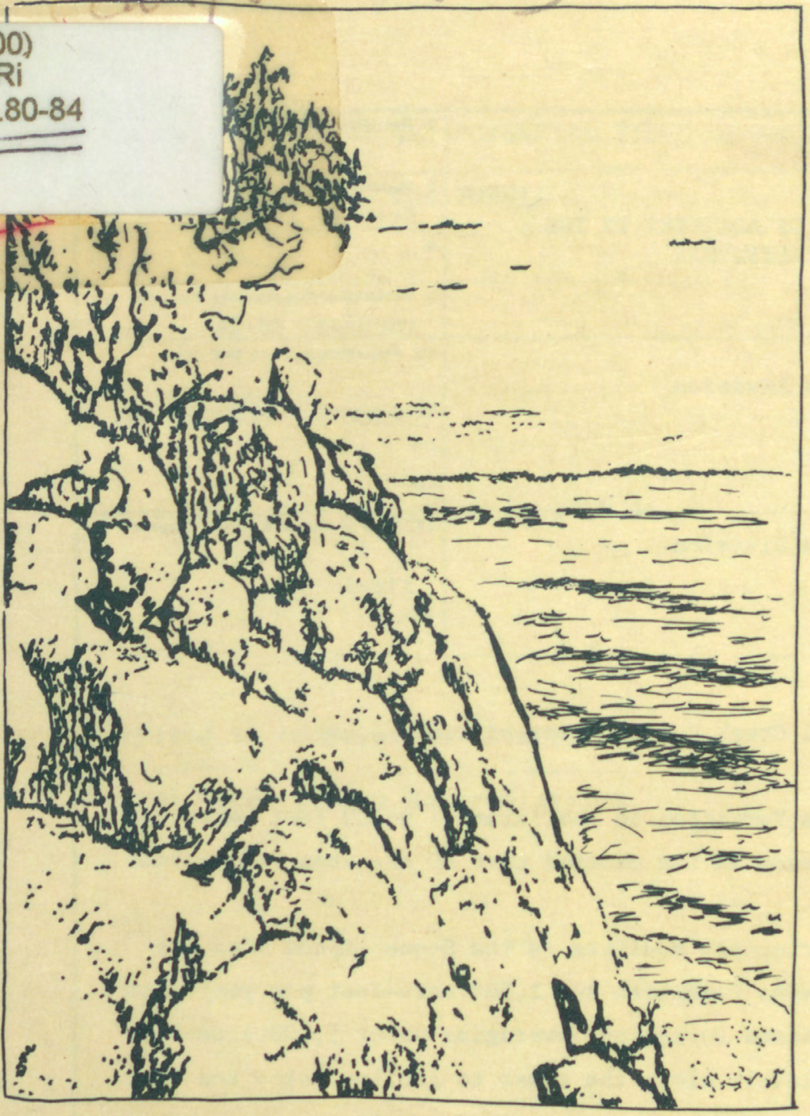

SEAWATER INTRUSION AND POTENTIAL YIELD OF AQUIFERS IN THE SOQUEL-APTOS AREA, SANTA CRUZ COUNTY, CALIFORNIA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 80-84

Prepared in cooperation with the
SOQUEL CREEK COUNTY WATER DISTRICT

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16. Abstract (Limit: 200 words)

Seawater has intruded the Purisima Formation in the interval 0-100 feet below sea level in the Soquel-Aptos area. It occurs in the central part of the area and extends inland about half a mile.

The potential yields of the two principal aquifers in the Soquel-Aptos area are 4,400 acre-feet per year from the Purisima Formation and 1,500 acre-feet per year from the Aromas Sand. Pumping from the Purisima Formation, averaging about 5,400 acre-feet per year since 1970, has caused water levels along the coast to decline below sea level and has allowed seawater to enter the aquifer.

Seawater intrusion and ground-water storage could be monitored in all depth zones by expanding the observation-well network to include a number of shallow wells, one deep well inland from the coast, and three deep wells along the coast.

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Soquel Creek County Water District

Menlo Park, California
October 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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Menlo Park, Calif. 94025

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CONVERSION FACTORS

For readers who prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	square hectometers
acre-ft (acre-feet)	0.001233	cubic hectometers
acre-ft/yr (acre-feet per year)	0.001233	cubic hectometers per year
ft (feet)	0.3048	meters
in (inches)	25.4	millimeters
mi (miles)	1.609	kilometers
mi^2 (square miles)	2.59	square kilometers

National Geodetic Vertical Datum of 1929 is a geodetic datum derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts and as such does not necessarily represent local mean sea level at any particular place. To establish a more precise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level." In the text of this report the term "sea level" is synonymous with "National Geodetic Vertical Datum of 1929."

SEAWATER INTRUSION AND POTENTIAL YIELD OF AQUIFERS IN THE SOQUEL-APTOS AREA, SANTA CRUZ COUNTY, CALIFORNIA

By K. S. Muir

ABSTRACT

Seawater has intruded the Purisima Formation in the interval 0-100 feet below sea level in the Soquel-Aptos area. It occurs in the central part of the area and extends inland about half a mile.

The potential yields of the two principal aquifers in the Soquel-Aptos area are 4,400 acre-feet per year from the Purisima Formation and 1,500 acre-feet per year from the Aromas Sand. Pumping from the Purisima Formation, averaging about 5,400 acre-feet per year since 1970, has caused water levels along the coast to decline below sea level and has allowed seawater to enter the aquifer.

Seawater intrusion and ground-water storage could be monitored in all depth zones by expanding the observation-well network to include a number of shallow wells, one deep well inland from the coast, and three deep wells along the coast.

INTRODUCTION

Purpose and Scope

This investigation was made by the U.S. Geological Survey, in cooperation with the Soquel Creek County Water District and with financial support from the city of Santa Cruz. The purpose of the study is to provide information to develop plans that will insure sufficient water for future needs of an increasing population. The district, the major public water-supply agency in the Soquel-Aptos area (fig. 1), obtains its supply from 15 wells in the Purisima Formation and the Aromas Sand. The city of Santa Cruz Water Department also withdraws water from the Purisima Formation. If ground-water sources are inadequate to supply the increasing demands projected to the year 2020, other water sources will have to be considered.

The two main factors that will limit ground-water development in the Soquel-Aptos area are seawater intrusion and potential yield of the aquifers. The scope of this report is to describe where and how seawater has intruded the aquifers in the Soquel-Aptos area, to determine the potential ground-water yield of the Purisima Formation and Aromas Sand, and to design an observation-well network for monitoring the status of ground-water storage and seawater intrusion.

Location and General Features

The Soquel-Aptos study area covers about 50 mi^2, extending south from the Zayante fault to Monterey Bay, west to Scotts Valley, and east to Watsonville (fig. 1). Terrain in the north is mountainous and grades to rolling hills. Well-developed marine terraces along the coastline are abruptly terminated by high cliffs.

Annual precipitation, almost entirely in the form of rainfall, ranges from 24 to 32 inches along the coast and from 40 to 50 inches at the higher altitudes along the northern boundary. Approximately 80 percent of the precipitation occurs between November and March. The principal streams in the area are Soquel Creek and Aptos Creek.

The study area is predominantly urban and is almost completely dependent on ground water for its water supply. In 1977, about 30,000 people used over 7,000 acre-ft of ground water to supply their domestic, irrigation, commercial, and industrial water needs. Increases are expected in both population and water needs for many years.

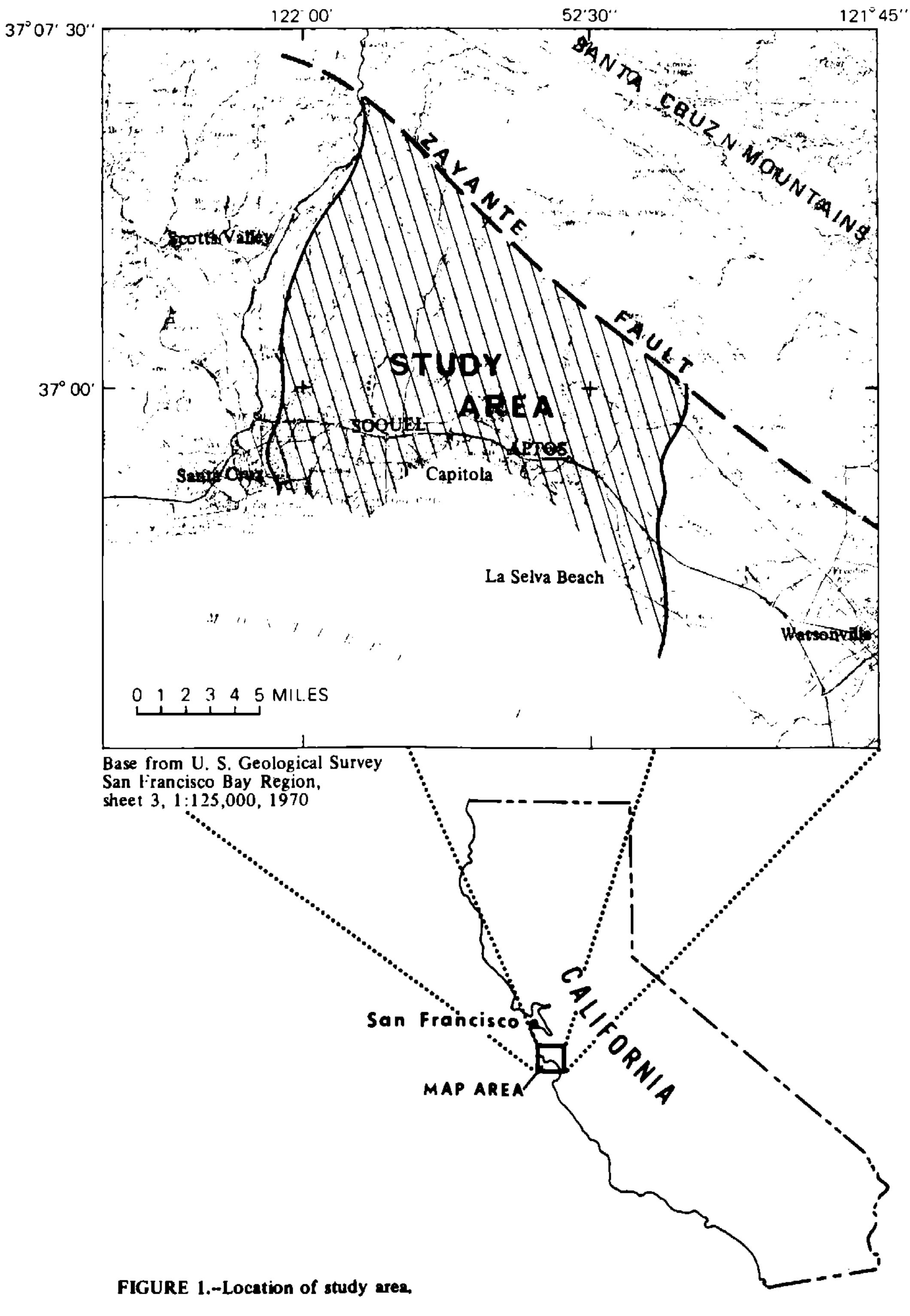


FIGURE 1.--Location of study area.

Acknowledgments

Special thanks are given to Robert M. Johnson, Jr., General Manager and Chief Engineer, and Hank Dodds, Assistant Chief Engineer, of the Soquel Creek County Water District for supplying geologic information, well data, water-level measurements, pumpage records, and chemical analyses of ground water. Appreciation is also expressed to the many residents of the Soquel-Aptos area who allowed the Geological Survey to measure and sample their wells.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in a well near the Pacific Ocean, 11S/1E-20E1, the part of the number preceding the slash indicates the township (T. 11 S.); the part of the number following the slash indicates the range (R. 1 E.); the number following the hyphen indicates the section (sec. 20); the letter following the section number indicates the 40-acre subdivision within the section, according to the diagram shown below; and the final digit is a serial number for wells in each 40-acre subdivision. All wells mentioned in this report are referenced to the Mount Diablo base line and meridian.

In table 3 of this report, the entire well number is given as described above; on the well-location map (fig. 2), only the letter and serial number are shown at the well location.

