UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATUS OF SALT-WATER CONTAMINATION IN THE COASTAL PART OF ORANGE COUNTY, CALIFORNIA, AS OF 1948-49

By

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Prepared in cooperation with the Orange County Flood Control
District and the Orange County Water District

August 1949

49-91

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STATUS OF SALT-WATER CONTAMINATION IN THE COASTAL PART OF ORANGE COUNTY, CALIFORNIA, AS OF 1948-49

INTRODUCTION

Previous investigation by the Geological Survey in the Long Beach-Santa Ana area

Early in 1940, a cooperative field investigation was started by the Geological Survey of all pertinent ground-water features in a coastal zone of 180 square miles that extends from Dominguez Hill on the northwest to Costa Mesa on the southeast. Also, general study was made of selected ground-water features in a contiguous coastal-plain area of some 380 square miles that extends inland to the enclosing mountains. These two areas together were designated the "Long Beach-Santa Ana area." This investigation was undertaken in cooperation with the Orange County Flood Control District, the Orange County Water District, the Los Angeles County Flood Control District, and the Board of Water Commissioners of the City of Long Beach.

Of the several objectives of the investigation, described in a progress report_/ released in August 1943, three, in particular, dealt

_/Piper, A. M., Poland, J. F., and others, Progress report on the cooperative ground-water investigation in the Long Beach-Santa Ana area, California, U. S. Geol. Survey duplicated report, 46 pp., August 1943.

with some phase of saline contamination of the main water-bearing zones along the coast. Of these three, one dealt with the determination of the lateral extent of existing saline intrusion, the second with the discrimination of sources of the contaminant, and the third with localizing the places in the coastal "barrier" through which sea water might ultimately reach the water-bearing materials in the main coastal basin. Of the several factual and interpretive reports released by the Geological Survey as a result of the cooperative investigation, four_/ are concerned

_/Garrett, A. A., and others, Partial chemical analyses of waters from wells, streams, ponds, and sumps in the coastal zone of the Long Beach-Santa Ana area, California, 1940-43, XX, 89 pp., July 1943.

Piper, A. M., Poland, J. F., and others, idem. (progress report).

Piper, A. M., Garrett, A. A., and others, Chemical character of native and contaminated ground waters in the Long Beach-Santa Ana area, California, U. S. Geol. Survey duplicated report, 355 pp., August 1946.

Poland, J. F., Hydrology of the Long Beach-Santa Ana area, California, with special reference to the watertightness of the Newport-Inglewood structural zone, U. S. Geol. Survey duplicated report, 198 pp., June 1946.

either wholly or in part with one or more of these three cited objectives. In those reports, the status of the several phases of the contamination problem was brought current to 1944.

These reports outlined the extent of sea-water contamination in the three gaps in Orange County and in the two in Los Angeles County, and also discussed contamination from sources other than the ocean.

Unpublished records,
subject to revision

Purpose and scope of report

discontinued

The studies of the Geological Survey were ended in about 1944. Subsequent analyses of water by other agencies, from wells in Santa Ana Gap then known to be contaminated, showed not only that the saline concentration in the contaminated wells was increasing but also that the saline front was continuing to move inland at an alarming rate. Contamination increase was noted locally along the coast to the northwest as well.

The need was therefore felt by both the Orange County Water District and the Orange County Flood Control District for a reappraisal of the status of coastal contamination. Accordingly, through a cooperative agreement with these agencies beginning in July 1948, the Geological Survey resumed work to reexamine the status of contamination along the coast of Orange County, with special reference to Santa Ana Gap. This progress report is the result of the first year of the program. Presented herein is factual chemical evidence showing the position of the present contamination front--insofar as ascertainable from the data available, the increase in salinity of wells known previously to have been contaminated, and the increase since 1944 in areal extent of lands in Santa Ana Gap underlain by the contaminated waters. Also presented is a summary of the water-level changes within the coastal plain of Orange County that doubtless have aggravated contamination along the coast.

Considerable geologic data have become available for the coastal part of Santa Ana Gap, as a result of the drilling of many oil wells in the Newport oil field since 1945. This geologic information should be of substantial use in the interpretation of contamination in the gap and future plans for its control. This geologic information was not collected or analyzed for inclusion in this report, because funds did not permit it.

Also, this year's program could not include field sampling and study of the extent of contamination as of 1949 on the central part of the Huntington Beach Mesa, where contamination is due to the disposal of oil-field brines._/ It is planned that the current status of contamination on Huntington Beach Mesa will be studied in 1950.

_/Piper, A. M., and others, op. cit. (report on chemical character), pp. 270-271.

Acknowledgments

With the exception of about 50 chemical analyses on water from wells and electrical-conductivity traverses on three wells, all in Santa Ana Gap, made by the Geological Survey, the basic chemical data used in preparing this report were obtained from the Orange County Flood Control District. That agency has collected water samples quarterly from about 40 wells in Santa Ana Gap and from 11 wells in Bolsa Gap, for the past several years. By means of these analyses it has been possible to trace the changes in contamination since 1944.

Water-level measurements for 14 wells in Santa Ana Gap were obtained from the Orange County Water District through Mr. W. D. Miller, and measurements for wells in the gap and in the main coastal plain in Orange County were obtained from the Orange County Flood Control District through Mr. J. A. Bradley. In all, measurements were obtained from these two agencies for about 350 wells. The use of both the chemical and the water-level information is gratefully acknowledged.

