UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

HYDROGEOLOGIC STUDY OF THE SOQUEL-APTOS AREA

SANTA CRUZ COUNTY, CALIFORNIA

By

John J. Hickey 1936-

Prepared in cooperation with
the Soquel Creek County Water District
the county of Santa Cruz, and
the city of Santa Cruz

OPEN-FILE REPORT

Menlo Park, California
April 10, 1968

CONTENTS

ILLUSTRATIONS

TABLES

HYDROGEOLOGIC STUDY OF THE SOQUEL-APTOS AREA, SANTA CRUZ COUNTY CALIFORNIA

By John J. Hickey

ABSTRACT

The geologic framework of the Soquel-Aptos area includes partly metamorphosed sedimentary rocks of pre-Cretaceous age, igneous and sedimentary rocks of Cretaceous age, and sedimentary rocks of Tertiary and Quaternary age.

The Cretaceous igneous rocks underlie the area and form the basement complex. The Tertiary rocks predominate and are chiefly a sequence of interbedded sandstone and siltstone. In this report they are subdivided into formally and informally named geologic formations including the Butano Sandstone (Eocene), unnamed sandstone and conglomerate (Eocene), the San Lorenzo Formation (Eocene and Oligocene), unnamed clay and shale (Miocene), Monterey Shale (Miocene), unnamed siliceous shale (Miocene), the Santa Margarita Formation (Miocene), and the Purisima Formation (Pliocene). In general, the older Tertiary rocks are more consolidated than the younger Tertiary rocks. The Quaternary rocks include the Aromas Red Sands of Allen (1946) (Pleistocene), terrace deposits (late Pleistocene), and alluvium (Recent).

Two well defined large faults trend approximately northwest through the area, the San Andreas fault which cuts through the northernmost boundary and the Zayante fault, roughly parallel to the San Andreas and 3 to 4 miles to the southwest.

The attitude and thickness of the Tertiary sedimentary rocks on either side of the Zayante fault are materially different. In the area between the Zayante and San Andreas faults, the rocks are intensively folded and faulted and are as much as 10,000 feet thick; whereas in the area between the Zayante fault and Monterey Bay the rocks, predominantly the Purisima Formation, are only slightly folded and faulted, and probably are not more than 3,000 feet thick. The sedimentary rocks southwest of the Zayante fault rest upon the Cretaceous igneous rocks.

The sedimentary rocks of Cretaceous age, of Tertiary age older than the Purisima Formation, and of Quaternary age are of minor significance to the present water-supply situation of the Soquel-Aptos area. The Butano Sandstone and the Santa Margarita (?) Formation of Tertiary age, and the Aromas Red Sands of Allen (1946) of Quaternary age may offer possibilities for future ground-water development. However, very few data are available to establish their potential.

The sandstone beds in the Purisima Formation are the most important ground-water source in the area. The Purisima Formation extends from the Zayante fault southward into Monterey Bay, and in this report has been arbitrarily divided into three subunits. All three subunits contain water but only the upper two, B and C, which are mainly sandstone, yield usable quantities. In general wells in subunit B yield more water than wells in subunit C.

Continuous long-term records of water levels from two wells in subunit B show no clear rising or falling trend, however, both wells are inland, distant from the areas of major withdrawals. Other wells in subunit B, nearer the coast, provide shorter, noncontinuous records that indicate that before present-day pumping rates were reached water levels were higher than now.

As fresh water is pumped from the Purisima Formation and the water levels are lowered, salt water enters. As yet, salt water has not penetrated inland to reach wells, but continued and perhaps increased pumpage may eventually bring about salt-water contamination of some wells. A system of specifically designed and located monitoring wells could provide warning of imminent contamination before it actually affects the supply.

The quality of water from subunit C is better than that from subunit B. Water from subunit B has a slight hydrogen-sulfide odor and its calcium, iron, manganese, sulfate, and total dissolved-solids concentrations generally exceed those of subunit C. Water from the Aromas Red Sands of Allen (1946) sampled at La Selva Beach has much better chemical characteristics than either subunit B or subunit C.

The ground water from five locations was tested and found to be moderately corrosive to mild steel and not at all corrosive to stainless steel.

INTRODUCTION

LOCATION AND GENERAL FEATURES

The Soquel-Aptos area, as considered in this report and shown in figure 1, extends from the San Lorenzo River and the drainage divide between Granite Creek and Carbonero Creek on the west, to the drainage divide between Valencia Creek and Corralitos Creek on the east, and from the San Andreas fault on the north to Monterey Bay on the south.

The area lies between lat. 36°55' and 37°10' and long. 121°45' and 122°05' W., and includes the eastern part of the city of Santa Cruz, which is about 70 miles south of San Francisco. Other towns within the area are Soquel, Aptos, Capitola, and Rio Del Mar. The major roads leading into the area are California State Highways 1 and 17. There are about 100 square miles in the study region and the population in 1967 was on the order of 10,000. Most of the development in the region is concentrated on the relatively flat lands between the mountains and the ocean.

The Soquel-Aptos area is in the Santa Cruz Mountains. In the northern part very steep valley side-slopes and angular landforms occur at altitudes as much as 3,000 feet above mean sea level. These give way southward to more gentle valley-side slopes and subrounded landforms that range from about 200 to 800 feet above mean sea level and which terminate against nearly flat marine terraces at altitudes between 20 and 200 feet. Sea cliffs as much as 100 feet high fall away from the terraces to narrow beaches that parallel Monterey Bay. The area is drained principally by Branciforte, Soquel, Valencia, and Aptos Creeks.

Precipitation in the Soquel-Aptos area is almost entirely rainfall. The infrequent snowfalls that occur at the highest elevations have little influence on runoff. Along the coast, mean annual precipitation ranges from 24 to 28 inches per year; at the higher altitudes along the northern boundary precipitation probably ranges from 40 to 50 inches per year. Approximately 80 percent of the precipitation occurs between November and March.

PURPOSE AND SCOPE

The purpose of this study is to describe the ground-water resources of the Soquel-Aptos area. The major emphasis is on the coastal part of the area where there is the greatest need for water and, therefore, the greatest need for knowledge with which to rationally develop and manage the subsurface water supply.

The prospect of increasing water-supply demands in the Soquel-Aptos area has caused concern to the water-service agencies. Because of their common interest, the Soquel Creek County Water District, the county of Santa Cruz, and the city of Santa Cruz entered into a cooperative agreement with the U.S. Geological Survey for this study. A previous report "Geohydrologic Reconnaissance of the Soquel-Aptos area, Santa Cruz, California," (Akers and Hickey, 1966) was prepared by the U.S. Geological Survey for the same cooperators in 1966.

This report was prepared under the overall supervision of R. Stanley Lord, California district chief for the Water Resources Division of the U.S. Geological Survey, and under the immediate supervision of L. E. Young, chief of the Menlo Park subdistrict office.

The Soquel Creek County Water District is the major public water-supply agency in the Soquel-Aptos area. The district obtains its supply exclusively from ground water near the coast and, therefore, needs an adequate description of the ground-water resource for planning purposes.

The county of Santa Cruz requires an adequate description of the Soquel-Aptos ground-water resource for its county-wide water-resource plan.

The city of Santa Cruz obtains all of its water supply from surface water and springs outside the boundaries of the Soquel-Aptos area. The city is interested in knowing whether or not a potential ground-water supply exists within the city boundary to supplement present sources.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report has been used by the Geological Survey in California since 1940. The system has been adopted by the California Department of Water Resources and the California Water Quality Control Board for use throughout the state.

Wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the number 11S/1W-15L1, the part of the number preceding the slash indicates the township T. 11 S.; the part between the slash and the hyphen is the range R. 1 W.: the number between the hyphen and the letter indicates the section (sec. 15); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram.

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

Within the 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well 11S/1W-15L1 is the first well to be listed in the SW¼NE¼NE¼ sec. 15, Mount Diablo baseline and meridian.

The numbering of springs in this report is the same as for wells except that an S is used between the 40-acre subdivision letter and the final digit as shown in the following spring number: 11S/1W-10RS1.

ACKNOWLEDGMENTS

Many people contributed substantially to the project. Among them are James Harris, manager, Soquel Creek County Water District; Kenneth F. Izant, president, Soquel Creek County Water District Board of Directors: Gene V. DeArmond, engineer, Charles S. McCandless and Company, consulting engineers; Weston L. Webber, director, city of Santa Cruz Water Department; Warren M. Harrison, director, county of Santa Cruz Department of Public Works; R. T. Holzworth, planning engineer, county of Santa Cruz Department of Public Works; and J. P. Akers, hydrologist, U.S. Geological Survey, Menlo Park, Calif.

HYDROGEOLOGY

GEOLOGIC FRAMEWORK

Rocks that range in age from pre-Cretaceous (included with rocks of Cretaceous age in figure 1) to Quaternary crop out in the Soquel-Aptos area. They include metasedimentary rocks of pre-Cretaceous age, igneous and sedimentary rocks of Cretaceous age, and sedimentary rocks of Tertiary and Quaternary age.

In this report, the geologic units are discussed from oldest to youngest with special reference to their hydrologic properties.

Rocks of Cretaceous Age

Igneous Rocks

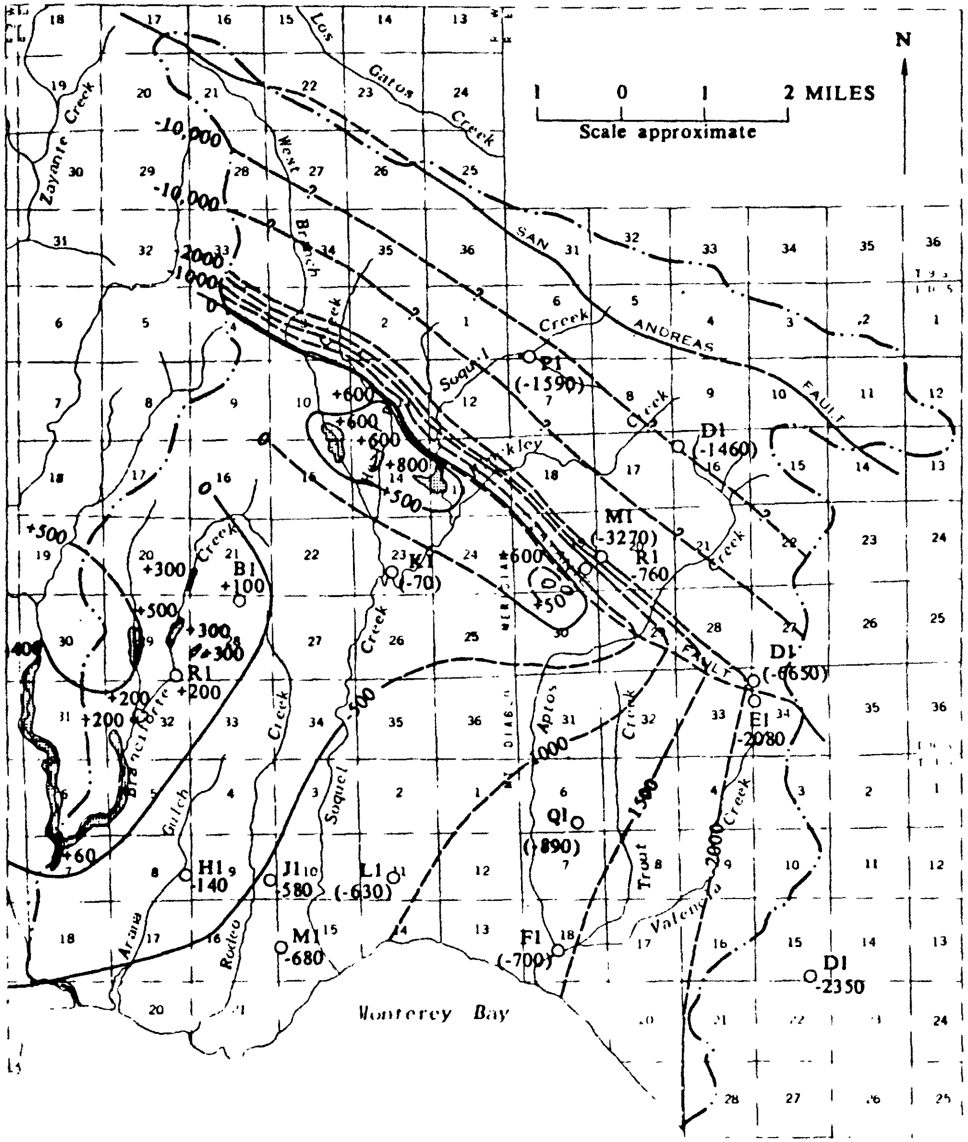
In the Soquel-Aptos area igneous rocks, of Cretaceous age, are chiefly quartz diorite, but include other granitic rock varieties such as granodiorite and quartz monzonite. Minor quantities of pre-Cretaceous metasedimentary rock also occur in the area, but for the purpose of this report they are included with the igneous rocks.

