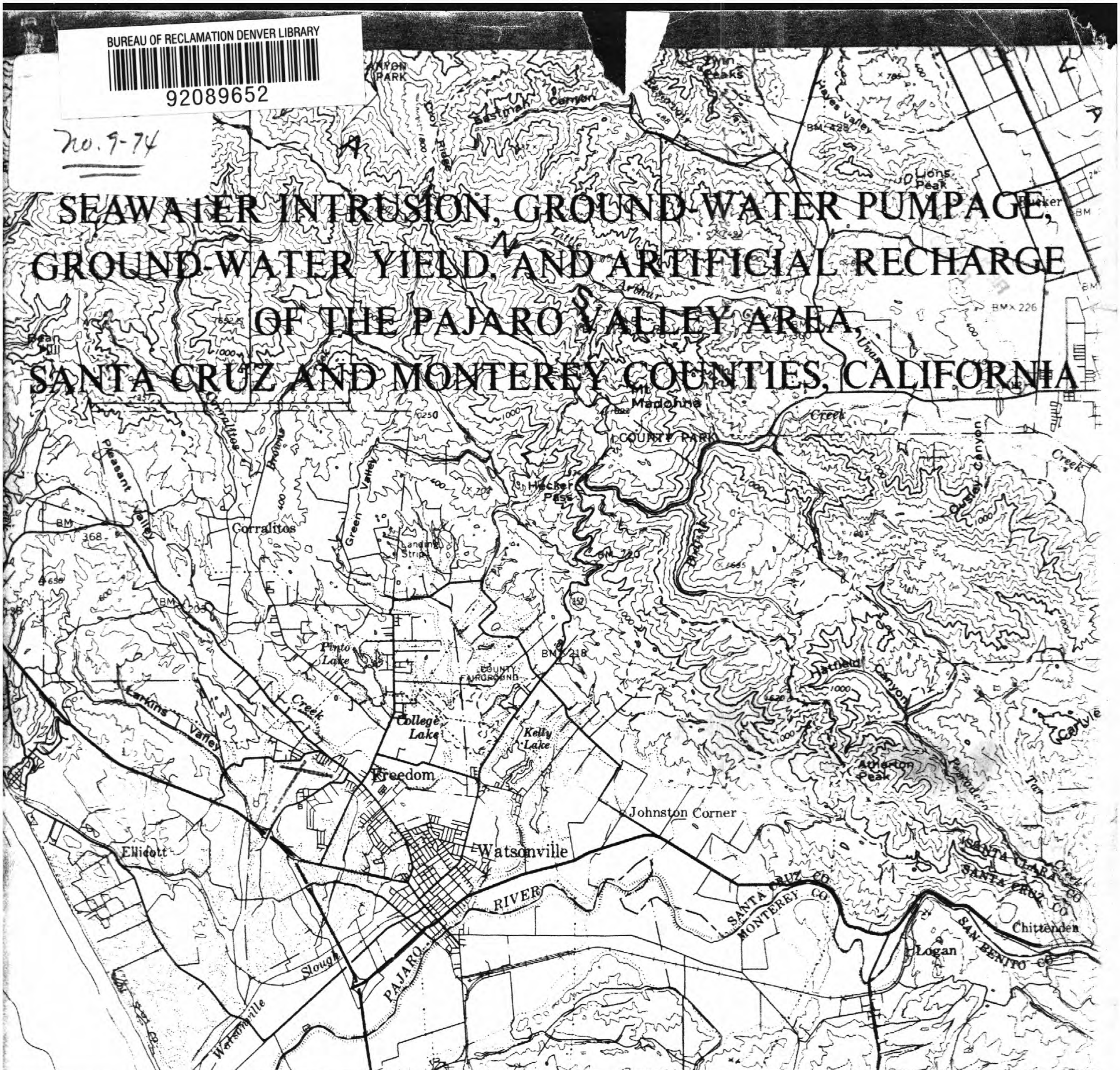
SEAWATER INTRUSION, GROUND-WATER PUMPAGE, GROUND-WATER YIELD, AND ARTIFICIAL RECHARGE OF THE PAJARO VALLEY AREA, SANTA CRUZ AND MONTEREY COUNTIES, CALIFORNIA



Water Resources Division.

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SANTA CRUZ COUNTY FLOOD CONTROL AND WATER CONSERVATION DIST

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TABLES

CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric (SI)*
inches (in)	2.540	centimeters (cm)
feet (ft)	3.048×10^{-1}	meters (m)
miles (mi)	1.609	kilometers (km)
acres	4.047×10^{-1}	hectares (ha)
square miles (mi^2)	2.590	square kilometers (km^2)
acre-feet (acre-ft)	1.233×10^{-3}	cubic hectometers (hm^3)
gallons per minute (gal/min)	3.785×10^{-3}	cubic meters per minute (m^3/min)
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic meters per second (m^3/s)
degrees Fahrenheit (°F)	5/9(°F - 32)	degrees Celsius (°C)

SEAWATER INTRUSION, GROUND-WATER PUMPAGE, GROUND-WATER YIELD, AND ARTIFICIAL RECHARGE OF THE PAJARO VALLEY AREA, SANTA CRUZ AND MONTEREY COUNTIES, CALIFORNIA

By K. S. Muir

ABSTRACT

The Pajaro Valley area, California, covering about 120 square miles (310 km^2), extends from the southern part of Santa Cruz County to several miles south of the county line into Monterey County. It borders the Pacific Ocean on the west and the Santa Cruz Mountains on the east. The city of Watsonville is the largest center of population.

Seawater intrusion is occurring in the Pajaro Valley area from several miles north to several miles south of the mouth of the Pajaro River and in a small area about 4 miles (6.5 km) north of the river. The intrusion extends inland about 1 mile (1.6 km). Two water-bearing zones are being intruded--the depth intervals 100-200 feet (30-60 m) and 300-600 feet (90-180 m).

Ground-water pumpage averaged 49,100 acre-feet per year (60.6 hm^3/yr) for the 9-year period 1963-71. The long-term ground-water yield of the Pajaro Valley is about 44,000 acre-feet per year (54.3 hm^3/yr). Artificial recharge can be effected through modified streambeds at infiltration rates as high as 3 feet per day (0.9 m/d). Injection wells may have recharge capabilities of as much as 500 gallons per minute (1.9 m^3/min).

INTRODUCTION

Purpose and Scope

Ground water is one of the more important natural resources in Santa Cruz County. This is especially true for the Pajaro Valley area (fig. 1), which is the largest farming area in the county. The economy of the valley is based on an irrigation-oriented agriculture, which, in turn, is dependent on a reliable water supply. Under present conditions surface water cannot meet this need--its distribution as to time and space does not lend itself to the seasonal demands of agriculture. People of the area have therefore turned to ground water to meet their water needs. They now pump large amounts of ground water from wells each year. In fact, 80 percent of all ground-water consumption in Santa Cruz County occurs in the Pajaro Valley area. Future economic development in Santa Cruz County will depend, in part, on the continued exploitation of the ground-water resources in the Pajaro Valley area. For county planners to make intelligent decisions regarding future long-term utilization of the ground-water resources of the Pajaro Valley area, data on the hydrologic system and the parameters that exert controls on this system must be known.

A previous report (Muir, 1972) described the geologic framework and the source, occurrence, movement, and quality of the ground water in the Pajaro Valley area. Also described in the report were the hydrologic units and areas that were potentially endangered by seawater encroachment and the areas that appeared favorable for recharge of imported water into the various hydrologic units. The report was the end product of a qualitative study that was designed to build a foundation of knowledge of the hydrologic system. The study showed that several aspects of the ground-water resources of the Pajaro Valley area should be investigated further. These were seawater intrusion, ground-water pumpage, ground-water yield, and artificial recharge. The aspects were studied and the findings are summarized in the present report.

The purpose of this report is to describe where and how seawater has intruded the aquifers in the Pajaro Valley area, present estimates of ground-water pumpage and, insofar as available data permit, ground-water yield, and discuss the best methods and areas for artificial recharge as well as estimates of potential artificial-recharge rates.

The scope of the report was designed to give the reader an overview of the hydrologic elements mentioned above. This report is not intended to give specific answers to any of the complex hydrologic problems facing the ground-water users in the valley. These would have to come from detailed studies.

This report was prepared by the U.S. Geological Survey in cooperation with the Santa Cruz County Flood Control and Water Conservation District.

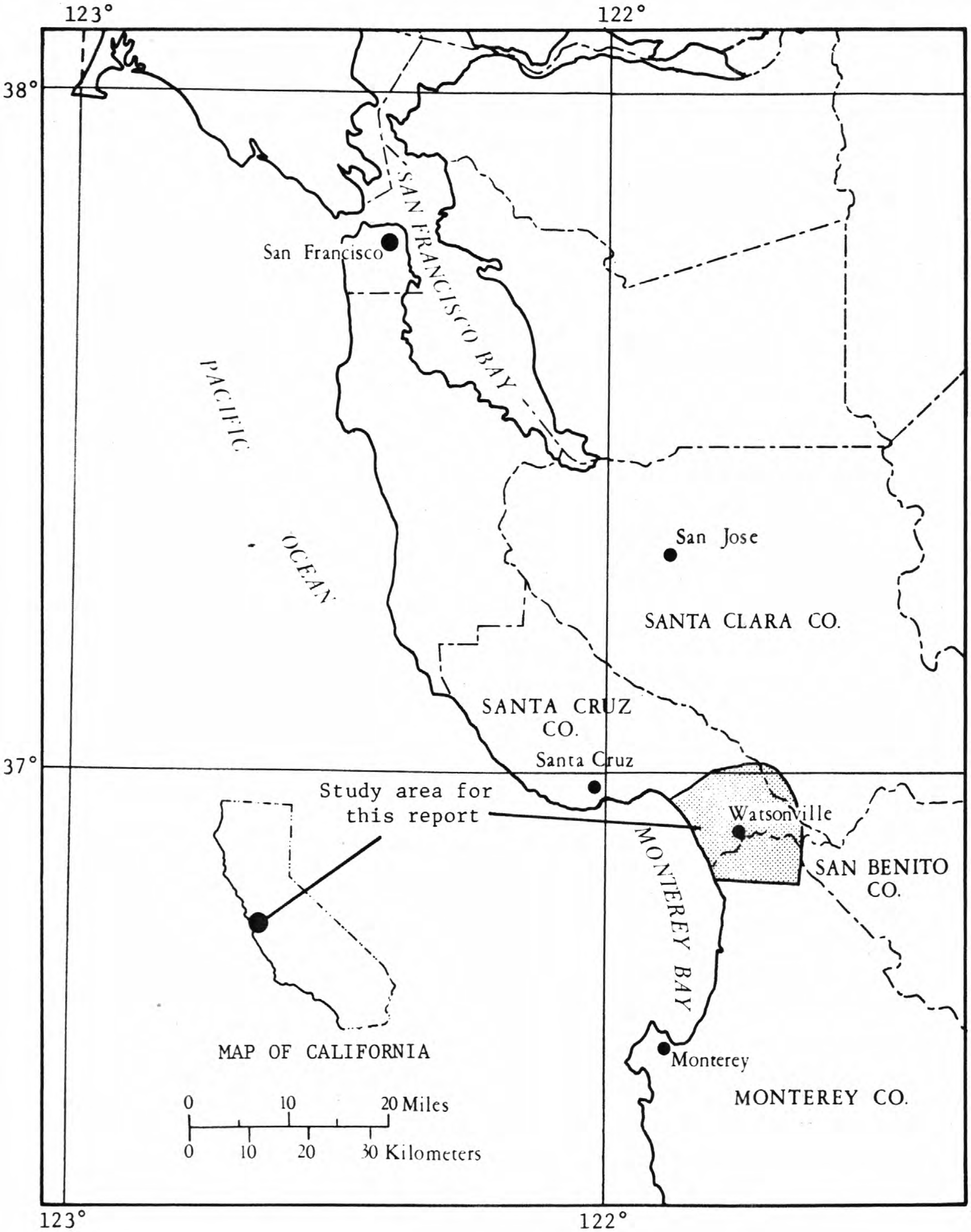


FIGURE 1.--Study area.

