W-7F1 in 1953 and the increases in chloride, sulfate, and TDS after that time.

Table 11 lists chloride concentrations at monitoring wells by 5-year increments. Recharge of captured storm flow at Twitchell Reservoir will help offset degradation from recycling.

Paso Robles Formation

Coastal A zone water beneath both the Pismo Plain and the western edge of Tri-Cities Mesa (within the pumping depression) is subject to recharge from overlying or flanking chloride-rich water of Recent alluvium. The affected area extends south beneath the Pismo Plain through Section 30, Township 32 South, Range 13 East, and east in Section 30 about 1,000 feet inland of Highway 1. A zone wells affected include the following:

32S/12E-24K1
-24R1 (P00-2)
-24R2 (P00-2)
32S/13E-30K6 (City of Pismo Beach)
-30L1
-30L2
-30P1
-30P2

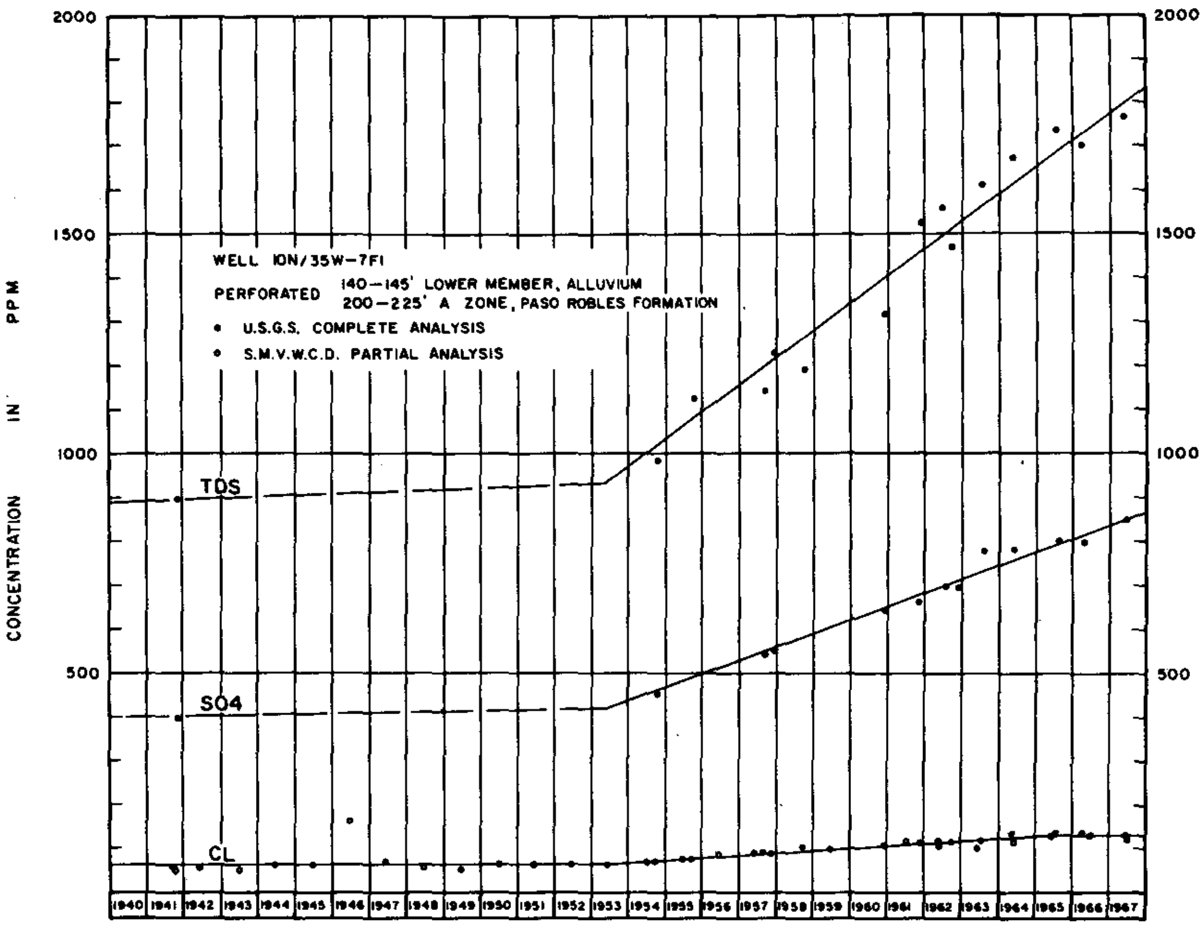

Figure 15. Cl, SO_4 AND TDS INCREASES RESULTING FROM RECYCLING OF APPLIED WATER— SANTA MARIA HYDROLOGIC SUBUNIT

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

Supporting the belief that the source of the chloride is water at or near the surface are the following:

1. The abrupt, transient chloride increases noted at well -30L2 and piezometer -24R1 as water levels rise in the spring months;

2. The greater concentration in chloride in the upper A zone water over that in the lower water at P00-2; and

3. The identical chemical quality of Pismo Lake water (sampled in October 1967) and upper A zone water (sampled in March 1967). (See Figure 16.)

Table 12 shows the slight degradation resulting from inland encroachment to wells 32S/13E-30K6, -30L1, and -30L2, and probable vertical leakage at well -30P1. The changes in sulfate and nitrate relative to the increase in chloride differentiate between landward encroachment of coastal water and vertical recharge from recycled sewage or irrigation return water.