The igneous rocks form the basement complex. They crop out only in small exposures along the western part of the area in the channel of Branciforte Creek, southwest of the Zayante fault at Sugarloaf Mountain, and in the channels of West Branch Soquel, Hester, and Bridge Creeks. Several oil- and water-test holes penetrate these rocks at depth between the Zayante fault and Monterey Bay. Most of the outcrops and test holes indicate that the rocks are fractured and deeply weathered. Figure 2 is a contour map showing the surface of the basement complex as interpreted from the outcrop patterns and well data. This surface marks the top of the weathered zone. No water wells that obtain water exclusively from these rocks were found in the area. The rocks probably can yield little water.

Sedimentary Rocks

Sedimentary rocks of Cretaceous age, are alternating strata of well consolidated conglomerate, sandstone, and shale of unknown thickness. They occur in the northeastern corner of the area, northeast of the San Andreas fault. The strata are thoroughly jointed and have attitudes that reflect their history of intense deformation; they strike east to southeast and dip at angles ranging from 40 to 70 degrees, into the San Andreas fault.

The ability of those rocks to yield water is a direct function of the fracture patterns. The fractures provide storage space and hydraulic continuity for a water mass. Large yields cannot be expected from these rocks. However, if a well site is chosen with care, taking into consideration the local fracture patterns, domestic supplies can probably be obtained.



EXPLANATION

+600

Basement complex

Number indicates altitude in feet of surface outcrop of basement complex

-500 ?

Structure contour

Dashed where control is poor. Number is altitude in feet. Queried where doubtful. Datum is mean sea level

H1
-140

Test hole or well

Letter indicates location in section. See text for description of well-numbering system. Number indicates altitude in feet of basement complex. Number in parentheses indicates altitude of bottom of well that did not reach basement complex

Boundary of study area

STRUCTURE CONTOURS SHOWING TOP OF BASEMENT COMPLEX

Rocks of Tertiary Age

Rocks of Tertiary age predominate in the area and consist of a sedimentary sequence that, for the most part, was deposited in a continually changing marine environment. The coastline during Tertiary time was shifting its position, as is indicated by a frequently recurring vertical repetition of siltstone and sandstone beds. In general, the silt was deposited in the deeper regions of an ocean basin and the sand was deposited in the shallower regions. Another depositional characteristic to be expected in such a changing environment is that the texture of the individual sandstone and siltstone beds changes laterally. For example, a well-defined sandstone bed at one point grades laterally into a well-defined siltstone bed at another point. In the study area, those lateral changes occur both abruptly and gradually.

Butano Sandstone

The Butano Sandstone, of Eocene age, is a consolidated, highly fractured, medium to coarse sandstone containing beds of conglomerate and siltstone. The thickness of the Butano was estimated by R. O. Burford, (written commun., 1961) to be about 4,000 feet. The rock crops out in a band paralleling the San Andreas and Zayante faults in the northern part of the area. It has been intensively folded and faulted and in places has been overturned; it dips into the San Andreas fault at angles ranging from 40 to 80 degrees.

A comparison between the geologic map (fig. 1) and a well-location map prepared by P. J. Creegan and E. M. D'Angelo (written commun., 1961) shows that numerous domestic-supply wells obtain water from the Butano in the northernmost part of the area along Summit Road. The Butano may be capable of yielding water in large enough quantities for public-supply demands. However, the complex arrangement of folds and faults and the occurrence of siltstone beds dictate a detailed geologic investigation for all proposed public-supply well sites.

Sandstone and Conglomerate of Eocene Age

An unnamed unit of sandstone and conglomerate, of Eocene age, (fig. 1) is exposed north of the San Andreas fault. That unit was not examined in detail during this study, but it seems to be similar to the Butano Sandstone lithologically and probably has similar hydrologic characteristics.

San Lorenzo Formation

The San Lorenzo Formation of Eocene and Oligocene age is primarily an interbedded sequence of shale and mudstone that has been moderately to very intensively fractured. R. O. Burford (written commun. 1961) estimated its thickness to be on the order of 2,000 feet. The San Lorenzo crops out in a band between the Zayante and San Andreas faults and dips to the southwest at angles ranging between 60 and 80 degrees.

This rock has negligible potential for public-supply ground-water development. However, small domestic supplies could possibly be obtained from zones of intensive fracturing. Although water may be yielded readily because of fracture permeability, the usable storage would be limited.

Vaqueros Formation

The Vaqueros Formation, of Oligocene (?) and Miocene age, is a firmly to moderately consolidated, massive- to thin-bedded, coarse to fine sandstone having siltstone and cobble conglomerate interbeds. According to Clark (1966) the estimated thickness is 3,000 feet. It crops out in the northern part of the area parallel to the Zayante fault. The strata are intensively folded and faulted and dip in general to the southwest, but segments are overturned and dip to the northeast.

A carefully selected well site in the coarser sandstone beds offers the best possibility for obtaining moderate supplies of water. However, the structural deformation of this formation dictates a detailed geologic investigation for all proposed wells.

Clay and Shale Units of Miocene Age

Rocks of Miocene age in the Soquel-Aptos area include an unnamed clay and shale unit, the Monterey Shale, and an unnamed siliceous shale unit. The thickness of the unnamed clay and shale unit was estimated by R. O. Burford (written commun., 1961) to be 900 feet. The thickness of the siliceous shale is unknown. However, Clark (1966) estimated that there may be as much as 350 feet of Monterey Shale on the western periphery of the Soquel-Aptos area. The unnamed units crop out as bands between the Zayante and San Andreas faults in the northern part of the area. The Monterey crops out just outside the western periphery of the area between the Zayante fault and Monterey Bay. Also according to Clark (1966) the Monterey Shale probably occurs within the area in the subsurface near Vinehill Road. All the clay and shale units of Miocene age are moderately folded.

These rocks are not known to contain water in the Soquel-Aptos area and probably would yield little or no water to wells.

Santa Margarita Formation

The Santa Margarita Formation, of Miocene age, is a poorly consolidated sandstone composed of well sorted, coarse to fine grains of quartz and feldspar. In the vicinity of Branciforte Creek it is approximately 20 to 30 feet thick, and pinches out a short distance to the east. The outcrops along Branciforte Creek are too small to represent on the geologic map (fig. 1). A sandstone in the northwestern part of the area and southwest of the Zayante fault is questionably assigned to the Santa Margarita. According to Clark (1966) this sandstone may be much older than the Santa Margarita that crops out along Branciforte Creek and that it thins eastward from Blackburn Gulch where it has a maximum thickness of 300 feet. No exposures of the Santa Margarita are known that provide satisfactory definition of the attitude of the strata; however, the attitude of the overlying and underlying rocks indicate that the unit is either horizontal or dips slightly to the southeast.

The poorly consolidated and well-sorted character of the Santa Margarita indicates that this formation should yield water readily to a well. However, in the vicinity of Branciforte Creek its small thickness and rapid pinchout to the east would allow only domestic-supply wells to be developed. The sandstone that crops out in Blackburn Gulch, and is mapped tentatively as Santa Margarita, could probably be developed by public-supply wells but the lateral extent of the unit should be determined before development is attempted.

Purisima Formation

The Purisima Formation, of Pliocene age, is a sequence of blue, moderately to poorly consolidated, silty to clean, very fine to medium sandstone containing siltstone interbeds. It underlies the southern two-thirds of the area and Martin (1964) indicated that it extends under Monterey Bay. Northeast of the Zayante fault the formation is folded into a syncline that plunges to the southeast; between the fault and the coast it is only slightly folded and has a regional dip of 3 to 5 degrees southeast.

Informal subunits.--For the purpose of this report, the Purisima Formation between the Zayante fault and Monterey Bay is subdivided into three informal subunits. The subunits in ascending order are: Subunit A, a siltstone with a few sandstone interbeds near its top; subunit B, a blue, silty to clean, fine- to medium-grained sandstone with siltstone interbeds; subunit C, a bluish-brown to blue, very silty to silty, very fine to fine-grained sandstone with siltstone interbeds.

The cross sections in figure 1, drawn along the regional dip (A-A') and strike (B-B') of the strata, show the thickness of these subunits. Subunit A is approximately 150 feet thick in the western part of the area and it thickens eastward to about 575 feet. Subunit B is, in general, about 230 feet thick throughout the area, but thins somewhat to the west. Subunit C has been partly removed by erosion. The remaining part has a thickness that ranges from a few feet in the western part of the area to a maximum of 1,400 feet in the eastern part of the area.

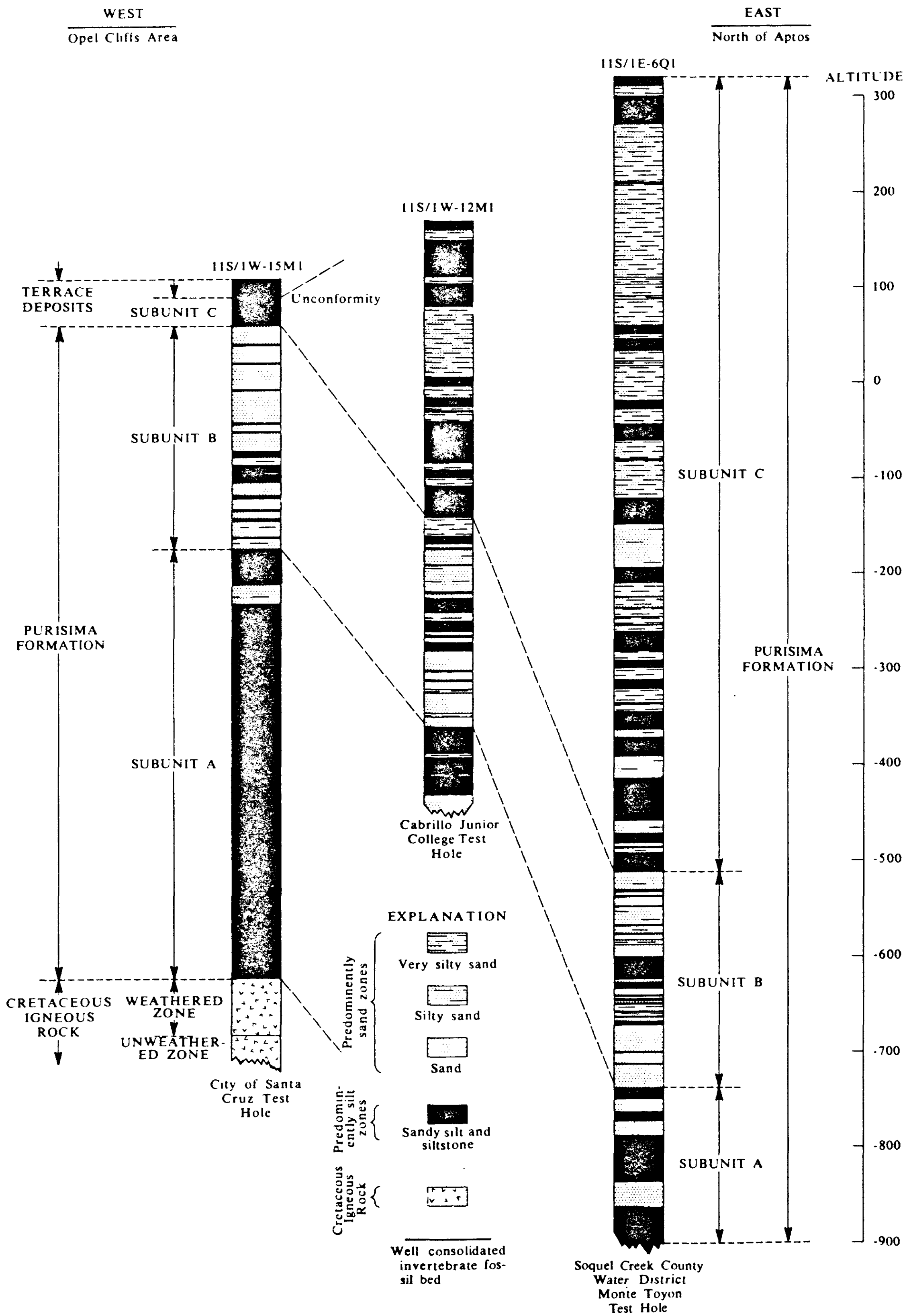
Many of the individual sandstone beds in subunits B and C change laterally to become more or less silty. Figure 3 shows these changes. Eastward from Opal Cliffs to the vicinity of Aptos, the upper part of subunit B become siltier and the lower part becomes sandier. In subunit C the silty sandstone beds in its lower part become sandier and thicken to the east from Soquel toward Aptos.

Many well-consolidated invertebrate fossil beds, commonly less than a foot thick, occur in subunits B and C (fig. 3). Subunit B contains the greatest number of these beds and they occur at intervals throughout its vertical extent. The invertebrate fossil beds act to confine the ground water but are less important in that respect than are the laterally extensive siltstone beds.

Many of the sandstone beds in subunits B and C have a "blue or black" appearance and are reported from well logs to occur at various depths and geographic locations. In outcrop, many of the sand grains composing the beds are coated with iron oxide, which gives a bluish-brown to brown appearance to the strata. In general, the "blue or black" color of the sandstone beds is caused by a high percentage of dark colored minerals and rock fragments. C. G. Davis and F. B. Henderson (written commun., 1957) determined the mineral and rock-fragment composition of 12 sandstone samples from subunit C along the coast between Capitola and Rio del Mar. They found the following ranges:

Samples	Percent
Quartz	34 to 45
Feldspars	25 to 35
Andesite fragments	10 to 25
Opaques (including magnetite)	0 to 6
Ferromagnesians	0 to 8
Clay	0 to 8

The sandstone beds in subunits B and C are the most important aquifers in the area. All the major public-supply wells along the coast withdraw water from them. Wells in subunit B, in general, yield from three to four times as much water for a given drawdown than most wells in subunit C. However, in the eastern part of the area one zone in subunit C has yield characteristics comparable to those of subunit B.



