Geology and Ground-Water Appraisal of the Naval Air Missile Test Center Area Point Mugu, California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-S

Prepared in cooperation with the Department of the Navy

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By R. W. PAGE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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GEOLOGY AND GROUND-WATER APPRAISAL OF THE NAVAL AIR MISSILE TEST CENTER AREA, POINT MUGU, CALIFORNIA

By R. W. Page

ABSTRACT

The Naval Air Missile Test Center at Point Mugu, Calif., is at the southeast edge of the Oxnard Plain in southern Ventura County. The Oxnard Plain is about 15 miles long and is traversed by the Santa Clara River near its northwest margin and by Calleguas Creek on the southeast. On the north and east the plain is bounded by highland areas underlain by rocks that are, for the most part, not water bearing. The water-bearing deposits beneath the plain are composed of floodplain and marine sedimentary deposits that yield large quantities of water to wells. The water body generally is semiconfined between lenses of clay and is contained in deposits of silt and sand of late Tertiary and Quaternary age. The semiconfined water body beneath the test center area extends continuously from beyond Hueneme Road on the north to beneath the Pacific Ocean on the south and west and to the base of the Santa Monica Mountains on the east.

The chemical quality of the ground water varies with depth. Water in the deposits extending from land surface to about 150 feet below land surface is reported to be brackish or salty, but in the deposits from about 150 to about 1,000 feet, the water is generally relatively fresh and is predominantly a calcium sodium sulfate type. The water from about 1,000 to about 1,550 feet below land surface is brackish or salty. Sea-water encroachment into the deposits containing fresh water has begun near Port Hueneme where water in some wells is reported to be salty. Owing to a landward hydraulic gradient, sea-water encroachment is a definite threat to the water supply at the test center. However, conclusive evidence of sea-water encroachment into the deposits beneath the test center is lacking.

Ground-water discharge (pumping and natural discharge) has exceeded recharge beneath the test center proper and the Oxnard Plain in general. Consequently, a decrease in the amount of ground water in storage has occurred. However, much of this decrease may have occurred in the area of unconfined aquifers to the north of the test center, and a lesser amount of this decrease has occurred in the semiconfined deposits of clay, silt, and sand underlying the test center.

An expanding need for water at the test center necessitates an orderly plan of development of the existing water supply in the area. To supply the increasing demand for water, three possible sources for future use are: continued use

of deep, 500 to 750 feet, aquifers at the test center and expansion of that source, either by construction of new wells or by purchase of existing wells, or both; development or purchase of a supply of water from a source outside the test center and far enough inland so that the threat of sea-water encroachment would be greatly reduced; and possible development of water from the depth between 750 and 950 feet beneath the test center.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The U.S. Naval Air Missile Test Center at Point Mugu, Calif., borders the Pacific Ocean and overlies part of a large ground-water basin from which the test center pumps its water supply. Owing to the expansion of its facilities, the test center increased its water consumption in 1959 by nearly 500 acre-feet more than that of 1958 and by nearly 1,100 acre-feet more than that of 1949. To meet the increasing demand for water, the test center must utilize fully its present water-supply facilities as well as develop further the supply of water beneath the test center. With continued expansion it also may ultimately be necessary to import water from a source outside the test center.

The U.S. Geological Survey began the ground-water investigation of the U.S. Naval Air Missile Test Center at Point Mugu, Calif., in October 1957. The investigation was made for the Department of the Navy to appraise the ground-water resources of the test center and to determine the adequacy of the water supply for present and future needs. Among the urgent questions concerning the test center's critical water-supply problem are the following:

1. What is the relative balance between the recharge and discharge as interpreted from hydrographs showing water-level fluctuations of ground water in the deposits beneath the test center?
2. Does sea-water encroachment threaten the test center ground-water supply?
3. What is the quality of water in the deposits beneath the test center?
4. What sources are available to develop an adequate water supply to meet increasing requirements?

The scope of the work required to answer these questions included data collection and a review of previous ground-water reports on the area. All known hydrologic data for the test center and vicinity were assembled, and nearly all wells south of Hueneme Road were field canvassed. The tabulation, review, and interpretation of this information provided the basis for the present report, which describes the hydrology of the area in relation to geology and the occurrence, movement, and chemical quality of the ground water. Geologic cross sections were prepared to show the lithologic character, thickness, and continuity of the water-bearing deposits beneath the test center and vicinity. Water-level fluctuations in wells were tabulated and interpreted in relation to ground-water pumpage which has created a possible critical overdraft from the ground-water reservoir. A water-level contour map shows that the hydraulic gradient is landward, permitting encroachment of sea water into the fresh-water zones, and thus posing a critical threat to the test center ground-water supply. Quality-of-water data provided information used to delineate depth zones containing water of significantly different quality and to help determine the rate of sea-water encroachment into the deposits beneath the test center area.

This study was made by the U.S. Geological Survey, under the general supervision of H. D. Wilson, Jr., district engineer, and under the immediate supervision of Fred Kunkel, geologist in charge of the Long Beach subdistrict office. L. C. Dutcher, geologist, contributed substantially to the preparation of the report by providing the author with technical and editorial guidance.

LOCATION AND GENERAL DESCRIPTION OF THE AREA

The area of investigation (fig. 1) lies between long 119° and 119°16′ W. and about lat 34°03′ and 34°15′ N. The area canvassed in detail for well data is bordered on the east by the Santa Monica Mountains, on the west by Port Hueneme, on the north by Hueneme Road, and on the south by the Pacific Ocean (pl. 1).

Oxnard, the principal town in the area, is reached from the north by U.S. Highway 101 and from the Los Angeles area by U.S. Highways 101 and 101 Alternate. The U.S. Naval Air Missile Test Center occupies an area of about 4 square miles at the south edge of the Oxnard Plain. The plain borders the Pacific Ocean and extends northwestward about 15 miles from Point Mugu to the city of Ventura, which is about 5½ miles northwest of the mapped area. The plain, which has an average width of about 10 miles, is traversed by the Santa Clara River on the northwest and by the Calleguas Creek on the southeast. On the north and east the Oxnard Plain is bordered by highland areas which are underlain mostly by consolidated rocks that yield little water. Alluvium-filled reentrant valleys locally extend deep into the highland areas, forming an irregular border with the flat lowlands of the Oxnard Plain. Except for the test center the principal land use in the area is for cultivation of row crops.

PREVIOUS INVESTIGATIONS

Several previous geologic and hydrologic reports on Ventura County, the Oxnard Plain, and the test center area contain data that are pertinent to the present study.

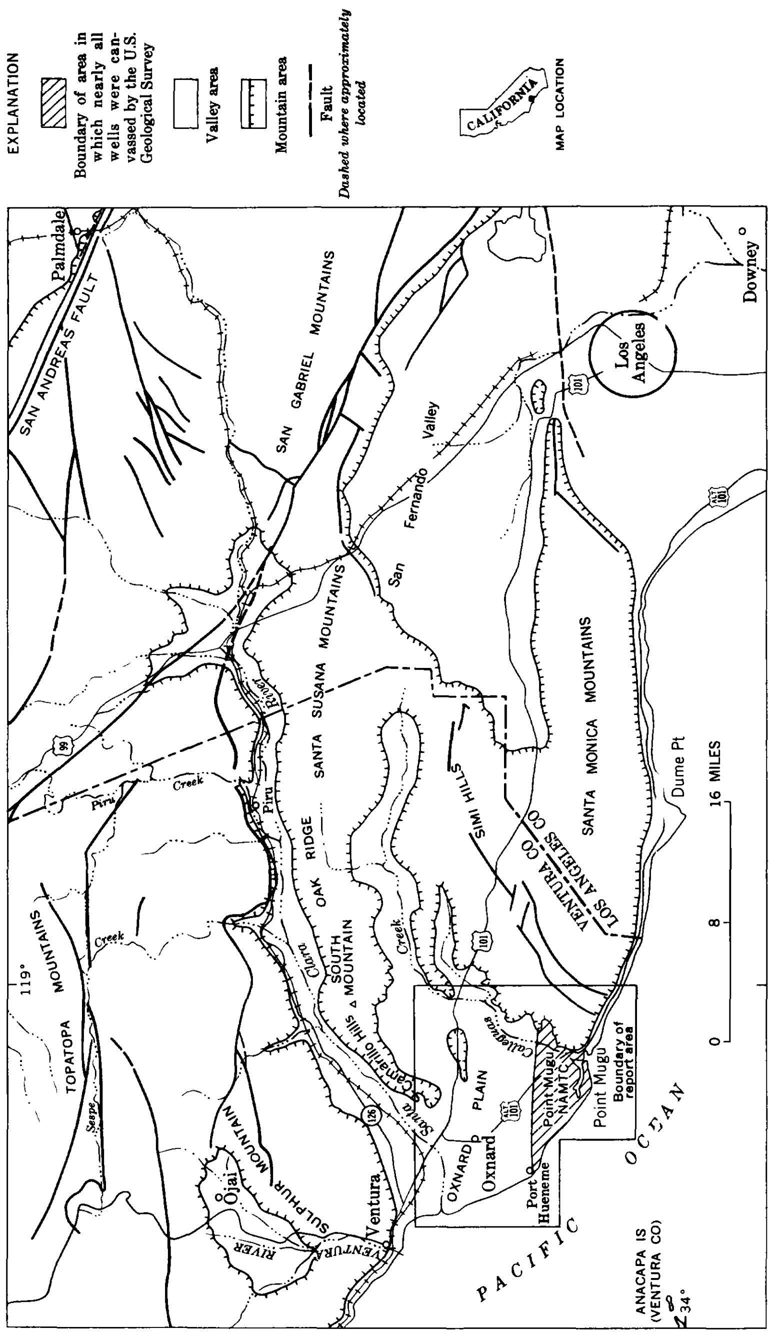

FIGURE 1.—Map of part of southern California showing area covered by this report.

Eldridge and Arnold (1907) described the geologic structure in several Ventura County oil districts as well as the lithology and distribution of the Modelo, which has since been restricted by Winterer and Durham (1958), and other geologic formations. Kew (1924) and Durrell (1954) reported on similar studies in Los Angeles and Ventura Counties, and Bailey (1935) described other geologic formations which underlie the test center area.

The earliest reports concerning the water supply for the area were by the California Division of Water Resources (1933 a, b). These reports describe the geology and hydrology of the Oxnard Plain and vicinity and contain much data on rainfall, percolation, and ground-water storage of the area.

In addition to the published reports the Navy made available to the Geological Survey several unpublished reports prepared for the Navy (written communications 1947, 1948, and 1949). These reports described the geology and hydrology of the Oxnard Plain and vicinity, the possible salt-water encroachment along the coast, the demand for water in the area, water-level contour maps for 1941 and 1946, other illustrations, and data showing the fluctuation of the water table, recharge, discharge, precipitation and runoff, chemical quality, and use of water in the area.

A report by Poland, Garrett, and Mann (1948) deals with the sources of an adequate future water supply at the test center. The report summarizes the available data and includes a brief statement of geologic and hydrologic conditions beneath the Oxnard Plain and a summary of the conditions with respect to possible sea-water encroachment near the test center and Port Hueneme.

The present and future demands for water within the district were reported on by the United Water Conservation District (1953). This report proposes dams, reservoirs, and spreading grounds to meet the water demand and also lists cost estimates for their construction.

