UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

GEOLOGY AND GROUND WATER OF THE PAJARO VALLEY AREA
SANTA CRUZ AND MONTEREY COUNTIES, CALIFORNIA

By

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Prepared in cooperation with the
Santa Cruz County Flood Control and
Water Conservation District

OPEN-FILE REPORT
73-199

Menlo Park, California
June 27, 1972

CONTENTS

ILLUSTRATIONS

TABLES

ND GROUND WATER OF THE PAJARO VALLEY AREA

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ABSTRACT

The Pajaro Valley area, California, covering about 120 square miles, 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.

Deposits that range in age from Pliocene to Holocene make up the ground-water reservoir. These include, from oldest to youngest, the Purisima Formation, Aromas Red Sands of Allen (1946), terrace deposits, alluvium, and dune sand. These deposits underlie an area of about 80 square miles and have a maximum thickness of about 4,000 feet. The alluvium yields most of the water pumped from wells in the area.

Pre-Pliocene rocks underlie and form the boundaries of the ground-water reservoir. These rocks contain ground water in fractures and in sandstone beds. However, they are not an important source of ground water. There is close continuity between the geology of the Pajaro Valley area and that of the Soquel-Aptos area, which is contiguous on the north.

Ground water in the Pajaro Valley area is derived from three sources: (1) Precipitation within the Pajaro Valley area that reaches the ground-water body by direct infiltration or by seepage from streams, (2) seepage from the Pajaro River as it crosses the Pajaro Valley carrying runoff which originates upstream from the valley, and (3) precipitation in the Soquel-Aptos area that infiltrates and then moves southeastward at depth into the Pajaro Valley area

Ground water in most wells in the Pajaro Valley area occurs under confined (artesian) conditions; the only exception is ground water in the upper, near-surface part of the alluvium and that in the dune sand. It moves south from the north part of the area and southwest away from the San Andreas fault toward and out under Monterey Bay. In the south part of the area, ground-water movement is almost due west. The San Andreas fault probably is the only fault that has a restrictive effect on the movement of ground water.

Water levels in wells in the Pajaro Valley area in 1970 averaged about 2 feet lower than that in 1950. Ground-water pumpage averaged 46,100 acre-feet per year during the period 1963 through 1969.

There are two distinct ground-water quality zones in the Pajaro Valley area: a shallow, semiperched zone of poor-quality water and a deeper, confined zone of good-quality water. Also, sea-water intrusion has occurred in limited areas near the mouth of the Pajaro River and in the vicinity of McClusky Slough.

The channel of the Pajaro River near Aromas and the beds of streams that drain the area north and northeast of Watsonville have the greatest potential for artificial recharge by surface infiltration of water. The gravel at the base of the alluvium is the best zone for injection of water through wells.

INTRODUCTION

Purpose and Scope

The purpose of this investigation is to assist the Santa Cruz County Flood Control and Water Conservation District in their attempt to develop plans that will insure sufficient water for the future needs of the county. Before any attempts can be made at long-range planning and utilization of the water resources, a general knowledge of the hydrologic conditions in the county is necessary. This report describes the geologic framework and ground-water resources of the Pajaro Valley area.

The scope of this investigation includes determining the geology with particular reference to the water-bearing deposits; determining the relation of the hydrologic units in the Pajaro Valley area with those in the Soquel-Aptos area; determining the source, occurrence, and direction of movement of water within the hydrologic units; computing ground-water pumpage; describing the chemical quality of the ground water; determining which hydrologic units and areas of the valley are potentially endangered by sea-water intrusion; and outlining areas that seem favorable for infiltrating imported water into the various hydrologic units.

This report was prepared by the U.S. Geological Survey, in cooperation with the Santa Cruz County Flood Control and Water Conservation District, under the general supervision of R. Stanley Lord and L. R. Peterson, successive district chiefs in charge of water-resources investigations in California, and under the immediate supervision of L. E. Young, chief of the Menlo Park subdistrict office.

Location and General Features

The Pajaro Valley area comprises about 120 square miles. The valley proper, about 10 miles long and 8 miles wide, is a coastal valley about 90 miles south of San Francisco (fig. 1) and is enclosed on three sides by mountains and hills (fig. 2). 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. The study area merges on the northwest with the Soquel-Aptos area described by Hickey (1968).

Watsonville, with about 13,000 people, is the largest center of population in the area. The economy 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 inches. The growing season is long with an average of 237 days between killing frosts. The average January temperature is 50°F and the average July temperature is 57°F.

The Pajaro Valley area is drained by Coward, Casserly, Browns, and Corralitos Creeks and the Pajaro River. There are five natural lakes in the area (fig. 2): Lake Tynan and Drew, Kelley, College, and Pinto Lakes.

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 third report by the Geological Survey that describes the water resources of parts of Santa Cruz County. The first two dealt with the Scotts Valley area (Akers, 1969) and the Soquel-Aptos area (Hickey, 1968). Several reports on the Pajaro Valley area have been prepared by the California Department of Water Resources, the U.S. Bureau of Reclamation, and private consultants (see the list of references at the end of this report).

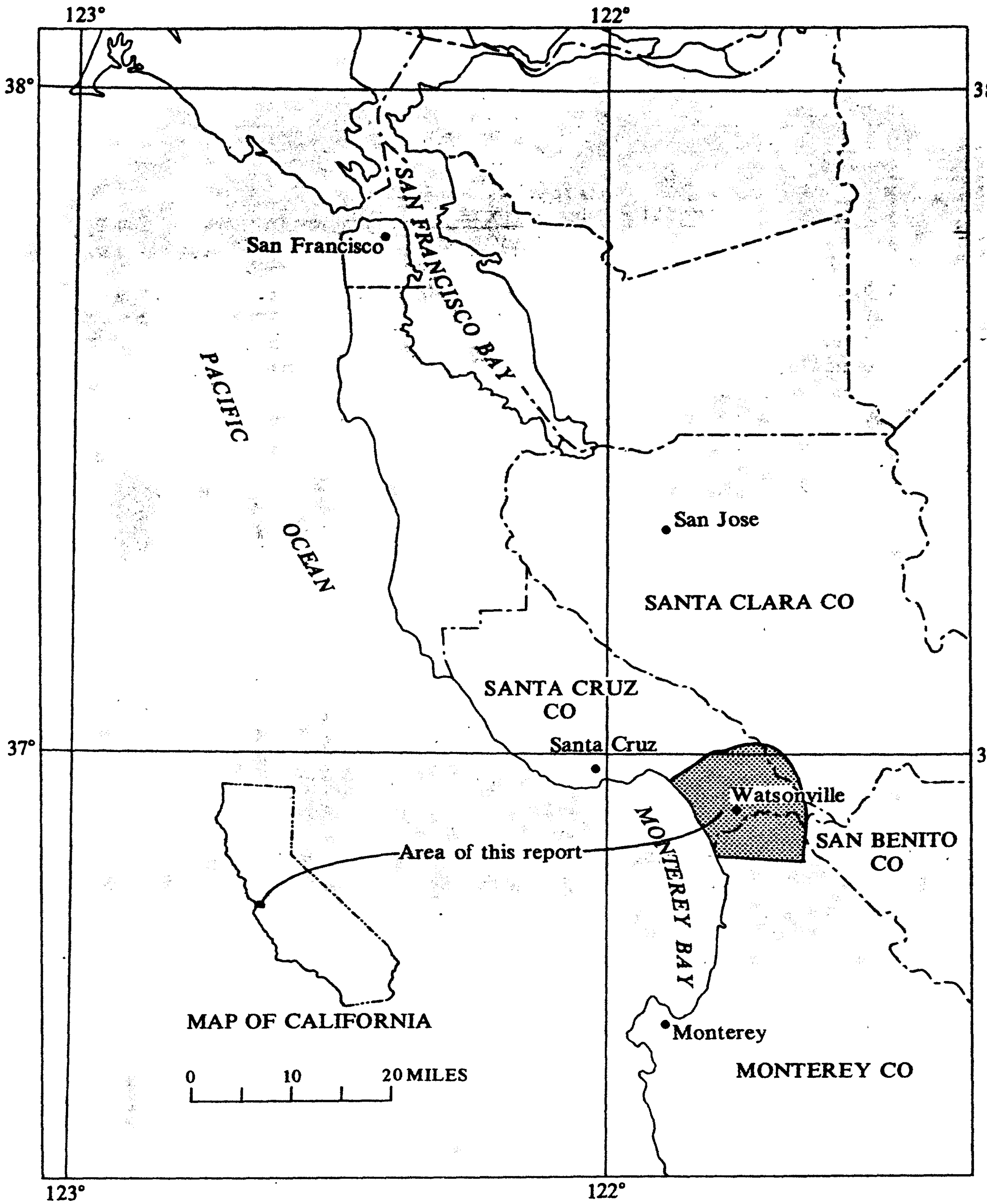


FIGURE 1.--Index map.

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.

Special thanks are extended to Edward Hanna and Phil Sanfilippo, of the Santa Cruz County Department of Public Works, for their cooperation and assistance.

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/2E-8F1, assigned to a well southwest of the city of Watsonville, 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. 2 E.); the number following the hyphen indicates the section (sec. 8); the letter following the section number indicates the 40-acre subdivision according to the following diagram. 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.

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

GEOLOGY

Geologic structure and topography in the Pajaro Valley area are closely related. The Santa Cruz Mountains and the areas north and northwest of Corralitos are areas of uplift and folding. The central part of the Pajaro Valley area is in an erosional and structural depression. Pliocene and younger deposits partly fill the depression and form the ground-water reservoir of the Pajaro Valley area. The deposits include the Purisima Formation, the Aromas Red Sands of Allen (1946), terrace deposits, alluvium, and dune sand (figs. 2 and 3). These deposits underlie an area of about 80 square miles and attain their maximum thickness of about 4,000 feet beneath Browns Valley.

Consolidated rocks of pre-Pliocene age of unknown thickness crop out in the mountains and underlie the unconsolidated deposits. They contain water in fractures and in sandstone beds and yield ground water to wells slowly. The rocks may be a source of some recharge by subsurface flow to the younger deposits. However, for this study they are considered to form the sides and boundaries of the ground-water reservoir.

Geologic Units and Their Water-Bearing Properties

In this report, the geologic units are divided into two categories: (1) Consolidated rocks which include granitic rocks of Cretaceous age, sedimentary rocks of Cretaceous age, and sedimentary and volcanic rocks of Tertiary age and (2) unconsolidated deposits that include the Purisima Formation of Pliocene age, Aromas Red Sands of Allen (1946) and terrace deposits of Pleistocene age, and alluvium and dune sand of Holocene age.

Figure 2 shows the outcrop patterns of the different units, figure 3 shows their stratigraphic and structural relations, and table 1 summarizes the sequence, general character, and water-bearing properties.