LITHOLOGIC COLUMNS OF THE PURISIMA FORMATION
(Based on electric-log interpretation and examination of test-hole cuttings)

Rocks of Quaternary Age

Aromas Red Sands of Allen (1946)

The Aromas Red Sands of Allen (1946), of Pleistocene age, make up a brown to red, poorly consolidated, clayey, fine- to coarse-grained sandstone containing lenses of silt and clay. It crops out in the eastern part of the area between the Zayante fault and Monterey Bay and overlies subunit C of the Purisima Formation. The thickness ranges from a few feet near Valencia Creek to a maximum of 450 feet near the eastern boundary of the area. The rocks dip to the southeast at 4 degrees.

Few, if any, wells produce from the Aromas within the study area, although some wells do produce fair yields from the Aromas east of the area. The sandy zones in the Aromas should yield water in quantities adequate for public supplies. However, development within the study area may be hindered by the limited thickness of the formation and the potential for salt-water encroachment along the coast.

Terrace Deposits

Terrace deposits, of late Pleistocene age, are interbedded silt, clay, sand, gravel, and conglomerate. They are very heterogenous both vertically and laterally. They occur at two levels along the coast, the younger at altitudes between 20 and 100 feet, and the older at altitudes between 200 and 300 feet. Both terraces rest uncomformably on the Purisima Formation. The lower level forms an irregular band, 1 to 2 miles wide, along the coast. The higher level is 2 to 3 miles inland from the coast, along the ridges between most of the streams in the area. The thickness of the lower terraces is variable and ranges from a few feet to a maximum of 50 feet. The higher terraces range in thickness from a few feet to as much as 100 feet.

The lithologic heterogenity and variable thickness of the terraces limit their ground-water potential for all uses except small domestic needs. No wells are known to obtain water from these rocks.

Alluvium

Alluvium, of Recent age, is a heterogeneous mixture of unconsolidated silt, clay, sand, and gravel. It is restricted largely to the valley bottoms of Soquel Creek, West Branch Soquel Creek, Aptos Creek, Trout Creek, and Valencia Creek. No direct evidence is available concerning the thickness, but it most likely is very small.

These deposits undoubtedly contain water, but because of their limited areal extent and thickness they probably would supply only domestic needs.

Structure

The Soquel-Aptos area consists of two structural blocks. One block lies between the San Andreas fault and the Zayante fault and contains sedimentary rocks of Cretaceous and Tertiary age. The other block lies between the Zayante fault and Monterey Bay and contains sedimentary rocks of Tertiary and Quaternary age.

The Zayante fault which separates these blocks was named by Branner and others (1909). It extends from Forest Springs in Big Basin through the Soquel-Aptos area and beyond the Pajaro Valley. The vertical displacement of the present basement surface on either side of the Zayante fault at Forest Springs, according to Branner, is on the order of 6,000 feet. In the Soquel-Aptos area, oil-test holes indicate displacement greater than 4,500 feet; Gribi (1957) estimated about 10,000 feet. The latter figure was used in the construction of the basement-complex structure contour map (fig. 2).

The Cretaceous and Tertiary sedimentary rocks between the Zayante fault and the San Andreas fault are intensively folded and faulted. The main fold in this region is a syncline that trends southeastward, as do all major structures in the Soquel-Aptos area.

The Tertiary and Quaternary sedimentary rocks between the Zayante fault and Monterey Bay are slightly folded and faulted. Those strata, except near the fault, dip gently to the southeast.

GROUND WATER

Most of the ground-water data for this report are from areas southwest of the Zayante fault and relate to rocks in the Purisima Formation near the coast. The area corresponds to the area of maximum ground-water use for public supply. The following discussion emphasizes that part of the Soquel-Aptos area.

OCCURRENCE

Ground water occurs in all the geologic formations in the Soquel-Aptos area. However, the space available for the storage of water within the rocks varies considerably. The Cretaceous igneous rocks contain a limited amount of water within fractures and weathered zones. The consolidated and fractured Cretaceous and older Tertiary sedimentary rocks contain less water than the younger Tertiary and Quaternary sedimentary rocks because the number and size of their original interstices have been reduced by compaction and by the deposition of cementing material. The poorly consolidated younger Tertiary and Quaternary sedimentary rocks contain the most water, per unit volume of rock, of all formations in the area.

The younger Tertiary and Quaternary rocks are principally siltstone and sandstone. Sandstone contains fewer openings between grains per unit of volume than siltstone. However, the openings in the sandstone are larger than those in the siltstone and thus allow freer passage of water. Consequently, a well that penetrates sandstone usually yields water more readily than a well penetrating siltstone.

The ground water in the Soquel-Aptos area is from precipitation, which, after reaching land surface, has infiltrated into the soil zone and subsequently has percolated into the various geologic units.

Specific information concerning the occurrence of water in the geologic units in the Soquel-Aptos area is restricted to two widely separated geographic localities. One area is in the vicinity of Summit Road, northeast of the Zayante fault; the other is in the vicinity of the coast, southwest of the Zayante fault.

Many small springs occur within the Soquel-Aptos area. They have a sporadic distribution controlled by local geologic conditions. Most of the springs occur northeast of the Zayante fault near to and above the major stream channels. In general, the springs drain small, perched ground-water bodies and discharge only a few gallons a minute. The springs are the source of low flow in the perennial streams.

Northeast of the Zayante Fault

The available data from wells northeast of the Zayante fault were reported by P. J. Creegan and E. M. D'Angelo (written commun., 1961). Their well-location map (not shown) and the geologic map in this report (fig. 1), indicate that most of the known wells penetrate the Butano Sandstone. The wells have an average depth of 72 feet and a range in depth from 12 to 165 feet. Most of the reported yields are between 2 and 25 gpm (gallons per minute); the maximum is 200 gpm.

Observations and measurements made during this study indicate that the low flow in Soquel Creek at Soquel is derived from many small springs occurring within the drainage area of West Branch Soquel Creek and Hinckley Creek. In September 1966 the discharge of Soquel Creek at Soquel was 1.3 cfs (cubic feet per second). At the same time West Branch Soquel was contributing 0.9 cfs to this flow, while Hinckley Creek was contributing 0.4 cfs. Soquel Creek was virtually dry above the confluence with Hinckley Creek. At that time the cluster of springs in Glenwood Basin, 10S/1W-3M1S, contributed 0.2 cfs or 90 gpm to the flow of West Branch Soquel Creek.

Southwest of the Zayante Fault

Purisima Formation.--Most of the wells in the Soquel-Aptos area are southwest of the Zayante fault in the Purisima Formation which contains the most important aquifers in the area. All three subunits of the Purisima contain ground water but only subunits B and C are capable of yielding considerable quantities. In general, wells in subunit B yield more than those in subunit C.

The ground water in subunit B is confined except in areas where the subunit is exposed. The confining strata are the lowermost siltstone bed in subunit C and the uppermost siltstone bed in subunit A. Subunit B may also contain within itself several confined zones that are partly or completely separated from each other depending upon the lateral continuity of the siltstone and well-consolidated invertebrate fossil interbeds discussed above. Public-supply wells that withdraw water only from subunit B range in depth from 137 to 630 feet and have reported yields between 240 and 940 gpm (table 1 and 2).

TABLE 1.–*Description of wells*

[Boxhead explanations are abstracted from U.S. Geological Survey "Instructions for Using the Punch-Card System for the Storage and Retrieval of Ground-Water Data"]

State well number: The wells are identified according to their location in the rectangular system for the subdivision of public land. The identification consists of the township number, north or south; the range number, east or west; and the section number. The section is further subdivided into 16 40-acre tracts lettered consecutively (excepting I and O), beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southeast corner. Wells within the 40-acre tract are numbered sequentially. The base line and meridian are indicated by the final letter, as follows: H, Humboldt; M, Mount Diablo; S, San Bernardino.

Owner or user: The name given is that of the apparent owner or user of the well on the date indicated. In some cases the local name of the well is given.

Ownership: C, county; F, Federal Government; M, city, town, or unincorporated village; N, corporation or company, churches, lodges, and other nonprofit, nongovernment groups; P, private; S, State agency; W, water district.

Use of water: A, air conditioning; B, bottling; C, commercial; D, dewatering; E, power generation; F, fire protection; H, domestic; I, irrigation; M, medicinal; N, industrial, includes mining; P, public supply; R, recreation; S, stock supply; T, institutional; U, unused; V, repressurization; W, recharge; X, desalination--public supply; Y, desalination--other use; Z, other.

Use of well: A, anode; D, drainage; G, seismic hole; H, heat reservoir; O, observation; P, oil or gas; R, recharge; T, test hole; U, unused; W, withdraw water; X, waste disposal; Z, destroyed.

Well data: Complete data on physical characteristics of the well include depth, diameter, and finish. Complete geologic information includes lithology and aquifer thickness. Complete water-level information includes altitude of land-surface datum, in feet above mean sea level; water level, in feet above(+) or below land-surface datum; and date of measurement. Complete yield data include rate of pumping and drawdown. Code symbols indicate amount of data, as follows: 1, complete physical, geologic, water-level, and yield data; 2, complete physical, geologic, and water-level, and no yield data; 3, complete water-level and yield, and partial physical and geologic data; 4, complete physical, geologic, and yield, and no water-level data; 5, complete physical and geologic, and no water-level and yield data; 6, partial physical, water-level, and yield, and no geologic data; 7, complete physical, geologic, and yield, and partial water-level data; 8, complete physical and water-level, and no geologic and yield data; 9, complete water-level, partial physical and geologic, and no yield data; 10, partial physical and yield, and no geologic and water-level data.

Chemical analyses: C, complete; G, dissolved gases; J, conductance and chloride; K, conductance; L, chloride; M, multiple (complete and one or more partials); P, partial; R, radiochemical (plus partial or complete chemical); S, special (tritium, carbon-14, and all other special determinations); T, trace elements (spectrographic).

Log data: A, drilling-time log; B, casing-collar log; C, caliper (diameter) survey log; D, driller's log; E, electric logs; F, fluid-conductivity or fluid-resistivity logs; G, geologist log or sample log; H, magnetic log; I, induction log; J, gamma-ray log; K, dipmeter or directional (inclinometer) survey logs; L, laterolog; M, microlog; N, neutron log; O, microlaterolog; P, photographic log (TV, still, movie); Q, radioactive-tracer log; R, radiation logs (includes both neutron and gamma ray); S, sonic log; T, temperature log; U, temperature and fluid-conductivity (resistivity) logs; V, fluid-velocity log; W, electric and radiation logs; X, electric, radiation, caliper, and fluid-velocity logs; Y, electric, radiation, and sample (or driller's) logs; Z, electric, radiation, temperature, and fluid-conductivity logs. Column may contain 1 or 2 code letters.

Depth of well: Given in feet below land-surface datum. May be reported by owner, driller, or others, or measured by the Geological Survey.

Depth cased: The length of casing to the top of the first perforations.

Diameter: The inside diameter of the well, in inches. For drilled cased wells, the diameter is the nominal inside diameter of the innermost casing at the surface.

Well finish: C, porous concrete; F, gravel wall, perforated or slotted casing; G, gravel wall, commercial screen; H, horizontal gallery or collector; O, open end; P, perforated or slotted casing; S, screen; T, sand point; W, walled or shored; X, open hole in aquifer (generally cased to aquifer); Z, other.

Method drilled: A, rotary; B, bored or augered; C, cable tool; D, dug; H, hydraulic-rotary; J, jetted; P, air-percussion; R, reverse rotary; T, trenching; V, driven; W, drive-wash; Z, other.

Lift type. A, air lift; B, bucket; C, centrifugal; J, jet; L, multiple (centrifugal); M, multiple (turbine); N, none; P, piston; R, rotary; S, submergible; T, turbine; Z, other.

Power: 1, hand; 2, natural gas, propane, or butane engine; 3, gasoline engine; 4, diesel engine; 5, electric motor; 6, wind; A, natural or LP gas engine through 20 hp; B, natural or LP gas engine >20 through 50 hp; C, natural or LP gas engine >50 to 100 hp; D, natural or LP gas engine >100 to 200 hp; E, natural gas engine, more than 200 hp; F, gasoline engine through 5 hp; G, gasoline engine >5 to 20 hp; H, gasoline engine >20 to 50 hp; J, gasoline engine >50 to 100 hp; K, gasoline engine >100 to 200 hp; L, gasoline engine, more than 200 hp; M, diesel engine through 50 hp; N, diesel engine >50 to 150 hp; P, diesel engine >150 to 400 hp; Q, diesel engine >400 to 750 hp; R, diesel engine, more than 750 hp; S, electric motor 1 hp or less; T, electric motor >1 to 5 hp; U, electric motor >5 to 15 hp; V, electric motor >15 to 100 hp; W, electric motor, more than 100 hp.