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

SEAWATER INTRUSION

The landward movement of seawater, induced by ground-water development of coastal aquifers, may be the most important element which must be considered in plans for the proper management of ground water in this area. Seawater intrusion is always a potential source of contamination of aquifers in areas where water is pumped from wells along a coast. This intrusion can occur by horizontal migration of a seawater wedge into the aquifer at depth, or by downward movement and subsequent lateral migration of seawater through shallow deposits adjacent to the coast or streams and estuaries containing seawater. Either way, the ground-water level in a coastal aquifer, in relation to sea level, is the factor that determines if seawater intrusion can occur. Under natural conditions, ground-water levels near the coast are above sea level, the potentiometric surface has a seaward gradient, and freshwater is discharged into the ocean offshore. If ground-water levels in the fresh part of the aquifer decline below sea level, the reversal of gradient will cause seawater to migrate landward. The actual seawater-freshwater front is not a sharp line of demarcation; it is a zone of diffusion where the two kinds of water intermingle, resulting in a transitional zone of mixed water having a composition intermediate between fresh and salt water. The width of the zone depends upon the hydraulic characteristics of the aquifer, the magnitude of the periodic movement of the seawater front in response to ocean tides, and the rise and fall of the water table due to recharge and pumping.

Another factor that determines whether seawater will intrude a coastal aquifer is the absence or presence of a ground-water barrier. If a ground-water barrier separates the landward side of the basin from its seaward extension, seawater intrusion may be impeded in the basin. The barrier could be a fault, a decrease in permeability, or any geologic feature that impedes the movement of water. On the other hand, if there are no barriers and if ground-water levels decline, seawater intrusion is likely to occur.

There are no vertical ground-water barriers in the coastal part of the Soquel-Aptos area. Consequently, the factor controlling seawater intrusion is the ground-water level at or near the coastline. Because the aquifers extend under Monterey Bay, they are in contact with the ocean either on the sea floor adjacent to the coast or on the sides of Monterey Submarine Canyon several miles offshore, and avenues are present for the movement of seawater into the coastal aquifer.

Geologic Framework

The regional geology of the Soquel-Aptos area has been described in a report by Hickey (1968). The present discussion is limited to the geology of the coastal area shown in figure 2. All the geologic units shown in figure 2 are water bearing, except the igneous rocks. The two principal water-bearing units are the Purisima Formation and the Aromas Sand. The alluvium and the terrace deposits are thin and yield only minor quantities of ground water to wells.

The Purisima Formation, of late Miocene and Pliocene age, is a sequence of blue, moderately to poorly consolidated, silty to clean, very fine to medium-grained sandstone beds interbedded with siltstone. The formation underlies the entire Soquel-Aptos study area and extends southwestward under Monterey Bay. It is exposed on the sea floor, except in the area between about 2 mi and 7 mi offshore, where bay mud overlies it (Gary Greene, U.S. Geological Survey, oral commun., 1978), and on the walls of Monterey Submarine Canyon. The formation is predominantly of marine origin and overlies all older units unconformably. In turn, it is overlain unconformably by all younger units. The formation has a regional dip of 3 to 5 degrees southeast. In the northwestern part of the area shown in figure 2 it is about 600 ft thick, near Soquel about 1,000 ft thick, and in the vicinity of La Selva Beach over 2,000 ft thick. Most of the ground water in the Purisima Formation is confined. Some areas of unconfined water occur in the foothills inland from the coast. It is in these inland areas that most of the recharge to the aquifer occurs. The Purisima Formation is the major aquifer in the Soquel-Aptos area and the one from which most wells pump.

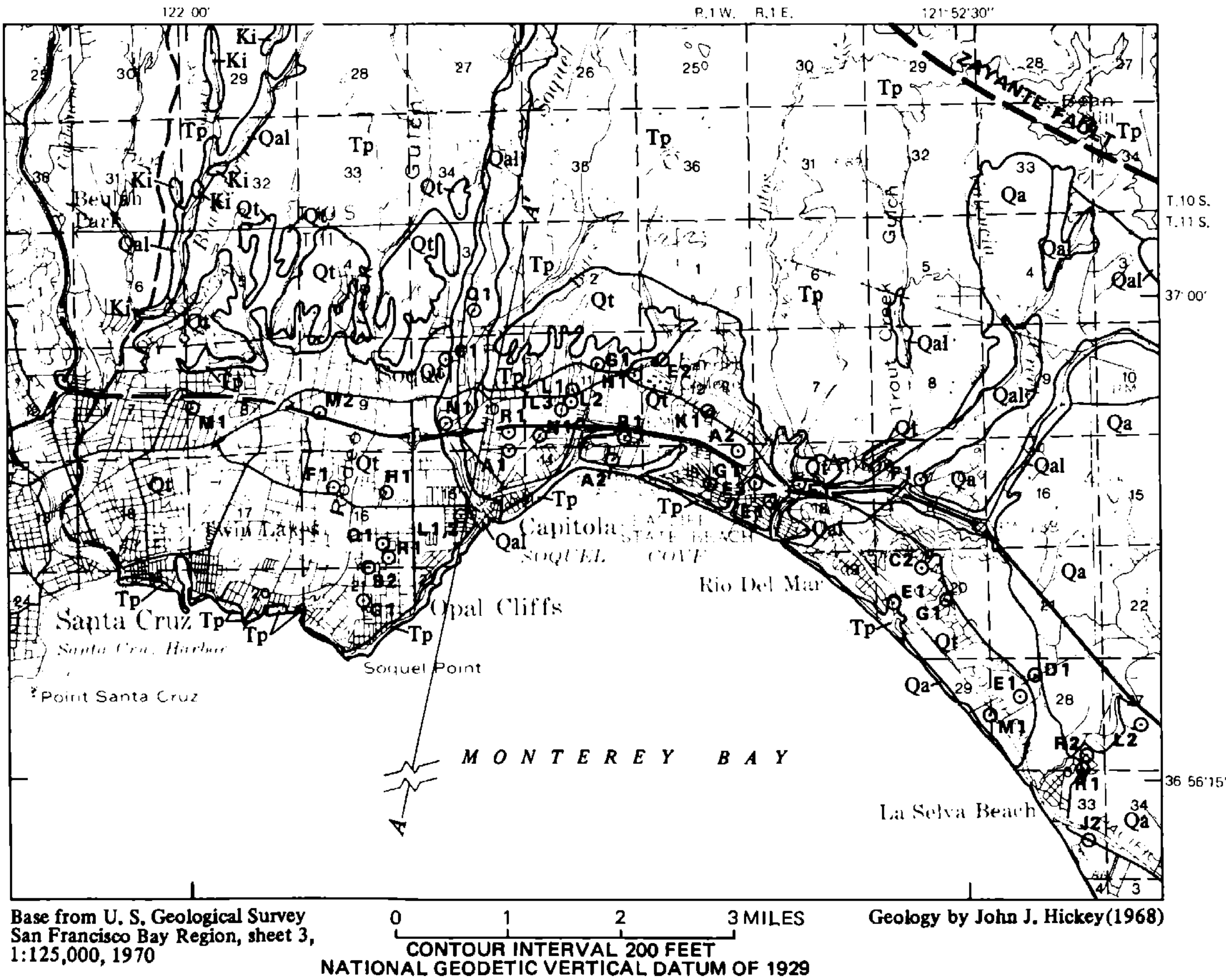
The Aromas Sand consists of well-sorted, quartzose, brown-to-red sand containing lenses of silt and clay and a few lenses of gravel. The sand, deposited during Pleistocene time in a lagoonal shoreline environment, rests unconformably on the Purisima Formation. The unit crops out only in the eastern part of the area. It dips about 4 degrees toward the southeast and ranges in thickness from zero near Aptos to an average of about 600 ft in the vicinity of La Selva Beach, extending under Monterey Bay and exposed on the sea floor.

Ground water in the Aromas Sand, in general, occurs under unconfined conditions, but is locally confined between silty and clayey beds. Recharge to the aquifer is mainly by direct infiltration of rainfall. The recharge water moves southward toward the coast and toward the southeast.

Indications of Seawater Intrusion

One of the best indications that seawater intrusion is occurring in an aquifer is an increase in the concentration of chloride in water from wells. Chloride, the major constituent in seawater, is relatively stable chemically and will move through an aquifer at virtually the same rate as the intruding water.

Another way to recognize seawater intrusion is to compare the chloride concentrations of water from wells near the coast with those in water from wells inland. If the chloride concentration of coastal well water is considerably higher than that of inland well water, seawater intrusion is suspect.



CORRELATION OF MAP UNITS

Qal	Holocene	QUATERNARY
Qt	Pleistocene	QUATERNARY
Qa	Pleistocene	QUATERNARY
Tp	Pliocene and Miocene	TERTIARY
Ki		CRETACEOUS

DESCRIPTION OF MAP UNITS

Qal	ALLUVIUM (Holocene)
Qt	TERRACE DEPOSITS (Pleistocene)
Qa	AROMAS SAND (Pleistocene)
Tp	PURISIMA FORMATION (Pliocene and Miocene)
Ki	IGNEOUS ROCKS

CONTACT—Approximately located

FAULT—Approximately located

BOUNDARY OF STUDY AREA

A———A' LINE OF GEOLOGIC SECTION (Fig. 9)

⊙M2 WELL LOCATION AND NUMBER—See text for explanation of well-numbering system

FIGURE 2.—Geology and location of wells.

Data from two principal sources were used to identify seawater intrusion in the Soquel-Aptos area: (1) Long-term chemical data collected by the Soquel Creek County Water District from their supply wells (fig. 3), and (2) chemical data collected by the Geological Survey in July 1978 from more than 20 private wells adjacent to the coast. In addition, some chemical data were available from wells owned by the city of Santa Cruz (fig. 3).

Seawater intrusion is occurring in the vicinity of Capitola in the upper part of the Purisima Formation 0-100 ft below sea level. It is evidenced by a concentration of chloride in well water exceeding 100 mg/L (milligrams per liter), which the author considers an indicator of seawater intrusion in the Soquel-Aptos area. In unintruded parts of the Soquel-Aptos area, the chloride concentration in ground water from the Purisima Formation ranges from about 20 to 80 mg/L, and in the Aromas Sand it is about 20 mg/L (fig. 3). Figure 3 shows the extent of the intrusion. It appears that intrusion has been progressing since 1959 or earlier. This is illustrated by figure 4, the 1959-78 plot of the chloride concentration of water from well 11S/1W-15L1, which obtains most of its water from the interval 0-100 ft below sea level. In 1959 the chloride concentration was about 45 mg/L--by 1978 it had increased to 90 mg/L. Seawater intrusion is also indicated by statements of some residents in the Capitola area who say that water from their shallow wells has, over the past few years, become salty to taste and unusable for garden and lawn irrigation.

Water pumped from intervals deeper than 100 ft below sea level shows little or no increase in chloride concentration, as illustrated by the plots shown in figures 5-8. These plots are for Soquel Creek County Water District supply wells in the Capitola-La Selva Beach area (fig. 3), all of which pump from the deeper intervals. No seawater intrusion is indicated in spite of the fact that the nonpumping water levels in most of the wells have been below sea level since the early 1970's. Probably the freshwater-seawater interface is advancing landward but still lies at some distance offshore or at depth.

Figure 9 is a diagrammatic geologic section showing how seawater may be intruding in the Soquel-Aptos area. The interval 0-100 ft below sea level is being intruded by seawater moving into deposits exposed on the sea floor near the shoreline, and then landward. The seaward end of the Purisima Formation probably contains seawater that enters through the wall of Monterey Submarine Canyon and through the sea floor.

Seawater intrusion is occurring because since the early 1970's ground-water pumpage, which is concentrated in an area from the shoreline inland about 1 mi, has reduced the head in the Purisima Formation and caused ground-water levels near the coast to decline and lie below sea level (figs. 4-8). Thus, a landward ground-water gradient has developed in the aquifer, allowing seawater to move shoreward (fig. 10).