The California State Water Resources Board (1956 a, b) prepared a report on the hydrology and geology of Ventura County which describes ground-water basins, reservoir sites, projects for importing water, and the possibility of sea-water encroachment in the Oxnard Plain. This report also includes data on precipitation, runoff, water requirements and uses, and chemical quality of ground water.

The California Department of Water Resources (1959 a, b) studied the quality of surface- and ground-water supplies in Ventura County, the probable effects of future development upon water quality, and the feasibility of reclamation of sewage water.

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The basic data for the present study have been tabulated through January 30, 1959, in a separate report by Page and Kunkel (1960).

ACKNOWLEDGMENTS

During this investigation much data were collected from the Los Angeles office of the California Department of Water Resources, the Ventura County Department of Public Works, the United Water Conservation District, and the Naval Air Missile Test Center. This information included well descriptions and logs, water-level records, and chemical analyses of ground water.

The collection of these materials, together with other data on individual wells, was greatly facilitated by the willing cooperation of well drillers, private individuals, and property owners who freely supplied information concerning their wells.

WELL-NUMBERING SYSTEM

Prior to the work done by the Geological Survey in the test center area, two well-numbering systems were in use. A "location" number which was based on an arbitrary grid was used by the Ventura County Department of Public Works and the United Water Conservation District. The California Department of Water Resources used a numbering system based on the location of the well in reference to the rectangular system for the subdivision of public land.

The system used in this investigation is the same as that presently used by the California Department of Water Resources and by the Geological Survey in all recent ground-water investigations in California. It has been adopted as a standard system by the State Department of Water Resources and by the California Water Pollution Control Board.

Wells are numbered according to their location in the rectangular system for the subdivision of public land. For example, in the number 1N/21–31L1, the part of the number preceding the slash indicates the township (T. 1 N.), the part between the slash and the hyphen indicates the range (R. 21 W.), the number between the hyphen and the letter indicates the section (sec. 31), and the letter indicates the 40-acre subdivision of the section as shown in figure 2.

Within each 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well 1N/21–31L1 is the first well to be listed in the NE¼SW¼ sec. 31, T. 1 N., R. 21 W., San Bernardino base line and meridian.

The wells in the test center area are either in the northwest or the southwest quadrant of the San Bernardino base and meridian lines. Thus, well 1S/21–4E1 is in the SW¼NW¼ sec. 21, T. 1 S., R. 21 W., and well 1N/21–25E1 is in the SW¼NW¼ sec. 25, T. 1 N., R. 21 W.

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

FIGURE 2.—Diagram showing well-numbering system.

Because all of the wells in the test center area are west of the San Bernardino meridian, no letter abbreviations are necessary in range designation.

For wells not field located by the Geological Survey, the letter designating the 40-acre tract has been omitted and replaced with the letter *Z*. Thus, 1S/22–1Z1 indicates a well that was plotted on the map from an unverified location description.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

The test center area is underlain by about 1,500 feet or more of unconsolidated water-bearing deposits from which the test center water supply is obtained. These, in turn, are underlain by consolidated, virtually non-water-bearing rocks which are exposed in the highland area bordering the Oxnard Plain (pl. 2).

The geologic units beneath the test center area are discussed in order of their age, from oldest to youngest, and are grouped either as consolidated rocks or unconsolidated deposits. The areal extent of the geologic units exposed in the area is shown on plate 1.

The consolidated rocks include sedimentary rocks of the Vaqueros formation of early Miocene age and sedimentary and volcanic rocks of the Topanga formation of middle Miocene age (Durrell, 1954, map sheet 8). The Pico formation of late Pliocene age, which does not crop out in the area but is encountered in wells, also is included in the consolidated rocks. These rocks are divided on plate 1 only into sedimentary and volcanic rocks. The unconsolidated deposits include the Santa Barbara formation (Bailey, 1935, p. 492–494) of early Pleistocene age, the San Pedro formation of early Pleistocene age, unnamed deposits of late Pleistocene age, and alluvial and coastal deposits of Recent age. Plates 1 and 2 show the generalized stratigraphic and structural relationships of the geologic units.

CONSOLIDATED ROCKS

Sedimentary rocks of Miocene age, the oldest consolidated rocks in the test center area, are about 7,800 feet thick as defined by Kew (1924, p. 8), but beneath the test center area they probably are not much more than 2,000 feet thick. The rocks crop out in the Santa Monica Mountains, east of the test center, where they consist primarily of sandstone, conglomerate, and shale. No wells are known in the outcrop area of the sedimentary rocks, but well 1N/21-31L1 (table 1) is believed to penetrate them at a depth of about 1,545 feet below land surface.[1] The water-bearing character of the consolidated sedimentary rocks has not been tested adequately, but the unit probably yields little water.

Volcanic rocks of Miocene age, which also crop out in the Santa Monica Mountains, are probably more than 2,000 feet thick. They consist of intrusive and extrusive basalt, andesite, and rhyolite and associated agglomerate and mudflows of the Topanga formation. No wells are known in the outcrop area but well 1N/21-31L1 reportedly penetrated volcanic rock between 1,573 feet and the bottom of the well at 1,583 feet below land surface (T. L. Bailey, written communication, 1949a). Although the water-bearing character of the volcanic rocks has not been tested adequately, they probably contain only small amounts of water in fractured zones.

The Pico formation of Pliocene age, which does not crop out in the area, is about 75 feet thick beneath the test center. The formation, consisting of marine clay, shale, and carbonaceous sandstone, was not differentiated from the Santa Barbara formation by Bailey (1935, p. 492-494). However, Bailey (written communication, 1949) states that in well 1N/21-31L1 the Pico was penetrated at a depth interval from about 1,470 to 1,545 feet below land surface. The water-bearing character of the Pico formation has not been tested adequately, but because the formation is consolidated, it is probably of low permeability.

UNCONSOLIDATED DEPOSITS

Although their water-bearing character has not been tested adequately to determine their full potential, the unconsolidated deposits are water bearing, and they are the source for the test center groundwater supply.

The Santa Barbara formation (Bailey, 1935, p. 492-494) of Pleistocene age does not crop out in the test center area, but is present in

[1] Well 1N/21-31L1, which penetrates the geologic units that do not crop out in the test center area, was logged by Bailey (written communication, 1949a), and his descriptions were used to interpret the subsurface geology. These units, though known to be present, cannot be differentiated on plates 1 and 2 without additional detailed paleontological studies which are beyond the scope of this report.

the depth interval from about 690 to 1,470 feet below land surface at the test center. It consists of about 780 feet of marine clay, shale, silt, sand, sandstone, and gravel, as shown by the log of well 1N/21-31L1 (table 1). The formation probably was penetrated in other deep water wells throughout the area, although it was not distinguished because the contact with the overlying younger deposits cannot be recognized readily in drillers' logs of wells. The Santa Barbara formation is a source of ground water at the test center.

The San Pedro formation of early Pleistocene age, which crops out in the Camarillo Hills, is present in the depth interval from about 420 to 690 feet below land surface in well 1N/21-31L1 at the test center. The formation consists of yellowish-brown to gray silt, sand, and gravel, and contains marine fossils. Though not differentiated from the unnamed deposits shown on plate 1 the San Pedro formation is known to be penetrated by numerous wells and yields water freely to many of them.

The unnamed deposits, which crop out in the low hills at Camarillo and in La Jolla Valley, are present in the depth interval from about 200 to 420 feet below land surface at the test center. They consist of nonmarine clay, silt, sand, and gravel and include some interbedded fossiliferous marine beds. The unnamed deposits, tentatively classified as late Pleistocene in age, are closely associated with the San Pedro formation and locally may belong to that unit, although the San Pedro formation is of early Pleistocene age. However, the unnamed deposits in La Jolla Valley may be of Recent age (Agmon, Emanuel, written communication, 1956). Where saturated, these deposits are highly permeable and yield water freely to many irrigation wells in the test center area.

The alluvial deposits of Recent age that underlie the Oxnard Plain and the stream channels range in thickness from a few inches at the margins of the hills to a maximum of about 200 feet beneath the test center. They consist of lenticular beds of unconsolidated gravel, sand, silt, and clay beneath the Oxnard Plain; mud, silt, and peat in the tidal marshes; and gravel and sand along the stream channels. The deposits along parts of the Santa Clara River, Calleguas Creek, and most smaller streams are estimated to be not more than about 30 feet thick. The channel deposits usually are not saturated during the dry season. However, during periods of runoff they transmit large quantities of water from the streams to the ground-water body. The alluvial deposits are highly permeable and, where saturated, yield water freely to wells.

Deposits of windblown sand and beach sand of Recent age, about 10 to 30 feet thick, form a narrow, almost continuous belt along the coast. For the most part they are not saturated, but where they contain water it is too salty for ordinary use.

The San Pedro formation cannot be differentiated from Recent alluvium or the Santa Barbara formation of Bailey (1935) from well logs showing only lithology. The logs (table 1) of wells 1N/21-31L1, 1N/21-32A1, 1N/21-32G1, and 1N/21-32K1 are representative of these deposits for the depths penetrated. Other logs in the area are given by Page and Kunkel (1960, table 4).

TABLE 1.—*Logs of selected water wells*

	Thickness (feet)	Depth (feet)
1N/21-27F1. Broome Ranch [Alt 13.7 ft. Drilled by Henry Hatherly in 1926. 18-in. casing, perforated 425-426, 457-460, 584-588, 611-616, 687-692, 705-710, 749-757, and 824-836 ft]		
Clay	134	134
Clay with a little gravel	1	135
Blue clay and hardpan	250	385
Red clay	36	421
Blue clay	4	425
Gravel, water-bearing	1	426
Red sandy clay	24	450
Blue clay	5	455
Gravel	2	457
Sand, blue clay	13	470
Blue sand	13	483
Blue clay	7	490
Red clay	30	520
Red clay and gravel, water	10	530
Blue clay with a little sand	50	580
Cemented gravel	4	584
Blue clay	24	608
Cemented formation	3	611
Blue sand	66	677
Blue clay	3	680
Sand, gravel, and shells	3	683
Cemented formation with shells	4	687
Blue sand	14	701
Layers of cement formation and shells	4	705
Blue clay and silt	38	743
Gravel, not much water	6	749
Sand	63	812
Gravel	12	824
Solid rock	16	840

TABLE 1.—*Logs of selected water wells*—Continued

1N/21-31L1 (supply well 3). NAMTC

[Alt 8.89 ft. Drilled by Van Noy in 1949. 26-in. casing to 310 ft, 16-in. casing to 350 ft, 12-in. casing to 1,000 ft; originally perforated 350–420, 476–530, 620–700, and 810–972 ft. Cement plug reportedly set in well at 750 ft after 1950. Log by T. L. Bailey, consulting geologist]

	Thickness (feet)	Depth (feet)
Sand, mostly fine	95	95
Sand, coarse, and gravel and streaks of blue clay	39	134
Sand, light-gray, fine, and blue clay	78	212
Gravel, light-gray, clean	59	271
Clay, blue, and thin silty sand and gravel streaks	79	350
Sand, gravelly and pebbly	70	420
Clay, blue-gray	20	440
Sand, fine, silty	12	452
Clay, dark-gray	15	467
Gravel and coarse sand	71	538
Sand, medium to fine, silty	64	602
Sand, dark-gray, silt and silty	18	620
Sand, coarse, and gravel	70	690
Clay, blue, fine to medium, and sandy silt	42	732
Sand, medium to fine, and gravelly streaks	50	782
Silt, blue and fine sand	28	810
Sand and gravel, medium to coarse	80	890
Sand, medium to coarse, and fine silty sand streak	68	958
Sand, medium to coarse (fair water)	42	1,000
Sand, medium to coarse (brackish water)	50	1,050
Silt, blue-gray, sandy and fine silty sand	60	1,110
Clay, blue-gray, shaly	50	1,160
Sand, dark-gray, medium to fine, carbonaceous	40	1,200
Clay, dark-gray, carbonaceous, shale, and sandy shale	18	1,218
Shale, gray, clayey, and shaly clay	128	1,346
Shale, light-gray, silty, thinner beds of friable sandstone	124	1,470
Shale, soft, carbonaceous	12	1,482
Sandstone, dark, friable, interbedded with brownish-black soft laminated clay-shale	61	1,543
Sandstone, dark-gray, hard	30	1,573
Basalt, dark-green, altered	10	1,583