Altitude of lsd: The altitude of land-surface datum. Land-surface datum is an arbitrary plane that closely approximates land surface at the time of the first measurement and is the fixed plane of reference for all subsequent measurements.

Water level: The water level is given with respect to land-surface datum. This is the water level as measured from the measuring point and corrected for the distance between the measuring point and land-surface datum.

Date measured: The month and year of the water-level measurement. Generally, the other data given apply for this date also.

Yield of well: Data are given for yield in gallons per minute, drawdown in feet.

State well number	Owner or user	Ownership	Use of water	Use of well	Well data	Chemical analyses	Log data	Depth of well (feet below lsd)	Depth cased (feet below lsd)	Diameter (inches)	Well finish	Method drilled	Year drilled	Lift type	Power	Altitude of lsd (feet)	Water level (feet below lsd)	Date measured	Yield of well: Gallons per minute	Yield of well: Drawdown (feet)
10S/01E-06P01M	OIL-WELL TEST			T				2394					1963			800				
10S/01E-16D01M	OIL-WELL TEST			T				3555					1962			2100				
10S/01E-19R01M	OIL-WELL TEST			T			E	1942					1949			1150				
10S/01E-20M01M	OIL-WELL TEST			T			DE	4570					1949			1350				
10S/01E-34C01M	OIL-WELL TEST			T			E	2575					1946			1460				
10S/01E-34D01M	OIL-WELL TEST			T			F	7747					1951			1120				
10S/01E-34D02M	OIL-WELL TEST			T				1800					1946			1300				
10S/01E-34E01M	OIL-WELL TEST			T			F	3569					1952			1500				
11S/01E-04Q01M	CSCCWCD 1	W	U	U	2		DF	248	90	10	P	C	1952	N		286	103	2-66		
11S/01E-12L01M	OIL-WELL TEST			T			F	7522					1954			380				
11S/01E-14A01M	OIL-WELL TEST			T			DE	3694					1951			415				
11S/01E-15D01M	UNKNOWN	P	U	U	6		F	587		12			1955	N		369		3-66	150	
11S/01E-16N01M	WAUGMAN	P	U	U	1		D	294	144	18	F	H		N		145	125	3-66	220	109
11S/01E-15Q01M	OIL-WELL TEST			T			DE	2670					1950			273				
11S/01E-17F01M	APTOS SCCWD	W	P	W	5			460	200	12	X	C	1927	T	V	200	162	12-58	475	29
11S/01E-17M01M	PALMER SCCWD	W	U	U	1		D	500	216	10	F	C	1953	N		188	169	4-66	210	40
11S/01E-18B01M	UNKNOWN		U	U			D	450		12			1946			120				
11S/01E-18F01M	SEACLIFF4 SCCWD	W	P	W	3			214		10		C	1935	T	V	110	103	5-62	185	54
11S/01E-18F01M	APTOS CR SCCWD	W	P	W	1		DF	725	243	12	F	H	1965	T	V	33	+1	2-66	780	185
11S/01E-18M01M	BEACH WELL	W	U	U	5			360		12		C	1924	N		13	2	2-66		
11S/01E-20B01M	APTOS GOLF CRSE	P	I	W	2			400				H	1956	T	V	160	147			
11S/01E-20E01M	CLIFF DR.SCCWD	W	P	W	2		DF	400	194	12	F	H	1961	T	U	80	54	2-67	208	46
11S/01E-20G01M	BERRYFARM SCCWD	W	P	W	2		D	495	254	12	P	H	1953	T	V	185	184	12-65	430	18
11S/01E-21K01M	DANNA	P	U	U	4		D	406	250	8	P	C	1964	N		200			150	35
11S/01E-27L01M	DELUCCHI	P	U	U	1			360		12		C		N		260	250	3-66	800	

State well number	Owner or user	Ownership	Use of water	Use of well	Well data	Chemical analyses	Log data	Depth of well (feet below lsd)	Depth cased (feet below lsd)	Diameter (inches)	Well finish	Method drilled	Year drilled	Lift type	Power	Altitude of lsd (feet)	Water level (feet below lsd)	Date measured	Yield of well: Gallons per minute	Yield of well: Drawdown (feet)
11S/01E-27M01M	WATER-WELL TEST			T			D	520					1957			280				
11S/01E-28D01M	SEASCAPE SCCWD	W	P	W										T	V	175				
11S/01E-28R01M	LA SELVA1 SCCWD	W	P	W	3			355	345	12	S	C	1935	T	V	120	102	3-67	153	26
11S/01E-28R02M	LA SELVA2 SCCWD	W	P	W	2			250		12		C	1960	T	V	130			116	21
11S/01E-35A01M	OIL-WELL TEST			T			DE	3100					1953			311				
12S/01E-11M01M	OIL-WELL TEST			T				2458					1953			80				
10S/01W-23K01M	HOLM	P	H	W	1		D	340	300	6	F	C	1964	S	T	266	12	2-66	20	185
10S/01W-28B01M	OIL-WELL TEST			T			D	495					1960			400				
10S/01W-34Q01M	ADV.CONF.GRD.	P	T	W	9									S	U	150	52	3-65		
10S/01W-35L01M	UNKNOWN	P	U	W	9		D	340		10	X	C	1950	S	T	660	280	3-66		
11S/01W-01J01M	VIENNA WOODS 2	N	P	W	2		D	432	260	10	P	C	1959	S	T	570	220	8-59	65	
11S/01W-01R01M	VIENNA WOODS 1	N	P	W	2		D	530	128	10	P	H	1959	S	T	430		7-66	60	
11S/01W-03C01M	ANGEL,N.H.	P	H	W	2		D	200	80	10	P	C	1954	T	U	134	60	2-66		
11W/01W-09L01M	ROHR WELL	P	U	U	5					14						125	57	2-66	440	44
11S/01W-10J01M	ROSEDALE SCCWD	W	P	U	3		D	250	160	10	P	C	1952	T	V	135	106	1-67	173	17
11S/01W-11L01M	MAPLETHORPE	W	P	W	1		DE	628	326	12	F	H	1956	T	V	129		4-65	800	40
11S/01W-11N01M	AIRPORT SCCWD	W	P	W	3			400		12				T	V	105	86	6-67	360	36
11S/01W-12E01M	CABRILLO JR COL	S	T	W	3		DE	400	200	12	F	H	1961	T	V	190	75	1-66	154	180
11S/01W-12J01M	SEACLIFF3 SCCWD	W	P	W	3			600	360	14	X	C	1926	T	U	302	232	8-60	52	74
11S/01W-12R01M	BONORA	P	I	W	9			405		12		C	1924	S	T	179	162	4-66		
11S/01W-12Q01M	SEACLIFF2 SCCWD	W	P	W	3		D	350	140	12	P	C	1949	T	U	170			90	33
11S/01W-13A01M	ST.PARK D.SCCWD	W	P	W	5		D	215	126	12	P	H	1959	T	V	150	118			
11S/01W-13G01M	SEACLIFF1 SCCWD	W	P	W	3			330	200	10	X	C	1923	T	V	135	131	12-60	180	30
11S/01W-14D01M	CAPITOLA SCHOOL	C	U	Z			D	270	40	10	F	C	1951			100				
11S/01W-15A01M	NUTTER	P	H	W	2		D	168	100	8	F	C	1950	T	T	61	30	2-66		

11S/01W-15D01M	BURJAS	P	H	W	2	D	99	75	8	F	C	1950	S	U	93	84	3-66		
11S/01W-15L01M	OPAL CL.1 SCCWD	W	P	W	9	D	211		10			1930	T	U	78	67	2-67		
11S/01W-15L02M	OPAL CL.3 SCCWD	W	P	W	3	D	256	184	12	F	C	1954	T	U	78	67	2-67	380	32
11S/01W-16H01M	BROWN BULB RCH	N	U	U	9		102								81	57	2-66		
11S/01W-21B01M	BELTZ,C.L.	N	P	W	1	D	137	92	10	F	C	1951	T	V	55	8	2-66	940	30
11S/01W-08H01M	WATER-WELL TEST			T		D	220					1957			40				
11S/01W-09J01M	WATER-WELL TEST			T		DE	700					1957			110				
11S/01W-09M01M	WATER-WELL TEST			T		D	374					1955			100				
11S/01W-12M01M	WATER-WELL TEST			T		DE	613					1960							
11S/01W-15M01M	WATER-WELL TEST			T		DE	802					1957			60				
11S/01W-16C01M	WATER-WELL TEST			T		D	310					1955			80				
11S/01W-18M01M	WATER-WELL TEST			T		D	200								7				
11S/01W-06Q01M	WATER-WELL TEST	W		T		DE	1205					1966			315				
11S/01W-13H01M	POOR CLARES	P	H	W		D	200		8		H				140				
11S/02W-12L01M	WATER-WELL TEST			T		D	97								22				
11S/02W-12N01M	WATER-WELL TEST		T	T		D	193					1957			45				
11S/02W-13P01M	WATER-WELL TEST			T		D	130								14				
11S/02W-13Q01M	WATER-WELL TEST			T		D	300								12				

Table 2.--Well characteristics of selected wells

Well name: Local name of well.

Well number: See text for explanation.

Perforated interval: Total length of casing perforations in feet.

Yield: Reported yield in gallons per minute.

Specific capacity: Discharge in gallons per minute divided by the drawdown in feet.

Name	Number	Depth (ft)	Perforated interval (ft)	Yield (gpm)	Specific capacity (gpm/ft)
	Purisima Formation subunit B				
Rohr	11S/1W-9L1	-	-	440	10
Rosedale	11S/1W-10J1	250	-	240	7
Maplethorpe	11S/1W-11L1	630	260	800	20
Airport	11S/1W-11N1	400	-	360	10
Opal No. 3	11S/1W-15L2	256	72	380	12
Blake	11S/1W-15M1	-	-	610	20
Beltz No. 3	11S/1W-21B1	137	45	940	30
	Purisima Formation subunit C				
Seacliff No. 3	11S/1W-12J1	515	-	50	1
Seacliff No. 2	11S/1W-12Q1	400	-	90	1
Seacliff No. 1	11S/1W-13G1	330	-	180	6
	11S/1E-4Q2	261	140	220	7
Waugman	11S/1E-16N1	294	150	220	2
Aptos	11S/1E-17F1	460	-	475	17
Palmer	11S/1E-17M1	500	160	405	5
Seacliff No. 4	11S/1E-18E1	214	-	185	3
Cliff Drive	11S/1E-20E1	400	200	208	5
Berry Farm	11S/1E-20G1	495	217	445	24
D'Anna	11S/1E-21K1	375	120	150	4

Table 2.--Well characteristics of selected wells--Continued

Name	Number	Depth (ft)	Perforated interval (ft)	Yield (gpm)	Specific capacity (gpm/ft)
		Purisima Formation subunit B and C			
Cabrillo Junior College	11S/1W-12E1	380	a200	154	1
Aptos Creek	11S/1E-18F1	713	b470	780	4
		Aromas Red Sands of Allen (1946)			
LaSelva No. 1	11S/1E-28R1	355	10	225	6
LaSelva No. 2	11S/1E-28R2	250	-	540	10

a Lower 60 feet perforated in Purisima Formation subunit B.
b Lower 110 feet perforated in Purisima Formation subunit B.

Figure 4 is a structure contour map of the top of subunit B near the coast. This map, when used in conjunction with a topographic map, gives the depth needed to reach the subunit. By adding 230 feet to that depth, the well depths necessary to completely penetrate subunit B are obtained.