TABLE 11

FIVE-YEAR INCREMENTAL CHANGES IN CHLORIDE
LOWER ZONE-OLDER AQUIFER WELLS
SANTA MARIA PLAIN

Well Number	1927	1942	1947	1952	1957	1962	1967
10N/35W-3N1	122	181	177	167	182	169	177
-4C1	-	-	-	<58	66	70	97
-4P1	-	160	149	117	123	144	125
-5J1	45	-	-	<68	64	67	-
-7F1	-	54	67	61	89	116	132
-7P1,2	48	69	-	-	91	-	-
-9F1	-	152	209	153	143	66	156 *
-15G1	-	106	96	109	116	128	122
-15M1	-	28	67	55	152	140	152
-16M1	-	-	-	170	140	168	-
-17D1	-	-	-	125	<142	147	-
-17E1	-	145	124	118	140	109	144
-21C1	-	85	106	114	128	142	149
-22M1	-	71	79	90	142	171	164
11N/35W-33F1	-	-	-	<88	<93	99	105
-33G2	-	43	46	54	70	72	84

*Well perforated only in lower member aquifer prior to June 1958. Deepened to A zone, January 1959. Chloride dropped from 148 ppm, June 1958, to 74 ppm, June 1959, and then increased gradually to 90 ppm, June 1966. 156 ppm value for June 1967 questionable.