Consolidated Rocks of Cretaceous and Tertiary Age

Granitic and sedimentary rocks (Cretaceous).--Granitic rocks of Cretaceous age are the oldest rocks in the Pajaro Valley area. They range in composition from gabbro to granite, but are predominantly quartz diorite and adamellite. These granitic rocks crop out in the vicinity of Pajaro Gap and in the southeast corner of the area (fig. 2) and lie at depth below most of the valley area (fig. 3). An unconformity exists between the granite and the overlying younger deposits. These rocks yield minor quantities of water to wells from fractures.

TABLE 1.--*Stratigraphic units of the Pajaro Valley area*

Period	Epoch	Formation	General character	Water-bearing properties
QUATERNARY	Holocene	Dune sand	Unconsolidated, well sorted, fine-to-medium grained, quartzose sand. In part, actively drifting.	Largely unsaturated but where saturated yields water to wells in small quantity.
		Unconformity		
		Alluvium	Unconsolidated gravel, sand, silt, and clay. Underlies the alluvial plain and extends into adjoining stream canyons.	Permeable; yields moderate quantities of water to wells.
		Unconformity		
	Pleistocene	Terrace deposits	Cross-bedded gravel, sand, silt, and clay. Marine origin near La Selva Beach. Nonmarine elsewhere.	Permeable; where sufficiently thick yield moderate quantities of water to wells.
		Unconformity		
		Aromas Red Sands of Allen (1946)	Unconsolidated, quartzose, brown-to-red sand with some clay interbeds. Deposited in lagoonal or near-shore environment.	Permeable; yields moderate quantities of water to wells.
		Unconformity		
TERTIARY	Pliocene	Purisima Formation	Poorly indurated sand, silt, clay, and shale; some gravel. Extensive shale beds in lower part of formation. Mostly marine in origin. Three subunits locally: upper member is a poorly indurated fine sand with silt and clay interbeds, some gravel; middle member is a poorly indurated medium to fine sand with silt and clay interbeds, some gravel; lower member is a poorly indurated sand with clay and shale interbeds.	Moderately permeable. Lies at considerable depth beneath the valley area, so tapped by few wells. Water-bearing properties largely unknown, but upper and middle members probably will yield moderate quantities of water.
		Unconformity		
	Eocene to Miocene	Sedimentary and volcanic rocks. Includes Monterey Formation, Lambert Shale, Vaqueros Sandstone, San Lorenzo Formation, and Butano Sandstone.	Consolidated or highly compacted sandstone, mudstone, and shale; some volcanic rocks. Marine in origin.	Yield water from fractures and from sandstone units. Water-bearing properties largely unknown.
		Unconformity		
CRETACEOUS		Sedimentary rocks	Conglomerate, sandstone, graywacke, and shale. Marine in origin.	Yield minor quantities of water to wells from fractures and sandstone units.
		Unconformity		
		Granitic rocks	Range in composition from gabbro to granite, with quartz diorite and adamellite predominant.	Yield minor quantities of water from fractures.

The sedimentary rocks of Cretaceous age are conglomerate, sandstone, graywacke, and shale. The rocks are marine in origin and are found near the San Andreas fault in the north part of the study area. They yield minor quantities of water to wells from fractures in the graywacke and shale, and from permeable zones within the sandstone.

Sedimentary and volcanic rocks (Eocene to Miocene).--These rocks range in age from Eocene to Miocene and are composed of sandstone, mudstone, shale, and some volcanic flows. They include the Monterey Formation, Lambert Shale, Vaqueros Sandstone, San Lorenzo Formation, and Butano Sandstone--all of marine origin.

The outcrops of these rocks in the Pajaro Valley area are associated with the San Andreas fault (fig. 2). A thick section of these rocks occurs at depth in a downdropped fault block between the Zayante fault and its southern extension and the San Andreas fault (fig. 3). In other areas beneath the valley these rocks, identified from deep oil well logs, are very thin or absent. These rocks underlie the younger deposits unconformably.

The sedimentary rocks of Eocene to Miocene ages in this area are not a good source of ground water because the fractures in the consolidated parts of the rocks are difficult to locate, and the sandstone units have low yields. They are important mainly because their outcrop establishes the eastern boundary of the ground-water basin.

Unconsolidated Deposits of Tertiary and Quaternary Age

Purisima Formation (Pliocene).--In the Pajaro Valley area, the Purisima Formation of Pliocene age is a sequence of highly variable sediments composed of poorly indurated sand, silt, clay, shale, and some gravel. The formation underlies all the valley area west of the San Andreas fault (fig. 3) and extends westward under Monterey Bay. It crops out in the north and in a narrow belt along the San Andreas fault (fig. 2). The formation is predominantly of marine origin and overlies all older units unconformably. In turn, it is overlain unconformably by the Aromas Red Sands of Allen (1946).

Maximum thickness of the formation in the Pajaro Valley area is about 3,500 feet beneath Browns Valley (fig. 3). It thins towards the south, and in the central part of the area near Watsonville is about 1,000 feet thick.

The Purisima Formation is in fault contact with rocks of Tertiary age along the San Andreas fault (figs. 2 and 3) and is on the southwest side of the fault. The formation may also be offset by the Zayante and Vergeles faults (fig. 2). However, there is no evidence that these faults act as barriers to the movement of ground water. In addition, deep oil-well test data from either side of the Zayante fault near Valencia Creek and Corralitos (fig. 3) indicate no displacement of the Purisima Formation. It is therefore assumed that the Purisima Formation is not displaced along the southern extension of the Zayante fault beneath the central part of the valley near Watsonville.

Hickey (1968, p. 11-12) subdivided the Purisima Formation in the Soquel-Aptos area into three subunits of slightly differing lithologic character. His subunit A is the basal unit, subunit B is the middle unit, and subunit C, the upper unit. These subunits are recognizable in the Pajaro Valley area and are used in the present report.

The following subsurface interpretations of the Purisima Formation are based mainly on information from deep test holes drilled by oil companies. Very few water wells penetrate the formation in the Pajaro Valley area, and where they do, they penetrate only a short distance.

Subunit A, in the Pajaro Valley area, is poorly indurated sand beds interbedded with clay and shale. Outcrops of this subunit occur along the west side of the San Andreas fault from Pajaro Gap to near the Hecker Pass road. This subunit is about 1,500 feet thick in the northern part of the area and thins toward the south to about 1,000 feet in the vicinity of Watsonville (fig. 3).

About 600 feet below the top of subunit A is a shale bed about 150 feet thick, which is continuous beneath all the Pajaro Valley. This bed is easily identified on electric logs of wells, and makes an excellent marker bed (Tpa shale, fig. 3). This subunit extends westward under Monterey Bay.

Subunit B consists of intercalated beds of poorly indurated sand, silt, and clay with some gravel. Some of the sand beds are as much as 50 feet thick. The sand is admixed with silt. The subunit crops out along the west side of the San Andreas fault from the Hecker Pass road north (fig. 2). The subunit occurs at depth beneath the northern half of the Pajaro Valley area (fig. 3) and extends out under Monterey Bay. It is absent beneath the central part of the area where it probably was removed by erosion prior to the deposition of the Aromas Red Sands of Allen (1946). The subunit averages about 600 feet in thickness.

Subunit C is made up largely of a sequence of poorly indurated, thin sand beds with interbeds of silt and clay, and some gravel. However, one sand bed near the base has an average thickness of about 200-250 feet. This subunit crops out in the northern part of the area, occurs at depth north of Watsonville, and is absent beneath the central part of the area (figs. 2 and 3). It has an average thickness of about 800 feet, but is considerably thinner near Monterey Bay.

All the subunits within the Purisima Formation are water bearing. The yield of the various beds is related to lithology: coarse-grained beds yield water freely, fine-grained beds do not. Good yields can be obtained only from those wells that penetrate the coarse-grained beds.

Few water wells penetrate into the Purisima Formation in the Pajaro Valley area because overlying deposits yield adequate quantities of water to wells. However, data from Hickey (1968) and lithological studies indicate that wells with sufficient penetration in subunit B should yield as much as 500 gpm (gallons per minute) of water and have specific capacities of 10-15 gpm per foot of drawdown. Wells in subunit C, which is finer grained than subunit B, should yield as much as 200 gpm with specific capacities of about 5 gpm per foot of drawdown. Subunit A probably has yield characteristics similar to those of subunit C.

Aromas Red Sands of Allen (1946) (Pleistocene).--The Aromas Red Sands of Allen (1946) consists of unconsolidated, well-sorted, quartzose, brown-to-red sand containing lenses of silt and clay and a few lenses of gravel. It was deposited during Pleistocene time in a lagoonal shoreline environment. It crops out extensively in the Pajaro Valley area and extends out under Monterey Bay (figs. 2 and 3). The Aromas Red Sands rests unconformably on the Purisima Formation. Its maximum thickness occurs in the southern part of the study area where it is about 1,000 feet. It thins northward and is absent in the north part of the area (fig. 2). The average thickness of the Aromas Red Sands in the Pajaro Valley is about 500 feet.

The Aromas Red Sands is a major aquifer in the Pajaro Valley area. Wells perforated opposite this formation have yields that average about 450 gpm and specific capacities of about 20 gpm per foot of drawdown.

Terrace deposits (Pleistocene).--The terrace deposits consist of beds of unconsolidated cross-bedded gravel, sand, silt, and clay. The gravel beds are as much as 50 feet thick. The deposits were laid down in late Pleistocene time and are of marine origin near the coast and of continental origin inland.

The terrace deposits occur north and northeast of Watsonville, south of the mouth of the Pajaro River, and in the vicinity of La Selva Beach. All are dissected by streams. The deposits lie unconformably on the Aromas Red Sands of Allen (1946). Their maximum thickness is about 200 feet.

The terrace deposits are permeable and, where saturated and sufficiently thick, should yield moderate quantities of water to wells. Most wells drilled in the terrace deposits also penetrate the Aromas Red Sands; thus, they obtain water from both units.

Alluvium (Holocene).--The alluvium in the Pajaro Valley area is a highly variable mixture of unconsolidated gravel, sand, silt, and clay. Logs of wells show that the alluvium in the upper part of the Pajaro Valley is generally coarser than that between Watsonville and the ocean. Also a continuous gravel layer, having an average thickness of about 50 feet, forms the basal unit of alluvium and is the main water-bearing zone in the area. This basal gravel unit is in direct contact with the underlying Aromas Red Sands of Allen (1946) beneath most of the area. The top of the gravel unit is indicated in figure 4; its vertical configuration and relation to older deposits is shown in figure 5.

The alluvium was deposited during Holocene time, when the floor of the basin into which the alluvium was deposited was at, or near, sea level.

The alluvium underlies the plain of the Pajaro Valley and extends into adjoining stream canyons (fig. 2). It unconformably overlies all older deposits. Its maximum thickness is about 200 feet and its average thickness about 150 feet (fig. 5).

The alluvium in the Pajaro Valley is permeable and yields water to wells. Pump efficiency tests, made by the Pacific Gas and Electric Co., on wells that penetrate only the alluvium indicate that these wells have yields of about 500 gpm and specific capacities that average about 50 gpm per foot of drawdown.