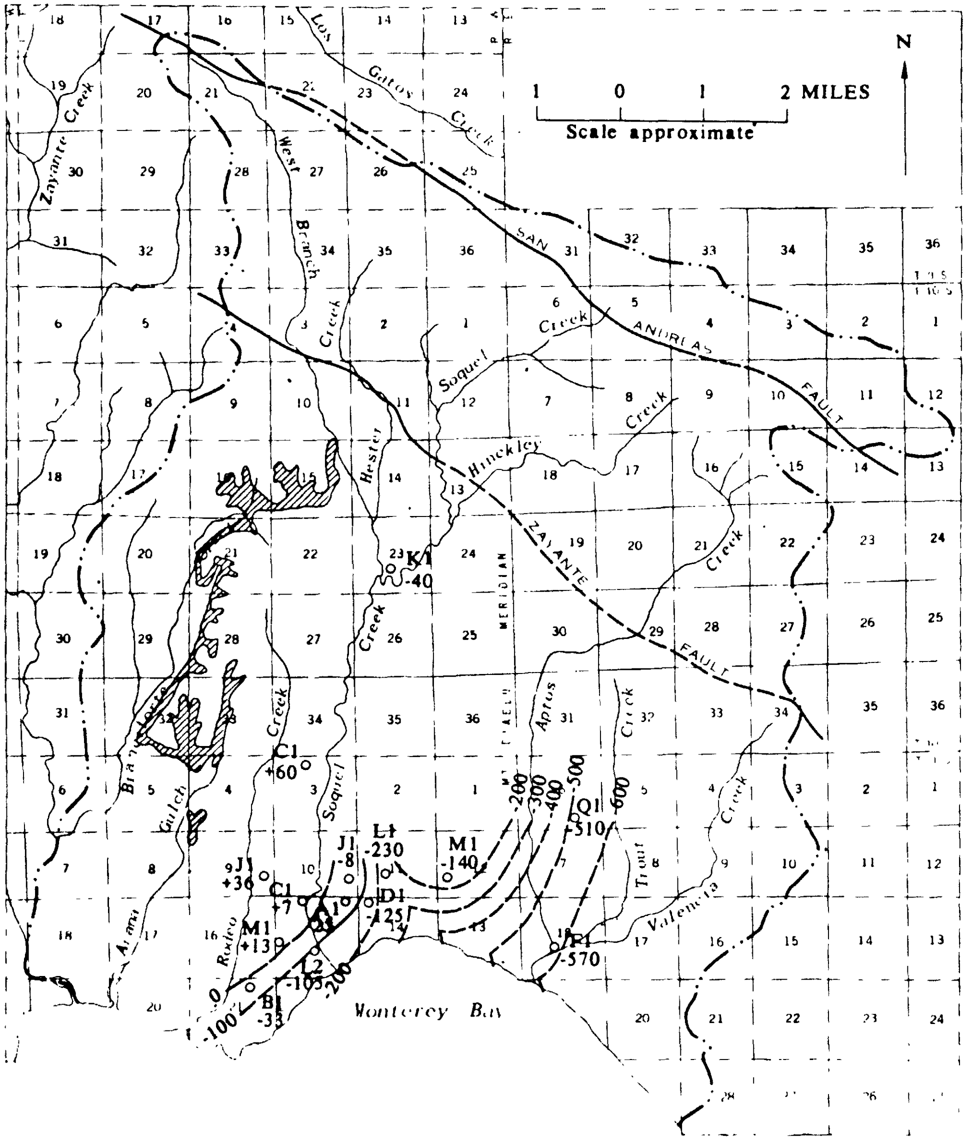
Most of the ground water in subunit C is confined as indicated by driller's logs and observations of the speed of water-level recovery. However, the lithologic columns (fig. 3) indicate that unconfined conditions may also exist at various stratigraphic positions within the subunit. Public-supply wells penetrating only subunit C have depths that range from 261 to 515 feet. Most of the reported yields are between 50 and 220 gpm. However wells 11S/1E-17F1 and 11S/1E-2061 have reported yields of 475 and 445 gpm respectively (tables 1 and 2). This indicates that the most productive zones within the subunit are east of Aptos near Valencia Creek and Rio del Mar. Small springs that have minor importance occur in subunit C along Rodeo Creek Gulch road (10S/1W-33H1S) and near Monte Toyon (11S/1E-16R1S).

Two wells are known to penetrate both subunits B and C; well 11S/1W-12E1 which has a depth of 380 feet and a reported yield of 154 gpm and well 11S/1E-18F1 which has a depth of 713 feet and a reported yield of 780 gpm.

Aromas Red Sands of Allen (1946).--Very few hydrologic data are available concerning the Aromas Red Sands of Allen (1946). The few available driller's and electric logs of wells in the Aromas suggest that the water, in general, occurs under unconfined conditions but is locally confined between silty and clayey lenses. The data also suggest that the Aromas in the eastern part of the area overlies a siltstone bed in the Purisima Formation subunit C that allows little or no hydraulic continuity between the Aromas and Purisima.

Two adjacent wells, 11S/1E-28R1 and -28R2, located in the Aromas outside the study area near La Selva Beach have depths of 355 and 250 feet and yields of 225 and 540 gpm.

Terrace deposits.--Just east of Opal Cliffs a line of seeps, 11S/1W-10R1S, occurs at the contact between the lower (youngest) marine terrace deposit and a siltstone bed in the Purisima Formation subunit C. The seeps are outlet points for a very shallow perched zone of water in the lower terrace.



EXPLANATION

Purisima Formation, subunit B

———-600— — — —

Structure contour

Dashed where control is poor. Number is altitude in feet

o A1
-25
Well

Letter indicates location in section. See text for discussion of well numbering system. Number indicates altitude of top of subunit B in feet, above or below mean sea level

—— · · —— · · —— · · ——

Boundary of study area

STRUCTURE CONTOURS SHOWING TOP OF PURISIMA FORMATION, SUBUNIT B

Aquifer Properties

The available data on aquifer properties are reported well yields in gallons per minute together with the water levels when the wells are being pumped and when they are not. Those data (tables 1 and 2) are from wells that penetrate the Purisima Formation subunits B and C near the coast and the Aromas Red Sands of Allen (1946).

The reported yields give, at most, a gross indication of the water-bearing character of the rocks. The yields have to be interpreted and compared with caution because they represent quantities determined by various methods from wells which have various types of construction.

The specific capacity (the yield in gallons of water per minute a well produces for each foot of drawdown) gives more useful information than the yield alone. Specific capacity allows the yielding capability of a well to be more reliably compared with those of other wells. Also, the specific capacity can be used to estimate the permeability of the water-bearing strata. Permeability is a measure of the ease of flow through the strata. The specific capacities discussed in this report are computed from the earliest data available because well-entrance losses were probably at a minimum at that time.

Purisima Formation Subunit B

The yields and specific capacities for subunit B (table 2) are from wells in the vicinity of Opal Cliffs and Soquel. The specific capacities of the wells range from 7 to 30 gpm per foot of drawdown and average 16 gpm per foot of drawdown. The variability in specific capacity is caused primarily by the lateral and vertical lithologic variations in subunit B (fig. 3).

The influence of lateral lithologic variations on specific capacity is demonstrated by comparing the data from well, 11S/1E-21B1 near Opal Cliffs and well 11S/1E-10J1, near Soquel. Both wells penetrate the upper part of subunit B. Figure 3 shows that in the Opal Cliffs area the upper part of subunit B is a sandstone whereas in the Soquel area the upper part of subunit B is a silty sandstone. Well 11S/1W-21B1, near Opal Cliffs, has a specific capacity of 30 gpm per foot of drawdown while well 11S/1W-10J1, near Soquel, has specific capacity of 7 gpm per foot of drawdown.

The average permeability of subunit B in the vicinity of Soquel is estimated at 200 gpd (gallons per day) per square foot. The specific capacity of well 11S/1E-11L1--the only well known to completely penetrate subunit B--was used for this estimate.

The influence of vertical lithologic variation on specific capacity is demonstrated by comparing the data from wells 11S/1W-10J1 and 11S/1E-11L1, near Soquel. Well 11S/1W-10J1 partially penetrates, and well 11S/1W-11L1 completely penetrates, subunit B. Figure 3 shows that in the Soquel area the upper part of subunit B is mainly a silty sandstone whereas the lower part is mainly a sandstone. Well 11S/1W-10J1 has a specific capacity of 7 gpm per foot of drawdown and well 11S/1W-11L1 has a specific capacity of 20 gpm per foot of drawdown.

The data in figure 3 and table 2 suggest that subunit B is the best aquifer in the Soquel-Aptos area. Wells drilled to completely penetrate subunit B would likely have yields and specific capacities comparable to those of well 11S/1E-11L1. However, since the available yield and specific-capacity data are from only a small part of subunit B, more data should be collected to test the validity of this hypothesis.

Purisima Formation Subunit C

The yield and specific-capacity data for subunit C in the vicinity of Seacliff Beach, Aptos, and Rio del Mar are shown in table 2. The specific capacities range from 1 to 24 gpm per foot of drawdown and average 6 gpm per foot of drawdown.

The permeability of subunit C in the vicinity of Aptos is estimated to be 20 gpd per square foot. A specific capacity of 4 gpm per foot of drawdown was used for this estimate.

The variation in specific capacity in subunit C also is probably caused by variations in lithology. As mentioned earlier, subunit C dips gently to the southeast and is mainly a silty, fine to a very fine sandstone having siltstone interbeds. The lower part of subunit C is predominantly siltstone whereas the upper part is predominantly silty sandstone. The westernmost wells in subunit C penetrate mainly the lower siltstone beds whereas the easternmost wells penetrate mainly the upper silty sandstone beds. The influence those vertical lithologic variations have on specific capacities is demonstrated by comparing well 11S/1E-12J1 near Seacliff Beach and well 11S/1E-17F1 near Valencia Creek. Well 11S/1W-12J1 penetrates the lower very silty part of subunit C and has a specific capacity of 1 gpm per foot of drawdown. Well 11S/1E-17F1 penetrates stratigraphically higher and sandier beds in subunit C and has a specific capacity of 17 gpm per foot of drawdown.

The data suggest that subunit C is not as good an aquifer as subunit B. In general, east of Seacliff Beach, properly constructed wells in subunit C should yield at least 200 gpm and have specific capacities of about 4 gpm per foot of drawdown. However the yields of well 11S/1E-17F1 and 11S/1E-20G1 suggest that in the vicinity of Valencia Creek and Rio del Mar some zones within subunit C have much more favorable aquifer properties and are comparable to those of subunit B. The Valencia Creek area, especially, should be studied to define the vertical and lateral position of the productive strata.

Vertical hydraulic continuity in the Purisima Formation subunits B and and C.--An indication of the small vertical hydraulic continuity between the strata comprising subunits C and B is suggested by the following observations, some of which were supplied by the Cabrillo Junior College. The college well (11S/1W-12E1) is 380 feet deep with casing perforations between 180 and 380 feet. The lower 60 feet of perforations are opposite subunit B and the upper 140 feet of perforations are opposite subunit C. An older well less than 50 feet from the college well is 148 feet deep with the lower 116 feet perforated in subunit C. The perforated intervals of one well do not overlap those of the other.

In the early 1960's the Cabrillo Junior College well was pumped continuously for two days at an average discharge of 154 gpm with an average pumping water level of 295 feet below land surface. Prior to pumping the static water levels below land surface in the college well and the adjacent well were 115 and 25 feet respectively. At the end of two days of pumping, the adjacent well showed a water-level decline of only 3 feet. The vertical movement of ground water through the 32 feet of strata separating the perforated intervals, therefore, was small, even under what would appear to be a very large head difference. This condition applies to both subunits B and C wherever laterally extensive siltstone or very silty sandstone beds occur in the vertical succession of strata.

Aromas Red Sands of Allen (1946)

The yields and specific capacities of wells in the Aromas Red Sands of Allen (1946) (table 2) are from two adjacent wells, 11S/1E-28R1 and -28R2 outside of the study area near La Selva Beach. They have specific capacities of 6 and 10 gpm per foot of drawdown, respectively.

The sparse well data available suggest that the Aromas near La Selva Beach yields more water than the Purisima subunit C. Outcrops of the Aromas near Rob Roy Junction appear to be very permeable and wells drilled into that formation may have yields exceeding those of subunit B. However, the thickness of permeable sands within the area may limit utilization of the Aromas as an aquifer. The Aromas should be studied in more detail so that an adequate evaluation of its water-yielding properties can be made within and immediately east of the study area.

Water-Level Fluctuations

Water-level fluctuations reflect complex interactions among ground-water discharge, ground-water recharge, and changes in ground-water storage. Interpretation of water-level fluctuations is dependent upon knowing whether the aquifer is confined or unconfined. Water-level changes in an unconfined aquifer that has a saturated thickness much greater than the amplitude of the fluctuations, reflect, mainly, changes in storage. Water-level changes in a confined aquifer, no matter what the thickness, reflect mainly changes in pressure and, therefore, changes in discharge. Water levels change much more rapidly in a confined aquifer than in an unconfined aquifer.

Water-level changes may be classified as long-term trends, seasonal variations, and short-term variations. A long-term trend is the net rise or decline of water levels over a period of years. A long-term trend is the most important feature of water-level change because it reflects the summation of all seasonal and short-term variations in discharge, recharge, and storage.

Continuous records of monthly water-levels for a period of 5 years or longer in the Soquel-Aptos are available for only two wells, 11S/1W-9L1 and 11S/1W-10C1. Both wells tap subunit B of the Purisima Formation and are located away from the areas of maximum ground-water withdrawals.

Continuous records of water-level data between the pumping areas and the coast, preferably right at the coast, are very important in the Soquel-Aptos area. These data are needed to evaluate the influence that withdrawals have on ground-water discharge to Monterey Bay. Unfortunately, few data of this nature are available.

