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GEOLOGICAL SURVEY

PROGRESS REPORT ON WATER SUPPLY FOR
THE POINT MUGU NAVAL BASE, VENTURA COUNTY, CALIFORNIA

BY

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Department of the Navy

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PROGRESS REPORT ON WATER SUPPLY FOR THE POINT MUGU NAVAL BASE, VENTURA COUNTY, CALIFORNIA

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INTRODUCTION

Purpose of report

At the request of the Bureau of Yards and Docks of the Navy Department, the U. S. Geological Survey is making an investigation of the underground water resources of the Naval Air Missile Test Center at Point Mugu, Ventura County, California. The study was requested with special reference to the Navy's planned expansion of this center and the contemplated requirement of about one million gallons a day of water. In its initiating request, the Bureau of Yards and Docks indicated that because of the current ~~recession~~ decline of ground-water levels, there appears to be a serious possibility of salt-water invasion into the well field at the Point Mugu Naval Base.

This progress report summarizes the factual data ~~which~~ that have been collected, includes a brief statement of geologic and hydrologic conditions beneath the Oxnard Plain, and summarizes the present knowledge with respect to possible sea-water invasion near the Point Mugu and Port Hueneme Naval Bases. It discusses briefly the several possibilities for obtaining the required supply of water and suggests development of a temporary supply at the Point Mugu Naval Base. Also, it outlines certain additional work by the Geological Survey to evaluate possibilities for development of deeper aquifers and to obtain field data relating to ocean-water intrusion.

Area of study

The Point Mugu Base occupies an area of about 4 square miles at the south edge of the Oxnard Plain, the coastal plain of Ventura County (see pl. 1). The Oxnard Plain borders the Pacific Ocean, has a length of about 15 miles extending northwestward from Point Mugu to the city of Ventura, and an average width of 10 miles. It is traversed by the Santa Clara River on the north and by a much smaller stream, Calleguas Creek, on the south. On the north, east, and south, the Oxnard Plain is bounded by highland areas, for the most part composed of non-water-bearing formations. The highlands are separated by tongues of alluvium which extend inland from the plain and comprise the Santa Paula, Las Posas, and Pleasant Valley Basins (pl. 1). The Santa Paula Basin is separated from the Oxnard Plain by a ground-water barrier; the divisions between the southern two basins and the Oxnard Plain are somewhat arbitrary, corresponding roughly with the mouths of the alluvial re-entrants.

About 7 miles northwest along the coast from Point Mugu is the Naval Construction Battalion Center at Port Hueneme. The water supply for this Base is taken from wells. Because the draft from this well field has decreased substantially since the war, it has been suggested that a firm water supply for the expanded Point Mugu Naval Base might be obtained by pumping so-called "surplus" water from these wells and transporting it through a pipe line to Point Mugu. Thus, the integrity of the ground-water supply at the Port Hueneme Base also is an issue in this investigation.

Because of the condition just outlined, an investigation relating ~~specifically to~~ of the water supply for the Point Mugu Naval Base ~~must~~ necessarily ~~concern itself with~~ must be extended to examine the geology and ground-water conditions beneath the Oxnard Plain as a whole.

Other investigations

1. The first intensive investigation of the water resources of Ventura County was carried on by the California Division of Water Resources from 1927 to 1932 and resulted in two publications.[1] This study was primarily an evaluation of water resources, both surface and ground waters, for the entire county. Although a large ~~amount~~ number of data were collected on water levels in wells and on quality of ground waters, the geology of the water-bearing deposits was not studied in any detail.

2. After completion of this investigation in 1932, Mr. R. H. Jamison, who had been in charge of field operations for the Division of Water Resources, was employed by Ventura County to continue the survey of water resources. From 1932 to date, Mr. Jamison's office has obtained continuing data on stream flow and on water levels in wells. Within the Oxnard Plain, for example, periodic measurements have been made about 3 times a year for about 150 wells and plotting of hydrographs for these wells is kept up-to-date. Mr. Jamison's office has collected a few well logs but has not had

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1/ Conkling, Harold, Ventura County Investigation: California Dept. Public Works, Water Resources Div., Bull. 46, 244 pp., 1933.

Anon., Ventura County Investigation, Basic data for the period 1927 to 1932, inclusive: California Dept. Public Works, Water Resources Div., Bull. 46-A, 574 pp, 1933.

the funds to make any interpretive studies of the ground-water conditions, nor to carry on any continuing program of water analysis.

3. The Santa Clara Water Conservation District was organized in 1923 for the purpose of protecting water rights and of conserving the waters of the Santa Clara River and its tributaries. This District embraces 110,000 acres of land, including most of the Oxnard Plain, and extending inland up the Santa Clara River Valley for a distance of about 23 miles from Saticoy. Under the direction of Mr. V. N. Freeman, Managing Engineer, the District has operated spreading works since 1928 and as part of its field program since 1932 has made measurements of depth-to-water and analyses of water quality in selected wells. For the Oxnard Plain, periodic measurements of depth-to-water have been made in 16 wells since 1933. Early in 1948 the number of wells being measured was increased to 37; all these wells now are measured bi-weekly. Periodic analyses for chloride content were made on waters from 8 wells in the middle thirties and as a result of the decline of water levels, since 1945, the District has accelerated this program. As of August 1948, periodic analyses for chloride are being made on waters from 25 wells. Representative "complete" chemical analyses also have been obtained.

4. In 1947 Mr. Harold Conkling, consulting engineer, made a report on the water supply of the Santa Clara Water Conservation District[2].

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[2] Conkling, Harold, Water supply of Santa Clara Water Conservation District, Ventura County, typewritten report to the Board of Directors of the Conservation District, 81 pp., 11 pls., 26 tables, November 1947.

Conkling's report treated in considerable detail the present conditions of water supply and use within the District, estimated the current annual deficiency in the Oxnard Plain area, presented ~~considerable~~ many data on water-level fluctuations, pointed out the danger of serious ocean-water invasion due to the current extensive drawdown of water levels below sea level, and indicated the need for construction of reservoirs to conserve surface water and of conduits for its distribution. To assist in making this investigation for the Navy, a copy of Mr. Conkling's report has been made available to the Geological Survey by Mr. Freeman.

5. In 1947 a report on water supply for the Point Mugu Naval Base was made for the Navy by the consulting firm of Leeds, Hill, and Jewett[3].

[3] Leeds, Hill, and Jewett, Water supply for Naval Air Missile Test Center, Point Mugu, California, duplicated report, 13 pp., 5 pls., January 1947.

This report discussed briefly the ground-water conditions in the southern part of the Oxnard Plain, pointed out the danger of ocean-water invasion, and suggested that arrangements be made for obtaining water from the city of Oxnard.

Scope of work by the Geological Survey

As background in the investigation for the Navy, the Geological Survey has obtained copies of the several reports from the earlier investigations and has reviewed pertinent sections. In addition, as products of their respective programs of investigation, the Ventura County Water Survey through Mr. Jamison has supplied water-level and well-log data, and the Santa Clara Water Conservation District through Mr. Freeman has supplied water-level records and chemical analyses of ground waters. The Leonard A. Anderson Drilling Company of El Rio supplied a very large block of logs for wells drilled in recent years. Mr. Conkling's office has furnished some well logs and data on withdrawals. The city of Ventura has supplied logs of its deep wells near the coast. Dr. Thomas Bailey, consulting geologist, has been very helpful in furnishing geologic data of considerable value for the Oxnard Plain area. The Public Works offices of the Navy both at Point Mugu and at Port Hueneme, have supplied pertinent basic data available for the active Navy well fields.

After these records had been collected and examined, it was apparent that there was a deficiency of geologic data for determination of the geologic structure of the water-bearing deposits beneath the Oxnard Plain, the hydraulic continuity of the deposits, the possibilities of saline encroachment, and the possibilities for development of fresh water at greater depths than are now reached by the Navy's water wells at Point Mugu and Port Hueneme.

Accordingly, the Geological Survey in April 1948 undertook a field program to collect additional water-well logs from well drillers and well owners, and to collect core records and electric logs of oil wells and test holes which furnish valuable information on the full thickness of the deposits containing fresh water.

To date, activity has been concentrated on the collection of water-well logs, on the field location of the wells for which logs have been obtained, and on the construction of a well-log peg model to present a three-dimensional picture of the water-bearing deposits beneath the Oxnard Plain. From many sources, logs of about 325 water wells have been assembled for study. Collection of electric log and core-hole data from oil companies is now under way.

Published topographic maps for the Oxnard Plain have contour intervals of 50 feet. These were ~~This was~~ inadequate for obtaining well altitudes to the desired accuracy of 1 or 2 feet. ~~Through the courtesy of an oil company which desires to remain anonymous,~~ an unpublished topographic map with 5-foot contour interval ~~control~~ was made available to the Geological Survey and a base map at a scale of 1:24,000 was drafted from this map and from other sources. The base map is included as plate 2 of this report. Wells plotted on this map include those shown on current maps of the Ventura County Water Survey, also wells for which driller's logs have been collected by the Geological Survey and which have been located by a field canvass.