1N/21-32A1 (supply well 5). NAMTC

[Alt about 10 ft. Drilled by Midway Drilling Co. in 1958. 16-in. casing perforated from 645–745 ft. Log by Geol. Survey]

	Thickness (feet)	Depth (feet)
Silts, greenish-brown, fine sand lenses	75	75
Sand, coarse, pebble-size, well-rounded, some marine shells	20	95
Clay, silty, fine sand	20	115
Sand, coarse, pebble-size, well-rounded, some fine sand, marine shells	21	136
Clay, silty, bluish-gray, some coarse sand	14	150

TABLE 1.—*Logs of selected water wells*—Continued

	Thickness (feet)	Depth (feet)
1N/21–32A1 (supply well 5). NAMTC—Continued [Alt about 10 ft. Drilled by Midway Drilling Co. in 1958. 16-in. casing perforated from 645–745 ft. Log by Geol. Survey]		
Sand, coarse, pebble-size, subrounded to rounded, some marine shells	20	170
Clay, bluish-gray, fine sand	9	179
Sand, fine to coarse, subrounded to rounded	10	189
Clay, bluish-gray, fine sand	10	199
Sand, fine, silty, well-rounded	9	208
Clay, bluish-gray, fine sand	7	215
Sand, fine to coarse, well-rounded, silts	14	229
Clay, fine sand	10	239
Sand, fine, to coarse, some silt	12	251
Clay, brown, silt and fine sand	18	269
Silt to coarse sand, little clay, shell fragments	113	382
Clay, silt, fine sand	13	395
Sand, fine to medium, some silt, clay, and shell fragments	65	460
Clay, silt, some fine sand	16	476
Sand, fine to medium, blue-gray, well-rounded, some silts and clays	134	610
Clay, blue-gray, fine sand and silt	26	636
Sand, fine to medium, well-rounded, blue-gray, some silts and clays	116	752
Sand, fine to medium, well-rounded, blue-gray, some silts and clays	51	803
1N/21–32G1 (supply well 1). NAMTC [Alt 10.00 ft. Drilled in 1943. 12-in. casing perforated 121–137, 311–32[illegible], and 417–432 ft. Log from Navy, presumably by driller]		
Soil	3	3
Clay, yellow	19	22
Clay, blue	12	34
Sand, fine	18	52
Clay, sandy	14	66
Clay, blue	12	78
Sand, fine	20	98
Clay, blue	24	122
Sand	14	136
Sand and 1-inch gravel	16	152
Clay, yellow	4	156
Sand, fine	12	168
Clay, yellow	12	180
Sand, fine, and gravel	12	192
Clay, blue	13	205
Sand, blue, fine	35	240
Clay, blue	4	244

TABLE 1.—*Logs of selected water wells*—Continued

	Thickness (feet)	Depth (feet)
1N/21–32G1 (supply well 1). NAMTC—Continued [Alt 10.00 ft. Drilled in 1943. 12-in. casing perforated 121–137, 311–325, and 417–432 ft. Log from Navy, presumably by driller]		
Sand, blue	12	256
Clay, blue	23	279
Sand, blue	3	282
Clay, blue, sandy	10	292
Sand, fine	6	298
Clay, blue	14	312
Gravel, 2-inch	12	324
Clay, blue	6	330
Sand, blue	36	366
Sand and gravel, cemented	12	378
Gravel	6	384
Sand, blue, coarse	14	398
Sand, blue, fine	8	406
Clay, blue	2	408
Sand, blue, fine	26	434
1N/21–32K1 (supply well 2). NAMTC [Alt 9.46 ft. Drilled in 1943. 12-in. casing perforated 460–470, 544–550, and 575–593 ft. Log from Navy, presumably by driller]		
Soil	3	3
Clay, yellow	17	20
Clay, blue	15	35
Sand, blue, fine	39	74
Clay, blue	20	94
Sand, blue, fine	4	98
Clay, blue	26	124
Clay, yellow	14	138
Sand, yellow, fine	12	150
Clay, blue	10	160
Sand, yellow	26	186
Clay, yellow	16	202
Sand, blue, fine	26	228
Clay, blue	62	290
Sand, blue, fine	6	296
Shale, blue	10	306
Sand, cemented	14	320
Sand, blue, fine	12	332
Sand, blue	28	360
Sand, blue, fine	30	390
Sand, blue	70	460
Sand and gravel	10	470
Sand, blue	38	508
Sand, blue, and some shells	12	520

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TABLE 1.—*Logs of selected water wells*—Continued

	Thickness (feet)	Depth (feet)
1N/21-32K1 (supply well 2). NAMTC—Continued [Alt 9.46 ft. Drilled in 1943. 12-in. casing perforated 460–470, 544–550, and 575–593 ft. Log from Navy, presumably by driller]		
Sand, blue, fine	24	544
Sand and gravel	6	550
Sand, blue	22	572
Sand and gravel	18	590
Clay, blue, sandy	32	622

GROUND WATER

In any area, records of water-level fluctuations in wells, discharge of water from the deposits, and quality of water in the deposits are helpful in interpreting past and present hydrologic conditions and in planning future ground-water development. This is particularly true in the test center area where the geologic and ground-water conditions are complex. The records that were collected were used to evaluate the problems described in the introduction, and to interpret the source, occurrence, and movement of ground water in the area.

All the ground water pumped from wells in the test center area is withdrawn from the unconsolidated deposits beneath the Oxnard Plain (pl. 1). These deposits contain a continuous ground-water body whose areal extent, as shown by logs of existing wells, is approximately coextensive with the Oxnard Plain (pls. 1 and 2). The bottom of the water body is poorly defined, but it coincides with the top of the consolidated rocks.

The water-bearing deposits in the vicinity of the test center range in thickness from a few inches along the landward margin of the Oxnard Plain to about 1,500 feet along the coast. Beneath the test center the thickness is shown to be more than 803 feet in the vicinity of well 1N/21–32A1 and about 1,500 feet in the vicinity of well 1N/21–31L1 (pl. 2). Bedrock was reported at a depth of 325 feet in well 1N/21–33E1, but that report is probably in error. The log of well 1N/21–27F1 (table 1), about 1½ miles north of the test center, shows consolidated rock at a depth of 824 feet, which indicates that the thickness of the water body is about 790 feet in this area (pl. 2). Other wells in the area south of Hueneme Road penetrate only water-bearing deposits and do not reach the consolidated rocks.

Ground water generally occurs either under unconfined (water-table) or confined (artesian) conditions. The water table, or surface of an unconfined water body, is the upper surface of the zone saturated with water under hydrostatic pressure; it is the level at which the hydrostatic pressure is equal to the atmospheric pressure. Above it is the capillary fringe, the lower part of which may also be saturated, but with water at less than atmospheric pressure. Confined water is contained in aquifers overlain by materials of sufficiently low permeability to hold water in the aquifer under artesian pressure. Even the least permeable confining beds in an area permit slow, perhaps imperceptible, movement into or out of confined aquifers.

Because of the heterogeneous character of the deposits beneath the test center, confinement in them is commonly a matter of degree, and the time element must be considered. In such deposits there is enough hindrance to the vertical movement of ground water between separate aquifers that differences in head between the aquifers exist during periods of heavy pumping. During periods of little draft, the head in all the aquifers may recover to a level common with the water table. Such conditions of occurrence commonly are called semiconfined to indicate that, although the aquifers are subject to pressure effects over short periods, the head adjusts to equilibrium with the water table over long periods of time and under steady-state conditions.

All the ground water beneath the test center is semiconfined between lenticular beds of clay and probably is in hydraulic continuity. The unconsolidated deposits are permeable, and, although lenticular, do not contain known barriers which would impede the horizontal movement of ground water.

The permeability of the unconsolidated deposits is highly variable, and therefore they do not yield water to all wells at the same rate. Ground water is readily obtainable, however, from wells penetrating sufficient thicknesses of sand and gravel. As stated previously, the ground water is semiconfined, but where a difference in head exists between adjacent water-bearing units the water can move vertically as well as laterally. For this reason, under present conditions of pumping in the area, it is most likely that the unconsolidated deposits act largely as a single ground-water body and that pumping from one part of the aquifer produces an effect on the entire body. Three separate water-yielding zones were described by the California State Water Resources Board (1956a, b) in the area north of the test center. These zones could not be differentiated by the author in the area south of Hueneme Road, and additional test drilling and test pumping would be required to demonstrate conclusively whether the zones exist in this area.

Many local water users have expressed the belief that a barrier to ground-water movement may be present between the coast and the test center supply wells, possibly because of differences between water levels in deep and shallow wells. The geologic sections and water-level contours do not substantiate this belief, however (pls. 1, 2). The different water levels observed in closely spaced wells of different depth south of Hueneme Road are attributed partly to differences in hydrostatic head caused by pumping. These wells obtain water from permeable sand and gravel lenses, separated by silty clay semiconfining beds. Under these conditions, when most of the pumping is from deep wells, the water level in shallower wells is nearest the land surface (pl. 1; fig. 3).[2]

In January 1959 the altitude of the water level in the wells south of Hueneme Road ranged from 12 feet above sea level in sec. 26, T. 1 N., R. 21 W., to about 40 feet below sea level in sec. 31, T. 1 N., R. 21 W. (pl. 1).

SOURCE AND MOVEMENT

The source of the potable ground water in the test center area is the precipitation that falls within the drainage areas of the streams tributary to the Oxnard Plain. Except for local sea-water encroachment there is no evidence of movement of ground water to the Oxnard Plain from other sources. Natural recharge to the ground-water body is by infiltration of water from streams during periods of heavy runoff and, to a lesser degree, by the infiltration of rainfall on the alluvial plain. In addition to natural recharge, some artificial recharge is done by the United Water Conservation District, formerly the Santa Clara Water Conservation District. Beginning about in 1928, surface water was diverted into spreading basins along the Santa Clara River and on the alluvial cone of Piru Creek, thus salvaging for beneficial use water that otherwise would flow into the ocean.

Under natural conditions ground water moved from the north and northeast beneath the Oxnard Plain toward the coastline. The ground-water discharged in part directly into the Pacific Ocean through permeable lenses that crop out on the ocean floor, by seepage at land surface, and in part by evaporation and transpiration from a large area where the head was near or above the land surface. In the spring of 1944 the direction of ground-water movement was nearly the same as that under natural conditions, although the gradient was affected locally by pumping from wells (pl. 3). Since 1944 the combined effects of heavy ground-water withdrawal and a series of dry years have been to reverse the slope of the piezometric surface and to induce the landward movement of water from the Pacific Ocean toward the test center. As shown on plate 1, a cone of depres-

[2] Under natural conditions the depth to water in the deeper wells was shallowest, and many of the deeper wells in the area flowed when first drilled.