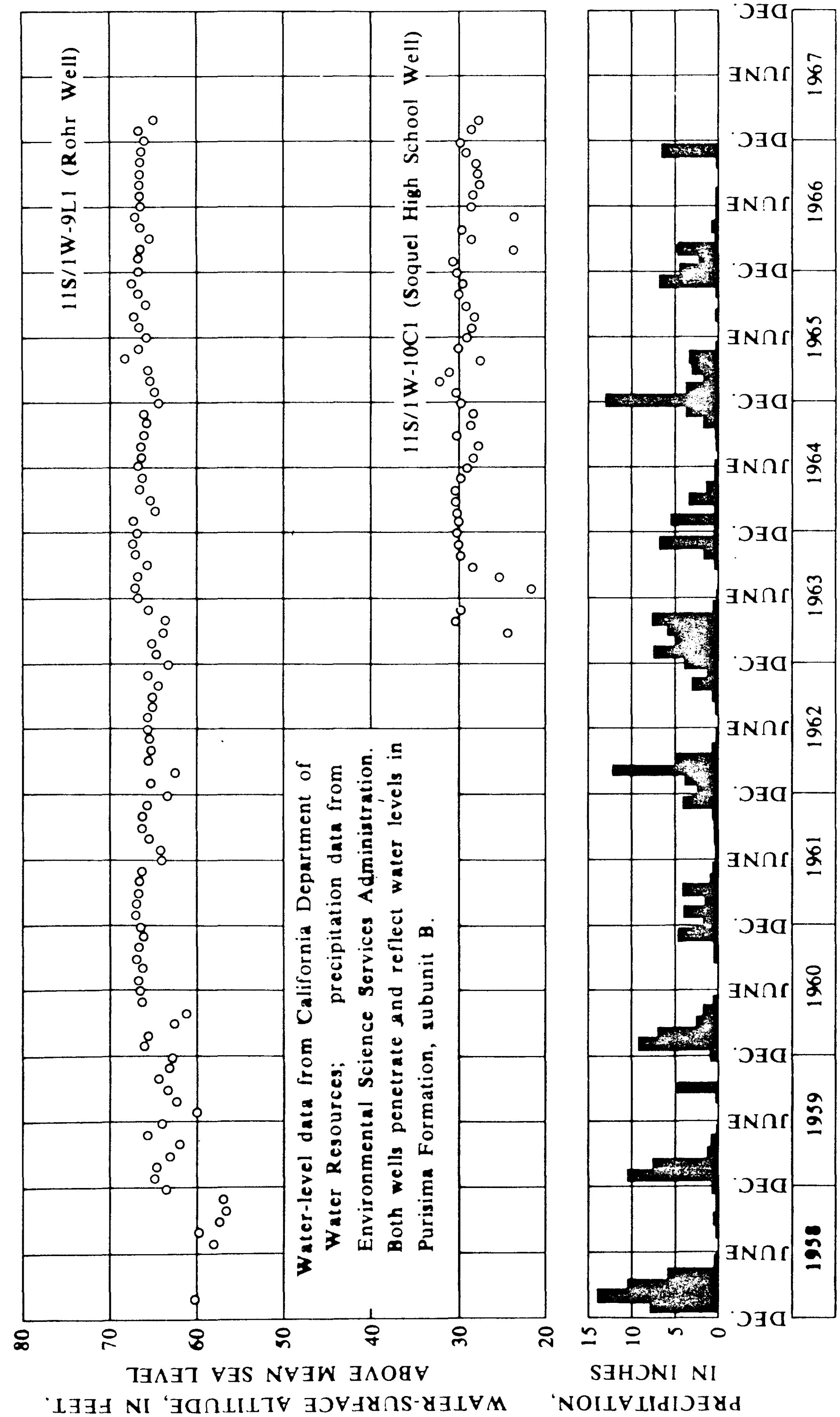
Purisima Formation

The California Department of Water Resources has made monthly measurements of water levels in well 11S/1W-9L1 for 10 years and in well 11S/1W-10C1 for 5 years. Well 11S/1W-9L1 is an abandoned irrigation well approximately 1.7 miles northwest from the coast at Opal Cliffs. Well 11S/1W-10C1, currently used by the Soquel High School, is approximately 1.4 miles northwest of the coast at Capitola. Both wells reflect water levels in subunit B of the Purisima Formation which is a confined aquifer.

Figure 5 compares the precipitation at Santa Cruz with the water-level fluctuations in both wells. There is little or no obvious correlation between the precipitation and the water-level fluctuations. The water-level fluctuations caused by variable recharge seem to have less amplitude than the fluctuations caused by pumping at and in the vicinity of the wells. This condition masks any relation there may be between the precipitation and the water levels.

Water-level fluctuations in well 11S/1W-10C1 reflect a distinct seasonal variation in pumping rate and those in well 11S/1W-9L1 reflect a seasonal variation only in the earliest part of the water-level record. Ground-water withdrawals from the Purisima Formation are seasonal with maximum withdrawals during the summer and minimum withdrawals during the winter. The water-level records from 11S/1W-10C1, although pertaining only to that well, show in a general fashion, the seasonal behavior of water levels in wells pumping from the Purisima Formation. The water levels in the two wells show no distinctive long-term trends although a very slight decline may have occurred in the level at well 11S/1W-10C1.

The water-level data are important in establishing the fact that withdrawals from subunit B in the vicinity of Soquel (11S/1W-10J1, 11S/1W-11N1, 11S/1W-11L1) and Opal Cliffs (11S/1W-15L1, 11S/1W-15L2) have had very little influence on water levels in the neighborhood of 11S/1W-9L1 and 11S/1W-10C1. However, the data have minimal value in determining the influence ground-water withdrawals have had on water levels at the coast.



COMPARISON OF PRECIPITATION AT SANTA CRUZ AND WATER LEVELS IN TWO NEARBY WELLS

A few nonpumping water-level measurements at the Opal Cliffs well field (11S/1W-15L1 and 11S/1W-15L2) between November 1955 and February 1967 suggest the influence that withdrawals near the coast have on water levels. In November of 1955 when withdrawals were at a minimum, the water level was 12 feet above mean sea level. A measurement made in May 1962 during the heavy pumping season indicated a water level of 1 foot above mean sea level; other measurements in November 1958, December 1960, and December 1965, indicated a water level 7 feet above mean sea level. In February of 1967, the water level was 11 feet above mean sea level after the well field had been shut down for approximately a month. The data suggest that, at least since 1958, the water levels were always below some truly static condition, which is possibly indicated by the December 1955 and February 1967 measurements. In other words, since 1958 the daily pumping periods were such that water levels never had enough time for complete recovery. Complete recovery to a static water-level condition, a relatively rare occurrence, took place only when enough time was allowed between pumping periods as suggested by the February 1967 measurement. Withdrawals from the Opal Cliffs well field, therefore, have had a real influence on the water levels at the coast during normal nonpumping and pumping periods. The effect will probably continue and increase as withdrawals continue and increase. The same argument can be applied to all wells in the Soquel-Aptos area.

Table 3 shows pumping water levels in selected wells near the coast. Those levels are all below mean sea level and are typical of most wells in the coastal area.

Aromas Red Sands of Allen (1946)

Water-level data are available for only one well, 11S/1E-28R1, that taps the Aromas Red Sands of Allen (1946). This is a public-supply well approximately 0.5 mile inland from the coast at La Selva Beach and adjacent to 11S/1E-28R2. In 1955, the water level was 20 feet above mean sea level and in March of 1967, it was 18 feet above mean sea level. Because the Aromas Red Sands of Allen (1946) is probably an unconfined aquifer for most of its extent, this small water-level change suggests only change in storage at the well site and is not significant enough to influence any appreciable area.

Table 3.--Pumping water levels in selected wells near the coast

Well number	Distance from coast (ft)	Discharge (gpm)	Water-surface altitude below m.s.l. (ft)
11S/1W-11L1	3,800	700-800	10
11S/1W-11N1	2,000	400	10-20
11S/1W-13G1	1,000	95-230	50-60
11S/1W-15L1 and -15L2[1]	1,000	300-600	20-40
11S/1E-18F1	2,700	780	150
11S/1E-20E1	1,000	210-240	10-20
11S/1E-20G1	3,200	430-445	20

[1]11S/1W-15L1 is within 100 feet of 11S/1W-15L2.

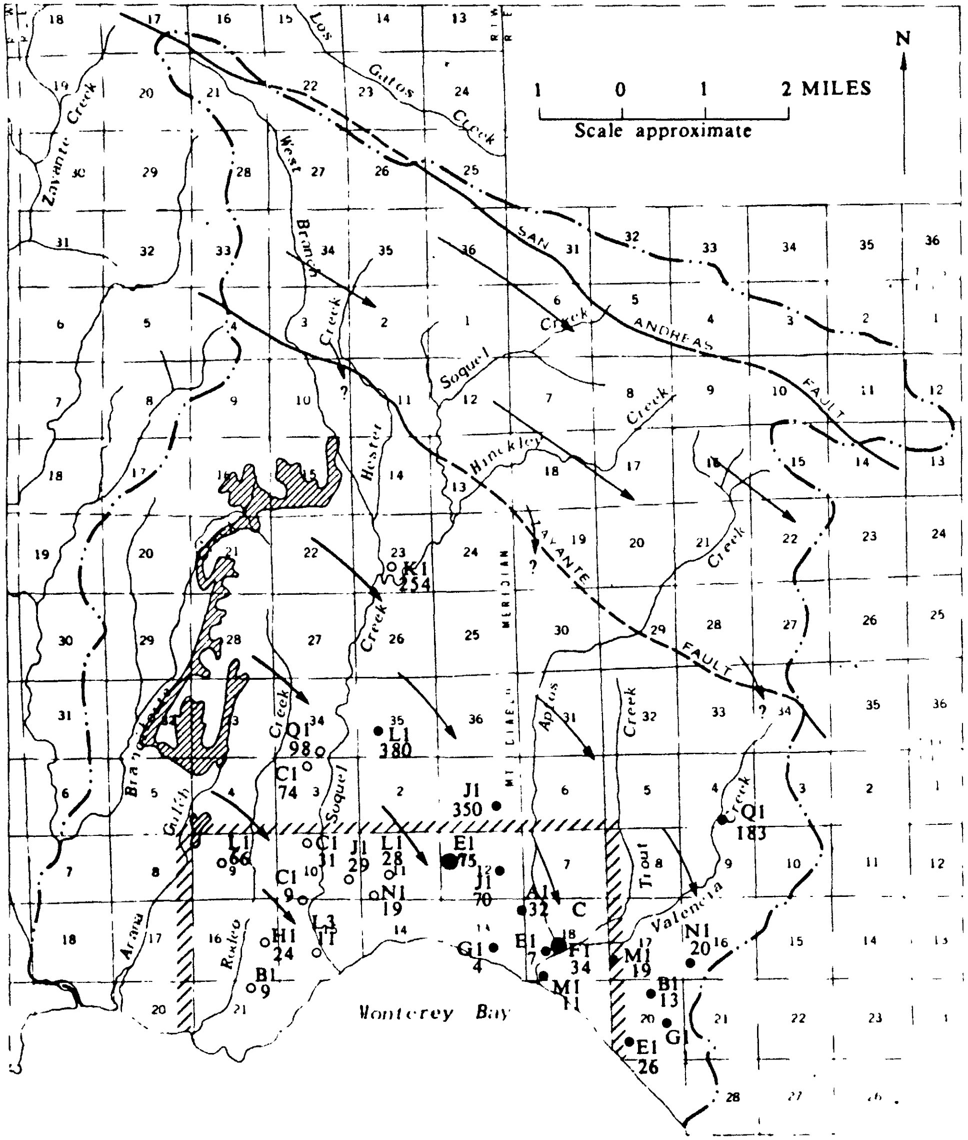
Movement of Ground Water

Figure 6 shows a hypothetical pattern of ground-water movement in the report area, together with the altitude of water levels in selected wells under nonpumping conditions. However, the position of each well's water level on a recovery curve is unknown. Also, the influence of the ocean's tidal motion on the water levels is unknown. Nevertheless, all the water levels are above mean sea level and tend to decrease in altitude toward Monterey Bay indicating that the principal ground-water movement is toward the southeast.

Northeast of the Zayante fault, the flow directions shown are those in formations capable of transmitting substantial quantities of ground water, such as the Butano Sandstone and the Purisima Formation. The water-level contour map by the California State Water Resources Board (1953, pl. 14) indicate that most of the water northeast of the fault moves southeastward toward the Pajaro Valley, however, some may move southward across the Zayante fault.

Southwest of the Zayante fault, the available water-level and geologic data suggest that the flow is toward the southeast and south, and that the water for the most part originates within the area. The water-level data from the Purisima Formation are difficult to interpret because all data may not be from the same ground-water zone or zones within the subunit penetrated. However, there is enough consistency to suggest that a large part of the ground water flows toward Monterey Bay and discharges into the sea at some point offshore.

Subunit A of the Purisima Formation is a siltstone that crops out along the western boundary of the area and is assumed to impede ground-water flow into the area. The Zayante fault is assumed to act as an impermeable barrier impeding the flow of ground water across the fault from northeast to southwest.



EXPLANATION

Purisima Formation, subunit B

o K1 254

Well in subunit B

Letter indicates location in section. See text for discussion of well-numbering system. Number indicates water surface altitude in feet, above or below mean sea level

• N1 20

Well in subunit C

Letter indicates location in section. See text for discussion of well-numbering system. Number indicates water surface altitude in feet, above or below mean sea level

● E1 75

Well in subunit B and subunit C

Letter indicates location in section. See text for discussion of well-numbering system. Number indicates water surface altitude in feet, above or below mean sea level

Direction of ground-water flow in subunit B

Direction of ground-water flow in subunit C and other hydrogeologic units

Area for which ground-water storage capacity is estimated

Boundary of study area

HYPOTHETICAL GROUND-WATER MOVEMENT

The available ground-water data, although sparse, allow a reasonable estimate of a quantity of ground water in the Purisima Formation subunits B and C. Discharge estimates were made using the Darcy equation for subunit B in the vicinity of Opal Cliffs and for subunit C in the vicinity of Aptos. Those estimates were then extrapolated and the total discharge passing the boundaries of the area from subunits B and C was approximated.