The well numbering system used here is the one established by the California Division of Water Resources in its investigation of 1927-32. Each well is numbered according to its location in an arbitrary grid system defined by vertical and horizontal control lines spaced 2 miles apart, numbered serially from west to east, and lettered serially from north to south. Thus, well 8-V-5 is well 5 in the 4-square-mile block 8-V. This well numbering system is in use by all local agencies and so was adopted by the Geological Survey for purposes of this investigation.

GENERAL GROUND-WATER CONDITIONS BENEATH THE OXNARD PLAIN

Geologic features

The Oxnard Plain is the flat coastal area of Ventura County, California, which was formed by flood deposits of the Santa Clara River and Calleguas Creek. The deposits of the Santa Clara River predominate, ~~those~~ of Calleguas Creek being confined to a narrow belt flanking the Santa Monica Mountains. The thickness of the alluvial blanket has not been determined, except in a few wells, but in general is believed not to exceed 500 feet. Near the present coast line, the alluvium is interbedded with sandy beach deposits and clayey lagoonal deposits, such as are developing there today. The upper part of the alluvial deposits is of Recent age; the lower part is probably of late Pleistocene age.

Unconformably underlying the alluvium is the San Pedro formation of early Pleistocene age. The San Pedro formation is composed of sand and gravel interbedded with relatively thick beds of silt, and reflects a progressive change from marine to continental deposition.

The Santa Barbara formation of Pleistocene age underlies the San Pedro formation and thickens greatly from southeast to northwest across the plain.

In the southeastern part of the Oxnard Plain, the Santa Barbara formation lies with marked unconformity upon (volcanic rocks of middle Miocene age which rest upon) hard shales, and sandstones~~, and volcanics that are correlated with~~ of the Temblor formation (Miocene). Farther northwest it rests upon a great series of Pliocene sediments which intervene between the Santa Barbara and the Temblor formations.

The alluvial deposits, the San Pedro formation, and much of the Santa Barbara formation contain permeable beds of gravel and sand interbedded with silt and clay. The permeable beds in the lower part of the San Pedro formation and in the underlying Santa Barbara formation are almost wholly sand; layers of gravel are scarce. In the southern part of the Oxnard Plain all these deposits are believed to contain fresh water. To the northwest — toward the Santa Clara River — the Santa Barbara formation thickens rapidly and contains fresh water only in its upper part.

The deposits containing fresh water thus constitute a wedge which thickens greatly from southeast to northwest. In connection with the possibilities of developing fresh water at depths below those now reached by water wells, the Geological Survey now is assembling available data; only a rough idea of the thickness of the wedge has been obtained to date. However, certain preliminary statements concerning the thickness of this wedge can be made from data now on hand.

For example, beneath the Naval Base at Point Mugu the thickness of the fresh-water wedge is on the order of 1,000 to 1,200 feet. About 3 miles southeast of Oxnard the thickness is about 2,000 feet. Just north of the Santa Clara River and 2 miles from the coast the thickness of the fresh-water wedge is almost 3,000 feet. It is near here that the city of Ventura recently developed a well yielding more than 1,000 gallons a minute from water-bearing deposits 800 to 1,400 feet below land surface in the San Pedro formation.

With respect to the water-bearing deposits now tapped by wells, study of the well logs collected and assembled on a peg model suggests a general pattern which is summarized in following paragraphs.

The most persistent and, with respect to ground-water recharge and movement, the most important single aquifer (water-bearing zone) of the Oxnard Plain extends southwestward from the mouth of the Santa Clara River Valley near Saticoy to the coast, about 10 miles distant. Its general northwestern boundary conforms roughly to a line drawn from Montalvo to the coast about at the intersection of Ocean Drive and Fifth Street west of Oxnard. Its southeastern boundary extends roughly along a line from the intersection of Santa Clara Avenue and U. S. Highway 101 to the coast at the south edge of the city of Port Hueneme. Thus, it is about 4 miles wide between Montalvo and Oxnard and about 5 miles wide at the coast. Its base ranges about from 220 to 250 feet below land surface. Coastward from U. S. Highway 101 it is confined by a variable thickness of fine-grained silty deposits interbedded with sand. The position, character, and continuity of this aquifer between Oxnard and the coast at Port Hueneme are shown on geologic section B-B' (pl. 3). At Oxnard, for example, in the city wells, this aquifer occurs as a gravel bed 120 to 230 feet below land surface and is overlain by 120 feet of fine sand and flood-plain silt. The thickness of 110 feet at Oxnard is fairly representative for the aquifer as a whole. From Port Hueneme northward along the coast for about 1½ miles the gravel is only 20 to 40 feet thick, suggesting that it may be wedging out seaward into fine-grained lagoonal deposits (see log for well 8-V-15, section B-B').

Inland from U. S. Highway 101, well logs show that this aquifer is overlain by gravel to the land surface. Near the spreading basins at Saticoy, gravel extends continuously from the land surface to depths of at least 250 feet; consequently there is continuous hydraulic continuity from the river channel and from the spreading basins through the main water-bearing zone to the coast at and north of Port Hueneme.

Northwest from this main aquifer, well logs indicate that the water-bearing zones are in general at greater depth, probably largely within the San Pedro formation of Pleistocene age. They are overlain at many places by 200 to 300 feet of impermeable silt and clay and thus are extensively confined.

Southeast of the main aquifer, the gravels become progressively thinner and grade into clays and silty sands. These thinner gravels are the source of water for wells located more than a mile west of Wood Road. Farther east, and north of the latitude of Hueneme Road, there are no important gravels within a few hundred feet of the surface, and water is obtained from numerous sands interbedded with clays, down to a depth of 1,000 feet or more. Somewhat sparse data for the Point Mugu coastal lobe show a very sandy series of strata down to a depth of more than 600 feet. The upper 150 feet of sediments consists of sands, silts, and minor gravels, in apparent continuity with the ocean very close to shore. Only a few wells, such as the NAMTC well 1, reach the zone of sand 300 to 600 feet below the land surface; the extent or continuity of this zone is not known. These geologic conditions are shown on geologic section A-A'. (See pl. 3, A.)

Hydrologic conditions

The Oxnard Plain is almost exclusively an agricultural area, and irrigation from wells is practiced throughout the plain. The water-bearing deposits tapped by these wells are replenished mainly by percolation from the Santa Clara River system, and to a small extent by percolation of water from rainfall on the pervious inland portions of the plain and by recharge from Calleguas Creek to the south.

Recharge from the Santa Clara River to the Oxnard Plain is almost wholly within the 5-mile reach of channel from Saticoy downstream to U. S. Highway 101. Since 1928 a substantial part of the river flow has been diverted to the spreading basins east of Saticoy and by the end of the water year 1946-47 about 188,000 acre-feet of water had been spread through these basins.

From the combined intake system of river channel and spreading basins, the ground water moves to the southwest and south beneath the plain. The general pattern of movement is best shown by water-level contour maps.

The Geological Survey has not prepared any water-level contour maps during the present investigation because attention has been focused chiefly on geologic features, and because such maps are available from the studies of other investigators. The latest water-level contour map available, for the spring of 1946, was prepared by Conkling for his report to the Santa Clara Water Conservation District. Through the courtesy of the District and Mr. Conkling it has been reproduced as plate 4 of this report to show (1) the general direction of ground-water movement at that time and (2) the position of the water table or of the pressure surface with respect to sea level. The direction of water movement is normal to the water-level contours. Thus, this map shows that in the spring of 1946 the movement of ground water was generally southwestward beneath the northern part of the plain and southward in the area east and south of Oxnard. In the eastern part of the plain (Pleasant Valley area) water levels had been drawn down so far by the heavy withdrawals from wells that water moving south past the west end of the Camarillo Hills was being diverted east into the Pleasant Valley. As of 1948 water levels have been drawn down substantially below those of the spring of 1946 and eastward movement of water from the Oxnard Plain to the Pleasant Valley area doubtless has been accelerated.

Although the general movement of ground water has been downward and coastward from the areas of recharge, the ground waters beneath the Oxnard Plain do not constitute one single mass of water homogeneous in chemical character and unrestricted vertically in freedom of circulation. With respect to occurrence and chemical character, three water bodies may be tentatively defined within the Oxnard Plain: (1) the shallow, unconfined water, generally of poor quality; (2) the main body of potable waters; and (3) a connate water body, containing highly saline waters. The shallow, unconfined water of poor quality occurs in the upper 50 to 100 feet of alluvium in the pressure area of the Oxnard Plain. (See pl. 1 for approximate boundary of pressure area.) These waters commonly are unfit for human consumption and for irrigation. The main water body is complex chemically and hydrologically. It is unconfined in the Montalvo area and probably also in parts of Pleasant Valley. In the pressure area, several different pressure levels may be observed locally. Generally, within the main water body, the shallowest waters are the lowest in dissolved solids; below these, the waters are somewhat higher in dissolved solids; beneath the southern part of the Plain the deepest fresh waters are sulfurous, at least locally.

Connate saline waters underlie the fresh-water wedge of the main water body in all parts of the Oxnard Plain.