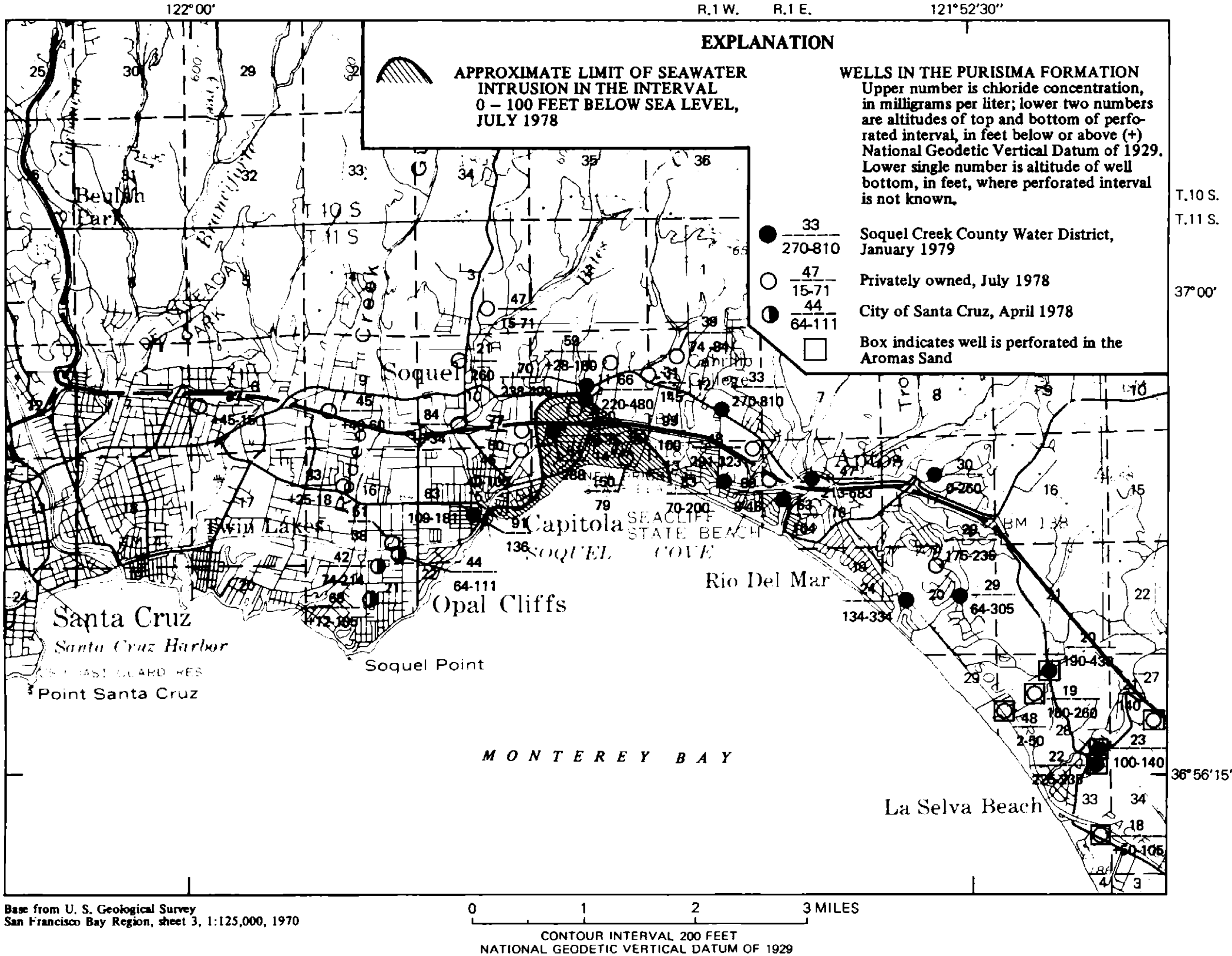


FIGURE 3. – Chloride concentration of water from wells, altitudes of perforated intervals, and approximate landward limit of seawater intrusion, July 1978.

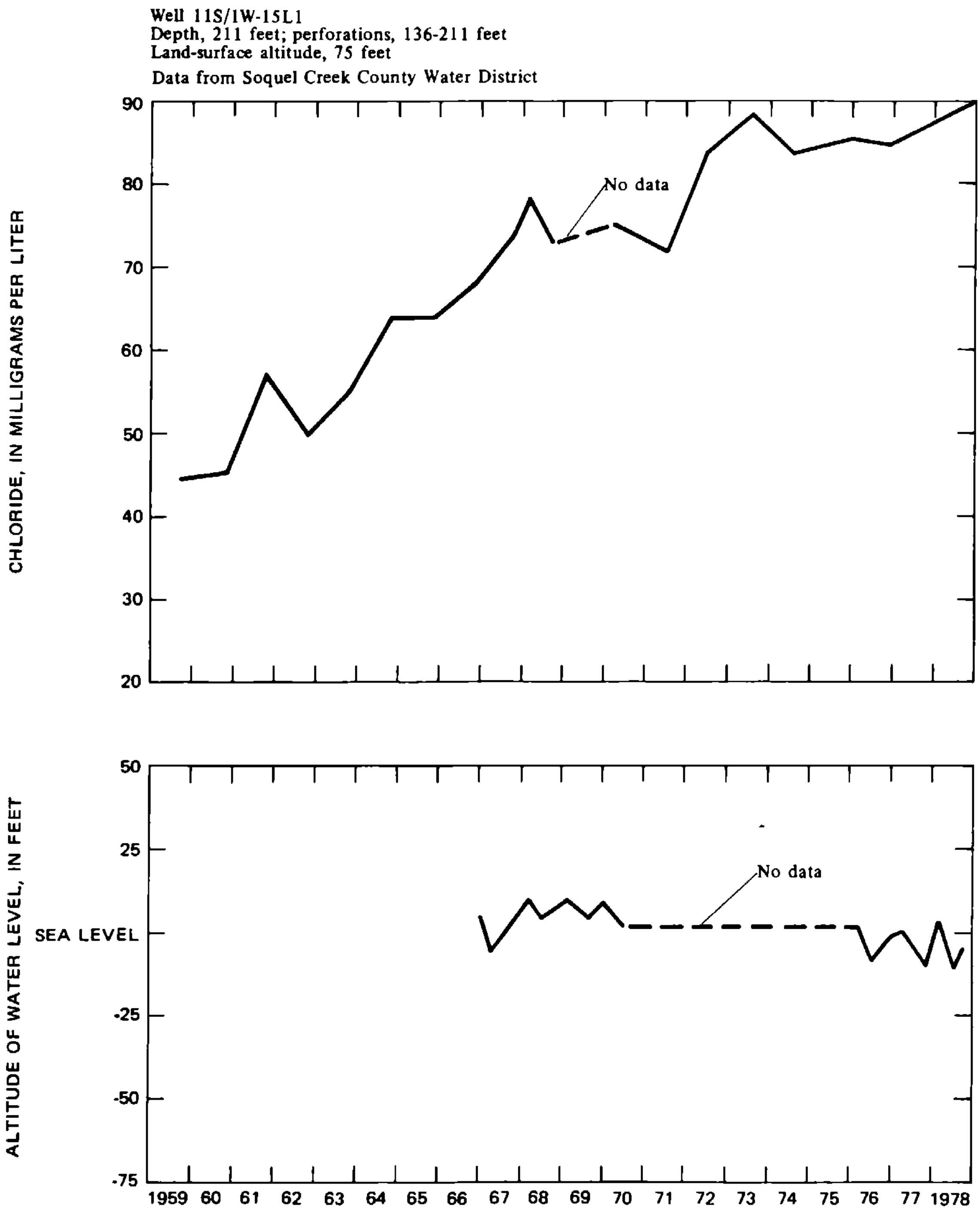


FIGURE 4.–Fluctuations of chloride and water level in well 11S/1W-15L1.

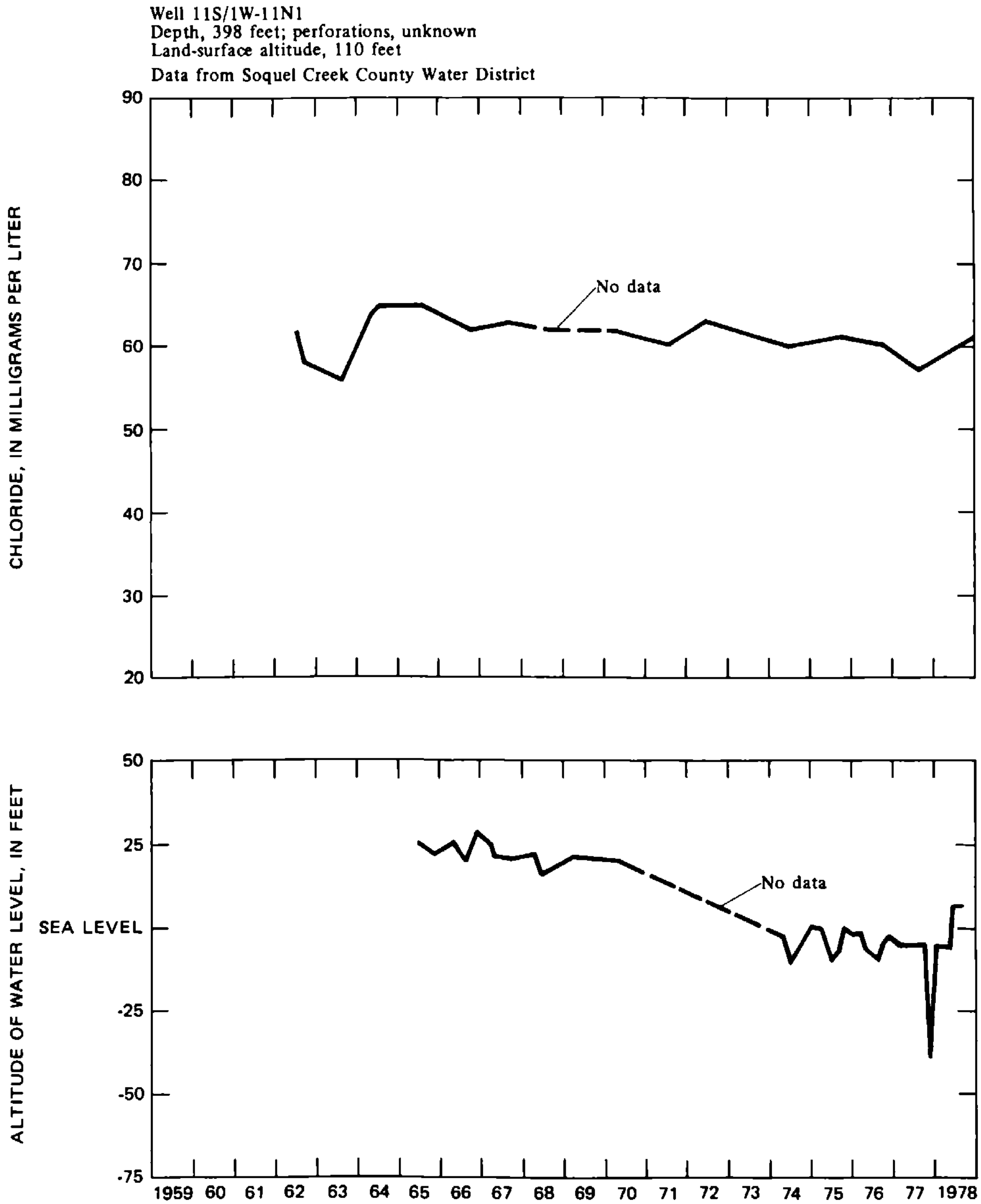


FIGURE 5.–Fluctuations of chloride and water level in well 11S/1W-11N1.