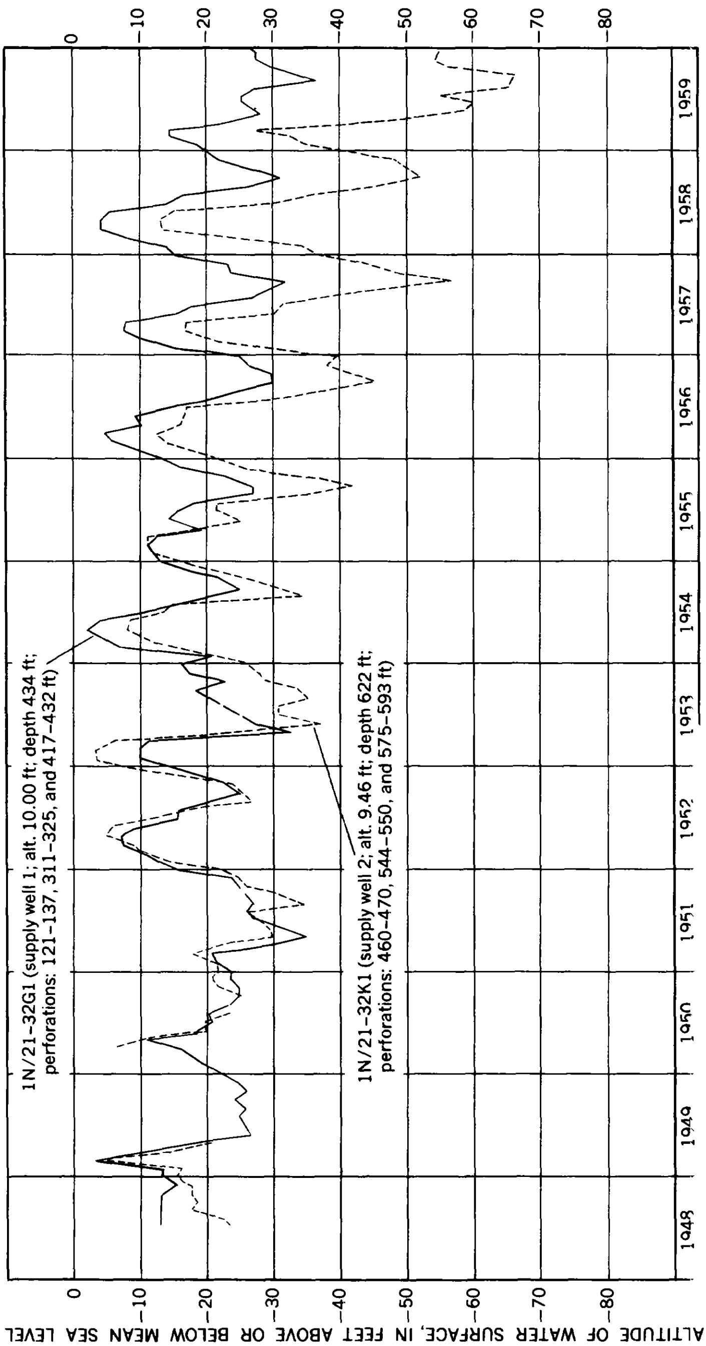


FIGURE 3.—Hydrographs of wells 1N/21-32G1 and 1N/21-32K1.

sion is centered in about the NE¼ of sec. 31, T. 1 N., R. 21 W., and the slope of the piezometric surface is landward in the area south of Hueneme Road as of January 1959.

Two sets of water-level contours (pl. 1) define the piezometric surfaces in wells 500 feet or less in depth and in wells greater than 500 feet in depth. The contours show that these two surfaces are distinct from each other. The piezometric surface in the zone deeper than 500 feet shows a more pronounced decline than does that in the shallower zone. Because water levels in confined aquifers drop more readily in response to withdrawal of ground water than do water levels in unconfined aquifers, this may indicate a greater degree of confinement in the lower part of the ground-water body.

Water-level contours based on measurements in wells completed in the upper 500 feet of the ground-water body show a ground-water divide extending northwestward from the NW¼ sec. 34, T. 1 N., R. 21 W. (pl. 1). From this divide ground water moves northeastward, toward an area of depressed water levels created by heavy withdrawals for irrigation, and southwestward, toward the depression caused by pumping at the test center (pl. 1). The pumping depression at the test center is elongated in an east-west direction and is centered in the vicinity of well 1N/21–31J1. Ground water moves toward this depression from all directions but principally from the north and from the Pacific Ocean on the southwest. As the water levels in the test center are everywhere below sea level, conditions are established under which salty water from the Pacific Ocean moves toward the area of ground-water withdrawal. Although data are not presently available to delineate the areas in which seawater encroachment already has occurred and to determine the rate of advance, continued pumping under the present conditions will result in continued encroachment, thus endangering the test center supply.

A similar pattern of ground-water movement is shown by water-level contours based on measurements in wells tapping deposits deeper than 500 feet (pl. 1). The water levels in these wells are about 10 to 20 feet lower than those observed in the shallower wells; however, the landward direction of movement, and thus the hazard of sea-water encroachment, is similar for the two zones, except, perhaps, for the greater distance to the submarine outcrop of the deeper deposits.

In January 1959 the head of the water in the shallow zone was higher than that of the water in the deep zone, as shown by the water-level contours (pl. 1) and by the hydrographs of wells IN/21–32G1 and 1N/21–32K1 (fig. 3). Because of this head differential, ground water can move downward from the shallow zone to the deep zone. Because the permeability of the deposits is unknown, the rate of ground-water leakage into the deposits below 500 feet could not be estimated.

WATER-LEVEL FLUCTUATIONS

Under the natural conditions, which prevailed in the test center area before large-scale pumping began, a state of equilibrium existed between natural discharge and natural recharge, the ground-water levels and the amount of ground water in storage varying only with alternate wet and dry periods. Because of a series of dry years and increased ground-water pumping since 1945, however, discharge has exceeded recharge, resulting in declines of water levels and depletion of ground water in storage (pl. 4).

Available water-level records for the test center area include periodic measurements made by the Ventura County Department of Public Works and the United Water Conservation District, and those made by the California Department of Water Resources and U.S. Geological Survey in connection with ground-water studies in the area.

Hydrographs of the water level in seven wells in the test center (pl. 4; figs. 3, 4, 5, and 9) show both the seasonal and long-term effects of pumping in the area, superimposed on the trends controlled by recharge during wet and dry cycles. From 1945 to 1959 a general decline of about 50 feet in the deep zone and about 20 feet in the shallow zone occurred (pl. 4). Well 1N/21–27F1, in which the decline of 50 feet was observed, is 840 feet in depth, and well 1N/22–25C2, in which the decline of 20 feet occurred, is 270 feet in depth. Thus, a direct relationship is shown between well depth and the rate and amount of water-level change which, under present pumping conditions, may indicate a lower coefficient of storage and greater degree of confinement in the lower part of the ground-water body.

Superimposed on the long-term trend is a marked seasonal fluctuation of the water level caused by heavy pumping during the summer months. Beginning in March or April of each year water levels decline in response to pumping for irrigation in the Oxnard Plain as well as to increased pumping at the test center. As with the long-term water-level trend, the seasonal fluctuation varies in rate and magnitude with the depths of the wells, those completed in the deep zone showing the greater declines.

At this time it is not known whether there is more pumpage from the shallow zone than from the deep zone. Although it appears that more wells south of Hueneme Road are pumping water from the shallow zone, many deep irrigation and supply wells pump water from the deep zone (below 500 ft), and the pumpage from them may be greater.

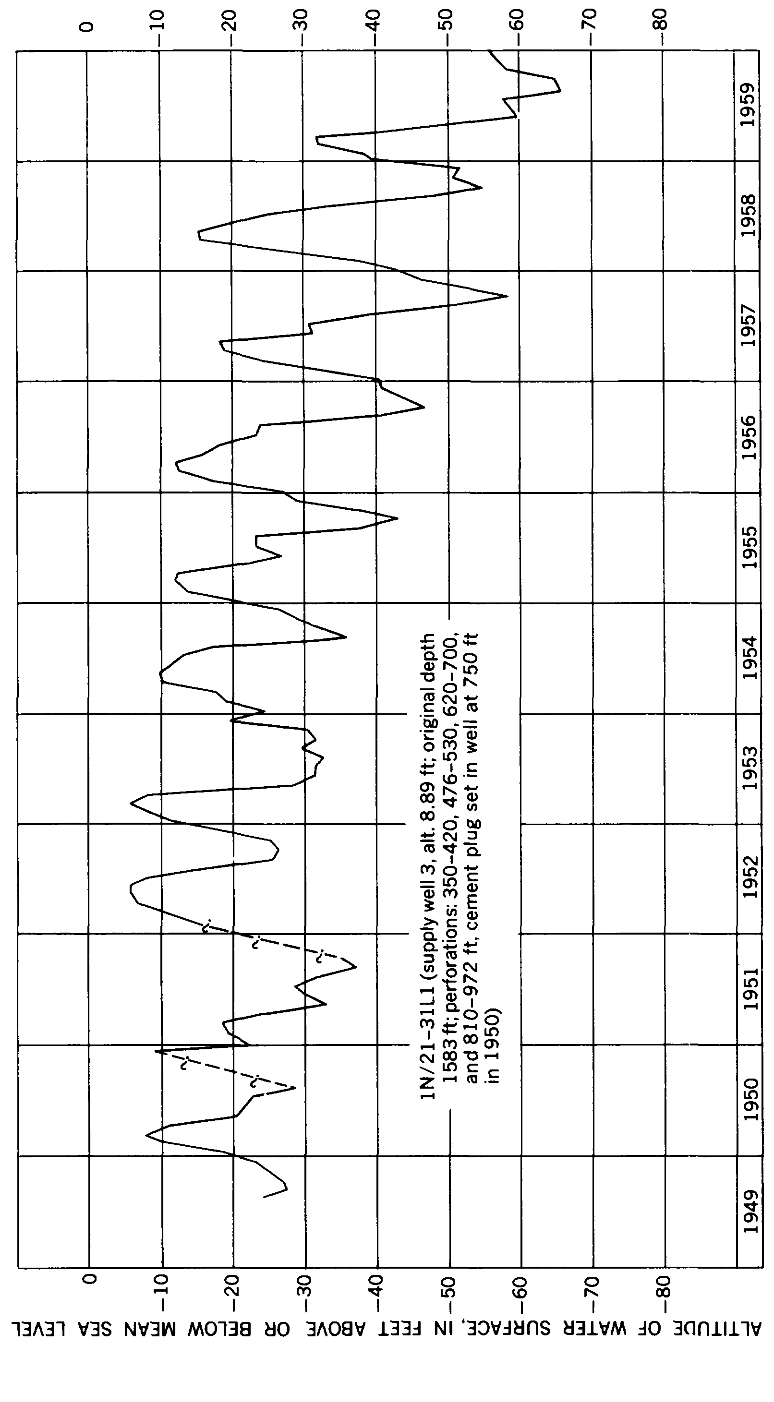


FIGURE 4.—Hydrograph of well 1N/21–31L1.

