STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 63-2

Sea-Water Intrusion:

BOLSA-SUNSET AREA ORANGE COUNTY

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JANUARY 1968

RONALD REAGAN
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Spence Air Photos

THE BOLSA–SUNSET AREA AND
COASTAL PLAIN OF ORANGE COUNTY

View east, February 1963, from Sunset Beach and Huntington Harbour across the coastal plain to Santiago Peak (Old Saddleback) and the Santa Ana Mountains. Snow-capped Mt. San Gorgonio, barely visible in left background, marks the headwaters of the Santa Ana River among the Transverse Mountains.

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FOREWORD

Bulletin No. 63-2, "Sea-Water Intrusion: Bolsa-Sunset Area, Orange County", reports on the occurrence of and the various factors affecting and relating to sea-water intrusion within the Bolsa-Sunset area, a small portion of the coastal ground water basin of Orange County. The investigation was conducted under authority of Section 229 of the Water Code.

The Bulletin No. 63 series was established to report on related investigations of sea-water intrusion into coastal ground water basins in California. Bulletin No. 63, "Sea-Water Intrusion in California", in addition to reporting on sea-water intrusion, describes methods of control and presents preliminary plans for prevention and control of sea-water intrusion into ground water basins. Bulletin No. 63-1, "Sea-Water Intrusion, Oxnard Plain of Ventura County", reports on the rate and extent of sea-water intrusion occurring within the aquifers underlying the Oxnard Plain. Bulletin No. 81, "Intrusion of Salt Water into Ground Water Basins of Alameda County", describes the extent, causes, and routes of salt water intrusion in the coastal plain of southern Alameda County.

William R. Gianelli
William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
November 17, 1967

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

RONALD REAGAN, Governor
WILLIAM R. GIANELLI, Director, Department of Water Resources
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SOUTHERN DISTRICT

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Civil and Professional Engineers' Act of the State of California.

David B Willets
Registered Civil Engineer

Registration No. C 5592

Date August 1, 1967

ATTEST:

JJ Doody
District Engineer
Southern District

Registration No. C 6500

Date October 5, 1967

AUTHORIZATION

Statutory authorization for the Department of Water Resources to conduct sea-water intrusion investigations is contained in Section 229, Chapter 2, Division 1, of the California Water Code. Section 229 is quoted as follows:

> "229. The department, either independently or in cooperation with any person or any county, state, federal or other agency, to the extent that funds are allocated therefor, shall investigate conditions of the quality of all waters within the State, including saline waters, coastal and inland, as related to all sources of pollution of whatever nature and shall report thereon to the Legislature and to the appropriate regional water pollution control board annually, and may recommend any steps which might be taken to improve or protect the quality of such waters."

ACKNOWLEDGMENT

Valuable assistance and data used in this investigation were contributed by agencies of the Federal Government, by county, city and public districts, and by private companies and individuals. This cooperation is gratefully acknowledged.

Special mention is made of the helpful cooperation of the following:

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Bookman-Edmonston, Inc.

City of Huntington Beach

City of Seal Beach

Huntington Harbour Corporation

Lomita Land and Water Company

Moffatt and Nichol Engineers

Orange County Flood Control District

Orange County Water District

Signal Oil and Gas Company

United States Geological Survey, Water Resources Division, Garden Grove

United States Naval Weapons Station, Seal Beach

ABSTRACT

The Bolsa-Sunset area, a 6.8-mile-long strip of alluvial-tidal flats and low structural hills and mesas, comprises 55 percent of the Pacific shoreline of the 330-square-mile coastal plain of Orange County. / Fresh confined ground waters containing less than 50 ppm chloride occur in moderately to highly permeable early Recent, Pleistocene, and upper Pliocene sand and gravel aquifers landward of the active Newport-Inglewood fault. The fault, located 3,000 to 5,500 feet inland from and approximately parallel to the coast, forms a variable watertight hydraulic barrier across the area, except in late Recent deposits. / Native brackish to saline ground waters, which predominate seaward of the fault, contain up to 18,800 ppm chloride in the upper five interconnected aquifers and up to 900 ppm chloride in the underlying Main aquifer. Levels of these coastal ground waters are essentially stable at sea level in the upper aquifers and at 13 to 15 feet below sea level in the Main aquifer. / Hydraulic continuity between the inland fresh ground waters and the brackish to saline coastal and overlying semiperched ground waters is impeded by the fault and by silt and clay aquicludes. / Pumping of fresh ground water in excess of recharge caused a 1945-57 decline of inland piezometric levels to elevations of 30 and 50 feet below sea level in the upper aquifers and in the Main aquifer, respectively. Inland and downward head differentials caused intrusion of saline ground waters through permeable portions of the fault barrier and through discontinuities in the upper aquiclude. Horizontal intrusion, the principal route of flow, began in the late 1940's and progressed until early 1962. Major intrusion wedges (chlorides more than 500 ppm) reaching inland 2,800 feet developed in the upper two Pleistocene aquifers. Slight to moderate intrusion (chlorides less than 500 ppm) developed in the next two underlying Pleistocene aquifers. Slight inland intrusion (chlorides less than 200 ppm) may have developed in the early Recent Bolsa aquifer but could not be differentiated from the previous lateral encroachment of oil field brines or concurrent lateral sea-water intrusion from flanking upper Pleistocene aquifers. No intrusion developed in the lower Pleistocene Main aquifer. / Artificial recharge to the basin forebay and a partial reduction in pumping caused a recovery of piezometric levels during 1959-65. Freshwater heads reached sea level in late 1964 and seasonal artesian flow has existed since. / Ion concentrations of ground waters degraded by sea-water intrusion, oil field brines and semiperched water have decreased from peaks limits reached in 1961-62. Intrusion and brine wedges have retreated or have become stabilized.

CHAPTER I. INTRODUCTION*

The Bolsa-Sunset area constitutes a small but important portion of the 330-square-mile Coastal Plain of Orange County, California. During the last 20 years and particularly since 1958, the coastal plain has been undergoing rapid transition from a major agricultural area to a sprawling urban metropolis. The increasing population, commerce, and industry along with sustained irrigated agriculture have greatly increased the need for water. Approximately one-half of this need is satisfied with water derived locally from sand and gravel aquifers.

Concurrent with the growing demand for water, natural replenishment to the basin was diminished because of an extended drought. Prior to the increased importation of Colorado River water, which began in 1956-57, extraction of ground water exceeded recharge. The resultant decline of the ground water surface to below sea level produced a sustained landward hydraulic gradient in coastal aquifers. Saline water, drawn inland by this reversed hydraulic gradient, intruded fresh ground waters, rendering them unfit for beneficial use.

Investigation of this process, termed sea-water intrusion, and the hydrogeologic conditions governing its advance is prerequisite to the formulation of control measures needed to protect ground water supplies from further loss.

Objectives and Scope of the Investigation

The objectives of this investigation were to determine the nature and extent of salt-water intrusion within the Bolsa-Sunset area, to define in greater detail the geologic and hydrologic conditions governing intrusion, and to make this information available for use in the development of plans for the protection and optimum planned operation of the coastal ground water basin.

The scope of this study was limited to the collection and evaluation of geologic, hydrologic, and water quality data within the study area. The hydrology of this area is governed primarily by the relationship between recharge and extraction of water within the entire coastal basin. For the purpose of this study, however, it was sufficient to determine only the local effects produced by hydrologic variables within the basin proper.

* Reports used in conducting this study are listed in Appendix A. Definitions of technical terms that appear in this report are given in Appendix B.

Conduct of Investigation

This investigation was initiated in the fall of 1960, following a preliminary study of sea-water intrusion conditions at Bolsa Chica Mesa in 1957. The first work consisted of a review of the numerous related reports and a compilation of available data. Initial field work included an inspection of the areal geology, location and description of existing water wells, and collection of ground water samples for mineral analysis. A well location map (Plate 1) and an areal geology map including the location of well logs and electric logs (Plate 2) were prepared, along with preliminary geologic sections and a map showing the areal extent of sea-water intrusion.

Evaluation of the available geologic, hydrologic, and water quality data furnished only a partial understanding of the problem. It was apparent that a data gap existed in much of the area, particularly where sea-water intrusion was most suspect.

An exploration drilling program to provide needed subsurface geologic data was formulated, and right-of-way agreements were obtained from local land owners. Eight contract rotary holes, Bolsa-Sunset (BS) 1 to 8, were drilled and electrically logged, and one piezometer, Bolsa-Sunset Observation (BSO) 4, was constructed during the summer of 1961. The locations of these test holes are shown on Plate 2. Lithologic and electric logs are included in Appendix C. Geologic study of the test hole logs led to the differentiation of aquifers within the sea-water intrusion area.

A contract for the construction of piezometers and wells to monitor ground water conditions in these aquifers was prepared and right-of-way agreements were negotiated with land owners. The piezometers were needed to provide water level and water quality data. In addition, the wells were designed to test aquifer transmissibility. During the summer of 1963, 24 piezometers and six wells were constructed under contract in 15 rotary-drilled holes. The locations of these monitoring sites, Bolsa-Sunset Observation (BSO) 1 to 9, are shown on Plates 1 and 2. Data for the wells and piezometers are included in Table 9, Appendix C, along with lithologic and electric logs for new well sites BSO-2, BSO-5, and BSO-8.

Additional exploration data became available from the construction of monitoring piezometers at five sites by the Huntington Harbour Corporation during the summer of 1964. These sites, Huntington Harbour (HH) 1 to 5, are shown on Plates 1 and 2. During the summer of 1965, 10 exploration holes were drilled and 26 monitoring piezometers were constructed under contract to the Department's Ground Water Basin Protection Studies Program. The observation sites, Bolsa-Sunset (BS) 101 to 109 and 111, are shown on Plates 1 and 2. Site BS-107 is situated landward of the study area. Right-of-way could not be acquired for site BS-110. Data for the piezometers are shown in Table 10, Appendix C.

Monitoring of water levels and water quality at the 82 observation wells and piezometers has been conducted by cooperative effort of the Orange County Water District and the Department. Additional data were provided from the existing well monitoring program shared by the Orange County Flood Control District and the Department, and from observation piezometers installed and maintained by the Los Angeles County Flood Control District.

Based upon the exploration data, subsurface geologic studies were expanded to determine in greater detail the occurrence, properties, and structural deformation of aquifers and confining beds and the location and effects of faulting and folding upon the movement and quality of ground waters. Well logs and electric logs were plotted and interpretative correlation of aquifers and aquicludes was developed on geologic sections. Nine of these geologic sections, showing representative subsurface conditions within the area, are included on Plates 3A and 3B. The thickness, lithology, and general hydrogeologic features of the aquifers and aquicludes are summarized in Figure 3. Structure contour maps were prepared for two important aquifers. One, drawn on the base of the Recent Bolsa aquifer, also shows the approximate areas of unconformable contact between the Bolsa aquifer and underlying Pleistocene aquifers (Plate 4). Contours on top of the lower Pleistocene Main aquifer (Plate 5) depict the general structural deformation of bedding within the area. Time-drawdown and time-recovery graphs of the aquifer pumping tests, run in the BSO observation wells during January 1965, are shown on Plate 6.

Hydrologic studies included a cursory evaluation of water supply conditions in the ground water basin and a more detailed analysis of water level fluctuations and ground water movement within the study area. Well hydrographs were prepared from long-term measurements of water wells (Plate 7) and from weekly measurements of observation wells and piezometers (Plate 8). From these hydrographs, hydraulic gradients affecting the lateral and vertical movement of ground water were determined.

Chemical analyses of ground waters were classified according to aquifer. The chemical character of water within each aquifer was then determined, along with the native range of principal ions. Similar studies were made for surface waters and industrial wastes. Processes and effects of fresh ground water degradation were investigated to preclude, where possible, these parameters from salt-water intrusion. Based on the foregoing, the rate, extent, and degree of salt-water intrusion were studied. Maps depicting the areal distribution of sea-water intrusion and other saline waters were prepared for each aquifer. These maps are included as Plates 9, 10, and 12 through 14. Plate 11 shows the vertical range and trend of chlorides in aquifers beneath Huntington Harbour.

Related Investigations and Reports

Sea-water intrusion has been developing along the Coastal Plain of Orange County since the late 1920's, giving rise to numerous studies and reports. A listing of those reports relative to the study area is given in Appendix A. Of special assistance to this investigation were the United States Geological Survey Water-Supply Papers, which provided comprehensive findings on the geology, hydrology and water quality of the area, and unpublished United States Geological Survey status reports of sea-water intrusion in the area during the early 1950's. Subsequent detailed reports on sea-water intrusion have been published by the Los Angeles County Flood Control District for the Alamitos Gap area to the northwest and by the Department for the Santa Ana Gap area to the southeast. Exploration techniques and findings of these reports have been of considerable assistance to this investigation. Detailed exploration of the shallow deposits relative to their effectiveness in limiting vertical percolation of tidal water is currently being conducted by the United States Geological Survey within the study area.

Area of Investigation

The Bolsa-Sunset area is located at the seaward edge of the coastal floodplain of Orange County (Figure 1). Rectangular in shape, it extends 6.8 miles in a northwest direction between the Cities of Huntington Beach and Seal Beach, reaches nearly 3 miles inland from the Pacific Ocean, and encompasses an area of about 20 square miles.

The land surface consists of (1) a broad alluvial flat yielding to coastal tidal marshes within 8,000 feet of the ocean, (2) a barrier beach, and (3) three separate low hills and mesas ranging in elevation up to 130 feet above sea level. The hills and mesas are late Pleistocene surfaces uplifted along the Newport-Inglewood structural zone, a belt of faults and anticlinal folds extending northwest across the area, 3,000 to 5,500 feet inland from the shoreline.

The climate of the Bolsa-Sunset area is dry-summer subtropical or Mediterranean with warm summers, tempered by ocean breezes and mild winters. Annual temperatures generally range between

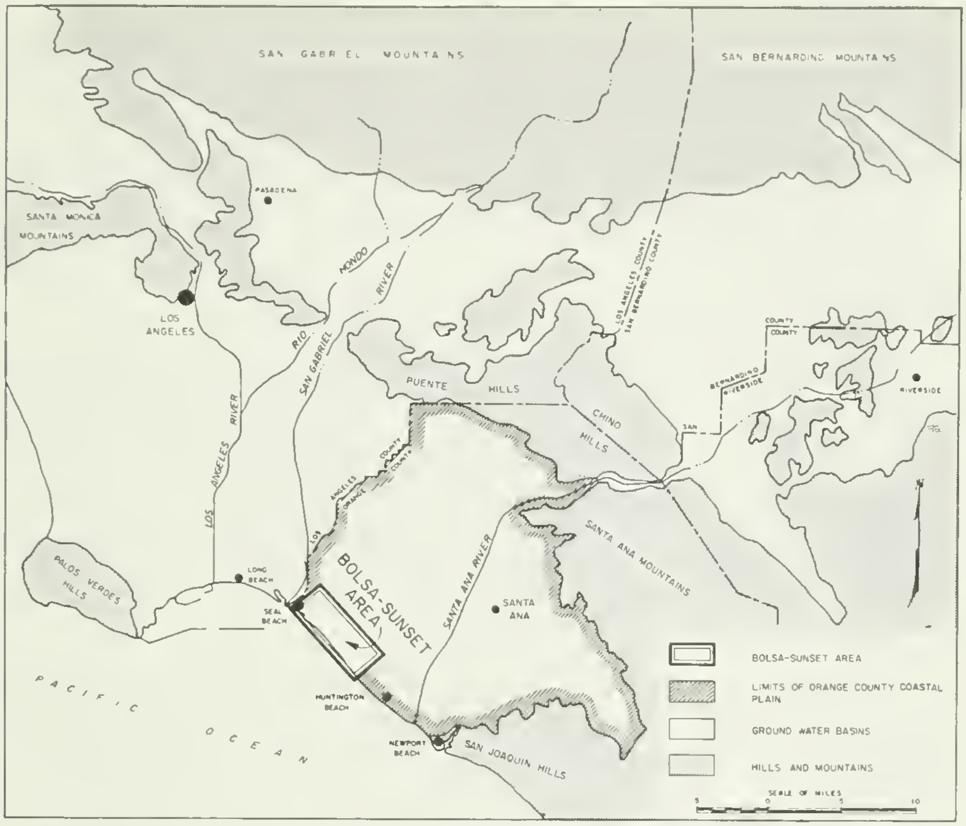


Figure I-VICINITY MAP

35 and 100 degrees Fahrenheit. The long-term mean annual rainfall of 12 inches occurs primarily between November and April.

Prior to 1900, the area was virtually undeveloped and inhabited only by the small settlement of Anaheim Landing, now Seal Beach, and a handful of ranch hands who served the large holdings of Rancho Los Alamitos ("little cottonwoods" or "willows"), Rancho Bolsa Chica ("little pocket" or "bay"), and Rancho Las Bolsas ("the pockets" or "bays"). Except for the hills and mesas, the area was largely a swamp, noted for its peat bogs and artesian springs and its dense thickets of tulles and phreatophytes, which provided refuge for thousands of waterfowl. Travel was limited to poorly defined trails that led inland to the communities of Westminster and Santa Ana.

Gradually the inroads of cultural development made their mark. Beginning in the late 1890's, the lowlands were cleared and drained. The rich organic soils were then cultivated for the growing of truck crops. The small, natural harbor of Bolsa Chica was dammed and a tidal gate was constructed in Bolsa Gap to limit the inland movement of sea water. Coastal lowlands unsuited for agriculture were used by gun clubs.

On July 4, 1904, the City of Huntington Beach was incorporated and the Pacific Electric Railroad, extending southeast along the coast from the City of Long Beach, was dedicated. The City of Seal Beach was incorporated on November 27, 1915. Until the 1920's, these small communities were supported by beach recreation and agriculture. Transportation between the two cities was improved by the construction of State Route 1 in 1926. This facilitated the later development of the small beach resorts of Surfside and Sunset Beach.

The discovery of the Huntington Beach Oil Field in August 1920 and the Seal Beach Oil Field in August 1926 provided an economic stimulus to the struggling resort communities. The boom years continued into the 1930's, following discovery of the tidelands pool at Huntington Beach. Since then, the operation of these oil fields has been the principal industry of the Bolsa-Sunset area. The discovery and subsequent development of the Sunset Beach Oil Field, beginning in June 1954, contributed further to this enterprise.

During the early 1940's, about 5,000 acres of land, including most of Sunset Gap and part of Landing Hill, were purchased by the Federal Government and used for the development of the Naval Weapons Station, Seal Beach. In addition, a 16-inch gun battery was constructed underground at the south edge of Bolsa Chica Mesa. This facility was abandoned after 1945. Military activities at the Naval Weapons Station were curtailed after 1945, but the base is still an active service facility for the Pacific Fleet.

The post-war boom of Southern California had little impact on the Bolsa-Sunset lands until the 1960's. Huntington Harbour, a residential marina, and numerous housing tracts have since been under construction around the east perimeter of the Naval Weapons Station and south across Bolsa Chica Mesa into Bolsa Gap. Since 1963, two aerospace industrial plants have been erected within and adjacent to the Naval Weapons Station. Expansion of these facilities, continued growth of tract housing, and the development of Bolsa and Sunset Gaps for residential marinas and small craft harbors will undoubtedly take place within the next decade.

History of Sea-Water Intrusion

Within the Bolsa-Sunset area, fresh ground waters containing less than 50 ppm chloride are held under pressure in early Recent, Pleistocene, and late Pliocene sand and gravel aquifers. The fresh ground water body terminates abruptly in a seaward direction along the Newport-Inglewood fault, which acts to varying degrees as a hydraulic barrier to lateral ground water movement. Across the fault, ground water in Recent and

Pleistocene aquifers is predominantly brackish to saline and contains up to 18,800 ppm chloride. The saline waters, for all practical purposes, may be considered synonymous with sea water, from which they were derived in the geologic past. Thus, the principal focus of sea-water intrusion within the area lies along the trace of the Newport-Inglewood fault (Plate 2), or approximately 3,000 to 5,500 feet inland from the ocean.

A second saltwater threat exists in tidal water and saline semiperched water, which extend more than 4,000 feet inland from the fault trace. Vertical percolation of these upper saline waters, however, is limited for the most part by relatively impervious beds of silt and clay.

Historically, fresh ground waters within the area were held under considerable hydraulic pressure and were discharged freely by artesian wells and springs. Heavy draft of ground water to satisfy expanding agricultural demands caused a reduction in artesian pressure and a decline of the ground water pressure (piezometric) surface. From 1930 to 1940, the piezometric surface of upper aquifers within the area dropped below sea level during the late summer pumping cycle. The maximum lowering of 15 feet below mean sea level (msl) occurred in 1936.

Due to above-normal rainfall during 1937-1945 recharge to the basin forebay was increased, causing the coastal piezometric surface to recover an average of 5 feet in upper aquifers. Although hydraulic conditions were improved, the piezometric surface surrounding heavily pumped wells continued to dip below sea level during late summer months.

Sea-water intrusion within the Bolsa-Sunset area was first evident in September 1941 at well 5S/12W-12P1, located less than 100 feet inland from the Newport-Inglewood fault on Landing Hill. A limited amount of salty water containing more than 1,350 ppm chloride was entering well -12P1 at an elevation of 170 feet below msl. It was concluded (Piper and Garrett, 1953) that saline ground water (sea water) had intruded inland across the fault barrier in response to a landward hydraulic gradient of up to 8.5 feet. Intrusion was limited to an upper aquifer (Beta aquifer) and had not affected a deeper aquifer (Main aquifer) tapped by nearby wells -12P3 and -12P4.

Following 1945, natural recharge to the ground water basin was reduced because of an extended period of predominantly subnormal precipitation. During this time, the use of ground water was increasing. As a result of these conditions, the piezometric surface was again lowered. Between 1948 and

1964, its elevation remained entirely below sea level. Thus, hydraulic conditions favoring sea-water intrusion were sustained for 17 years.