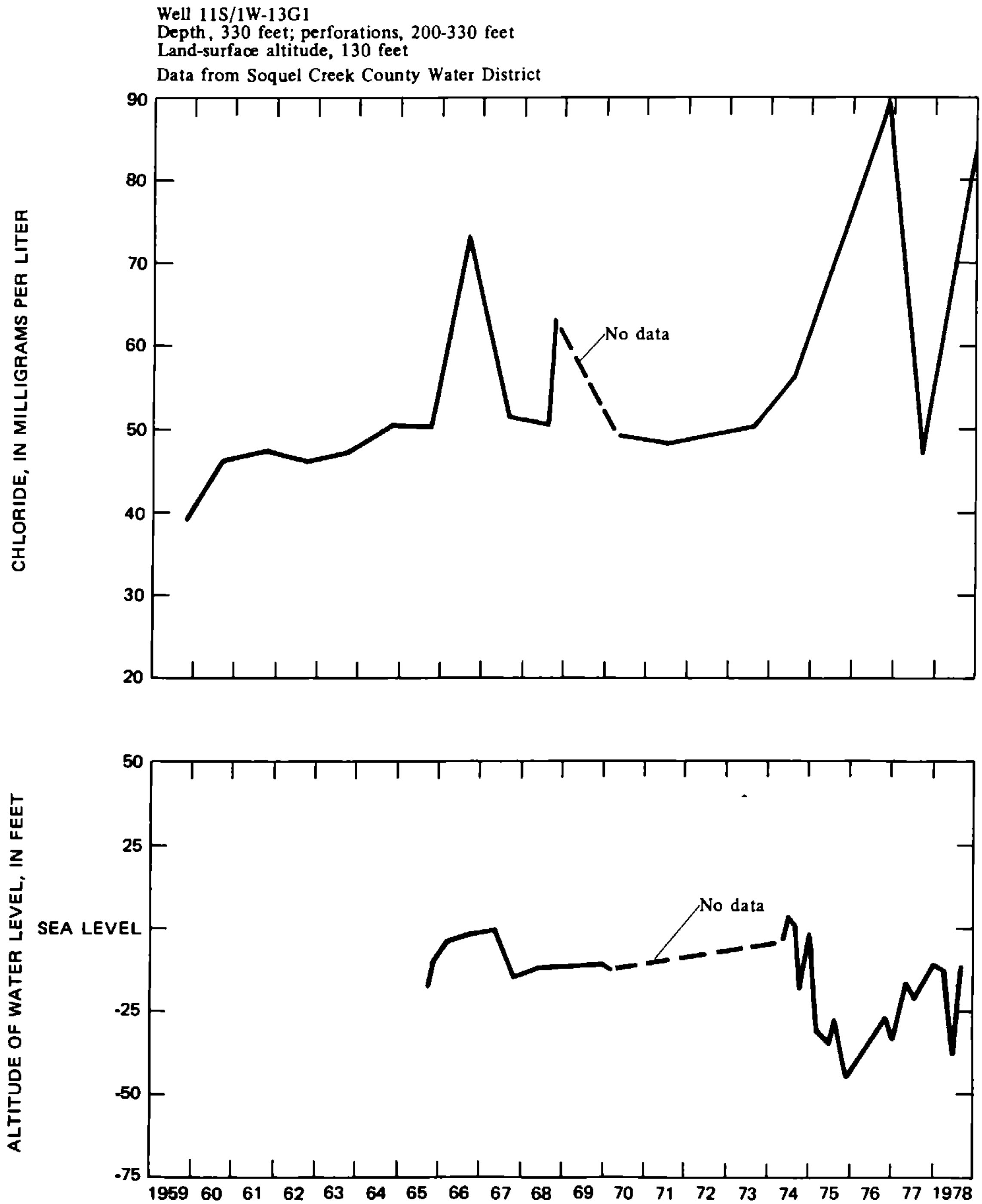


FIGURE 6.–Fluctuations of chloride and water level in well 11S/1W-13G1.

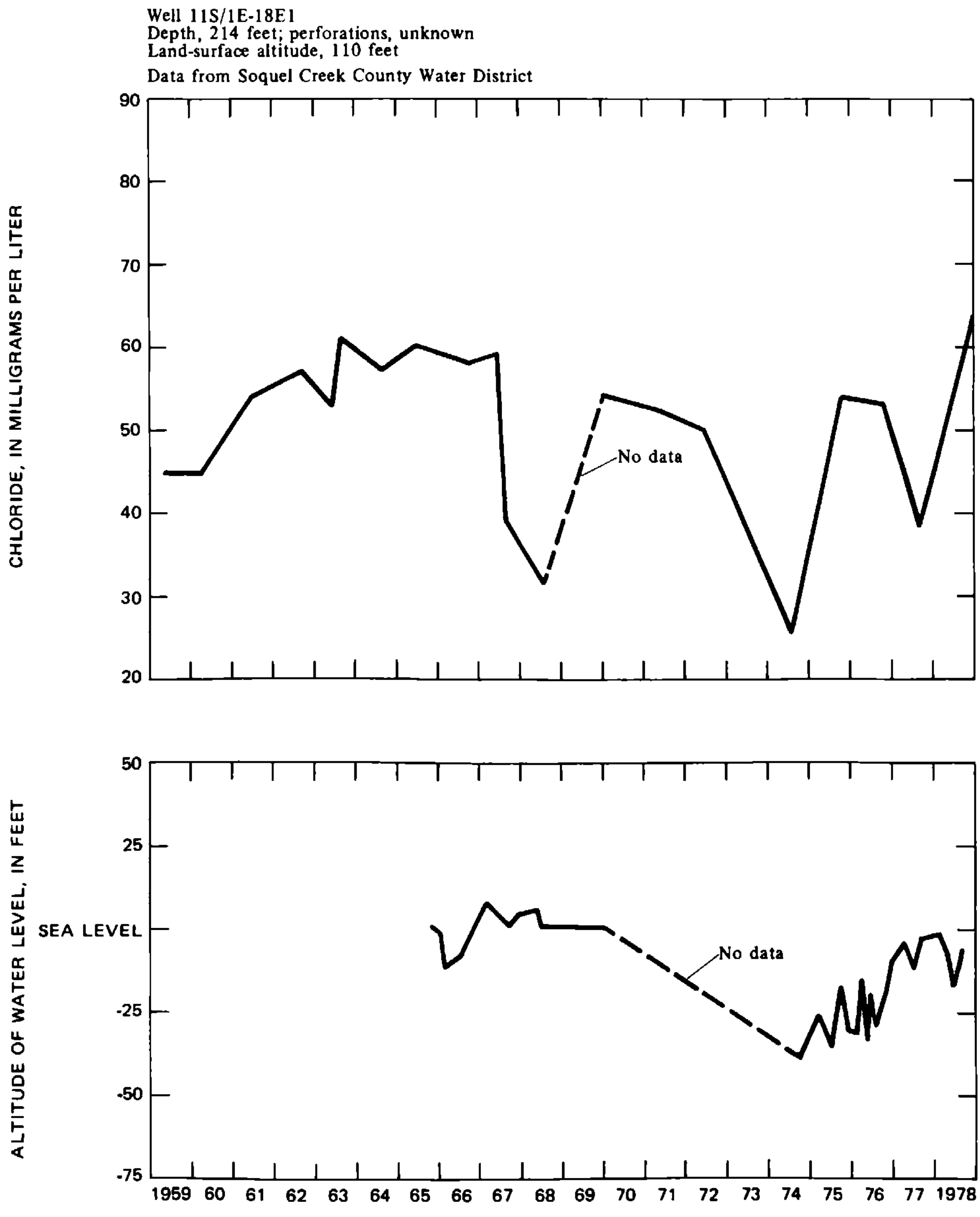


FIGURE 7.–Fluctuations of chloride and water level in well 11S/1E-18E1.

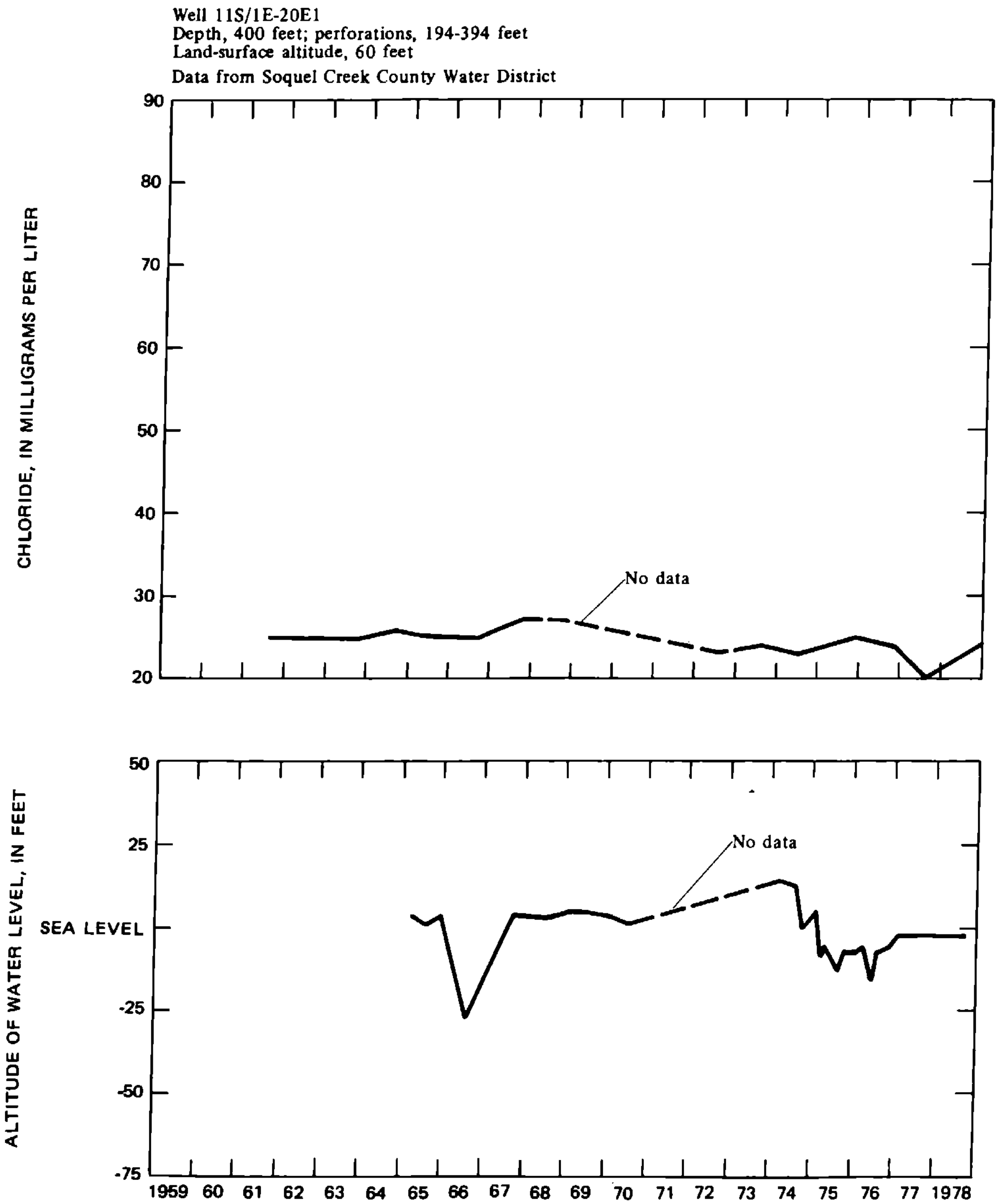


FIGURE 8.–Fluctuations of chloride and water level in well 11S/1E-20E1.