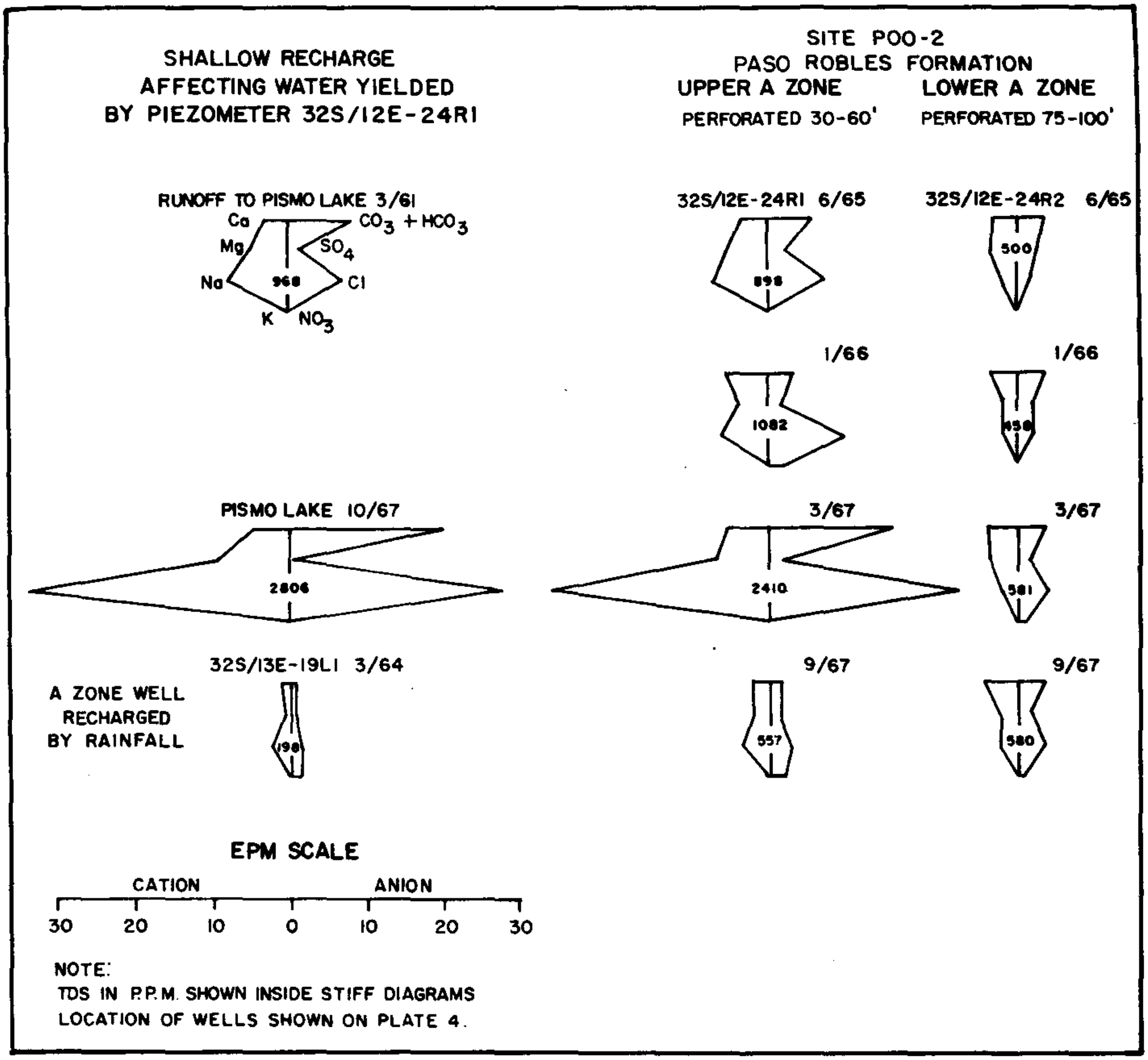

Figure 16 - STIFF DIAGRAMS OF A ZONE AND SHALLOW RECHARGE WATERS
SITE POO-2

TABLE 12

CHANGES IN CHEMICAL CONSTITUENTS
COASTAL A ZONE WATER
1961-1967

Well number 32S/13E-30	TDS	Cl	SO_4	NO_3	Month/Year
	In parts per million				
K6	545	42	130	24	11/50
	655	39	123	6	4/51
	535	54	111	10	3/57
	638	100	142	62	8/60
	904	184	158	67	1/63
	801	143	165	85	10/67
L1	605	53	138	27	11/61
	604	69	137	13	1/63
	730	85	132	25	9/63
	814	111	144	22	10/64
L2	580	43	124	20	9/54
	637	51	115	5	8/57
	590	52	95	22	2/58
	529	59	103	67	2/59
	645	57	115	28	9/59
	590	85	125	35	2/60
	686	50	134	22	9/60
	1,064	255	160	16	3/61
	658	97	140	26	6/64
	725	130	151	24	10/65
	-	134	-	19	10/66
P1	512	32	105	15	11/50
	574	76	110	20	3/61
	694	106	119	13	8/62
	682	99	120	15	10/62
	570	77	124	34	5/65
	653	105	134	27	1/66
	736	108	147	35	10/67

CHAPTER VII. CURRENT AND POTENTIAL SALT WATER INTRUSION

As has been emphasized, sea-water intrusion is not an immediate critical problem onshore at present. Slight intrusion is evident in shallow terrace deposits and a deep intrusion wedge is apparent in the Careaga Sand, both at the north limit of the study area. Both are essentially unused aquifers. Little is known concerning the hydraulic gradient in these deposits. The intrusion poses no significant threat to the principal aquifers; both intruded aquifers are relatively stable and will not be grossly affected by future pumping in the principal aquifers.

South of POO-2, coastal ground waters (excluding those degraded by environmental salts) show no saline degradation in pumped or deeper undeveloped aquifers. However, the electric log for POO-3 suggests, but does not confirm, onshore intrusion in a thin bed of the Paso Robles B zone opposite the pumping depression at Tri-Cities Mesa. This aquifer may be hydraulically subject to sea-water intrusion during the summer and early fall. Confirmation of intrusion will require further drilling and well construction.

Present Status of Intrusion

The discussion that follows gives more information on the three formations that have shown evidence of intrusion.

Terrace Deposits

Upper Pleistocene terrace deposits north of Pismo Creek form a minor unconfined aquifer capping a wave-cut beach. Because this aquifer terminates at the sea cliff and has limited fresh water recharge and storage, it is naturally subject to onshore intrusion where depressed below sea level.

Drainage of the aquifer during the summer and early fall lowers the water table and facilitates slight intrusion during high tides. Recharge of the aquifer during the wet season raises the water table, which in turn repels the intrusion front. This seasonal pulsing of the fresh water-salt water interface and the daily pulsing resulting from well pumping and ocean tides create a zone of diffused fresh and salty water at the seaward and south limits of the aquifer (Plate 4). There it is in hydraulic continuity with sea-water-bearing beach sand and brackish water of Recent alluvium and with the tidal lagoon of Pismo Creek.

Paso Robles Formation

Although it did not show up in the water quality analysis, possible sea-water intrusion in the B zone at POO-3 is suggested by the electric log, which exhibits a sharp decrease in apparent resistivity (Section B-B', Plate 2A). Low resistivity is caused by increased salinity. The suspected bed is at a depth of 160 to 167 feet below ground surface (140 to 147 feet below sea level).

Whether this represents a salt water-bearing sand and gravel or a residual salt-laden silt and clay lense is the question. Drill cuttings of a rotary hole penetrating thin alternating fine and coarse-grained beds (typical of the Paso Robles Formation) are mixed. Accurately logging individual beds and precisely defining the boundaries are extremely difficult.

If the suspected bed is a salt water-bearing sand and gravel, it is of concern. But if it is a silt and clay lense filled with residual salt water, then it would pose no threat to fresh ground water.

Emphasis at P00-3 was given to overlying aquifers, which were believed to be influenced by brackish water, and to the Careaga Sand. Lacking access to the suspected bed, neither water level nor water quality data were available. Because P00-3 is in the center of the pumping depression, water level data from the B zone at sites P00-1 and P00-4, which surround P00-3, are not applicable.

Careaga Sand

Sea-water intrusion deep in the Careaga Sand is evident north of P00-3 (Section A-A', Plate 2A), even though the formation is essentially unpumped and yields coastal artesian flow in excess of 10 feet above sea level. This paradox is explained by the Ghyben-Herzberg Principle which states that the depth of fresh water below sea level is related to the height of fresh water above sea level.

Under static conditions, 1 foot of positive fresh water head is required to sustain a 40-foot column of fresh water below sea level. Under dynamic field conditions, where frictional head loss occurs in the salt water wedge, this ratio is increased. In a deep confined aquifer, an intrusion condition can exist whenever the positive artesian head is less than the effective salt water head at some point below sea level. The extent of intrusion is a function of the relative fresh and salt water heads, depth, distance from the salt water forebay, and frictional head loss in the salt water mass.

With respect to the Careaga Sand, the rising elevation of the salt water body northward toward where the formation outcrops on the ocean floor clearly defines the focus of saline degradation. Such peripheral (as opposed to frontal) intrusion is to be expected along the rising truncated limbs of synclinal basins.