REGIONAL GROUND-WATER CONDITIONS

A comprehensive treatment of regional ground-water conditions in Orange County to 1944 is included in an earlier report._/ Two of the

_/Poland, J. F., op. cit. (report on hydrology).

illustrations accompanying that report have been modified by the addition of recent data and are included in this report as plates 101 and 102.

Plate 101.- Representative long-term hydrographs for wells in Orange County.

Plate 102.- Water-level profiles for the Talbert water-bearing zone from Santa Ana Gap to Santa Ana Canyon, 1904-48.

These two, together with a water-level contour map for August 1948 (pl. 103)

Plate 103.- Map of the coastal plain in Orange County showing water-level contours for August 1948.

present a graphic picture of changes in ground-water conditions in Orange County since 1944. Plate 101 (adapted from pl. 904 of the report on hydrology) was plotted to show annual and seasonal changes of water level in wells tapping the principal aquifers in the main coastal basin in Orange County. The locations of all wells for which hydrographs are plotted are shown on plate 103.

In the western part of the county (pl. 101, A), levels in three wells tapping confined water in the San Pedro formation declined steadily from 1930 into 1936, recovered into 1945, then declined again into 1949. For all three, the recovery into 1945 was not sufficient to regain altitudes of the water levels in 1930. Since 1945, the rate of decline has been so great that the 1949 spring highs for all three wells were the lowest of record. Water levels for wells 4/11-19K1 and 5/11-16D2 were below sea level for most of the year in 1948. The greatest decline for the 5-year period 1944-49 was 22.2 feet for well 3/11-36Q2, and the least 12.7 feet for 5/11-16D2.

For wells tapping the Talbert water-bearing zone (pl. 101, B), the amount of decline from 1930 into 1936, recovery into 1945, and lowering since 1945, diminishes coastward. Of the four wells shown, well 4/9-7B1 is only 0.3 mile from the Santa Ana River east of Anaheim; its water level responds rapidly to variations in stream flow. Although, as seen from the graph, recharge from the river was very large in 1941 and 1943-45, recharge has been small since 1945, particularly in 1948. For nearly all these years to 1948, however, the average recharge must have been much greater than in the middle thirties. That is, for the period 1941-47 the average spring high for well 4/9-7B1 was 82.3 feet or about 56 feet above the spring high of 1936. During this whole period of very great fluctuation in water level in the recharge area near Anaheim, the water level in the confined segment of the Talbert zone near the coast has remained comparatively quiet (see hydrograph for well 6/11-13G2 which is within the area of saline contamination where pumping draft is negligible and water levels are adjusted to sea level as well as to inland pumping).

Unpublished records,
subject to revision

Because the Talbert water-bearing zone can be recharged easily, provided that water is available in the Santa Ana River, and because recharge since 1938 has been about equal to net draft in the same period, the water levels have not since exceeded the 1936 record low throughout the horizontal reach of the zone. Referring to plate 102 (adapted from pl. 908 of the report on hydrology), which shows a series of profiles of ground-water level at selected time intervals from the eighties into 1948 for the Talbert zone, the levels for the low period of 1948 were above those of the comparable period of 1936 in the coastal two-thirds of Santa Ana Gap and also for the reach about from U. S. Highway 101 to the mouth of Santa Ana Canyon. (For position of the section along which the profiles have been drawn, see pl. 103.) However, the 1936 low has been exceeded through about 8 miles of reach; the average difference in 1948 was on the order of 4 feet. The greatest lowering noted was at well 4/10-27Q1, about 9 feet below the 1936 low; the least was at well 6/11-13G2, about 10 feet above the 1936 low.

To show fluctuations in water level from 1930 into 1949 for the two water-bearing zones of Newport Mesa, hydrographs for three wells are plotted on plate 101, C. Of the three, well 6/10-1L2 taps the deposits of upper Pleistocene age; the others--6/10-3H2 and 11G2--tap the underlying principal water-bearing zone within the San Pedro formation. Although the local draft from upper Pleistocene deposits is light, the level in well 6/10-1L2 for the late summer of 1948 was about 3.5 feet below that of 1936. Also, except for 1928, the seasonal range of more than 9 feet in 1947-48 is the greatest of record, and is three times as great as the normal seasonal range.

Unpublished records,
subject to revision

The level in the underlying San Pedro formation, as shown by the graphs for both wells 6/10-3H2 and 6/10-11G2, declined to a record low in 1948--at least 10 feet below that of 1936. The failure of the level in well 11G2 to respond to the regional increase in water levels lasting until about 1945 has been explained elsewhere._/ The graph for well

_/Poland, J. F., op. cit. (report on hydrology), p. 115.

6/10-3H2 shows nearly consistent spring high levels for the years 1941-45. The observed decline has taken place since early in 1945.

The regional water-level decline within the coastal plain of Orange County occurring since 1945 has been due to combined effect of heavy draft (the average annual overdraft in the lower Santa Ana River area for the 21-year period 1922-23 to 1942-43, inclusive, is estimated by Gleason_/ as 10,240 acre-feet) and markedly subnormal rainfall. For

_/Gleason, G. B., South coastal basin investigation, overdraft on ground-water basins: California Dept. Public Works, Water Resources Div. Bull. 53, table 211, p. 252, 1947.

instance, since 1944-45 the cumulative deficiency in rainfall for Los Angeles is 15.08 inches and for Tustin, 8.31 inches, based on the average rainfall for 68 seasons._/ For agricultural use, this deficiency has

_/Poland, J. F., op. cit. (report on hydrology), pp. 44-45.

been made up in large part by added draft from the ground-water body.