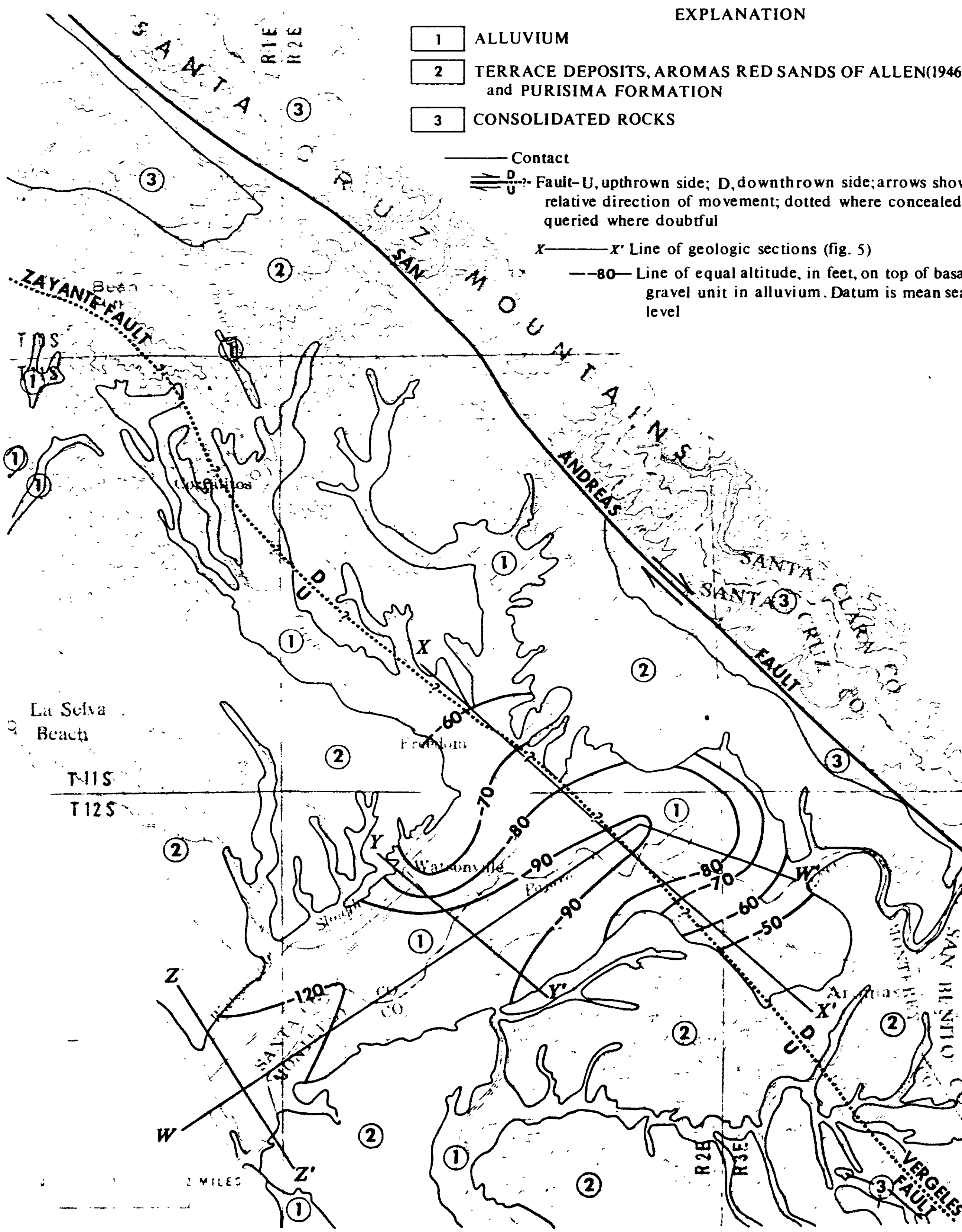


FIGURE 4.--Areal distribution of alluvium and altitude of top of basal gravel unit in alluvium.

Dune sand (Holocene).--The dune sand, which is made up of fine-to-medium grained, quartzose sand, is of Holocene age. The dunes have an eolian origin and overlie all older geologic units unconformably. In part, they are actively drifting. The dune sand occurs along the coast to the north and south of the mouth of the Pajaro River. Its thickness is not known, but is probably less than 100 feet.

The dune sand is moderately permeable, but probably contains little water because most of the sand lies above the zone of saturation and it has a limited areal extent. Locally, small perched or semiperched water bodies within the dune sand could supply small quantities of water to wells.

Geologic Relation--The Pajaro Valley and the Soquel-Aptos Areas

The geologic units and structures of the Pajaro Valley area (fig. 2) and those of the Soquel-Aptos area (Hickey, 1968, fig. 1) are continuous through both areas (fig. 6). The San Andreas fault, the dominant regional structural feature, passes through both the Soquel-Aptos and the Pajaro Valley areas. Its trace strikes northwest (fig. 2 and Hickey, 1968, fig. 1). The Zayante fault--which is continuous with the Vergeles fault (Clark, 1970)--parallels and lies about 3 to 4 miles west of the San Andreas fault. It passes through the Soquel-Aptos area and is unnamed beneath the Pajaro Valley area.

At the common boundary of the Soquel-Aptos and Pajaro Valley areas, igneous and consolidated rocks of Cretaceous age and pre-Pliocene rocks of Tertiary age form the basement complex (fig. 6). Directly overlying these rocks is the Purisima Formation. The formation has a gentle dip of about 4 degrees in both the Soquel-Aptos area and the Pajaro Valley area (fig. 6). Its thickness is about 3,500 feet where the two areas meet. The Aromas Red Sands of Allen (1946) lie stratigraphically just above the Purisima Formation. In the Soquel-Aptos area the unit crops out only in the southeast part of the area (Hickey, 1968, fig. 1). It dips about 4 degrees toward the southeast and thickens from a featheredge in that area to an average of about 500 feet in the Pajaro Valley area (fig. 6) where it crops out extensively (fig. 2). There is no physical connection between the alluvium in the two areas.

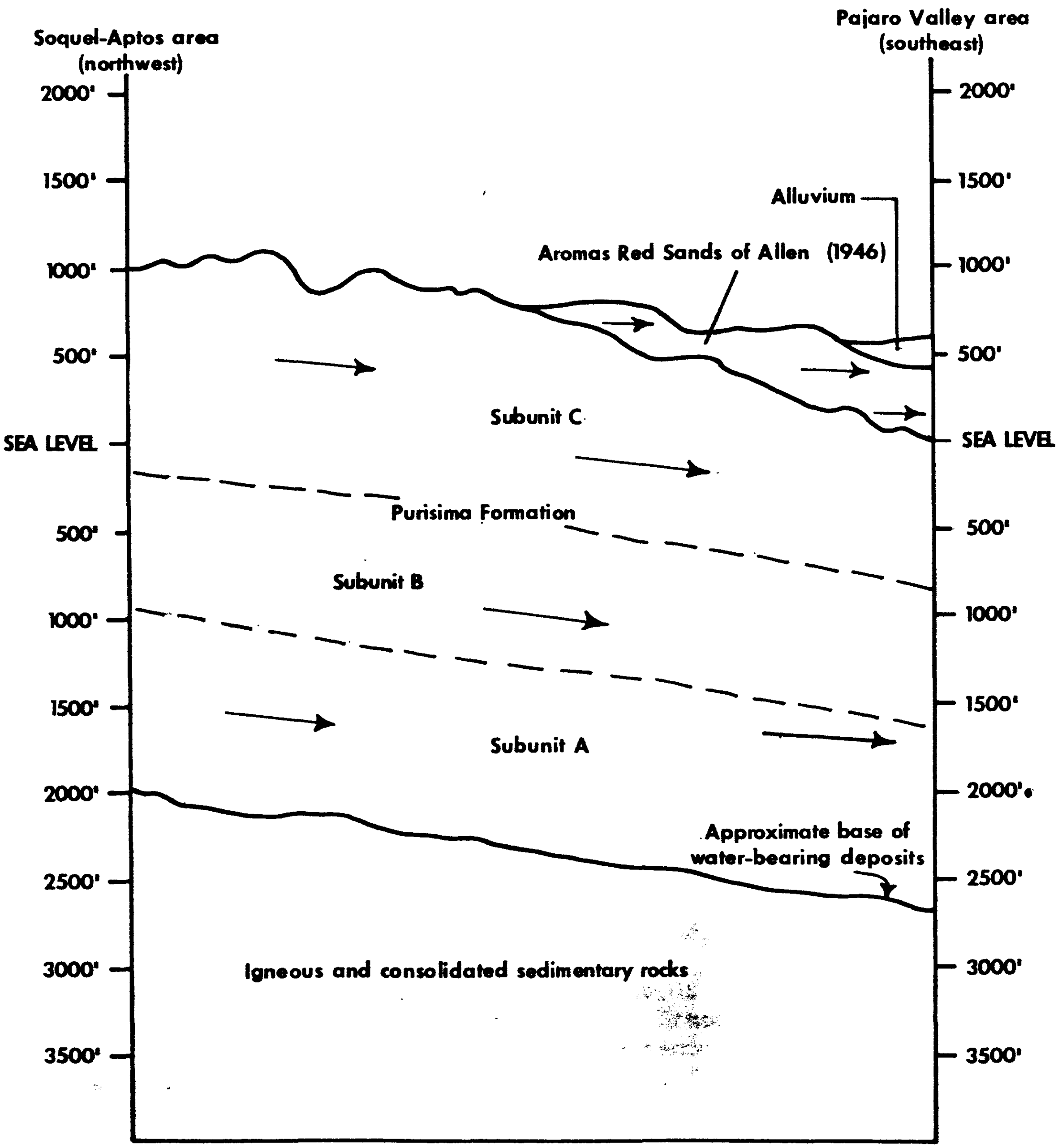


FIGURE 6.--Schematic geologic cross section across intersection of Soquel-Aptos area and Pajaro Valley area, showing stratigraphic relations and direction of ground-water flow. (Arrows indicate direction of ground-water flow.)

GROUND WATER

Source

Ground-water recharge in the Pajaro Valley area is derived from direct precipitation within the Pajaro Valley, seepage from the Pajaro River and other streams, and underflow from adjacent areas (figs. 6 and 8).

The quantity of rain that infiltrates to a ground-water body can vary considerably, depending mostly upon type of soil, density of vegetation, intensity of the rainfall, rate of evapotranspiration, and terrain. Much of the infiltrating rain water is held within the root zone that extends from the land surface to a depth of 10 to 15 feet; but, after the soil-moisture deficiency within this zone is satisfied, the excess water will continue downward until it eventually reaches the water table.

Rainfall infiltration is an important source of recharge for the water-bearing zones in the Purisima Formation, Aromas Red Sands of Allen (1946), and terrace deposits in the Pajaro Valley area. Ground-water recharge to the alluvium from direct rainfall infiltration is small, mainly because of the extensive clays at shallow depth in the alluvium which impede the downward movement of water. Some of the recharge from rainfall infiltration in the Purisima Formation, Aromas Red Sands, and terrace deposits moves laterally into the alluvium. This occurs where alluvium fills valleys that have been incised into the older units.