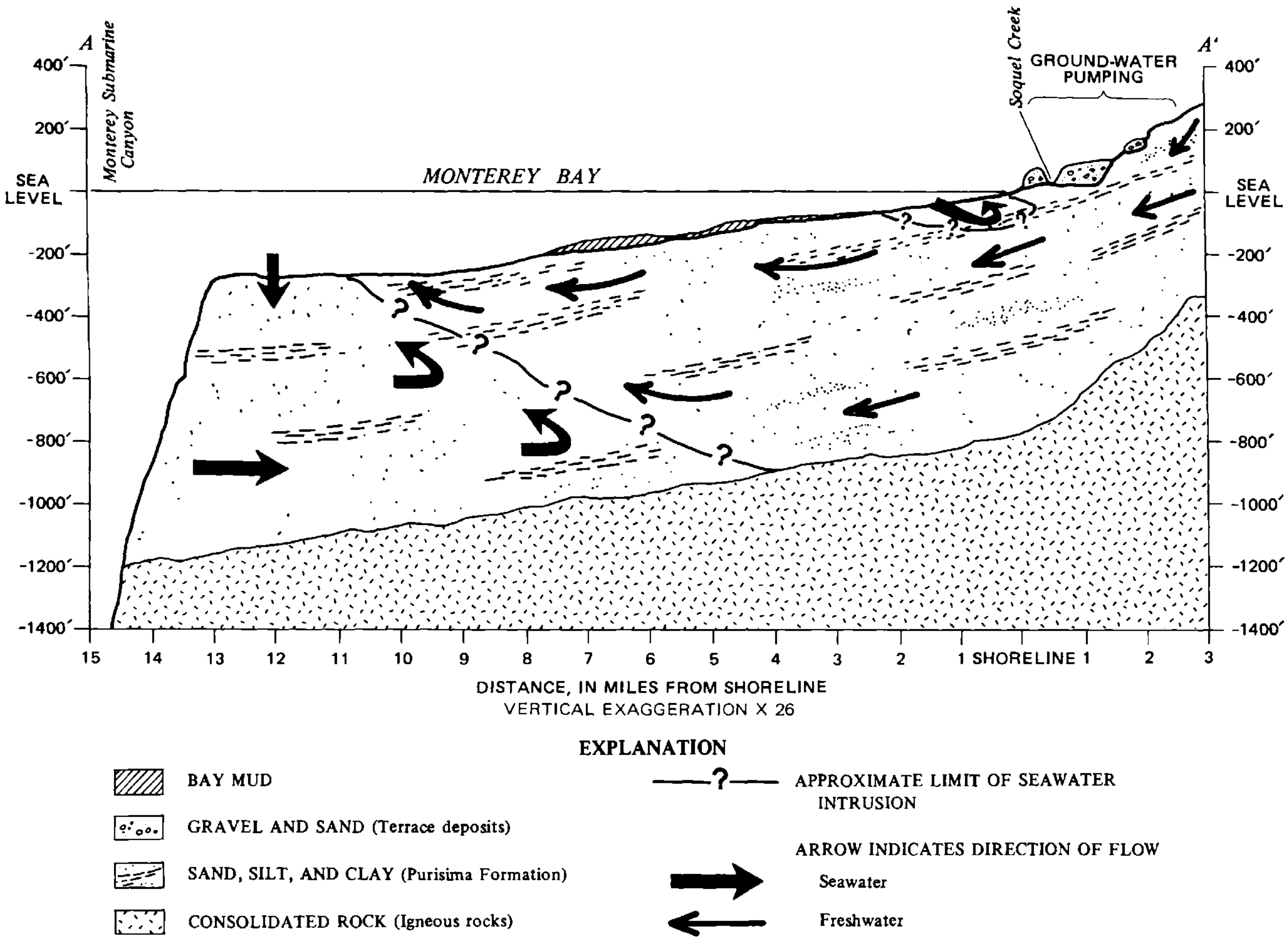


FIGURE 9.–Generalized geologic section showing zones intruded by seawater (see fig. 2 for location of section).

Methods for Controlling Seawater Intrusion

The following discussion of methods for controlling seawater intrusion is intended only as general background on the subject. Schematic diagrams are included to illustrate principles (figs. 10-13).

Seawater intrusion might be controlled by one or more of the following actions: (1) Reduce ground-water pumping in the coastal area; (2) artificially recharge the aquifers; (3) modify the pumping pattern; (4) maintain a pressure ridge of fresh ground water above sea level in the intruded aquifers along the coast; or (5) establish a pumping trough in the seawater adjacent to the coastline. The first four methods control the intrusion by maintaining the inland potentiometric surface above sea level. The fifth removes the seawater before it can migrate inland.

Pumping could be reduced by changing to crops requiring less water, by having only one harvest per year, or by taking some lands out of production. Pumping in coastal areas could be reduced by importing supplemental water. Artificial recharge could be implemented by using either this supplemental water or reclaimed wastewater.

Changing the pumping pattern would help to keep intrusion from advancing inland. Pumping wells near the coast causes seawater intrusion, because seawater moves inland when the potentiometric surface seaward of the pumping wells is below sea level (fig. 10). If the wells adjacent to the coast were abandoned and the pumping centers were shifted farther inland, the potentiometric surface would be above sea level, and the pressure gradient would be toward the ocean (fig. 11). Careful regulation of the pumpage would be necessary to prevent a return to the conditions shown in figure 10.

A pumping trough parallel to the coast could be developed to control seawater intrusion. A line of pumping wells along the coast stabilizes the seawater wedge near the trough if the amount of water pumped is carefully regulated (fig. 12). The disadvantage of this method is that it wastes a large amount of freshwater.

A ground-water pressure ridge parallel to the coast controls seawater intrusion by keeping the potentiometric surface above sea level and maintaining the seaward flow of fresh ground water (fig. 13). This method requires a line of recharge wells along the coast and a supplemental water supply to create the freshwater barrier unless some pumpage from the aquifer inland is used for recharge.

Many factors must be considered in developing plans for controlling seawater intrusion. These factors include capital outlay and recurring costs of the required physical works (for example, wells, pumps, distribution lines, and treatment facilities); legal aspects (for example, water rights and rights of way); availability and cost of supplemental water; physical aspects of the aquifer system and overlying soils; and the chemistry of the different kinds of water in the system.

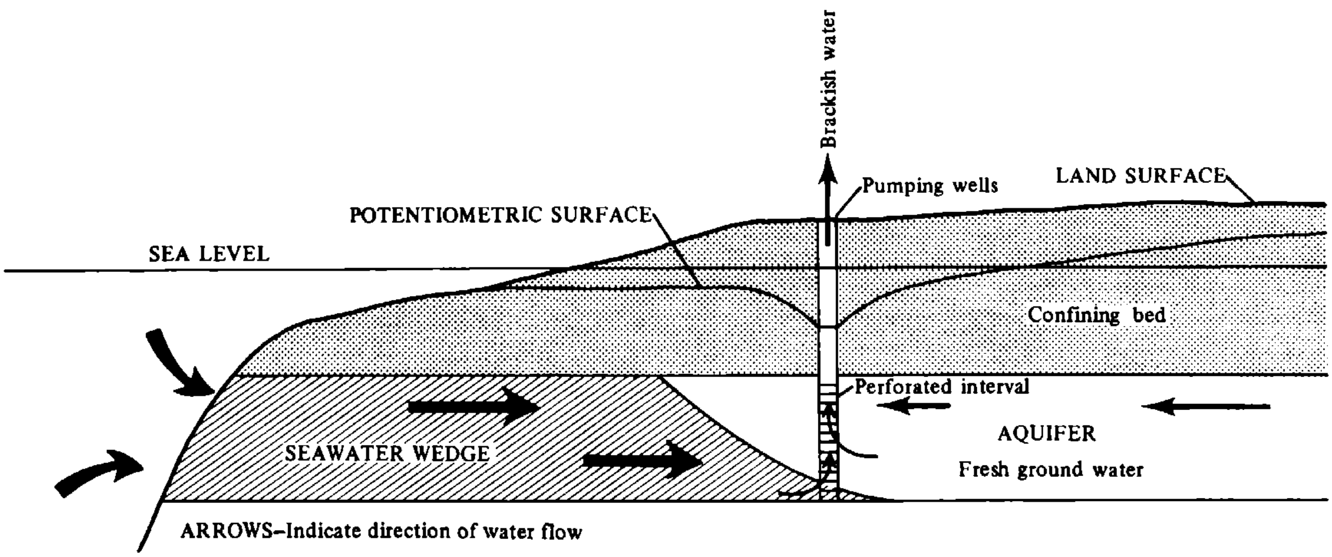


FIGURE 10.–Schematic section at coast, showing influence of coastal pumping on seawater intrusion.

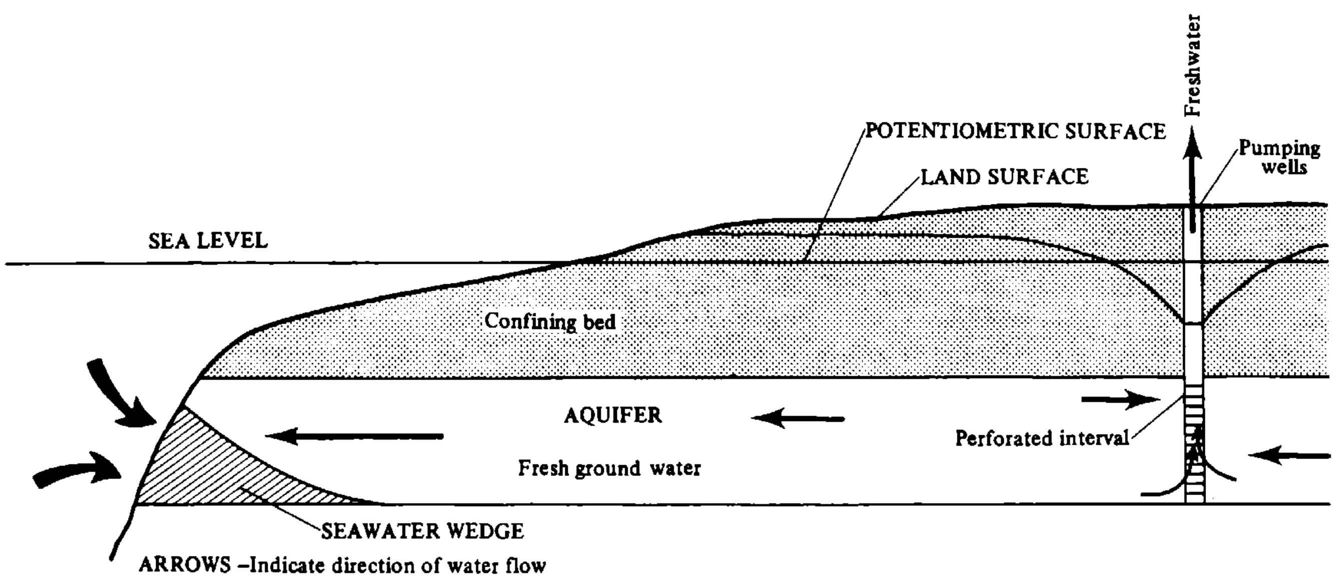


FIGURE 11.–Schematic section at coast, showing influence of inland pumping on seawater intrusion.

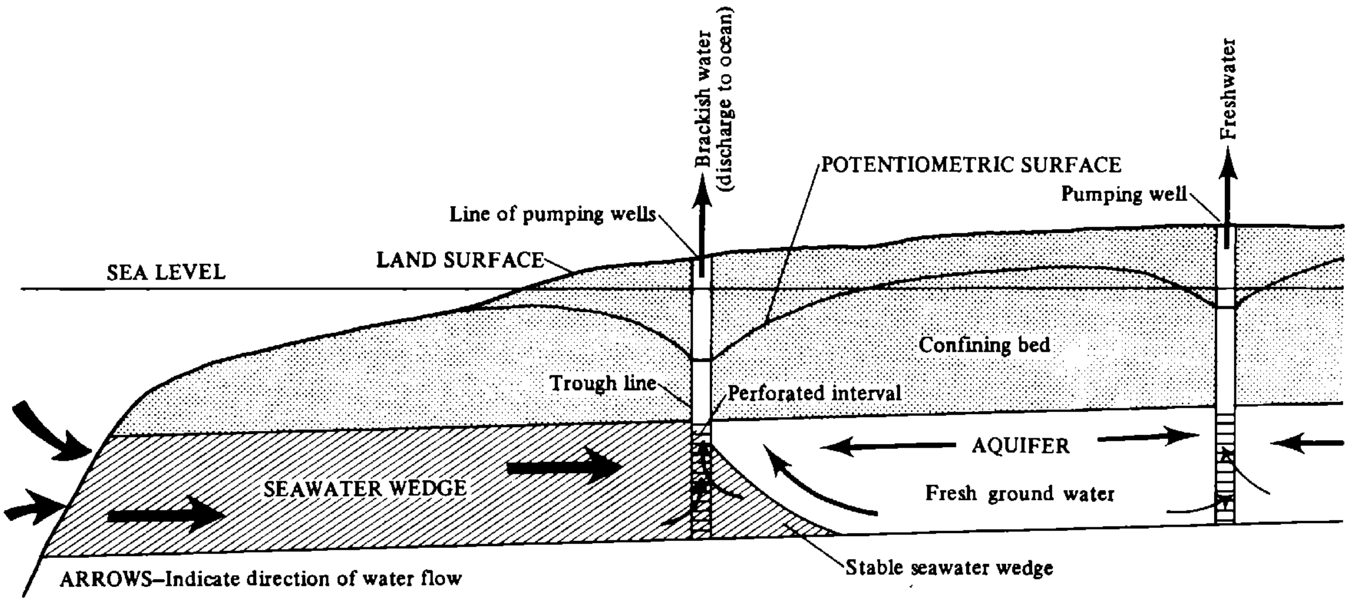


FIGURE 12.–Schematic section at coast, showing effects of a pumping trough on seawater intrusion.