Electric log data for P00-1 indicate the top of the salt water zone to be approximately 410 feet below sea level and for P00-2 to be approximately 505 feet below sea level. The median seasonal artesian head during 1967-68 (Figure 7) at P00-2 was approximately 7.7 feet; the median seasonal head at P00-1 is estimated at 8.2 feet. Comparing these median artesian heads to salt water depths in March and June 1965 (when the electric logs were recorded) yields the following ratios:

P00-1	8.2:410	or	1:50
P00-2	7.7:505	or	1:64

Even assuming that artesian head at each site was higher in 1965 (as suggested by Figure 7), the positive fresh water head to salt water depth ratios favor sea-water intrusion. The greater ratio at P00-2 agrees with an expected head loss in the salt water mass from frictional resistance to flow between P00-1 and P00-2.

The intrusion wedge in the basal Careaga Sand is, in other words, essentially a natural phenomenon attributable to insufficient positive artesian pressure. To some extent this condition is affected by pumping-induced water level declines in the overlying Paso Robles Formation. Water level data for P00 sites show an upward hydraulic differential between the Careaga and Paso Robles; recharge occurs from the Careaga to the Paso Robles. Lowering of water levels in the Paso Robles increases this differential, effecting a higher recharge rate and a consequent reduction in Careaga fluid pressure.

Potential for Future Intrusion

Although sea-water intrusion is not a critical onshore problem in principal aquifers now, it is undoubtedly occurring offshore and may, in time, reach coastal wells. When this will occur cannot be determined with certainty because the offshore storage of fresh water, the submarine geologic regimen, and the future hydraulic influences are unknown. These factors, however, can be evaluated from onshore reservoir conditons, offshore topography, analogy to other California basins, and projected net water requirements.

Projected Net Water Requirements

Projected net water requirements (consumptive use) in basins bordering the study area have been determined recently by the Bureau of Reclamation, consulting civil engineers, and the Department of Water Resources. These investigations are summarized below.

Agricultural demand and consumption of water in the Santa Maria and Arroyo Grande Hydrologic Subunits and the Pismo-Shell Beach area will remain essentially at present levels through 1990.

A projected gain in demand and net use of water will result chiefly from a moderate growth in population. The largest urban expansion will occur in the Pismo-Shell Beach area and the coastal Arroyo Grande Valley.

Increasing water demand in that portion of Zone 3* will be met through the early 1980's by the Lopez Dam and Reservoir constructed on Arroyo Grande Creek (1969) by the San Luis Obispo County Flood Control and Water Conservation District. Lopez Reservoir will provide an anticipated gross safe yield of 6,600 acre-feet per year.

Assuming that long-term mean precipitation prevails during 1970-90, the effect of increasing net water use on water levels in each subunit is projected as follows:

Arroyo Grande Subunit. As has been pointed out earlier, hydrographs of wells in the northern portion of the subunit (Figure 4) exhibited cyclic lowering and rising of water levels with changing precipitation during 1951-68, but little if any net decline. This indicates a long-term balance between replenishment and discharge of ground water.

Increasing urban water use will be nearly offset by delivered supply from Lopez Reservoir. Until the applied yield of Lopez water is exceeded by increased consumptive use, a change in past water level trends would not be expected. Further, supplemental water from Nacimiento River or the State Water Project may be allocated to zone 3 during the 1980's when local water demands exceed supply. If this is done, increased draft of ground water would not be required, all other conditions being equal.

Conditions in the southern part of the subunit are different. Hydrographs show a sustained decline in water levels, indicating a deficiency between ground water replenishment and discharge. This is clearly attributable to increasing suburban and agricultural consumptive use. Because water users are more scattered than in the northern part of the subunit, the total need is less; also, use centers

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* San Luis Obispo County Flood Control and Water Conservation District Zone 3 encompasses the Arroyo Grande area.

are inland from the ocean and elevated topographically. Allocations from Lopez or further supplemental supplies will probably be insufficient both in amount and distribution to arrest over-pumping. Accordingly, water levels are projected to decline at present or greater rates.

Santa Maria Subunit. Hydrographs (Figure 5) in the Santa Maria Subunit show a sustained water supply deficiency has existed since 1945. Supplemental water created by salvaged storm flow and controlled recharge from Twitchell Reservoir since 1958 have apparently stabilized the rate of decline, but not diminished it.

Assuming that the proposed Round Corral Dam (safe yield 7,000 acre-feet per year) on the Sisquoc River is not constructed, projected net water demands will necessitate increasing draft of ground water. This should cause a slight increase in the rate of water level decline through 1990. If the Round Corral project is constructed, water levels should decline at present rates.

Offshore Reservoir Conditions

Information on subsurface reservoir conditions offshore is unavailable. However, onshore hydrogeologic data and the known topography of the ocean floor provide important clues on probable submarine reservoir conditions, the seaward outcrop of aquifers, the westward extent of fresh ground water, and the anticipated pattern of sea-water intrusion.

A knowledge of the geologic structure, discussed earlier, and a projection of the conditions to the offshore area indicate the following:

1. The Santa Maria syncline extends seaward to the Santa Lucia bank, located 39.5 statute miles offshore from the middle of Santa Maria Valley.