The main area of ground-water recharge by rainfall infiltration in the Pajaro Valley area is north, east, and west of Corralitos, an area of about 15,000 to 20,000 acres underlain by the Purisima Formation and the Aromas Red Sands, both of which have permeable soils. The average rainfall in this area is between 30 and 35 inches per year.

A secondary area, about 30,000 acres, favorable for rainfall infiltration is south of Corralitos and north of the Pajaro River. This area is underlain by the Purisima Formation, Aromas Red Sands, and terrace deposits (fig. 2), which have permeable soils. The soils of the Aromas Red Sands are especially permeable, being mostly sand. Average yearly rainfall over the area is about 20 inches. However, most of this rainfall is lost through stream runoff, evapotranspiration, and satisfying soil-moisture deficiency, so that not much is left for deep percolation to ground-water recharge.

Some rainfall probably infiltrates the Aromas Red Sands and terrace deposits in the area south of the Pajaro River. However, the quantity that infiltrates probably is small, because the average yearly rainfall in this area is less than 20 inches.

Little recharge to the Pajaro Valley aquifers occurs from rain infiltration on areas underlain by rocks of Miocene or older age (fig. 2). These rocks crop out in areas of high relief which are heavily forested, and even though the average yearly rainfall is in excess of 30 inches most runs off or is consumed by trees. The remainder is largely retained in the joints and fractures of these consolidated or semiconsolidated rocks and little reaches the valley area.

Another important source of ground-water recharge in the Pajaro Valley area is seepage from streams. This occurs mainly along the Pajaro River and the network of streams that drain the north and northeast part of the area (fig. 2). Observations made by the Geological Survey indicate that although some seepage occurs along other reaches of the Pajaro River most of the seepage takes place in the reach from Carpenteria Road to 3 to 4 miles downstream (fig. 2). Recharge in this reach moves to the gravels at the base of the alluvium and thence out under the valley. Clay lenses that form the confining beds within the alluvium are discontinuous in this area of the valley--allowing downward movement of water. Some of this water percolates downward and recharges the underlying Aromas Red Sands of Allen (1946) and the Purisima Formation. The actual rate and quantity of recharge is unknown.

The Pajaro River at the gaging station at Chittenden, several miles upstream from Pajaro Gap, has an average-yearly discharge of 108,700 acre-feet of water and a median of yearly mean discharges of 56,500 acre-feet. These data indicate that, in most years, there is flow in the Pajaro River available for ground-water recharge.

Recharge to ground water from stream seepage also occurs from the network of streams that drain the north and northeast parts of the area. Most of the recharge takes place in the areas where the streams flow over the Purisima Formation, Aromas Red Sands of Allen (1946), and the terrace deposits (fig. 2). Some stream losses, and resultant recharge, also occur where streams flow across the alluvium in areas north of Freedom (fig. 2). Streambeds in all these areas are moderately permeable. The quantity of recharge by these streams is unknown.

The quantity of water that moves in the subsurface into the Pajaro Valley area from the Soquel-Aptos area is unknown. Its determination was beyond the scope of the present study.

Occurrence

Ground water in the Pajaro Valley area occurs in the dune sand, alluvium, terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation. The units below the Purisima Formation probably are highly compacted and do not contain appreciable quantities of recoverable water.

The main ground-water body, in actuality a series of interconnected ground-water bodies contained in permeable sand and gravel beds sandwiched between beds of clay and silt, extends westward from the San Andreas fault to some point offshore beneath Monterey Bay. It extends upgradient northward into the Soquel-Aptos area. The location of the south boundary of the ground-water body is uncertain; but, on the basis of the geology of the area and water levels in wells, the boundary may lie along a line drawn from sec. 6, T. 13 S., R. 2 E. to sec. 27, T. 12 S., R. 3 E. (fig. 2).

A shallow ground-water body in the upper part of the alluvium throughout most of the valley area is separated from the main water-bearing zones by beds of clay and silt. Few wells tap this shallow zone because the yield is small and the water quality is marginal for most uses.

Ground water in most wells in the Pajaro Valley area occurs under confined (artesian) conditions. That is, ground water rises in well casings above the level in which it is first encountered when drilling in the different deposits. The only exception is ground water found in the upper, near-surface part of the alluvium, as discussed previously, and that found in the dune sand. There, ground water is unconfined and occurs under water-table conditions.

The six hydrographs shown in figure 9 illustrate the confined nature under which ground water occurs in the Pajaro Valley area. Three of the wells were drilled in the alluvium, and one each was drilled in the terrace deposits, the Aromas Red Sands, and the Purisima Formation. All six of these hydrographs indicate a rapid change of water level in response to recharge and discharge.

Ground water in the different units is also under different hydrostatic head. That is, if there were two wells side by side and each were drilled and completed in a different geologic unit, the water level in the wells would be different. This is illustrated in figure 7; the deeper wells which are perforated in the Aromas Red Sands (11S/1E-13A2, 13G2, 24G1, and 11S/2E-29F2, 29L3) have water levels that average about 100 feet less than those in adjacent wells which are perforated only in the alluvium (11S/1E-24A1, 24H3, 24J1, 11S/2E-19Ne, 19N4, 33A3, and 12S/2E-3A2).

A well drilled and completed only in the Purisima Formation--which contains water under artesian pressure--probably would have a water level that would differ from that in the overlying Aromas Red Sands, the terrace deposits, or the alluvium. These different water levels occur principally because of the variations in the lithology of the sediments which compose the water-bearing section. The sediments, as mentioned in the section on geology, are a heterogeneous interbedded series of gravel, sand, silt, and clay. Most of the ground water is found in the beds that are predominantly gravel and sand; the silt and clay interbeds act as confining beds and yield very little water.

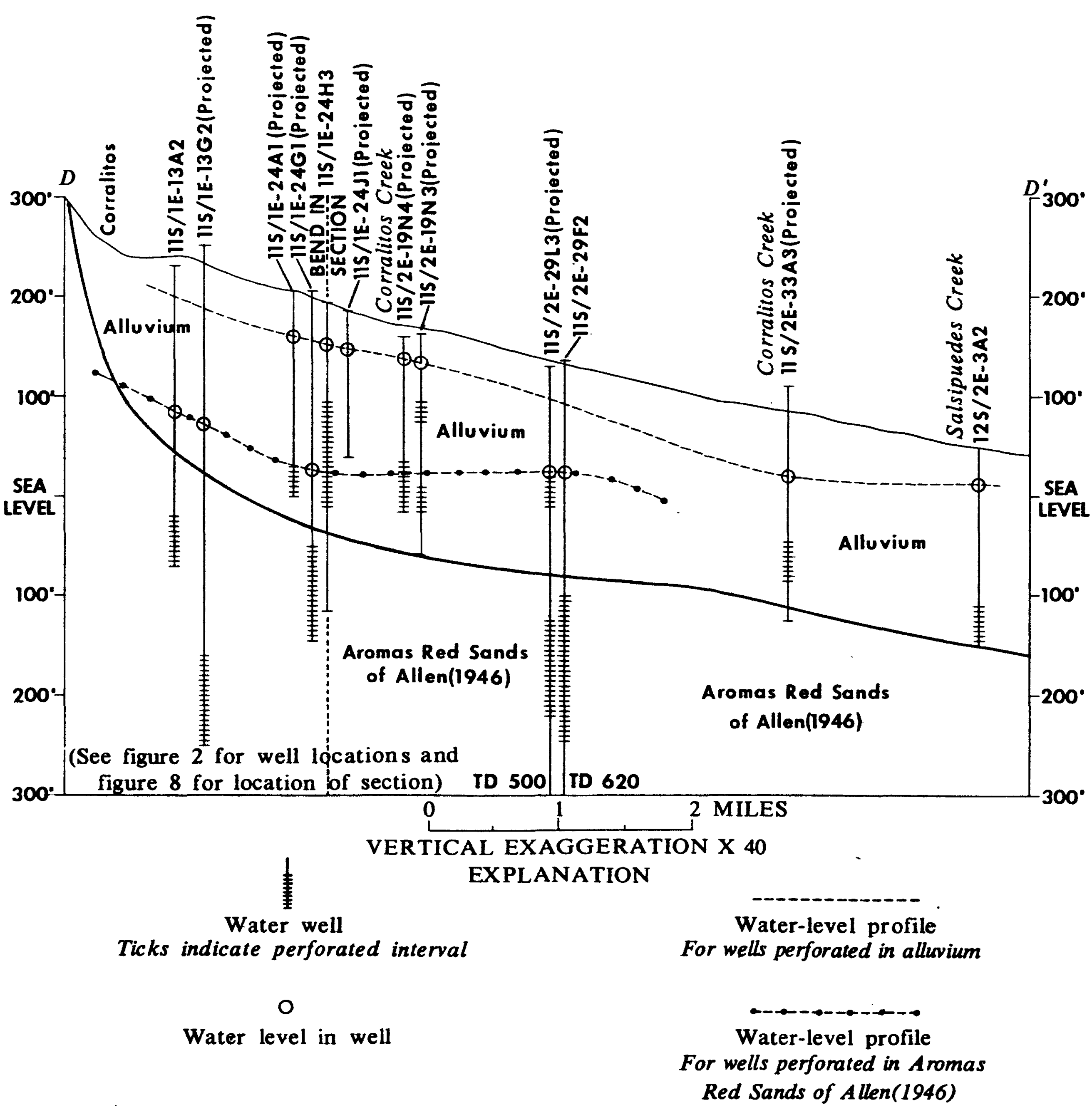


FIGURE 7.--Geologic section D-D', showing water-level profiles in the water-bearing deposits, winter 1970.

Movement

The direction of movement of ground water beneath the Pajaro Valley area is influenced mainly by the structure and lithology of the water-bearing deposits and to some extent by the topography. Figure 8 shows the direction of movement of ground water within the area. Ground water moves southeast from the Soquel-Aptos area into the north part of the Pajaro Valley area, then south toward Watsonville and southwest toward and out under Monterey Bay. It moves southwestward from areas near the San Andreas fault. Along the south boundary of the study area, ground-water movement is almost due west.

Because data on water-level altitudes in the terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation are insufficient, ground-water gradients were not determined for these units. Data on water levels in the alluvium in December 1969 (fig. 8) indicate ground-water gradients from Corralitos to Freedom of about 30 feet per mile (nearly the same as the land-surface gradient); in the upper part of the valley in the vicinity of Murphy Crossing and near Freedom, 10 feet per mile; for the central part of the valley northeast of Watsonville, about 5 feet per mile; and for the area from Watsonville to the ocean, 2 feet per mile. There has been no apparent change in ground-water gradients in the alluvium for the past 20 years (fig. 8).