Protracted sea-water intrusion in the study area began at Bolsa Chica Mesa in early 1949 but was restricted to the Alpha and Beta aquifers less than 170 feet below msl. Ground water extracted from well 5S/11W-29C4, located about 400 feet inland from the Newport-Inglewood fault, increased in chloride from 14 ppm in June 1949 to 285 ppm in June 1952. Water from well -29D1, located less than 200 feet inland of the fault, increased in chloride from 455 ppm in September 1951 to 1,300 ppm in December 1954. Due to the presence of confining beds above the aquifer, evidenced by previous artesian conditions, it was concluded (Garrett, 1952) that salt water, acting under a reverse gradient of 10 feet, had breached the fault and had moved inland a distance of over 400 feet. This conclusion was supported by the seaward increase in chloride between the two wells.

Continued decline of the piezometric surface caused sea water at Bolsa-Chica Mesa to move inland 2,400 feet to well 5S/11W-20Q3 by August 1955. Based on data for this well, the rate of salt-water intrusion was about 400 feet per year.

In 1957, the piezometric surface reached its lowest elevation of 35 feet below msl in intruded aquifers. That same year, a study was conducted by county and state agencies to determine if oil field brines were contributing to the problem at Bolsa-Chica Mesa. By coincidence, development of the Sunset Oil Field was concurrent with sea-water intrusion. Local residents logically correlated the increasing salt taste in their well water to oil field brines which were being discharged to the tidal sloughs. Attempts to differentiate between brine and sea-water degradation by bromide-iodide analysis proved disappointing due to unreliable laboratory data. However, no reasonable evidence was collected to substantiate the brine theory. Rather, the vertical and areal distribution of chlorides substantiated the earlier conclusion that salt water was entering the aquifer by underflow across the fault.

Through 1962-63, chloride ion concentrations beneath Bolsa Chica Mesa increased rapidly in the Alpha and Beta aquifers within 2,400 feet landward of the fault trace. For example, chlorides at well 5S/11W-20Q5, constructed in the Alpha aquifer, increased from 30 ppm in December 1956 to 4,200 ppm in June 1963. However, the inland advance of the salt water front was limited essentially to its 1955 position due to the apparent boundary effects of the inland Bolsa-Fairview fault (Plate 2).

Concurrent with the increasing saline degradation of shallow ground waters, wells 5S/11W-29C1 and -29C2 continued to yield less than 20 ppm chloride water from the underlying Main aquifer 600 feet landward of the Newport-Inglewood fault. From this it was evident that the fault became a more effective barrier with depth, a condition found previously at Landing Hill in 1941.

Since the summer of 1961, electric logs and water quality data from exploration drilling and well construction have provided the means for differentiating the widespread but irregular vertical and horizontal distribution of salt water intrusion between Bolsa and Sunset Gaps. By 1963, highly saline waters had moved inland across relatively permeable portions of the Newport-Inglewood fault into the upper Pleistocene Alpha and Beta-Lambda aquifers. At observation wells within a distance of 1,100 feet inland of the fault trace (Plate 2), chloride ion concentrations ranged from 95 to 16,840 ppm in the Alpha aquifer and from 145 to 6,825 ppm in the underlying Beta-Lambda aquifers. The deeper lower Pleistocene Meadowlark aquifer, however, had been only slightly intruded in local areas; chloride ion concentrations ranged from 14 to 260 ppm. Because of the slight hydraulic differential between these aquifers, thin confining beds of silt and clay, in some cases less than 10 feet thick, separated saline and fresh ground waters. The underlying Main aquifer was not found to be intruded anywhere within the area, despite an inland hydraulic differential of up to 50 feet. Chloride ion concentrations in the Main aquifer were less than 25 ppm.

Paradoxically, there had been little or no intrusion of salt water into the Recent Bolsa aquifer, which prior to this report was thought to be unaffected by the Newport-Inglewood fault. However, despite an inland hydraulic differential of up to 28 feet, chloride ion concentrations within 600 feet of the fault ranged from 85 to 145 ppm in June-October 1963. And in large part, these had resulted from the northern movement of oil field brines from Huntington Beach Mesa.

The "town lot" development of the Huntington Beach oil field, beginning in 1920, led inevitably to the expedient land disposal of brines. These industrial wastes percolated downward and began contaminating ground water as early as 1925. With the lowering of water levels, the brines spread north and east, first degrading water in Pleistocene aquifers beneath Huntington Beach Mesa, and ultimately encroaching into Recent and Pleistocene aquifers beneath Bolsa Gap. The highest recorded chloride ion concentration attributed to brines was 2,450 ppm at well 5S/11W-35E1 in 1963. However, the maximum effects of brine contamination were reached in 1961-62.

Because oil field brines and sea water cause similar chemical degradation of fresh ground water as measured by major ions, the differentiation of these agents requires trace element analysis. Such data are unavailable. However, shallow oil well electric logs at Huntington Beach Mesa clearly show that a pronounced seaward increase in salinity occurred within the Alpha and Beta aquifers after 1948. From these data, it is highly probable that sea-water intrusion became active beneath Huntington Beach Mesa in upper Pleistocene aquifers during the late 1940's.

Since 1961-62, the toe of the sea-water intrusion wedge and the oil field brine wedge have retreated or stabilized. This is attributable primarily to the substantial post-1949 recharge of imported water to the basin forebay by the Orange County Water District. This recharge caused a rapid rise in the piezometric surface to above sea level, and the consequent freshwater flushing of intruded aquifers. As of July 1965, chloride ion concentrations of sea-water-intruded aquifers had diminished as much as 4,635 ppm. Chloride ion concentrations of oil field brine-degraded ground water had diminished by 500 ppm as of December 1965.

CHAPTER II. GEOLOGY

The water-bearing deposits of the Bolsa-Sunset area have been generally described in the regional investigation of Eckis* (1934) and in the comprehensive study of Poland and Piper (1956) on the Long Beach-Santa Ana coastal zone. Recent and Pleistocene aquifers have subsequently been differentiated by detailed sea-water intrusion investigations at Alamitos Gap (Los Angeles County Flood Control District, 1961) and at Santa Ana Gap (DWR Bulletin No. 147-1, 1966). Sea-water intrusion locally, and in these two peripheral areas of the coastal basin, is governed by the barrier effects of faults and the interconnection of aquifers across discontinuous or eroded confining beds of silt and clay. A principal objective of this investigation, therefore, was to determine the nature and relationship of aquifers and boundary conditions within the study area.

Interpretation of subsurface geologic conditions was based on the correlation of lithologic and electric logs of test holes, the micropaleontologic study of drill cuttings and core samples, and the comparison of ground water quality and water level data collected from observation wells and piezometers. Oil well electric logs, drillers' well logs, soil boring logs, and ground water quality and water level data from water wells were used to supplement the foregoing controls. The areal geology, shown on Plate 2, was taken largely from Poland and Piper (1956), with local modifications based upon new data.

Physiographic Features

The land surface of the Bolsa-Sunset area is characterized by three principal forms: (1) a narrow barrier beach, (2) an alluvial floodplain grading seaward to a tidal marsh, and (3) an interrupted belt of structural hills or mesas. The locations of these land features are shown on Plate 2 and in Figure 2.

Barrier Beach

A narrow beach forms the coastal perimeter of the area except where interrupted by the improved military harbor of Anaheim Bay. The beach ranges in maximum elevation from 10 to 15 feet above sea level and extends inland a maximum distance of about 800 feet. It acts as a barrier to the ocean but is occasionally overtopped by winter storm waves.

* Bulletin No. 45 published by California Department of Public Works, Division of Water Resources.

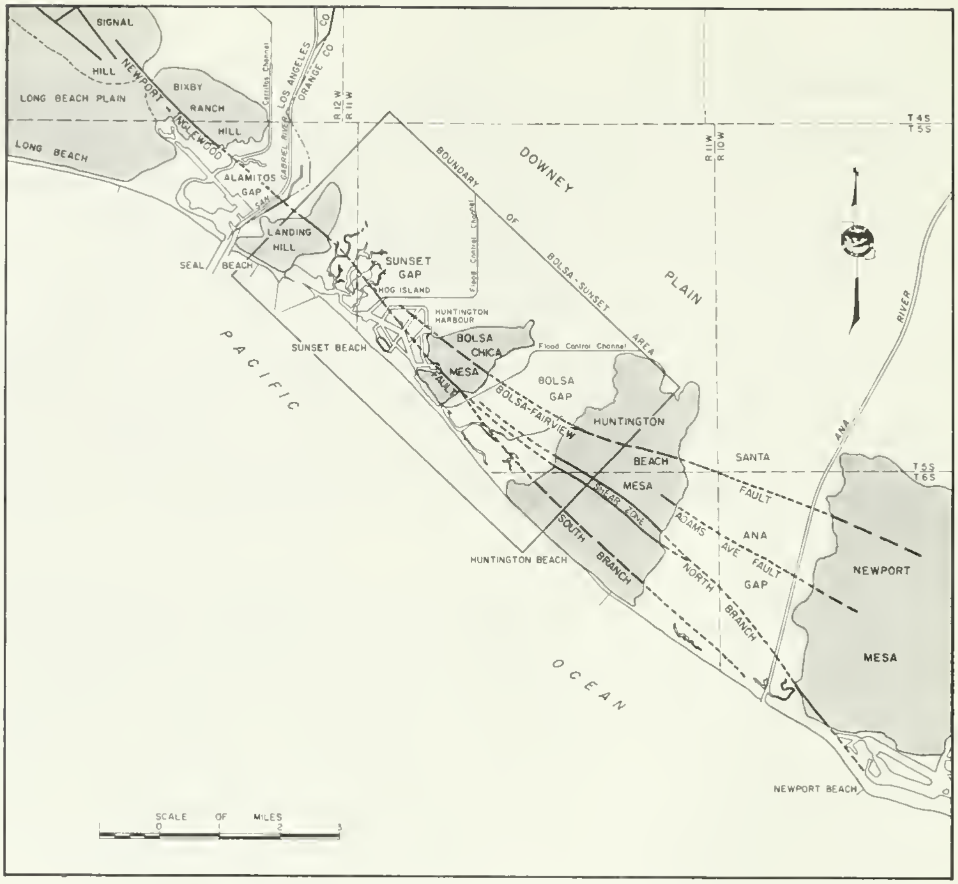


Figure 2-PHYSIOGRAPHIC FEATURES

Floodplain and Gaps

The Recent alluvial floodplain of the Santa Ana River forms the inland surface of the area and extends seaward to the beach through two gaps. Its slight relief of 15 feet is interrupted only by minor streams, now improved to flood control channels, and by subsidence depressions associated with peat deposits. Historically, the gaps were largely freshwater swamps merging seaward to tidal marshes. After drainage and clearing of the dense phreatophytic growth during the early 1900's, the swamp lands were reclaimed. The tidal marsh now extends inland 7,000 to 8,000 feet where it is contained by low dikes or by land fill. It is subject to the tidal prism which ebbs and flows within a sinuous network of shallow sloughs converging to Anaheim Bay. At Huntington Harbour, the sloughs have been improved and deepened to marina channels.

Sunset Gap. Sunset Gap, 2.2 to 3.8 miles wide, occupies a structural saddle only slightly deepened by Recent erosion and partially backfilled by lagoonal, tidal marsh, and alluvial floodplain deposits. It is bordered by the gentle slopes of Landing Hill to the northwest and Bolsa Chica Mesa to the southeast. Hog Island and another unnamed upper Pleistocene hillock which interrupt the Recent surface (Plate 2) are small features, less than 400 feet across and 12 feet above sea level. They are probably remnants of a dissected scarp of the Newport-Inglewood fault.

Bolsa Gap. Bolsa Gap is an ancient beheaded stream channel eroded across the Huntington Beach anticline and partially backfilled by basal sand and gravel deposits (Bolsa aquifer) and by overlying alluvial, lagoonal and tidal marsh deposits. The gap ranges from 1.4 to 2 miles in width. It is bordered by the 25- to 70-foot high stream bluffs of Bolsa Chica Mesa to the northwest and Huntington Beach Mesa to the southeast. The area is known locally for its peat deposits and historic artesian wells and springs, which fed the now depleted Freeman River. Description of these conditions, as given by Talbert (1952), is noteworthy:

> "The superabundance of surface water, swamps, natural springs and artesian wells of Gospel Swamp (Santa Ana and Bolsa Gaps) seemed inexhaustible. Many places, among them Springdale and Fountain Valley, took their names from natural flowing springs and wells. Peat springs bubbled and boiled out of holes in the ground large enough to hold a good sized house without it touching the bottom or sides.
>
> "The extensive upper bay (Bolsa Bay) was fed by a stream of fresh water called the Freeman River, a short river, but one which carried a considerable volume of water. It headed in Westminster and carried the storm drainage, peat springs, and artesian flow of water through what is known as the old peat land section (Bolsa Gap). The State, in a survey made in July 1918, found that the stream was flowing 500 inches of water into the bay at the driest time of the year."

A perennial brackish-water lake now occupies part of the southwest corner of Section 26, T5S, R11W. According to local residents, this lake was historically a sizable peat spring, and is so named in this report. The lake is now contained within a strip-mined and subsided peat deposit and is maintained by artesian ground water. Geologic conditions favoring this local discharge of ground water are shown on Section B-B', Plate 3A.

Hills and Mesas

Landing Hill, Bolsa Chica Mesa and Huntington Beach Mesa are upper Pleistocene surfaces elevated by faulting and anticlinal folding along the Newport-Inglewood structural zone. Northwest trending escarpments, narrow linear gullies, and displaced edges of these land forms are primarily of structural origin. Except for Huntington Beach Mesa, their surfaces are virtually unmodified by erosion.

Landing Hill. Landing Hill extends 1.8 miles inland from the beach and reaches a maximum elevation of 70 feet above sea level. It constitutes the southeastern surface expression of the Seal Beach dome and is crossed by a 15-foot east-facing scarp of the Newport-Inglewood fault. Landing Hill is bordered to the northwest by Alamitos Gap, an erosional backfilled stream channel, and to the southeast by Sunset Gap. The hill takes its name from the historic harbor of Anaheim Landing.

Bolsa Chica Mesa. Bolsa Chica Mesa extends 2.1 miles inland from the shallow frontal estuaries of Bolsa and Sunset Bays and rises to a maximum elevation of 65 feet above sea level. The mesa, which forms the northwest surface expression of the Huntington Beach anticline, rises gently to the southeast from Sunset Gap, terminating in a stream bluff against Bolsa Gap. Displacement of the mesa surface along the Newport-Inglewood fault is marked by a 20- to 40-foot west-facing escarpment. The Bolsa-Fairview fault is not evident at land surface.

Huntington Beach Mesa. Huntington Beach Mesa constitutes the principal surface expression of the Huntington Beach anticline. It is the largest and most complex positive land form in the area, extending nearly 4 miles inland from the beach and reaching a maximum elevation of 130 feet above sea level. Its topography consists of a coastal bench, two linear belts of low hills which mark principal faults of the Newport-Inglewood zone, and an inland dipping plane cut by prominent gullies, several of which are developed along the Bolsa-Fairview fault. The mesa is bordered on the northwest and southeast by the erosional Bolsa and Santa Ana Gaps, respectively.

As shown on Plate 2, three perennial ponds or small lakes occupy excavated sand and gravel quarries in the inland portion of the mesa. Under present conditions, these excavations extend below the water table and are maintained principally by ground water discharge.

Spence Air Photos

PHYSIOGRAPHY OF THE BOLSA-SUNSET AREA

View southeast along the coast, January 1961.

From lower left to upper right, tidal sloughs and marshes of Sunset Gap, Bolsa Chica Mesa, Bolsa Gap, and Huntington Beach Mesa. Hog Island (below bend in flood control channel) and low escarpment across Bolsa Chica Mesa show the trace of the Newport-Inglewood fault. Wave erosion of the barrier beach is evident at the two small berms above the rock jetty of the Naval Weapons Station Harbor.

Geologic Setting

The Bolsa-Sunset area is located within the extensive Los Angeles sedimentary basin and is crossed along its long axis by the northwest-trending Newport-Inglewood structural zone. Marine deposition and intermittent faulting and folding prevailed during much of the post middle-Miocene time. Of the thick marine sedimentary section accumulated, however, only the very late Pliocene to Recent deposits are freshwater bearing. Underlying Tertiary beds contain saline connate water and are sufficiently indurated and impermeable to function as basement rock. Geologic processes affecting the storage, movement, and quality of fresh ground water include the deposition of sand and gravel aquifers and interbedded silt and clay confining beds and their subsequent structural deformation and erosion.

During late Pliocene and Pleistocene time, coarse-grained sediments derived from uplifting inland mountain ranges were transported to the basin and, after reworking by waves and offshore currents, were deposited with interbedded silts and clays in a marine embayment of moderate to shallow depths. Except for localized erosion of areas uplifted along the Newport-Inglewood zone, deposition was essentially continuous from late Pliocene through early Pleistocene time. In Pleistocene time, major changes in sea level resulted from the advance and decline of intercontinental glaciation. The early Pleistocene land surface, where uplifted along the Newport-Inglewood structural zone, was exposed and slightly eroded. This surface of unconformity was then overlain by shallow marine, littoral, and continental clastics and relatively thin, discontinuous silts and clays during late Pleistocene time.

At the end of Pleistocene time, during the Wisconsin glacial age, a major decline in sea level lowered the base level of deposition. Coastal rivers, adjusting to this lowered gradient, eroded channels across the basin and through Pleistocene beds uplifted along the Newport-Inglewood zone, thereby forming the erosional Alamitos, Bolsa and Santa Ana Gaps. In each gap, the entire upper Pleistocene section and the uppermost lower Pleistocene aquifer were exposed. Following the retreat of Wisconsin glaciation about 15,000 years ago, sea level rose rapidly and Recent channel deposits backfilled the floor of these gaps. Thus, an important unconformity between Recent and Pleistocene aquifers was developed. As a consequence, these gaps remain as principal areas of hydraulic continuity between aquifers generally separated by interbedded silts and clays.

About 9,000 years ago, the rapid rise in sea level abated, and thereafter, predominantly fine-grained floodplain sediments were deposited across the coastal perimeter of the basin. These deposits constitute the uppermost confining beds of the area and form the present land surface. Within the gaps, peat deposits developed where dense phreatophytic growth collected around gravity and artesian springs. Concurrently, a barrier beach was formed along the coast, sheltering inland lagoons and peripheral tidal marshes in which fine sand, silt, clay, and organic muck were deposited.

Concurrent with these sedimentary processes, anticlinal folding and faulting occurred intermittently along the Newport-Inglewood structural zone. Two anticlinal folds, the Seal Beach dome and the Huntington Beach anticline, and an interspaced gentle synclinal depression were formed within the area. Displacement of late Pliocene through early Recent aquifers along the main Newport-Inglewood fault developed an important coastal barrier to the landward and seaward movement of ground water. Although the late Recent deposits were not seriously deformed, numerous small magnitude earthquakes, instrumentally located in the vicinity of the fault since 1934, and the damaging Long Beach earthquake of 1933 (magnitude 6.3), attest to the continuing stresses developing along the Newport-Inglewood zone.

Stratigraphy

The water-bearing sediments of the Bolsa-Sunset area are Recent deposits, upper Pleistocene deposits of the Lakewood Formation, lower Pleistocene deposits of the San Pedro Formation, and upper Pliocene deposits of the Pico Formation. Description of these formations and the aquifers differentiated within them follows in order from youngest to oldest. Plate 2 shows the areal distribution of the Recent deposits and the Upper Pleistocene Lakewood Formation; the Lower Pleistocene San Pedro Formation and the Upper Pliocene Pico Formation are not exposed in the area. Generalized stratigraphic relationships of these water-bearing formations are shown in Figure 3.

Recent Deposits

The Recent deposits include beach and dune sands, lagoonal, tidal marsh, and alluvial sediments, and the basal stream channel deposits of Bolsa Gap.

Beach and Dune Deposits. Fine to coarse sands occur along the barrier beach. These deposits reach a maximum thickness of 30 feet and extend inland about 800 feet. They conformably overlie and merge landward with the lagoonal deposits.