2. There is no topographic or regional geologic evidence of a major fault barrier limiting the seaward extent of fresh ground water or, conversely, the landward encroachment of sea water.

3. Faults along the fold limbs parallel the fold axis and, if present offshore, they may impede (but probably not prevent) peripheral escape or infiltration of fluids along truncated edges of the basin.

4. Multiple, confined aquifers prevail offshore.

5. Downwarped aquifers (Paso Robles and Careaga) intercept the ocean floor in elliptical, or egg-shaped, bands scribed around the seaward perimeter of the basin. Thus, aquifers are exposed near shore along the rising limbs of the fold, but further and further offshore, they approach the nose, or center, of the depression. The older and deeper the aquifer, the greater the potential fresh water storage capacity.

6. Recent aquifers intercept the ocean floor in a linear band at their submarine mouth. Projecting alluvial aquifers seaward at onshore attitudes, the lower Arroyo Grande aquifer would crop out approximately 15 miles from shore, and the lower Santa Maria aquifer approximately 17 miles from shore.

7. Salt water access to aquifers is limited to their submarine exposures. Vertical movement of salt water between aquifers is negated by confining beds which probably increase in thickness and lateral continuity as they progress seaward (away from depositional source areas).

These indicated offshore reservoir conditions favor an extensive and thick accumulation of fresh ground water below the ocean floor and separate intrusion advances in each of the multiple confined aquifers. Similar conditions exist in the Oxnard Ground Water Basin, which has undergone extensive sea-water intrusion.

The Santa Maria and Oxnard Ground Water Basins are similar hydrogeologically in all respects except that the Oxnard Basin is cut by a submarine canyon which has routed sea water onshore in the Recent Oxnard aquifer. Deeper aquifers underlying Oxnard Plain remain unintruded onshore. Oil exploration electric logs (1967) in the Oxnard Basin show fresh ground water offshore more than 4.5 miles in aquifers that are between 300 feet and 1,270 feet below sea level.

The 100-meter (328-foot) submarine contour of the sea floor off Santa Maria Valley lies 7 to 11 statute miles from the coast. Whether or not fresh ground water extended that far offshore during glacial sea level declines is unknown, but it is clear that the high native artesian pressures and probable offshore geologic conditions were conducive to the accumulation of an extensive submarine fresh water reservoir.

This pattern of intrusion--upper aquifer invaded, but underlying aquifer not invaded--has developed in all large coastal ground water basins in California (such as southern Alameda County Plain, Salinas Valley, and Oxnard Plain) where multiple confined aquifer conditions prevail.

Man's lowering of water levels has initiated offshore intrusion in pumped aquifers, and salt water wedges are advancing landward, replacing fresh water. Arrival of intrusion at the coast may not, however, occur for some time and when it does, it should be selective. Recent aquifers, which have the least offshore storage of fresh ground water and the greatest onshore pumping, should be affected first. Deeper aquifers, which probably contain a larger mass of fresh ground water offshore and are pumped less (or not at all), should be affected last.

The system of piezometers that were installed for this investigation should serve to warn local water agencies when intrusion begins. Thus, corrective measures can be taken in time to preserve the basin.

APPENDIX A

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APPENDIX A
BIBLIOGRAPHY

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APPENDIX B
DEFINITIONS

Words and terms as used in this report are defined as follows:

Acre-foot - The volume of water required to cover one acre to a depth of one foot (43,560 cubic feet or 325,851 gallons).

Anticline - Convex fold where strata dip in opposite directions from a common axis.

Apparent Resistivity - The recorded electrical resistivity in ohms-meters squared per meter measured by the long normal (64 inches) or lateral (18 feet 8 inches) curves of an electric log.

Artesian Water - Ground water in a confined aquifer that is under sufficient hydraulic pressure to rise above the level at which it is contained and to flow naturally from a well or spring.

Aquiclude - A geologic formation or zone which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply to a well or spring. In the Pismo Beach-Guadalupe area, it is chiefly beds composed of silt and clay. It is synonymous with confining bed.

Aquifer - A geologic formation or zone that transmits water in sufficient quantity to supply a well or spring. In the Pismo Beach-Guadalupe area, it is chiefly beds composed of sand and gravel. Aquifers, either confined or unconfined, form the principal ground water reservoir.

Artificial Recharge - The process of adding water to the ground water body through facilities primarily designed for that purpose, such as spreading basins or injection wells.

Brackish Water - Water containing more than 1,500, but less than 5,000, parts per million total dissolved solids.

Confined Aquifer - An aquifer containing confined ground water.

Confined Ground Water - A body of water which is immediately overlain by material sufficiently impervious to sever free hydraulic connection with the water above it, and which is moving under gradient or pressure caused by the difference in head between the intake, or forebay area, and the discharge area.

Confining Bed - See aquiclude.

Connate Water - Ground water entrapped in the interstices of sediments at the time they were deposited. In this report, applied to saline waters of sedimentary deposits.

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Contamination - Defined in Section 13005 of the California Water Code: "... an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which creates an actual hazard to public health through poisoning or through the spread of disease ...." Jurisdiction over matters regarding contamination rests with the California Department of Public Health and local health officers.

Deterioration - An impairment of water quality.

Drawdown - The lowering of the water table or piezometric surface by the pumping of ground water.

Electric Log - The record obtained by lowering electrodes in a bore hole and measuring, as the electrodes are withdrawn, continuous changes in electrical resistivity and spontaneous potential (SP) of geologic formations. Changes in resistivity and SP result principally from differences in lithology and ground water salinity.