As may be determined from plate 103, the area beneath which the ground-water level was below sea level was about the same for the low period of 1948 and for the low of 1936--145 square miles. However, within this 145 square miles, conditions are definitely worse at two distinct places. In the vicinity of Los Alamitos, where water levels in 1936 were on the order of 5 feet below sea level (see pl. 103), the water level in 1948 was 20 feet below sea level beneath about 6 square miles. Also, south of Santa Ana in parts of T. 5 S., Rs. 9 and 10 W., and in the western part of the Irvine Tract, water levels in 1948 were materially lower than in 1936.

CONTAMINATION IN THE COASTAL PART OF ORANGE COUNTY

Along the coast in Orange County and in the extreme southeastern part of Los Angeles County--that part of the Long Beach-Santa Ana area covered by this report--the contamination problem is influenced locally by certain pertinent geologic features. These features have been treated at length in an earlier report._/ However, a brief review of them will

_/Poland, J. F., Piper, A. M., and others, Geologic features in the coastal zone of the Long Beach-Santa Ana area, California, with particular respect to ground-water conditions: U. S. Geol. Survey duplicated report, pp. 66-73, May 1945.

be made here in introducing data concerning the present extent of contamination along the coast.

Unpublished records,
subject to revision

Within the extent of plates 103 and 104, the hills and mesas of the

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Plate 104.- Map of the coastal part of Orange County showing extent of waters containing more than 50 parts per million of chloride as of 1949.

Newport-Inglewood belt are interrupted by four "gaps" through which tongues of the central lowland (Downey Plain) extend to the coast. Of the four, three are in Orange County and the other is chiefly in Los Angeles County. In this report conditions of saline contamination are appraised for all four gaps, namely, Alamitos Gap in Los Angeles County, and Sunset, Bolsa, and Santa Ana Gaps in Orange County, and for the intervening mesas except for Huntington Beach Mesa. Although all four gaps are floored by deposits of Recent age, only in two do these deposits include a basal gravel sufficiently thick and permeable that it can be used to yield water extensively to wells.

In Santa Ana Gap, the Recent deposits are about 150 feet thick and include a basal gravel--the Talbert water-bearing zone--ranging in thickness from 40 to 70 feet. In Bolsa Gap, sediments of Recent age are about 80 feet thick and include a basal gravel--the "80-foot gravel"--ranging in thickness from 5 to 20 feet; locally north of Huntington Beach Mesa it is in contact with the Talbert zone (see pl. 103). In Sunset Gap, on the other hand, the Recent deposits are wholly fine-grained and probably are no more than 30 feet thick; in Alamitos Gap they are presumably about 90 feet thick and contain a thin basal bed of gravel, but one of low permeability.

With respect to transverse faulting across the gaps (see pls. 103 and 104 for location of known and inferred faults) the available geologic and hydrologic evidence suggests no discontinuity within the deposits of Recent age; faulting does transect all deposits of Pleistocene or greater age. Therefore, in Santa Ana Gap, in Bolsa Gap,_/ and probably in

_/In Bolsa Gap, the existence of the basal gravel within a mile of the ocean is shown at only one place--at well 5/11-29P1. However, it is believed that the basal gravel extends through the gap. (See p. 98 of the report on geology of the Long Beach-Santa Ana area.)

Alamitos Gap, inland progress of contamination is dependent largely upon the position and slope of the hydraulic gradient within the water bodies in the deposits of Recent age. The inland advance of contamination in Sunset Gap and on the adjoining Landing Hill and Bolsa Chica Mesa, however, is dependent not only upon the direction of the hydraulic gradient but more basically on whether the transverse fault barriers, which produced a reasonably effective seal with high native water levels and a seaward gradient, will continue to be reasonably effective with water levels below sea level and a reversed or landward gradient.

On the following pages are summarized the extent of current contamination under existing hydraulic gradients and the comparison of the present extent to that of 1944, for Alamitos Gap to Santa Ana Gap, inclusive. The extent of the contaminated area as of 1949 and the locations of the wells discussed are shown on plate 104.

Contamination from Alamitos Gap to the Huntington Beach Mesa

In the coastal area northwest from the Huntington Beach Mesa, and extending beyond the boundary of Orange County to Long Beach, native waters of high salinity are thought to occupy all the Pleistocene deposits between the coast and the principal faults of the Newport-Inglewood structural zone. For the area just inland from the structural zone, the earlier investigation by the Geological Survey_/ revealed only two places where increase in chloride concentration of the ground water had occurred--specifically, in Alamitos Gap and on Landing Hill.

_/Piper, A. M., and others, op. cit. (report on chemical character).

Alamitos Gap

Alamitos Gap is bordered on the northwest by the Long Beach Plain and on the southeast by Landing Hill. So far as known, waters of high salinity were present under native conditions in the Pleistocene deposits beneath the gap as far inland as the main fault of the Newport-Inglewood structural zone--that is, about 1 mile inland from the coast. Of the two places between Huntington Beach Mesa and Long Beach Plain where the saline water was suspected of breaching or crossing over the fault in response to drawdown of inland water levels, one is within this gap, specifically, in the vicinity of well 5/12-11G1._/ This well, which is about 200 feet inland from the main fault, has been pumped regularly for industrial purposes and has been sampled periodically since 1933 by the Los Angeles Flood Control District. Plate 105 shows that the chloride content of the water yielded from the well increased from about 20 parts per million in 1933 to about 50 parts in 1943, then jumped to more than 300 parts in 1946. The chloride content subsequently declined to a low of about 95 parts late in 1947 but then reversed its trend through 1948 and into 1949.

_/Idem., pp. 280-284.