In a report to the Santa Clara Water Conservation District in 1947, Conkling estimated that in a dry period similar to that of 1923-36 the annual supply of water from the Santa Clara River to the Oxnard Plain area as here defined would be about 25,000 acre-feet, and that 5,000 acre-feet a year would percolate into the ground from rainfall and from minor streams, giving a total average supply of about 30,000 acre-feet a year. He estimated further that the present annual use of water on the Oxnard Plain (including the west end of Pleasant Valley now dependent on recharge from the Santa Clara River) is about 60,000 acre-feet. Thus the indicated deficiency during a dry period similar to that of 1923-36 is 30,000 acre-feet a year under the present conditions of development on the Oxnard Plain.

To show the fluctuations of water level that have occurred during the period of record, four hydrographs have been selected as typical for wells tapping the main aquifers beneath the Oxnard Plain. (See pl. 5; locations of these wells are shown on pl. 2.) These hydrographs reflect the combined effects of the increased demand and the variation in replenishment. The similarities among these hydrographs are evident. The hydrograph for the City of Oxnard well (9-U-9) is the longest available for this area, and is believed to be representative. At times during the period 1916-1922 the well was flowing, but during the subsequent period of deficient rainfall extending into the middle thirties, the water level was drawn down below sea level at times. Compared with previous dry periods, this dry period was not unusually severe, but still the water demands were such as to draw down the water level in this well below sea level intermittently from 1931 into 1934. The succeeding period of above-normal rainfall extending from 1936 into 1944, was the wettest period of similar length in the history of southern California. Nevertheless, the water level did not recover to the previous levels of 1916-1923, and the well did not flow in the early forties. Rapid expansion of lands under irrigation and consequent heavy pumping may be cited as the causes of the failure to recover to previous high levels. The average downward trend in the 3 years since 1945 is alarmingly steep. With water levels already about as low as in 1951, and with the possibility of several more years of deficient rainfall, water levels may be headed for unprecedented lows. Obviously the average supply of water entering the main aquifers under the present conditions is insufficient to replace withdrawals.

Plate 6 presents water-level profiles across the Oxnard Plain from near the city of Port Hueneme to the Saticoy spreading grounds (along line C-C' of pl. 2). These profiles are for August 1931, April 1944, August 1947, and March-April 1948. They are believed representative for the main water-bearing zone (p. 12). The water-level profiles of 1931 and 1948 present the low levels of record and the profile of 1944 one of the highest of record. They have been introduced to show the magnitude of the drawdown below sea level that has occurred in the coastal area at times of low water level. The plate shows that the water levels of March-April 1948 near Port Hueneme were the lowest of record — about 14 feet below sea level.

Quality of water

Analyses of waters from 15 wells tapping the shallow unconfined water body show a very great range in quality — from 50 to 5,825 parts per million of chloride. Most of the analyses show a chloride content greater than 150 parts per million. These waters have an unusually high sulfate content — as much as 28,000 parts in an analysis showing 5,825 parts of chloride.

Underlying the relatively unimportant unconfined water body are the most prolific water-bearing beds, occurring within 500 feet of the surface. Analyses from about 50 wells show a regional chloride content beneath the Oxnard Plain of a little less than 50 parts per million. Analyses from marginal areas near Ventura and near the Santa Monica Mountains show chloride contents ranging from 60 to over 200 parts per million. These higher concentrations are presumably due to blending with more saline waters from deeper aquifers which these marginal wells reach. Nearly all waters show high sulfate content, ranging from 350 to 475 parts per million.

Chemical analyses of waters from 10 wells on the western part of the Oxnard Plain, made in the period 1945-48, are presented in the following table. These analyses are considered representative for the native waters within the range tapped by water wells.

Analyses of waters from wells in the western part of the Oxnard Plain

[From records of the Santa Clara Water Conservation District. Quantities in parts per million.]

Well	8-V-10	8-V-11	8-W-1	9-U-9	10-W-10	10-W-28	11-U-13	11-W-10[a]	11-W-11[b]	11-W-12
Depth (feet)	235	175	225	232	236	- -	1,345	602	432	570
Date of sampling	9/27/45	9/27/45	3/31/47	3/31/47	4/22/47	7/15/47	5/2/47	2/9/48	2/9/48	4/22/47
Dissolved solids[c]	830	787	818	1,013	800	782	559	778	768	736
Calcium (Ca)	128	123	124	159	126	126	73	90	118	112
Magnesium (Mg)	44	40	41	54	34	38	22	43	37	30
Sodium (Na)	92	89	89	100	86	85	92	117	92	94
Bicarbonate (HCO_3)	225	229	253	295	251	275	294	254	281	267
Sulfate (SO_4)	409	377	395	495	383	354	171	333	333	317
Chloride (Cl)	44	43	42	57	45	41	54	68	47	49
Boron (B)	0.70	0.63	0.52	0.57	0.59	0.46	0.22	0.30	0.37	0.39
Hardness as $CaCO_3$[c]	500	472	478	619	454	471	273	401	447	403

a/HAMTC, well 2.
b/HAMTC, well 1.
c/Calculated.

WELL FIELD AT POINT MUGU NAVAL BASE

The Point Mugu Naval Base depends upon two wells for its present water supply. (See pl. 2.) The two wells are about 2 miles north of the ocean and about 1,000 feet apart. Well 1 was drilled early in 1943 to a depth of 432 feet and its 12-inch casing was perforated 121-137, 311-325, and 377-397 feet below the land surface. In September 1943, the casing was reperforated 130-137, 187-192, and 382-394 feet below the land surface. Well 2 was drilled in August 1943 to a depth of 602 feet and 12-inch casing was perforated 460-470, 544-550, and 575-593 feet below land surface. Logs of both wells are shown on plate 3, section A-A'.

No production figures are available for either of these wells prior to 1947. In 1947, the daily pumpage ranged from 150,000 to 240,000 gallons, according to estimates supplied by the Point Mugu Naval Base. It is understood that sand trouble has been experienced in both ~~of the~~ wells, partly because of excessive rates of pumping. In addition, the frequent starting and stopping of the pumps under automatic control has caused a continued surging and loosening of the sandy water-bearing materials.

In May 1948 the Parsons-Aerojet Company made a 48-hour pumping test on well 2 and a check test on well 1 to determine the relation of yield to drawdown and to check sand conditions, for the purpose of recommending optimum performance conditions. Mr. Hammond of Parsons-Aerojet has supplied the following data.

The test on well 2 was made May 10 to 12. The well was disconnected from the system and discharged to waste. Static water level was 55.2 feet below center of air gage (about 53.7 feet below pump-house floor and 19.5

feet below mean sea level). Drawdown was as follows: 6.0 feet at 100 g.p.m., 11.3 feet at 200 g.p.m., 18.0 feet at 300 g.p.m., 28 feet at 400 g.p.m., and 42.3 feet at 500 g.p.m. The well did not yield much sand until the pumping rate was about 350 g.p.m. (drawdown 22.5 feet) but the amount of sand produced increased rapidly at higher discharge rates.

The test on well 1 was made with water discharging into the system. Although specific data on static level, yield, and drawdown were not supplied, Hammond reports that the yield-drawdown curve of well 1 is similar to that of well 2, and that the well begins to yield sand at 300 to 350 g.p.m.

As a result of these pumping tests it is understood that a pumping rate of 200 to 250 gallons a minute was recommended for each well, with a change in the system to eliminate the frequent on-off pumping action conducive to sand production.

The Geological Survey desired to cooperate in the pumping tests of the two wells to obtain information on transmissibility and permeability of the deposits tapped by these wells. However, the water-supply system at the Base was so assembled that it was impracticable to shut off either pump continuously during the pumping test on the other well; also, only air-gage readings of depth to water could be obtained. Thus it was not possible to obtain data suitable for calculating transmissibility of the deposits.

In February 1948, air gages were installed in both wells. Periodic water-level observations should be made in these wells, both for pumping and nonpumping conditions. It is suggested that these be made weekly.

No chemical analyses of water were obtained from the Base. Therefore, in February this office deposited sample bottles at the Base for weekly sampling of each well. Between February and July 19, Base personnel collected

32 samples which were analyzed by the Geological Survey. These analyses indicate that for each well the chloride content has remained nearly constant from February into July. For well 1 all the chloride values were between 43 and 47 parts per million; for well 2 they were between 66 and 69 parts per million. The results are comparable to those obtained by the Santa Clara Water Conservation District from several samples taken from each well in the same period. A complete analysis of the water from each well was obtained by that agency in February 1948; analyses have been included in the table on page 19. Both wells are yielding water of native quality and no saline contamination has occurred.

WELL FIELD AT PORT HUENEME NAVAL BASE

The Naval Base at Port Hueneme (Naval Construction Battalion Center) occupies about 2.5 square miles immediately northwest of the city of Port Hueneme (see pls. 1 and 2). There are 10 active water wells on the Base, of which 9 currently are supplying the water requirements. Most of the wells were used for irrigation until the property was acquired by the Navy. The Navy drilled one or two additional wells to insure an adequate supply. Logs of only two wells within the Base are available, but it is believed that all the wells tap the same aquifer and are about 250 feet deep. The logs of well CBC 11 (8-V-8) and of well 8-V-9, an unused well on the Base, are shown on geologic section B-B' (pl. 3).