AGE	FORMATION (MAX THICKNESS IN FEET)	HYDROGEOLOGIC UNIT	MAXIMUM THICKNESS IN FEET	LITHOLOGY	HYDROGEOLOGIC FEATURES
RECENT	Beach Deposits (30)	Semiperched zone	35	Gray to light brown medium to coarse sand. Shells.	High permeability. Contains sea water. Gradational to lagoonal and tidal marsh sands. Unconfined.
	Lagoonal and Tidal Marsh Deposits (35)			Gray very fine to medium silty sand. Abundant shells near the coast.	Low permeability. Contains brackish to saline water. Unconfined to semiconfined.
	Alluvium (90)	Aquiclude	55	Dark gray, dark brown, and green silt and sandy to silty clay. Lenses of peat and organic silt. Stringers of fine to coarse silty sand. Shells near the coast.	Relatively impermeable but broken by lenses of sand and peat. Uppermost confining bed.
		Bolsa aquifer	45	Gray, locally oxidized, fine to coarse sand and granuleto pebble gravel. Minor lenses of silt, clay, and peat. Wood fragments and shells.	High permeability. Merged with the Alpha, Beta, Lambda and Meadowlark aquifers. Youngest fresh water aquifer. Confined. Important aquifer in Bolsa Gap.
LATE PLEISTOCENE	Unconformity Lakewood Formation (400)	Semiperched zone	55	Oxidized fine to coarse silty sand and gravel. Calcareous seams. Interbedded sandy silt and clay. Wood fragments. Barren.	Low to moderate permeability. Contains brackish to saline water. Locally merged with the Alpha aquifer but in these areas, generally unsaturated. Discontinuous. Confined to unconfined.
		Aquiclude	30	Oxidized or gray-green fine silty sand, sandy silt, and sandy clay. Calcareous seams. Interbedded dirty sand and gravel. Some peat and wood fragments. Barren.	Relatively impermeable. Discontinuous. Gradational to semiperched zone.
			45	Blue-gray to blue-green silt and sandy to silty clay. Lenses of fine to medium silty sand and peat. Prolific shell horizon at base.	Relatively impermeable. Discontinuous Principal confining bed above the Alpha aquifer.
		Alpha aquifer	110	Gray or oxidized fine to coarse sand with granule to pebble gravel. Locally subdivided by interbedded silt and clay. Numerous shells. Some wood fragments.	Moderate to high permeability. Merged with the Bolsa and Beta aquifers. Continuous except where eroded in Bolsa Gap. Locally exposed. Confined to unconfined. Developed to numerous domestic wells.
		Aquiclude	25	Blue-gray silt and sandy to silty clay. Wood fragments and shells.	Relatively impermeable. Discontinuous.
		Beta aquifer	80	Gray-green or oxidized granule to cobble gravel and fine to coarse sand. Thin interbedded light green, light gray, and brown silt and clay. Abundant wood fragments. Few shells. Grades locally to fine sand and silt.	Moderate to high permeability. Merged with the Bolsa, Alpha and Lambda aquifers. Continuous except where eroded in Bolsa Gap. Confined to unconfined. Principal upper Pleistocene aquifer.
		Aquiclude	70	Blue-gray silt and sandy to silty clay. Wood fragments and shells.	Relatively impermeable. Discontinuous.
		Lambda aquifer	90	Gray-green or oxidized fine to coarse sand and granule to pebble gravel. Thin interbedded silt and clay. Grades locally to fine sand and silt. Wood fragments and shells.	Moderate to high permeability. Merged with the Bolsa, Beta and Meadowlark aquifers. Continuous except where eroded in Bolsa Gap. Confined. Important upper Pleistocene aquifer.
EARLY PLEISTOCENE	Local unconformity San Pedro Formation (1,050)	Aquiclude	45	Blue-gray silt and silty clay. Minor lenses of silty sand. Wood fragments and shells. Uppermost occurrence of lower Pleistocene foraminifera.	Relatively impermeable. Discontinuous.
		Meadowlark aquifer	120	Blue-gray to gray-green fine to coarse sand and gravel grading downward to fine silty sand. Commonly subdivided by interbedded silt and clay. Wood fragments and numerous shells.	Low to high permeability. Merged with the Bolsa and Lambda aquifers. Continuous except where eroded in Bolsa Gap. Confined. Developed to a few wells.
		Aquiclude	150	Blue-gray silt and silty clay. Interbedded basal fine to medium silty sand grading to coarse sand and gravel beneath Huntington Beach Mesa. Wood fragments and numerous shells. Prolific foraminifera horizon.	Relatively impermeable. Continuous. Important confining bed above the Main aquifer. Interbedded sand and gravel of low to high permeability, discontinuous, and confined.
		Main aquifer	365	Blue-gray to gray-green medium to coarse sand and gravel. Basal portion locally fine to medium sand grading to silt. Interbedded silt and clay. Wood fragments and shells.	Moderate to high permeability. Continuous. Confined. Principal aquifer in the area. Only developed aquifer presently not intruded by salt water.
		Aquiclude	260	Blue-gray silt and silty clay. Minor stringers of fine silty sand. Scattered shells.	Relatively impermeable. Continuous.
		Lower zone	120	Blue-gray to gray-green fine to coarse sand and some gravel. Interbedded silt and clay. Few shells.	Moderate permeability. Discontinuous. Confined. Essentially undeveloped in the area.
		Aquiclude	140	Blue-gray compact silt and silty clay. Minor stringers of fine silty sand. Similar to underlying upper Pico formation.	Relatively impermeable. Discontinuous.
LATE PLIOCENE	Local unconformity Upper Pico Formation (1,400)	Undifferentiated fresh water bearing deposits	1,400	Thick blue-gray compact silt and silty clay aquicludes. Partially cemented sand and gravel aquifers up to 420 feet thick.	Aquifers probably moderately permeable. Areal continuity of units undetermined. Confined Undeveloped.

Figure 3-GENERALIZED STRATIGRAPHIC COLUMN OF WATER-BEARING FORMATIONS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

Tidal Marsh, Lagoonal, and Alluvial Deposits. The tidal marsh, lagoonal and alluvial deposits of Bolsa and Sunset Gaps are predominantly fine silty sands, clayey silts, and silty clays with lenses of peat and irregular stringers of medium to coarse silty sand. As shown on Section G-G', Plate 3B, the sediments grade landward from sands, generally highly fossiliferous, to silts and clays.

Lenses of peat ranging up to 18 feet thick are common along both edges of Bolsa Gap, landward of the Newport-Inglewood fault, North Branch. A similar belt of peat is located inland of the fault at the south edge of Landing Hill. There are lesser bodies of peat within the interior portions of Bolsa and Sunset Gaps. Peat cores obtained in Santa Ana Gap from a depth of 35 to 40 feet have been dated by radiocarbon methods as 8,030 to 8,140 years old, plus or minus 300 years (DWR Bulletin No. 147-1, 1966).

In Sunset Gap, the lagoonal-alluvial sediments overlie a slightly eroded upper Pleistocene surface and reach a maximum thickness of 35 to 40 feet. In Bolsa Gap, they conformably overlie stream channel deposits of the Bolsa aquifer and range from 40 feet to 75 feet thick.

Bolsa Aquifer. The Bolsa aquifer, termed the "80-foot gravel" by Poland and Piper (1956) comprises the basal Recent channel deposits of Bolsa Gap. These deposits extend inland from the gap to the City of Westminster, where they abut the younger Talbert aquifer, the principal channel deposit of the Santa Ana River. Sediments comprising the Bolsa aquifer are fine to coarse sand, and granule to pebble gravel with occasional cobbles to 5 inches in diameter. Marine shells and thin lenses of silt, clay, and peat are lesser constituents. The aquifer ranges from 5 to 40 feet in thickness.

The Bolsa aquifer unconformably overlies upper and lower Pleistocene deposits across the floor and along the edges of Bolsa Gap. Areas where the Alpha, Beta, Lambda, and Meadowlark aquifers outcrop beneath the Bolsa aquifer and contours on the base of the Bolsa aquifer are shown on Plate 4. The unconformable contact between the Bolsa aquifer and Pleistocene aquifers is also shown by the several geologic sections which cross Bolsa Gap (Plates 3A and 3B). It is noteworthy that similar unconformities between equivalent Recent and Pleistocene aquifers are developed in Alamitos and Santa Ana Gaps.

Upper Pleistocene Deposits

Upper Pleistocene deposits of the Lakewood Formation include the "Terrace cover, Palos Verdes Sand, unnamed upper

Pleistocene deposits, and the upper portion of the San Pedro Formation" of Poland and Piper (1956). Reclassification of these sedimentary units is based upon the subsequent correlation of exploration and microfossil data locally and in Alamitos and Santa Ana Gaps.

The Lakewood Formation consists of shallow marine, littoral, and continental deposits ranging in thickness from an erosional edge in Bolsa Gap to a probable maximum thickness of 400 feet in the inland portion of Sunset Gap. The upper beds are exposed across the hills and mesas of the Newport-Inglewood structural zone (Plate 2) and occur beneath Recent deposits in Bolsa and Sunset Gaps. In Bolsa Gap, the upper Pleistocene section has been extensively eroded across the Huntington Beach anticline and is stripped away across the fold crest between the Bolsa-Fairview and Newport-Inglewood faults. Except where down-dropped within the Newport-Inglewood shear zone (Section G-G', Plate 3B), it is essentially removed from Bolsa Gap seaward of the North Branch fault.

The Lakewood Formation lies conformably upon the lower Pleistocene San Pedro Formation in Sunset Gap, but across the Huntington Beach anticline and probably across the Seal Beach dome, the contact becomes one of slight unconformity. Basal marine facies of the Lakewood Formation are best differentiated from the lower Pleistocene deposits by micropaleontological data. The younger beds are either barren of Foraminifera or contain only very shallow water forms of <u>Elphidium sp.</u> and <u>Discorbis sp.</u> in association with <u>Rotalia becarri</u>. The upper Pleistocene beds are also distinguishable by their common oxidized state, by the dominant or relatively high concentration of calcium in contained ground water and, generally, by a lesser concentration of shells.

The Lakewood Formation is differentiated into an upper semiperched zone and three interconnected aquifers and confining beds. Description of these units is given next in descending stratigraphic order.

<u>Semiperched Zone</u>. The upper Pleistocene semiperched zone is irregularly distributed throughout the area, except in Bolsa Gap, where it has been entirely stripped away by erosion. The sediments consist of moderately to well oxidized, generally dirty fine to coarse sand and fine gravel. These coarse deposits are irregularly interbedded with and gradational to oxidized or gray-green sandy silt and sandy clay. Organic silt, lenses of peat, bits of wood, and thin calcareous seams of cemented silt and sand are minor constituents. Except for kitchen middens scattered on the land surface, the deposits are practically barren of marine shells.

The semiperched zone generally includes one or two permeable beds from 1 to 20 feet thick, which are separated by silt and clay. Locally, the fine-grained separator is not developed and the zone thickens to as much as 55 feet (site BS-109). In much of the area, the semiperched zone conformably overlies a blue-gray to blue-green confining bed of marine silt and clay from 10 to 45 feet thick. Progressing southeast beneath Bolsa Chica Mesa, this bed thins or grades to sand and is generally not encountered south of Warner Avenue. Locally, along the south edge of Bolsa Chica Mesa, at Landing Hill, and particularly within the central portion of Huntington Beach Mesa, the semiperched zone occurs from ground surface to the top of the Alpha aquifer. This is shown by Sections D-D', F-F', and J-J' which may be seen on Plate 3B.

At Huntington Beach Mesa and Bolsa Chica Mesa, oil field brines, oil refinery wastes and brackish semiperched water have percolated downward where the semiperched zone directly overlies the Alpha aquifer. This unfavorable condition was not encountered at the observation well sites within the salt water intrusion belt between Landing Hill and Bolsa Gap. At these sites, the semiperched zone and the Alpha aquifer are separated by silt and clay. Subsequently, detailed exploration of the shallow deposits has been conducted by the United States Geological Survey. In Sunset Gap, inland of site BSO-9, predominantly sandy deposits were encountered from ground surface to the top of the Alpha aquifer (Wall and others, 1966). The degree of downward salt water movement in this area has not yet been determined, but such degradation appears areally restricted, based on water quality data for observation wells at site BSO-9. This is described in Chapter V.

Alpha Aquifer. The Alpha aquifer is the uppermost Pleistocene water-bearing zone developed to wells in the area. It is correlative to the B and C zones identified in Alamitos Gap and to the upper portion of the Alpha aquifer, identified in Santa Ana Gap. In the seaward two-thirds of Bolsa Gap, the aquifer is largely stripped away by erosion, but otherwise it is continuous throughout the area.

In local exposures along the stream bluff of Huntington Beach Mesa, Section 34, T5S, R11W, the sediments are fine to coarse sand, and cross-bedded pebbly sand and gravel with some cobbles up to 6 inches in diameter. Drill cuttings are predominantly fossiliferous fine to coarse sand, with granule to pebble gravel. They generally become cleaner and coarser with depth. Silt and clay occur as minor interbeds, locally thickening and separating the aquifer into an upper and lower zone, as shown on Section E-E', Plate 3B.

The aquifer ranges in thickness from a thin erosional edge in Bolsa Gap up to 110 feet in Sunset Gap, but is generally from 60 to 80 feet thick. Its base ranges from an upper elevation of sea level, across the Huntington Beach anticline, to 200 feet below sea level at well 5S/11W-8C1, inland of Sunset Gap. In this depression, the Alpha aquifer conformably overlies a marine silt and clay confining bed from 10 to 25 feet in thickness. This bed thins and pinches out across anticlinal folds, and in these areas, the Alpha and Beta aquifers merge and are difficult to differentiate. Such areas of hydraulic interconnection underlie Landing Hill and, generally, from the middle of Bolsa Chica Mesa southeast to the limit of the area. Mergence of the two aquifers in these areas is shown by the geologic section on Plates 3A and 3B.

Beta Aquifer. Based on its generally coarse texture, the Beta aquifer is ranked as the principal upper Pleistocene ground water zone. It is correlative to the coarse upper portion of the A Zone in Alamitos Gap and to the Beta aquifer and locally, the basal Alpha aquifer, as identified in Santa Ana Gap. Except where eroded in Bolsa Gap, the Beta aquifer is practically continuous within the area. Locally, however, it is transitional with or enclosed within a matrix of fine sand and silt.

The Beta aquifer is not exposed within the area. Drill cuttings are medium to coarse sand and granule to cobble gravel. Recovered whole pebbles up to 1/2 inch in diameter were fairly well-rounded. Silt and clay occur as thin interbeds. The aquifer ranges in thickness up to 80 feet, but is commonly 40 to 50 feet thick. Its base ranges in elevation from 35 feet below sea level across the Huntington Beach anticline to 280 feet below sea level at site BS-108.

Throughout most of the area, the Beta aquifer overlies a marine silt and clay confining bed, generally less than 30 feet thick but locally up to 70 feet thick. Beneath portions of Huntington Beach Mesa and Bolsa Chica Mesa, just inland from the Newport-Inglewood fault, this bed thins and pinches out. In these areas, the Beta and underlying Lambda aquifers form one merged zone, as shown by the several geologic sections on Plates 3A and 3B.

Lambda Aquifer. The Lambda aquifer is the deepest permeable zone overlying marine beds containing lower Pleistocene Foraminifera. It is equivalent to the basal portion of the A Zone identified in Alamitos Gap and to the Lambda aquifer differentiated in Santa Ana Gap. Within the study area, the aquifer is relatively persistent, except where stripped away by erosion in Bolsa Gap.

Drill cuttings of the Lambda aquifer consist of fossiliferous fine to coarse sand with granule to pebble gravel and interbedded silt and clay. The aquifer varies considerably in texture within the area, generally becoming fine-grained, progressing downdip from the Newport-Inglewood structural zone. Where silty and fine-grained, the permeable beds are sometimes logged as sea mud or sandy clay by well drillers.

The aquifer may attain a maximum thickness of 90 feet at well 5S/11W-9M1, but usually is from 30 to 50 feet thick. It thins across the Newport-Inglewood structural zone to between 10 and 20 feet across the Huntington Beach anticline. The base of the aquifer reaches an upper elevation of 70 feet below sea level in Bolsa Gap and drops to a minimum elevation of nearly 420 feet below sea level at well 5S/11W-9M1 inland of Sunset Gap.

The Lambda aquifer conformably overlies a marine silt and clay bed of the lower Pleistocene San Pedro Formation beneath Sunset Gap and most of Landing Hill and Bolsa Chica Mesa. This bed ranges from less than 10 feet to 45 feet in thickness. Beneath Bolsa Gap, it has been stripped away by erosion, and the Lambda aquifer overlies and is practically indistinguishable from the Meadowlark aquifer. The approximate contact between these zones is shown on geologic section B-B', Plate 3A, and Sections G-G' and H-H', Plate 3B. Available data suggest a similar mergence of the two aquifers at Landing Hill, (Section A-A', Plate 3A and Section D-D', Plate 3B).

Lower Pleistocene Deposits

Marine deposits of the lower Pleistocene San Pedro Formation underlie upper Pleistocene and Recent formations throughout the area at depths ranging from 70 feet below sea level in Bolsa Gap to a probable 420 feet below sea level inland of Sunset Gap. Where depressed in the latter area, the formation reaches a maximum thickness of about 1,050 feet and extends to an estimated depth of 1,450 feet below sea level. Due to thinning and erosion across anticlinal folds, the formation is reduced to a thickness of 550 to 650 feet at Landing Hill, Bolsa Gap, and Huntington Beach Mesa. Its base reaches a probable maximum elevation of 750 feet below sea level at Huntington Beach Mesa.

The San Pedro Formation conformably overlies and is apparently gradational with the upper Pliocene Pico Formation in most of the area, but this contact may change to one of unconformity over the axis of the Huntington Beach anticline. Lacking any distinct lithologic break, the division between Pliocene and Pleistocene beds is differentiated mainly by micropaleontological data. However, such data are unavailable. Based on a slight decrease in the apparent electrical resistivity of silts and clays and the deepest micropaleontological data from exploration, the Plio-Pleistocene contact is placed several hundred feet below previous estimates.

Lower Pleistocene sediments are best differentiated from the overlying Lakewood Formation by a characteristic assemblage of Foraminifera, which include: Nonionella basispinata, Nonionella miocenica stella, Cassidulina limbata, Elphidium spinatum and Elphidiella hanni. Generally, the predominance of sodium among the cations and the lesser anion concentration of sulfate are relatively good indicators of lower Pleistocene ground waters.

The San Pedro Formation is differentiated into three principal aquifers and confining beds which are described below in descending stratigraphic order.

Meadowlark Aquifer. The term Meadowlark aquifer is given to the several interconnected permeable beds in the uppermost San Pedro Formation. Stratigraphically equivalent beds in Alamitos Gap have been identified as the I zone. In Santa Ana Gap, these beds are differentiated into the Omicron and Upper Rho aquifers. The Meadowlark aquifer occurs throughout the study area, except where stripped away by Recent erosion beneath Bolsa Gap (geologic sections G-G', and H-H', Plate 3B).

Drill cuttings consist of fossiliferous fine to coarse silty sand and fine gravel. Interbeds of silt and clay up to 25 feet thick commonly separate the aquifer into two or three zones. The lower one-half to two-thirds of the aquifer is locally fine to medium silty sand and is frequently logged by well drillers as bay mud, sea mud, or sandy clay. These lower beds are seldom developed to wells.

The aquifer ranges up to 120 feet in thickness at site BSO-9, but nearly 40 feet of the zone is silt and clay. Where not dissected by erosion, the aquifer is 80 to 100 feet in thickness. The base of the aquifer ranges in elevation from 80 feet below sea level in Bolsa Gap to 520 feet below sea level at well 5S/11W-9M1.

Throughout the study area, the Meadowlark aquifer conformably overlies a zone of blue-gray silt and clay with thin stringers of sand grading locally to gravel. The upper portion consists predominantly of silt and clay and is generally from 75 to 85 feet in thickness. The basal portion consists of alternating relatively thin beds of fine to medium silty sand, silt, and clay. It is generally from 30 to 45 feet in thickness. Progressing southeast from Bolsa Gap to Huntington

Beach Mesa, the sands thicken, become cleaner and coarser, and grade to gravel. This is shown on Section C-C', Plate 3A. In Santa Ana Gap, this coarse-grained bed is differentiated as the lower Rho aquifer.

The predominantly fine-grained zone overlying the Main aquifer is a good geologic and micropaleontologic marker and constitutes an important aquiclude separating overlying and interconnected Recent and Pleistocene aquifers from the underlying Main aquifer. This aquiclude is not breached by erosion within Alamitos, Bolsa, and Santa Ana Gaps, but decreases in effective thickness to 25 feet beneath Huntington Beach Mesa due to the facies change previously described.

Main Aquifer. The Main aquifer is the principal water-bearing zone developed to wells along the seaward perimeter of the coastal plain of Orange County. The aquifer is continuous from Alamitos Gap through the study area to Santa Ana Gap and is identified by the same name along this entire reach. In the Central and West Coast ground water basins of Los Angeles County, it is referred to as the Silverado aquifer.

The Main aquifer consists of fossiliferous beds of medium to coarse sand and gravel, fine to medium sand, and silt and clay. Coarse-grained sediments commonly occur in the upper portion of the aquifer, but beneath Landing Hill and Huntington Beach Mesa the upper beds are fine silty sand and/or predominantly silt and clay. This is shown on geologic sections C-C' and E-E', Plates 3A and 3B, respectively.

Due to relatively abrupt basal facies change, the aquifer varies considerably in thickness along the Newport-Inglewood structural zone. Along geologic section A-A', it ranges from a maximum thickness of 365 feet at site BS-3 in Bolsa Gap to a minimum thickness of 95 feet at site BSO-9 in Sunset Gap. Progressing inland from the Newport-Inglewood structural zone, the aquifer is from 150 to 250 feet in thickness.

Contours on the top of the Main aquifer which illustrate the general structural deformation of Pleistocene beds within the area are shown on Plate 5. The base of the aquifer ranges in elevation from 350 feet below sea level across the axis of the Huntington Beach anticline to nearly 900 feet below sea level inland of Sunset Gap.

The Main aquifer conformably overlies a confining zone of silt and clay with thin stringers of fine to medium silty sand and locally coarse sand and gravel. These beds are probably continuous within the area, and from the few deep logs available, apparently range from 150 to 350 feet in thickness.

Lower Zone. Fine to coarse sand and gravel deposits with interbedded silt and clay occur locally at or near the base of the San Pedro Formation and from 150 to 350 feet below the Main aquifer. These permeable beds are tentatively correlated with the Lower Zone of equivalent stratigraphic position in Alamitos Gap. As shown on Geologic Section A-A', Plate 3A, the sand and gravel beds are discontinuous along the Newport-Inglewood structural zone, where they range in thickness from less than 5 feet up to 120 feet. In this area, the base of the zone ranges in elevation from 720 to 980 feet below sea level. The beds overlie basal fine-grained sediments of the San Pedro Formation or equivalent deposits of the upper Pliocene Pico Formation.

Upper Pliocene Deposits

Although not locally developed as a water supply, permeable beds of the upper division of the Pico Formation contain fresh ground water. In portions of the study area these beds are sufficiently thick and near the surface to warrant development. Deeper fresh water beds may become economically feasible to exploit in the future. Therefore, the general stratigraphy and water-bearing character of these beds are described herein. Sedimentary rocks of the lower division of the Pico Formation contain brackish to saline ground water and description of these beds is beyond the scope of the report.

The upper division of the Pico Formation occurs throughout the area beneath Pleistocene and Recent deposits. Over the crest of the Seal Beach dome in Alamitos Gap, the beds occur from 770 to 2,170 feet below sea level and have a thickness of 1,400 feet. At the anticlinal fold crest beneath Huntington Beach Mesa, they lie between 750 and 1,780 feet below sea level and are approximately 1,000 feet thick. From these structural uplifts, the beds dip into the structural saddle beneath Sunset Gap and inland toward the synclinal axis of the basin. At the northeast corner of the area, they occur between 1,450 and 2,720 feet below sea level and attain a thickness of nearly 1,300 feet.