Location and General Features

The Pajaro Valley area, about 90 mi (145 km) south of San Francisco (fig. 1), comprises about 120 mi^2 (310 km^2). The valley proper, about 10 mi (16 km) long and 8 mi (13 km) wide, is a coastal valley enclosed on three sides by mountains and hills (fig. 13). The valley floor slopes gently westward from the base of the Santa Cruz Mountains to the ocean. The southern boundary of the valley is a series of hills that extend westward from the Santa Cruz Mountains to Monterey Bay. The northern boundary is a series of hills that lie north and northwest of Corralitos.

Watsonville, with about 13,000 people, is the largest center of population in the area. The economy of the valley is based mainly on agriculture. The principal crops grown are lettuce, apples, sugar beets, tomatoes, artichokes, and grains.

The area has a mild and equable climate, with dry summers and wet winters. About 90 percent of the precipitation occurs from November through April, and the average yearly rainfall at Watsonville is about 21 in (53 cm) (fig. 15). The growing season is long with an average of 237 days between killing frosts. The average January temperature is 50°F (10°C) and the average July temperature is 57°F (14°C).

Most water users in the valley area obtain their supply from wells. However, part of the municipal supply for Watsonville and Freedom is from Corralitos Creek.

Previous Investigations and Acknowledgments

This is the fourth report by the Geological Survey that describes the water resources of parts of Santa Cruz County: One dealt with the Scotts Valley area (Akers, 1969), one with the Soquel-Aptos area (Hickey, 1968), and one described the geology and ground water of the Pajaro Valley area (Muir, 1972).

The cooperation and assistance of the city of Watsonville, the California Department of Water Resources, the Aromas County Water District, the Soquel Creek County Water District, and the Pacific Gas and Electric Co. in supplying geologic information, well data, water levels, pumpage, and chemical quality of ground water are gratefully acknowledged.

Data collected by the Monterey County Flood Control and Water Conservation District, which has a continuing cooperative program with Santa Cruz County to locate wells, make ground-water level measurements, and collect ground-water samples in the Pajaro Valley area, are used in the present study.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the number 12S/1E-24L3, assigned to a well near the Pacific Ocean, that part of the number preceding the slash indicates the township (T. 12 S.); the part of the number following the slash indicates the range (R. 1 E.); the number following the hyphen indicates the section (sec. 24); the letter following the section number indicates the 40-acre (18 ha) subdivision according to the following diagram. The final digit is a serial number for wells in each 40-acre (18 ha) subdivision. All wells mentioned in this report are referenced to the Mount Diablo base line and meridian.

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

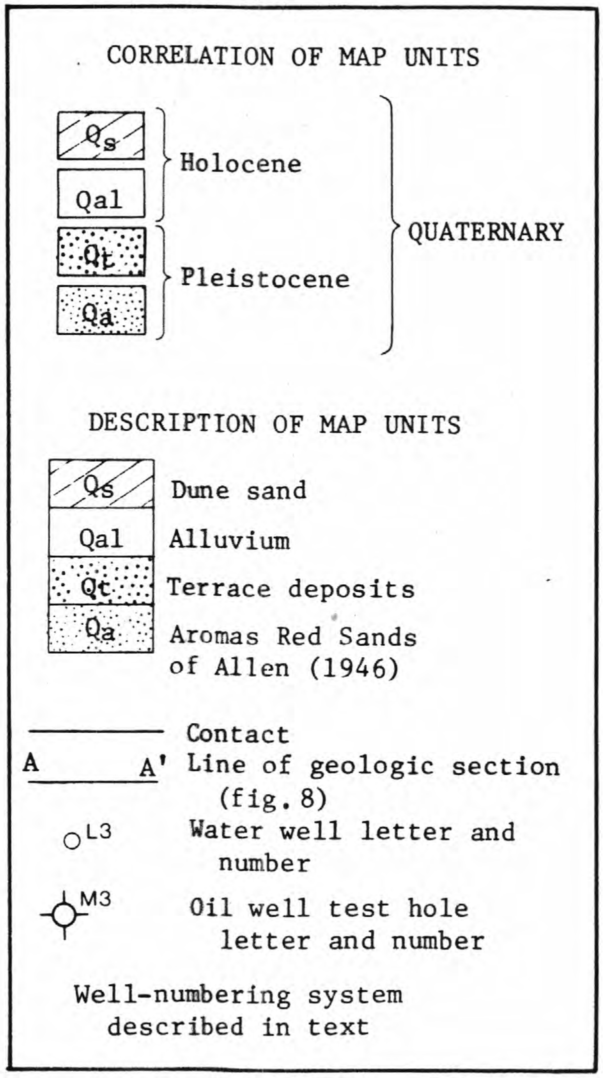
SEAWATER INTRUSION

The landward movement of seawater within coastal aquifers is called seawater intrusion. Seawater intrusion is an important element to consider in plans for the proper management of ground water in coastal aquifers. In fact, it can be the controlling factor for determining the use of ground water from these areas. Under predevelopment conditions, ground water in aquifers adjacent to the coast has a seaward gradient resulting in fresh ground water being discharged into the ocean at or seaward of the coastline. If this seaward gradient is reversed as the result of an increase in ground-water pumpage, the flow of freshwater into the ocean will cease. If the condition which caused the reversal continues, seawater will displace the fresh ground water in the offshore part of the aquifer and move landward.

The interface between the seawater and the fresh ground water is not sharp. Instead, the two kinds of water intermingle, resulting in a transitional zone of mixed water having a composition intermediate between the fresh and salt water. This zone, called the zone of diffusion, results from the gradual merging of seawater and fresh ground water through the process of mechanical dispersion aided by chemical diffusion (Cooper, 1964, p. C8-C11). The width of the zone depends upon the hydraulic characteristics of the aquifer and upon the relative magnitude of the periodic movement of the seawater front due to ocean tides and the rise and fall of the water table due to variations in recharge and pumping.

Geologic Framework

The regional geology of the Pajaro Valley area, including the coastal part, has been described in a report by Muir (1972). Therefore the present discussion will be limited to the area shown in figure 2, the geology of the coastal area. All the geologic units shown in figure 2 are water bearing. The two principal water-bearing units are the alluvium and the Aromas Red Sands of Allen (1946). Figure 8 shows their spatial relation. The Purisima Formation, which does not crop out within the study area of this report but lies at about 800–900 ft (240–270 m) below the land surface, probably is a potential aquifer. However, it has not been tapped by water wells in the study area, so its water-bearing potential is not known.



Briefly, the alluvium and Aromas Red Sands are made up of a heterogeneous mixture and beds of gravel, sand, silt, and clay. Some of the clay beds are several tens of feet thick and are fairly continuous beneath the area. Where these beds occur they form impermeable boundaries between the sand and gravel beds. Water in the sand and gravel is confined and under artesian pressure. Also, confining clay beds near the land surface locally prevent any appreciable recharge to the aquifers from direct infiltration of rain and seepage from the Pajaro River. Most of the recharge to the aquifers occurs inland and then this water moves horizontally down the hydraulic gradient to the coast.

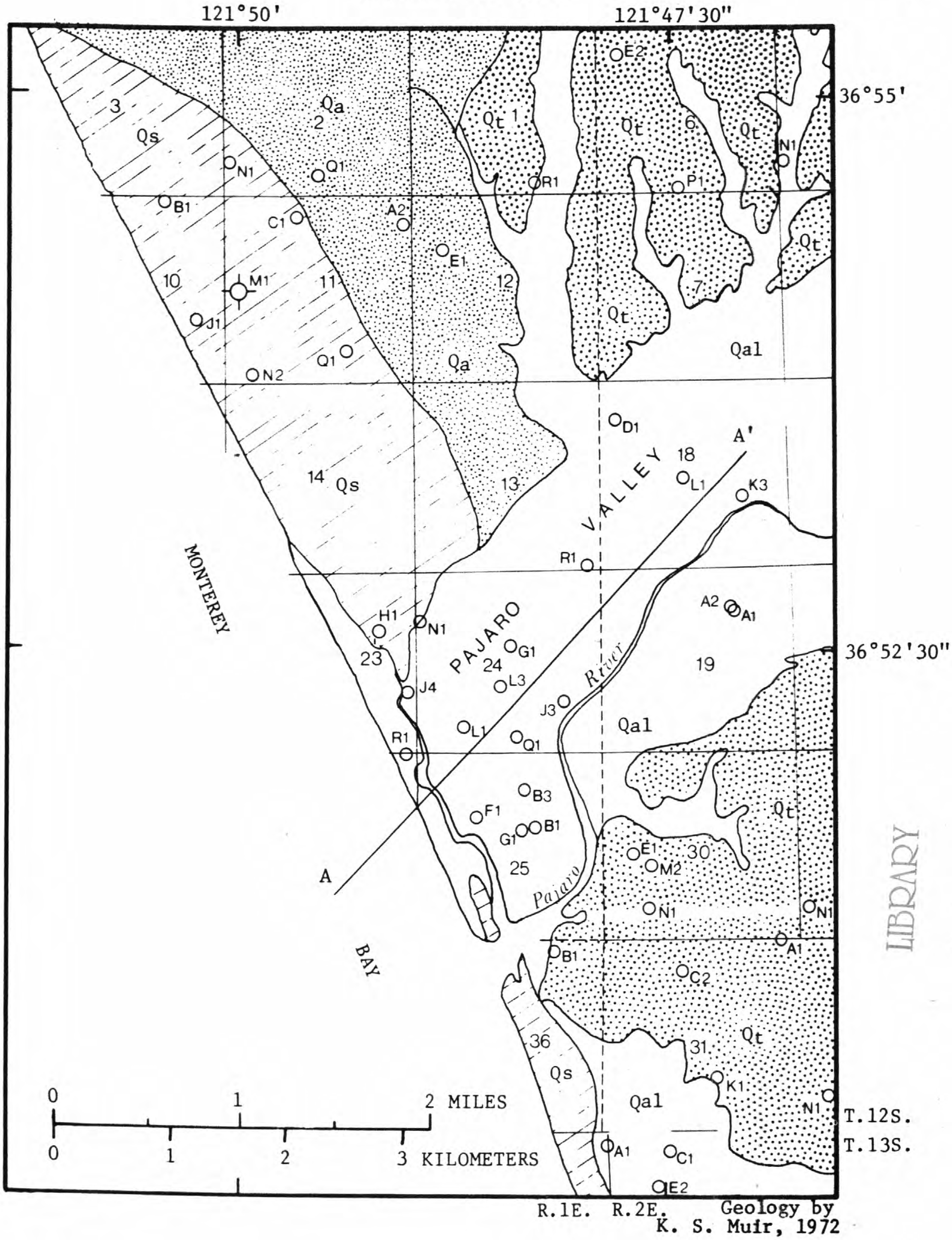


FIGURE 2.--Geologic map of the coastal part of the Pajaro Valley area, Santa Cruz and Monterey Counties, California.