Pumping of ground water, at the present time, does not seem to have influenced the general gradient or direction of movement of ground water in the Pajaro Valley area. However, there are two local areas where pumping during the summer for the past few years has lowered heads to below sea level and has caused a temporary seasonal change in direction of movement and gradient. This has occurred near the mouth of the Pajaro River and in the southeast corner of the study area. (See section, "Sea-Water Intrusion.")

There is vertical movement of ground water between units because of differences in head (fig. 7). The rate of ground-water movement is dependent upon the magnitude of the head difference and also on the ability of the units to transmit water (permeability). Little is known about either one of these items. Most water wells deeper than several hundred feet are gravel packed and have casings perforated opposite more than one water-bearing zone. The head in these wells reflect the composite head of all the water-bearing units penetrated. In some of these wells water may flow from one zone into another.

Prior to the 1940's, several wells that tapped the gravel at the base of the alluvium in the area between Watsonville and the ocean (fig. 5) flowed. Since then, pumping for irrigation has reduced the head in this area to the extent that in 1970 there were no known flowing wells.

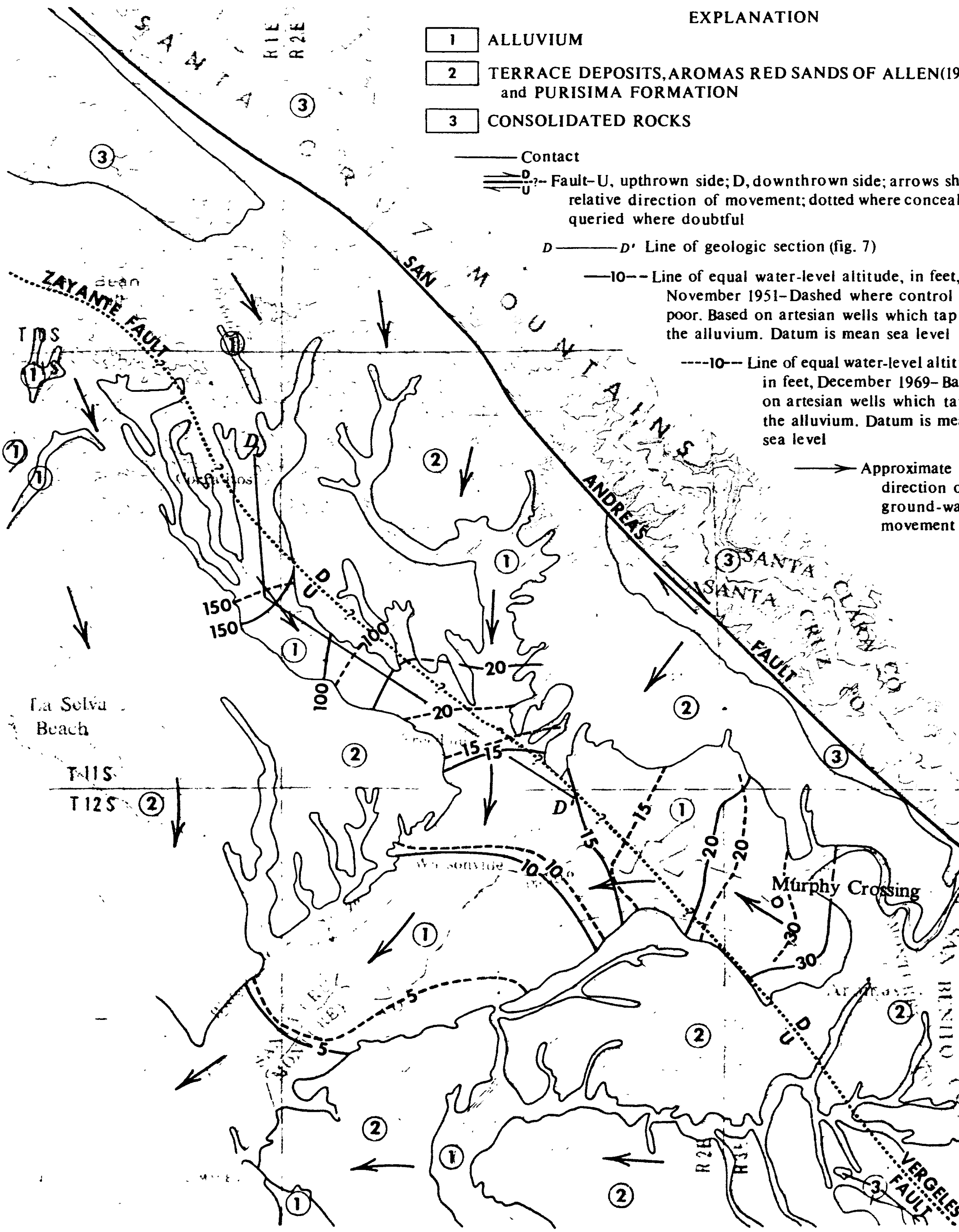


FIGURE 8.--Lines of equal water-level altitude in alluvium, 1951 and 1969, and direction of ground-water movement.

Of the two fault systems in the Pajaro Valley area (the San Andreas fault and the Zayante-Vergeles fault, fig. 2) only the San Andreas fault has a restrictive effect on the movement of ground water. The San Andreas fault acts as a barrier because impermeable Tertiary rocks lie on the east side of the fault (figs. 2 and 3). Evidence is scanty regarding the Zayante-Vergeles fault, but that which is available indicates that this fault does not influence the movement of ground water in the Pajaro Valley area.

Ground water moving out of the Pajaro Valley area discharges into Monterey Bay offshore. The discharge occurs from upward leakage to the floor of the bay or in Monterey Canyon, which intersects the water-bearing units under the bay about 7 miles offshore.

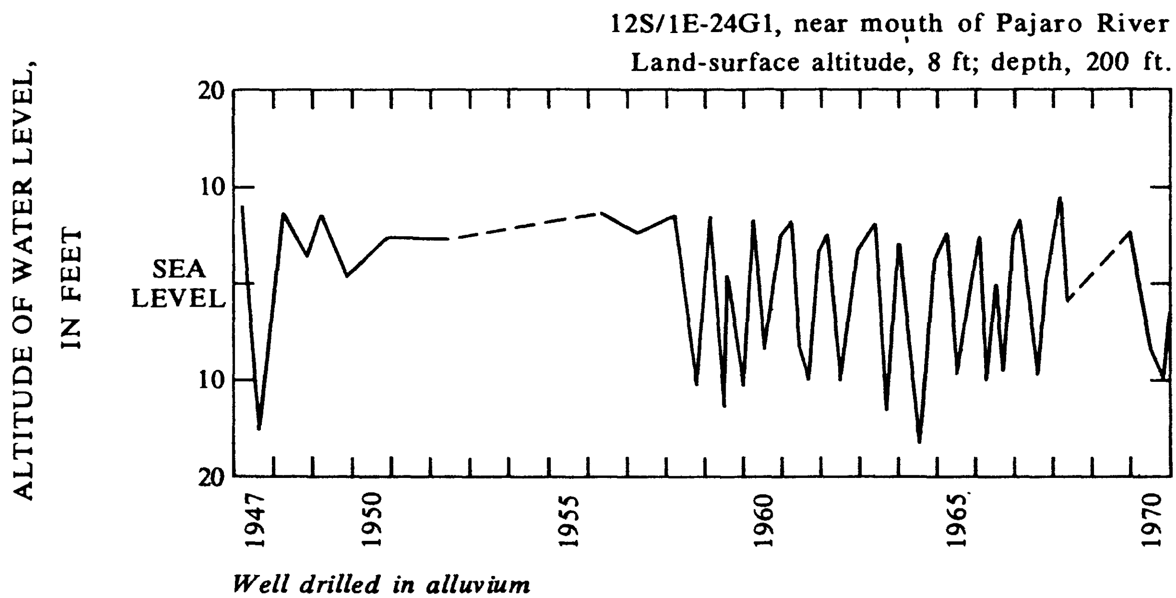
Water-Level Fluctuations

Few water-level measurements were made in the Pajaro Valley area prior to the late 1940's. Since that time, the California Department of Water Resources has measured water levels in a few wells monthly. In addition to the monthly measurements, they have made miscellaneous measurements in other wells at different times. In 1969, the Monterey County Flood Control and Water Conservation District started making water-level measurements in a network of wells in the Pajaro Valley area for Santa Cruz County. The hydrographs in figure 9 and the water-level contours shown in figure 8 were prepared using data from both these agencies.

Typical water-level fluctuations in the valley area are illustrated by the hydrographs in figure 9, which are considered representative of water-level fluctuations in the four main water-bearing units: alluvium, terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation. They show long-term trends and response to precipitation and recharge, and pumping and discharge. Declining water levels indicate decreases in ground-water storage and rising water levels indicate increases in ground-water storage.

The hydrographs (fig. 9) of wells 12S/1E-24G1, 12S/2E-9C1, and 12S/2E-16J1, are representative of water-level fluctuations in the alluvium. The three graphs show virtually the same trends: (1) A water-level decline of about 4 feet from 1947 (from 1931 for 12S/2E-9C1) to 1966, (2) a rise of about 3 feet during the 1967-68 period, and (3) a decline of about 3 feet during 1969-70.

The hydrograph of well 11S/2E-32K3, which indicates water levels in the terrace deposits, shows an overall pattern similar to that of wells drilled in the alluvium, and indicates a decline of about 2 to 4 feet from 1948 to 1966, a small rise in water levels in 1967 and 1968, and then a declining trend since 1969.



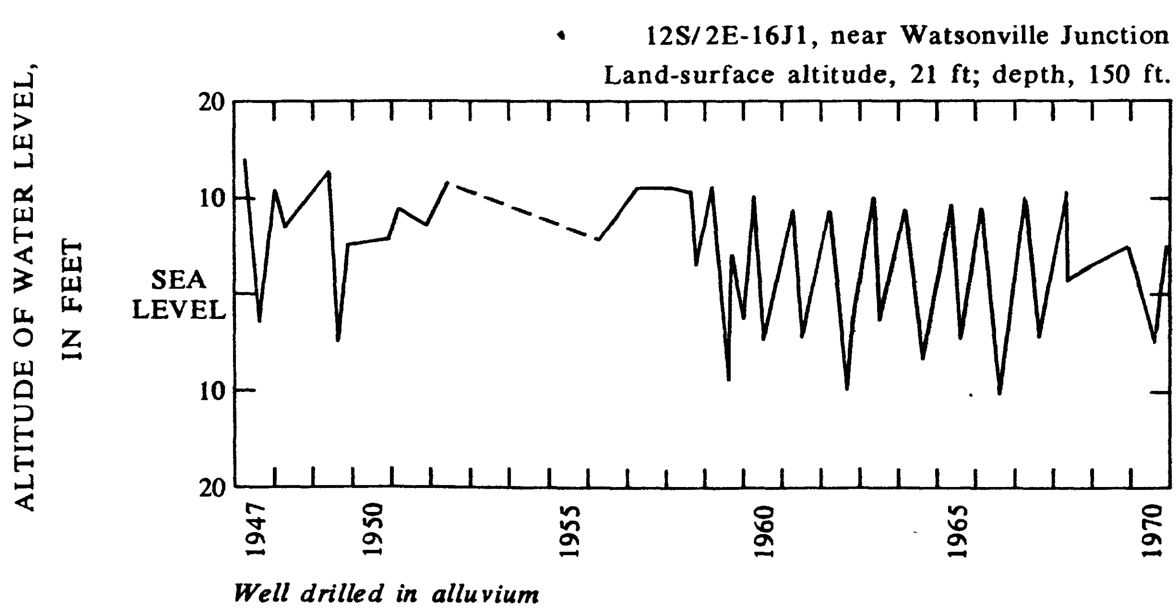


FIGURE 9.--Fluctuation of water levels in six wells in the Pajaro Valley Area.