The deposits consist of partially consolidated gravel, sand, silt, and clay of marine origin. Foraminifera of the Wheelerian biofacies, including Uvigernia peregrina, Epistominella pacifica, and Bolvina sp., distinguish upper Pliocene from lower Pleistocene deposits. These microfossils were sparse and not predominant in deep samples collected from exploration holes.

Within several thousand feet of the Newport-Inglewood fault, the shallowest Pico beds are predominantly fine-grained with one to four separate permeable beds ranging from 10 to 40 feet in thickness. Between Landing Hill and Bolsa Chica Mesa, this fine-grained section is 600 to 800 feet in thickness. Apparently, because of fault uplift and erosion, it thins to between 370 to 200 feet in thickness progressing southeast to Huntington Beach Mesa.

Below the upper confining beds occur one to four freshwater zones up to 100 feet thick separately and 210 feet thick collectively. From their high apparent electrical resistivity (greater than 60 ohm meters) shown on electric logs, these water-bearing zones between Alamitos Gap and Bolsa Chica Mesa appear worthy of exploration. However, wells reaching these aquifers would have to extend to depths ranging from 2,200 feet to 1,600 feet below ground surface. From Bolsa Chica Mesa southeast to Huntington Beach Mesa, electric logs indicate that these permeable beds become silty and pinch out.

At the inland edge of the study area, electric logs of wildcat oil wells 5S/11W-16Qa, -22Ea, -22Ma, and -26Ga show a thick, relatively shallow freshwater-bearing section, which is tentatively assigned to the Pico Formation. These permeable beds unquestionably constitute an important aquifer, which on electric logs appears equivalent to the Main aquifer. Collectively, these beds range in thickness from 150 to 420 feet and occur above a depth of 1,700 feet below ground surface. They are underlain by fine-grained deposits ranging from 550 to 630 feet in thickness. Beneath these confining beds occur several basal freshwater zones ranging from 10 to 120 feet in aggregate thickness. These beds appear significant as aquifers only at wells -16Qa and -26Ga, where they occur to depths of 2,600 and 2,300 feet below ground surface, respectively.

Permeability of Stratigraphic Units

Permeability is the capacity of a porous media for tranmitting a fluid. Within sedimentary deposits, this property is dependent upon the size, shape, orientation, sorting, and packing of grains. These parameters determine the size, shape, and interconnection of pores in which ground water is stored and through which it moves. Permeability, therefore, has a wide range among materials of diverse texture. Permeability is greatest in a plane parallel to the bedding of sedimentary deposits and is lowest perpendicular to the bedding. As unconsolidated deposits lie practically flat, their permeability components may be considered as horizontal and vertical. Within stratified sand and gravel aquifers, horizontal permeability will generally exceed vertical permeability by 2 to 20 times. The contrast between horizontal aquifer permeability and the vertical permeability of interbedded silts and clays is considerably greater. Ratios of several hundred thousand up to one million to one are common. The relatively low permeability of silts and clays, commonly referred to as confining beds or aquicludes, greatly impedes the vertical movement of water. This causes water in an aquifer bounded by aquicludes to be held under hydraulic or artesian pressure. Such conditions are characteristic of the study area and limit in large part the vertical intrusion of sea water. Discontinuities in silt and clay beds, which occur over a broad area, provide major routes of vertical flow. In basins covering hundreds of square miles, the magnitude of water moving through aquicludes from one aquifer to another can be significant.

The permeability of stratigraphic units most subject to intrusion, primarily Recent and upper Pleistocene deposits, was determined by field and laboratory methods. Aquifer permeabilities were computed by well discharging methods and aquiclude permeabilities were measured by laboratory tests run on formation samples. The permeability of lower Pleistocene aquifers and aquicludes was estimated from lithology and from values computed for the younger deposits.

Permeability of Aquifers

Well discharging tests were conducted in the six BSO observation wells perforated throughout the Bolsa, Alpha, and Beta-Lambda aquifers. The wells were pumped for 12 hours at constant rates of from 179 to 319 gallons per minute. The time rate of recovery of the piezometric surface was measured in the pumped well and these data were used to compute permeability by the Theis Recovery Formula. In addition, the time rate of drawdown and recovery of the piezometric surface was measured in HH observation piezometers located 400 and 1,100 feet from pumped well BSO-6A. These data were used to compute permeability by the modified Theis Nonequilibrium Formula in conjunction with type curves developed by Stallman (Plate 3 of USGS WSP 1545-C, 1963).

The time-drawdown and time-recovery graphs of the well discharge tests and transmissibility and permeability computations are shown on Plate 6. Except for well BSO-3A, the semilog recovery plots do not form a straight line. Changes in slope to the right during the early recovery period show fault boundary conditions at wells BSO-7A and BSO-9A, recharge conditions at well BSO-1A, and apparent recharge at BSO-2 and BSO-6A. Due to these influences affecting the recovery of the cone of depression, Δs values given by the left hand portion of the semilog plots were used to compute transmissibility. At well BSO-9A, the semilog plot to the left of t/t' intercept 30 was probably influenced by tidal loading. High and low tide arrivals at the military harbor in Anaheim Bay plot at t/t' intercepts 2.55 and 7.65, respectively. These arrivals agree fairly well with the deflection of the semilog plot above and below the approximately located straight-line average.

The log-log plots of drawdown at piezometers HH-3A and HH-4A track above the Standard Type Curve. This shows that the expanding cone of depression intercepted a geologic boundary, either the Newport-Inglewood or Bolsa-Fairview faults. Using the graphical method of Moulder (Stallman, 1963), possible boundary reflection points for test data at HH-3A and HH-3B bracket the Bolsa-Fairview fault, 100 to 200 feet from its approximate trace. The closest possible boundary reflection points for the Newport-Inglewood fault plot 680 to 730 feet from its trace. Comparatively, these data indicate that the Bolsa-Fairview fault was the principal geologic boundary affecting the cone of depression. Table 1 lists the permeability and transmissibility coefficients determined by the well discharge tests.

TABLE 1

PERMEABILITY AND TRANSMISSIBILITY COEFFICIENTS OF AQUIFERS

Aquifer	Well number	Type of well test	Transmissibility in gpd/ft	Permeability in gpd/sq ft
Bolsa	5S/11W-33B2 BSO-1A	Recovery	46,000	2,300
Bolsa-Meadowlark	5S/11W-28M2 BSO-2	Recovery	10,000	200
Alpha-Beta	5S/11W-29J2 BSO-3A	Recovery	89,300	1,370
Alpha	5S/11W-20M2 BSO-6A	Recovery	27,400	550
	5S/11W-20M6 HH-3A	Drawdown Observation	60,900	810
	5S/11W-20N1 HH-4A	Drawdown Observation	43,000	570
	5S/11W-20N2 HH-4B	Drawdown Observation	40,300	540
Beta-Lambda	5S/11W-19B2 BSO-7A	Recovery	59,500	920
Beta-Lambda	5S/12W-13A2 BSO-9A	Recovery	37,800	500

Average coefficients of permeability were computed by dividing the effective aquifer thickness (producing thickness) into the transmissibility coefficients. Effective aquifer thicknesses were found by subtracting beds of silt and clay, which yield negligible amounts of water, and unsaturated aquifer intervals (BSO-3A) from the total aquifer thicknesses.

With one exception, the data in Table 1 show that Recent and Pleistocene aquifers within the area of sea-water intrusion range in permeability from 500 to 2,300 gallons per day per square foot (gpd/sq. ft.) and transmit water readily. The 200 gpd/sq. ft. permeability computed for the Bolsa aquifer (well BSO-2) is not consistent with the coarse clean texture of the deposits. It is probably a measure of the effective permeability of the well perforations and gravel pack, which apparently had become partially plugged.

Based upon the lithology of the aquifers, the computed values of permeability, and the factors limiting these computations, the Bolsa aquifer has the highest average horizontal permeability; the Beta-Lambda aquifer is intermediate; and the Alpha aquifer is somewhat lower in rank.

The lithology of the Meadowlark aquifer, which varies from fine silty sand to well graded sand and fine gravel, suggests a horizontal permeability of from 100 to 800 gpd/sq. ft. The Main aquifer, which varies in texture from fine to medium sand and well-graded sand and coarse gravel, is estimated to range in horizontal permeability from 400 to 1,500 gpd/sq. ft.

Permeability of Aquicludes

The vertical permeability of silt and clay aquicludes was determined in the laboratory by measuring the rate of movement of water or air through undisturbed push samples. Ten samples were taken in Recent and upper Pleistocene aquicludes overlying the Bolsa, Alpha, and Beta-Lambda aquifers, and one sample was taken in the lower Pleistocene aquiclude overlying the Main aquifer. The vertical permeability coefficients of the samples are listed in Table 2.

Except in two cases, vertical permeability coefficients of the nine aquiclude samples ranged from 0.001 to 0.023 gpd/sq. ft. Relative to the horizontal permeability of underlying aquifers, the vertical permeability of these aquicludes is on the order of 55,000 to 2,300,000 times lower. The continental upper Pleistocene beds overlying the Alpha aquifer have the highest vertical permeability of 0.002 to 0.57 gpd/sq. ft., but as will be explained, the two greater values may be in error. Marine beds of Recent and Pleistocene age have the lowest vertical permeability of 0.001 to 0.003 gpd/sq. ft. These values are considered representative of the aquiclude overlying the Meadowlark aquifer, which was not sampled.

Nine of the eleven aquiclude samples were broken down by mechanical analyses after the permeability tests were conducted. The grain size curves of these mechanical analyses are shown in Figure 4.

Of the five samples for which complete mechanical analyses were run, particles smaller than 0.0025 millimeters, which may be considered as clay, comprised from 7 to 48 percent of the whole. The corresponding vertical permeability of these samples was 0.023 to 0.001 gpd/sq. ft. Comparing the percent clay with the vertical coefficient of permeability for all samples having complete mechanical analyses, permeability decreased with an increase in clay up to 30 percent, but was not significantly changed by an increase in the clay above 30 percent.

The partial grain size curves of the remaining four samples suggest that the vertical permeability coefficients for the two samples at site BSO-6 may be too great. For example, the two samples taken at site BSO-7 consisted of 38 to 63 percent fine sand and ranged in permeability from 0.002 to 0.017 gpd/sq. ft. By comparison, the sample taken at site BSO-6 having the highest vertical permeability (0.57 gpd/sq. ft.) contained the least amount of sand (less than 10 percent). Unless the residual 90 percent material is uniformly graded silt, the tested permeability of this sample appears unreasonably high by about 10 times.

Geologic Structure

The salient geologic structure within the Bolsa-Sunset area is the Newport-Inglewood structural zone, a northwest trending belt of anticlinal folds and faults which disrupt early Recent and older deposits. Crustal strain along this structural zone is believed to have originated in middle Miocene time, some 20 million years ago. Since then, deformation has been recurrent to the present. Because of repeated tectonic activity, deformation is greatest among Miocene and older rocks and is progressively diminished among younger formations. The last major deformational event is expressed at ground surface by the gentle upwarping and displacement of upper Pleistocene deposits at Landing Hill and Bolsa Chica and Huntington Beach Mesas and by the landward tilting and apparent displacement of the Bolsa aquifer. The Recent land surface of Bolsa and Sunset Gaps is not deformed. However, there are several data which attest to the seismic disturbance of Recent deposits.

TABLE 2

VERTICAL PERMEABILITY COEFFICIENTS
OF SELECTED AQUICLUDES

Field number	State well number	Sample depth in feet	Vertical permeability coefficients			Underlying aquifer
			In millidarcys*	In feet/day**	In gpd/sq. ft.	
BS-2	5S/11W-33B1	48.0- 48.5		0.0031	0.023	Bolsa
		48.5- 49.0		0.00011	0.001	Bolsa
BS-3	5S/11W-28P1	146.8-147.3		0.0004	0.003	Main
BSO-6	5S/11W-20M2	15.5- 16.0	31.3		0.570	Alpha
		16.0- 16.5	26.4		0.480	Alpha
		16.5- 17.0	0.53		0.010	Alpha
BS-6	5S/11W-20M1	46.5- 47.0		0.00013	0.001	Alpha
		139.3-139.8		0.00013	0.001	Beta
BSO-7	5S/11W-19B2	19.5- 20.0	0.91		0.017	Alpha
		20.0- 20.5	0.63		0.011	Alpha
		20.5- 21.0	0.13		0.002	Alpha

*Vertical permeability tests were conducted at Oilwell Research, Inc., of Long Beach, California, in November 1964. Values were converted from millidarcys to gallons per day per square foot by the factor 0.0182.

**Vertical permeability tests conducted at Department of Water Resources Soils Laboratory in Sacramento during February 1962. Values were converted from feet per day to gallons per day per square foot by the factor 7.48.

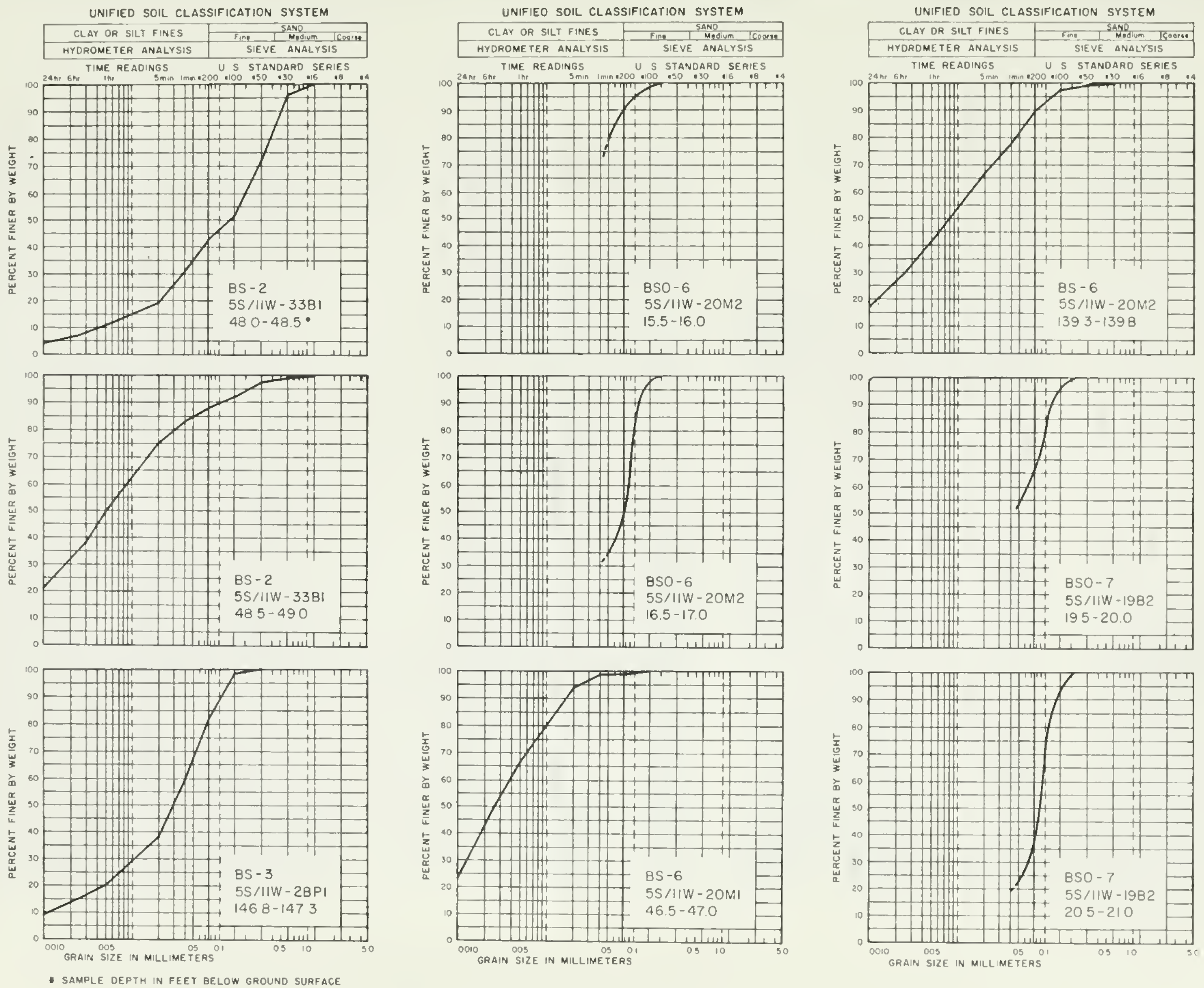


Figure 4- GRAIN SIZE CURVES OF AQUICLUDE SAMPLES

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

Deformation of the water-bearing sediments during and subsequent to their deposition has had an important effect upon the movement of ground water and especially upon the intrusion of sea water. The major folds and faults of the Newport-Inglewood zone and their importance to ground water movement are described below.

Folds

Pleistocene and older deposits within the area have been uplifted across the Seal Beach dome (Landing Hill) and across the larger Huntington Beach anticline (Bolsa Chica Mesa, Bolsa Gap, and Huntington Beach Mesa). Between these positive folds, the beds have been depressed into a structural saddle which underlies Sunset Gap. This folding along the Newport-Inglewood zone is shown on Geologic Section A-A', Plate 3A. From the Newport-Inglewood zone, the beds dip gently inland at less than 6° toward the South Gate-Santa Ana syncline, whose axis is located about 11 miles northeast of the study area. This folding of Pleistocene and older beds is illustrated by structure contours drawn on the top of the Main aquifer (Plate 5).

Folding of the early Recent Bolsa aquifer across the Huntington Beach anticline, previously noted by Poland (1956), is shown by the structure contours on the base of that aquifer (Plate 4).

The effect of anticlinal folding upon ground water movement is primarily one of increasing flow between aquifers. This is because the aquifers merge across the fold crests due to thinning, facies change, and/or erosion of intervening confining beds. Principal areas of hydraulic interconnection (Bolsa Gap) are across the Huntington Beach anticline where unconformities are developed among the Bolsa, Alpha, Beta, Lambda, and Meadowlark aquifers.

Faults

The axis of the Newport-Inglewood structural zone is coincident with a major fault or shear zone which is apparently continuous across the Bolsa - Sunset area and within this reach acts as an important hydraulic barrier limiting ground water flow. This structure, referred to in this report as the Newport-Inglewood fault, is known locally as the Seal Beach fault or the High School fault (Huntington Beach and Sunset Oil Fields). Two faults of lesser rank which probably affect the ground water movement to some degree are the inland Bolsa-Fairview fault and the seaward South Branch fault, a splinter break diverging from the Newport-Inglewood fault (North Branch) in Bolsa Gap. The locations of these faults and several minor faults which do not affect ground water movement are shown on Plate 2.

Newport-Inglewood Fault (North Branch). The Newport-Inglewood fault is a major zone of complex shearing which dips steeply southwest beneath the ocean.* This principal fracture has been active intermittently since Miocene time and historically has been the focus of numerous small tremors. Included among these tremors is the damaging Long Beach earthquake of March 11, 1933 (magnitude 6.3), whose epicenter was located about 17 miles downcoast from Long Beach and about 4 miles seaward of Newport Beach.

Effects of the Newport-Inglewood fault among water-bearing deposits include:

1. Topographic expression.
2. Surface cracks and sand boils.
3. Offset bedding and stratigraphic discontinuities.
4. Pronounced hydraulic discontinuities in early Recent and older aquifers.
5. Abrupt changes in ground water quality in early Recent and older aquifers.
6. Differences in the age of ground water within the Main aquifer.

Because of its northwest trend, generally paralleling that of the San Andreas fault, the Newport-Inglewood fault is considered to be a predominantly right lateral tear. That is, the major displacement has been horizontal with the seaward block moving northwest or upcoast relative to the landward block. The amount of horizontal displacement among water-bearing deposits within the study area is indeterminable. Based on greater subsurface data in Santa Ana Gap, the maximum apparent horizontal displacement of lower Pleistocene beds is estimated to have been about one-half mile (DWR Bulletin No. 147-1, 1966).

Within the study area, vertical displacement along the Newport-Inglewood fault is evident from topography and from the subsurface offset of bedding. Topographic expression of the fault trace is given by linear escarpments or depressions across Landing Hill, Bolsa Chica Mesa, and Huntington Beach Mesa and two small remnant escarpments of upper Pleistocene deposits in Sunset Gap. From Hog Island southeast across Huntington Beach Mesa, seaward-facing escarpments and the higher inland elevation indicate a 20-foot to 40-foot apparent vertical displacement of the upper Pleistocene land surface. Well logs and electric logs across the fault zone at Hog Island and Bolsa Chica Mesa indicate

* As depicted on Plates IV, V, and VI in Hazenbush, George C., and Dennis R. Allen, "Huntington Beach Oil Field"; Summary of Operations, California Oil Fields; Vol. 44, No. 1, pp. 13-25; San Francisco: California Division of Oil and Gas, 1958.

a maximum apparent vertical displacement of 35 feet among upper Pleistocene beds and 50 feet among lower Pleistocene beds.

In Bolsa Gap, where closely spaced electric logs are available, the fault is not one master break but a shear zone up to 900 feet wide and cut by at least three closely spaced essentially parallel faults (Geologic Sections G-G' and H-H', Plate 3B). Within this shear zone, the top of the Main aquifer is down-dropped an apparent 300 feet between sites BSO-1 and BS-3. As shown on Section G-G', a 250-foot section of younger Pleistocene beds is entrapped within the shear zone and faulted against the Main aquifer and its overlying aquiclude. This considerable offset represents the greatest known structural deformation of Pleistocene deposits within the study area. Such deformation is not elsewhere evident between wells spaced on either side of the fault trace.