Pumpage figures, available for the period July 1947 to June 1948, indicate that the average daily pumpage is about 1 million gallons (about 90 acre-feet a month).

Since January 1948 the Public Works Office at the Port Hueneme Base has been making readings of depth to water every 3 to 5 days. Records were supplied to this office and hydrographs for three representative wells have been plotted on plate 7. These are for Navy wells 1, 4, and 9, located respectively in the southern, central, and northern parts of the property. Water levels in all three wells were below mean sea level in March 1948, when pumping for irrigation throughout the Oxnard Plain was excessively heavy. From mid-April to July all water levels except for Naval Base well 1 were above sea level. Water levels in well 1, nearest the coast, have been below sea level since mid-June.

Since February 1948 the Public Works Office at the Port Hueneme Base has made chloride analyses weekly from each well. From records supplied to the Geological Survey, chloride graphs have been plotted for four representative wells, Navy wells 1, 2, 4, and 12 (fig. 1). Wells 1 and 2 (CBC 1 and CBC 2 of plate 2) are only a few hundred feet from the harbor but the chloride content for each is between 30 and 40 parts per million, as is true for all other wells on the Base. The cause of the irregular fluctuation in chloride from week to week is not known but the nature and magnitude of the fluctuations preclude salt-water contamination.

POSSIBILITIES OF OCEAN-WATER INTRUSION

The Oxnard Plain is a ground-water basin in which the water-bearing sediments are believed to be in contact with the salt water of the ocean along the coast. Whenever coastal water levels beneath the Oxnard Plain are drawn down to or below sea level, ground water no longer escapes to the sea and saline ocean water can advance inland ~~wherever the permeable beds are in hydraulic contact with the ocean.~~ The amount of the advance or encroachment beneath the Plain will depend on the magnitude of the landward hydraulic gradient, the permeability of the aquifer, and the length ~~amount of~~ of time that water levels remain below sea level.

In the period of deficient rainfall from 1918 to 1936 water levels beneath the Oxnard Plain were lowest late in the summer of 1931. (See pls. 5 and 6.) A water-level contour map for autumn 1931, published in Bulletin 46 of the California Division of Water Resources (pl. 49 of that report) indicates that water levels then were below sea level beneath about 17 square miles in the southern part of the plain — within the rough triangle formed by Pleasant Valley Road on the north, Wood Road on the east, and Mugu Lagoon on the south. Hydrographs for wells 9-V-6 and 10-W-9 (pl. 5) show, however, that at a distance of less than 2 miles from the ocean, water levels were below sea level for not more than half the year during the early thirties, recovering to about 10 feet above sea level in the winter months of the low-water years 1931-33. There was no long-continued drawdown of the pressure surface below sea level in the early thirties. Assuming that ocean water had free access to the aquifers as geologic and hydrologic data suggest, landward hydraulic gradients were not maintained for a length of time sufficient to induce appreciable sea-water invasion.

From 1937 to 1946 water levels were above sea level throughout the Oxnard Plain. The sharp drawdown that began in 1945 has depressed the pressure surface below sea level at an increasing rate in the past 3 years. In the spring of 1946 water levels were below sea level in only a small area (see pl. 4). However, by the spring of 1947 they had been drawn down below sea level in almost all of the area south and southeast of Oxnard. This area has been colored red on plate 4 (from Conkling). During the winter of 1947-48 water levels remained below sea level continuously in much of the area south of Hueneme Road, thereby developing conditions favorable for continuous landward advance of ocean water through permeable beds. The water-level profile of March-April 1948 (pl. 6) shows the pressure surface below sea level for 2.5 miles northeast of Port Hueneme, and 17 feet below sea level in well 9-W-4, about half a mile from the coast.

The evidence concerning salt-water invasion in these two periods of very low water levels is summarized in following paragraphs.

Conditions near Port Hueneme

Fourteen wells along the coast between the Santa Clara River and Point Mugu, and within a mile of the shore were sampled in the early thirties. Waters from three wells, all within 500 feet of the shore, showed chloride concentrations suggesting contamination, either from the ocean or from shallow saline waters. The wells are 8-V-11 and 9-W-2 near Port Hueneme, and well 11-X-1 near the entrance to Mugu Laguna (see pl. 2.) Waters from four other wells, also within a few hundred feet of the coast, showed a chloride content normal for native waters of the area, and indicated no contamination. Waters from wells 9-W-1 and 10-W-8, immediately west of the present Point Mugu Naval Base, appear to have been slightly contaminated but evidence of the source is lacking.

As of July 1948, except for the chloride tests being made by the Navy for its wells at the Port Hueneme Naval Base (see p. 24, and fig. 1), only three wells within a mile of the coast are being sampled periodically for chloride analysis. They are wells 8-V-10, 8-V-11, and 8-W-1, all near the Port Hueneme Naval Base and within 1,000 feet of the shore. These wells have been sampled periodically since 1931 by the Santa Clara Water Conservation District; records for each are plotted on figure 2. The chloride graph for well 8-V-11 (Silver Strand well) is the only one of the three indicating contamination. In this well the chloride content was about constant from 1931 to 1935 (39 to 47 p.p.m.), increased to 154 parts in 1936, then decreased gradually to about 45 parts early in 1947. In the summer of 1947 the chloride content began to increase and by July 30, 1948, it was 262 parts per million. It is increasing currently at an alarming rate. The well is 175 feet deep, but whether it penetrates the main aquifer tapped by the Port Hueneme Naval Base wells is not known. Wells 8-V-10 (Hollywood Beach Resort) and 8-W-1 (city of Port Hueneme) are within 1,000 feet of the shore and, respectively, about a mile northwest and southeast of contaminated well 8-V-11. Both tap the main aquifer from which the Port Hueneme Naval Base wells draw their supply. (See pl. 3, B.) Neither has ever shown evidence of contamination.

Analyses of water from unused well 9-W-2 at Port Hueneme showed a maximum chloride concentration in June 1931 of 2,269 parts per million; the water level in the well then was 3 feet below sea level. By March 1935 the chloride had decreased to 42 parts, after substantial recovery of the water level. This well has not been sampled since that date, so far as known. Its depth is reported to be 150 feet, and it may penetrate the same aquifer as that tapped by the Port Hueneme Naval Base wells. The water level was 10 feet below the land surface in August 1931 and 2 feet above the land surface in

March 1952; this fluctuation suggests that it taps the main aquifer.

The evidence presented here, although inconclusive, suggests that ocean water may now be present in the main aquifer near Port Hueneme for at least a few hundred feet inland from the coast. Furthermore, the head of Hueneme submarine canyon is about 0.2 mile off shore and the bottom slope at the head is about 20 percent. Because of this condition ocean water may have access to the main aquifer as close as 0.3 mile to the shore. Water-level contours for the spring of 1944 (the time of highest water levels in recent years), projected to sea off Port Hueneme, suggest that escape of ground water to the ocean then was occurring about 1 mile offshore. With no evidence of an impermeable barrier interrupting hydraulic continuity in the main aquifer and considering the high permeability of this water-bearing bed it would appear that if water levels in the Port Hueneme Naval Base wells should be drawn down to or below sea level for a period of substantial length — a year or more — ocean-water intrusion into the coastal wells of the Base would be a serious threat.

According to the Ghyben-Herzberg principle developed through the study of coastal ground waters in Holland and Germany, the inland movement of ocean water is closely related to the height at which the fresh water is maintained with reference to sea level. Brown[2], in a study of the coastal

[2] Brown, J. S., A study of coastal ground waters with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 527, 101 pp., 1925.

waters of Connecticut, has showed that a column of ocean water must be balanced by a somewhat higher column of the lighter fresh water in order to prevent ocean-water invasion.

The conditions at Port Hueneme might be compared to a U-tube containing two immiscible liquids of different specific gravity. The aquifer at Port Hueneme can be considered a more or less horizontal part of the U-tube connecting a column of sea water at the outcrop of the aquifer with a column of fresh water in one of the wells at the Port Hueneme Naval Base. As the specific gravities of ocean water and fresh water are in the ratio of 1.025 to 1.0, the heights of the balancing columns of water must show the same ratio, but in an inverse relation. Taking 220 feet as the average depth to the base of the aquifer, it may be computed that the static water level in wells of the Port Hueneme Naval Base must be maintained at 6 feet or more above mean sea level to prevent sea-water invasion.

As of July 1948 water levels at most of the Port Hueneme Naval Base wells are a few feet above mean sea level (see pl. 7). However, the present water demand at the Base is well below that of a period of national emergency; also, regional conditions of water level suggest that levels here may not remain above sea level for an extended period. Hence, under the present conditions of heavy overdraft the well field of the Port Hueneme Naval Base may not yield water of good quality indefinitely. If the present dry period continues for several years more, as seems likely, a critical test of the Port Hueneme Naval Base water supply is imminent. Periodic sampling and measurement of water level should be continued through this critical period.

It is suggested that so long as water levels at the Base remain at or near sea level, withdrawal should be concentrated in the inland wells and that the coastal wells, especially Navy wells CBC 1 and CBC 2, be pumped as little as possible to avoid increasing the landward hydraulic gradient. This well field should not be considered as a source to supply the Naval Base at Point Mugu.