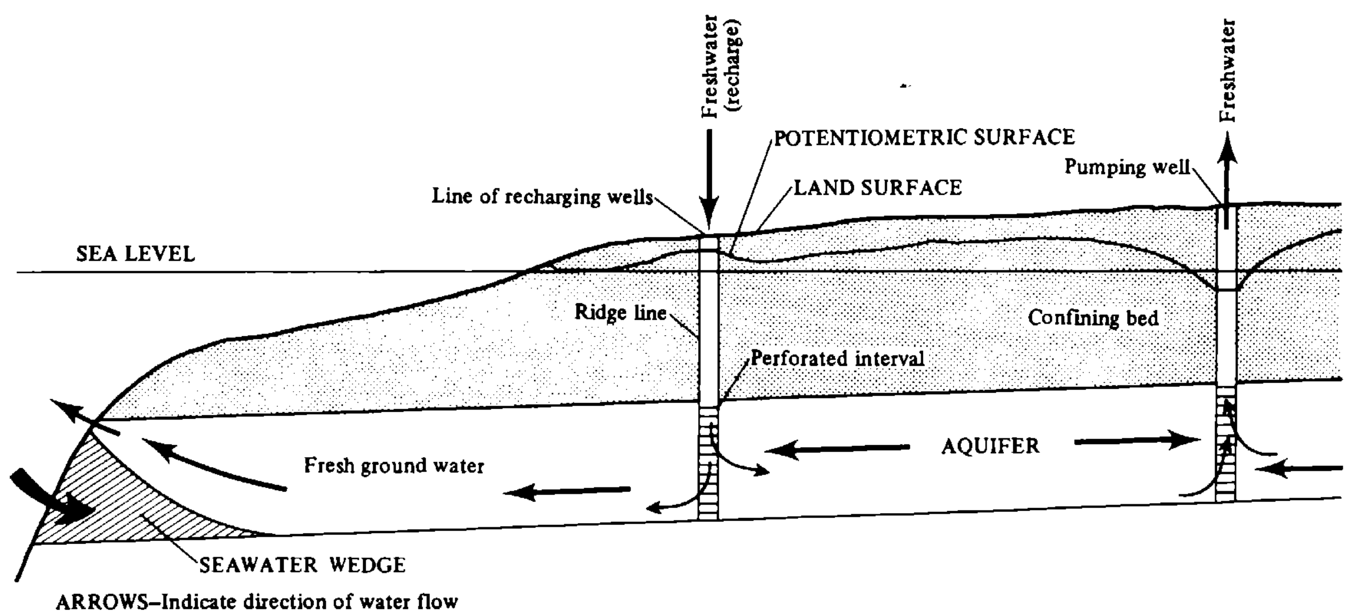


FIGURE 13.–Schematic section at coast, showing effects of a pressure ridge on seawater intrusion.

POTENTIAL AQUIFER YIELD

In this report, the potential aquifer yield in the Soquel-Aptos area is defined as the long-term average inflow to the ground-water reservoir minus unrecoverable water lost to evapotranspiration and the quantity of underflow to the ocean necessary to maintain a barrier against seawater intrusion.

The Soquel Creek County Water District and city of Santa Cruz Water Department pump water from the Purisima Formation, which is the main aquifer in the area. The Soquel Creek County Water District also pumps from the Aromas Sand, located in the vicinity of La Selva Beach (fig. 14). A separate potential yield value was determined for each of the aquifers.

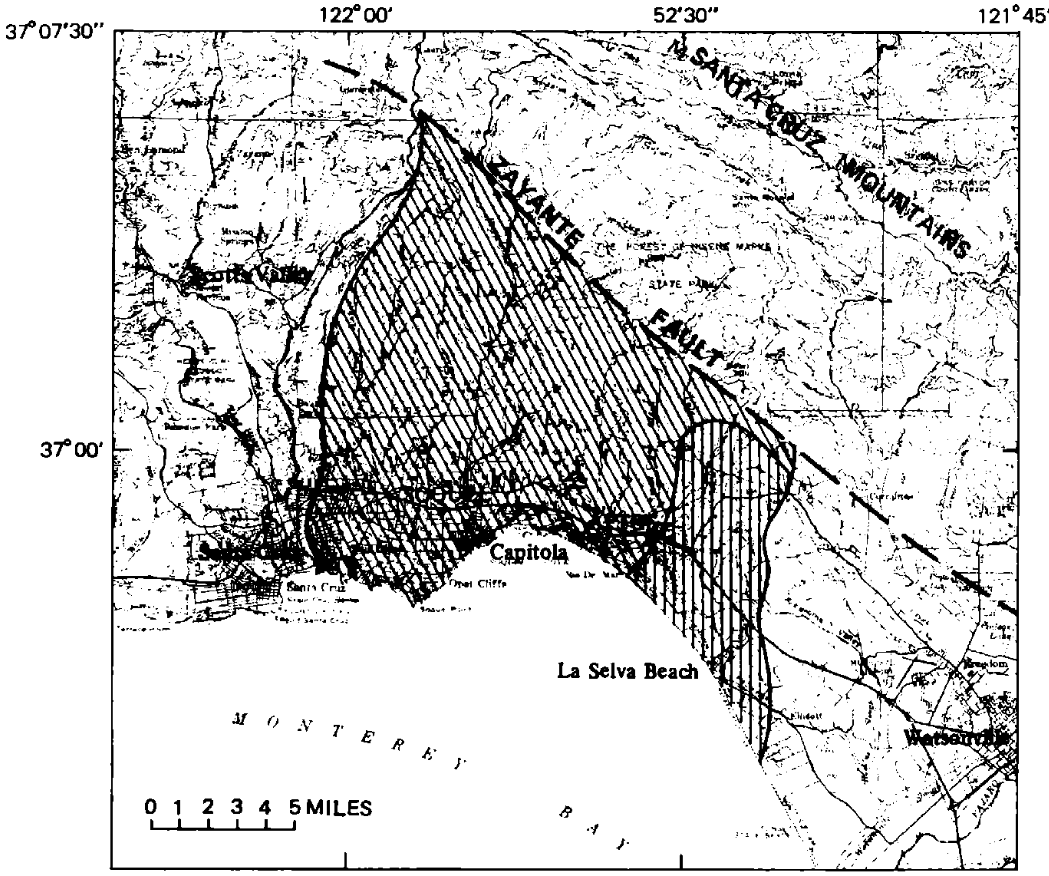
The techniques used to estimate potential ground-water yield for this report have been used by many investigators (see Todd, 1964, p. 206-208). Those used to determine the yield for the Purisima Formation and Aromas Sand, although not specifying an item-by-item evaluation of inflow and outflow, are based on the general equation of hydrologic equilibrium,

Surface inflow		Surface outflow
+ Subsurface inflow		+ Subsurface outflow
+ Precipitation	=	+ Consumptive use
+ Imported water		+ Exported water
+ Decrease in surface storage		+ Increase in surface storage
+ Decrease in ground-water storage		+ Increase in ground-water storage.

Purisima Formation

The potential yield of the Purisima Formation is shown by the relation between average annual pumpage and the corresponding average annual net change of ground water in storage for a base period in which climatic conditions approximate the long-term average. For simplicity the base period spring 1962 to spring 1975 was selected because ground-water storage was the same at the end of the period as it was at the beginning. Therefore average inflow was equal to average outflow, and potential yield was equal to the average pumpage. The hydrograph for well 11S/1W-10C1 has water-level fluctuations considered representative of those in the Purisima Formation and was used to make the estimates of potential yield (fig. 15).

On the cumulative departure curve (fig. 16) a line joining the beginning and end of the period 1962-1975 would be nearly horizontal, indicating that the average rainfall for that period was close to the long-term average. In fact, rainfall was 98 percent of the 100-year average. To be representative climatically, a base period should include a wet period and a dry period. The base period spring 1962 to spring 1975 includes parts of two dry periods and a complete wet period. It is important also to select a period that does not begin after or end with an extremely wet year, because of the "water-in-transit" problem. It may take a year or more for the water levels to fully reflect recharge from a wet year. Figure 16 indicates that neither the 1960-61 or 1974-75 rainfall years were wet years.



Base from U. S. Geological Survey
San Francisco Bay Region, sheet 3, 1:125,000, 1970

EXPLANATION

PURISIMA FORMATION

AROMAS SAND

FAULT – Approximately located

FIGURE 14.–Areas for which potential aquifer yield was determined.

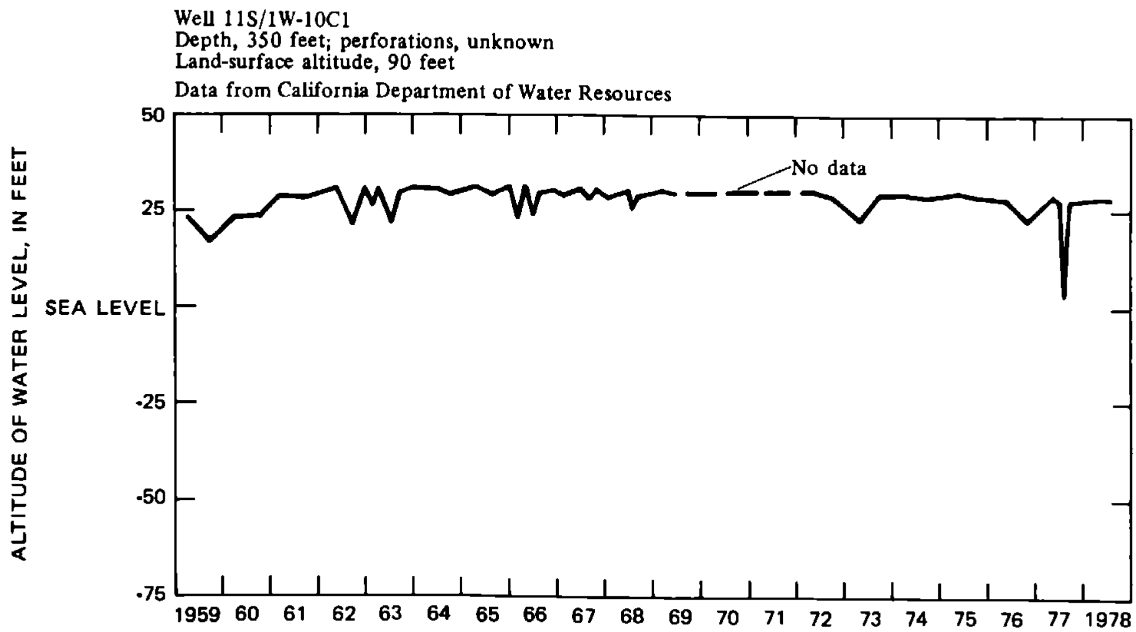


FIGURE 15.–Fluctuation of water level in well 11S/1W-10C1.

The 1962-75 period fits the required criteria for a valid base period. Therefore, the potential ground-water yield of the Purisima Formation in the Soquel-Aptos area, based on 1962-75 conditions and on average annual pumpage (4,400 acre-ft) as determined from table 1, is about 4,400 acre-ft/yr.