The topography of Landing Hill indicates that the vertical displacement along the fault is reversed in the extreme northwest part of the area. That is, the seaward block has been uplifted an apparent distance of 15 feet relative to the landward block. This same relative movement was mapped to the northwest in the subsurface at Alamitos Gap, both in the deep oil-bearing strata and in the Pleistocene and upper Pliocene water-bearing deposits. Along Section D-D', Plate 3B, however, well logs at the south slopes of Landing Hill show no apparent vertical displacement of Pleistocene aquifers.

The most striking effects of the Newport-Inglewood fault among Pleistocene deposits are its effects upon ground water. These effects will be described in detail in Chapter III, Ground Water Hydrology, and Chapter IV, Ground Water Quality, and have been covered thoroughly by Piper and Garrett (1953), Poland and Piper (1956), and Poland and Sinnott (1959).

In brief, the Newport-Inglewood fault acts as a partial to virtually complete hydraulic barrier within Pleistocene aquifers and probably within the early Recent Bolsa aquifer as well. From the few short-term hydrographs available, water levels seaward of the fault are influenced by tidal loading but exhibit little or no response to the seasonal or long-term decline or recovery of the inland piezometric surface. Even more pronounced are the changes in ground water salinity across the fault plane. Historically, the fault separated inland fresh ground water of less than 50 ppm chloride from predominantly saline ground water in the Bolsa, Alpha, Beta-Lambda, and Meadowlark aquifers and from brackish ground water in the Main aquifer. This abrupt discontinuity in ground water salinity has subsequently been altered in part due to the selective intrusion of saline ground waters across more permeable portions of the fault plane, primarily in upper Pleistocene aquifers. In other aquifers, there has been only slight or no measurable underflow of saline water across the fault plane.

Further evidence of the Newport-Inglewood fault is the difference in age of ground waters within the Main aquifer landward and seaward of that structure. Radiocarbon dating of samples from well 5S/11W-29C2 (landward) and piezometer BSO-4 (seaward) was conducted by Nicholas (1964). The calculated ages of these water samples are:

5S/11W-29C2	4,030 ± 230 years
5S/11W-32A1 BSO-4	5,700 ± 160 years

From these data, ground water seaward of the fault is 1,400 or more years older. The 5,700-year age of the coastal ground water is probably not significantly influenced by younger sea water. This is because the theoretical ratio of fresh water to sea water is 96:4. Secondly, ground water in the aquifer is not in hydraulic continuity with the ocean because its piezometric surface is nearly constant at 14 feet below msl.

Prior to this investigation, it was inferred by analogy to other areas that the Bolsa aquifer (80-foot gravel) was not cut by the Newport-Inglewood fault (Poland and Piper, 1956). However, it was concluded that the aquifer had been tilted landward due to structural uplift. Based upon the few data subsequently collected, and by analogy to other areas, there is reasonable evidence at present to suggest that the Bolsa aquifer is displaced by the Newport-Inglewood fault and that such a geologic boundary has substantially limited sea-water intrusion.

Logs of test holes BS-2 (landward) and NB-1 (seaward) indicate an apparent 20-foot displacement of the Bolsa aquifer across the Newport-Inglewood fault, as shown on Geologic Section G-G', Plate 3B. This apparent offset, inland block down, may be due to a normal stratigraphic discontinuity or a meander of the ancient stream channel. However, it is consistent with the displacement of underlying Pleistocene beds.

Further evidence of faulting of the Bolsa aquifer is given by water quality data. Water samples of the Bolsa aquifer collected from test hole NB-1 (seaward) in April 1960 contained from 285 to 850 grains per gallon sodium chloride, which is equivalent to a chloride ion concentration of 2,960 to 8,820 ppm. Well BSO-1A (landward) perforated throughout the aquifer, has yielded water containing less than 200 ppm chloride since August 1963.

Considering that the Bolsa aquifer is a highly permeable stream channel deposit and that its inland piezometric surface was below sea level between 1948 and 1964, reaching a minimum elevation of minus 28 feet in 1957 (wells 5S/11W-27H1 and -27H4), the pronounced lack of sea-water intrusion within the aquifer is most reasonably explained by a geologic boundary. By comparison, aquifers of equivalent age, origin, and permeability in Santa Ana Gap and Alamitos Gap, which are not displaced by the Newport-Inglewood fault, have been grossly intruded by sea-water. Hydraulic conditions in these aquifers were practically equivalent to those existing in the Bolsa aquifer during 1948-64. In Santa Ana Gap, intrusion causing a chloride ion concentration in excess of 500 ppm had progressed 2 miles inland of the fault trace in 1963. This is in contrast to the less than 200 ppm chloride content of Bolsa water within 600 feet of the fault trace in 1963.

Based upon the little data available, the essential lack of sea-water intrusion into the Bolsa aquifer, and the comparative gross intrusion of equivalent aquifers at Alamitos Gap and Santa Ana Gap, it is tentatively concluded that in addition to being uplifted across the Huntington Beach anticline, the Bolsa aquifer is displaced by the Newport-Inglewood fault. Such displacement of this 20-foot-thick aquifer appears to have developed a sufficient hydraulic boundary to have checked the intrusion of sea water under past hydraulic conditions. Considering that the Newport-Inglewood zone is an active structural system, it is entirely reasonable that during the past 10,000 years, one or more major earthquakes could have caused such structural deformation.

As mentioned previously, the Newport-Inglewood fault does not displace the Recent land surface. However, Recent deposits have been affected by seismic activity. In reference to the Long Beach earthquake of 1933, Poland (1959), citing personal communication from C. R. Browning, states:

> "Although the earthquake is not known to have caused any vertical displacements, many cracks developed in the land surface along and near the structural zone, especially near Hog Island in the Sunset Gap and near the coast in Santa Ana Gap."

Regarding these features in Santa Ana Gap, Mr. Penn Rowe (written communication) states that Mr. Browning also noted sand boils and flowing water along the fault trace in Santa Ana Gap following the 1933 earthquake.

In addition to these temporary conditions, Recent deposits exposed in vertical channel walls within 400 feet of the fault trace at Huntington Harbour appear to have been deformed by compression. This is indicated by:

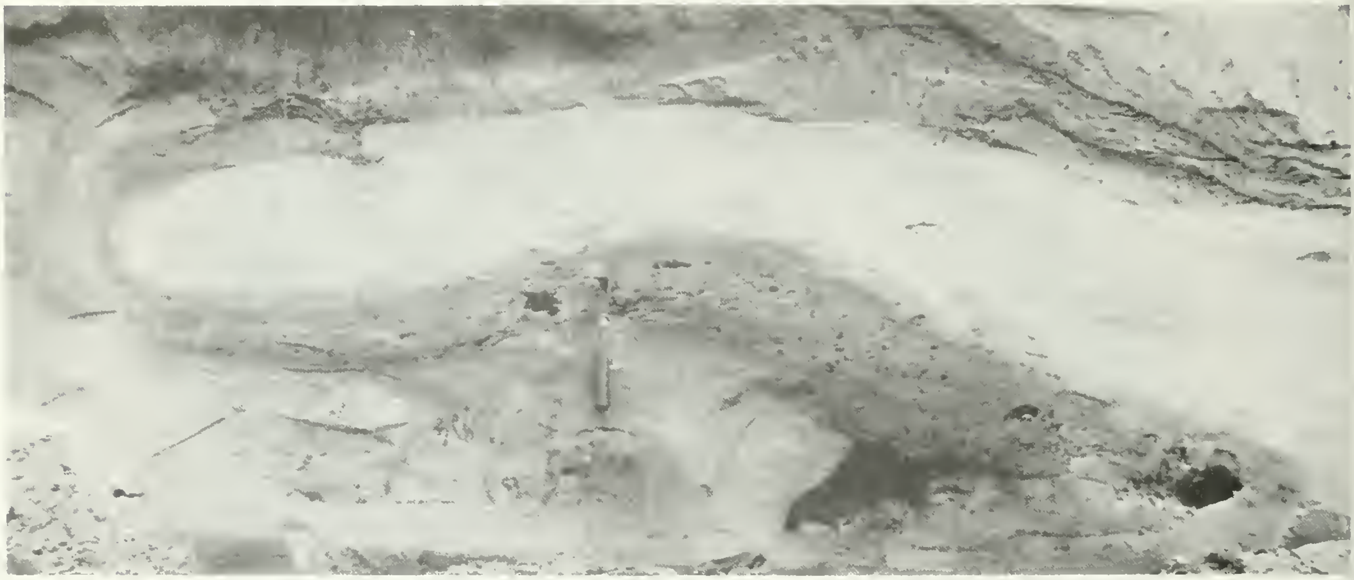
(1) parallel isoclinal, fan, and recumbent folds, small shears, and cavities developed in the fine-grained loose sands, (2) the lateral dislocation and slumping of rough-edged and fractured chunks of tough clayey silt, and (3) the chaotic and jagged lateral contact of the sand and silt (see photographs). Considering that the depositional environment of these materials was a tidal lagoon of negligible relief sheltered by a barrier beach, it is difficult to explain these features by sedimentary processes or by slumping due to current scour. Rather, it is more plausible that they developed quickly, probably due to liquefaction of the loose sand and slumping of the silt resulting from seismic compression. Support for such liquefaction is given by the sand boils noted by Browning in 1933.

Newport-Inglewood Fault (South Branch). Poland and Piper (1956) mapped an inferred fault coincident with a low escarpment on Huntington Beach Mesa and extended this structure across Bolsa Gap to mergence with the main fault trace at Bolsa Chica Mesa. In Santa Ana Gap, this structure was subsequently identified as the South Branch of the Newport-Inglewood fault (DWR Bulletin 147-1, 1966). In that area, more than 100 feet of vertical and right lateral displacement of the San Pedro Formation is indicated in the subsurface. Within the study area, displacement along the South Branch fault is indeterminable from the little data available. In Bolsa Gap, it approximately overlies a zone of faulting mapped in Tertiary deposits. Displacement is inferred to extend upward within the San Pedro Formation and act as a hydraulic barrier within the Main aquifer. Evidence for this is given by shallow oil well electric logs, which show fresh water throughout the Main aquifer landward of the fault trace. Seaward of the fault, electric logs show salty water in all but the upper portion of the aquifer.

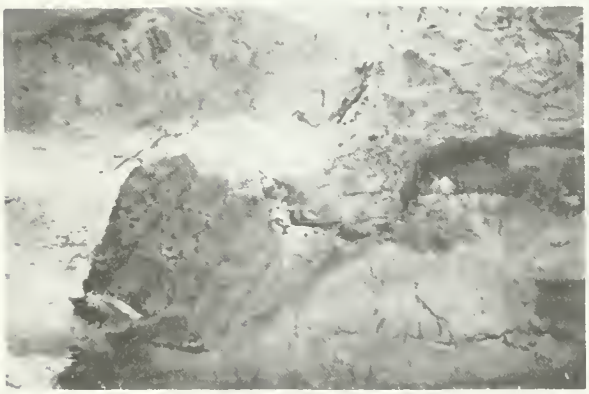
Bolsa-Fairview Fault. From the south of Sunset Gap into Huntington Beach Mesa, stratigraphic discontinuities within Pliocene and lower Pleistocene beds are attributed to lateral displacement along a fault as shown on Sections E-E' through J-J', Plate 3B. This structure is tentatively aligned with a northwest-trending fault identified at the inland portion of Newport Mesa and subsequently mapped in the subsurface across Santa Ana Gap and the east edge of Huntington Beach Mesa. The term Bolsa-Fairview fault is given to both. However, the connection of these faults beneath Huntington Beach Mesa has not been substantiated and it is possible that the Bolsa-Fairview fault, located within the study area, is an extension of the Adams Avenue fault as defined in DWR Bulletin No. 147-1.

Deformation of upper Pleistocene beds and the Bolsa aquifer along the Bolsa-Fairview fault is suggested by the alignment of several anomalous conditions:

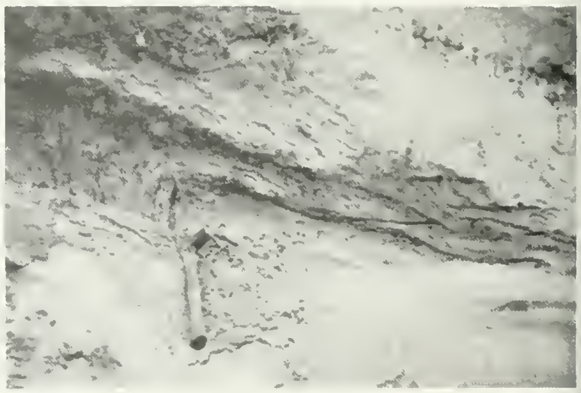
Recumbent fold with detached nose, overturned fold, and flow contact of light sand against dark clayey silt. Two dark areas opposite man's leg are natural cavities. Overburden is undeformed sand and silt capped by fill. View east at excavated wall of marina channel, 5S/11W–19H



Enlarged view of recumbent fold, overturned fold, and cavities.

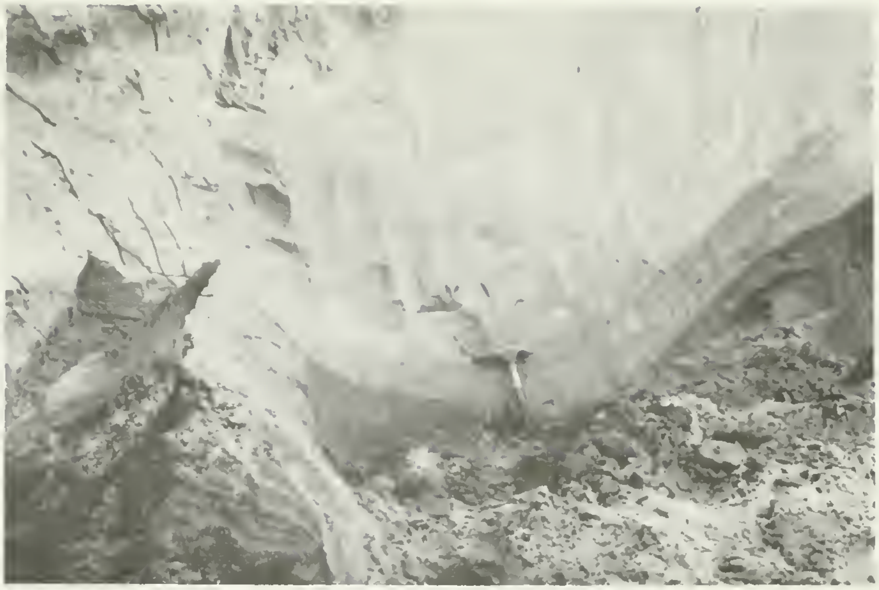


Detail of slump block in contorted sand matrix showing right to left separation of silt



Overturned fold axis.

Anticlinal *(left)* and synclinal *(center)* folding of light sand and dark clayey silt contact and contorted, isoclinal folding of sand. View northwest at excavated wall of marina channel, 5S/11W–19G.



Above – enlarged view of isoclinal folding of sand.

Left – contorted sand cut by minor shear at pencil.

COMPRESSIONAL FLOW STRUCTURES IN RECENT DEPOSITS

1. The topography of Huntington Beach Mesa.

2. The vertical offset or tight folding of the base of the Bolsa aquifer.

3. The abrupt drop in chloride ion concentration within the Alpha aquifer between closely spaced wells.

4. The limited inland advance of sea-water intrusion beneath Bolsa Chica Mesa and the south portion of Sunset Gap.

5. Aquifer pump test data.

The trace of the Bolsa-Fairview fault at the west edge of Huntington Beach Mesa is marked by a northwest-trending, linear gully approximately 2,000 feet long. Similar features of lesser magnitude mark the surface trace of the Newport-Inglewood fault across the mesa surface.

Ten-foot vertical offset of the base of the Bolsa aquifer is suggested by available well logs spaced across the fault trace as shown on Sections G-G' and H-H', Plate 3B.

Although no appreciable vertical offset of the Pleistocene beds is evident on Section F-F', Plate 3B, the inland advance of sea-water intrusion at Bolsa Chica Mesa and the south limits of Sunset Gap has been thwarted by some boundary. An abrupt landward drop in chloride ion concentrations is evident in closely spaced wells tapping the Alpha aquifer, particularly between wells 5S/11W-20Q3 and -20Q12, both 120 feet deep.

Water from well -20Q3 exhibited a steady gain in chloride up to 700 ppm in April 1962, and a subsequent steady decline in chloride to 350 ppm in September 1965. Water from well -20Q12, located 150 feet inland, has yielded less than 60 ppm chloride water since first sampled in January 1961. This abrupt change in water quality occurring within 150 feet is relatively good evidence of a nearly vertical boundary restricting the inland movement of the sea water. This boundary aligns with subsurface stratigraphic discontinuities between oil wells to the northwest and southeast at Bolsa Chica Mesa.

As shown on the sea-water intrusion maps of the Alpha and Beta-Lambda aquifers (Plate 10 and Plate 12), only incipient advance of sea water has occurred landward of the mapped trace of the Bolsa-Fairview fault. Considering that 15,000 ppm chloride ion concentrations developed within the Alpha aquifer adjacent to the Newport-Inglewood fault zone, the inland extent of sea-water intrusion appears constricted. That is, salinity decreases markedly in a relatively shorter linear distance from the focus of intrusion.

Time-drawdown curves for two piezometers in the Alpha aquifer at sites HH-3 and HH-4 are shown on Plate 6. These plots measure the time-drawdown of the piezometric surface of the Alpha aquifer in response to pumping at well BSO-6A. The respective locations of these well sites are shown on Plate 2. The plot of the data curves above the "Type Curve" indicates that the expanding cone of depression around well BSO-6 intercepted a boundary that restricted ground water flow. As previously explained, the data indicate that this boundary was the Bolsa-Fairview fault.

Judging from pump test data and water quality data, the Bolsa-Fairview fault limits ground water movement in Pleistocene aquifers in local areas. However, it does not affect the piezometric surface of Recent and Pleistocene aquifers. These conflicting data indicate that sufficient hydraulic gaps exist along the fault plane to transmit changes in artesian pressure. This transmission is aided by unconformable contacts between aquifers.

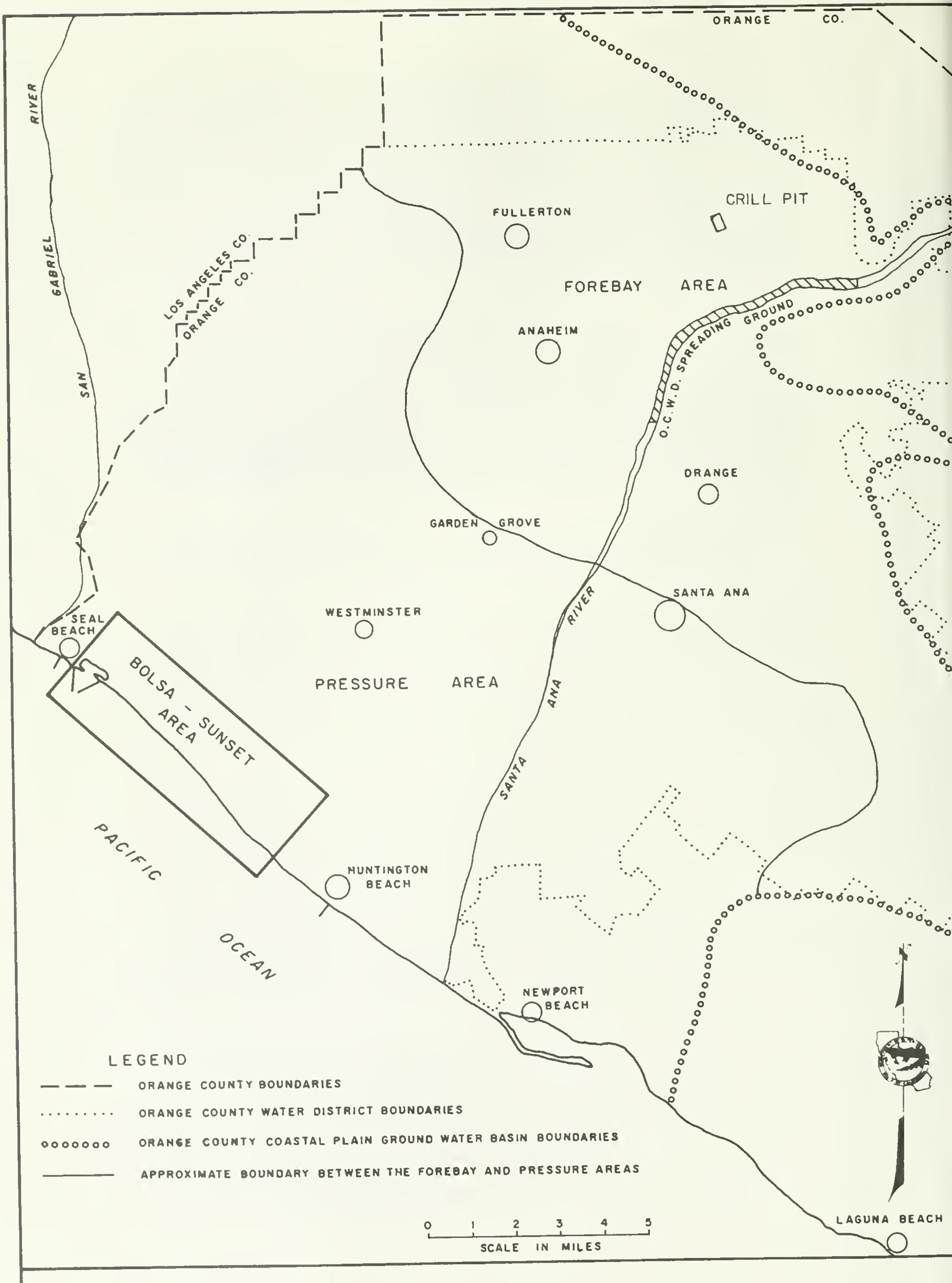


Figure 5—ORANGE COUNTY COASTAL PLAIN - HYDROLOGIC FEATURES

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

CHAPTER III. GROUND WATER HYDROLOGY

The Bolsa-Sunset area comprises a small portion of the large ground water basin which underlies the Coastal Plain of Orange County. Recharge to and extraction from the basin govern the elevation, fluctuation and trend of piezometric levels within the study area. During periods of deficient recharge, withdrawal of stored ground water causes a lowering of coastal piezometric levels. Conversely, recovery of coastal piezometric levels occurs when recharge exceeds ground water extraction and natural discharge.