Indications of Seawater Intrusion

An indication that seawater intrusion is occurring in the Pajaro Valley area is the progressive increase in the concentration of chloride in water from wells. Chloride, the major chemical constituent in seawater, is relatively stable chemically, and it will move through an aquifer at virtually the same rate as the intruding water. Therefore, a progressive increase in the chloride concentration in fresh ground water usually is the first sign of the approach of the seawater front. Ground water that moves from the inland recharge areas of the Pajaro Valley toward the coast has a chloride concentration of less than 40 mg/l (milligrams per liter), whereas ocean water has a chloride concentration of about 19,000 mg/l. It follows, then, that ground water in the coastal part of the Pajaro Valley area with a chloride concentration in excess of 40 mg/l can be assumed as being in the zone of diffusion--a zone experiencing seawater intrusion--a zone in which the ground water is a mixture of fresh and seawater.

Seawater intrusion is occurring in the coastal parts of the Pajaro Valley area (fig. 3). The most extensive inland intrusion is in the interval 100-200 ft (30-60 m) below sea level. Historically, this was the first interval to be developed by wells for the irrigation needs of the coastal area. The casings of most of the wells were perforated in the gravel bed in the lower 50 ft (15 m) of this interval (fig. 8). Long-time farmers in the area say that by the 1940's ground water from this 100-200-ft (30-60-m) interval was becoming too saline for most uses, and for this reason they discontinued use of some wells. An alternate source of ground water having a low chloride concentration was found in the 300-600-ft (90-180-m) interval, and most irrigation wells in recent years have been completed in this interval. Most drillers try to seal off the 100-200-ft (30-60-m) interval in these deeper wells. In turn, the chloride concentration in ground water in the 300-600-ft (90-180-m) interval indicates that seawater intrusion is now occurring in that interval (fig. 3).

Seawater intrusion is occurring because ground-water pumpage in Pajaro Valley apparently exceeds, and has for some time exceeded, the long-term replenishment of freshwater. This pumpage during the past 20 to 30 years has progressively reduced the pressure head in the aquifers. Before the 1940's many wells flowed during the winter--there have been no known flowing wells in recent years. This reduction in pressure causes ground-water levels near the coast to remain below sea level for a good part of each year (figs. 4 and 5). This, in turn, causes a landward ground-water gradient to develop in the aquifers, allowing seawater to move inland.

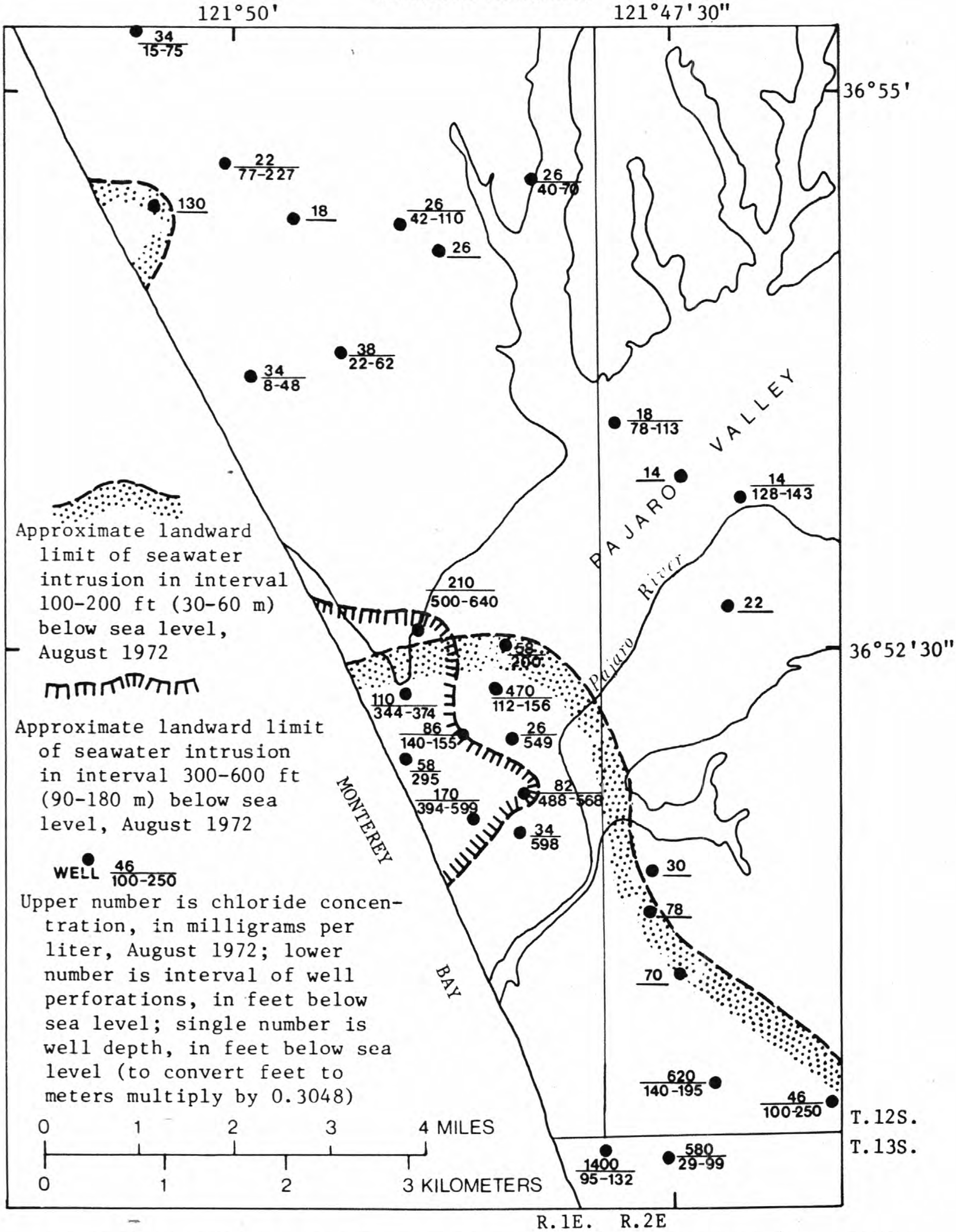


FIGURE 3.--Approximate landward limit of seawater intrusion, August 1972.

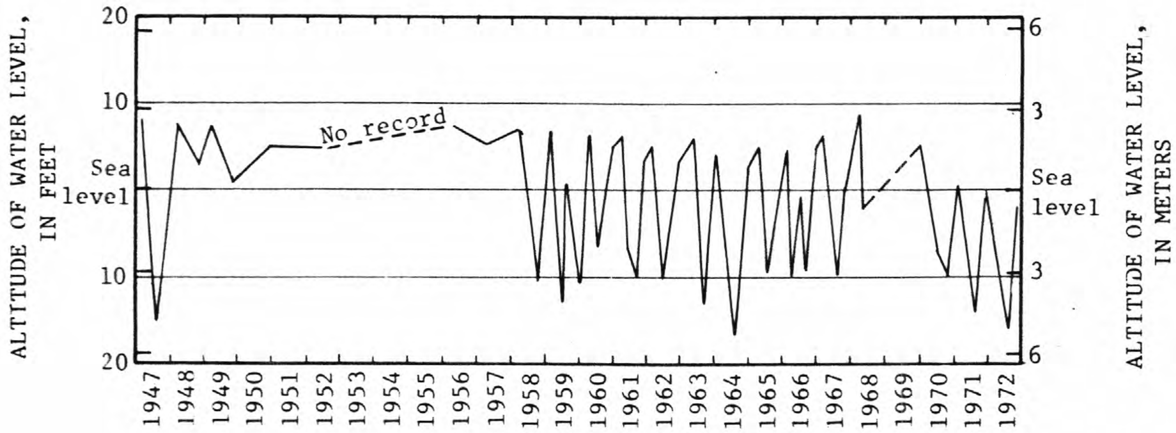


FIGURE 4.--Fluctuation of water level in well 12S/1E-24G1, near mouth of Pajaro River. Land-surface altitude 8 ft (2 m). Well depth 200 ft (60 m).

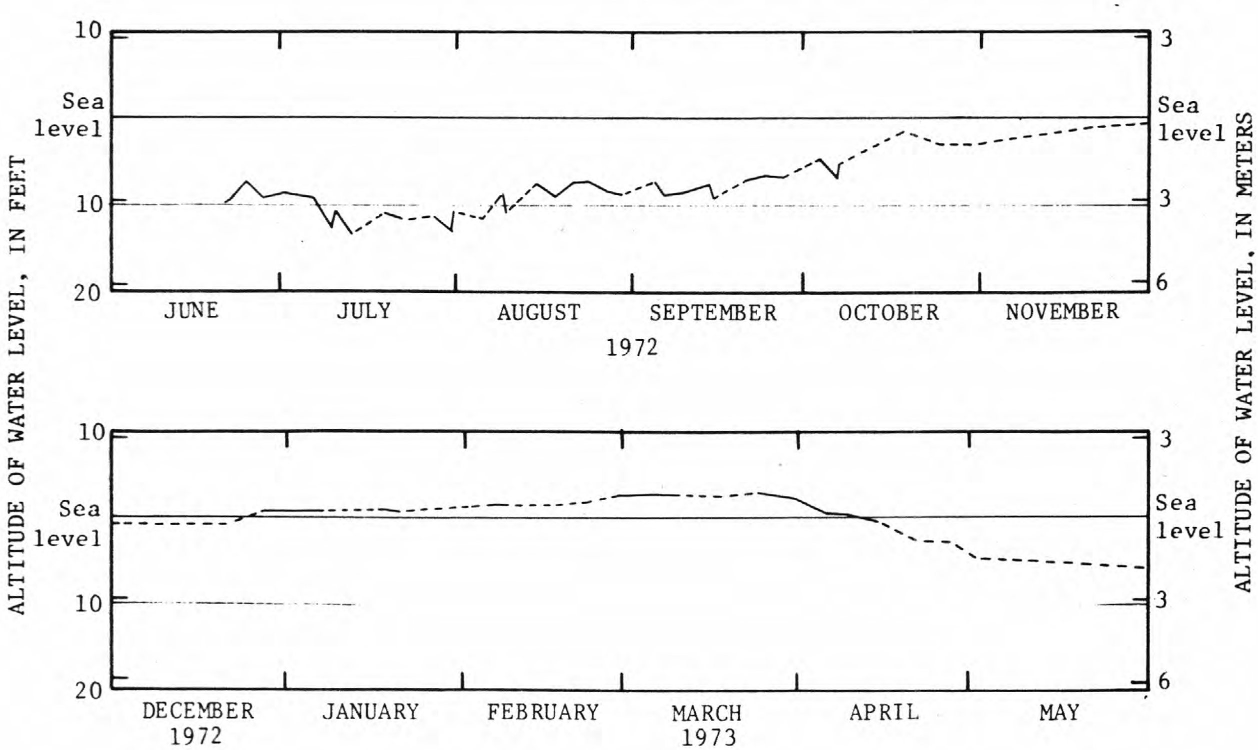


FIGURE 5.--Fluctuation of water level in well 12S/1E-25B1. Well is 0.5 mi (0.8 km) from the Pacific Ocean.