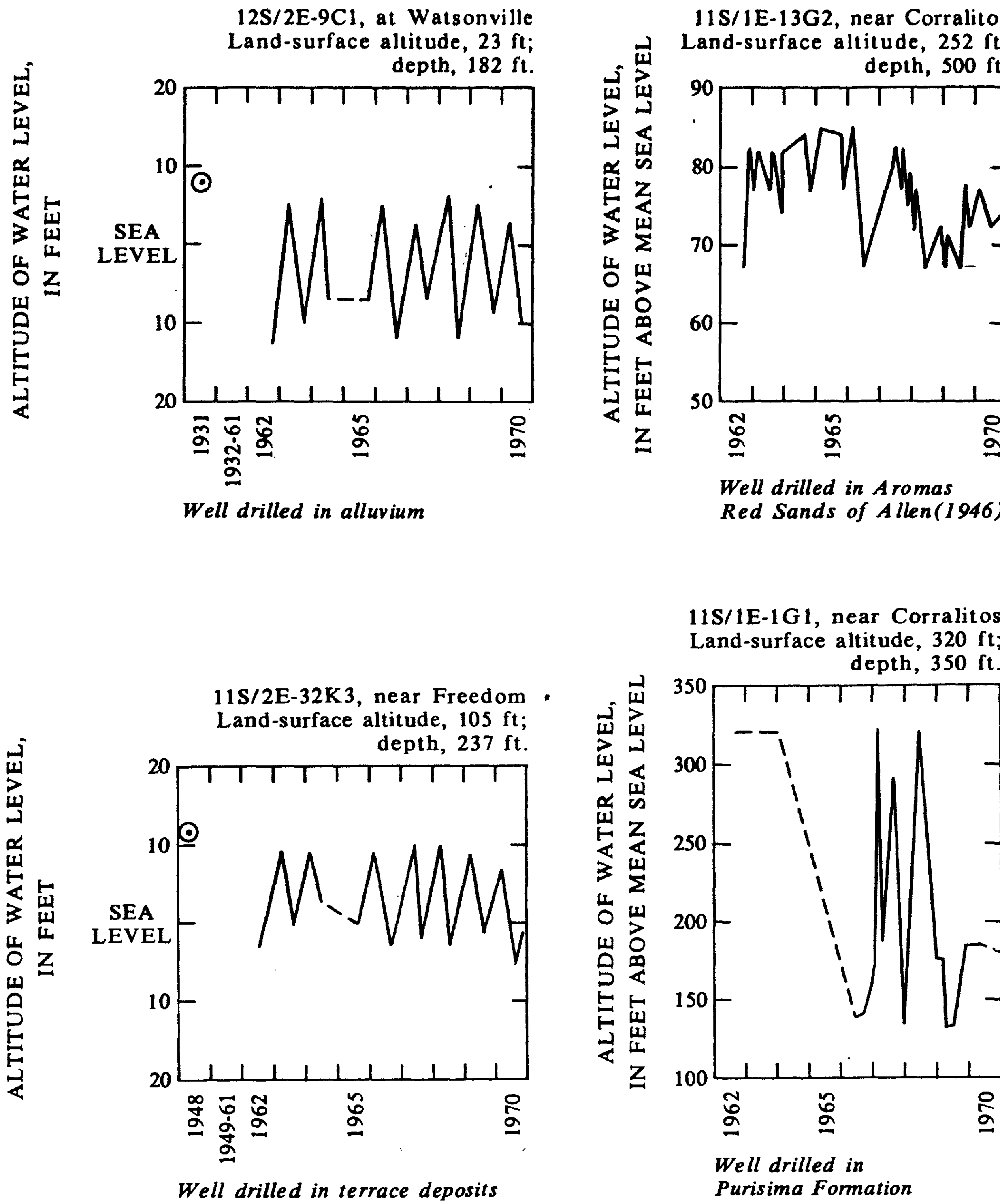


FIGURE 9.--Continued.

Water-level fluctuations in the Aromas Red Sands of Allen (1946), as represented by the hydrograph for well 11S/1E-13G2 (fig. 9), show a rise from 1962 to 1965 and then a decline from 1966 to 1970. The character of water-level fluctuations as shown by the hydrograph for this well, is different from that for wells drilled in the alluvium and in the terrace deposits (fig. 9). Vertical hydrologic separation between the aquifers or a different pumping regime could be the cause of these differences.

No long-term water-level records are available for wells drilled in the Purisima Formation in the Pajaro Valley area. The hydrograph of well 11S/1E-1G1 (fig. 9), which taps the Purisima Formation near Corralitos, represents only about 5 years of record. The hydrograph indicates that there was no overall change in water level in this area during the period 1962-68. This well is a public-supply well for the city of Watsonville and it is sometimes pumped year round. This is what occurred through the winter of 1969-70. The low water levels during this period reflect a local cone of depression caused by pumping rather than an actual storage depletion.

All the hydrographs in figure 9 indicate only a small change in water levels for the period of record--an average decline of about 2 feet from 1950 to 1970. This is also shown by the water-level contours in figure 8. The contours indicate that there was very little overall change in water levels in the alluvium between 1951 and 1969. However, because the Pajaro Valley area comprises about 120 square miles, a small change in water levels may represent a considerable quantity of ground water removed from storage.

Pumpage

Ground water pumped from wells is the major source of water used in the Pajaro Valley area. Some surface water is diverted from stream channels for irrigation and domestic use; however, in comparison to ground water the quantity of surface water used for beneficial use is small, amounting to about 3,000 acre-feet per year.

Table 2 shows ground-water pumpage for the pumpage years 1963-67. A pumpage year begins May 1 of the designated year and extends to April 30 of the next year--corresponding to the irrigation season.

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 as described by McClelland (1963). Data on the electrical energy (kilowatthours) used for pumping were obtained from accounts of the Pacific Gas and Electric Co. The electrical energy required to pump a unit volume of water (acre-feet) was computed from pump-efficiency tests made by the Pacific Gas and Electric Co.

Pumpage for most public-supply and industrial use is metered, and was determined from the records of the users. About 5,000 people in the valley area obtain their water supply from individual family wells. Estimated pumpage for these wells was based on domestic water-supply requirements.

Pumpage was calculated back only to 1963, because data on the amount of electric energy used for pumping irrigation water were unavailable for the years prior to that time. However, it would be safe to assume that irrigation pumpage has not changed appreciably since about 1959--irrigated acreage, crop patterns, and agricultural practices in the valley area have remained virtually the same since that time. (Creegan and D'Angelo-McCandles, Consulting Engineers, 1968a, p. 35-37).

TABLE 2.--*Ground-water pumpage, Pajaro Valley area, 1963-69*

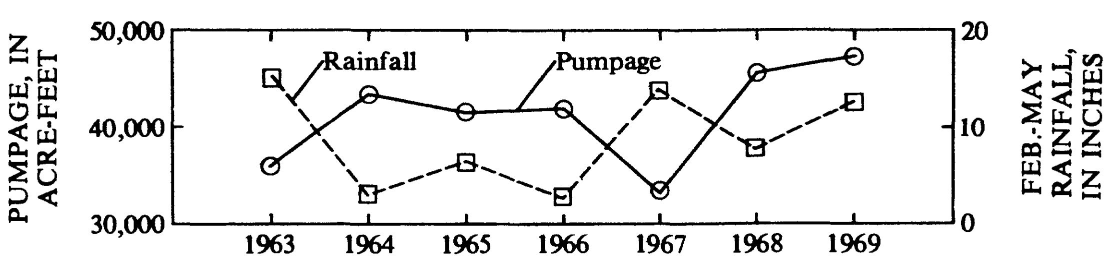
Pumpage year[1]	Gross pumpage (acre-feet)		
	Irrigation	Other[2]	Total
1963	36,000	[3]4,900	40,900
1964	43,100	[3]4,900	48,000
1965	41,800	[3]4,900	46,700
1966	42,000	[3]4,900	46,900
1967	33,200	4,200	37,400
1968	45,400	4,700	50,100
1969	47,000	6,000	53,000
7-year average	41,200	4,900	46,100

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

[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.

The yearly variations in irrigation pumpage, which are apparent in table 2, are somewhat the reflection of how much rain occurred near the beginning of the irrigation season. If soil moisture is high at the start of the season (April or May) then less irrigation water is required for germination of seed or to satisfy initial moisture requirements of perennial crops--and the total quantity of ground water pumped during that season would reflect this. This is illustrated in the following graph, which compares February-May rainfall with agricultural pumpage--when rainfall is up, pumpage is down, and when rainfall is down, pumpage is up. The 1969 data plots seem not to follow this general rule; however, in actuality they do. In 1969, 70 percent of the total rainfall for the February-May period fell in February. By the time the irrigation season began, soil moisture was low and and irrigation water was needed; thus pumpage went up, even though the total rainfall was also up.



The quantity of water pumped for irrigation is a gross draft. It is not the net draft on the ground-water reservoir. When water is applied to crops, part of the water is consumed by the plants, part is lost by evaporation, part runs off on the surface, and the remainder percolates downward and is returned to storage. The quantity of water that returns to storage in the Pajaro Valley area is unknown.

Chemical Quality

All natural water contains mineral matter dissolved from soils or rocks. The quantity of dissolved-mineral matter in natural water depends primarily on the type of rocks or soils through which the water has passed. Ground water generally has a larger concentration of dissolved solids than surface water. The value of a water supply depends, in part, upon the character and quantity of this dissolved-mineral matter and the use for which the water is intended.

Most of the dissolved-mineral matter in natural water is in the form of ionized particles. Ionized particles are positively charged cations and negatively charged anions. The most common cations are calcium, magnesium, sodium, and potassium. The most common anions are bicarbonate, carbonate, sulfate, chloride, and nitrate.

In the Pajaro Valley area, two distinct ground-water-quality zones can be defined: (1) The shallow, semiperched ground water in the upper part of the alluvium and (2) the deeper, confined ground water in the lower part of the alluvium, terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation--which, collectively, supply all the usable ground water that is pumped in the Pajaro Valley area.