Ground water hydrology, as treated in this chapter, includes: a generalized description of the ground water basin; a brief account of recharge and extraction conditions; and a detailed analysis of piezometric levels, fluctuations and trends pertinent to sea-water intrusion.

Hydrologic Environment

The hydrologic environment of the Coastal Plain of Orange County is a complex, interrelated system of: (1) artificial and natural recharge, (2) ground water extraction and natural discharge, (3) hydraulic continuity and discontinuity of aquifers and aquicludes, and (4) vertical deep percolation and restrictions to deep percolation. Of the several parameters that have affected the decline or rise of water levels, and therefore the intrusion of sea water, artificial recharge and ground water extraction have been the most significant.

A detailed evaluation of basin-wide hydrology is beyond the scope of this report. However, a brief analysis is made to show that the hydrology of the Bolsa-Sunset area is influenced by the hydrology of the entire Coastal Plain of Orange County, and vice versa. The study area comprises less than 7 percent of the 330-square-mile Coastal Plain. However, it controls 6.8 miles, or about 55 percent, of the 12-mile Orange County coastline that is susceptible to sea-water intrusion. Figure 5 depicts the location of the Bolsa-Sunset area with respect to the Coastal Plain.

The large synclinal ground water basin which underlies the Coastal Plain of Orange County is composed of a pressure and nonpressure area, as shown on Figure 5. The nonpressure, or forebay, area is located in the northeastern portion of the basin and supplies the recharge, both artificial and natural, to the aquifer systems. The southwestern area of the basin consists of a pressure area where ground water is confined in a series of multiple aquifers.

Ground water flow in the Coastal Plain is from the forebay to the pressure area, with subsurface discharge to the Pacific Ocean during periods when piezometric levels are above sea level. Subsurface outflow occurs primarily at the Santa Ana and Alamitos Gaps in Recent aquifers not affected by faulting. Some discharge takes place across the Newport-Inglewood fault in the Bolsa and Upper Pleistocene aquifers. Under artesian conditions, discharge and evapotranspiration of ground water occur at peat springs located within the alluvial gaps or at excavations on Huntington Beach Mesa.

When piezometric levels of discharging coastal aquifers are lowered below the critical head necessary to repel salt-water encroachment or below the head of semiperched water, the flow of ground water is reversed. Landward and downward hydraulic gradients cause these aquifers to be recharged by sea-water intrusion and locally by downward percolation of semiperched water. Whether discharge or recharge occurs is dependent upon the elevation of the piezometric surface, which in turn is determined by the cumulative balance between recharge, both natural and artificial, and extraction within the entire basin.

Recharge

The primary area of artificial recharge for the Coastal Plain is the Orange County Water District spreading grounds (Santa Ana riverbed and Crill Pit). They are located in the Coastal Plain forebay area, as shown on Figure 5. Historically, only runoff from the Santa Ana River watershed was spread to replenish the ground water basin. However, in 1949, because of falling water levels, imported Colorado River water was used to supplement available runoff. At first, small quantities were spread, but in 1956-57, 102,426 acre-feet of Colorado River water were artificially supplied to the underground reservoir. In 1961-62, a maximum recharge of 220,192 acre-feet was reached. This compares with an artificial recharge of approximately 20,000 acre-feet of runoff water in the same year. No waters, imported or runoff, are spread in the Bolsa-Sunset area.

Recharge in the form of deep percolation from precipitation and applied irrigation water also occurs in the forebay area. These waters, after percolating to the water table, commingle with the artificially recharged waters and are available for extraction or passage into the pressure area.

Because the Bolsa-Sunset area is entirely within the pressure area, no significant amount of precipitation or applied water can deep-percolate due to the shallow confining silt and clay beds. Exceptions to this occur on the Huntington Beach and Bolsa Chica Mesas, at Landing Hill, and locally in Bolsa and

Sunset Gaps, where the confining beds are lacking. However, the quantities of deep percolation in these areas are small when compared with the recharge in the forebay area.

Extractions

The Orange County Water District, whose boundaries closely approximate those of the Coastal Plain, reported a maximum extraction of 226,024 acre-feet of ground water in 1960-61. This amount, incidentally, was nearly 1 percent of the total ground water production in the United States for that year. Since that time, the extractions from the area have been declining because of direct delivery of Colorado River water to the consumer. In 1964-65, extractions within the District's boundaries had decreased to 179,376 acre-feet.

Extractions in the Bolsa-Sunset area account for less than 5 percent of the total extractions in the Coastal Plain. In 1960-61, wells in the Bolsa-Sunset area extracted about 9,400 acre-feet. In 1964-65, extractions in the area had declined to about 7,300 acre-feet.

Fluctuations of the Piezometric Surface

With the population explosion in Orange County and the extended series of drought years following World War II, there was increased ground water use until 1960-61 and a decrease in stored ground water. Extractions throughout the Coastal Plain caused the piezometric surface along the coastline and in the Bolsa-Sunset area to decline. Landward hydraulic gradients were developed and sea-water intrusion occurred where geologic conditions were conducive to flow.

The piezometric surfaces of all fresh water aquifers within the study area are similar with respect to seasonal and long-term trends but vary in elevation. Head differentials among the Bolsa, Alpha, Beta, Lambda and Meadowlark aquifers are slight due to their geologic interconnection. Heads in the Main aquifer and the Lower Zone differ from those of the upper aquifers from which they are geologically separated. Due to these relative head conditions and the fragmentary construction data for water wells with long-term water level measurements, aquifers in the study area were grouped, for study purposes, into upper (Bolsa, Alpha, Beta, Lambda, and Meadowlark) and lower (Main and Lower Zone) aquifer systems.

Long-term well hydrographs for the upper and lower aquifers are shown on Plate 7. (Starting at the upper left-hand corner, the hydrographs are listed in order of location, proceeding southeast and inland across the study area.) Beginning in 1936, piezometric levels in both groups of aquifers recovered from a previous decline and were seasonally or entirely above sea level during a period of surplus water years lasting through 1944-45. This condition existed throughout the study area, with artesian flow occurring in low-lying areas.

Decreased natural recharge and increased pumpage caused piezometric levels to decline after 1944-45. Hydrographs for upper-aquifer wells 5S/11W-16D2, -18J3, -21A1, -27H4, -34A1, and 5S/12W-12P1 show an average maximum lowering of the piezometric surface to 30 feet below sea level in 1957 and 1959. Hydrographs for lower-aquifer wells 5S/11W-21F1, -28K1, -29C1, and 5S/12W-12C1 show a comparative piezometric decline to an average of 50 feet below sea level. The rise of piezometric levels in 1952 and 1958 was caused by increased natural recharge from above-normal precipitation and reduced pumpage during the rainy season.

Lowering of the piezometric surface created a landward hydraulic differential across the Newport-Inglewood fault, causing sea-water intrusion across more permeable portions of that structural barrier, primarily in upper Pleistocene aquifers. Among these aquifers, the maximum landward head differential probably reached 30 feet during September 1957. Average conditions for 1957 are shown by Figure 6. Although heads seaward of the fault were not measured in 1957, data for other years indicate that the coastal ground waters are essentially stable and unaffected by inland hydrologic conditions. Thus, seaward heads in 1957 were probably at or near sea level. Inland of the fault, the piezometric surface sloped gently seaward, reaching its lowest level at pumping wells near the fault plane. Data for 1945 and 1966 show a similar but steeper slope of the inland piezometric surface, higher inland heads and a seaward hydraulic differential across the fault plane.

Because of advancing sea-water intrusion in Santa Ana Gap and the intrusion threat along the rest of the coastline, the Orange County Water District began an artificial recharge program in 1949 to combat declining water levels. In 1956-57, the amounts of recharged and delivered Colorado River water were increased sufficiently to balance the draft on the ground water basin. This stopped the decline of piezometric levels in the study area. Increased recharge and direct delivery of Colorado River water after 1959 exceeded extraction from the basin, causing a recovery of piezometric levels. A partial reduction in pumping, due to changing water uses (agriculture to urban), was a contributing factor. The rates of recovery of piezometric levels in the upper and lower aquifer systems are shown by the hydrographs on Plate 7. Wells perforated in the upper aquifers (5S/11W-16D2, -20C3, -20C5, and -27H4) show a recovery of about 5 feet per year in piezometric levels. Lower-aquifer wells (5S/11W-28A1 and -29C1) show a rise of

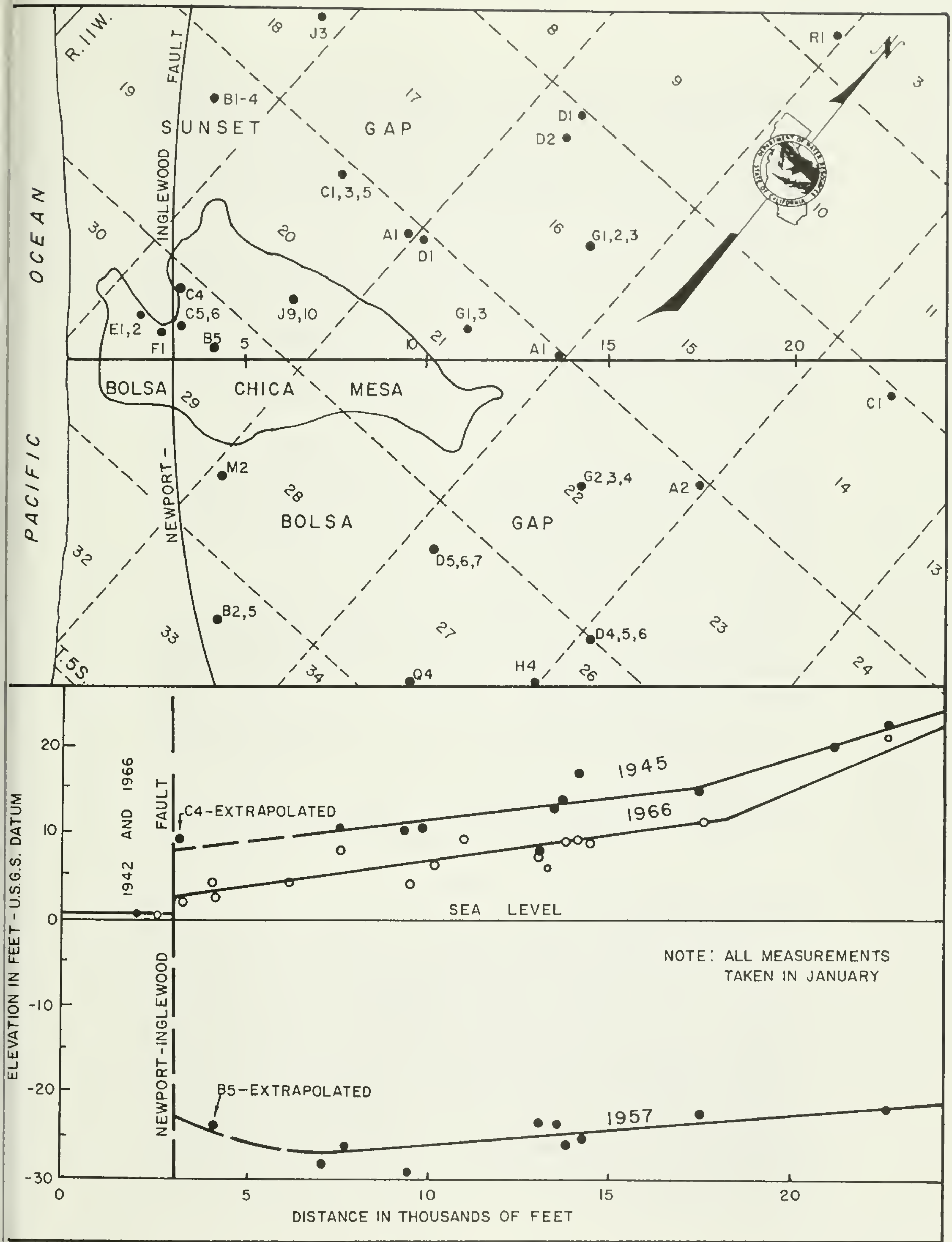


Figure 6 - SEAWARD PIEZOMETRIC GRADIENT OF UPPER AQUIFERS

about 10 feet per year in piezometric levels. By late 1964, the piezometric surfaces of both aquifer systems of the area had reached sea level (except at local pumping depressions) and were about 5 feet above sea level as of January 1966. This recovery of freshwater heads caused a flushing of degraded waters, as will be explained in Chapters IV and V, but also caused seasonal artesian flow of springs and wells in low lying areas.

Seasonal fluctuations (rise and fall) of the piezometric surface within the study area may be as much as 20 to 30 feet. This fluctuation is governed by all recharge-extractions conditions but is related in large part to the needs of the irrigator, who is the prime user of water in the surrounding area. His needs depend upon the amount of precipitation during the year and the water requirements of various crops.

The hydrographs on Plate 7 show that piezometric levels usually decline from late January through early March during the rainy season. This drop is due to early irrigation for such items as strawberries and other truck crops. During a wet year, early irrigation is not carried on. After the early irrigation period, piezometric levels rise and by middle or late April reach their highest annual level.

Irrigation pumps are again turned on during the dry summer months of May, June, July, and August and by September the lowest piezometric level of the year is reached. During October through December, piezometric levels exhibit a sharp rise as irrigation pumping is reduced. These seasonal piezometric fluctuations occur not only at the pumping wells, but are distributed outward for many miles, due to the aquifer pressure system.

The fluctuations in specific aquifers and areas and their relationship to sea-water intrusion will not be discussed.

Upper Aquifers

The upper aquifers consist of the Alpha, Beta, Lambda, and Meadowlark aquifers, which underlie the entire study area, except locally in Bolsa Gap, and the Bolsa aquifer, which occurs only in Bolsa Gap. The semiperched zones which occur throughout most of the study area are not part of the upper aquifer system but will be included here for discussion purposes. The hydrographs on Plate 8 show the piezometric level relationships between these various aquifers. (Starting at the upper left-hand corner, the hydrographs are arranged in order of location, progressing southeast across the study area.)

Sunset Gap. The hydrographs for piezometers at sites BSO-8 and BSO-9 (Plate 8) show representative fluctuations for the Anaheim Bay portion of Sunset Gap. Piezometric levels for the Meadowlark aquifer at both sites show the same fluctuation as the Beta and Alpha aquifers, but almost consistently the Meadowlark has a 1- to 2-foot higher head. The levels in the Beta, with a few exceptions, are higher than those in the Alpha. Thus, any vertical movement of water within the upper aquifer system at Sunset Gap during 1963-65 was upward. In general, this flow component was from fresh to salty ground waters.

Whether an upward flow component existed during 1949-62, as sea-water intrusion was advancing, is uncertain. At Alamitos Gap, a downward flow component existed in 1959-60 (Los Angeles County Flood Control District, 1961).

Electric logs for the BS exploration holes (1961), however, show abrupt changes in ground water salinity across silt and clay beds less than 10 feet thick. From these records, it is apparent that head differentials were insufficient to cause vertical intrusion from an overlying aquifer to an underlying aquifer.

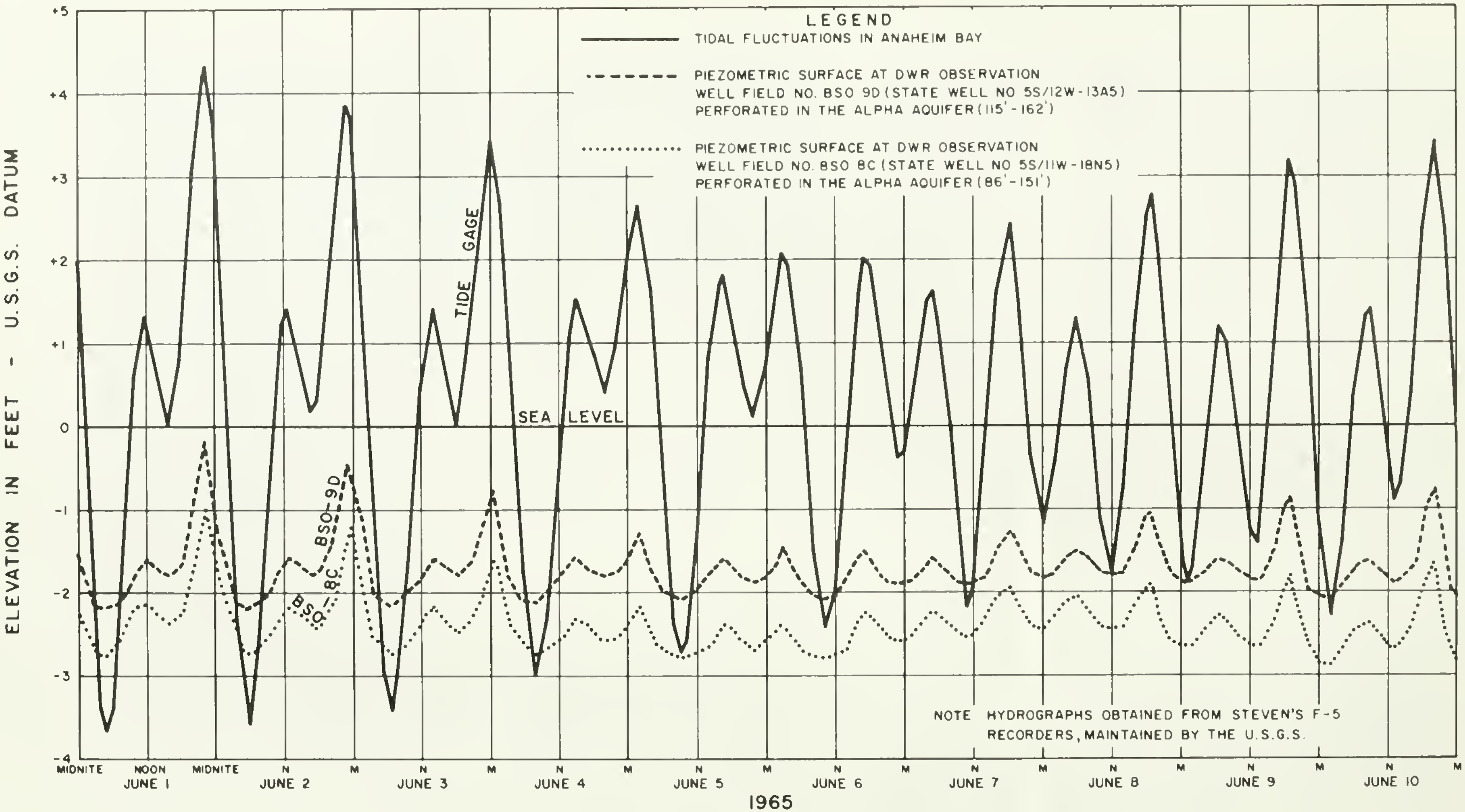
The seasonal and long-term piezometric fluctuations measured at sites BSO-8 and BSO-9 show the influences of basin pumping and recharge. No pumping from these aquifers occurs at the Naval Weapons Station, the nearest draft being from domestic wells 8,000 feet away. Therefore, these fluctuations indicate good confinement of the aquifers and wide transmission of pressure changes.

Figure 7 shows a 1- to 2-foot piezometric fluctuation in the Alpha aquifer, which correlates with daily tide levels. The aquifer fluctuations are caused by the vertical loading of the incoming and outgoing tides in Sunset Bay.

The hydrographs for BSO-8A and BSO-9B indicate that the semiperched zones in this area are not in free hydraulic continuity with the underlying aquifers. The zones are in hydraulic continuity with tidal water. They also appear to be influenced by hydraulic pressure exerted upward from underlying aquifers or laterally from the inland basin.

Huntington Harbour, located mostly in Sunset Gap, is covered with an extensive network of piezometers (BSO-5, -6, and -7, and HH-1, -2, -3, -4, and -5), for which hydrographs are shown on Plate 8.

The hydrographs for BSO-6D and -7F, and HH-1D, -2C, -3C, -4C, -4D, and -5D, all perforated in the semiperched zone, indicate no free hydraulic continuity between that zone and underlying



TIDAL AND AQUIFER FLUCTUATIONS IN THE ANAHEIM BAY PORTION OF THE BOLSA - SUNSET AREA

Figure 7 - TIDAL EFFECTS UPON THE ALPHA AQUIFER

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

aquifers. Water level fluctuations in the semiperched zone show little or no response to seasonal or long-term fluctuations within the upper aquifer system. Rather, they are apparently caused by one or a combination of the following conditions:

1. Vertical hydraulic continuity with sea water from the sloughs and canals traversing the Harbour.

2. Horizontal hydraulic continuity with the ocean.

3. Hydraulic loading caused by tidal fluctuations.

Evidence in support of items 1 and 3 above can be found in hydrographs for BSO-6D, HH-2C, and HH-3C. These three piezometers are located near canals that were drained for construction and then flooded on August 13, 1964, and again on May 28, 1965. The water surface in the piezometers rose sharply in both instances, indicating pressure loading from the increased weight of water or rapid vertical percolation or both.

The only piezometer constructed in the semiperched zone with fluctuations resembling those of the underlying pressure aquifers was HH-5C. Geologic Section E-E', Plate 3B, shows that this piezometer, perforated from 32 feet to 38 feet, is located in the aquiclude. The water in the piezometer is coming from clayey gravel deposits in the clay, and the rise and fall of the water surface is due to the pressure effect of the underlying aquifer.

Data for all piezometers perforated in the Alpha, Beta-Lambda, and Meadowlark aquifers at Huntington Harbour show seasonal and long-term fluctuations of confined ground waters. The piezometric surface in the Meadowlark aquifer, as in the Anaheim Bay area, has a higher head than that in the Beta aquifer. The Beta has a higher piezometric head than that in the Alpha aquifer. Piezometers perforated at different intervals in the Alpha aquifer show lower piezometric levels in the bottom of the aquifer, where these waters are highly intruded, and thus denser.