Conditions near Point Mugu

Of the wells along the coast in the vicinity of the Point Mugu Naval Base, only well 11-K-1 on the beach 1,000 feet west of the entrance to Mugu Laguna has shown definite evidence of contamination. Analyses of water from this well are available for the period 1931-33. The minimum chloride content during this time was 546 parts per million in October 1931; the maximum chloride was 2,079 parts in March 1933. No analyses of water from this well have been made since 1933, so far as known. Although the depth of the well is not known, it probably taps permeable beach deposits; if so, the presence of saline water in the well is not surprising.

Near the west end of the Point Mugu Naval Base, wells 10-W-8 (135 feet deep) and 9-W-1 (207 feet deep) in 1931 yielded water in which the chloride content was slightly above that of native water. However, neither can be considered as having been definitely contaminated by ocean water at that time.

In July 1948, wells 11-W-2 and 10-W-28, both on the south side of the east-west segment of Caspar Road and about 0.5 mile and 1.5 miles west, respectively, from NAMTC well 2, were sampled by the Geological Survey ~~this office~~. The chloride content was 63 parts per million for well 11-W-2, and 41 parts for well 10-W-28. Both wells are yielding uncontaminated water as of August 1948.

There are no water wells between the two active wells at the Point Mugu Naval Base and the coast, 2 miles to the south. Logs of the test holes bored in this area for foundation exploration within the Naval Base (holes NT 2 to NT 18 inclusive, pl. 2) are useful in indicating the nature of the deposits to depths of 150 feet (see geologic section A-A', pl. 3); however, they were not sampled for water analysis at the time of boring, and are not accessible now.

Geologic section A-A' (pl. 3) through wells of the Point Mugu Naval Base, shows clearly the sandy nature of the sediments underlying this area to a depth of at least 800 feet. The deposits less than 300 feet below land surface are composed of layers of sand interbedded with silt and clay. The sands seem to be in free communication with the ocean, and a barrier that might prevent sea water encroachment can not be detected. The perforated zones (121-137 and 187-192 feet) in NAMTC well 1, as far as can be determined at present, are directly, though probably not immediately, susceptible to sea-water contamination. The possibility of sea-water encroachment in the sands and gravels encountered below 300 feet in these wells is somewhat problematical because no information is available for these water-bearing beds seaward of the active Navy wells. The deeply incised Mugu submarine canyon which reaches a depth of 1,200 feet less than 3 miles offshore from the Point Mugu Naval Base, and in which these deeper zones presumably crop out, might offer ready access to salt water in all the water-bearing strata underlying the Base.

The hydraulic gradient now is landward from the coast at Mugu Lagoon through the Navy wells and inland to Pleasant Valley. The static level at NAMTC well 2 is now about 20 feet below sea level and the landward gradient from the coast to the Navy wells is approximately 10 feet to the mile.

Northeast of the wells at the Point Mugu Naval Base — toward Pleasant Valley — water levels in some wells are as much as 30 to 40 feet below sea level. Conditions favorable to sea-water intrusion now exist, and continuance of the dry period with the same pumping draft would steepen the landward hydraulic gradient. Even if recharge from the Santa Clara River system to the Oxnard Plain should be average or better for the next few years, it is doubtful that water levels beneath the Point Mugu Naval Base would rise above sea level for a year or two.

POSSIBLE SOURCES OF ADDITIONAL WATER SUPPLY

The present condition of overdraft of ground-water supplies beneath the Oxnard Plain, and the resulting drawdown of water levels below sea level that has occurred extensively beneath the southern part of the plain, create a difficult problem with respect to development of a water supply of a million gallons a day for the expanded Naval Base at Point Mugu. As discussed earlier, the well field at the Port Hueneme Naval Base is not considered to be a suitable source, because of the danger of ocean-water intrusion.

Three other possibilities for development of the required supply are considered, as follows:

1. Continued use of the two active wells at the Point Mugu Naval Base, and expansion of the well field, either by construction of new wells or by purchase of existing wells, or both, to supply the required amount.

2. Development or purchase of a supply from a source within the shallow deposits now tapped by wells but far enough inland ~~from the shore~~ to essentially remove the danger of ocean-water invasion and to avoid ~~responsibility for~~ steepening the landward hydraulic gradient near the coast.

3. Development of water from aquifers deeper than those now tapped by water wells, if productive aquifers overlain by impervious capping deposits can be found beneath the southern part of the Oxnard Plain.

Possibility No. 1 would be the least expensive undertaking for the immediate future but it has two specific disadvantages. First, expanding the well field at the Naval Base would not yield a firm supply of water because of the probability of ocean-water invasion. Second, taking of a million gallons a day from water-bearing deposits beneath the Naval Base would serve to depress water levels near the coast to depths greater than if the supply were obtained from an inland source. Thus, in a dry period, which may now be developing, withdrawal of a million gallons a day from wells at the Point Mugu Naval Base would contribute directly to an increase in the landward hydraulic gradient and in the rate of ocean-water intrusion, unless by purchase of lands now irrigated the Navy should acquire an established equivalent irrigation use.

Possibility No. 2 (development or purchase of a supply from a relatively shallow source far enough inland from the coast to diminish the danger of ocean-water invasion) would eliminate the two disadvantages resulting from the expansion of the well field at the Naval Base. Considering (1) the character and distribution of the water-bearing zones beneath the Plain, (2) the location of the major source of replenishment (the Santa Clara River intake area), and (3) the present distribution of pumping draft beneath the Plain, it would appear that development of an inland source, to be worthwhile, should be at least 4 to 5 miles to the northwest, in an area where the possibility of salt-water contamination is remote. Such a location would be in the general direction of Oxnard but east of U. S. Highway 101-A. Acquisition of property sufficient to obtain necessary water rights, purchase or construction of wells, and installation of a pipe line would be very expensive, possibly within the range of 1 to 2 million dollars. It is doubtful that the increase in expenditure above the costs of expanding the local well field could be justified by the gain in ~~firmness~~ permanence of supply and ~~improvement~~ lack of impairment of coastal ground-water gradients.

If water were to be brought to the Naval Base from such an inland source, ~~it would appear that~~ initial costs probably could be reduced substantially by purchasing the water from the city of Oxnard, as recommended by Leeds, Hill, and Jewett. Such an arrangement would eliminate the large investment in lands and wells that would otherwise be required for inland development. On the other hand, the Oxnard area now is the most concentrated area of withdrawal within the Plain and a direct increase of possibly as much as 1,800 acre-feet of water ~~to~~ in the draft from the city well field, which was about 3,000 acre-feet in 1947, would certainly have some effect on water levels in the coastward extension of the main aquifer — that is, in the vicinity of the well field at the Port Hueneme Naval Base.

Possibility No. 3 (development of water from aquifers deeper than those now tapped by water wells, if productive aquifers overlain by impervious capping deposits can be found) is now being investigated by this office. Pumping from such aquifers should not affect water levels in the overlying deposits and so should not contribute to a steepening of the landward hydraulic gradient and the acceleration of ocean-water invasion in those deposits. Therefore, location of such a development could be near the coast, if other conditions were suitable. But such wells presumably would have to be 1,000 feet or more in depth, probably should be of gravel-pack construction, and therefore would be expensive.

Such a development would involve the same problem of acquisition of land and of water rights as possibility No. 2. Presumably, therefore, development of deeper confined water ~~could not be preferred,~~ would not be economical ~~economically over possibility No. 2~~ for economic reasons at the present time unless the length and cost of the pipe line required were low enough to more than offset the increased cost of well construction. However, if the Navy should develop a temporary expanded supply at the Point Mugu Base, and if in the future landward advance of ocean water should be sufficient to force abandonment of the well field, much of the coastal part of the Oxnard Plain also would be invaded by saline waters; under such conditions, development of a deeper supply of confined water somewhere within the southern part of the Plain would be the only recourse until water could be imported from inland parts of the county.

It should be borne in mind that regardless of the choice made by the Navy, the water supply for the Point Mugu Naval Base will be drawn from the common water supply of the Oxnard Plain and will be an addition to the present overdraft, unless by purchase of lands now irrigated the Navy acquires rights to and supplants an established ~~use~~ supply.

Suggested development of supply

After consideration of the three possibilities, insofar as they can now be evaluated, it ~~would~~ appears that if the proposed expansion of the Point Mugu Naval Base is to include lands having an established irrigation ~~use~~ supply approximately equivalent to the estimated requirements, the Navy should plan to obtain the additional water on or adjacent to the expanded Point Mugu Naval Base by construction of new wells or by purchase of existing wells, or both. The specified requirement of 1 million gallons a day is inferred to represent peak daily rather than average demand. Accordingly, it is assumed that the yearly withdrawal from Navy wells may be within the range of 750 to 900 acre-feet.