Ground water in the shallow zone, which extends to a depth of 30 to 40 feet beneath most of the main valley area, is being affected by return irrigation water and organic wastes from domestic septic tanks and industrial plants. In general, the shallow, semiperched ground water contains a large dissolved-solid content--with individual concentrations of sulfate, nitrate, chloride, and magnesium commonly exceeding 100 mg/l (milligrams per liter) (California Water Resources Board, 1953, table 18). This poor-quality ground water is a source of contamination to the deeper aquifers by downward leakage during periods when the head in the deep aquifers is lower than the head in the shallower aquifer.

The chemical quality of the ground water in the deep aquifers within the main zones of pumping in the Pajaro Valley area is good. The quality characteristics, both as to major constituents and dissolved solids, however, vary over the area. These waters of differing chemical character fall into three general areal regions and are shown in figure 10 as north area, east area, and south area.

The best-quality water occurs in the north area. The range of dissolved solids in 42 ground-water samples collected in the area in July 1970 was 145-630 mg/l with an average of 340 mg/l.

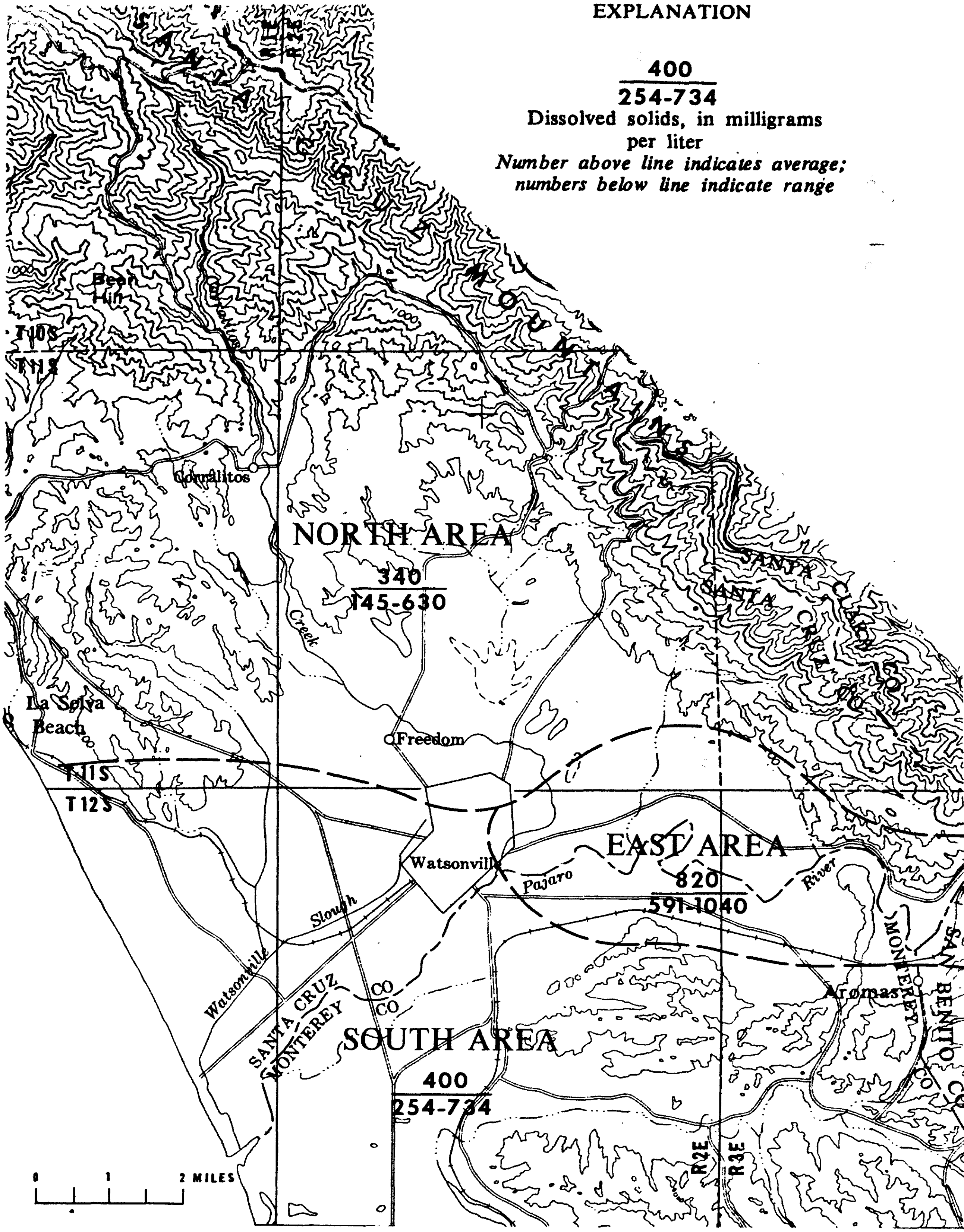


FIGURE 10.--Average and range of dissolved solids in ground water from the main zones of pumping, July 1970.

Ground water in the east area is of a poorer quality than that in the north area. Its dissolved-solids range, based on 15 ground-water samples collected in July 1970, was 591-1,040 mg/l, with an average of 820 mg/l. This water is of marginal quality for domestic purposes. According to the U.S. Public Health Service (1962), dissolved solids in drinking water should not exceed 500 mg/l. However, if water of this quality is not available, a dissolved-solids content of as much as 1,000 mg/l is permitted. The main source of recharge in this area is water from the Pajaro River. Flow in the Pajaro River in this area averages less than 45 cubic feet per second 70 percent of the time. During these periods of low flow, most of the water in the river is irrigation wastewater averaging about 1,000 mg/l in dissolved solids. This is undoubtedly the reason why ground water in this area is of a poorer quality than that in the north area.

Ground water in the south area is an admixture of that in the north and east parts of the valley area. This agrees with the flow lines shown in figure 8, which indicate ground-water movement from the east toward the west, and from the north toward the south and west. The range of dissolved solids in 37 ground-water samples collected in the south area in July 1970 was 254 to 734 mg/l with an average of 400 mg/l.

Hardness of the ground water from the main water-bearing units in the Pajaro Valley area is objectionably large for domestic or industrial use, averaging more than 100 mg/l and in water from some wells is as much as 500 mg/l. Hem (1959, p. 147) stated that hardness of a domestic or industrial water supply does not become objectionable until it reaches about 100 mg/l. Hardness is undesirable because of its scale-forming and soap-consuming properties that are caused by carbonate and bicarbonate salts, principally of magnesium and calcium.

The quality of ground water in the deeper parts of the Pajaro Valley aquifers is unknown; no water wells are known to penetrate the complete water-bearing section of the Purisima Formation. There is the probability that these deeper waters are saline because the Purisima Formation and the units underlying the Purisima were laid down in a marine environment. Thus, salt water was placed in the interstices of these deposits at the time of deposition. If these formational waters have not been flushed out by fresh water, then saline water will be encountered in deep water wells.

Sea-Water Intrusion

Where there is pumping from wells along a coast, sea-water intrusion must always be considered as a potential source of contamination to aquifers in that area. The intrusion of sea water into coastal aquifers can occur in two ways: by horizontal migration of a sea-water wedge into the aquifer at depth or by lateral movement of sea water through shallow deposits adjacent to the ocean and subsequent downward migration. Either way, the ground-water level in an aquifer at the coast in relation to sea level is the factor that determines if sea-water intrusion could occur. Under natural conditions, ground-water levels near the coast would be above sea level, the potentiometric surface would have a seaward gradient, and fresh water would be discharged into the ocean at some area offshore. If ground-water levels in the aquifer near shore decline to below sea level, a reversal of gradient will occur and the sea-water wedge will migrate shoreward. The actual sea-water fresh-water front would not be a sharp line of demarcation; it would be an area of dispersion or a zone of diffusion. In addition to this horizontal landward migration of sea water at depth, vertical intrusion can also occur. This can occur in areas where sea water overlies an aquifer. Sloughs or stream channels which are under the influence of tidal surge are examples of such areas. The head relations within the aquifer system control the intrusion, and the permeability of the deposits controls the speed with which intrusion will occur. Abandoned wells, wells constructed with a gravel envelope outside of the casing, or well casings with multiple perforations provide an artificial access between sea water and the aquifer, and, if present, will greatly accelerate intrusion.

Another factor that determines whether sea water 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, then sea-water intrusion will not occur in the basin. The barrier could be a fault barrier, or a permeability barrier--any geologic feature that impedes the movement of water. On the other hand, if there are no barriers and if ground-water levels decline, then sea-water intrusion is likely to occur.

No vertical ground-water barriers exist in the coastal portions of the Pajaro Valley area from La Selva Beach on the north to south of the mouth of the Pajaro River (figs. 2, 3, and 5). Consequently, the factor controlling sea-water intrusion in the Pajaro Valley area is the ground-water level at or near the coastline. Because the main aquifers extend out and 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 Canyon several miles offshore. Avenues for the movement of sea water into the Pajaro Valley area at depth, therefore, are present.

The contamination of ground water by downward movement of salt water is also a real probability in the lower part of the Pajaro Valley adjacent to the river, from several miles west of Watsonville to the ocean (fig. 2). The Pajaro River is tidal in this reach, and the river water is extremely saline during periods of low flow. This saline water could move laterally away from the river in the near-surface part of the alluvium. The shallow part of the alluvium in this area is predominantly clay which serves to impede both the lateral and downward migration of the salt water. However, a number of abandoned wells, gravel-packed wells, and wells of poor construction, pass through this clay layer. These wells act as avenues through which salt water would enter the fresh-water aquifers beneath.

Sea-water intrusion has occurred in the Pajaro Valley area. However, the intrusion is limited to two areas: (1) Near the mouth of the Pajaro River and (2) near McClusky Slough (fig. 2). This is illustrated by the chloride concentration in ground-water samples collected in July 1970:

Well number	Chloride (mg/l)	
12S/1E - 1C2	22	
2Q1	18	
3B1	38	
11C1	26	
12E1	26	
13R1	22	
23R1	34	
24G1	30	
24N1	186	(intrusion)
24Q1	58	
25F1	170	(intrusion)
25G1	30	
12S/2E -31K1	542	(intrusion)
13S/1E - 1A1	1244	(intrusion)
13S/2E - 6C1	610	(intrusion)

The extent of the intrusion and the zones intruded are unknown at this time.

The key to the intrusion is the water levels in the irrigation wells in the two areas. The water-level fluctuations shown in figure 9 for well 12S/1E-24G1, are representative of those for irrigation wells in the intruded areas. The records indicated that during the summer pumping season, water levels have been averaging about 10 feet below sea level for some time. A localized reversal in ground-water gradients has undoubtedly accompanied these below sea-level water levels. The result is that sea water has been induced to migrate into the pumped zones.

Potential for Artificial Recharge

Artificial recharge is accomplished through structures designed to maintain high infiltration rates, increase the wetted area, and lengthen the period of infiltration beyond that which exists under natural conditions. These structures can be ponds, pits, shafts, modified stream channels, or injection wells.