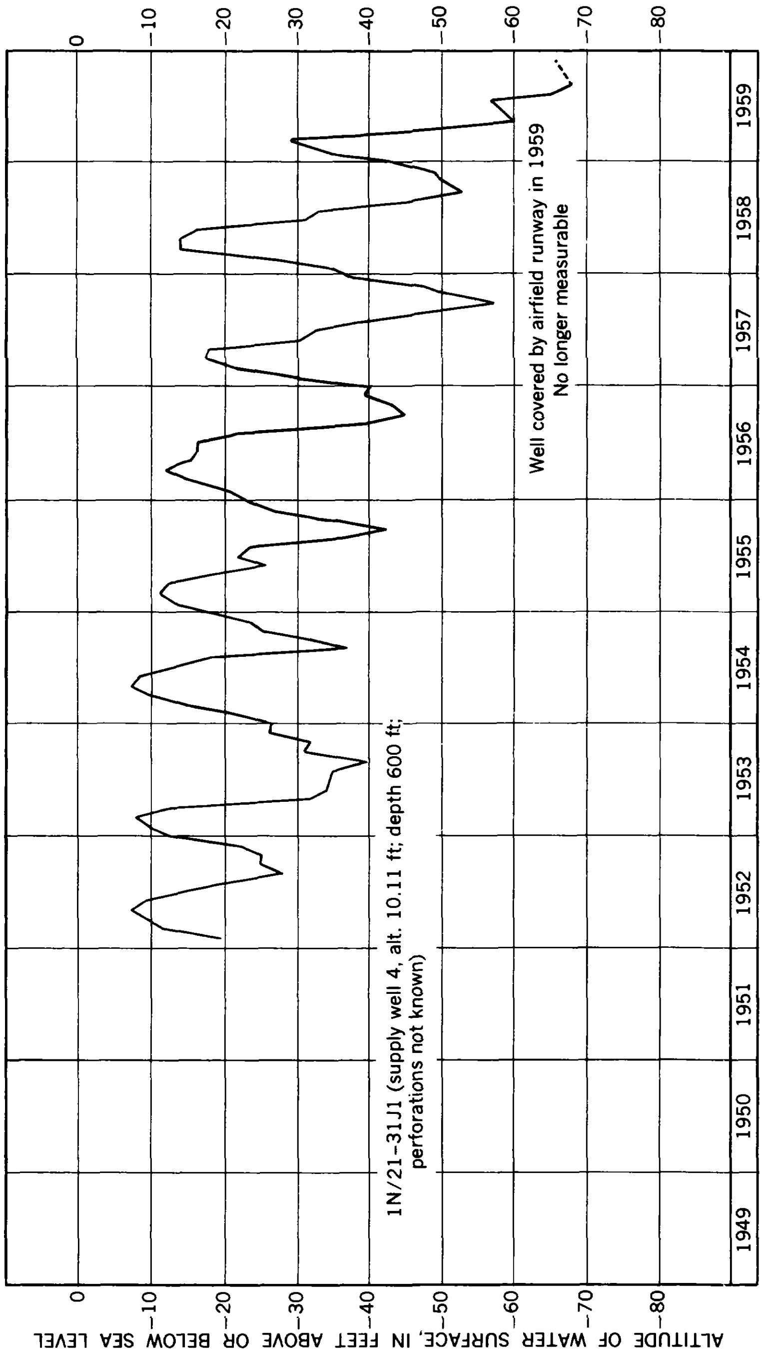


FIGURE 5.—Hydrograph of well 1N/21-31J1.

PUMPAGE

The annual water requirements for the test center have increased from about 175 acre-feet in 1948 to about 1,255 acre-feet in 1959, as shown below.

Annual pumpage from wells at the Naval Air Missile Test Center, Point Mugu, Calif., 1948–59

Year	Pumpage (acre-ft)	Year	Pumpage (acre-ft)	Year	Pumpage (acre-ft)
1948	[a] 175	1952	342	1956	444
1949	239	1953	438	1957	490
1950	301	1954	400	1958	762
1951	295	1955	411	1959	1,255

[a] Estimated by the Geol. Survey.

This increase in water consumption, together with irrigation pumping in the Oxnard Plain north of the test center, has caused the water level to decline at a rapid rate.

The peak water consumption for the test center usually occurs during the late spring and summer months (fig. 6), when water levels are lowest. However, the water-supply pumping at the test center is not as great as the irrigation pumping in the area. In 1958 a housing project was constructed at the test center and was occupied during the late summer and early autumn. This resulted in a peak water

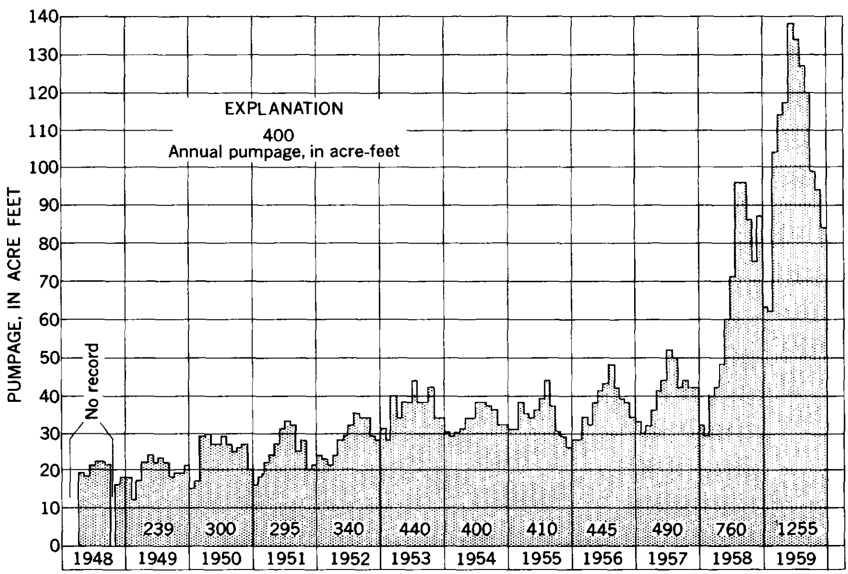


FIGURE 6.—Pumpage from wells at the Naval Air Missile Test Center, Point Mugu, Calif., 1948–59.

consumption during the months of August, September, October, and November. Despite the continued high use of water at the test center in the autumn of 1958, however, the water levels in the supply wells began to rise in September as a result of decreased pumping for irrigation outside the center.

QUALITY OF WATER

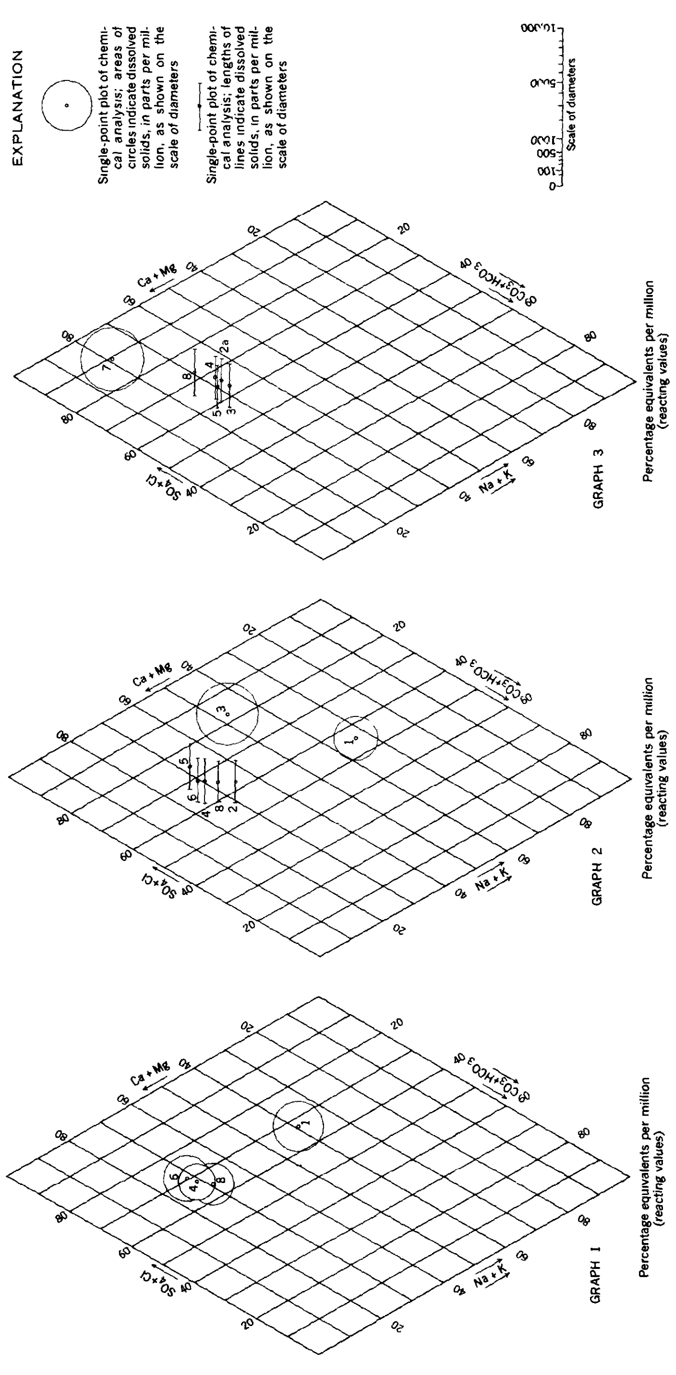
The chemical quality of ground water in the test center area differs with depth and locally sea water has intruded the ground-water body. Consequently, a knowledge of the water quality is necessary for obtaining the best possible water supply, planning of a pumping regimen that will minimize sea-water encroachment, determining the extent of sea-water encroachment, and establishing a system for observing future changes in ground-water quality.

During the field canvass of wells, the Geological Survey collected water samples for chemical analysis and assembled existing analyses of water from more than 25 wells. These analyses are listed by Page and Kunkel (1960, tables 5, 6, and 7). In addition, the U.S. Navy supplied analyses of water from the test center wells, and the Ventura County Department of Public Works and the United Water Conservation District supplied analyses for the area outside the test center.

The suitability of ground water for general use is determined by the concentration of dissolved solids and the relative proportion of the various ions in solution.

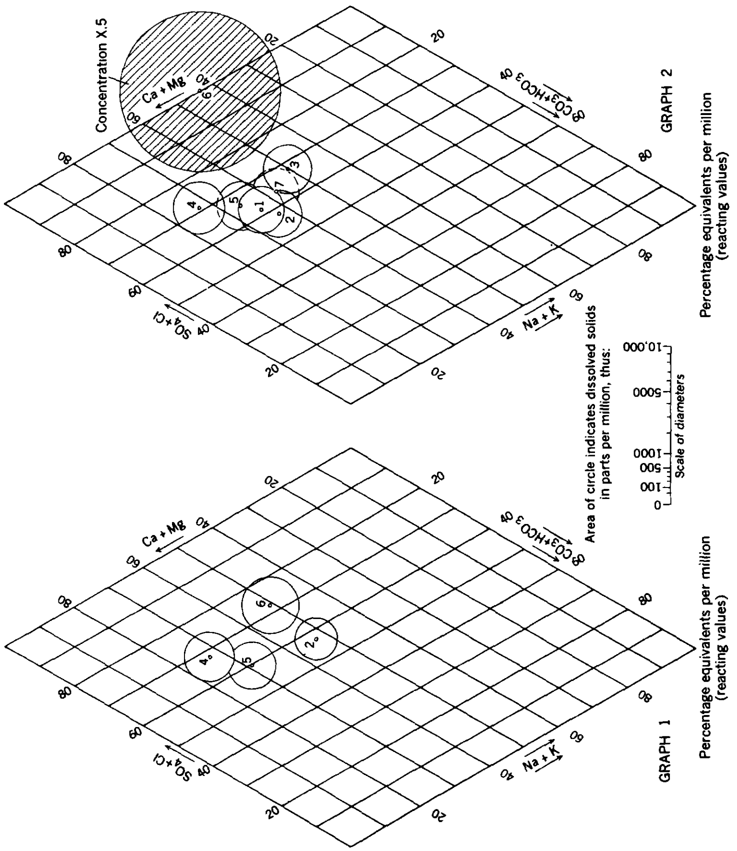
In this report, the chemical character of selected water samples (table 2) is shown graphically (figs. 7, 8) by use of the rectilinear plot described by Piper (1944, p. 914–923). By this method the common cations—calcium, magnesium, and sodium plus potassium—are plotted as one coordinate and the common anions—bicarbonate (including carbonate), sulfate, and chloride—are plotted as the other, all expressed in percentage equivalents per million. This method permits a one-point plot for each analysis and an immediate determination of the general character of the water by location of the point on the graph.