The Alpha aquifer hydrographs for BSO-5A and HH-5A and -5B, located within 600 feet of each other but on opposites sides of the Newport-Inglewood fault, show the barrier effects of that structure. Geologic section F-F', Plate 3B, indicates only partial displacement of the aquifer between these two sites. Thus the fault plane is the principal barrier feature.

The piezometric fluctuations at BSO-5A (seaward) are relatively flat but suggest a slight seasonal oscillation. Water quality data show a 1963-64 decrease in chlorides at BSO-5A of 1,180 ppm. These conditions indicate some outflow from the inland basin. At HH-5A and -5B, the piezometric fluctuations are indicative of a pressure aquifer in hydraulic continuity with the inland basin. Piezometric levels between the sites BSO-5 and HH-5 differ by as much as 8 feet, due to the barrier effects of the Newport-Inglewood fault. However, chloride ion concentrations, due to intrusion at site HH-5, are 16,700 ppm. From a hydrologic standpoint, it appears that the Newport-Inglewood fault causes a major hydraulic discontinuity but does not prevent ground water flow (either intrusion of sea water or outflow of fresh water).

Bolsa Gap. BSO-1 and -2 are the only sites in Bolsa Gap at which piezometers are installed in the upper aquifers. Because these sites are landward of the Newport-Inglewood fault, no analysis of the fault as an effective barrier to ground water flow could be made as was done for sites HH-5 and BSO-5.

BSO-1, however, is located within the fault zone, as shown on geologic section G-G', Plate 3B. Hydrographs on Plate 8 show a damping of piezometric levels, particularly in the Meadowlark aquifer between BSO-1D and BSO-3B. The fluctuations at BSO-1D are about one-third as great as those at BSO-3B. Similar damping of levels is evident in the Bolsa aquifer between wells BSO-1A and BSO-2. This contradicts a statement made by Poland and Piper (1956) that in the 80-foot gravel (Bolsa aquifer) there was no structural barrier to the movement of water. This conclusion was not based upon hydrologic evidence, but was inferred from analogy in geologic features among several coastal gaps. Based upon these piezometric fluctuations, there is some hydraulic evidence that the fault zone is at least a partial barrier to ground water flow in the Bolsa aquifer. Further, the piezometric fluctuations at BSO-1 and BSO-2 do not suggest direct hydraulic continuity of these aquifers with the ocean. This is strengthened by geologic and water quality data presented in Chapters II and IV.

Piezometric levels in the semiperched zone at BSO-1B and -1C indicate some continuity with the underlying confined ground waters, probably from inland discontinuities in the upper aquiclude, but no apparent continuity with the ocean. The lack of free hydraulic continuity with tidal or coastal saline semiperched water is evident from its low salinity (less than 3,500 ppm chloride).

Lower Aquifers

The lower aquifers consist of the Main and Lower Zone aquifers. Known ground water producing wells in the Lower Zone are limited to two, of which well 5S/11W-28K1 is perforated in both the Main and the Lower Zone. Its hydrograph is shown on Plate 7. No water level data are available for well 5S/11W-34F3, which extracts water exclusively from the Lower Zone. None of the DWR piezometers were perforated in the Lower Zone aquifer. However, it is probable that the Lower Zone's piezometric surface behaves in a pattern similar to that of the Main. Therefore, any further discussion about the Main can be construed to apply also to the Lower Zone aquifer.

The piezometers perforated in the Main aquifer, for which hydrographs are shown on Plate 8, are BSO-4, -5B, -7E, and -9F. BSO-7E and -9F are located landward of the fault zone, while BSO-4 and -5B are seaward of the Newport-Inglewood fault. Because the Main aquifer underlies the entire study area and the long-time piezometric fluctuations in the lower aquifers are similar throughout the area, a separate discussion of Sunset Gap and Bolsa Gap will not be given.

Hydrographs for BSO-7E and -9F are similar to the lower aquifer hydrographs of extraction wells on Plate 7, showing both seasonal pressure changes and the recent rise of levels to above sea level. The high degree of confinement and lateral continuity of the aquifer is indicated by the transmission of these changes 7,000 feet from the nearest pumping wells.

Seasonal peaks and troughs in the piezometric surface of the Main aquifer do not occur at the same time as in the upper aquifers. Generally, they lag by one or two months, the peaks extending into June and the troughs extending into October. The Main aquifer is the chief source of ground water supply within the Bolsa-Sunset area. This heavier draft on the Main aquifer for municipal uses could be the cause for the irregularities in seasonal fluctuations between it and the upper aquifers. Another reason may be a time lag in the pressure wave affecting Main aquifer piezometric levels. However, no definite conclusions can be drawn because of the limited number of weekly measured piezometers perforated in the Main.

Whatever the reasons for the difference in piezometric fluctuations between the upper and lower aquifers, the aquiclude separating them is obviously an effective one. The effective permeability of the aquiclude would have to be very low to withstand the great pressures applied to it by the differences in piezometric heads.

Piezometric conditions in the Main aquifer seaward of the Newport-Inglewood fault are shown on Plate 8 by hydrographs for piezometers BSO-4 and BSO-5B. The piezometric levels do not fluctuate with inland seasonal or long-term trends, due to the barrier action of the Newport-Inglewood fault. Rather, the hydraulic head is relatively stable at 13 to 15 feet below sea level. The slight cyclic variation in elevation is attributed to tidal pressure loading. A continuous recorder on BSO-4 showed a half-foot daily fluctuation with the tide. Since the piezometric surface is below sea level and the ground water ranges from fresh to brackish (chlorides less than 1,000 ppm), it is evident that the aquifer is not in free hydraulic continuity with the ocean or overlying saline ground water (both having heads at sea level).

Why the coastal piezometric level of the Main aquifer is below sea level is uncertain. There is no pumping seaward of the fault within Orange County or the southeast portion of Los Angeles County. Burnham (Los Angeles County Flood Control District, 1961) suggested that this subnormal head, also existing at Alamitos Gap in 1959-60, was caused either by drainage northwest to the heavily pumped Silverado aquifer in the West Coast Basin or by leakage across the Newport-Inglewood fault. Available data are insufficient to determine which of these is the major factor. As no structural barrier is known to interrupt flow between the seaward portion of Alamitos Gap and West Coast Basin, head release to the northwest would appear to be the most logical possibility.

The effective barrier action of the Newport-Inglewood fault is evident from the contrast of hydrographs for well 5S/11W-29C1 (Plate 7) and piezometer BSO-5B (Plate 8), located 900 feet apart. Geologic Section F-F' (Plate 3B) shows that the Main aquifer is only partially offset between these wells. Assuming that seaward heads were 15 feet below sea level in 1957 and 1959, the fault zone between these well sites appears impermeable to flow under head differentials of up to 50 feet. Chlorides in the Main aquifer at wells -29C1 and -29C2 have not exceeded 20 ppm.

The data for AE-13 (5S/12W-13J2), however, suggest some hydraulic continuity across the fault zone at Alamitos Gap. During 1962-64, the piezometric surface at AE-13 rose 2 feet as heads inland of the fault rose an average of 20 feet. In comparison, piezometric levels of the Silverado aquifer in West Coast Basin remained essentially stable at minus 90 feet during the same time. Seasonal 1-foot fluctuation of the piezometric surface at AE-13 is evident from monthly measurements during 1962-64. The highest levels occurred in April and the lowest levels occurred in September. Spot measurements at AE-13 since June 1964 indicate that the piezometric rise has stabilized, with heads averaging approximately minus 13 feet. This compares favorably with the stabilization of inland heads since 1965.

At Bolsa Gap (BSO-4), the 1961-65 rise in the piezometric surface of 1 foot may reflect outflow across the fault. However, this piezometer discharges considerable gas and slow, natural development of the gravel pack and the formation near the piezometer by gas discharge could account for this slight rise.

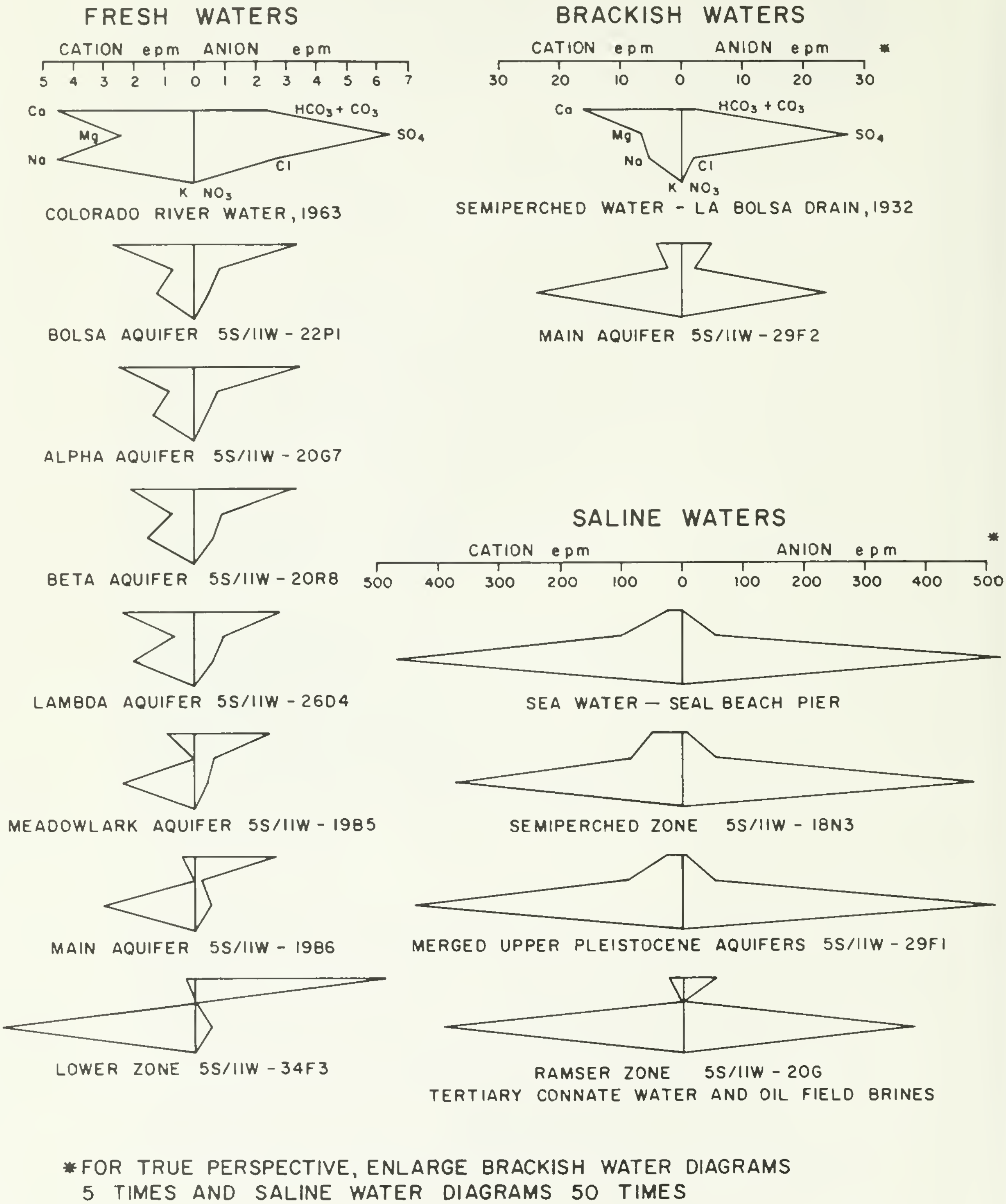


Figure 8 - STIFF DIAGRAMS OF NATIVE AND IMPORTED WATERS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

CHAPTER IV. GROUND WATER QUALITY

Ground waters within the Bolsa-Sunset area are characterized by a wide areal and vertical range in chemical character and in total dissolved solids. The four native ground water bodies are:

1. Shallow brackish to saline semiperched water contained in upper Recent and upper Pleistocene deposits.

2. Fresh water contained in lower Recent, Pleistocene, and upper Pliocene aquifers landward of the Newport-Inglewood fault.

3. Predominantly brackish to saline water contained in lower Recent, Pleistocene, and upper Pliocene aquifers seaward of the Newport-Inglewood fault.

4. Underlying saline connate water contained in basal upper Pliocene and older deposits.

Use of fresh ground waters within the area began in the late 1800's and was subsequently increased, primarily for agricultural purposes. Since 1960, agricultural lands have been rapidly developing to urban tracts and the major water use has changed accordingly. Numerous wells tapping the Bolsa aquifer and upper Pleistocene aquifers have been abandoned (Plate 1) and the principal draft has shifted to municipal wells drawing primarily from the Main aquifer. Abandonment of wells has also resulted from the degradation of the quality of fresh ground waters due to the influx of sea water (saline ground water), oil field brines, oil refinery wastes, and brackish semiperched water.

This chapter describes the native chemical character of ground waters and the chemical alteration of the fresh ground waters due to degradation from factors other than sea-water intrusion. These conditions are substantiated by a large file of ground and surface water analyses compiled by the Department. Representative analyses and water quality criteria are given in Appendix D. Investigation of water quality conditions within the area was greatly assisted by the previous work of Piper and Garrett (1953).

Native Quality of Waters

The chemical character and the relative concentration of dissolved solids in waters native or imported to the study area are most easily compared by visual means, such as the Stiff Diagrams shown on Figure 8. These diagrams show the equivalent parts per million (epm) concentration of the principal ions plotted from a zero reference line, with these plot points connected by lines to form a closed pattern.

The large range in chemical character and total dissolved solids among the waters on Figure 8 is evident from the relative sizes and shapes of the Stiff Diagrams. Note that the epm scale differs among the fresh, brackish, and saline waters. For true perspective, the diagrams of brackish water should be enlarged five times and the diagrams of saline water should be enlarged 50 times.

Native fresh ground waters of the area are all bicarbonate in anion character and are characteristically low in chloride and sulfate (less than 50 ppm each), the other two major anions. This compares with the dominant chloride character of brackish water in the Main aquifer and saline waters, and the dominant sulfate character of Colorado River water and inland semiperched water. These differences in anion character provide the most ready means for determining the causes of fresh ground water impairment. However, this procedure is generally insufficient to distinguish a degradent among the saline waters. The low sulfate content of oil field brines (Tertiary connate water) provides some means for differentiating between this degradent and sea water or saline ground water, but sulfate is subject to reduction, and conclusions based on this indicator are subject to error.

The vertical change in chemical character among the native ground waters is also clearly indicated by Figure 8. Progressing downward, the dominant cation character of inland waters changes from calcium (semiperched, Bolsa, and Alpha) to calcium-sodium (Beta and Lambda) to sodium (Meadowlark, Main, and Lower Zone). Accompanying this progression is a decrease in magnesium and, within lower Pleistocene and older deposits, a decrease in sulfate and an increase in bicarbonate. The downward change in cation character is a natural softening resulting from base exchange. The depletion of sulfate, increase of bicarbonate, and hydrogen sulfide (H_2S) odor of the deeper waters are attributable to the oxidation of organic matter within the aquifer, and the reduction of sulfate ions by anaerobic bacteria. Accordingly, among the fresh ground waters, hardness decreases and percent sodium and H_2S odor increase with depth. Thus, the shallow waters, low in percent sodium, are better suited for agriculture and the deeper, softer waters are better for domestic purposes.

Description of the chemical character of the native ground waters by aquifer or formation is given next in chronological order, progressing from the semiperched water body downward through the fresh water body to the underlying connate water body.

Semiperched Zone

Semiperched ground water occurs at shallow depths, generally above 50 feet, in permeable deposits of upper Recent and upper Pleistocene age. Its wide range in concentration of dissolved solids and in chemical character is attributed to several factors, which include: (1) restricted mobility within lenticular deposits of relatively low permeability, (2) the influence of the tidal prism, (3) the solution of evaporite deposits, and (4) the influx of return irrigation water, oil field brines, and other wastes. Because of these factors and because recharge from the forebay is limited, semiperched water is characteristically saline or brackish and is inferior for domestic and municipal use and is Class 3, injurious to unsatisfactory, for agricultural use. Locally, however, the water is freshened by artesian ground water around springs and at contacts between the semiperched zone and underlying aquifers.

Beneath the tidal sloughs and Huntington Harbour, semiperched water is sodium chloride in chemical character within Recent deposits and sodium to calcium chloride in chemical character within upper Pleistocene deposits. Salinity commonly decreases markedly with depth and varies erratically with area. Within Recent deposits, semiperched water generally contains from 2,200 to 78,000 ppm total dissolved solids and 900 to 42,000 ppm chloride. Total hardness ranges from 650 to 15,000 ppm. Within underlying upper Pleistocene beds, semiperched water contains from 1,300 to 36,500 ppm total dissolved solids, 440 to 21,400 ppm chloride and ranges in total hardness from 380 to 18,770 ppm.

Landward from the tidal sloughs, the salinity and chemical character of semiperched water usually change abruptly within several hundred feet. Based upon analyses of a few wells, ponded water, seeps, springs, and discharge from tile drains, the semiperched water ranges from fresh to brackish. The brackish water is calcium sulfate in chemical character. Total dissolved solids range from 300 to 5,400 ppm, sulfate (when reported) from 160 to 1,850 ppm, and chloride from 20 to 450 ppm. Among these waters, total hardness ranges from 180 to more than 2,000 ppm. In the vicinity of the Peat Springs and Huntington Lake (Plate 1), semiperched water has been degraded by oil field brines and chlorides are increased to as much as 1,700 ppm. Nitrate, presumably originating from agricultural fertilizers, or the decay of organic matter, is commonly more than 10 ppm, the maximum recorded concentration being 85 ppm. All underlying native ground waters within the area contain less than 5 ppm nitrate.

Bolsa Aquifer

Native fresh water of the Bolsa aquifer is predominantly calcium bicarbonate in chemical character, but ranges from calcium-sodium to sodium bicarbonate within 5,000 feet of the Newport-Inglewood fault. This change is caused by the influx of ground water from the Meadowlark aquifer where the two zones are in hydraulic continuity. The calcium bicarbonate water ranges from 250 ppm to 330 ppm in total dissolved solids and from 15 ppm to 30 ppm chloride. The water is moderately hard to hard, ranging from 175 ppm to 230 ppm in total hardness. The modified water is equivalent in concentration of total dissolved solids and chlorides but ranks lower in total hardness, between 110 ppm and 150 ppm. Except for hardness, fresh water of Bolsa aquifer is suitable for domestic and municipal purposes and is Class 1, good to excellent, for irrigation purposes.

The native quality of Bolsa water seaward of the Newport-Inglewood fault is conjectural, for no wells were constructed in that area until 1966. The only analytical data available for the study period are for water samples extracted from bucket auger cuttings taken during the drilling of four exploration holes in April 1960. Sodium chloride ion concentrations of these samples, as determined by the Signal Oil and Gas Laboratory, are listed in Table 3.

TABLE 3

WATER QUALITY DATA FOR THE BOLSA AQUIFER
SEAWARD OF THE NEWPORT-INGLEWOOD FAULT

Test hole	Depth of sample in feet	Stated NaCl in grains per gallon	Computed NaCl in ppm	Computed chloride ion in ppm
NB1	59	285	4,874	2,958
	61	375	6,413	3,892
	67	850	14,535	8,823
	72	320	5,472	3,321
SB1	59	140	2,394	1,453
	63	340	5,814	3,529
SB2	49	250	4,275	2,595
	51	800	13,680	8,304
	61	205	3,506	2,127
	63	340	5,814	3,529

TABLE 3

WATER QUALITY DATA FOR THE BOLSA AQUIFER
SEAWARD OF THE NEWPORT-INGLEWOOD FAULT
(Continued)

Test hole	Depth of sample in feet	Stated NaCl in grains per gallon	Computed NaCl in ppm	Computed chloride ion in ppm
SB3	61	670	11,457	6,955
	76	750	12,825	7,785
	99	165	2,822	1,713

These data show a range in chloride ion concentration of 1,450 ppm to 8,820 ppm and a general increase in chloride ion concentration with depth. This pattern typifies a salt-water intrusion wedge. The lowermost data for NB1, SB2, and SB3 show a decrease in chloride ion concentration among sediments of lower permeability. This indicates that fresher water occupied the aquifer in the past and has been replaced to a lesser degree in finer-grained beds. It is concluded that the aquifer has been partially reoccupied by sea water and that chloride ion concentrations of Bolsa water seaward of the fault zone were formerly less than 1,450 ppm. When this partial reoccupation took place is indeterminable.

Upper Pleistocene Aquifers

Native fresh waters of the Alpha, Beta, and Lambda aquifers are typically calcium bicarbonate to calcium-sodium bicarbonate in chemical character but range to sodium bicarbonate within the Lambda aquifer. A general increase in calcium occurs areally toward mergence of these Pleistocene aquifers with the Bolsa aquifer, due to the influx of ground water from that aquifer. The ranges in concentration of chloride, total dissolved solids, and total hardness for each aquifer water are listed below:

	Cl in ppm	TDS in ppm	Hardness in ppm
Alpha Aquifer	15-30	230-310	135-180
Beta Aquifer	15-30	230-290	100-175
Lambda Aquifer	15-30	220-275	75-180

Seaward of the Newport-Inglewood fault, ground waters native to the upper Pleistocene aquifers are predominantly saline, are inferior for domestic and municipal use, and are Class 3, injurious to unsatisfactory, for agricultural use. However, they are tapped as a salt water supply for injection into the oil-bearing strata of the Huntington Beach field. The water is sodium chloride in chemical character and contains from 17,900 ppm to 34,440 ppm total dissolved solids and 9,750 ppm to 18,940 ppm chloride. The origin of these saline ground waters is attributed to the partial or nearly complete reentrance of sea water into the aquifers after the barrier effects of the Newport-Inglewood fault zone had been created (Piper and Garrett, 1953).