An automatic water-level recorder was installed on well 12S/1E-25B1, an unused irrigation well, in June 1972 to monitor continuously water-level fluctuations in the coastal area of the Pajaro Valley. The recorder was operated until May 1973. Previous to June 1972, only occasional measurements had been made. Well 12S/1E-25B1 is 186 ft (57 m) deep and about 0.5 mi (0.8 km) from the ocean (fig. 2). The land-surface altitude at the well is about 6 ft (2 m). This well was chosen because (1) it taps the 100-200-ft (30-60-m) interval, (2) it is near the ocean, (3) it is nearly in the center of the main intruded area, and (4) it is about 20 ft (6 m) from an active irrigation well (12S/1E-25G1) 604 ft (184 m) deep that is pumping from the 300-600-ft (90-180-m) interval.

The purpose of obtaining the continuous record was to answer some key questions about the aquifer system, such as how much drawdown occurs in the 100-200-ft (30-60-m) interval during the irrigation season, how soon water levels recover following the irrigation season, what is the nature or degree of hydraulic connection between the 100-200-ft (30-60-m) and 300-600-ft (90-180-m) intervals, and what is the nature or degree of hydraulic connection between the 100-200-ft (30-60-m) interval and the ocean. It would have been desirable also to monitor fluctuations in the 300-600-ft (90-180-m) interval, but no usable wells exist. Figure 5 was constructed from data collected by the recorder. Figures 6 and 7 are actual segments of charts from the recorder.

Figure 5 shows that the water level in the 100-200-ft (30-60-m) interval remained near 10 ft (3 m) below sea level throughout the 1972 irrigation season (May through September), and that when most pumping ceased in late September the water-level recovery was slow, taking nearly 3 months to reach sea level. In contrast, the water level in pumping well 12S/1E-25G1 recovered quickly, in late September, after cessation of pumping, and by November it was higher than that in the recorder well, indicating a higher head in the lower interval.

The 100-200-ft (30-60-m) interval is hydraulically connected with the 300-600-ft (90-180-m) interval. When the pump in well 12S/1E-25G1 is turned on, the water level in well 12S/1E-25B1 declines almost instantaneously (fig. 6). When the pump in well 12S/1E-25G1 is shut off the water level in well 12S/1E-25B1 recovers rapidly. The response in well 12S/1E-25B1 reflects pressure change rather than actual transfer of water from one aquifer to the other, although if a pressure differential were maintained long enough, there probably would be an exchange of water.

Figure 7 shows water-level fluctuations in the recorder well when no nearby irrigation wells were pumping. The water-level fluctuations traced on the recorder chart were caused by the ocean tides. The reflection of the four ocean tides which occur during any 24-hour period can be seen. The fluctuations were caused by the pressure transfer from the actual movement of seawater in and out of the offshore extension of the aquifer[1] and the pressure response from tidal loading. It is not possible with the data available to separate the effect of each from the total water-level fluctuation.

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[1]Seismic data indicate that the offshore extension of the aquifer is open to the ocean (Gary Green, oral commun., 1972).

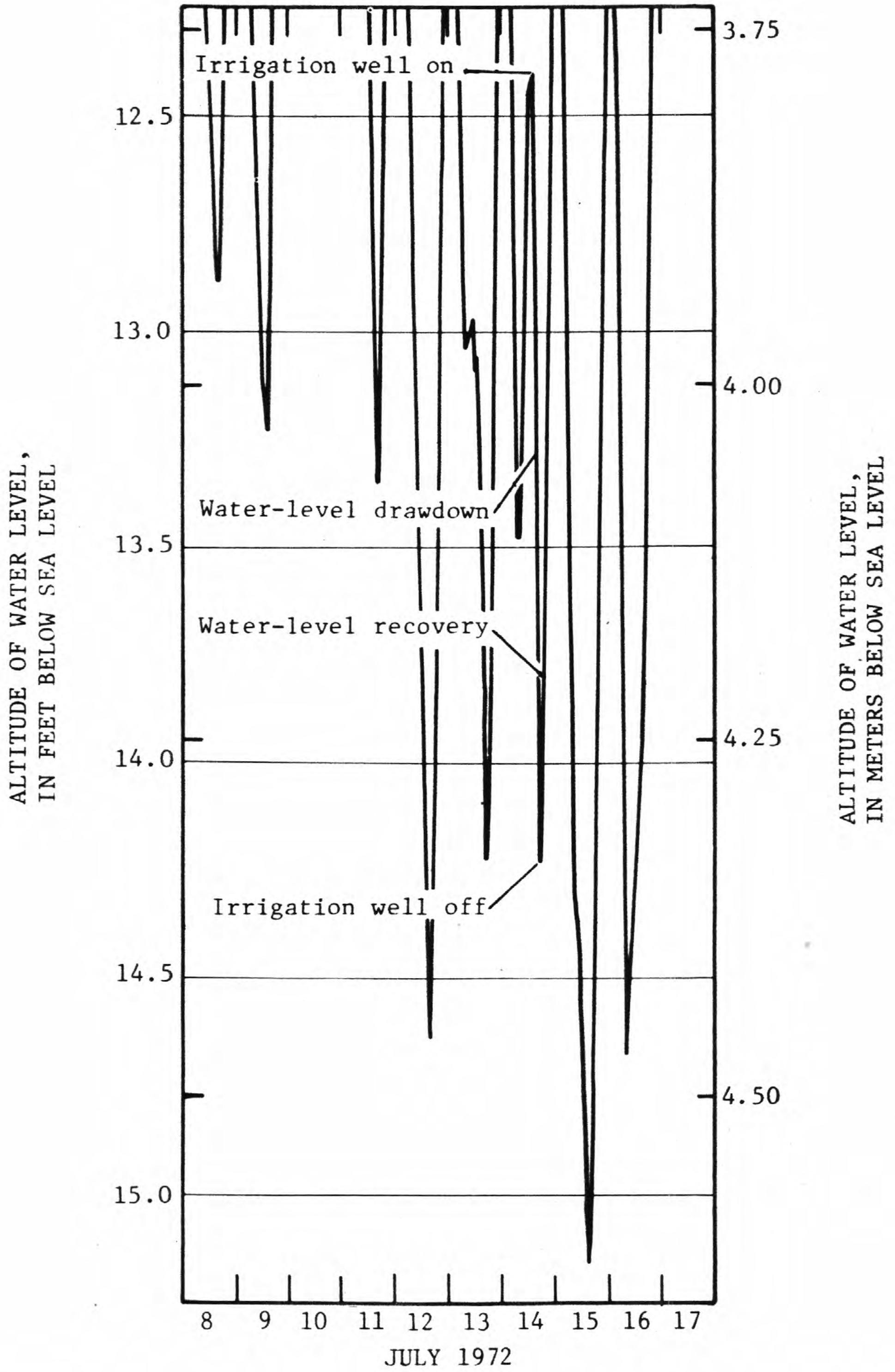


FIGURE 6.--Fluctuation of water level in well 12S/1E-25B1 showing influence of pumping in nearby irrigation well.

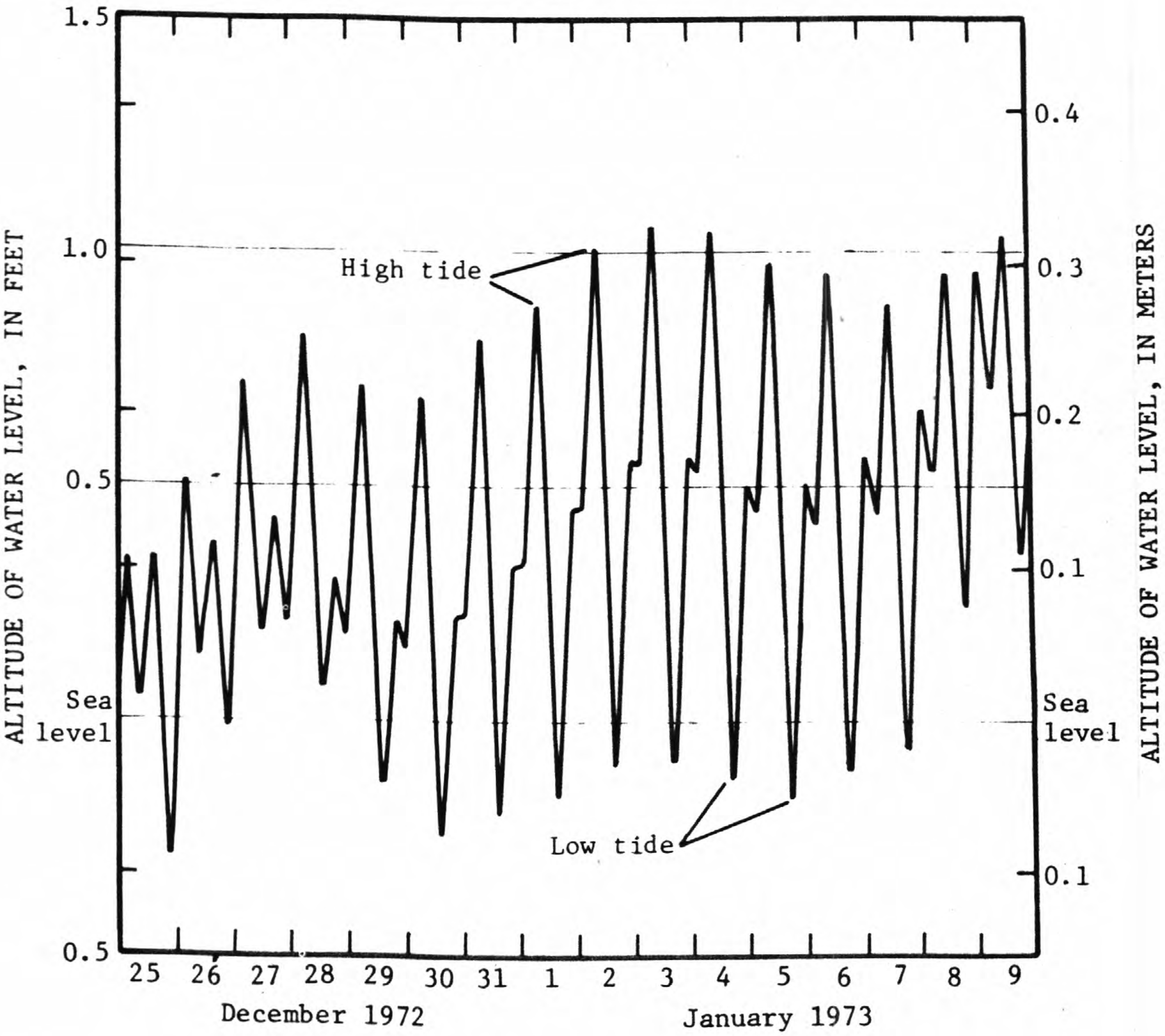


FIGURE 7.--Fluctuation of water level in well 12S/1E-25B1 showing influence of tides.

Seawater is intruding into the coastal part of the aquifers of the Pajaro Valley area mainly by horizontal migration. Figure 8 shows diagrammatically how fresh ground water at the freshwater-saltwater interface would move seaward and up over the toe of the seawater wedges, thereby "eroding" the toe of the wedge. This is occurring in both the 100-200-ft (30-60-m) and 300-600-ft (90-180-m) intervals. There is a dynamic balance between the amount of fresh ground water in storage and the intrusion of seawater. If storage of fresh ground water in the basin decreases below a certain critical level, and this is what is occurring at the present time, seawater will advance landward. Conversely, if storage of fresh ground water increases, the interface will move seaward. The quantity of freshwater in storage needed to halt or reverse seawater intrusion in the Pajaro Valley area is unknown.