On the basis of those assumptions and estimates, the natural ground-water discharge from subunits B and C of the Purisima Formation is on the order of 10,000 acre-feet per year; subunit B discharges approximately 7,000 and subunit C approximately 3,000 acre-feet per year. In 1966, wells removed approximately 30 percent of the total discharge from subunit B and approximately 40 percent from subunit C.

The recharge necessary to balance the natural ground-water discharge from the subunits, assuming that there is no change in storage, is 4 inches per year. This is approximately 13 percent of the estimated 30- and 32-inch average annual precipitation southwest of the Zayante fault.

Recharge to the ground-water reservoir is not distributed evenly throughout the area. Most of the recharge to subunit B probably occurs from water percolating through the channel reaches of Arana Gulch in 10S/1W-33, and unnamed tributary to Arana Gulch in the eastern part of 10S/1W-34, and Rodeo Creek Gulch in 11S/1W-16. Figure 1 suggests that Arana Gulch and its tributary are incised into subunit B of the Purisima Formation; figures 1 and 4 suggest that Rodeo Creek Gulch also may be incised into subunit B. In subunit C, recharge water infiltrates the soil zone and the stream channels of Aptos Creek and Trout Creek and subsequently percolates through the most permeable strata. Soquel Creek contributes little, if any, water to subunit C because its channel is incised into relatively impermeable siltstone and very silty sandstone.

An estimated 800,000 acre-feet of water is stored within subunits B and C of the Purisima Formation near the coast. This estimate is for the strata in the area shown in figure 6 using a porosity value of 30 percent. The quantity of water stored within the strata is estimated only to give an indication of the magnitude of the ground-water system, and not to imply that this volume of water is available for use. If there were no potential for salt-water encroachment, possibly a quarter of the estimated volume could be mined. However, because there is a potential for salt-water encroachment, little, if any, of the water in storage along the coast can be removed for water supply needs and only the perennial supply of water discharging past the coastline can be safely developed for public supply.

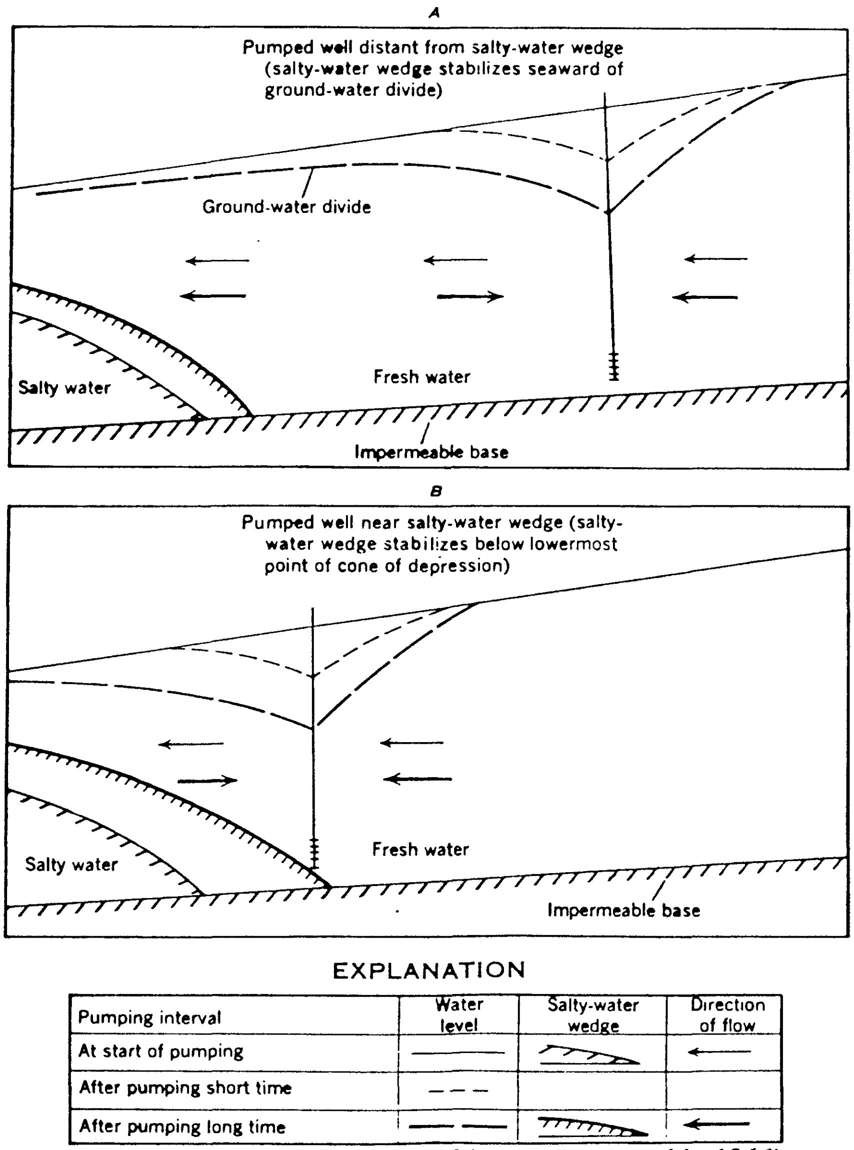
Salt-Water Encroachment

The fresh water in subunits B and C of the Purisima Formation is in contact with sea water somewhere seaward of the coast. The exact position of the contact zone is unknown, but the hydraulic gradients in subunits B and C suggest that it may be fairly close to the coastline.

Under natural conditions, before ground-water withdrawals were initiated, a salt-water wedge was in contact with the ground water at some offshore position determined by the quantity of fresh-water flow and the level of the sea. Withdrawals of fresh ground water inland from the coast have reduced the seaward flow and have caused the wedge to move toward the coast from its original position. The salt-water wedge is still located at some unknown, but possibly close, position offshore.

The rate and direction of movement of the salt-water wedge toward the coast in subunits B and C are dependent upon the location of pumping wells, the thickness of the aquifers, the amount of recharge and withdrawals, and the permeability of the aquifers. Figure 7 shows the theoretical movement of a salt-water wedge in an isotropic and homogeneous aquifer responding to distant and nearby withdrawals. The figure clearly shows how withdrawals near the salt-water wedge can have an immediate influence in starting and maintaining the movement of the wedge landward. Most of the wells that penetrate subunits B and C are within 1,000 to 5,000 feet of the coast. The historic and present withdrawals probably have had a significant influence on the position of the salt-water wedge. For 1966, the withdrawals are estimated to be 30 and 40 percent of the total discharge in subunits B and C. As those estimates are for the total discharge, the percentage of depletion of discharge to the ocean near the pumped areas in the subunits is probably greater. The withdrawals along the coast will most likely tend to increase, causing an acceleration of the landward movement of the salt water. When the wedge reaches the coast, it will move inland to the pumping wells because the pumping levels along the coast are at or below mean sea level (table 3).

The region of contact between the fresh-water and the salt-water wedge is a zone of finite width in which the fresh water and salt water are mixed. The width of the zone is determined by tidal movements in the ocean, by fluctuations in ground-water levels, and by the ground-water discharge.



(Luszczynski and Swarzenski, 1966)

THEORETICAL MOVEMENT OF SALT-WATER WEDGE IN RESPONSE TO DISTANT AND NEARBY WITHDRAWAL

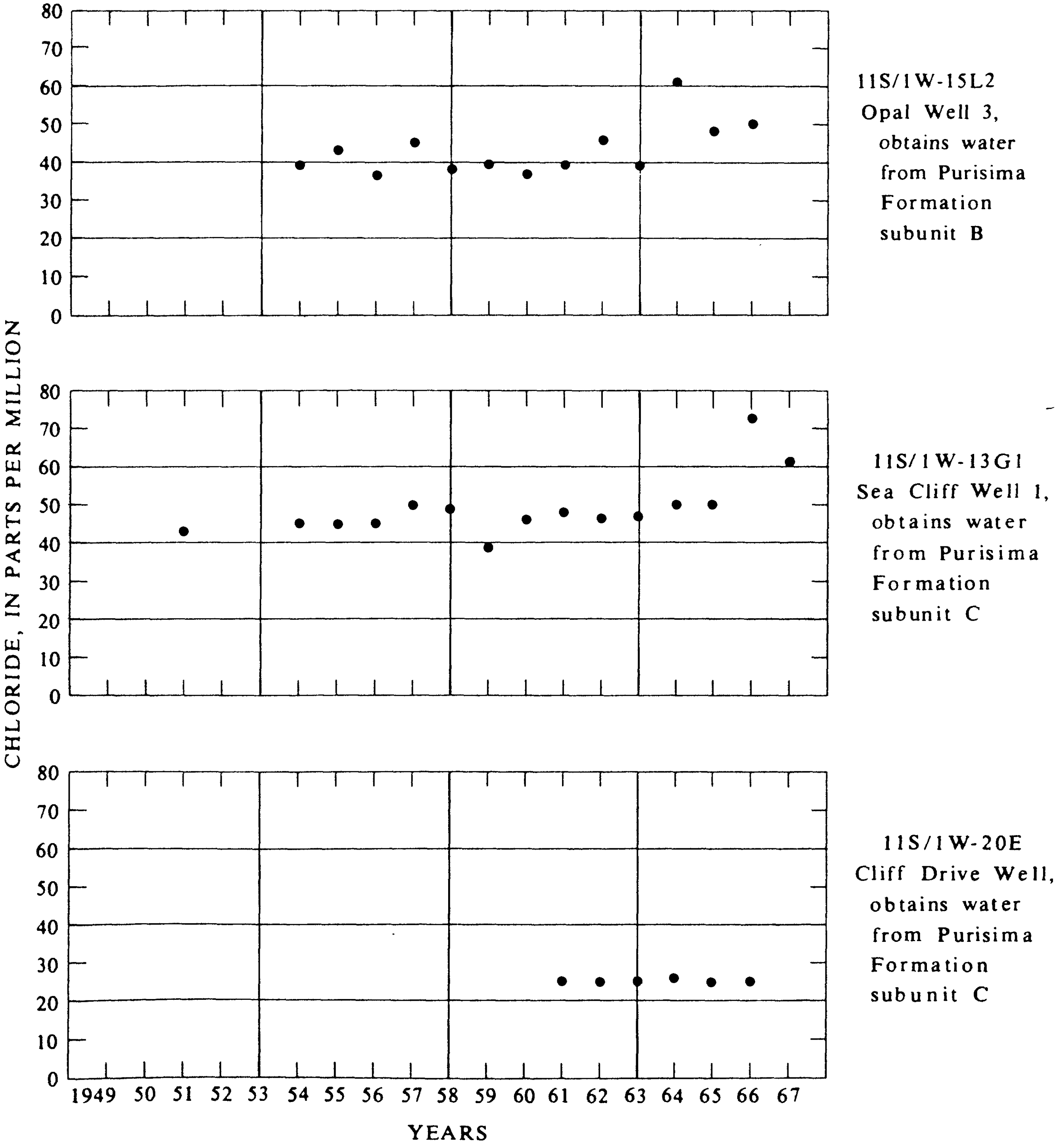
The recognition of the leading edge of the fresh water-salt water contact zone is very important so that steps can be taken to correct or reduce the detrimental effects of salt-water intrusion. An increase in chloride concentration may be the first indication of salt-water intrusion. The chloride-to-bicarbonate ratio may also be used to diagnose sea-water intrusion; sea water is low in bicarbonate and high in chloride, whereas the reverse is commonly true in fresh ground water. The ratio increases as salt-water encroachment occurs.

The available chemical data for the Soquel-Aptos area suggest that salt-water encroachment inland from the coast probably has not yet occurred in subunits B and C of the Purisima Formation. Figure 8 shows chloride trends for three wells; 11S/1W-15L2 withdrawing water from subunit B and 11S/1W-13G1 and 11S/1E-20E1 withdrawing water from subunit C. All of the wells are about 1,000 feet from the coast. With the exception of a slight chloride increase in 11S/1E-15L2 and 11S/1W-13G1 during the last few years of record, no obvious long-term trends are apparent from the data. The chloride-to-bicarbonate ratios for the most recent data, also, suggest no salt-water encroachment. Wells 11S/1W-15L2 and 11S/1W-13G1 have a ratio of 0.4 and 11S/1E-20E1 has a ratio of 0.2. Wells withdrawing water from subunits B and C further inland have similar chloride-to-bicarbonate ratios.

The time of arrival of the salt-water wedge at the coast cannot be predicted from present data. For optimum management of the ground-water reservoir the best course of action probably is to establish a system of monitor wells that hopefully, will record the initial appearance of salt water. Steps could then be taken to minimize the detrimental effects by decreasing withdrawals in the affected area and by establishing new wells as far inland from the coast as practical.