The estimated yield value was checked by plotting the annual average change in ground-water levels in all wells measured against annual pumpage (fig. 17). If inflow to the aquifer is reasonably constant, the points can be fitted to a straight line, and pumpage corresponding to zero change in water level equals the potential yield. The zero change in water level in figure 17 is at a point corresponding to 4,100 acre-ft, a quantity which agrees reasonably well with the yield figure determined in the previous paragraph.

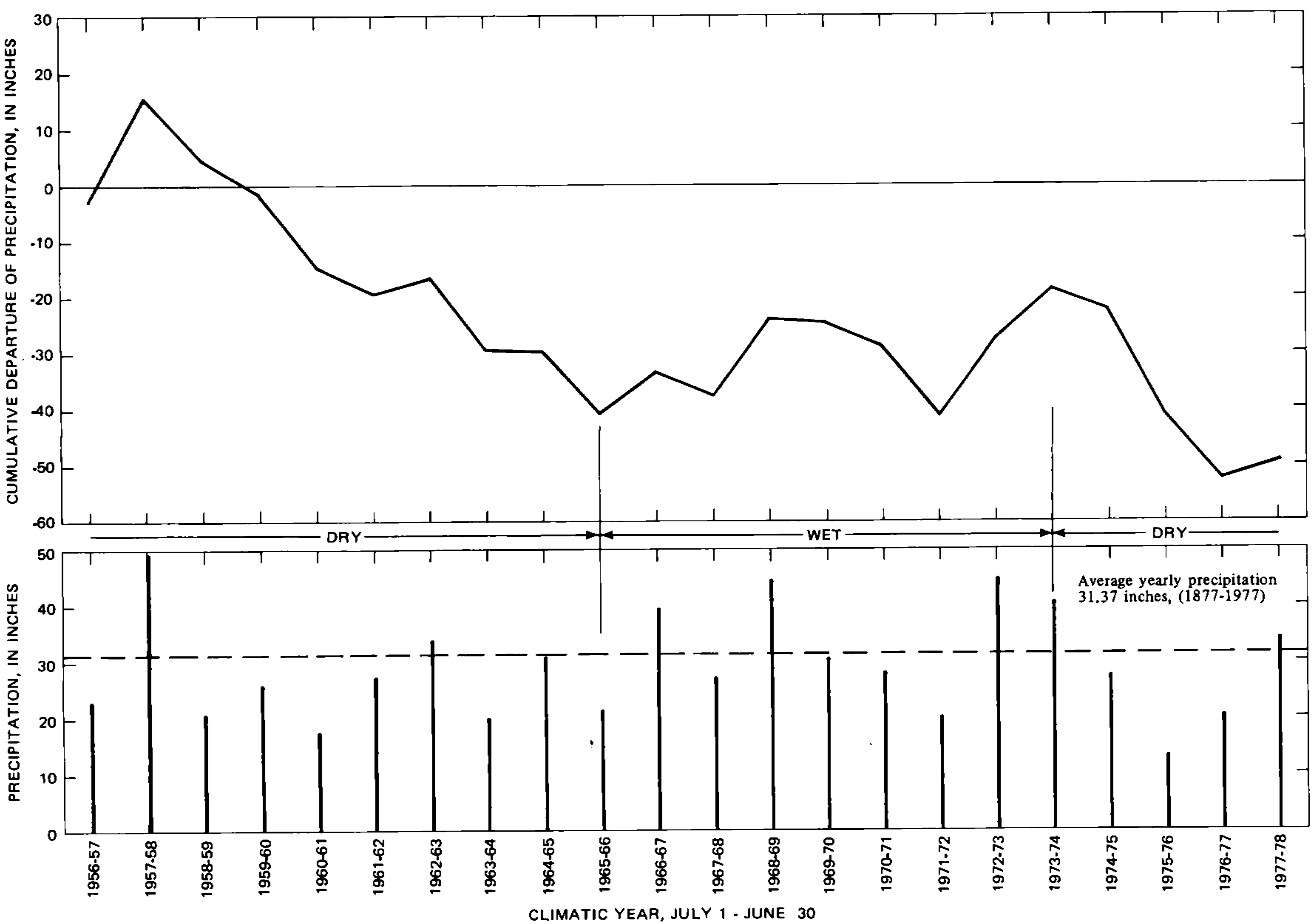


FIGURE 16.–1956-77 Santa Cruz precipatation and cumulative departure curve.

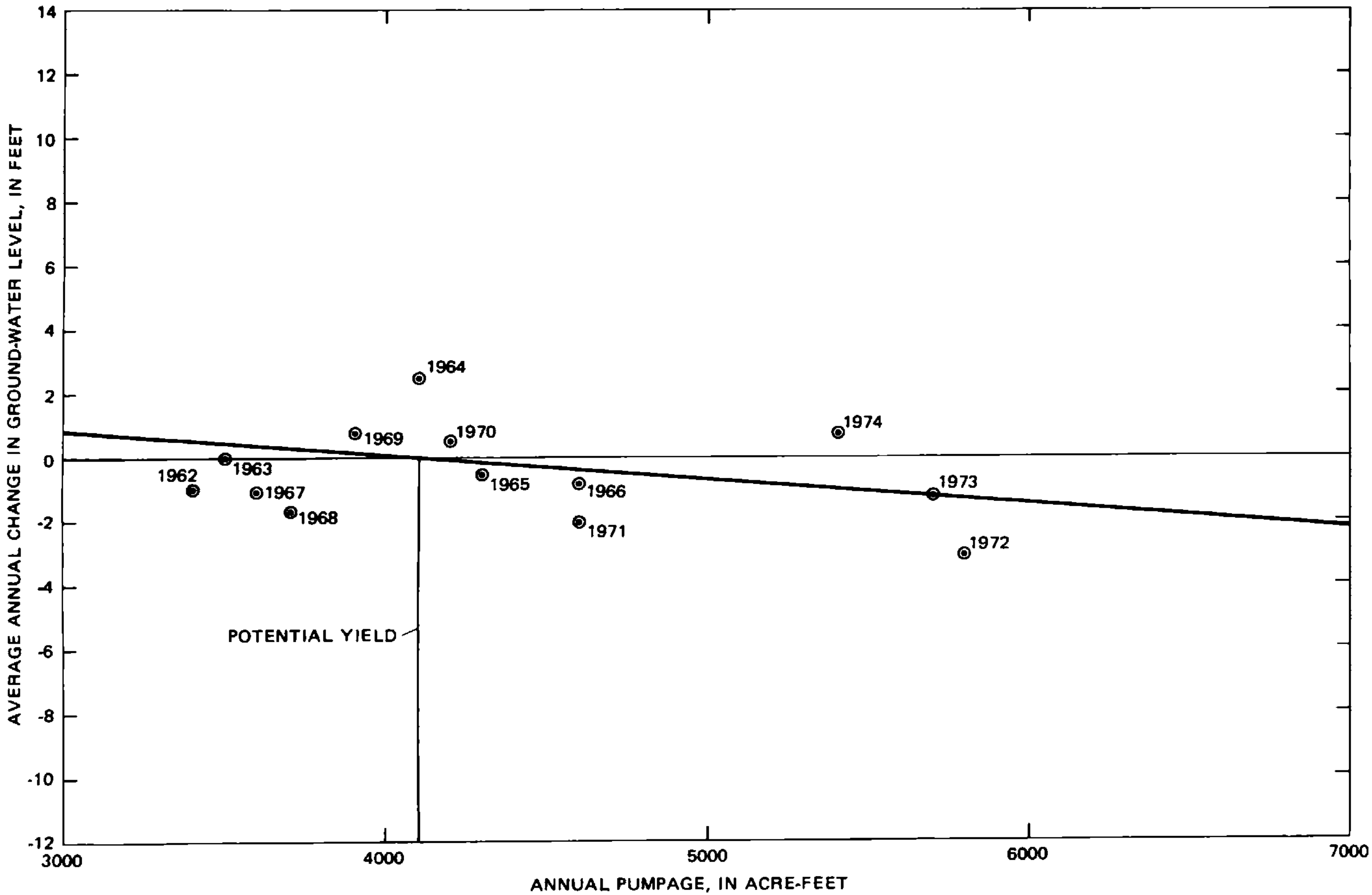


FIGURE 17.--Annual pumpage versus average annual change in ground-water level.

TABLE 1. - Pumpage, in acre-feet, from Purisima Formation, 1962-74

Year	Soquel Creek County Water District[1]	Agri-culture[2]	Miscel-laneous water pur-veyor[3]	City of Santa Cruz[1]	Indus-trial[3]	Central Santa Cruz County Water District[1]	Miscel-laneous domestic wells[3]	Total
1962	1,380	800	70	583	20	116	450	3,400
1963	1,479	800	70	598	20	100	450	3,500
1964	1,847	800	70	752	20	118	450	4,100
1965	1,975	900	70	782	20	142	450	4,300
1966	2,227	900	70	813	20	112	450	4,600
1967	1,735	900	70	141	20	112	600	3,600
1968	1,825	900	70	170	20	112	600	3,700
1969	2,010	1,000	70	134	20	112	600	3,900
1970	2,286	1,000	70	133	20	112	600	4,200
1971	2,426	1,200	70	171	20	112	600	4,600
1972	2,790	1,200	70	827	20	112	750	5,800
1973	2,921	1,200	70	657	20	112	750	5,700
1974	2,821	1,200	70	420	20	106	750	5,400
Total								56,800
13-year average								4,400

[1]Metered.

[2]Agriculture pumpage was computed from total electrical energy used for pumping water and the electrical energy required to pump a unit volume of water.

[3]Estimated.

Aromas Sand

The potential yield of the Aromas Sand was estimated by comparing the average annual pumpage with the corresponding average annual net change of ground water in storage. The estimate does not have the same degree of accuracy as that determined for the Purisima Formation, because long-term water-level fluctuations are available only for the coastal part of the aquifer and not for the large part of the recharge area several miles inland. The hydrographs of wells 11S/1E-28D1 and 11S/1E-28R2 (fig. 18) indicate that ground-water storage in 1977 was about the same as in 1966. Therefore, average

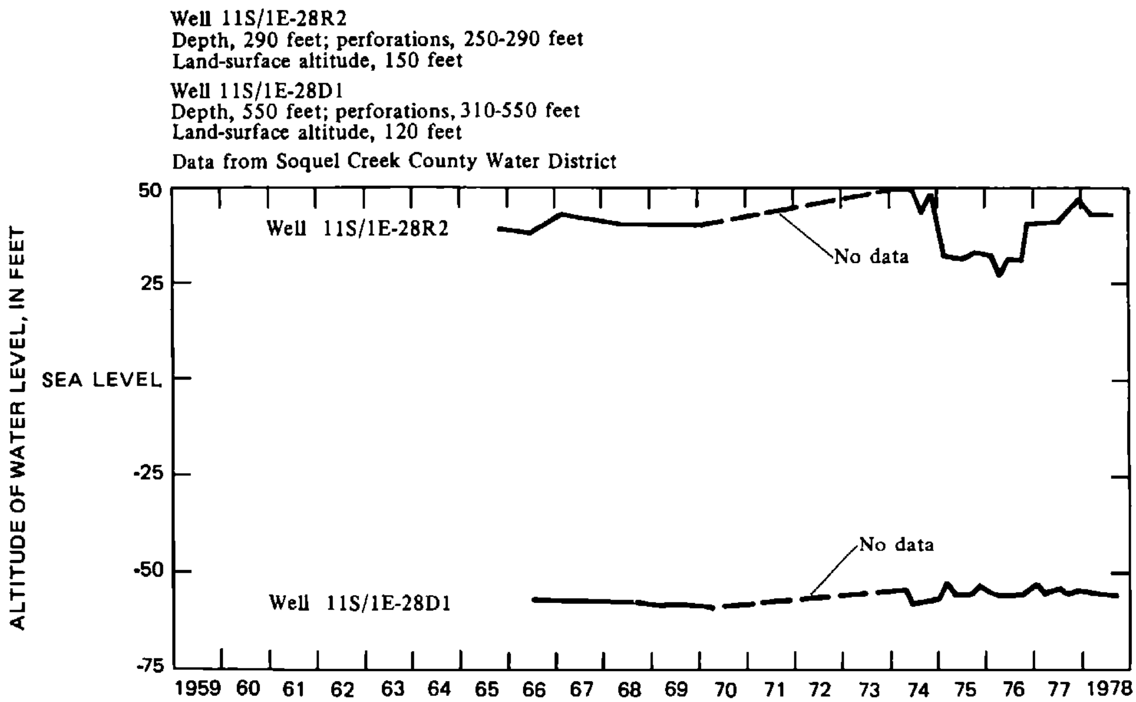


FIGURE 18.–Fluctuation of water level in wells 11S/1E-28D1 and 28R2.

inflow for the 1966-77 period was equal to average outflow, and ground-water yield is equal to average annual pumpage. The period includes a wet cycle (fig. 16) and 3 years of a dry cycle, including the drought years 1975-76 and 1976-77. Neither the 1964-65 nor the 1976-77 rainfall year was extremely wet, so there is no "water-in-transit" problem with the base period. Average rainfall for the 1966-77 base period was 29.46 inches, about 94 percent of the 100-year average. This means that inflow to the ground-water reservoir for the 1966-77 period was slightly less than the long-term average, and an estimate of ground-water yield based on average annual pumpage for this period is probably conservative. The ground-water yield of the Aromas Sand in the Soquel-Aptos area, based on 1966-76 conditions and on average pumpage as determined from table 2, is about 1,500 acre-ft/yr.