In addition to the horizontal migration of seawater at depth there is also some downward movement, especially in the alluvium in secs. 24 and 25, T. 12 S., R. 1 E., and sec. 19, T. 12 S., R. 2 E. At these locations poor-quality water is found in the shallow near-surface deposits (California Water Resources Board, 1953, p. 42) which are in contact with the Watsonville Slough and the Pajaro River. Both the slough and river are tidal in their lower reaches. The vertical permeability of the near-surface deposits is low, so the downward movement of the poor-quality water through the deposits would normally be low. However, unused wells, wells with gravel envelopes, and well casings with multiple perforated intervals provide access and opportunity for the interchange of water between the different depth intervals of the aquifers, which greatly accelerates the downward movement of saltwater. Very few, if any, abandoned wells in the coastal area have been adequately sealed.

Schemes for Controlling Seawater Intrusion

The following discussion of schemes for controlling seawater intrusion is intended only to give the reader a general background on the subject. The figures presented are schematic examples of principles; they are not intended as design drawings.

Seawater intrusion might be controlled by one or more of the following approaches: (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 adjacent to the coastline. The first four of these approaches control the intrusion by maintaining the potentiometric surface above sea level in the coastal part of the aquifers. The last one works on the principle of using a ground-water trough near the coastline to block the landward migration of seawater.

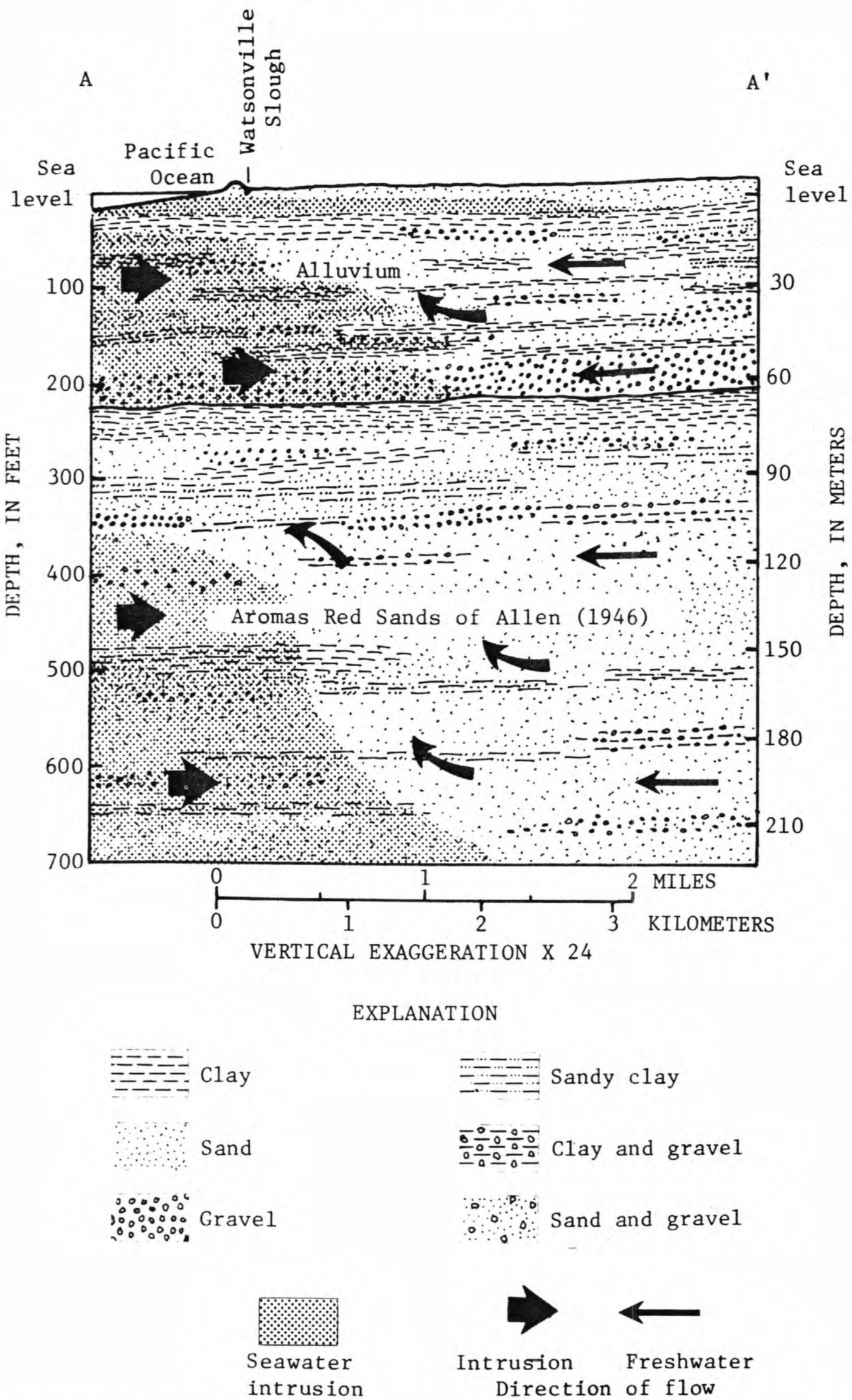


FIGURE 8.--Generalized geologic section showing intervals intruded by seawater.

Pumping could be reduced by changing to crops which require less water, by allowing one harvest per year, or by taking certain lands out of production. This has been tried in southern California with some success (Banks, Gleason, and Richter, 1950). If this is not feasible, reduction of pumpage would require supplemental water. Artificial recharge also would require supplemental water. This supplement water could be either imported or be reclaimed treated sewage wastewater from the sewage disposal plant at Watsonville (fig. 2).

Figures 9 and 10 illustrate diagrammatically how changing the pumping pattern would help to keep intrusion from advancing inland. Figure 9 shows conditions similar to those that are found at the present time in the Pajaro Valley area. Seawater is moving inland because the potentiometric surface seaward of the pumping wells is below sea level.

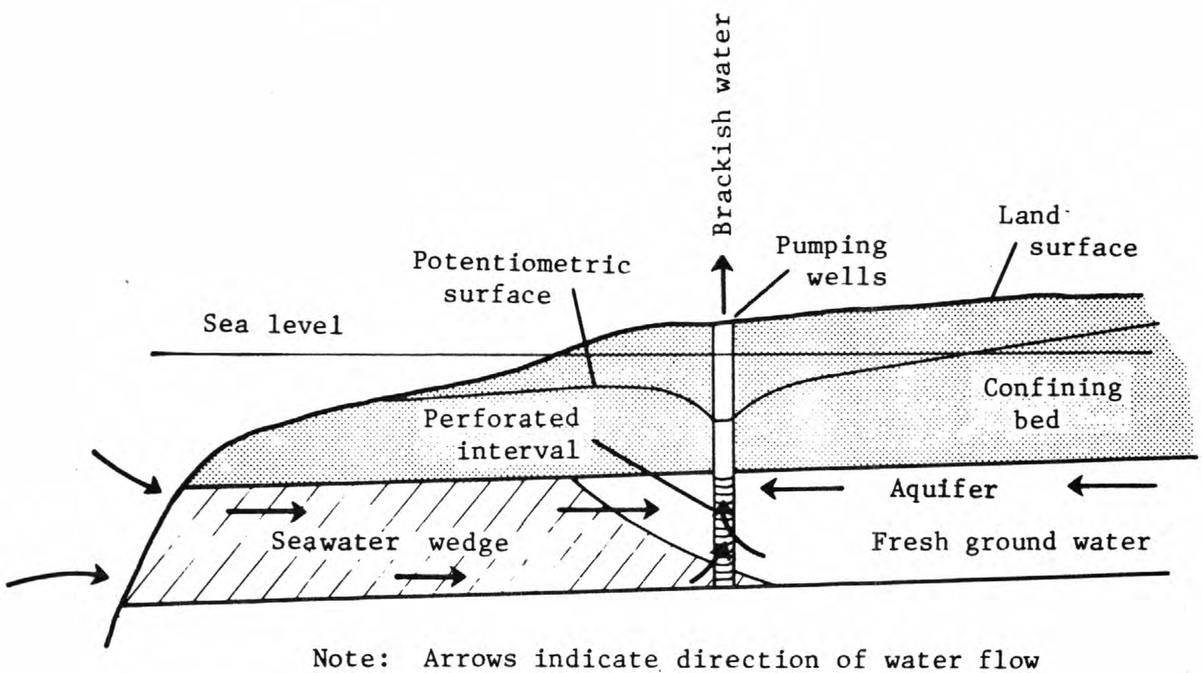


FIGURE 9.--Schematic cross section at coast showing influence of coastal pumping on seawater intrusion.