U.S. GEOLOGICAL SURVEY

FIGURE 8



CHLORIDE TRENDS FOR SELECTED WELLS PENETRATING THE PURISIMA FORMATION NEAR THE COAST
(Data from Soquel Creek County Water District)

Chemical Quality of Ground Water

The chemical quality of ground water from subunits B and C of the Purisima Formation and from the Aromas Red Sands of Allen (1946) is distinctly different. Representative chemical analyses of water samples from those aquifers are shown in figure 9 and table 4. Ground-water samples from subunit B commonly have a greater concentration of calcium, iron, manganese, sulfate and total dissolved solids than water samples from either subunit C or the Aromas Red Sands of Allen (1946). The water from subunit B also has a slight hydrogen sulfide odor. The Aromas Red Sands of Allen (1946), at least in the vicinity of La Selva Beach, contains water having the best chemical characteristics in the region. However, La Selva Beach is outside of the study area.

Corrosiveness of the Ground Waters

The corrosiveness of the ground water was measured at five locations by means of corrosometer probes. A corrosometer probe is basically a wire loop that changes resistance as it corrodes.

The electrical conductivity of most metals is very great compared to that of nonmetals. As the corrosion process converts metal to nonmetal, the cross-sectional area of the wire loop decreases. As the electrical resistance of a length of wire is a function of its cross section, a measure of the rate of change of resistance gives an index of the corrosion rate of the wire loop. Multiplying the index value by an empirically determined conversion constant gives the corrsion rate in inches per year.

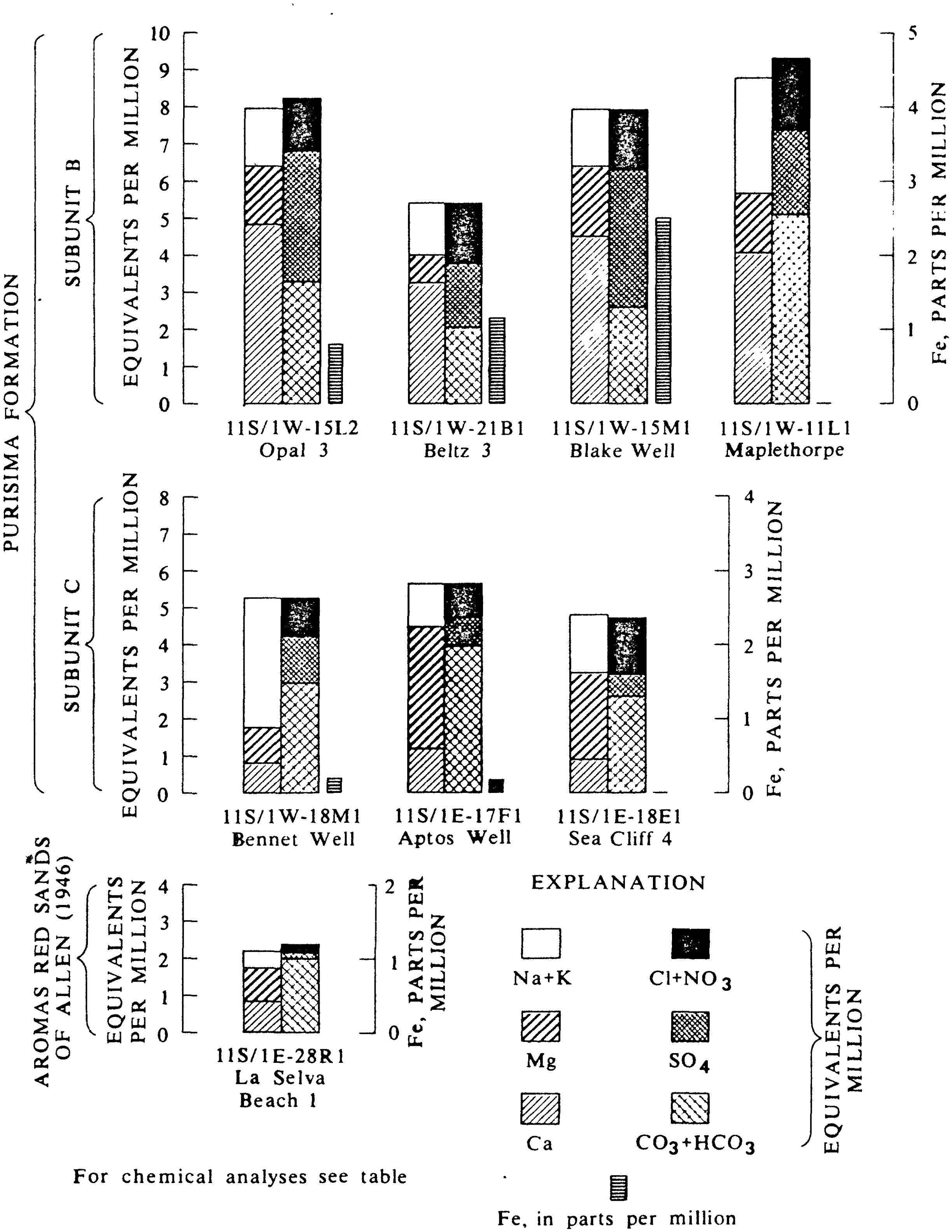
Three types of metal probes were installed; a 304 stainless steel, a 1010 steel, and a 1020 steel.[1] A 304 stainless steel probe and a 1020 steel probe were installed at well 11S/1W-15L1 and at well 11S/1E-28R1; a 1010 steel probe was installed at the discharge end of the reservoir connected to well 11S/1W-15L1; and a 1020 steel probe was installed at well 11S/1W-11L1 and well 11S/1E-18F1.

The ground water sampled is moderately corrosive to steel and not at all corrosive to stainless steel. Table 5 shows the corrosion rates in inches per year for the probes. The greatest corrosion rate for the steel probes was 0.002 inch per year at well 11S/1E-18F1, which withdraws water from both subunits B and C of the Purisima Formation and 11S/1W-11L1 which withdraws water from subunit B only. The smallest corrosion rate was 0.0004 inch per year at 11S/1W-28R1 which withdraws water from the Aromas Red Sands.

---

[1] American Iron and Steel Institute specification numbering system.

FIGURE 9



CHEMICAL ANALYSES OF WATER FROM THE PURISIMA FORMATION AND AROMAS RED SANDS

Table 4.--Chemical analyses of water

Values for sodium preceded by the letter "a" are a combination of sodium and potassium.

Values for dissolved solids indicate the residue on evaporation at 180°C, except those preceded by the letter "b," which have been calculated (sum of determined constituents).

Laboratory and sample number: BC Brown and Caldwell; GS U.S. Geological Survey; SCL Soil Control Laboratory; u unknown

Well number	Date of collection	Depth of well (feet)	Water temperature (°F)	Concentrations in parts per million (ppm)																Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory and sample number
				Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$				
U.S. Public Health Service drinking-water standards (1962)					0.3	0.05							250	250	1.5	45		500					
11S/1E-17F1[1]	8- -59	460			.2	.9	24	40	25	2.3	242	0	37	31	.1				222	20		8.1	u
18E1[1]	1-26-67	214	65		.04	<.01	18	28	32	4.7	158	0	28	52					160	30	472	7.8	GS54883
18M1[1]	10-28-66			22	.22	.02	21	12	a78		180	0	61	34				307	100	65	500	8.4	BC7400
28R1[2]	10-25-66	355	68	67	0	.01	17	11	9.1	2.3	123	0	5.1	7.6	0	.1	.02	b180		18	220	7.5	GS32428
11S/1W-11L1[3]	10-21-66	628	74	65	.01	.13	83	19	66	8.4	309	0	113	67	0	.1	.15	b574		34	853	7.2	GS32438
15L2[3]	10-19-66	256	69	68	.8	.4	96	19	32	5.5	201	0	170	50	1.4	.2	.05	b542		18	748	7.3	GS32434
15M1[3]	3- -57			51	2.5	.5	91	23	a34		165	0	174	55				558	321	19	802	7.5	BC13583
21B1[3]	6- 2-65	137			1.18	.23	66	9	32		104	0	88	54	1.1	.6			202	26		7.5	SCL96862

[1]Well withdraws water from Purisima Formation subunit C.
[2]Well withdraws water from Aromas Red Sands of Allen (1946).
[3]Well withdraws water from Purisima Formation subunit B.

Table 5.--Ground-water corrosion rates from corrosometer probes

Well location	Corrosion rate (inches per year)
1020 steel	
11S/1W-15L1	0.001
11S/1W-11L1	.002
11S/1E-18F1	.002
11S/1E-28R1	.0004
1010 steel	
Discharge end of reservoir at 11S/1W-15L1	.001
304 stainless steel	
11S/1W-15L1	0
11S/1E-28R1	0

Conclusions and Suggestions

The Purisima Formation is the predominant geologic unit and its sandstone beds are the most important aquifers in the Soquel-Aptos area. All three subunits of the Purisima contain ground water but only subunits B and C are capable of yielding usable quantities. The water in subunit B is confined and most of the water in subunit C is confined. In general, wells finished in subunit B consistently vield more than those in subunit C. All of the ground water in subunits B and C originates within the boundaries of the area.

The chemical quality of water from subunit B is not as good as that from either subunit C or from the Aromas Red Sands of Allen (1946).

The ground-water discharge through subunits B and C prior to development was probably on the order of 10,000 acre-feet per year of which about 7,000 acre-feet per year was discharged by subunit B. A large part of the total discharge was to Monterey Bay and this discharge stabilized the salt-water wedge at some position offshore. Withdrawals through wells have reduced the discharge to Monterey Bay and probably have shifted the position of the salt-water wedge landward. Salt-water encroachment past the coast has not yet occurred. However, with increasing withdrawals and the consequent reduction of discharge to Monterey Bay, the eventual encroachment of salt water into wells at the coast is to be expected.

The major problem of the Soquel-Aptos ground-water resource is the management of the ground water discharging to Monterey Bay. The guiding management principal should be to minimize the influence that withdrawals have on the position of the salt-water wedge offshore. Because hydraulic gradients suggest that the salt-water and fresh-water interface may not be very far offshore, steps should be taken as soon as practical to monitor the water supply and to insure maximum utilization of the ground water.

Some steps that could be taken are:

1. The establishment of a line of wells at the coast that would be used to continuously record water levels and to periodically monitor the chemical characteristics of the water.

2. The selection of favorable ground-water sites as far inland as practical for the future withdrawals of water.

3. The shifting of pumpage away from wells having the greatest influence on water levels at the coast.

SELECTED REFERENCES

Akers, J. P., and Hickey, J. J. 1966, Geohydrologic reconnaissance of the Soquel-Aptos area, Santa Cruz County, California: U.S. Geol. Survey open-file rept., 58 p.

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

Bramlette, M. N., 1946, The Monterey Formation of California and the origin of its silliceous rocks: U.S. Geol. Survey Prof. Paper 212, 57 p.

Branner, J. C., Newson, J. F., and Arnold, Ralph, 1909, Description of the Santa Cruz quadrangle, California: U.S. Geol. Survey Geol. Atlas, Folio 163.

California Department of Water Resources, 1958, Sea-water intrusion in California: California Dept. Water Resources Planning Bull. no. 63, 89 p.

______1959, Ground-water conditions in central and northern California, 1957-58: California Dept. Water Resources Planning Bull. no. 77-58 XIV, 79 p.

California State Water Resources Board, 1951, Water resources of California: Bull. no. 1, 648 p.

______1953, Santa Cruz-Monterey Counties investigation: Bull. no. 5, 230 p.

Clark, J. C., 1966, Tertiary stratigraphy of the Felton Santa Cruz area, Santa Cruz mountains, California: Stanford Univ. (Stanford, Calif.), unpubl. thesis (PhD), 184 p.

Davis, F. F., and Jennings, 1954, Mines and mineral resources of Santa Clara County: California Jour. Mines and Geology, v. 50, no. 2 p. 320-430.

Fitch, A. A., 1907, The geology of Ben Lomond Mountain: California Univ. Dept. Geol. Sci. Bull., v. 21, no. 1, p. 1-13.

Gribi, E. A., Jr., 1957, Santa Cruz basin holds important promise: Oil and Gas Jour. v. 55, no. 13, p. 113-116.

Hubbard, H. G., 1943, Mines and mineral resources of Santa Cruz County: California Jour. Mines and Geol., v. 39, no. 1, p. 11-52.

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

Lael, W., and Cory, W. H., 1932, The Vaqueros Formation of lower Miocene of California: California Univ. Pub. Geol. Sci., v. 22, no. 3, p. 31-410.

Lusczynski, N. J., and Swarzenski, W. V., 1966, Salt-water encroachment in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613-F, 76 p.

Martin, Bruce, 1916, Pliocene of middle and northern California: California Univ. Dept. Geol. Sci, Bull., v. 9, no. 15, p. 215-259.

Martin, B. D., 1964, Monterey Submarine Canyon, California: Genesis and relationship to continental geology: Univ. Southern California (Los Angeles, Calif.), unpubl. thesis (PhD), 249 p.

Page, B. M., and Holmes, C. N., 1945, Geology of the bitiminous sandstone deposits near Santa Cruz, Santa Cruz County, California: U.S. Geol. Survey Oil and Gas Inv. Prelim. map 27.

Rummer, R. R., Jr., and Harleman, D. R. F., 1963, Intruded salt-water wedge in porous media: Jour. of the Hydraulics Div., ASCE, v. 89, no. HY6, p. 193-220.

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.

Taliaferro, N. L. 1943, Geologic history and structure of the central cost ranges of California: California Div. Mines Bull. 118, 126 p.