Plate 105.- Chloride content of water from well 5/12-11G1 in the Alamitos Gap, 1933-49.

Unpublished records, subject to revision

It was concluded in the earlier report_/ that the contaminant may

_/Piper, A. M., op. cit., p. 280.

have reached the well (1) by percolation downward from the unconfined water of poor native quality, (2) by crossing above or through the Seal Beach fault, or (3) from or through unused well 5/12-11H1, which is about 350 feet northeast and contained saline water. Of the three, the first was considered the least likely.

In order to eliminate the possibility of contamination through the open casing of well 5/12-11H1, it was plugged in October 1944. The water from well 5/12-11G1 did improve substantially. However, because the improvement was delayed until late in 1946—two years later—the relation of cause and effect probably should not be accepted without some additional supporting evidence, particularly when contamination of water from well 11G1 is again increasing. For instance, if the saline waters actually had crossed over or through the Seal Beach fault, decreased pumping from well 5/12-11G1 and general recovery of levels inland from the fault might have produced a decrease in salinity of the water. It is not known whether or not decrease in pumping has occurred. However, there has been no recovery of water levels for the years 1946-47; in fact, regional water levels have been declining since 1945. Therefore, it is believed that the temporary improvement in quality of water from well 5/12-11G1 was due to plugging of adjacent well 11H1, and hence, that well had been contributing a major part of the contaminating water to the pumped well.

However, a striking feature shown by the graph (pl. 105) is that the increase in salinity occurring through 1948 and into 1949 seems to be a continuation of a gradual increase that began as early as mid-1942, as suggested by the dashed line. That is, the intense contamination noted especially for the years 1944-46 appears to be a superposed contamination that ceased to be a contributing factor late in 1947. In other words, the sealing of well 5/12-11H1 apparently eliminated the superposed contamination but did not eliminate the cause of the more gradual increase in salinity. It will be noted further that the current increase in salinity is rather uniform; only minor deviation from the over-all trend is taking place.

Therefore, it is concluded that the saline water causing the slow and reasonably uniform increase in chloride content at well 5/12-11G1 has invaded the main water-bearing zone generally, and hence, could most likely originate coastward from the Seal Beach fault, where an unlimited supply of water, similar in concentration to ocean water, is available. It is tentatively concluded, therefore, that—at least at this place in Alamitos Gap--saline water actually has crossed the Seal Beach fault, very possibly over the top of the fault, which is inferred to be about 90 feet below the land surface. This saline water has appeared, very much diluted by native fresh water, at well 5/12-11G1.

Landing Hill

Of the two places where contamination was earlier noted inland from the barrier features, the one in Alamitos Gap has just been discussed. The other is on Landing Hill, specifically including well 5/11-12P1 and part of the nearby well field of the City of Seal Beach.

Contamination there was covered at length in the earlier report on chemical character._/ However, for purposes of review, several

_/Piper, A. M., and others, op. cit., pp. 276-280.

pertinent features of the earlier discussion will be set forth here, before additional data are presented.

Well 5/12-12P1 is about 100 feet inland from the Seal Beach fault. The well was reported as originally about 400 feet deep, but a measurement in 1942 indicated a depth of only 185.3 feet; presumably only a part of its perforated casing is open. The well taps the upper part of the San Pedro formation, and yielded water in 1931 containing about 19 parts of chloride. In 1942, the chloride content of water from the well was as great as 346 parts per million, and dissolved solids about 900 parts. Later in that year, the well was probed with conductivity equipment and it was found that water with a dissolved-solids content as great as 1,350 parts per million existed below a depth of 180 feet, that is, in about the bottom 5 feet. The quality of the water pumped from the well under stabilized conditions represented a blend of native fresh water and a saline water at least four times as concentrated as the blend itself. Under nonpumping conditions the level in the well through 1943 ranged from 9.9 feet above to about sea level. The pumping level commonly was 8 to 12 feet lower. It was concluded that the saline water had been drawn inland across the fault as a result of inland water-level gradient.

In 1944 the lands adjacent to the well were purchased by the United States Government and the well was no longer used. Hence, only a small amount of additional information is available concerning the well. Weekly water-level measurements on the well were discontinued by the Orange County Flood Control District in December 1944. In October 1945, monthly measurements were begun by the City of Long Beach. In May 1949, the Geological Survey attempted to obtain a water sample from the well by means of a manually-operated plunger pump. The pump would not draw water from the existing water level 24 feet below land surface. It was not thought feasible to bail a sample from the well because of the large amount of oil on the water surface and also because a sample so obtained would be unlikely to represent conditions within the water body.

As the saline contamination at the well doubtless was brought about by a reversal of the initial seaward hydraulic gradient, the position of the water level should be a good index as to whether contamination in the vicinity of the well has increased since the cessation of pumping of the well. The hydrograph for the well (not included in this report) shows that during the period of incipient contamination--the early forties--static levels in the well generally were above sea level but dropped in accord with the regional water-level decline that began in 1945-46, and since February 1948 have been continuously below sea level. It is reasonable to believe, then, that contamination here has continued and probably is still increasing.

Part of the lowering of water level in this well has been due to the pumping of the two active wells of the City of Seal Beach, a few hundred feet to the northwest. Chemical evidence from these wells confirms the conclusion that the further lowering of water levels has brought about an increase in contamination.

Unpublished records,
subject to revision

As of 1943, the active wells were 5/12-12P4, 620 feet deep; and well 5/12-12P6, 670 feet deep (City Nos. 4 and 5). Then, the chloride content from both wells was less than 20 parts per million. Early in 1949, the water from well P6 still contained less than 20 parts but that from well 4 contained nearly 200 parts per million of chloride.