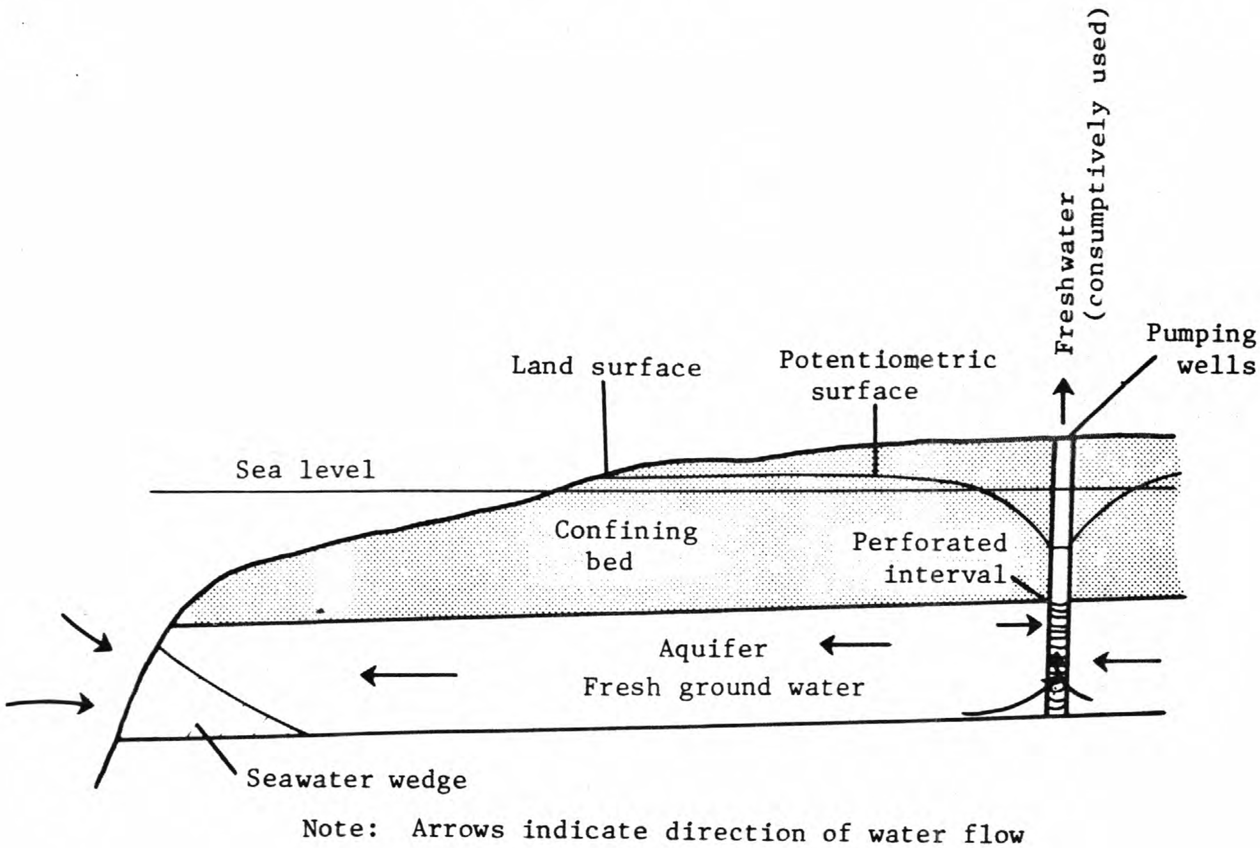
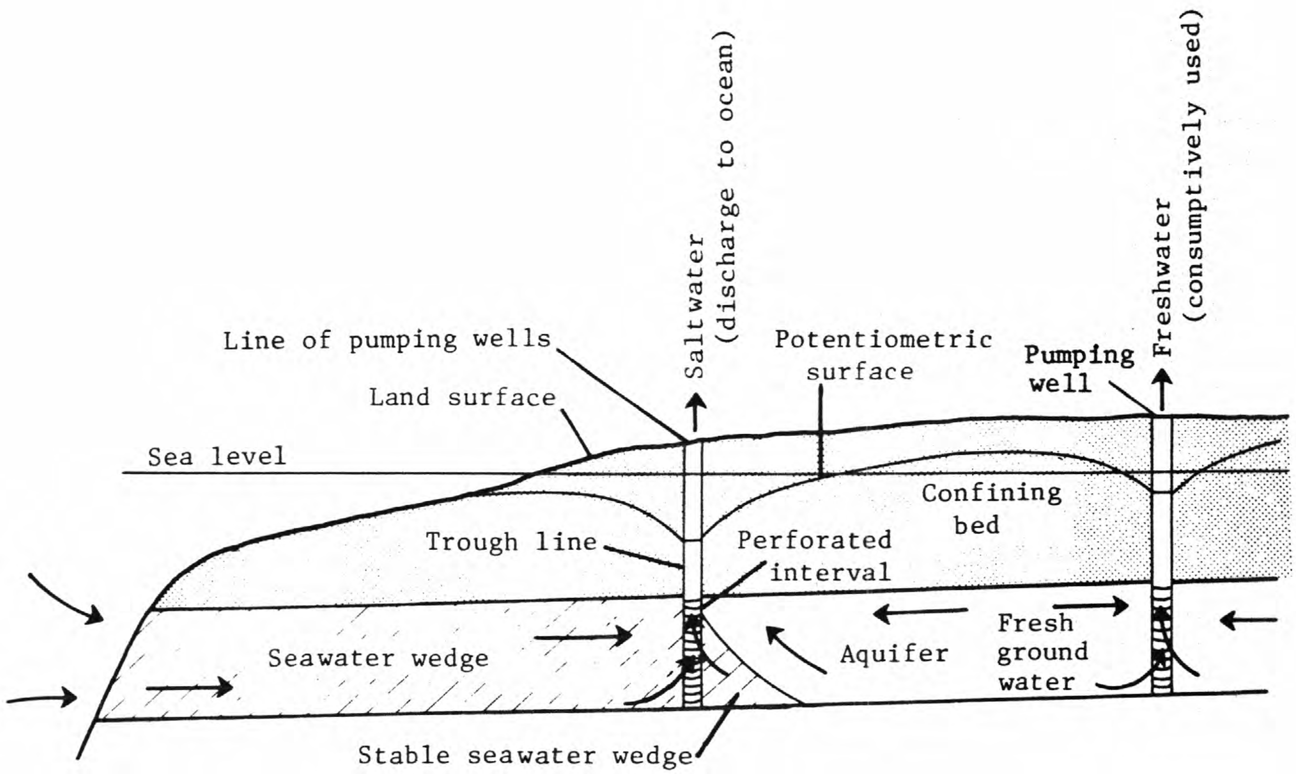


FIGURE 10.--Schematic cross section at coast showing influence of inland pumping on seawater intrusion.

Figure 10 shows what would happen if the wells adjacent to the coast were abandoned and the pumping centers shifted farther inland. The potentiometric surface would then be above sea level, and there would be a pressure gradient toward the ocean. Careful regulation of the pumpage would be necessary. Otherwise, the same conditions as shown in figure 9 would again develop.

Figure 11 illustrates how developing a pumping trough parallel to the coast can control seawater intrusion. This method requires a line of pumping wells along the coast. The purpose would be to stabilize the seawater wedge near the trough. It requires that the amount of water pumped be carefully regulated. The big disadvantage of this approach is that it wastes a large amount of freshwater. There are no known examples of this approach actually being tried in the field.



Note: Arrows indicate direction of water flow.

FIGURE 11.--Schematic cross section at coast showing how a pumping trough controls seawater intrusion.

Figure 12 illustrates how a ground-water pressure ridge parallel to the coast can effectively control seawater intrusion. The ridge keeps the potentiometric surface above sea level and maintains the seaward flow of fresh ground water. This method requires a line of recharge wells along the coast. A supplemental water supply is needed for this approach unless some pumpage from the aquifer inland is recharged near the coast to create the freshwater barrier. This method has been used successfully in coastal areas of California (Laverty, Jordan, and Van Der Goot, 1951).

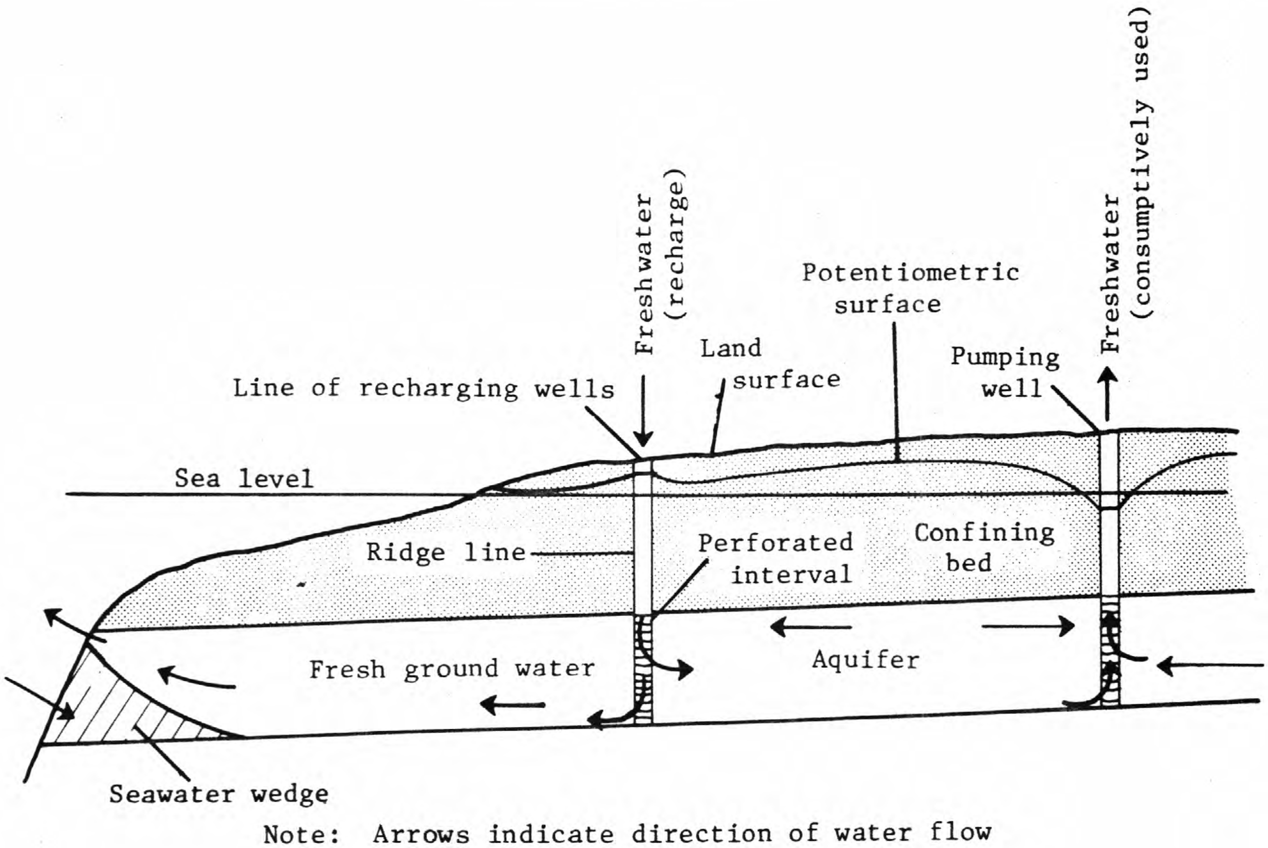


FIGURE 12.--Schematic cross section at coast showing how a pressure ridge controls seawater intrusion.

Many factors must be considered in developing plans for the effective control of seawater intrusion. These include the capital and annual costs of the physical works required (for example, wells, pumps, distribution lines, and treatment facilities), the legal aspects (for example, water rights and rights of way), the availability of supplemental water and its cost, the physical aspects of the aquifer system and overlying soils, and the chemistry of the different kinds of water in the system, to mention a few.

GROUND-WATER PUMPAGE

Ground water pumped from wells is the major source of water used in the Pajaro Valley. A small quantity of surface water is diverted from stream channels for irrigation and domestic use--about 3,000 acre-ft/yr (3.70 hm^3/yr).

Table 1 shows ground-water pumpage for the pumpage years 1963-71. A pumpage year begins May 1 of the designated year and extends to April 30 of the next year--so as to include the entire irrigation season.

TABLE 1.--*Ground-water pumpage, Pajaro Valley area, 1963-71*

Pumpage year[1]	Gross pumpage (acre-ft)[4]		
	Irrigation	Other[2]	Total
1963	36,000	[3]4,900	40,900
1964	43,100	[3]4,900	48,000
1965	41,800	[3]4,900	46,700
1966	42,000	[3]4,900	46,900
1967	33,200	4,200	37,400
1968	45,400	4,700	50,100
1969	47,000	6,000	53,000
1970	50,800	6,900	57,700
1971	56,000	5,700	61,700
9-year average	43,900	5,200	49,100

[1]The pumpage year is defined as that 12-month period beginning May 1 of the designated year and ending April 30 of the next year.

[2]Includes ground water pumped by the city of Watsonville, the Aromas County Water District, the Soquel Creek County Water District, private water companies, miscellaneous domestic users, and for industrial plants.

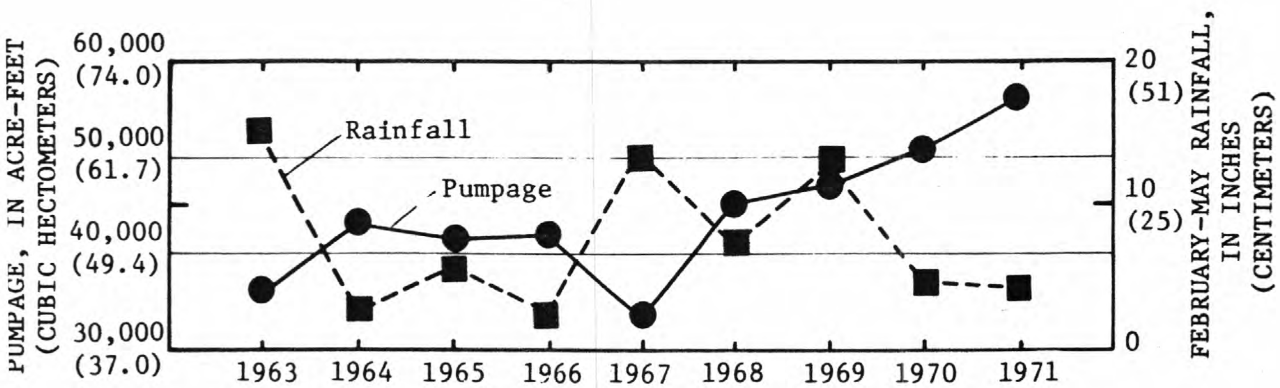
[3]No data available--estimated.