A study of the available analytical data and electric logs indicated that the water-bearing deposits can be subdivided into three distinct depth zones with respect to water quality, as follows: (1) A shallow zone extending from the water surface to a depth of about 150 feet, in which the water is salty; (2) an intermediate zone from about 150 feet to 1,000 feet below land surface, in which the water generally is fresh but locally is brackish; and (3) a deep zone from 1,000 feet to 1,500 feet below land surface, in which the water is salty.


EXPLANATION
Single-point plot of chemical analysis; areas of circles indicate dissolved solids, in parts per million, as shown on the scale of diameters
Single-point plot of chemical analysis; lengths of lines indicate dissolved solids, in parts per million, as shown on the scale of diameters
Scale of diameters
0
100
500
1000
5000
10,000
Ca + Mg
SO_4+Cl
CO_3+HCO_3
Na + K
GRAPH 1
GRAPH 2
GRAPH 3
Percentage equivalents per million (reacting values)

Graph 1				Graph 2				Graph 3			
No.	Well	Date	Depth of well (ft)	No.	Well	Date	Depth of well (ft)	No.	Well	Date	Depth of well (ft)
1	1N/21–27F1	Nov. 25, 1932	840	1	1N/21–27F1	July 27, 1949	840	2a	1N/21–29D2	Oct. 24, 1957	602
4	1N/22–26A1	Apr. 15, 1931	236	2	1N/21–29D1	Apr. 22, 1947	570	3	1N/21–29R1	Oct. 16, 1956	205
6	1N/22–29A2	Mar. 3, 1933	225	3	1N/21–29R1	Dec. 6, 1950	205	4	1N/22–26A1	Oct. 16, 1956	236
8	1N/22–36K1	Apr. 3, 1933	186	4	1N/22–26A1	May 5, 1949	236	5	1N/22–28A1	Oct. 24, 1957	-----
				5	1N/22–28A1	May 5, 1949	-----	7	1N/22–28B1	May 8, 1958	230
				6	1N/22–29A2	Mar. 31, 1947	225	8	1N/22–36K1	Oct. 28, 1957	186
				8	1N/22–36K1	May 5, 1949	186				

FIGURE 7.—Chemical character of ground water from wells outside the test center.


Concentration X.5
Ca + Mg
SO4 + Cl
Na + K
CO3 + HCO3
20
40
60
80
GRAPH 1
GRAPH 2
Percentage equivalents per million
(reacting values)
Area of circle indicates dissolved solids
in parts per million, thus:
0
100
500
1000
5000
10,000
Scale of diameters

No.	Well No.	Test center No.	Date	Depth of well (ft)
2	1N/21-31L1	Supply well 3	Feb. 15, 1949	750
4	1N/21-32G1	Supply well 1	Feb. 9, 1948	434
5	1N/21-32K1	Supply well 2	Feb. 9, 1948	622
6	1S/21-4E1	Observation well 2	July 7, 1949	350

No.	Well No.	Test center No.	Date	Depth of well (ft)
1	1N/21-31J1	Supply well 4	Jan. 7, 1958	600
2	1N/21-31L1	Supply well 3	Jan. 7, 1958	750
3	1N/21-32A1	Supply well 5	Oct. 23, 1958	750
4	1N/21-32G1	Supply well 1	Jan. 7, 1958	434
5	1N/21-32K1	Supply well 2	Jan. 7, 1958	622
6	1S/21-4E1	Observation well 2	Jan. 10, 1958	350
7	1S/21-6F1	Observation well 1	Jan. 10, 1958	350

FIGURE 8.—Chemical character of ground water from wells at the test center.

TABLE 2.—*Chemical analyses of waters from selected wells*

[Constituents (in parts per million). The sum of determined constituents is the sum of the constituents analyzed except for bicarbonate which is divided by 2.03 (Collins, 1928, p. 253). All values have been rounded where necessary to conform to the standards of the Geological Survey. Analyzing laboratory. DA, U.S. Dept. of Agriculture; DWR, California Dept. Water Resources; F, Fruit Growers Association; GS, Geol. Survey; N, U.S. Navy; U, United Water Conservation District]

Well	Analyzing laboratory and number	Depth (ft)	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	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 $CaCO_3$	Sum of determined constituents	Percent sodium	Specific conductance (Micromhos at 25°C)	pH
1N/21-27F1	F-2128	840	Nov. 25, 1932				72	58	[1] 295		431		292	283				1,430	418	1,210	60		
	F-9369-5		July 27, 1949				72	29	[1] 278		404	41	74	302					299	995	67		
28G2	F	370	Feb. 9, 1927				138	59	[1] 93		401		163	206				1,060	588	857	26		
	F-7890		May 14, 1947				135	43	[1] 115		305		351	106			0.33	1,060	514	900	33		
29D1	F-7865	570	Apr. 22, 1947				112	30	94	12	267	0	317	49			.39	881	403	746	33		
29D2	4031A	602	Oct. 24, 1957				120	37	[1] 97		284		358	42			.66	938	452	795	32		
29R1	F-182A	205	Dec. 6, 1960				160	67	333	17	307		535	430				1,850	675	1,690	51		
	F-3432A		Oct. 16, 1956				115	39	[1] 99		300		328	54			.47	935	448	783	32		
31J1	GS-25033	600	Jan. 7, 1958	75	43	0	86	39	96	5.7	266	0	250	68	0.3	1.0	.40	747	375	720	35	1,070	7.4
31L1	F-8996	750	Feb. 15, 1949				74	36	136	4	332		198	110				890	333	722	47		
	GS-25032		Jan. 7, 1958		44		84	37	96	5.7	290	0	240	52	.3	1.3	.49	736	362	704	36	1,000	7.2
32A1	GS-28199	750	Oct. 23, 1958		46		98	42	182	6.6	316	0	261	192		.6	.6		416	985	48	1,590	7.5
32G1	F-8316	434	Feb. 9, 1948				118	37	[1] 92		281	2	333	47			.37	908	447	767	31		
	GS-25030		Jan. 7, 1958	69	39	0	162	42	99	4.9	274	0	355	140	.3	.6	.63	1,010	575	978	27	1,410	7.3
32K1	F-8317	622	Feb. 9, 1948				90	43	117		254		333	68			.30	905	402	776	39		
	GS-25031		Jan. 7, 1958		39	0	108	38	96	5.6	276	0	293	75	.3	2.2	.57	819	425	794	33	1,160	7.1
1N/22-26A1	DA-4031	236	Apr. 15, 1931				122	38	[1] 84		253		362	41			.54		461	773	28	1,140	
	F-9196		May 5, 1949				125	34	[1] 90		255		361	44				909	452	780	30		
	F-3431A		Oct. 16, 1956				128	32	100		263		365	42			.49	930	451	797	32		
28A1	F-9193		May 5, 1949				147	44	[1] 121		255		490	56			.64	1,110	548	985	32		
	F-4033A		Oct. 24, 1957				119	39	[1] 94		280		358	40			.66	930	458	789	31		
28B1		230	May 8, 1958				370	137	[1] 182		241		463	850					1,490	2,120	21		
29A2	DWR-1900		Mar. 3, 1933				126	41	[1] 98		245		404	52			.62	966	483	843	31		
	U-7808	225	Mar. 31, 1947				124	41	99	7	253	0	395	42		3	.52	954	479	827	28		
36K1	U-1960	186	Apr. 3, 1933				119	36	95		275	0	353	40			.60	918	445	779	32		
	F-9195		May 5, 1949				119	32	[1] 94		265		335	45		1		891	429	757	32		
	F-4048A		Oct. 28, 1957				154	39	[1] 112		265		331	162			.60	1,060	545	930	31		
1S/21-4E1 (below packer)	N	350	July 7, 1949				125	51	[1] 229		279	49	385	307		Trace		1,420	522	1,280	49		
	GS-24811 [2]		Jan. 10, 1958		8.2	.13	1,720	75	4,380	65	105	0	1,110	11,600	.2	9.6	1.0	20,300	7,360	19,000	56	30,400	6.4
6F1 (above packer)	GS-24808	350	Jan. 10, 1958								254	4		90					376			1,130	8.3

[1] Potassium included.
[2] CO_2, 66 ppm.

SHALLOW ZONE

Electric logs of wells 1N/21–31L1, 1S/21–4E1, and 1S/21–6F1 indicate that water having a high dissolved-solids content is contained in this zone, which is about 150 feet thick. In addition, several well owners report that they obtained water of poor quality from the deposits in this zone. Detailed analyses of water are not available,[3] but, on the basis of a few partial analyses, the water is believed to be predominantly of the sodium chloride type.[4] However, chemical analyses of water from well 1N/22–36K1, 186 feet deep, indicate that water of potable quality may be obtained from the shallow zone locally. The chloride content of water from well 1N/21–29R2 (perforated 88–120 ft) was 150 ppm (parts per million) in May 1948 (Page and Kunkel, 1960, table 6).

Analyses of water from well 1N/22–36K1 (perforated 150–168 ft) show chloride contents that range from 40 ppm in 1933 to 162 ppm in 1957 (table 2). These analyses indicate a variation in the chloride content of the water in the shallow zone; however, there is not sufficient evidence to conclude that the increase in chloride between 1933 and 1957 at well 1N/22–36K1 was caused by sea-water encroachment.[5]

The sulfate content of water in the shallow zone varies, but in at least one well perforated in this zone the sulfate content of water has remained relatively constant. Analyses of water from well 1N/21–28G2 (perforated 138–180 ft) show sulfate contents of 163 ppm in 1927, 418 ppm in 1932, and 351 ppm in 1947 (table 2). The sulfate content of water from well 1N/22–36K1 (perforated 150–168 ft) was 353 ppm in 1933, 354 ppm in 1947, and 331 ppm in 1957. Because the degree of hydraulic continuity between the shallow and deep zones is not known, it cannot be demonstrated, at this time, how the quality of water from the shallow zone affects that of the intermediate and deep zones. However, if there are no extensive impermeable beds separating the shallow water from deeper water, the lowering of head

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[3] The analysis of water taken on January 10, 1958, from well 1S/21–4E1 probably is an exception to this statement. This water probably leaked into the well from the shallow depth zone, as it is of a sodium chloride type.