Both wells tap aquifers below 500 feet, hence the difference in chloride content probably is due to relative distances from the focus of contamination. As stated earlier, well 5/12-12P1 is probably not more than 100 feet from the fault; well 12P4 is probably on the order of 250 feet, and 12P6, about 600 feet from the fault. The front of contamination, then, has passed beyond both 12P1 and 12P4 and is somewhere between well 12P4 and 12P6. Further, inasmuch as well 12P1 taps the upper part of the water-bearing zone, it is tentatively concluded that the contamination is distributed throughout the vertical range of the San Pedro formation from near land surface to a depth of at least 600 feet. Also, because the direction of progress of contamination seems normal to the fault, the concept is strengthened that saline water has breached the fault locally in response to the reversal of the initial seaward hydraulic gradient.

Sunset Gap

Sunset Gap, next in order southeast from Alamitos Gap, is bordered on the northwest by Landing Hill and on the southeast by Bolsa Chica Mesa. At its narrowest part it is 2.2 miles across. Observation wells drilled in Sunset Gap by the Geological Survey, immediately coastward from the main fault of the Newport-Inglewood zone, show that, at least for the deeper part of the range penetrated, water as saline as the ocean is found. Here, the fault is about 0.65 mile inland from the shore line.

There are no active wells less than half a mile inland from the fault barrier. To date, no further sampling of water from wells in Sunset Gap has been undertaken. Therefore, it is not known whether any wells in the gap, other than those already discussed, have become contaminated since 1942.

Bolsa Chica Mesa

As of 1943, salt water had not advanced inland beneath Bolsa Chica Mesa beyond the barrier fault of the Newport-Inglewood uplift. For many years the water supply for Sunset Beach has been taken from wells 5/11-29C1 and C2, about 700 feet inland from the fault. The water from well C1 has been sampled for chloride analysis irregularly since 1930 by the Orange County Flood Control District. As of April 1949 the chloride content for well C1 was 12 parts per million, still the native quality for the area. In addition, on June 20, 1949, a sample of water collected by the Geological Survey from unused well 5/11-29C4, at a depth of 150 feet below land surface, contained 15 parts of chloride. Well 29C4 is about 400 feet inland from the fault and a quarter of a mile northwest of wells 5/11-29C1 and C2. Thus, even though water levels beneath the mesa were as much as 10 feet below sea level in 1948 (see pl. 103), salt water presumably has not crossed the fault. If the water level here is depressed below sea level for extensive periods, however, the barrier features may not be sufficiently impermeable to hold back the coastal saline waters.

Unpublished records,
subject to revision

Bolsa Gap

Bolsa Gap, about 1.6 miles wide, lies between Bolsa Chica Mesa on the northwest and Huntington Beach Mesa on the southeast. Saline water is inferred to exist seaward from the coastward fault of the two crossing the gap (see pl. 104)--well 5/11-29P1, about 0.25 mile from the coast, yielded water in 1941 containing more than 2,000 parts of chloride. This well casing is perforated 484-524 feet below the land surface, in the San Pedro formation.

In Bolsa Gap no pumping of water for use occurs immediately landward of the fault system. Therefore any inland movement of saline water over or through that barrier feature must be in response to regional lowering of water levels, rather than to local pumping effects such as have occurred on Landing Hill. So far as available records indicate (pl. 103), water levels within the gap are mainly below sea level. In September 1948, the water level in well 5/11-28K1, about 0.8 mile inland from the fault, was nearly 15 feet below sea level. Nearby wells show water levels with similar altitudes. On the basis of long-term records of water level for wells there and elsewhere, it is concluded that levels have been below sea level in the gap for at least the greatest part of each year since 1946.

Because there are no water wells in Bolsa Gap just inland from the fault zone, it cannot be determined whether saline water actually has penetrated inland beyond the faults in response to inland gradients. For the gap as a whole, recurrent chloride determinations are available for six wells. For all these wells, sampling was begun in 1930. The series of analyses show essentially no increase in chloride for any of the wells for the period of record. Therefore, it is concluded that there has been no change in the quality of water withdrawn from wells in Bolsa Gap since 1943, but it cannot be said whether salt water has passed inland beyond the fault zone.

Unpublished records,
subject to revision

Because of the existence of contamination on the Huntington Beach Mesa, which locally has spread into the gap,_/ a complication is present

_/Piper, A. M., and others, op. cit., pp. 243-245.

that would obscure the picture if any of these wells in the gap, now yielding fresh water, should suddenly become contaminated. The question would arise as to whether the saline water originated seaward from the fault or from the Huntington Beach Mesa. Such cases, of course, would have to be examined in the light of evidence existing at the time contamination was noted. As stated earlier, it was not possible to include in this report an examination of current contamination resulting from oil-field-brine disposal on, or near the periphery of, the Huntington Beach Mesa.

Contamination in Santa Ana Gap

In 1930, waters containing more than 50 parts per million of chloride had advanced inland in the Talbert water-bearing zone of the Santa Ana Gap, beneath about 1,900 acres along the coast; also, the inland fringe of contaminated waters was between 0.9 and 0.4 mile from the coast._/

_/Piper, A. M., Garrett, A. A., and others, op. cit. (report on chemical character), p. 197, pl. 812A.

By 1944 the area of contaminated water in the Talbert zone had increased by about 500 acres, or from 1,900 to 2,400 acres. In the western part of the gap, the contamination fringe had moved inland between 0.1 and 0.3 mile, and from Cannery Avenue to Bushard Street it had moved inland about 0.7 mile. This greatest inland movement coincided with the area of greatest withdrawals of ground water in the Santa Ana Gap during the period. The position of the contamination front for 1944 is shown by the dotted lines on plate 104.