On the basis of the tests by the Parsons-Aerojet Company, it is assumed that wells 1 and 2 at the Point Mugu Naval Base will be capable of yielding at least 200 gallons a minute each for the immediate future. To make up the estimated requirements of 1 million gallons a day (equivalent to a continuous 24-hour discharge of 700 gallons a minute), and to provide a safety factor, it is assumed that additional well capacity of possibly 1,000 gallons a minute may be desired. It is believed that this yield could be obtained by drilling two additional wells of gravel-pack construction. Such wells, if drilled, should be located to the northwest or north of NAMTC wells 1 and 2, so as to withdraw water from an area as far as possible from the ocean. Also, they should be spaced so as to distribute the withdrawal widely and to keep the cone of pumping drawdown as flat as feasible. It is suggested that the centers of pumping be at least 2,000 feet apart, and at least an equal distance from the present wells.

These wells, if drilled, would be in sandy deposits, similar to those encountered by present wells 1 and 2. (See pl. 3, A.) The upper 300 feet of beds contains layers of clay or silt which may extend some distance oceanward and may give partial protection to the underlying sand beds from ocean-water intrusion at shallow depth. Furthermore, water of poor quality is found in nearby wells 11-W-15 and 11-W-20, respectively, 135 and 300 feet deep, and about half a mile north of NAMTC well 1. Water from well 11-W-20 (Avalon Motor Court) has contained as much as 578 parts per million of chloride (July 30, 1948). From available data, and from similar occurrences to the north and northeast, it is inferred that contamination is from shallow deposits. Therefore, in any new wells, the upper 250 to 300 feet of deposits should be sealed off by landing and cementing blank outer casing in clay or silt beds that occur irregularly from 250 to 300 feet below land surface.

The wells should be drilled to a depth of at least 600 feet in order to penetrate the thick sand encountered in NAMTC well 2. To obtain the maximum yield of sand-free water with a minimum drawdown, it is suggested that they be of gravel-pack construction, and drilled by the rotary method with a preliminary test hole. It is strongly urged that the test hole for the first well be drilled to bedrock to explore the full thickness of the water-bearing deposits beneath the Naval Base. The base of these deposits probably would be encountered between 900 and 1,200 feet below land surface. An electric log should be run to obtain information on the character of the sediments and on the quality of the basal water-bearing beds. The findings from this test hole probably would not modify the suggested program for construction of the initial well outlined below but plans for subsequent well construction should be delayed until after completion of this deep exploratory test hole.

For the initial well, construction could be accomplished as follows:

1. Drill an exploratory test hole of suitable diameter to penetrate the full thickness of water-bearing deposits, the depth estimated to be between 900 and 1,200 feet below the surface, and run an electric log.

2. Ream the upper 250 to 300 feet of hole to a diameter large enough for running 22- to 24-inch casing with bottom of casing hung opposite a clay bed as logged in the test hole.

3. Place and cement the surface string of casing.

4. Ream the hole 300 to about 600 feet below land surface to the maximum possible diameter (20- to 22-inch), run 12- or 14-inch casing with centering guides, and pack the space outside the casing with screened fine gravel, preferably not larger than 1/16 to 1/8 inch in diameter.

5. Develop as required by washing and surging.

Establishment of observation wells near the coast

If withdrawal of ground water is to be continued at the Point Mugu Naval Base, the Navy should have knowledge of the position and rate of landward movement of the front of sea-water intrusion, ~~— adopting the~~ conservative by assuming ~~outlook~~ that the dry period will continue for some years and that the landward hydraulic gradient will be steepened. Only ~~by~~ with ~~gaining~~ such information can the period of utility of the well field be evaluated, and, if it becomes necessary to develop another supply, can the forewarning be sufficient to provide adequate time for planning and construction.

It is recommended that observation wells be drilled as soon as possible at two locations, about 7,000 feet S. 30° E. and 7,000 feet S. 30° W. of NAMTC well 2. The immediate objective ~~of these wells~~ will be to determine if the saline front has reached as far as those locations, each about 1,000 feet inland from the north shore of the present Mugu Lagoon. This information can be obtained by drilling test holes of 6-inch diameter by the rotary method to a depth of about 350 feet, and by running electric logs immediately. Examination of the electric logs will offer a quick means of determining whether or not substantial sea-water invasion has occurred at the position of the test hole; if it has, test holes should be drilled 2,000 feet farther inland. If the electric logs show no ~~negative~~ evidence of salt-water contamination, the test holes should be completed as observation wells. The following general procedure is suggested:

1. Ream hole to 8-inch diameter down to a clay bed at about 300 feet. Clay beds are expected at about this depth and the exact position can be determined from the electric log.

2. Run 6-inch casing with oversize shoe and seat in clay at bottom of reamed hole. Have one or more 20-foot lengths of 6-inch casing preperforated so they can be placed opposite permeable zones selected from the electric log.

3. Clean out ~~out~~ hole below bottom of 6-inch casing.

4. Run 2-inch pipe with perforated 20-foot length on bottom and with a packer placed to be landed 10 feet below the shoe of the 6-inch casing.

5. Pump grout down to fill open hole above packer and to fill a few feet of the annular space between the 2-inch and 6-inch pipes.

6. Equip both 2-inch and 6-inch pipes for sampling — preferably with a portable centrifugal pump.

After completion of these observation wells, a program of water sampling and water-level measurement should be set up to assure continuous control. With such control, so long as the wells showed no contamination, the front would be known to be seaward of these wells. If and when the wells did show contamination, additional test wells should be drilled farther inland so that the rate of advance of the salt-water front could be evaluated. It would be advisable to obtain data on the transmissibility of the water-bearing deposits by pumping one well and measuring the drawdown and recovery of water levels in one or more nonpumped wells. Such data would be invaluable in estimating the rate of inland advance of ocean water, once the position of the intrusion front has been determined.

FUTURE PROGRAM OF THE GEOLOGICAL SURVEY

To obtain additional information pertinent to the water-supply problem of the Point Mugu Naval Base, the Geological Survey is proceeding with field investigation of the following two elements:

1. Field location and sampling of all active wells and all open casings between the Naval Bases at Port Hueneme and at Point Mugu and within a mile or so of the coast. For wells having no pump in place, the general quality of the water will be determined by making an electrical conductivity traverse of the entire fluid column in the casing. For water samples obtained from pump discharges, partial chemical analyses will be made. The purpose of this field investigation is to determine whether saline waters have invaded any wells beyond those previously cited, and to define the present position of the front of the saline water, insofar as possible.

2. Investigation of the possibilities for development of water from aquifers deeper than those now tapped by water wells, provided that productive aquifers overlain by impervious capping deposits can be found beneath the southern part of the Oxnard Plain. Available data from oil-test holes and oil-well electric logs are being collected and correlated. Findings should be of interest with respect to possible need for a replacement supply at the Port Hueneme Naval Base as well as at the Point Mugu Base.

A brief report covering these two phases of investigation will be submitted as soon as feasible. Also Geological Survey personnel will be available for assisting the Navy in connection with construction of water wells or observation wells, particularly in the interpretation of electric logs, and in planning construction features of the outpost observation wells. It is desirable to obtain samples of the formation encountered in drilling wells on the Naval Base, and Survey personnel will be available for such sampling, if the Navy will ~~keep the Geological Survey~~ advise them of developments and drilling schedules. If the expanded supply is developed at the Base, as suggested, the periodic sampling of wells can be undertaken by Survey personnel, if desired. On the other hand, this program could be carried on by Navy personnel, or an arrangement might be worked out in cooperation with the Santa Clara Water Conservation District. Regardless of the arrangements made, it is imperative that periodic sampling for water quality and periodic measurements of the depth to water be carried out, both for active water wells and for outpost observation wells.

ULTIMATE SOLUTION FOR A ~~FIRM~~ PERMANENT SUPPLY

The development of a supply of a million gallons a day of water by expansion of the present well field at the Point Mugu Naval Base, as outlined in preceding paragraphs, presumably is only a temporary expedient. It does not provide a ~~firm~~ permanent supply.

The County of Ventura and the Santa Clara Water Conservation District are now investigating remedies for the overdraft within the Oxnard Plain. In his report of November 1947 to the Conservation District, Mr. Harold Conkling made certain recommendations for providing an adequate water supply for the area included in the Conservation District, as follows:

> "It is necessary that a reservoir or reservoirs for conservation of water, and conduits for its distribution can be constructed.
>
> "It will also be necessary in the future to increase the amount of water salvaged and the amount distributed by surface conduits.
>
> "It is necessary that the present program for securing records of precipitation, streamflow, fluctuation of ground-water level, and quality of water be enlarged to provide adequate data for future planning.
>
> "It is therefore recommended that the Board of Directors of the Santa Clara Water Conservation District take steps at the earliest feasible date to outline and solve the engineering, legal, and financial phases of the problem which confronts the District."

It is understood that in pursuance of these recommended steps, the Flood Control District of the County of Ventura has retained Mr. Conkling to investigate and report on the possibilities of storing surface water in the drainage basins of Piru and Sespe Creeks, for utilization in the Oxnard Plain, and in the Calleguas Creek drainage area. The combined discharge of Piru and Sespe Creeks constitutes about 60 percent of the total flow of the Santa Clara River.