TABLE 2. - Pumpage, in acre-feet, from Aromas Sand, 1966-77

Year	Soquel Creek County Water District[1]	Agri-cul-ture[2]	Miscel-laneous water pur-veyor[3]	Indus-trial[3]	Central Santa Cruz County Water District[1]	Miscel-laneous domestic wells[3]	Total
1966	205	800	30	10	28	15	1,100
1967	374	800	30	10	28	30	1,300
1968	375	800	30	10	28	30	1,300
1969	375	900	30	10	28	30	1,400
1970	375	900	42	10	28	30	1,400
1971	375	900	42	10	28	30	1,400
1972	375	1,000	42	10	28	45	1,500
1973	375	1,000	42	10	28	45	1,500
1974	386	1,000	42	10	26	45	1,500
1975	400	1,100	42	10	64	45	1,700
1976	400	1,100	42	10	75	45	1,700
1977	400	1,100	42	10	44	45	1,600
Total							17,400
12-year average							1,500

[1]Metered.
[2]Agriculture pumpage was computed from total electrical energy used for pumping water and the electrical energy required to pump a unit volume of water.
[3]Estimated.

OBSERVATION-WELL NETWORK

The objective of an observation-well network in the Soquel-Aptos area is to function as an early warning system to alert those responsible for managing and protecting the ground-water resources of the area from adverse changes. Water-level measurements in wells are necessary to indicate the effects of pumping on the ground-water system and the status of ground-water storage. Ground-water sample analyses are needed to monitor seawater intrusion and other water-quality changes.

At the present time the Soquel Creek County Water District makes monthly pumping and nonpumping water-level measurements in 15 supply wells. The same wells are sampled every autumn and analyzed for major-ion concentration, including total alkalinity (as $CaCO_3$), bicarbonate, boron, calcium, chloride, specific conductance, dissolved solids, fluoride, iron, magnesium, potassium, silica, sodium, sulfate, and nitrate plus nitrite as nitrogen. The California Department of Water Resources measures water levels in wells 11S/1W-10C1 and 15E2 (USGS 16H1) at monthly intervals.

TABLE 3. - Potential observation-well network

Well No.	Depth (ft)	Type of data and frequency of collection				
		Water level		Water quality		
				Chloride and specific conductance		Major ions
		Monthly	April and September	April	September	September
10S/1W-27J1	238		X			
11S/1W-9M2	110		X	X	X	
11S/1W-10C1	350	X		X	X	
11S/1W-11L1	628	X		X		X
11S/1W-11L2	650	X		X		X
11S/1W-11L3	150		X	X	X	
11S/1W-11N1	398	X		X		X
11S/1W-11R1	220		X	X	X	
11S/1W-12K1	1,020	X		X		X
11S/1W-13[1]	700-800		X	X	X	
11S/1W-13G1	330	X		X		X
11S/1W-14A2	194		X	X	X	
11S/1W-15[1]	700-800		X	X	X	
11S/1W-15A1	168		X	X	X	
11S/1W-15L1	211	X		X		X
11S/1W-15L2	256	X		X		X
11S/1W-16H1	101	X				
11S/1W-16Q1	98		X	X	X	
11S/1E-17F1	460	X		X		X
11S/1E-18E1	214	X		X		X
11S/1E-18F1	713	X		X		X
11S/1E-19[1]	700-800		X	X	X	
11S/1E-20E1	400	X		X		X
11S/1E-20G1	495	X		X		X
11S/1E-28D1	550	X		X		X
11S/1E-28M1	184		X	X	X	
11S/1E-28R1	355	X		X		X
11S/1E-28R2	290	X		X		X
11S/1E-33J2	205		X	X	X	

[1]Well to be drilled.

Table 3 and figure 19 show the wells in the current observation network and the wells that could be used to expand the network for more effective monitoring. Additional shallow wells that might monitor the depth interval now being intruded by seawater are: 11S/1W-9M2, 11L3, 11R1, 14A2, 15A1, and 16Q1, and 11S/1E-28M1 and 33J2. Observations made at these wells would be most effective if made twice yearly, in April when ground-water storage is highest and in September when ground-water storage is lowest. Water-level measurements will show the status of ground-water storage, and determination of chloride concentration and specific conductance in water samples will show changes in water quality. The 15 district supply wells would also be most effectively monitored in April and September. The April samples need only be analyzed for chloride and the specific conductance determined. Complete chemical analyses of the September samples would be needed. Water-level measurements are currently being taken at district supply wells at monthly intervals. The addition of April and September water-level data from well 10S/1W-27J1 would help to monitor changes in ground-water storage in the Purisima Formation in the central part of the Soquel-Aptos area.

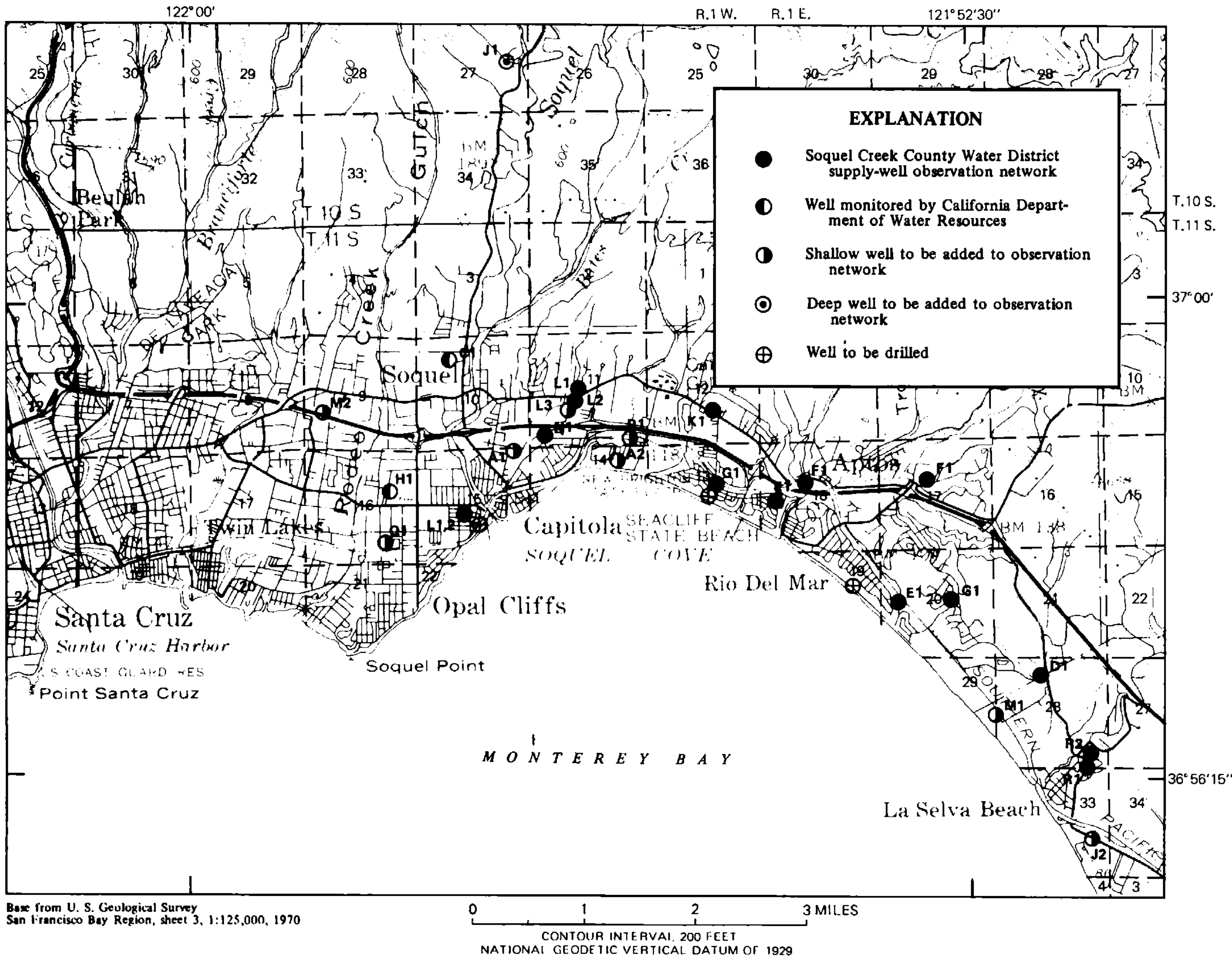


FIGURE 19. – Potential observation-well network.

Three new wells, 700-800 ft deep and adjacent to the coast, one in SW¼ sec. 13, T. 11 S., R. 1 W., one in SE¼ sec. 15, T. 11 S., R. 1 W., and one in SW¼ sec. 19, T. 11 S., R. 1 E., could monitor the lower part of the Purisima Formation. Data from these wells might be used to detect the advancing sea-water front at depth before it reaches the Soquel Creek County Water District wells.

CONCLUSIONS

Ground-water pumpage from the Purisima Formation, a confined aquifer, has averaged about 5,400 acre-ft/yr since 1970--1,000 acre-ft/yr more than its potential yield of 4,400 acre-ft/yr. This pumping has caused a decrease in freshwater head, and water levels in wells along the coast have declined to below sea level. Prior to the 1970's the head was sufficient to produce a seaward gradient, and freshwater was discharged into the ocean at the outcrop of the aquifer, maintaining the freshwater-seawater interface an unknown but probably considerable distance offshore. Since the early 1970's the reduction of head has reversed the ground-water gradient in the aquifer and has brought about conditions that are favorable for migration of seawater landward. Seawater intrusion has resulted and has progressed, in the interval 0-100 ft below sea level, to the vicinity of Capitola. Intrusion has been detected in this shallow interval first, probably because it crops out, near shore, on the floor of Monterey Bay, and seawater had only a short distance to travel to reach shallow wells.

It is unknown how long it will take seawater to intrude the inland parts of the deeper zones, if indeed it ever does. It will depend on how carefully pumpage, with its effect on freshwater head, is managed. As the freshwater head is reduced, seawater will move landward and a new freshwater-saltwater interface will be established. If the interface reaches deep wells, then saltwater will be pumped. Conversely, if the freshwater head is increased, the interface will move seaward, and the threat of seawater intrusion will be eliminated.

Ground-water pumpage from the Aromas Sand in the vicinity of La Selva Beach (fig. 14) has been near its potential yield--about 1,500 acre-ft/yr--since the early 1970's. No changes in the quantity of ground water in storage or in water quality have been observed.

An observation-well network could be established to monitor status of ground-water storage and water quality.

REFERENCES CITED

Hickey, J. J., 1968, Hydrogeologic study of the Soquel-Aptos area, Santa Cruz County, California: U.S. Geological Survey open-file report, 48 p.

Todd, D. K., 1964, Ground water hydrology: New York, John Wiley, 336 p.

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