In the 5-year period 1944-49, the contamination front continued to advance, but, because of certain limitations to be set forth here, any figure given for the additional area underrun by contaminated water must be acepted as extremely rough. However, using the concept discussed on page 27, the position of the contamination front for April 1949 has been drawn on plate 104, and, as shown, includes an additional area of 275 acres since 1944, or a total of about 2,700 acres underlain by saline water in the coastal portion of Santa Ana Gap.

The fact that the saline front in the gap is continuing its inland advance has been determined chiefly by means of data obtained from four wells, of which three yielded native water in 1944. These three wells are Nos. 6/10-18B4, 18C1, and 6/11-13A1. The other, 6/10-18B6, was drilled in February 1944, and, although it yielded essentially native water in 1946, one analysis in each of the years 1944 and 1945 showed the chloride content then to be above 450 parts per million. (See page 25.) All the available chloride analyses for these wells are plotted on plate 106; they show that,

Plate 106.- Chloride content of water from four wells in Santa Ana Gap.

as late as 1947, the wells yielded reasonably fresh water. However, the salinity increased sharply once the contamination front had reached the wells. The chloride analyses of water from well 6/10-7L1, which is about a quarter of a mile inland beyond the estimated front of contamination and 0.4 mile north of well 18B6, have also been plotted on plate 106. It will be noted that no evidence is present that might suggest incipient contamination at well 7L1.

Unpublished records,
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The two wells 6/10-18B4 and 18B6 afford a good opportunity to determine whether any difference in salinity occurs with increasing depth, at least locally. The two wells are about 100 feet apart, 18B6 being farther east than 18B4. Well 18B6 is perforated from 90 to 141 feet below land surface, tapping virtually the entire thickness of the Talbert water-bearing zone. Well 18B4 is only 89 feet deep, extending just into the Talbert zone. The range of perforations for this well is not known, although it may extend fairly close to the surface./ Although the two wells yield from different

/The log of well 6/10-18B3, within 400 feet of 18B4, reported sand and small gravel from 24 to 107 feet; the casing was perforated throughout the full thickness of this material.

parts of the ground-water body, both became intensely contaminated about at the same time, and the amount of contamination is roughly the same in each. However, the chloride content for well B6 passed 50 ppm about August 1946, [illegible] for well 18B4 this occurred in January 1948, over a year later.

The high salinity noted in 1944 and 1945 in water from well 6/10-18B6, based on an analysis in 1944 (within a few days of the time the well was drilled) and on another in 1945, cannot be explained simply by assuming the existence of incipient contamination in the lower part of the range penetrated. Well 6/10-18C1 also taps the full thickness of the Talbert zone and is somewhat closer to the source of contamination, but for those years it yielded water that was entirely free of contamination.

A possible cause for the apparently erratic chloride values may lie in the time of year the samples were taken. The chloride content of water from well 18B6 may have been as saline in the late spring of 1946 and 1947 as in the late spring of 1944 and 1945. As noted, the graph is dashed through the years shown, insufficient analyses are available to show seasonal trends.

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Of the four wells whose chloride analyses are shown on plate 106, 6/11-13A1 was the latest to become saline; not until 1948 did the well begin to yield definitely inferior water. Also, since then, the rate of salinity increase has been so great that, of the four, it is by far the most highly contaminated. Although no log is available for the well, it is presumed to tap the whole range of the Talbert zone; its depth is reported as 300 feet, whereas the base of the Talbert zone is not more than 150 feet below the surface.

The chloride determinations just discussed show definitely that the contamination front has passed beyond the wells from which the water samples were taken, but the wells do not provide sufficient data to show, even approximately, the new position of the front. About all that can be said is that along Bushard Street it is somewhere between wells 6/10-18B6 and 7K5; along Cannery Avenue it is somewhere between wells 6/11-13A1 and 12J2, and along Newland Street, extended, it is somewhere between Atlanta Avenue and Indianapolis Avenue. (See pl. 104.) The contamination front near the margins of the gap is less mobile--to the west, only a small amount of pumping takes place, to the east, the contour for 50 parts per million represents a boundary between native fresh water and native inferior water.

One possible method that might be used to give a rough approximation of the position of the contamination front is based on the premise of a constant chloride gradient seaward of the front, regardless of its position, for any time period. Of course, before any such method could be considered valid, proof of the existence of a constant gradient with time for any given place along the front would have to be made. An attempt at such proof is beyond the scope of this investigation at present; nevertheless, the method and the results obtained are presented here in order that some idea may be gained concerning the amount of salinity advance that has occurred in recent years. Using the concept, the assumption is made that the contour for 50 parts per million is as far inland from the contour for 1,000 parts now as it was in 1943-44. For that time period, both the 50-part and the 1,000-part contours were reasonably well controlled._/

_/Piper, A. M., Garrett, A. A., and others, op. cit., (report on chemical character) pl. 812.

Also for April 1949, the 1,000-part contour seems reasonably accurate. Projecting the 50-part contour inland, it crosses Wright Street about 0.1 mile south of Atlanta Avenue, extended; Bushard Street about 350 feet north of Atlanta Avenue; and Cannery Street about half way between Atlanta and Indianapolis Avenues. The 50-part contour, as thus established, was used to determine the 275-acre increase cited on page 24. Without additional field investigation, requiring, in part, the construction of several observation wells tapping the Talbert at critical places to be discussed later, nothing further can be done to locate the contamination front more accurately than has been done here.