[4]To convert acre-ft to cubic hectometers multiply by 1.233×10^{-3}.

Irrigation pumpage was computed from the total electrical energy used for pumping water and the electrical energy required to pump a unit volume of water. Data on the electrical energy used for pumping were obtained from metered accounts of the Pacific Gas and Electric Co. The electrical energy required to pump a unit volume of water was computed from pump efficiency tests made by the Pacific Gas and Electric Co. Pumpage was calculated back only to 1963, because data on the quantity of electric energy used for pumping irrigation water were unavailable for the years prior to that time.

Table 1 indicates a steady increase in the quantity of ground water pumped from the Pajaro Valley area since 1963. Pumpage for 1967 does not fit the general pattern because this was a wet year.

There is a relation between the quantity of rain that falls immediately prior to an irrigation season and that year's agriculture pumpage (Muir, 1972). Briefly, when February-May rainfall is up, pumpage is down, and when rainfall is down, pumpage is up. This relation is illustrated in the graph below.



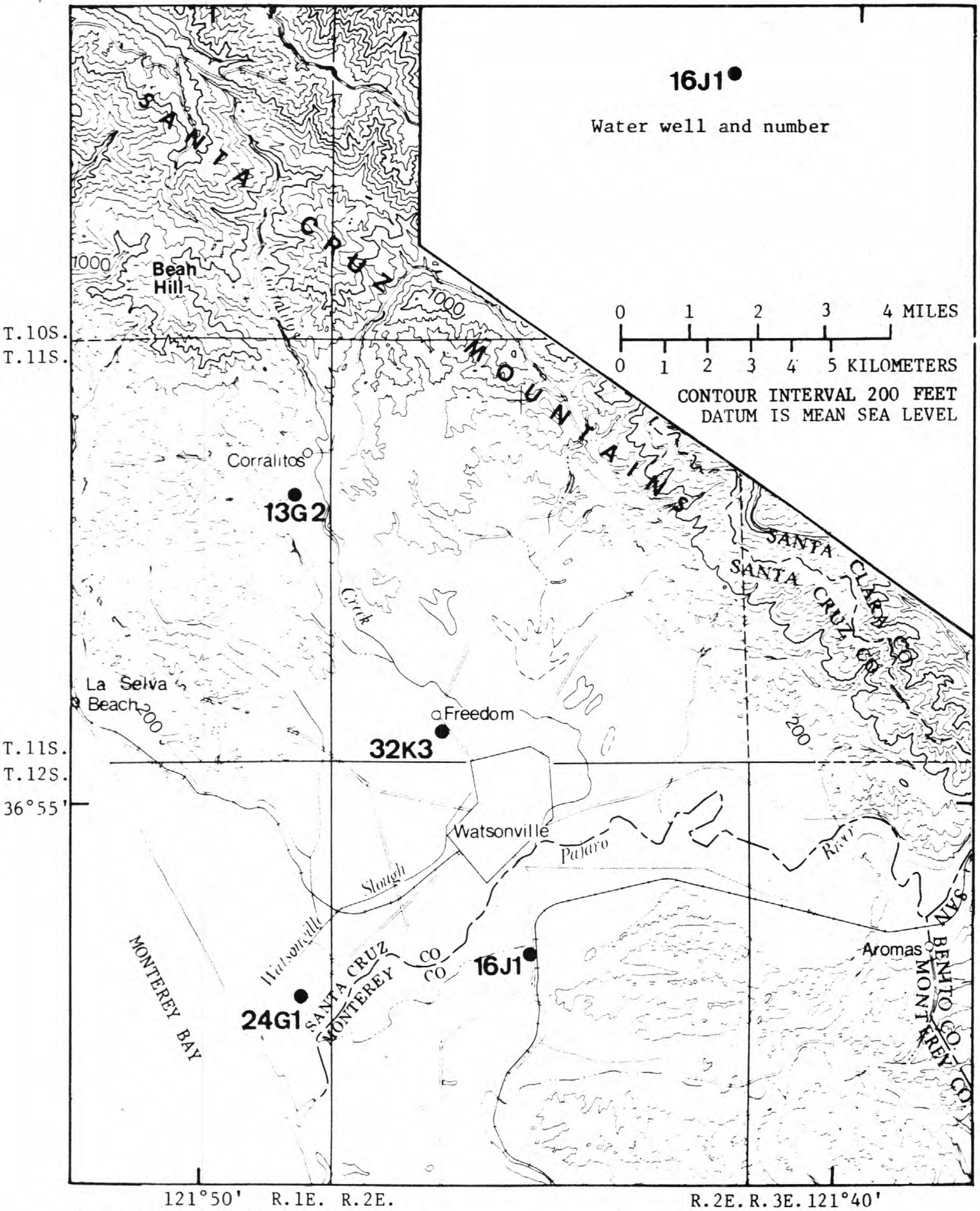
GROUND-WATER YIELD

In this report, the ground-water yield of the Pajaro Valley 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 ground-water yield of the Pajaro Valley area cannot be estimated with a high degree of accuracy because of a lack of complete data on inflow and outflow. Also contributing to the difficulty are the lack of sufficient data concerning the change in the quantity of water stored in large parts of the recharge area and the fact that the north and south hydrologic boundaries of the area have not been delineated.

An approximation of the ground-water yield of the Pajaro Valley area can be made by referring to the hydrographs of four wells whose locations are shown in figure 13. The hydrographs (fig. 14) show that for the 5-year period 1963-67 the net quantity of ground water in storage, as reflected by the average water levels, remained about constant. During this period, inflow was approximately equal to outflow. Thus, the average ground-water yield for the 5-year period would be practically equal to the average pumping draft (table 1), or about 44,000 acre-ft/yr (54.3 hm^3/yr). Furthermore, annual rainfall during the period was near the long-term average (fig. 15)--about 21 in (53 cm). This means that inflow to the system during the estimate period was probably near the long-term average. Therefore, the long-term ground-water yield of the Pajaro Valley area based on 1963-67 conditions is about 44,000 acre-ft/yr (54.3 hm^3/yr).

It should be emphasized that conditions within the ground-water reservoir are not static; the inflow-outflow relations of the reservoir system change as components of inflow and outflow change. Pumping ground water from wells is one component of outflow that can change these relations. If pumping causes water levels to decline, the decline in turn may cause subsurface inflow or influent seepage from streams to increase. This is why an agency charged with managing the ground-water resources of an area must maintain a continuing data-collection program that monitors the hydrologic factors affecting ground-water yields.



Base from U.S. Geological Survey
1:250,000, Santa Cruz, 1965.

FIGURE 13.--Location of four wells whose hydrographs are shown in figure 14.

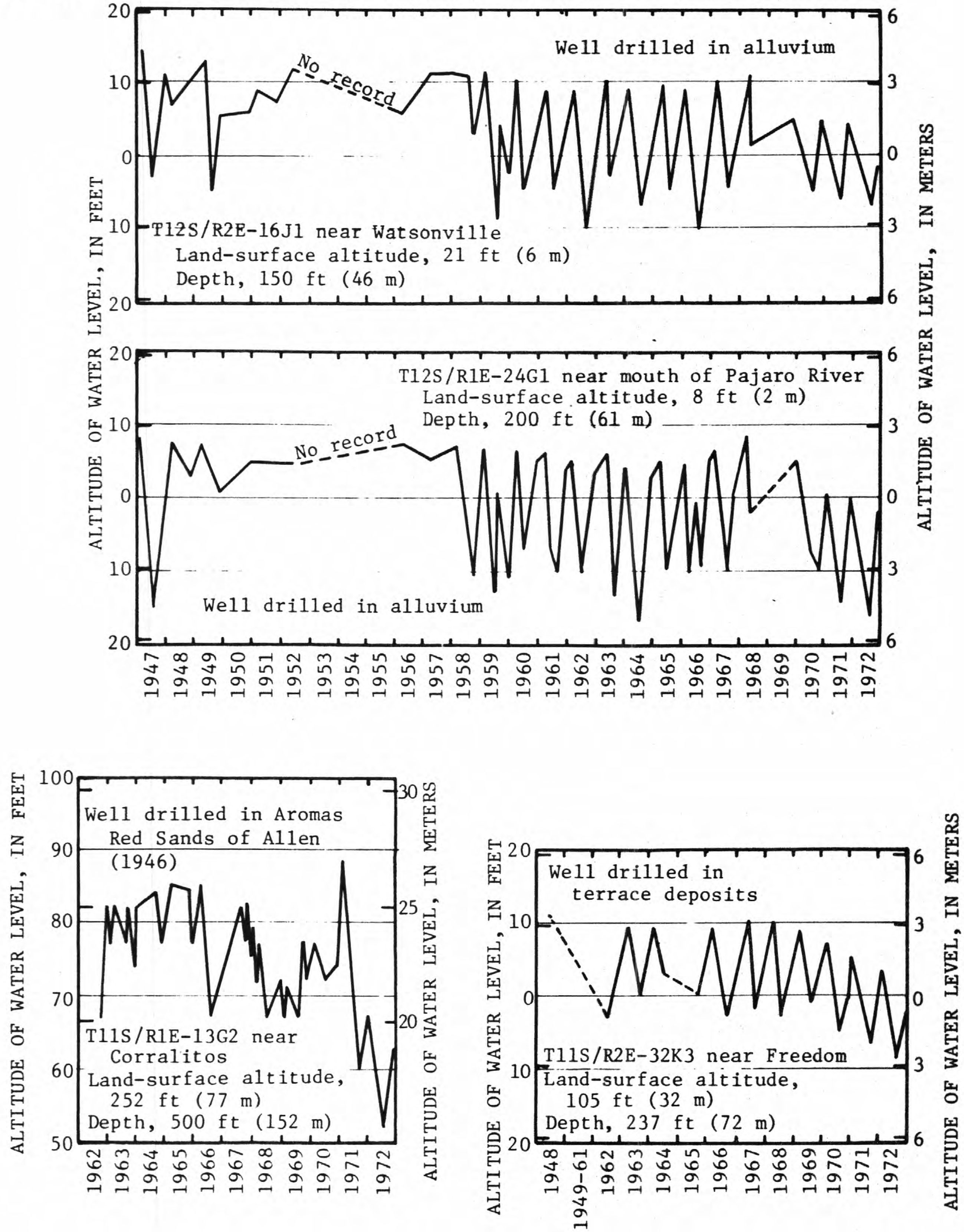


FIGURE 14.--Fluctuation of water levels in four wells in the Pajaro Valley area. (Well locations shown in fig. 13.)