It is suggested that the Navy keep informed about any planned developments for rectifying the serious water shortages now existing. It would appear that the possibilities now being investigated may ultimately provide ~~a firm~~ an adequate supply of water for the Point Mugu Naval Base as well as for the Oxnard Plain. It would seem wholly advisable and proper for the Navy to cooperate as fully as possible in implementing sound engineering proposals to provide the solution to the present overdraft.

The Navy has a large investment at Port Hueneme as well as at Point Mugu. With the proposed expansion at Point Mugu, the joint water demand for the two Naval Bases will be about 2 million gallons a day, or about 2,200 acre-feet a year, almost 4 percent of the present ground-water withdrawals from beneath the Oxnard Plain. It is suggested that the Navy interest might well warrant financial cooperation in a project for water conservation if that project could be shown to be a solution to the overdraft ~~on~~ from the Oxnard Plain.

SUMMARY AND CONCLUSIONS

• Under present conditions of deficient rainfall, the quantity of ground water withdrawn from wells on the Oxnard Plain far exceeds the replenishment. So long as the period of deficient rainfall prevails, and the present rate of pumping is maintained, the deficiency in water supply will be on the order of 30,000 acre-feet a year.

• Water levels have been drawn down sharply since 1944 and now are as much as several tens of feet below sea level beneath the southern part of the Oxnard Plain. The hydraulic gradient is landward in almost all the area southeast of Port Hueneme. There is no known physical barrier to ocean-water intrusion into the water-bearing beds. Although such intrusion is not known to have advanced more than a few hundred feet beneath the land, conditions are wholly favorable to accelerated invasion.

• The well field at the Port Hueneme Naval Base is not considered an adequate source to supply a million gallons of water a day to the Point Mugu Naval Base because of the danger of ocean-water intrusion at Port Hueneme.

• Three other possibilities are considered, as follows:

1. Expansion of the present well field at the Point Mugu Naval Base.

2. Development or purchase of a supply from a source within the deposits now tapped by wells but far enough inland to eliminate any reasonable danger of ocean-water invasion.

3. Development of water from aquifers deeper than those now tapped by water wells, if productive aquifers overlain by impervious capping deposits can be found.

It is concluded that regardless of the source selected, water would be taken from the common supply of the Oxnard Plain. The ultimate solution to the overdraft and to critical ocean-water intrusion depends on storage and distribution of flood waters now wasting to the sea; a program for such a solution is understood to be in the investigative stage.

In view of the ultimate solution, and the magnitude and large cost of undertaking possibilities 2 or 3, it is suggested that the Navy expand its well field at the Point Mugu Naval Base to develop a temporary supply. If the well field is expanded, the centers of pumping should be distributed so as to produce as gentle a cone of depression as economically feasible. Observation wells would be needed near the coast to check on position and rate of advance of ocean-water intrusion which is expected to move inland as long as landward gradients prevail. There is a reasonable chance that wells properly distributed at the Point Mugu Naval Base may yield an adequate supply of water to the Base through the present period of deficient rainfall. If so, development of an ~~ultimate firm~~ adequate future supply presumably can be worked out in cooperation with County agencies.

Long Beach, California
August 20, 1948

MEMORANDUM ON DEEPER SOURCES OF WATER
to supplement
Progress report on water supply for
the Point Mugu Naval Base, Ventura County, California
By John F. Mann, geologist

In the event the present shallow water supply of either the Point Mugu Naval Base or of the Port Hueneme Naval Base becomes contaminated by invading ocean water, an alternative source of supply will have to be found. One possible source, development of water from deeper aquifers capped by one or more impermeable layers, was discussed briefly in the body of the progress report (pp. 34-35), and it was indicated that further investigation was being made. This memorandum summarizes in brief the conclusions of the Geological Survey concerning possibilities for development of deeper aquifers.

The test hole for the first new well at the Point Mugu Naval Base should be drilled through the entire water-bearing sequence to hard bedrock of Miocene age, which probably will be reached at a depth between 900 and 1,200 feet. (See progress report, page 37.) The probability of encountering in this test hole a thick aquifer beneath an extensive impermeable cap does not seem strong, in light of the evidence available for the upper 600 feet; nevertheless, the expenditure required to determine the character of the deeper deposits is justified, because the cost of drilling to bedrock, below the depth otherwise necessitated by the test hole, would be small.

An investigation of the deeper water-bearing zones by the Geological Survey using electric logs and formation logs of scattered oil wells and test holes reveals that an aquifer with the necessary characteristics does occur to the north. The best information concerning this aquifer has been obtained from electric logs and a core hole in the Oxnard oil field (about 2 miles east of Oxnard), where it is almost 300 feet thick and between 1,000 and 1,500 feet below land surface. It is predominantly sand, with little gravel, and with irregular interbeds of clay. The same sandy zone was penetrated by a well 2 miles northwest of Oxnard, and by another well near the southwest end of the Camarillo Hills. The aquifer seems to be fairly persistent, and probably extends westward beneath the Port Hueneme Base, where its thickness may be somewhat less than 300 feet. The northeast corner of the Port Hueneme Base would seem to be one of the most favorable places on Navy property for developing a source of deeper water. Accordingly, it is suggested that if the currently developed water supplies at either the Point Mugu Base or the Port Hueneme Base become contaminated, a test hole be drilled by the rotary method in the northeastern part of the Port Hueneme Naval Base. This test hole should be drilled to a depth of about 2,000 feet, followed by the running of an electric log to determine the exact locations of aquifers and thicknesses of capping beds. If the results of the test hole should be favorable and decision reached to complete a well, a string of casing should be seated in the impermeable capping deposits to prevent effectively contamination of the aquifer by shallower waters. Any aquifers which might be encountered are expected to be chiefly sand; therefore, the well should be of gravel-pack construction.

U. S. Geological Survey
Long Beach, California
September, 1948.

MEMORANDUM ON PRESENT STATUS OF THE SALINE FRONT
to supplement
Progress report on water supply for
the Point Mugu Naval Base, Ventura County, California
By Arthur A. Garrett

The progress report of August 1948 for the Bureau of Yards and Docks indicated (p. 40) that the Geological Survey was proceeding with field location and sampling of active wells and open casings between the Port Hueneme and the Point Mugu Naval Bases, and within a mile or so of the coast, to determine whether ocean water has advanced inland in the coastal aquifers and to define the present position of the front of such ocean-water intrusion, insofar as possible.

The sampling was done July 21 and August 25-27, 1948. In all, 23 active wells and two open casings were sampled. The waters in the open casings were tested with portable electrical conductivity equipment to determine their salinity. Of the three wells cited on page 26 of the progress report as suggesting contamination, Nos. 9-W-2 and 11-X-1 were not found, and it is likely they have been destroyed. Well 9-W-1, also mentioned on page 26, was inactive when canvassed by the Geological Survey so that a water sample could not be obtained. Plate 8, accompanying this memorandum, shows the wells sampled by the Geological Survey, critical wells for which analyses have been made by other agencies, and the chloride content of the waters, as described on the plate explanation.

Two important features were disclosed by the field canvass. This memorandum summarizes in brief these features:

1. The quality of water yielded from the unnumbered well 0.5 mile south of Hueneme Road and just east of Perkins Road is suggestive of

contamination, possibly from the ocean. The sample taken August 26 contained 450 parts per million of chloride. The owner of the well reported that the water "recently had become unfit for use." Thus, this well may be about at the present front of active saline-water migration landward through the coastal aquifers. Well 9-W-4, 0.25 mile north of the unnumbered well and 143 feet deep, was traversed with the conductivity electrode. No log is available for the well and the position of the perforations is not known. From water surface (15.1 feet below land surface) to 135 feet below land surface the water contained about 200 parts per million of dissolved solids. From 135 feet to bottom the dissolved solids content increased linearly to about 540 parts. The dissolved solids content of native waters of that part of the Oxnard Plain for which the chloride content ranges from 45 to 50 parts is about 650 parts per million based on electrical conductivity. Hence, water of somewhat lower dissolved solids content must have collected in the well since it was last pumped. If the perforations in the well are now open to one or more of the coastal aquifers, it is reasonably certain that contamination has not yet reached the well. Thus, the front of contamination presumably lies somewhere between this well and the unnumbered well 0.25 mile south.

2. Analyses of water from wells 10-W-8, 10-W-15, and 11-W-3, all south of Caspar Road (pl. 8), suggest the existence of a local area yielding water definitely poorer in quality than is normal for the area as a whole. This condition may represent a lobe or wedge of saline water extending inland from the ocean to the south. However, until further evidence can be obtained, this inference is unsubstantiated. More likely is the possibility that

conditions here are similar to those at wells 11-W-15 and 11-W-20, about 2 miles northeast, which yield water containing from 58 to 578 parts of chloride. The latter area is thought to yield water naturally more saline than the adjacent areas of normal water because of the presence of shallow aquifers that contain natively inferior water which can enter the casing in varying quantities depending upon existing water-level differentials.

The chloride content of water from well 10-W-14 (16,500 parts per million) is not representative. The well was drilled to a depth of 250 feet in 1922, and as inferred from the log, the casing presumably was perforated below 140 feet. When visited in August 1948, the well was only 86 feet deep and the water level was about 8 feet below land surface — at least 8 to 10 feet above the "static" levels in nearby active wells. The conductivity traverse run by the Geological Survey showed some vertical change in salinity which is not considered significant because the well probably is not now open to any of the coastal aquifers. The casing of the well is corroded off at land surface and is within a few feet of a drainage ditch. Hence, at some period of tidal over-run the well may have been filled with ocean water thereby accounting for the extremely high chloride content of the water now present.