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It was not determined in the field whether any waters of extremely high concentration (at or near the salinity of sea water) had reached any of the wells previously known to be contaminated. However, for seven of these wells, the chloride analyses have been plotted on plate 107, and

Plate 107.- Chloride content of water from seven grossly contaminated wells in Santa Ana Gap.

they show roughly what the contamination trends have been for these wells since 1944. The chloride analyses for some of these wells were shown on graphs accompanying the earlier report on chemical quality. Of the seven wells, all were then active except 6/11-13D1. With the exception of 6/10-17L5, all are now abandoned for use so that the samples must be bailed from near the water surface and are not necessarily representative; hence, the graphed analyses do not show precise quality trends. Nevertheless, they do suggest accelerated rates of contamination in recent years.

It will be noted that the graph for well 6/11-13K2 shows that in 1948 the water contained nearly 27,000 parts per million of chloride, which is about 9,000 parts more than that occurring in sea water. Obviously a contaminant considerably more concentrated than sea water is present near this well. Such a contaminant has not yet been identified here, however table 1 (p. 34) shows that, of recent analyses of water from the several shallow Geological Survey observation wells_/ along Bushard Street, two

_/Poland, J. F., and others, op. cit. (report on hydrology), p. 35, 38).

yield water more saline than sea water, and, of the two, well 6/10-19F2 yielded water nearly as concentrated as that from 6/11-13K2. It is possible that the very saline water from No. 13K2 originated within the near-surface deposits and entered the well through a defective casing. The well casing collapsed in 1948, and no further sampling of the well can be done.

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During the study of all the available recent chloride analyses of water from wells near the coast in Santa Ana Gap, waters anomalous with respect to chloride content were found at a few places. These waters were obtained from idle wells, from which the samples were bailed or removed from or near the water surface. For these, the chloride was abnormally low, relative to representative samples taken from nearby active wells. Doubtless such bailed samples represent small quantities of near-native ground waters or surface water that would be soon removed if the wells were to be pumped at a considerable rate, such as several tens of gallons a minute.

SUMMARY STATEMENT

Since 1945 rainfall and recharge in Orange County have been far below normal and pumping of ground water consequently has been very heavy. As a result, water levels have fallen several tens of feet below the 1945 levels in much of the county and in 1949 are at or below the 1936 level beneath most of the coastal plain. As of August 1948 water levels were below sea level beneath about 145 square miles in Orange County--about the same as during the prior historic low of 1936. This sharp recession of water levels has reemphasized the continuing danger of serious and extensive salt-water encroachment into the precious ground-water supplies that support the agricultural life of the county.

In at least three places along the Orange County coast, encroachment of saline waters is continuing. In Alamitos Gap the water at well 5/12-11G1 is becoming increasingly saline. It appears that the main contaminant is crossing the Seal Beach fault. Because the deposits of Recent age there are probably 90 feet thick, rest on top of the Seal Beach fault, and contain a basal water-bearing zone, the saline water probably is passing inland over the top of the fault rather than through it. On Landing Hill, where the water-bearing zones are wholly of Pleistocene age, the fault zone seems to have been breached locally, resulting in contamination of wells near the inland side of the fault zone. Water at one place each in Alamitos Gap and on Landing Hill is becoming more saline with continued depressed water levels and inland gradients and will increase in salinity until a reversal of such gradients occurs—that is, until water levels are raised above sea level.

In Bolsa and Santa Ana Gaps, most wells tap water-bearing zones of Recent age which are not transected by any barrier features such as exist in the Pleistocene and older deposits along the Newport-Inglewood fault. In both the gaps, water levels in general have been depressed below sea level. The encroachment of sea water into the "80-foot gravel" of Bolsa Gap has not yet been observed, probably because no active wells from which chemical and other data can be obtained occur sufficiently near the coast. In Santa Ana Gap the contamination is marching inland and the area underrun by saline water since 1944 is believed to be about 275 acres--about half that underrun in the preceding 14 years (pp. 23-24). Encroachment is the most serious along Bushard Street, where pumping has been relatively heavy and where wells, already contaminated, are increasing markedly in salinity. On both margine of the gap, the salinity increase probably has been small; however, wells are not available to give close control on the change since 1944.

NEED FOR PILOT WELLS

Although need exists for one to three pilot wells in Bolsa Gap, by far the greater need at present is for several such wells in Santa Ana Gap, located at strategic places so that the position of the salt-water front can be measured with a reasonable degree of precision. It will be noted from plate 104 and from the discussion on page 26 that, even through use of all available data, the position of the contamination front was established arbitrarily within possible limits as much as half a mile apart, and that some additional control is highly desirable.

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The most satisfactory method of determining the quality of ground waters at any place is through actual samples of the ground waters taken under representative conditions. It is therefore proposed that several wells of small diameter be so placed as to supply the chemical information needed in Santa Ana Gap. Pilot wells should be constructed to penetrate the full thickness of the Talbert water-bearing zone and capable of being pumped at the rate of at least several gallons a minute.

Although the actual location of the wells should depend on the position of the contamination front (as shown by up-to-date analyses for existing wells) at the time the wells are drilled, it is suggested that six wells be drilled, and located about as follows:

1. On Wright Street at Atlanta Avenue, extended.
2. On Wright Street, about 1,500 feet north of Atlanta Avenue, extended, if well 1 encounters saline water; about 1,500 feet south of Atlanta Avenue, extended, if well 1 does not encounter saline water.
3. On Bushard Street about 1,000 feet north of Atlanta Avenue.