Some of the factors that must be evaluated prior to any artificial recharge project are as follows (American Society of Civil Engineers, 1961, p. 72-90):

1. Soil horizon--critical in the establishment of initial and sustained infiltration rates. Items to consider are texture, permeability, claypan or hardpan development, depth of soil profile, and organic-matter content.
2. Infiltration rate below soil profile--determined by the physical character and permeability of the subsurface deposits and depth to ground water.
3. Storage capacity of subsurface deposits--based on permeability, specific yield, thickness of the deposits, and the position and allowable fluctuation of the water table.
4. Transmission rates--the rate of movement of ground water from beneath the recharge site to other parts of the ground-water basin; must know the transmissivity of the deposits and the hydraulic gradient of the water table or potentiometric surface.
5. Quality of the recharge water. In surface infiltration methods, adverse chemical reactions between the recharge water and the local ground water can cause clogging of the aquifer; turbid recharge water will cause silting. If injection wells are to be used, silting, bacterial and algal growths, air entrapment, and deflocculation caused by reactions of high sodium water with soil particles can cause decreases in infiltration rate.

Evaluation of the preceding items for the Pajaro Valley area was beyond the scope of the present investigation. However, if it becomes a certainty that imported water will be available for recharge in this area, a detailed study of the items listed should be made.

A potential for artificial recharge to ground water beneath the Pajaro Valley area exists both from surface infiltration and subsurface injection. How much water can be recharged is unknown, but it probably could be determined by detailed studies.

The best areas for surface infiltration are shown in figure 11. They include the bed of the Pajaro River from Pajaro Gap to about Murphy Crossing and the streambeds and adjacent soils in and along Corralitos and Casserly Creeks, and in Green, Pleasant, and Larkins Valleys (fig. 2). The streambeds and adjacent soils are predominantly sand in these areas. Water recharged would move into the alluvium, terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation.

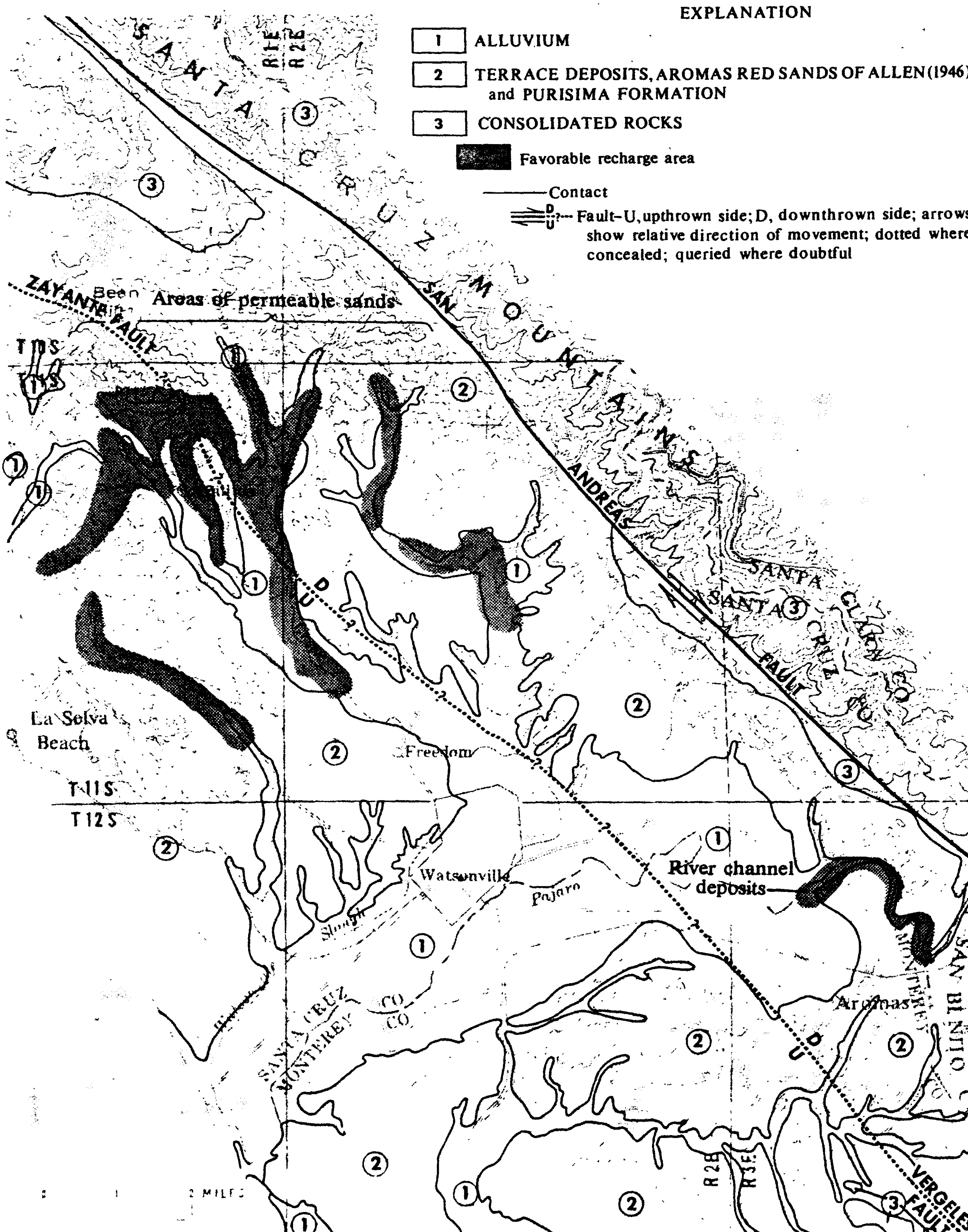


FIGURE 11.--Areas favorable for artificial recharge by surface infiltration.

Injection wells could be installed in all four main water-bearing units in the Pajaro Valley area (the alluvium, terrace deposits, Aromas Red Sands of Allen (1946), and Purisima Formation) with probably some success. The gravel at the base of the alluvium would be the best zone in which to inject water (see figs. 4 and 5) because data from drillers' logs indicate that it is highly permeable.

SELECTED REFERENCES

Akers, J. P., 1969, Ground water in the Scotts Valley area, Santa Cruz County, California: U.S. Geol. Survey open-file rept., 12 p.

Alexander, C. S., 1953, The marine and stream terraces of the Capitola-Watsonville area: California Univ. Press, Berkeley, Pub. Geography, v. 10, no. 1, p. 1-44.

Allen, J. E., 1946, Geology of the San Juan Bautista quadrangle, California: California Div. Mines Bull. 133, 112 p.

American Society of Civil Engineers, 1961, Ground-water basin management: Manual Eng. Practice 40, 160 p.

Bradley, W. C., 1957, Origin of marine-terrace deposits in the Santa Cruz area, California: Geol. Soc. America Bull., v. 68, no. 4, p. 421-444.

Brown and Caldwell, Consulting Engineers, 1967, Water supply and distribution, city of Watsonville: San Francisco, Rept. to the city of Watsonville, 127 p.

California Department of Public Health, 1965, Sanitary engineering survey of Monterey Bay beaches in the vicinity of the city of Watsonville outfall, 1964-65: Bur. Sanitary Eng., 24 p.

California Department of Water Resources, 1955-62, Quality of ground waters in California: Bull. 66 series.

______1958, Sea-water intrusion in California: Bull 63, 91 p.

______1958-62, Ground water conditions in central and northern California: Bull. 77 series.

______1963-69, Hydrologic data, volume 3: Central coastal area: Bull. 130 series.

______1968, Special investigation Pajaro River basin: Rept. to the Central Coastal Water Quality Control Board, 157 p.

______1970, Sea-water intrusion into the lower Salinas Valley, a progress report: Sacramento, 28 p.

California Division of Mines and Geology, 1966, Geology of northern California: Bull. 190, 508 p.

California Water Resources Board, 1953, Santa Cruz-Monterey Counties investigation: Bull. 5, 230 p.

California Resources Agency, 1968, Water quality control policy for Pajaro River basin and underlying ground water: Central Coastal Regional Water Quality Control Board, 27 p.

Clark, J. C., 1970, Preliminary geologic and gravity maps of the Santa Cruz-San Juan Bautista area, Santa Cruz, Santa Clara, Monterey, and San Benito Counties, California: U.S. Geol. Survey open-file map.

Creegan and D'Angelo, Consulting Engineers, 1957, Report on the proposed Pajaro zone of the Santa Cruz County Flood Control and Water Conservation District: Rept. to the Santa Cruz County Flood Control and Water Conserv. Dist., 10 p.

Creegan and D'Angelo-McCandles, Consulting Engineers, 1968a, 1968 master plan for water development in Santa Cruz County, 1968 to 2020, planning data [2d ed.]: Rept. to the Santa Cruz County Flood Control and Water Conserv. Dist., v. 1, 183 p.

______1968b, 1968 master plan for water development in Santa Cruz County, 1968 to 2020, details of proposed plans [2d ed.]: Rept. to the Santa Cruz County Flood Control and Water Conserv. Dist., v. 2, 211 p.

Greene, H. G., 1970, Geology of southern Monterey Bay and its relationship to the ground-water basin and salt-water intrusion: U.S. Geol. Survey open-file rept., 50 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural waters: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

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

Jones, W. F., 1911, The geology of the Sargent oil field: California Univ., Berkeley, Dept. Geol. Sci. Bull., v. 6, no. 3, p. 55-78.

Mackie, W. W., 1910, Soil survey of the Pajaro Valley, California: U.S. Dept. Agriculture Soil Survey, 46 p.

McClelland, E. J., 1963, Methods of estimating ground-water pumpage in California: U.S. Geol. Survey open-file rept., 19 p.

Santa Cruz County Flood Control and Water Conservation District, Monterey County Flood Control and Water Conservation District, and Public Works Department of the city of Watsonville, 1969, Summary of flood control program for Pajaro River at Watsonville: 13 p.

Storie, R. E., and others, 1944, Soil survey of the Santa Cruz area, California: U.S. Dept. Agriculture Soil Survey, ser. 1935, no. 25, 90 p.

Starke, G. W., and Howard, A. D., 1968, Polygenetic origin of Monterey Submarine Canyon: Geol. Soc. America Bull., v. 79, no. 7, p. 813-826.

Taliaferro, N. L., 1934, Geologic history and structure of the central coast ranges of California: California Div. Mines Bull. 118, 126 p.

Todd, D. K., 1959, Ground-water hydrology: New York, John Wiley and Sons, Inc., 336 p.

U.S. Bureau Reclamation, 1967, A report on the San Felipe Division, Central Valley project, California, pursuant to the provisions of 53 stat. 1187: U.S. 89th Cong., 2d sess., House Doc. 500, 135 p.

U.S. Public Health Service, 1962, Public Health Service drinking water standards, 1962: Pub. 956, 61 p.

Yancey, T. E., 1968, Recent sediments of Monterey Bay, California: California Univ., Berkeley, Hydraulic Eng. Lab., 145 p.