The information on chemical quality of well waters shown on plate 8 indicates that, as of August 1948, if salt water is moving inland from the ocean into the producing coastal aquifers in the reach between the Port Hueneme and Point Mugu Naval Bases:

1. Near Port Hueneme the front of this saline contamination has not advanced inland more than 0.4 mile.

2. Along the northwest lobe of the Point Mugu Naval Base property,

the front has not advanced inland more than 0.6 mile (well 10-W-21) to 0.8 mile (well 10-W-8).

For the present, therefore, there is no danger of saline intrusion from the west or southwest into the existing or proposed wells at the Point Mugu Naval Base. The conditions of saline intrusion directly to the south of the Point Mugu well field can be learned only by constructing observation wells, as described on pages 38 and 39 of the progress report.

U. S. Geological Survey
Long Beach, California
September 1948

GEOLOGICAL SURVEY

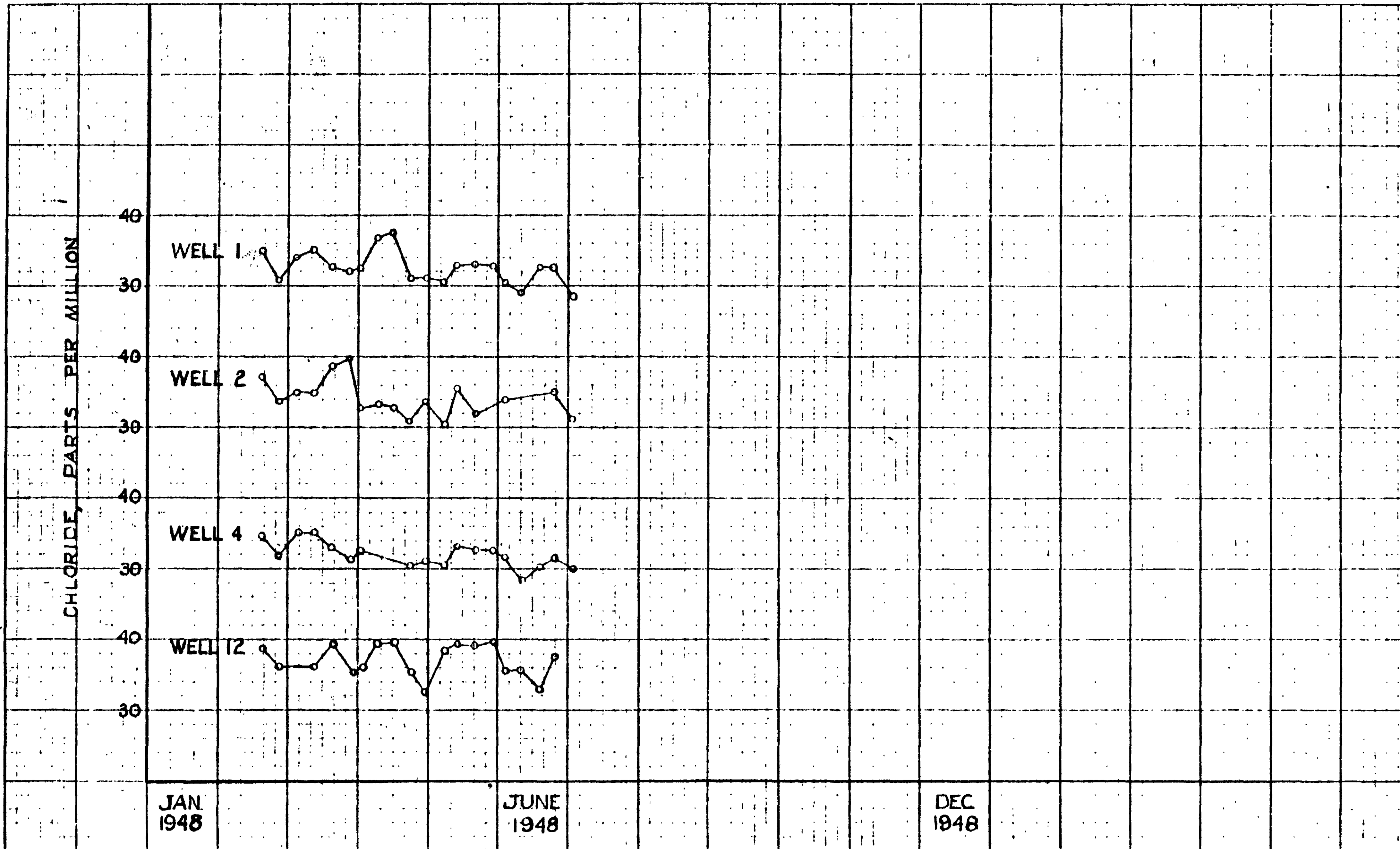

Figure- 1 - Chloride content of waters from selected wells at Port Hueneme Naval Base
(Analyses by Port Hueneme Naval Base)

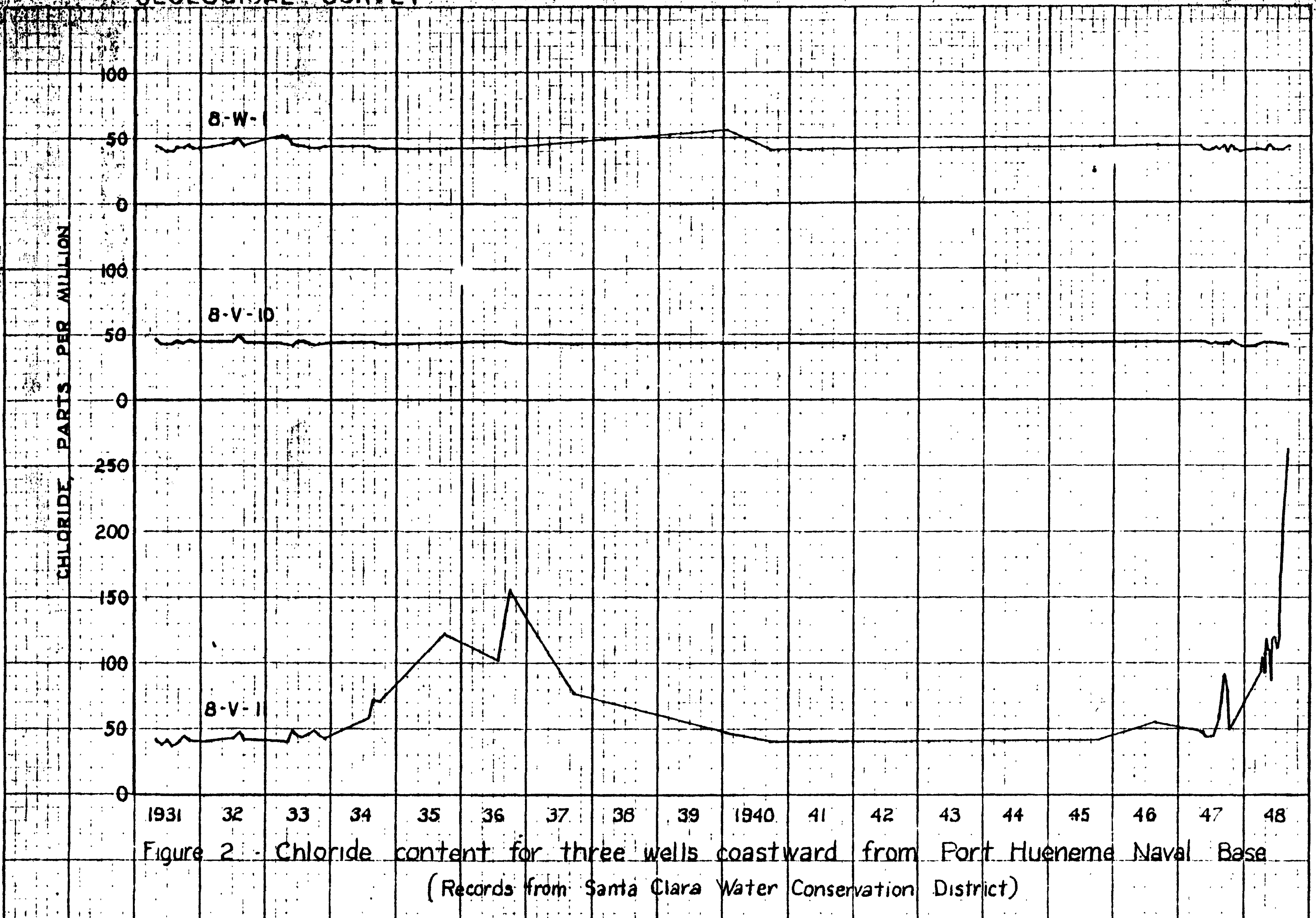

Figure 2. - Chloride content for three wells coastward from Port Hueneme Naval Base
(Records from Santa Clara Water Conservation District)