4-5. On Cannery Avenue about 1,000 and 2,000 feet respectively, north of Atlanta Avenue.

6. On Newland Street, extended, about 1,500 feet north of Atlanta Avenue.

The diameter of the wells will depend in part on the contractual arrangements made with the driller; however, the minimum size should be 2½ inches. It is also suggested that one small-diameter well (½- to 3/4-inch diameter), tapping only the uppermost part of the Talbert zone, be placed at or near each of several of the larger pilot wells. This type of very small well could be drilled with equipment of the Orange County Flood Control District. Samples taken from both shallow and deep wells would give information as to whether important differences in quality occur from top to bottom of the Talbert zone at or near the contamination front.

Table 1.- Partial chemical analyses of water samples from wells along the coast in Orange County.

[Analyses by Geological Survey]

Well numbers USGSa/	Well numbers OCFCDb/	Date	Chloride parts per million	Total hardness as $CaCO_3$, parts per million	Specific conductance K x 10^5 at 77° F.	Depth, feet
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5/11-26M2	C-998h	5-20-49	409	460	184	282
26M5	. . .	5-20-49	17	30	37.0	. .
26N2c/	. . .	5-10-49	239	. .	135	13.3
28J2c/	. . .	5-10-49	13,400	. .	5,030	14.3
29C4	. . .	6-20-49	15	120	40.5	157
33A1c/	. . .	5-10-49	12,300	. .	1,930	11.3
33M1c/	. . .	5-10-49	26,900	. .	16,400	11.6
33N1c/	. . .	5-10-49	13,900	. .	. .	11.3
5/12-11G1	. . .	5-20-49	129	110	70.7	740
6/10-7B2	. . .	2-10-49	17	150	44.7	. .
7G1	C-1266v	12-16-48	16	300	43.4	30
		2-10-49	16	150	42.9	
		4-15-49	15	150	43.0	
7K1	C-1266j	12-16-48	15	150	42.3	415
		2-10-49	15	150	39.2	
		4-15-49	17	100	37.8	
7K5	C-1266q	5-27-49	14	. .	41.9	202
7L1	C-1262b	12-16-48	15	300	43.3	81.4
		2-10-49	14	225	42.3	
		4-15-49	18	140	41.6	

Footnotes at end of table.

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Table 1.- Continued.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
6/10-7L3	. . .	12-16-48	16	300	44.8	128
		2-10-49	16	160	43.8	
		4-15-49	18	150	42.9	
7L4	. . .	5-9-49	53	. .	172	18.4
7L5	. . .	4-15-49	15	145	41.9	160
7N1	C-1262a	12-16-48	16	250	42.4	. .
		2-10-49	15	175	39.9	
7N3	C-1266x	2-10-49	930	950	328	. .
7P1c/	. . .	5-9-49	56	. .	151	17.3
8G1	C-1262h	6-1-49	127	35	82.3	303
8M2	C-1266y	12-16-48	21	250	38.2	. .
17L5	. . .	2-10-49	. .	1,300	719	238
18B4	C-1266t	12-16-48	310	550	133	89.0
		2-10-49	434	600	171	
		4-15-49	722	700	281	
		6-1-49	730	295	262	
18B5	C-1266u	12-16-48	2,140	1,300	678	173
18B6	C-1266s	12-16-48	848	1,100	294	171
18B7	(d)	. . .	486	. .	178	100
18P1	C-1272	4-15-49	3,590	1,700	1,090	16[illegible]
18P2c/	. . .	5-9-49	5,110	. .	1,810	13.6
19C1c/	. . .	5-9-49	6,390	. .	2,060	14.2
19C2c/	. . .	5-9-49	20,400	. .	7,200	13.0
19F2c/	. . .	5-9-49	23,200	. .	8,550	8.0
19L1c/	. . .	5-9-49	164	. .	114	11.2
6/11-11J4	. . .	6-1-49	1,090	850	346	. .
11K2	. . .	6-1-49	152	185	65.1	90

Footnotes at end of table.

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Table 1.- Continued.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
6/11-12E3	. . .	6-1-49	141	285	99.5	89
12F3	. . .	12-16-48	16	200	41.9	161
12H2	. . .	12-16-48	18	250	46.2	164
		2-10-49	32	225	46.5	
		4-15-49	29	150	47.1	
13A1	C-1262	12-16-48	405	675	162	300
		2-10-49	546	675	205	
		4-15-49	1,115	1,050	377	
13A2	(e)	7-20-48	146	. .	82.2	86
13C2f/	C-1261a	2-9-49	427	550	169	230
13F2f/	C-1263d	2-9-49	15	140	26.7	111
		5-4-49	17	. .	40.0	
13G1	. . .	12-16-48	1,375	1,450	739	170
		2-10-49	. .	2,100	734	
		4-15-49	2,990	1,500	910	
13G2	C-1263a	5-4-49	4,900	. .	1,750	141
13H1	(g)	. . .	18		42.7	85
13K3	C-1264e	12-16-48	2,710	1,400	1,190	157
		2-10-49	3,910	1,800	1,290	
		4-15-49	4,030	1,800	121	
14A1	. . .	12-16-48	306	450	114	40
		4-15-49	349	475	146	

a Number assigned by Geological Survey.
b California Division of Water Resources serial number used by Orange County Flood Control District.
c Geological Survey shallow observation well.
d Orange County Flood Control District, well point 3.
e Orange County Flood Control District, well point 1.
f Orange County Flood Control District, well point 2.
g Sample taken after several hundred gallons of water was pumped from well with manually operated pump.

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