Equivalents Per Million (epm) - Chemically equivalent weights of solute contained in one million parts by weight of solution. Parts per million (ppm) divided by the combining weight of an ion.

Fault - A fracture or fracture zone along which the two sides have been displaced relative to one another. The displacement may be a few inches or many miles.

Fault Breccia - A rock made up of highly angular coarse fragments formed by crushing or grinding along faults.

Fault Gouge - Finely abraded material occurring between the walls of a fault, the result of grinding movement.

Ground Water - Subsurface water occurring in the zone of saturation and moving under control of the water table or piezometric gradient.

Ground Water Basin - An area underlain by one or more permeable formations and containing and capable of furnishing a substantial water supply.

Ground Water Storage - That stage of the hydrologic cycle during which water occurs below ground surface in the zone of saturation.

Hydraulic Gradient (Head)- Under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the slope of the profile of the piezometric surface.

Impairment - A change in quality of water which makes it less suitable for beneficial use.

Impermeable, Impervious - Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Oil Field Brines - Saline connate waters extracted by oil wells and discharged as industrial wastes.

Other Waste - Defined in Section 13005 of the California Water Code: "... any and all liquid or solid waste substance, not sewage, from any producing, manufacturing or processing operation of whatever nature."

Parts Per Million (ppm) - One part by weight of solute in one million parts solution at a temperature of 20° centigrade.

Percolation - The movement, or flow, of water through interstices of porous media.

Permeability - The capacity of a porous media for transmitting a fluid. The degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Permeability, Coefficient of - The rate of flow of water in gallons per day through a cross-sectional area of one square foot under a hydraulic gradient of one foot per foot at a temperature of 60° F.

Permeability, Field Coefficient of - The amount of water moving through a unit area of aquifer per unit time under unit hydraulic gradient at the natural temperature. It is usually expressed in gallons per day per square foot.

Piezometer - A small-diameter observation well used to monitor the positive pressure exerted by a water table or pressure aquifer or to obtain ground water samples for chemical analysis.

Piezometric Surface - The surface to which confined ground water will rise in wells under full aquifer head.

Pollution - Defined in Section 13005 of the California Water Code: "... an impairment of the quality of the waters of the State by sewage or other waste to a degree which does not create an actual hazard to the public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation."

Porosity - The ratio of the volume of voids of a given soil mass to the total volume of the soil mass, usually stated as a percentage.

Pressure Area - An area of the ground water basin underlain by confined ground waters which are not in free hydraulic continuity with ground surface or semiperched ground waters and which are recharged by underflow from a forebay area.

Saline Water, Salt Water - Water containing more than 5,000 parts per million total dissolved solids.

Saltwater Wedge - The inland-pointing saltwater body which develops and advances along the bottom of an aquifer by virtue of the greater specific gravity of saline water compared to fresh water.

Saturation, Zone of - The zone below the water table in which all interstices are filled with ground water.

Sea Water - Ocean water containing approximately 36,000 parts per million total dissolved solids.

Sea-Water Intrusion - The encroachment of sea water into fresh water aquifers under a landward or downward hydraulic gradient.

Semiperched Ground Water - Shallow ground water within the zone of saturation having a different hydraulic head and usually a different chemical quality than underlying confined ground waters. Free hydraulic continuity with the underlying water is interrupted by an aquiclude.

Storage, Coefficient of - The volume of water released from storage in each vertical column of aquifer having a base one foot square when the water level declines one foot. In an unconfined aquifer, the storage coefficient approximates specific yield; in a confined aquifer, it is related to the elasticity of the aquifer and usually is very small.

Syncline - A concave fold where strata dip toward a common axis.

Tidal Water - Sea water that is driven inland by virtue of tidal action.

Total Dissolved Solids (TDS) - The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Transmissibility, Coefficient of - The rate of flow of water at the prevailing water temperature in gallons per day through each vertical strip of the aquifer one foot wide, extending the full saturated height of the aquifer, under a hydraulic gradient of 100 percent.

Unconfined Aquifer - An aquifer containing a water table which is at atmospheric pressure and above which water can, in most cases, percolate freely to the zone of saturation.

Unconfined Ground Water - Ground water whose upper surface forms a water table at atmospheric pressure and in which hydraulic pressure is equal to the depth from that water table to the point in question. It moves under gravity according to the slope of the water table.

Unconformity - A surface of erosion or, sometimes, of nondeposition, that separates younger strata from older rocks.

Water Table - The surface of ground water at atmospheric pressure in an unconfined aquifer. It forms the upper limit of the zone of saturation.

APPENDIX C

WATER QUALITY CRITERIA

Appendix C

WATER QUALITY CRITERIA

This appendix contains water quality criteria as adopted by the Department of Water Resources for irrigation, municipal, and domestic uses, and an explanation of the state well and spring numbering system.

Water Quality Criteria

The suitability of a given water for a particular use is dependent upon its bacteriological, chemical, physical, and radiological character. Only the chemical aspect of water quality will be emphasized here.