[4] In this report, terms describing the general chemical character of a water follow the usage of Piper, Garrett, and others (1953, p. 26, footnote) and are used in particular senses, as in the following examples: "(1) 'Calcium bicarbonate' designates a water in which calcium amounts to 50 percent or more of the bases and bicarbonate to 50 percent or more of the acids, in chemical equivalents; (2) 'sodium calcium bicarbonate' designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the bases but neither amounts to 50 percent of all the bases; and (3) 'sodium sulfate bicarbonate' designates a water in which sulfate and bicarbonate are first and second, in order of abundance among the acids, as above."

[5] Analyses of water from well 1N/22–36K1 for 1933, 1949, and 1957 (fig. 7) indicate an appreciable shift in the relative concentrations of chloride with no comparable increase in the concentrations of the other constituents.

in the deeper zones by pumping would cause a movement of water from the shallow zone into the intermediate zone.

INTERMEDIATE ZONE

The intermediate zone beneath the test center is about 850 feet thick, extending from about 150 to 1,000 feet below land surface. The quality of water from wells that tap this zone has remained stable since at least 1931, as indicated by records of water quality of well 1N/21-26A1 (perforated 188-229 ft). The water is generally of the calcium sodium sulfate type, but other types are present locally, such as calcium magnesium chloride water from well 1N/22-28B1 (fig. 7, analysis 7). Water from the latter well may show the effect of the encroachment of sea water of modified character.

Chloride content of the water in the intermediate zone, as indicated by repeat analysis, does not appear to be increasing, but it varies considerably among individual wells (Page and Kunkel, 1960, tables 5, 6, and 7). Chloride contents range generally from about 40 to 70 ppm, with a few analyses showing as much as 300 or 400 ppm. However, in 1958 the water from well 1N/22-28B1 (table 2) had a chloride content of 850 ppm. Also, in 1958 the water from well 1S/21-4E1 had a chloride content of 11,800 ppm. However, the water from well 1S/21-4E1 may be from a tidal slough that is about 100 feet north of the well and may not represent the true character of the water in the intermediate depth zone.

Sulfate content of the water in the intermediate zone of the test center area ranges from about 191 ppm in well 1N/22-23R1 to about 463 ppm in irrigation well 1N/22-28B1 (Page and Kunkel, 1960, table 5). Water from well 1N/21-32G1 (supply well 1) contains 355 ppm, which is considered to be a detriment to photographic processing at the test center. For this reason, that well at times is cut off from the water-distribution system. An unusually high sulfate content, more than 1,100 ppm, was observed in water from well 1S/21-4E1 in 1958. As described previously, however, it probably is not representative of the zone.

The hardness of water from the intermediate zone of the test center area ranges from 291 ppm in well 1N/21-28C1 to 924 ppm in well 1N/22-28B1. Without treatment such water is not suitable for general use, as it forms scale in boilers and on utensils and requires excessive amounts of soap for laundering.

Babbitt and Doland (1949, p. 388) classify hardness of water as follows:

Hardness classification for domestic water

Class	1	2	3	4
Degree of hardness	Soft	Slightly hard	Moderately hard	Very hard
Hardness (ppm)	0–55	56–100	101–200	201–500

Water from the intermediate zone is "very hard" and should be treated for domestic use.

DEEP ZONE

Water in the depth zone from about 1,000 feet to about 1,500 feet below land surface appears to be salty, as indicated by an electric log of well 1N/21–31L1 (supply well 3). This well, drilled to a depth of 1,583 feet, indicated salty water below 1,000 feet and was therefore plugged at 750 feet and completed in the intermediate zone. Because no other wells penetrate the deep zone and no water analyses are available from it, the exact lower limit of fresh water has not been determined for the area.

Salty water contained in the deep zone probably is connate sea water trapped in the rock interstices at the time the rocks were deposited.

SEA-WATER ENCROACHMENT

Encroachment of sea water into the deposits beneath the Oxnard Plain is known to have occurred in the vicinity of Port Hueneme. Wells 1N/22–29A1, 29A2, and 29C1 were reported to have been destroyed because they yielded salty water. Because water from well 1N/22–29A2 had a chloride content of only 41 ppm in 1947 (table 2), it is inferred that the encroachment in this area has occurred since that time. More recent evidence of possible sea-water encroachment is the chloride content of the water in well 1N/22–28B1, which was 850 ppm in May 1958. This well is about half a mile inland from the Pacific Ocean and about 1 mile east of the area where encroachment of the Oxnard Plain was initially observed. The presence of high chloride water at this point probably reflects an expansion of the encroached area and an increased rate of encroachment caused by pumping in the Port Hueneme area.

Since 1949, samples of water from well 1S/21–4E1 (obs. 2) have been collected periodically for chloride analyses to observe the effect of sea-water encroachment into the upper 500 feet of the deposits in the test center. These analyses (fig. 9) show an increase in chloride content from about 300 ppm in 1949 to more than 5,000 ppm in 1953 and about 12,000 ppm in 1958. The well was designed to permit inde-

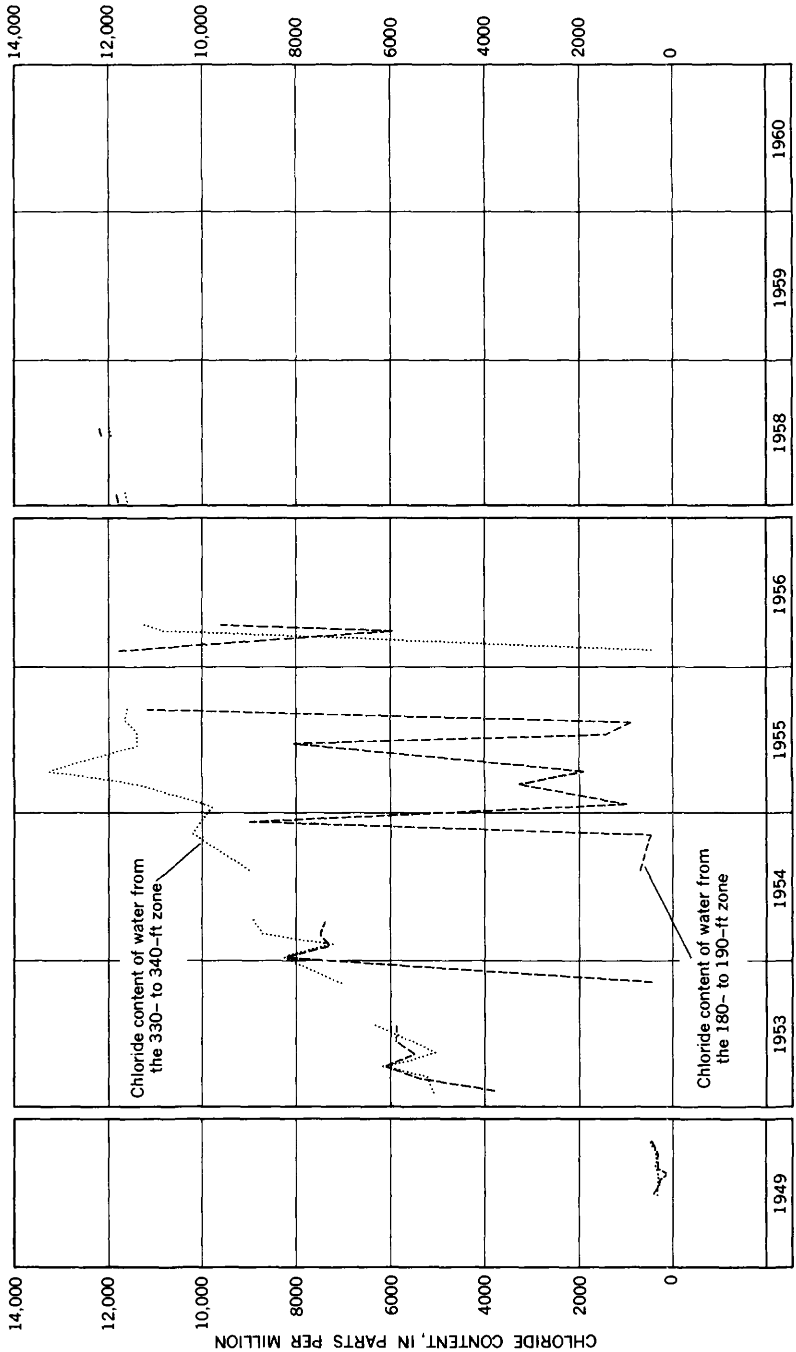

FIGURE 9.—Chloride content of water from well 1S/21-4E1 at the Naval Air Missile Test Center.

pendent observations of water levels in and collection of water samples from the intervals between 180 and 190 feet and between 330 and 340 feet below land surface. However, pump tests at the well indicate that the rubber packer set at a depth of 210 feet has failed, and the perforations in both depth zones appear to have been plugged. Therefore, the water levels after 1951 are not representative for the aquifer (fig. 10). Figure 9 shows, however, a steady increase in chloride content of water in the zone perforated from 330 to 340 feet, which possibly could be attributed to sea-water encroachment. However,

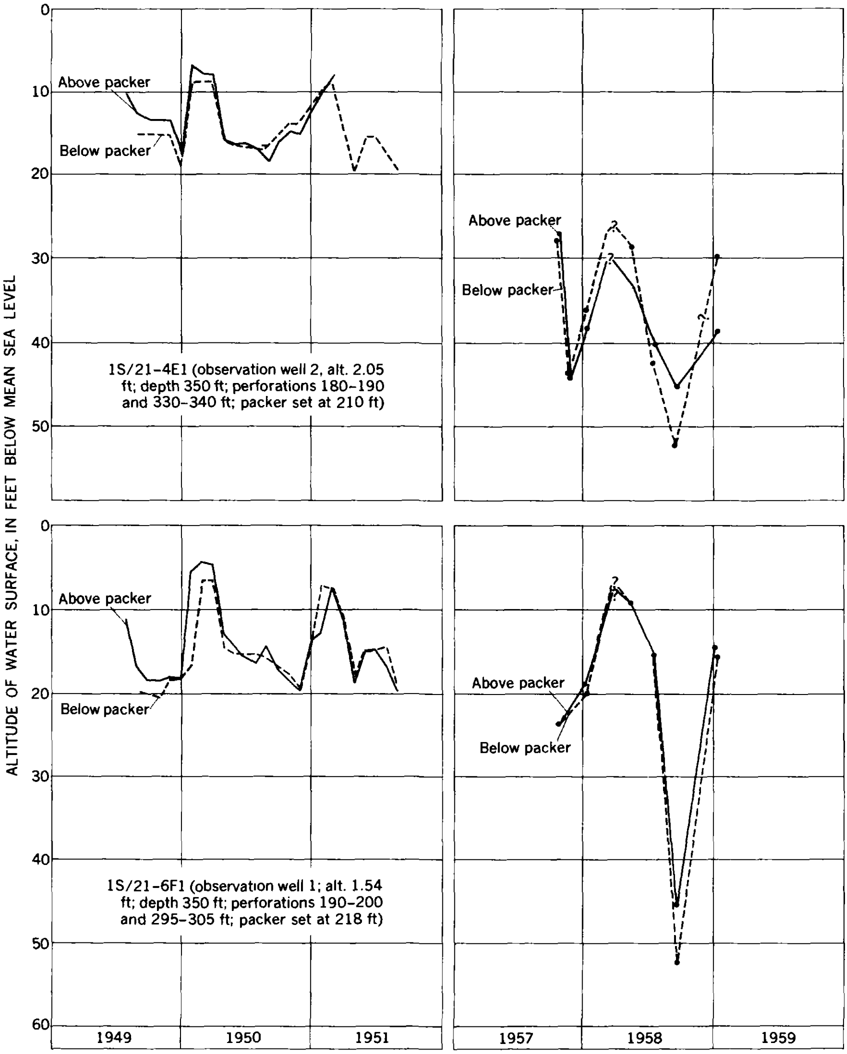

FIGURE 10.—Hydrographs of observation wells 1S/21-4E1 and 1S/21-6F1.

the lower chloride contents observed during the early parts of some years after 1952 may coincide with periods of runoff in Calleguas Creek and of decreased pumping in the test center area. The runoff and reduction of pumping may be reflected by dilution of incoming fresh water from the east, possibly including recharge from Calleguas Creek.