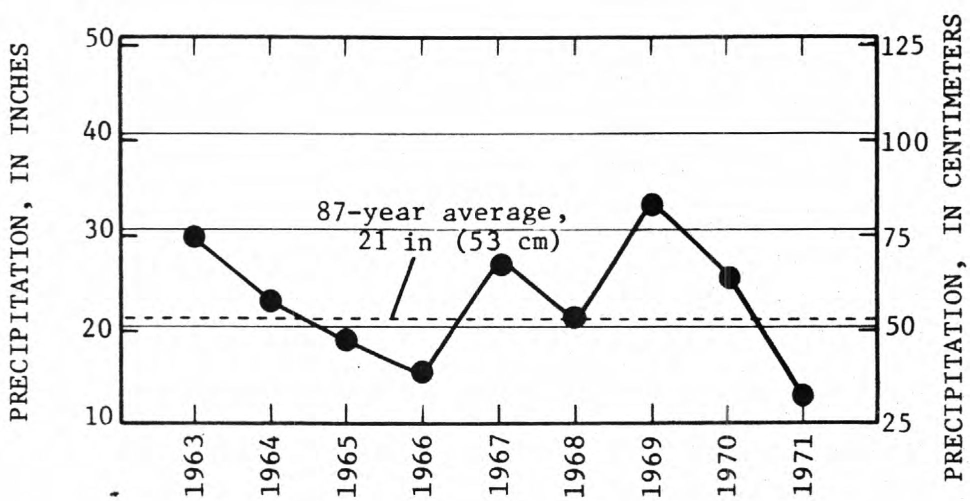


FIGURE 15.--Annual rainfall at Watsonville, California. (From U.S. Weather Bureau climatological data.)

ARTIFICIAL RECHARGE

Artificial recharge is defined as the augmentation of the natural processes of infiltration from precipitation and streamflow that replenish ground water in aquifers through works of man. Artificial recharge is accomplished primarily through works designed to maintain infiltration rates, increase the wetted area, and to increase the period of infiltration beyond that which would exist under natural conditions. These works may be ponds, modified streambeds, pits, shafts, ditches or furrows, floodings, or injection wells. The purpose of most artificial recharge projects is to (1) combat adverse conditions resulting from overdevelopment of ground water, (2) increase conservation of local runoff, and (3) increase the quantity of ground water available for use.

In the Pajaro Valley area artificial recharge could be used to combat the encroachment of seawater, increase the conservation of stream runoff that now discharges to the ocean, possibly make beneficial use of sewage effluent that is now being discharged into the ocean, and utilize now unsaturated underground space for the storage of water. All these uses would increase the ground-water yield of the area.

Four specific methods of artificial recharge seem suited to the Pajaro Valley area: Modification of streambeds and the construction of pits, injection wells, or shafts. Present land use and hydrologic conditions were taken into consideration in making these choices. Following is a brief discussion of the four methods:

1. Modification of streambeds.--The natural recharge from streambeds in the Pajaro Valley area constitutes a large percentage of the total recharge to the ground-water reservoir. When streamflow exceeds the natural infiltration rate of the streambeds the excess is lost to runoff. The aim of an artificial recharge project would be to control the rate of flow in the streams to increase the amount of water that percolates. Check dams and dikes could be placed across streams to reduce water velocity, increase the length of streambed material inundated, or spread flow over the entire width of the stream channel. The advantage to this method is its relative low cost. The Los Angeles County Flood Control District has been using this method of recharge for many years (Haile, 1966).

2. Pits.--Steep-sided pits work well for artificial recharge (Suter, 1954). In addition, the cost of constructing the pits is generally low. Also, it is possible that the cost of their construction could be offset by the sale of sand and gravel excavated from the pits. The big advantage to steep-sided pits is their high tolerance to water containing suspended sediment. The sediment settles to the bottom of the pit, leaving the steep sides free for continued infiltration of water. However, provision must be made for the periodic removal of this sediment.

3. Wells.--Recharge through wells involves the direct introduction of surface water into underground formations and offers several advantages over other methods of recharge. Recharge rates can be relatively high, and because the recharge is directly into the depleted aquifers there is an immediate and positive response of water levels or fluid pressures in the injected zone. Another advantage is that the wells can be multipurpose and be used for recharge during periods of surplus supply and can be pumped during periods of deficient supply. Also, wells require little space so are advantageous in areas where land values are high. Recharge by injection through wells requires that the water to be recharged must be of good quality, low in suspended sediment, and chemically compatible with the native ground water. If this is not the case recharge rates may be difficult and costly to maintain--suspended sediment, bacterial and algal growths, and chemical reactions between the recharge water and soil particles can clog and seal the water-bearing formations. Care also must be taken not to contaminate the water-bearing formations with biological or chemical pollutants.

The number and spacing of injection wells in a recharge project depends upon the amount of water to be recharged and the acceptance rate of the receiving formation. The acceptance rate is a function of how permeable the receiving formation is, the hydraulic gradient, the length of perforated casing penetrating the formation, and, to some extent the number of casing perforations. Sniegocki and others (1965) made studies of artificial recharge using wells in the Grand Prairie region of Arkansas. Their findings indicate that with proper well construction and water-quality control, artificial recharge by this method is practical.

4. Shafts.--Shafts are similar to wells except that they are usually larger in diameter. The value of shafts, as with wells, is that they can be constructed so that recharge from surface water reaches subsurface water-bearing formations without first passing vertically through overlying strata of low permeability. Shafts require little space so are advantageous in areas where land values are high. Sediment removal and problems associated with algal and bacterial growths must be considered when using this type of recharge facility.

Of the four methods of artificial recharge, modification of streambeds and injection wells seem especially adaptable to hydrologic conditions in the Pajaro Valley area.

The channel of Corralitos Creek, the channel of the unnamed creek that flows through Green Valley, and the upper reaches of the Pajaro River (fig. 16) are hydrologically suitable for artificial recharge through streambed modifications; there seem to be no confining clay beds in these areas that would prevent downward recharge. These modifications would consist of channel widening, leveling, and streambed scarifying. Check dams and dikes would be placed across the channels to reduce water velocity and increase the wetted area. Table 2 lists the potential artificial recharge for the streams previously mentioned.

The channel widths shown in table 2 were chosen arbitrarily. The infiltration rates were estimated from data on soils, land-surface gradients, and channel-bed material collected from streambed locations using methods developed by Richter and Chun (1964). Of course, sustained artificial recharge rates depend upon a comprehensive streambed maintenance program and also upon the availability of space in the water-bearing formations. It is obvious that when these formations become completely saturated, no more water can be recharged. Also, to achieve a successful artificial recharge program in the Pajaro Valley area imported water or impoundment facilities in the upper reaches of some streams would be necessary. This is because the time distribution of stream runoff and the amount available is extremely variable.

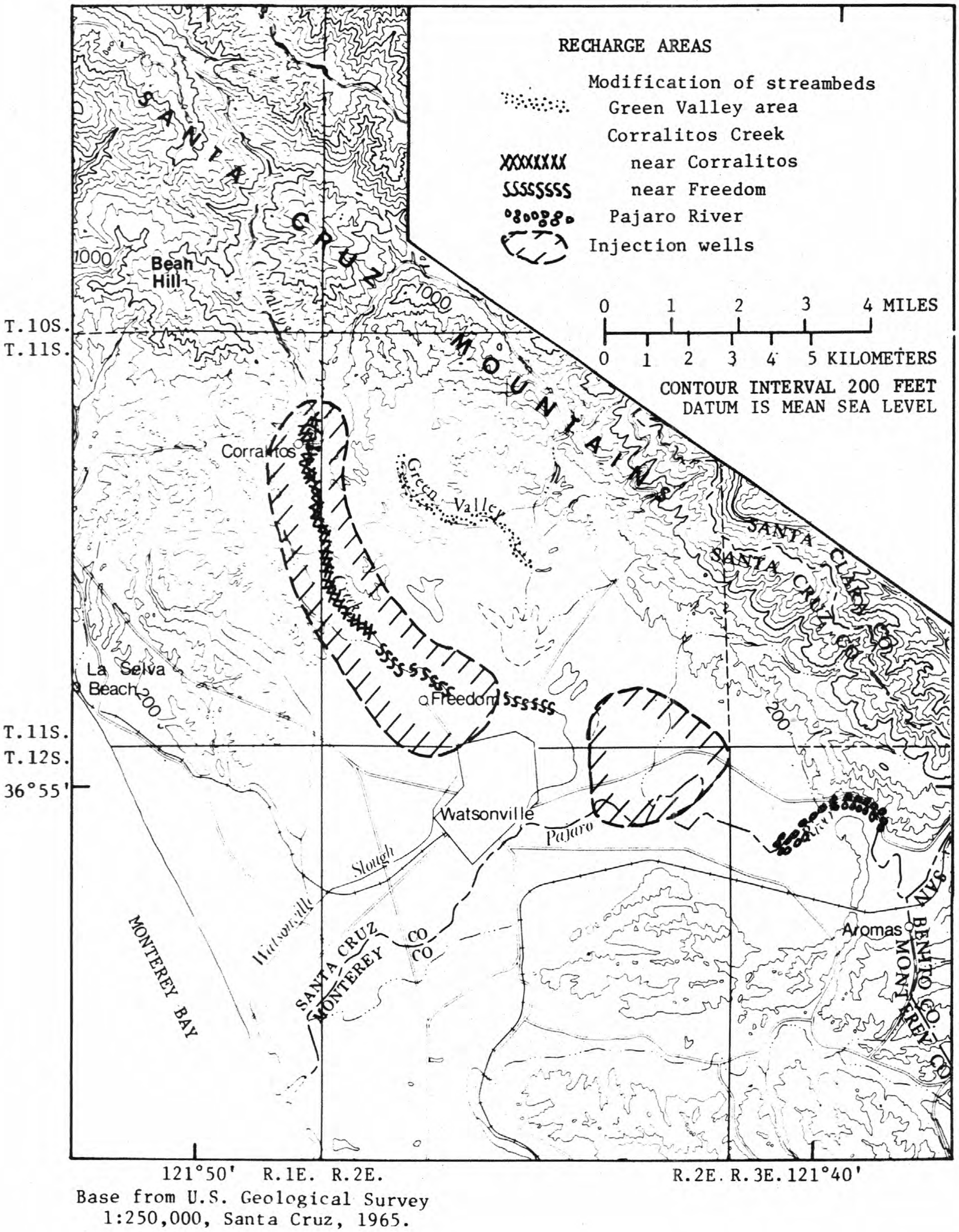


FIGURE 16.--Areas for artificial recharge using streambed modifications and injection wells.

TABLE 2.--*Potential artificial recharge from modification of streambeds in the Pajaro Valley area*

Location	Modified channel width (ft)	Infiltration rate (ft/d)	Potential artificial recharge per mile of stream channel per day (acre-ft)	Effective stream-channel length (mi)	Potential artificial recharge (acre-ft)	
					Per day	Per year
Corralitos Creek near Corralitos	30	3	12	3	36	13,000
Corralitos Creek near Freedom	30	2	8	3	24	8,600
Unnamed creek in Green Valley	15	3	6	3	18	6,500
Pajaro River downstream from Aromas	200	1	25	2	50	18,000
Total					130	48,000

Artificial recharge by use of injection wells would be possible in areas near Corralitos and Freedom and east of Watsonville (fig. 16). The following estimates of injection capacities and well depths are based on information supplied by well drillers and from pump efficiency tests made by the Pacific Gas and Electric Co. Injection wells about 300 ft (90 m) deep in the area between Corralitos and Freedom should have initial injection capacities of about 200 gal/min (0.8 m^3/min). Those just south of Freedom should have initial injection capacities of about 300 gal/min (1.1 m^3/min) at well-completion depth of about 250 ft (76 m). The most hydrologically suitable area for injection wells is about 2 mi (3.2 km) east of Watsonville (fig. 16). In this area wells 150-250 ft (46-47 m) deep developed in the extensive gravel bed at the base of the valley alluvium (Muir, 1972, fig. 5) would probably have an initial injection capacity of about 500 gal/min (1.9 m^3/min).

Water would have to be injected under pressure to obtain the estimated capacities. Proper well construction and development would be essential, and an extensive and well planned maintenance program would be necessary.

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