Due to a high solvent capacity, naturally occurring water available for man's use contains dissolved mineral salts dissociated into positively charged cations and negatively charged anions. These dissolved ions are generally ranked as major and trace constituents. A complete chemical analysis lists the relative concentrations, by weight of the major cations (calcium, magnesium, sodium, and potassium), the major anions (carbonate, bicarbonate, sulfate, chloride, and nitrate), and generally silica, boron and fluoride. Also listed are the pH (hydrogen ion concentration), temperature, electrical conductance, total dissolved solids, total hardness, and percent sodium. The relative concentrations, or values, of these chemical and physical parameters determine the suitability of a water for particular uses.

Standards are those values established by a regulatory agency as obligatory limits beyond which water is rejected for a particular use. Criteria are general guidelines, not obligatory, for judging water quality.

Domestic and Municipal Use

Water used for drinking and culinary purposes should be clear, colorless, odorless, pleasant tasting, and free from toxic salts. It should not contain excessive amounts of dissolved minerals and it must be free from pathogenic organisms. In addition to these requirements, certain qualifications are generally placed on chemical quality by a regulatory agency or for comparative grading of different waters.

The 1962 Drinking Water Standards of the United States Public Health Service are the most recent in a series started in 1914 to serve as guides for protecting the health of the traveling public. Since 1914, they have been revised several times in the light of increasing medical and engineering knowledge. The Drinking Water Standards are legally applicable only to drinking water and water supply systems used by interstate carriers and others subject to Federal quarantine regulations. Table 14 presents the standards. The recommended values are those which should not be exceeded in a water supply if other more suitable supplies are or can be made available. The mandatory values are those which, if exceeded, constitute grounds for rejection of the supply.

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TABLE 13

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962

Substance	Recommended limits of concentrations, in mg/l	Mandatory limits of concentrations, in mg/l
Alkyl benzene sulfonate (ABS)	0.5	--
Arsenic (As)	0.01	0.05
Barium (Ba)	--	1.0
Cadmium (Cd)	--	0.01
Carbon chloroform extract (CCE)	0.2	--
Chloride (Cl)	250	--
Chromium (hexavalent) (Cr^{+6})	--	0.05
Copper (Cu)	1.0	--
Cyanide (CN)	0.01	0.2
Fluoride (F)	**	**
Iron (Fe)	0.3	--
Lead (Pb)	--	0.05
Manganese (Mn)	0.05	--
Nitrate (NO_3)*	45	--
Phenols	0.001	--
Selenium (Se)	--	0.01
Silver (Ag)	--	0.05
Sulfate (SO_4)	250	--
Total dissolved solids (TDS)	500	--
Zinc (Zn)	5	--

*In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

**See Table 14

The standards for fluoride are related to the annual average maximum daily air temperatures based on a minimum five-year record. The average concentration should not exceed the appropriate upper limit in Table 14. The presence of fluoride in average concentrations greater than twice the optimum values constitutes grounds for rejection of the supply. The standards further state that, where fluoridation is practiced, the average fluoride concentration shall be kept within the upper and lower control limits.

TABLE 14

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962 -- FLUORIDE

Annual average of maximum daily air temperatures, in degrees Fahrenheit	Recommended control limits -- fluoride concentrations, in mg/l		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

In California, the State Board of Public Health issues water supply permits in accordance with its "Interim Policy on Mineral Quality of Drinking Water", as adopted September 4, 1959, and in accordance with "Policy Statement and Resolutions by the State Board of Public Health with Respect to Fluoride Ion Concentrations in Public Water Supplies", as approved August 22, 1958. The interim policy on mineral quality is presented as follows:

"1. Water supply permits may be issued for drinking and culinary purposes only when the Public Health Service Drinking Water Standards of 1946[1/] and the State Board of Public Health policy on fluorides are fully met.

"2. In view of the wide variation in opinion in this field, the uncertainty as to the long-time health effects, the uncertainty of public attitude concerning various mineral levels, and the obvious need for further study, temporary permits may be issued for drinking water supplies failing to meet the Drinking Water Standards if the mineral constitutents do not exceed those listed under the heading 'Temporary Permit' in the following table:*

UPPER LIMITS OF TOTAL SOLIDS** AND SELECTED MINERALS
IN DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit
Total solids	500 (1,000)***	1,500 parts per million
Sulphates	250 (500)***	600 " " "
Chlorides	250 (500)***	600 " " "
Magnesium	125 (125)	150 " " "

1/ Author's Note: It is assumed, in the absence of any later proclamation, that the 1962 Drinking Water Standards now apply.

*This interim policy relates to potable water and is not intended to apply to a secondary mineralized water supply intended for domestic uses other than drinking and culinary purposes.

**Waters having less than 32 milliequivalents per liter of dissolved munerals or 1,600 micromhos electrical conductance will usually have less than 1,000 parts per million total solids.

***Numbers in parentheses are maximum permissible, to be used only where no other more suitable water is available in sufficient quantity for use in the system.

"3. Exception: No temporary permit for drinking water supplies in which the mineral constituents exceed those listed under the heading 'Temporary Permit' as set forth in No. 2 above may be issued unless the Board determines after public hearing:

(a) The water to be supplied will not endanger the lives or health of human beings; and

(b) No other solution to meet the local situation is practicable and feasible; and

(c) The applicant is making diligent effort to develop, and has reasonable prospect of developing a supply of water which will warrant a regular permit within an acceptable period of time.

The burden of presenting evidence to fulfill the requirements as set forth in (a), (b), and (c) above is upon the applicant."