The water samples from well 1S/21–4E1 (obs. 2) may have contained some water that leaked into the well from very shallow zones in direct hydraulic continuity with the tidal sloughs. The excessively high chloride contents in this case would obscure the results of sea-water encroachment and it therefore cannot be concluded that the high chloride content, above and below the packer, in well 1S/21–4E1 is caused entirely by sea water moving into the ground-water body through its submarine outcrop.

The rate of sea-water encroachment into the deposits beneath the test center is unknown. However, the possibility of contaminating all the fresh water beneath the test center area will be greatly increased if sea-water encroachment reaches the well field in the deposits of shallow depth. Because of the higher head in the shallow deposits, downward leakage of any intruded salt water would occur and would contaminate the supply wells.

SUGGESTIONS FOR FUTURE STUDIES

OBSERVATION WELL NETWORK

In 1959 the Geological Survey measured water levels in 37 wells south of Hueneme Road of which 16 wells are measured periodically by either the United Water Conservation District or the Ventura County Department of Public Works (pl. 1). The six supply wells and the two observation wells at the test center are included in the network.

The water-level measurements from the wells are used to maintain current water-level data and to show hydraulic gradients and differentials of head in the water-yielding deposits. Also, periodic chemical analyses are made from the water from 16 wells south of Hueneme Road by the United Water Conservation District, the Ventura County Department of Public Works, or the Geological Survey, in order to provide data used in detecting and monitoring the rate of sea-water encroachment into the water-yielding deposits beneath the test center. Therefore, because of the threat of sea-water encroachment, it is suggested that the observation well network be expanded and that the measuring and sampling of wells be continued.

In the critical area, between the ocean and the test center supply wells, the network of wells for observing changes in water levels and quality of water in the shallow zone consists only of wells 1S/21–4E1 (obs. 1) and 1S/21–6F1 (obs. 2). This is an insufficient number of wells to detect adequately and monitor the rate of sea-water encroachment into the shallow zone, which is the zone subject to the greatest danger. Furthermore, the water-level and chemical-quality data from well 1S/21–4E1 (obs. 1) may not be reliable. In order to insure reliable data, both observation wells should be rehabilitated. Also, well 1N/22–27F2 (perforated from 130 to 230 feet but now inaccessible for water-level measurements)[5] should be added to the observation well network. In addition, one observation well, perforated from 10 to 150 feet, should be drilled in the NW¼SE¼ sec. 35, T. 1 N., R. 22 W.

The work suggested here would provide a minimum number of wells to detect and monitor the rate of sea-water encroachment beneath the test center, and should help the Navy to plan for a supplemental supply of water before the fresh water in the deposits beneath the center is contaminated.

TEST DRILLING

In addition to drilling a new observation well in the NW¼SE¼ sec. 35, T. 1 N., R. 22 W., as suggested in the previous section, test wells should be drilled to determine more accurately the thickness of the water-bearing zones, the hydraulic gradient in each zone, and the hydraulic characteristics of the deposits. Collection of data for the deposits between 750 and 950 feet is particularly critical because these deposits are a source of water, which if properly developed, may be relatively free from sea-water enroachment for many years. However, to date virtually no data have been collected for these deposits.

To supply the necessary data, two sets of three closely spaced wells should be drilled. One set of wells should be near well 1S/21–4E1 (obs. 2) and the other set should be near well 1S/21–6F1 (obs. 1). They would be used to determine the character of the deposits and could be used as permanent observation wells for water-level and chemical-quality data. The generalized specifications for proposed test wells are given below.

[5] There is no access for measuring the water level in well 1N/22–27F2. It is suggested that the Navy secure permission and arrange for such access by means of a hole in the casing.

Depth of proposed test wells

	Location of well	Estimated maximum depth of well (feet)	Perforated zone (feet)
1	Near 1S/21-6F1 (obs. well 1)	200	10- 150
2	Near 1S/21-6F1 (obs. well 1)	750	200- 750
3	Near 1S/21-6F1 (obs. well 1)	1, 200	800-1, 200
4	Near 1S/21-4E1 (obs. well 2)	200	10- 150
5	Near 1S/21-4E1 (obs. well 2)	750	200- 750
6	Near 1S/21-4E1 (obs. well 2)	1, 200	800-1, 200
7	NW¼ SE¼ sec. 35, T. 1 N., R. 22 W	200	10- 150

If the two existing observation wells can be rehabilitated it would not be necessary to redrill wells 1 and 4 shown in the preceding table.

Depending on the results of drilling and testing the wells described above, it may be necessary to drill and test pump 1 or 2 additional observation of wells of intermediate depth (750 ft) to determine the coefficients of transmissibility and storage of the deposits.

TEST PUMPING

Testing of the water-bearing deposits beneath the test center would be done by using the test wells described in the preceding section. Test pumping under carefully controlled conditions can be used to determine whether the aquifers of each zone are in hydraulic continuity with each other and the ocean. Also, if the tests are successful, the data from several tests can be used to estimate the coefficients of transmissibility and storage. It is necessary to know these coefficients, together with quality of water data from the test wells to estimate the rate of sea-water enroachment into the aquifers beneath the test center.

Hydraulic continuity between the water-bearing deposits could be evaluated by pumping the wells which tap the deposits between 200 and 750 feet at the sites of wells 1S/21-4E1 and 1S/21-6F1. If these wells of intermediate depth are pumped the drawdown effects, if any, in the shallow and deep test wells, would demonstrate hydraulic continuity between the three zones. If the testing at these two sets of three wells does not show hydraulic continuity between all of the aquifers and if the coefficients of transmissibility and storage cannot be computed, it will be necessary to drill another observation well of intermediate depth (750 ft) near well 1N/21-32A1 (supply well 5). A pumping test, using well 5 as the pumping well and the new well as the observation well, would provide data for computing the coefficients of transmissibility and storage of the deposits between 200 and 750 feet.

If the testing at the sites of existing observation wells 1 and 2 shows hydraulic continuity between the zones at these sites, it will be necessary to drill two observation wells of intermediate depth near supply well 5 to determine the coefficients of transmissibility and storage. These two additional observation wells at supply well 5 would be necessary because, in a leaky aquifer, one observation well or several penetrating wells do not provide reliable data for determining the coefficients of transmissibility and storage.

It will be necessary to drill the proposed wells and make the test at the sites of observation wells 1 and 2 before a final decision can be made regarding the need for drilling and testing near supply well 5.

In any event, the drilling of the seven proposed wells should be completed in order to detect and monitor the rate of sea-water enroachment into the water-bearing deposits beneath the test center.

DEVELOPMENT OF ADDITIONAL SUPPLIES

Conditions have been established under which sea-water encroachment has begun in the seaward extension of the deposits underlying the test center. Continued withdrawal of ground water at the present rate will result in the continued advance of sea water, thus endangering the test center water supply. Poland, Garrett, and Mann (1948, p. 32) listed the following possible sources of additional water supplies, which are the only economical sources at the test center: (1) development of water-bearing deposits between 500 and 750 feet deep, (2) development or purchase of a supply from a source outside the test center and far enough inland to reduce the danger of sea-water encroachment, or (3) tapping aquifers, which are deeper than those now tapped by existing wells.

Future supply wells at the test center should be completed to tap the deposits more than 500 feet below land surface. Because the outcrop of the shallower deposits is nearer the coast than the outcrop of the deeper deposits, increased or continued pumping from the deposits shallower than 500 feet below the surface will cause sea water to enter those deposits and override a large amount of fresh water contained in deposits deeper than 500 feet. Because the head in the shallower deposits is higher than the head in the deeper deposits, sea-water encroachment into the shallow deposits could, by downward leakage, contaminate and destroy for future use the fresh water in the deeper deposits. Therefore, to retard or prevent sea-water encroachment into the shallow deposits, the test center first should utilize the large quantity of water contained in the deeper deposits and then conserve for later use the water contained in the shallower deposits.

In addition to ground water beneath the test center, sources of ground water outside the test center area may be considered, the use of which would reduce or delay sea-water encroachment and reserve the test center well field for emergency or supplemental supplies. One such outside source is the property, with related water rights for development of ground water from existing or new wells, to the northeast of U.S. Highway 101–A and between the test center and the town of Oxnard (Poland and others, 1948, p. 33). An alternate area would be approximately 2 or 3 miles directly north of the test center.

A third source of water outside the test center would be the purchase of water from the United Water Conservation District. Purchase of water from this source would result in a decrease of ground-water withdrawal at the test center well field, thereby reducing the threat of sea-water encroachment, making it possible to artificially recharge the ground-water reservoir. The United Water Conservation District operates spreading basins near Saticoy into which floodwater is diverted during the rainy season to augment the natural ground-water recharge. Presumably, water purchased from the district would be pumped from wells in the Saticoy area, about 10 miles northwest of the test center and would be carried by pipeline to the center.

In addition to the sources described above, the depth zone from 750 to 900 feet should be considered as a possible source of ground water. Wells 1N/21–31L1 (supply well 3) and 1N/21–32A1 (supply well 5) were drilled to depths of 1,583 feet and 803 feet, respectively, to explore the deposits beneath the test center for productive confined aquifers. The logs of these wells, however, indicate no confining strata of low permeability which would prevent contamination of the water in the deep zone by salty water moving downward from the shallow deposits. However, the electric log of well 1N/21–31L1 shows water of fair quality in the zone of permeable deposits between 750 and 950 feet below land surface, underlain by salty water below 1,000 feet.

Although no extensive confining layer appears to be present, the 750- to 950-foot zone should be considered as a potential source of ground-water supply, as there is presently no withdrawal of water from this zone in the test center area. Development of this zone for the greater part of the test center supply would permit a reduction of pumping from the shallow deposits and thus would slow the advance of sea water in the shallower zones. Such development may result eventually in some encroachment into the deeper zone, either from the sea or by upward migration of saline water beneath this zone. However, because of the greater distance of the seaward out-crops of the deposits from the test center, the threat of sea-water encroachment into the deposits beneath the test center would be reduced to the minimum.

Any plan utilizing one or more of the suggested sources for the test center water supply should provide for reducing withdrawal of water from the deposits shallower than 500 feet. If all the future water supply is obtained by continued and expanded use of the present well field, all future wells should be completed at depths greater than 500 feet, and preferably in the zone between 750 and 950 feet below land surface, where the water is of good quality. Therefore, the following wells which are perforated above 500 feet should not be used except for emergency use.

USGS Well	Navy No.	Perforated interval (feet)
1N/21-31L1	Supply well 3	350-420; 476-530; 620-700
1N/21-32G1	Supply well 1	121-137; 311-325; 417-432

The remaining supply wells are perforated and pump almost exclusively from the deposits below 500 feet; therefore, their continued use does not seriously affect the status of sea-water encroachment in the shallow zone. This pattern of pumping, however, does not preclude sea-water encroachment into the deposits below 500 feet.

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