With respect to fluoride concentrations, the State Board of Public Health has defined the maximum safe amounts of fluoride ion in relation to mean annual temperature as shown in Table 15

TABLE 15

CALIFORNIA STATE BOARD OF PUBLIC HEALTH
MAXIMUM FLUORIDE ION CONCENTRATIONS

Mean annual temperature, in degrees Fahrenheit*	:Mean monthly fluoride concen- :tration, in parts per million
50	1.5
60	1.0
70 - above	0.7

*For temperature values between those shown in the table, the fluoride ion concentrations may be obtained by interpolation.

The State Board of Public Health's policy on fluoride ion further states that:

"1. The concentration of the fluoride ion in public water systems, whether added or naturally occurring, should not exceed the fluoride ion concentrations stated in the above table.

"2. In the development of new public water systems used for drinking and culinary purposes the above fluoride ion concentrations shall not be exceeded.

"3. In existing public water systems used for drinking and culinary purposes in which the above fluoride ion concentrations are exceeded the fluoride ion concentration shall be reduced to a safe level by the use of methods acceptable to the State Department of Public Health. Exception: In cases where the Department determines after investigation that it is not practicable and feasible to reduce the fluoride ion concentration in the entire supply to a safe level, special methods acceptable to the State Department of Public Health, shall be provided by the applicant to furnish water of suitable fluoride ion concentration to all children 10 years of age or under."

Another common criteria for judging the suitability of water for domestic use is hardness, a measure of the soap-consuming power of the water. In general, hardness results from the presence of cations, principally calcium and magnesium, which form insoluble compounds with soap. For classifying water, the following definitions of relative total hardness are used in this report:

1. Soft - waters containing less than 100 ppm of total hardness.

2. Moderately hard - waters containing 101 to 200 ppm of total hardness.

3. Hard - waters containing more than 200 ppm of total hardness.

Agricultural Use

The major criteria for judging the suitability of water for irrigation are chloride concentration, specific electrical conductance (presented as EC x 10^6 at 25° C), boron concentration, and percent sodium.

Chlorides are present in nearly all waters. They are not necessary to plant growth, and in high concentrations they cause subnormal growing rates and burning of leaves.

Electrical conductance indicates the total dissolved solids and furnishes an approximate indication of the overall mineral quality of the water. For most waters, the total dissolved solids measured in parts per million (ppm) may be approximated by multiplying the electrical conductance by 0.7. As the amount of dissolved salts in irrigation water increases, the crop yields are reduced until, at high concentrations (the value depending on the plant, type of soil, climatological conditions, and amount of water applied), plants cannot survive.

Boron is never found in the free state but occurs as borates or boric acid. This element is essential in minor amounts for the growth of many but not all plants. It is, however,extremely toxic to most plants in high concentrations. Limits of tolerance for most irrigated crops vary from 0.5 to 2.0 ppm. Citrus crops, particularly lemons, are sensitive to boron in concentrations exceeding 0.5 ppm.

The percent sodium, as reported in analyses, is 100 times the proportion of the sodium cation to the sum of all cations, all expressed in equivalents per million (epm). Water containing a high percent sodium has an adverse effect upon the physical structure of soils that contain clay by dispersing the soil colloids. This reduces soil permeability, thus retarding the movement of water and the leaching of salts, and makes the soils difficult to work. The effect of potassium in water is similar to that of sodium.

Because of the diverse climatological conditions, crops, soils, and irrigation practices in California, criteria which may be set up to establish the suitability of water for irrigation must necessarily be general, and judgment must be used in applying these criteria to individual cases.

Based on results of studies by Dr. L. D. Doneen, Professor of Water Science and Engineering at the University of California at Davis, three general classes of irrigation water have been established.

Class 1 Excellent to good. Regarded as safe and suitable for most plants under any condition of soil or climate.

Class 2 Good to injurious. Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 Injurious to unsatisfactory. Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Limiting values for concentrations of chloride, boron, specific electrical conductance, and percent sodium for these three classes of irrigation water have been established and are shown in Table 16.

TABLE 16

CRITERIA FOR IRRIGATION WATERS

Factors	Class 1 - Excellent to good	Class 2 - Good to injurious	Class 3 - Injurious to unsatisfactory
Specific electrical conductance, $ECx10^6$ at 25^oC	Less than 1,000	1,000-3,000	More than 3,000
Boron, ppm	Less than 0.5	0.5-2.0	More than 2.0
Chloride, ppm	Less than 175	175-350	More than 350
Percent sodium	Less than 60	60- 75	More than 75

Well and Spring Numbering System

For convenience in recording wells and springs and pertinent data, the following system has been used.

Water Wells

Wells from which samples of water or measurements of depth to ground water have been obtained are assigned state well numbers. These wells are referenced by the United States Public Land Survey System. The well number consists of the township, range, and section numbers, a letter to indicate the 40-acre lot in which the well is located, and a number to identify the particular well in the 40-acre lot.

Sections are subdivided into 40-acre lots as shown below. For example, well 12N/35W-31N3 denotes the third well to be assigned a number in Lot N of Section 31 of Township 12 North, Range 35 West.

D	C	B	A
E	F	G	H
M	L	K	J
N3 N	P	Q	R

Springs

Springs are assigned state well numbers on the same basis as water wells, but the letter S is inserted immediately after the lot identification. For example, 4S/11W-20MS1 is the first spring assigned a number in Lot M of Section 20 of Township 4 South, Range 11 West.