The past occurrence of native fresh water in upper Pleistocene aquifers, seaward of the Newport-Inglewood fault, is known at two areas along the coast of Orange County. One of these areas is located within the study area. In July 1941, a lense of fresh water was discovered at USGS exploration well 5S/11W-18N1, located about 200 feet seaward of the fault at Hog Island. Ground water produced from the Alpha aquifer, from 109 feet to 124 feet below ground surface, contained only 35 ppm chloride after the well had been developed for 82 minutes. The origin of this fresh water body within the area of native salt water was attributed by Piper and Garrett (1953), to seaward flow of fresh water through the fault plane.

Lower Pleistocene Aquifers

With slight exception, native fresh waters of the Meadowlark aquifer, the Main aquifer, and the Lower Zone are sodium bicarbonate in chemical character and are soft to very soft. In and near areas of hydraulic continuity with overlying aquifers, water of the Meadowlark aquifer is altered to sodium-calcium or calcium-sodium bicarbonate in chemical character and is moderately hard.

Due to sulfate reduction within the aquifer, suspended organic matter in colloidal suspension, and the oxidation-precipitation of iron, waters of the Main aquifer and the Lower Zone are characterized by a hydrogen sulfide odor and an amber color. Except for these objectionable features, which can be removed by treatment, the waters are excellent for domestic and municipal use. They are Class 3, injurious to unsatisfactory, for irrigation because of high (70 to 90) percent sodium. Water of the Meadowlark aquifer is generally colorless, has little or no hydrogen sulfide odor, and is excellent for domestic and municipal purposes. Depending upon the percent sodium (25 to 80) the water is Class 1, good to excellent, to Class 3, injurious to unsatisfactory, for irrigation.

The range in concentrations of chloride, total dissolved solids, hardness, and percent sodium of the three aquifer waters is listed below:

	Cl in ppm	TDS in ppm	Hardness in ppm	Percent Sodium
Meadowlark Aquifer	15-20	200-300	45-180	25-80
Main Aquifer	5-25	160-300	10- 60	70-90
Lower Zone	15-30	315-515	15- 45	85-95

Seaward of the Newport-Inglewood fault, ground waters native to the lower Pleistocene aquifers are predominantly brackish to saline, are sodium chloride in chemical character, and are unsuitable for domestic, municipal, and irrigation uses. They are a blend of native fresh water and sea water which entered the aquifers after the barrier effects of the fault zone were created.

Among the three lower Pleistocene aquifers, the most saline water occurs within the Meadowlark aquifer. Electric logs show no change in apparent resistivity between the overlying upper Pleistocene aquifers and the Meadowlark aquifer. From this, it is concluded that water of the Meadowlark aquifer is saline, with chloride ion concentrations in excess of 10,000 ppm.

Analytical data for the Main aquifer are available for piezometers BSO-4 and BSO-5A (1961-65) and well 5S/11W-29P1 (1925 and 1941). Water from the two piezometers contains 1,490 to 1,670 ppm total dissolved solids and 740 to 840 ppm chloride. The water is very hard, ranging from 260 to 325 ppm. Water from well -29P1, located seaward of the South Branch fault, was higher in the constituents when sampled in 1929 and 1941. Total dissolved solids were 3,610 ppm, chlorides 1,820 to 2,050 ppm, and total hardness 550 ppm. A considerable discharge of gas is associated with piezometer BSO-4 and formerly with well -29P1. In fact, well -29P1, which proved unsuitable as a water well, was developed as a gas well for the Bolsa Chica Gun Club.

Based on electric logs (BSO-4 and BSO-5, Appendix C), limited amounts of fresh water occur scattered within the Meadowlark aquifer, within thin permeable beds overlying the Main aquifer, and within the top of the Main aquifer where it "floats" upon underlying brackish water. At the north edge of Landing Hill and at Alamitos Gap, fresh water occurs throughout the Main aquifer. Water yielded by piezometer AE-13 (Plate 1), constructed in the lower portion of the aquifer, is sodium bicarbonate in chemical character, and contains 100 ppm chloride and 560 ppm total dissolved solids. Electric logs also show fresh water within the lower portion of the Main aquifer between the North Branch and South Branch faults of the Newport-Inglewood zone in Bolsa Gap.

Upper Pliocene Aquifers

Native fresh water occurs in the upper division of the Pico Formation both landward and seaward of the Newport-Inglewood fault, but on the coastal side is present in limited amounts. This deep fresh water body lies below the present range of coastal wells but is evident on oil well electric logs. Within the study area, it has been tapped by only one well, 5S/11W-23P, which is now abandoned.

In 1925, water yielded by well -23P was sodium bicarbonate in chemical character, and contained 316 ppm total dissolved solids and 14 ppm chloride. The water was very soft, only 13 ppm in total hardness. From this one analysis and the analyses of water from wells 5S/11W-28K1 and -34F3, which tap the Lower Zone immediately above the Pico Formation, it can reasonably be concluded that fresh ground water of the upper Pico Formation is exclusively sodium bicarbonate in chemical character, contains from 300 to 500 ppm total solids, is very soft and has an amber color and a hydrogen sulfide odor.

Connate Water-Bearing Zones

Ground waters contained in the lower division of the Pico Formation and in older sedimentary formations of Tertiary age are saline and unsuitable for beneficial use. These waters are extracted locally by several hundred oil wells and, after being separated from the crude petroleum, are discharged as industrial wastes. The careless surface disposal of these brines was extensively practiced at Huntington Beach Mesa before control measures were enacted. Contamination of aquifer waters by these wastes will be described later.

The connate ground waters of the Tertiary rocks are sodium chloride in chemical character but exhibit a fairly wide range in concentration of individual and total dissolved solids. In part, this range can be attributed to native differences and in part is a result of the point of collection of samples. Water collected from sumps, or skimming tanks, is subject to the concentration of solids due to evaporation, or conversely, may be diluted by rain water or other fresh waters. Total dissolved solids of the connate waters range from 8,400 to 57,800 ppm but generally are less than 30,000 ppm. Chlorides range from 5,300 to 35,400 ppm but usually do not exceed 20,500 ppm.

In comparison with sea water, the connate waters are normally lower in dissolved solids and chlorides. They are characteristically higher in boron and bicarbonate and are lower in sulfate and magnesium. Connate waters are also higher in iodide, bromide, barium, and probably germanium, but these trace elements are seldom tested for.

Impairment of Ground Water Quality

Fresh ground waters of the area, primarily those within the Bolsa, Alpha, Beta, and Lambda aquifers, have been degraded or contaminated, beginning in the middle 1920's, as a result of man's development of the land and underground resources, both locally within the Bolsa-Sunset area and throughout the entire coastal plain. This impairment of the ground waters has resulted from: (1) draft of the ground water basin in excess of replenishment, (2) the careless surface disposal of brines within the Huntington Beach oil field, and (3) the disposal of oil refinery wastes and other unidentified wastes in dumps situated within highly permeable deposits. Lowering of the piezometric surface created the hydraulic condition for lateral and vertical movement of inferior waters. Such movement has occurred by natural means and via improperly sealed well bores or improperly abandoned well casings.

Degradation from Oil Field Brines

Oil was discovered at Huntington Beach on May 24, 1920. Exploration established the wide limits of the oil field and well construction followed at an accelerated pace. Many of the early wells were completed by small companies on closely spaced "town lots". This unorganized development of the oil field by independent operators led inevitably to the expedient disposal of saline waste waters produced in association with the crude petroleum. Commonly, these brines (connate ground water of the Tertiary formations) were discharged into unlined sumps, abandoned sand and gravel pits, natural depressions or ravines, and were left to dissipate either by evaporation, percolation or by surface flow into Bolsa and Santa Ana Gaps. This practice was still prevalent in the early 1940's, but by 1952, over 95 percent of the brines of the Huntington Beach oil field were piped to the ocean. The remainder was discharged to sumps on the mesa.

As shown by Section J-J', Plate 3B, the upper Pleistocene deposits within the central portion of Huntington Beach Mesa are permeable sand and gravel with only a few thin clay stringers. In this area, there is little natural impedance to the vertical flow of water. Thus, as a result of oil industry waste practices at Huntington Beach Mesa, saline waters percolated downward to the upper Pleistocene ground water reservoir. From the central portion of Huntington

Beach Mesa, brine contamination spread north into Bolsa Gap, entering the Bolsa aquifer along its contact with the upper Pleistocene aquifers. Ground water of lower Pleistocene aquifers was also slightly degraded by the downward movement of brines in wells perforated both in upper and lower Pleistocene zones.

Ground waters within the central area of brine degradation have been chemically modified to sodium chloride in chemical character. The maximum recorded degradation is for well 5S/11W-35E1 which, in December 1956, yielded water containing 7,405 ppm total dissolved solids and 3,600 ppm chloride. However, more complete records of other wells consistently show a peak in brine degradation from late 1961 to early 1962.

Progressing north and east of the central portion of Huntington Beach Mesa, the chemical character of degraded water changes from sodium chloride to native conditions, calcium or calcium-sodium bicarbonate. Since 1945, ground waters of the Bolsa aquifer and the upper Pleistocene aquifers in Bolsa Gap, and in the northeast corner of Huntington Beach Mesa, have also been affected by an increase in calcium and sulfate and not uncommonly by a slight increase in nitrate. The increase of these ions through early 1962 is not associated with brine degradation. Sulfate averages less than 10 ppm in brines, and nitrates are usually zero. The source of these ions is the semiperched water body, as described later in this chapter.

Analysis of the practices and effects of oil field brine disposal within the Huntington Beach oil field has been made by Piper and Garrett (1953) and by the Department in an unpublished report entitled "Survey of Oil Industry Wastes in Orange County" (1954). Figure 9, taken in part from these reports, shows the progressive outgrowth of brine degradation during the period 1931-32 to 1962 and the subsequent recession of brine degradation during the period 1962-65. Isochlors of 50 ppm denote the outer perimeter of the brine front. The isochlor lines are in part only approximately located, because of the poor distribution of wells and the availability of data. Chloride ion concentrations near the fault at Huntington Beach Mesa have undoubtedly been contributed by sea-water intrusion since the late 1940's, as indicated by electric logs. However, analytical data are unavailable for differentiating between sea-water intrusion and oil field brine invasion in this area.

Figure 10 shows chloride and sulfate concentrations in ground water extracted from wells 5S/11W-26M1, -26M2 and -27H4 versus the hydrograph of wells 5S/11W-27H1 and -27H4 during 1939-65. The location of the wells is shown on Plate 1. In 1939, wells -26M1 and -26M2 yielded water of

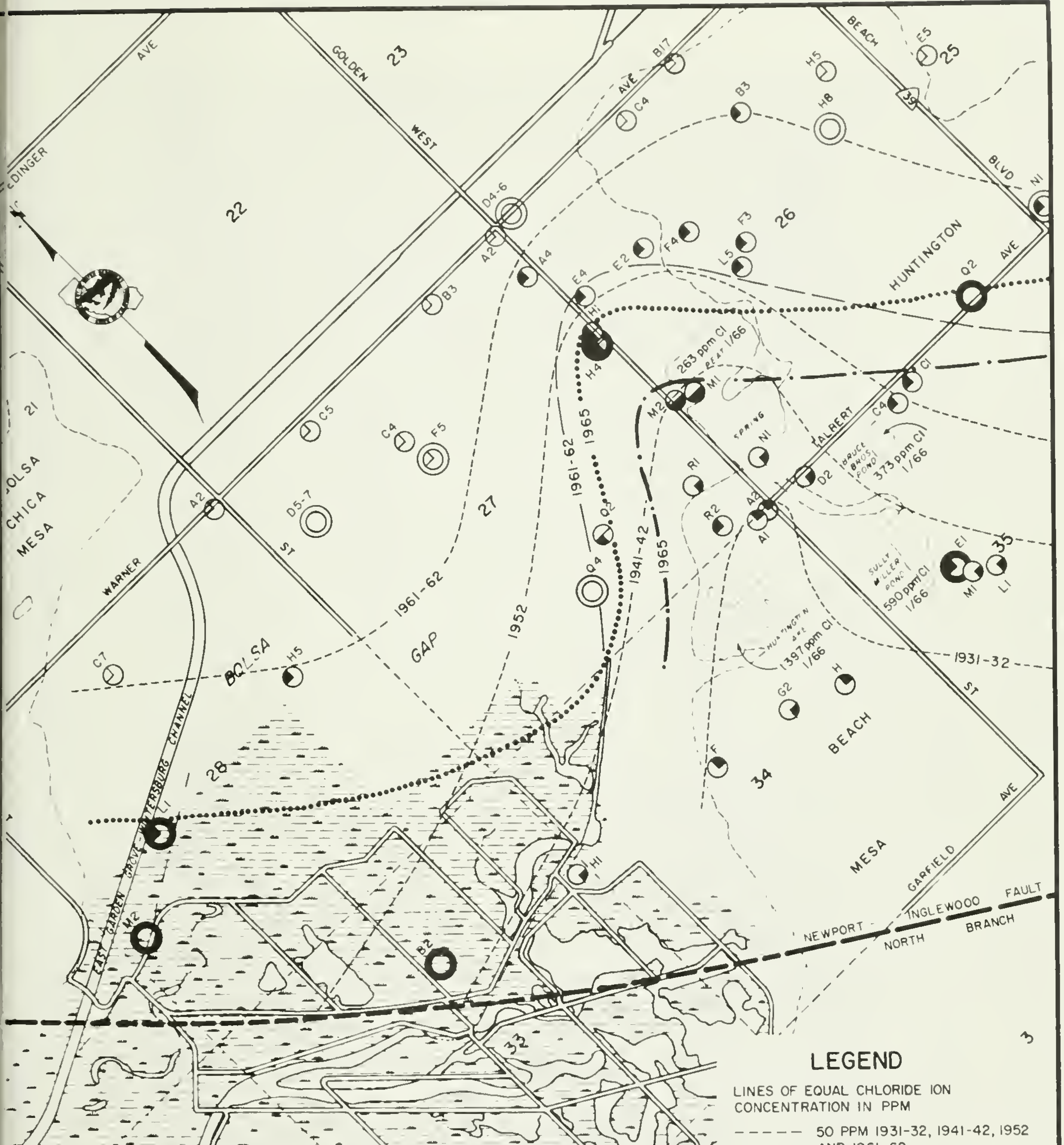


Figure 9- EXTENT OF OIL FIELD BRINE DEGRADATION — UPPER AQUIFERS

EPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

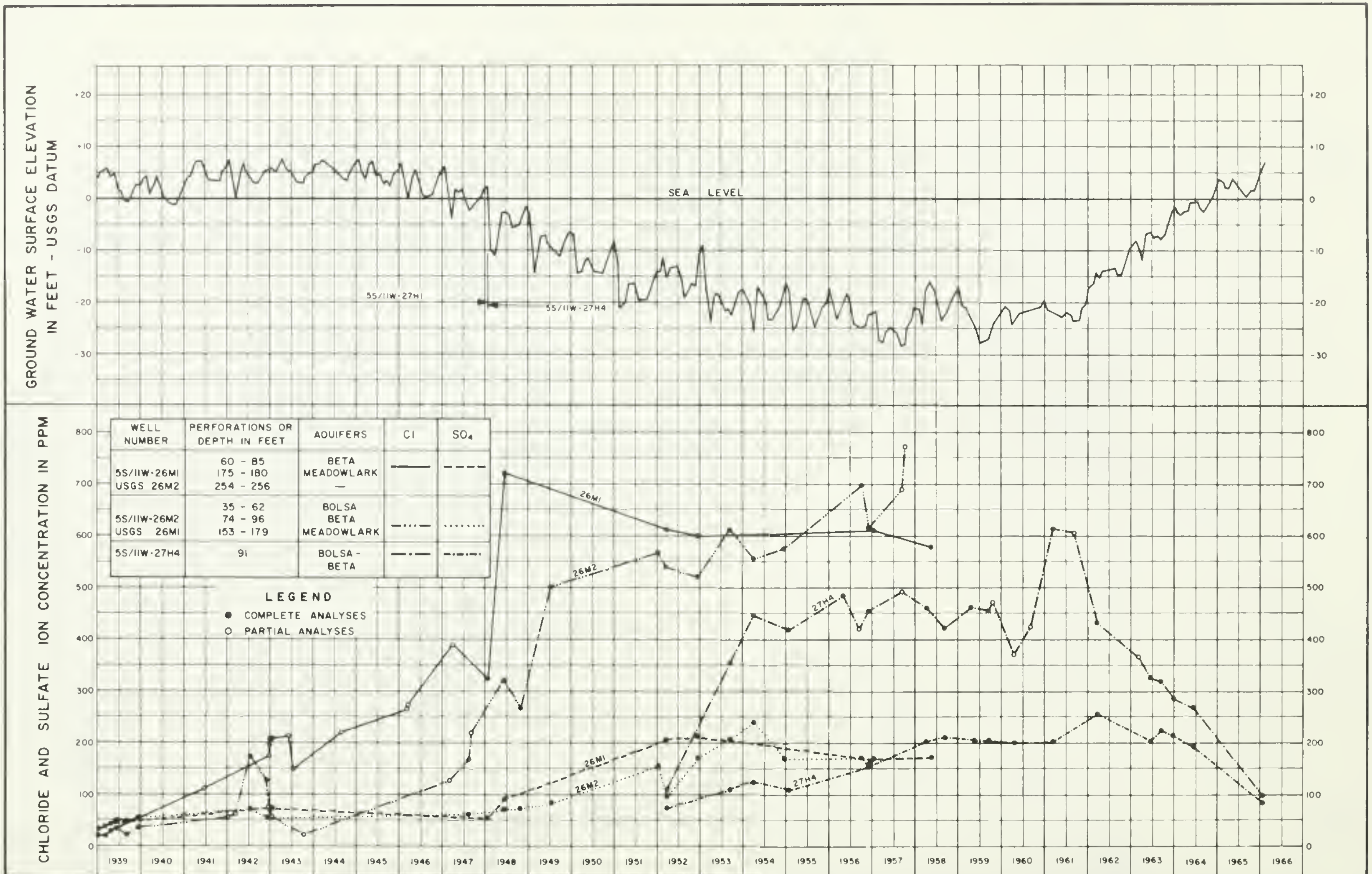


Figure 10-CHLORIDE AND SULFATE ION TRENDS IN BRINE-DEGRADED UPPER AQUIFERS-BOLSA GAP

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

native quality (chloride and sulfate less than 50 ppm). Movement of brine-degraded water to and past the wells, toward areas of agricultural pumping in Bolsa Gap, is shown by the increase in chloride. Note that sulfate exhibits only a slight increase prior to 1947 while chlorides were rising sharply. With the post-1945 recession of the piezometric surface, chloride shows an accelerated increase, occurring first at well -26M1 and then at -26M2. This increase in chloride was not evident at well -27H4 until 1952-54, a lag of about 5 years. With respect to location, well -26M1 is nearest to the brine source, well -26M2 is about 100 feet farther away, and well -27H4 is 1,300 feet beyond well -26M1.

After its accelerated increase, chloride concentrations in water from wells -26M1 and -27H4 remained essentially stabilized, with the higher (about 150 ppm) concentrations occurring at well -26M1, nearer the source area. In contrast, chloride concentrations of water extracted from well -26M2 continued to increase, but at a reduced rate. This is attributed to the contribution of water from the shallow (35 to 60 feet) zone. Since late 1961, chlorides at well -27H4 have diminished rapidly from 610 to 100 ppm, and sulfate has declined from 255 to 80 ppm. During this time, the piezometric surface has risen about 30 feet, causing a flushing of the degraded waters.

Degradation from Semiperched Water

An increase in calcium and sulfate, frequently with an associated slight increase in nitrate, is fairly widespread in ground waters beneath Bolsa Gap, Bolsa Chica Mesa, and Huntington Beach Mesa. This degradation is most pronounced within the Bolsa and Alpha aquifers, but is evident in all the upper aquifers as well. In most cases, the calcium, sulfate, and nitrate concentrations recorded through 1965 have been only slight to moderate. Nevertheless, this degradation of ground waters is significant, specifically as an index to the permeability of the uppermost confining beds, and in regard to well construction and destruction practices.

Downward movement of semiperched ground water is indicated by the greater concentration of calcium, sulfate, and nitrate within the first aquifer beneath the semiperched water body and by the decrease of these ions in progressively deeper aquifers. Areally, the pattern of degradation is sufficiently widespread, with scattered peak concentrations, to preclude any one waste disposal source. Also, pockets of native fresh water occur within the area of influence. These conditions, shown by the relative sulfate concentrations plotted on Figure 11, indicate localized downward movement of a degradent, rather than lateral inflow. Specific evidence is given by the following data for Alpha aquifer wells 5S/11W-21P4 (an old well) and -22M4 (a gravel-packed well):

Well	Ca in ppm	SO_4 in ppm	NO_3 in ppm	TDS in ppm	Date	
5S/11W-21P4	60	47	4	306	March	1952
	107	218	8	600	June	1957
	165	394	29	805	March	1961
	198	459	78	1,002	April	1962
5S/11W-22M4	69	84	4	338	March	1952
	257	636	4	1,336	June	1961
	166	576	0	1,130	December	1963

The foregoing indicate localized flow, either through permeable discontinuities in the aquiclude, in the gravel-packed envelope of well -22M4, or in well -21P4 via a break in the casing. The 1963 data for well -22M4 show early flushing due to the rise in freshwater head.

In the vicinity of the Bolsa Chica Dump, located in 40-acre plot 5S/11W-28D, ground water of the Alpha, Beta, and Lambda aquifers has unquestionably been degraded by semiperched water. In this instance, the source of degradation can be traced to a point of origin within the vertical range of the semiperched zone by means of an alien odor. As shown on Figure 11, nine wells in this area have yielded or currently yield ground water with a slight to strong garlic odor, in addition to increased calcium and sulfate. The origin of the garlic odor is mercaptan sulfate, an oil refinery acid sludge which was formerly discharged into the dump.

At most of the wells, degradation from semiperched water increased until early 1962, and has subsequently decreased. This trend is consistent with the changing elevation of the piezometric surface. It shows that movement of semiperched water in response to the former downward hydraulic gradient has ceased, an upward hydraulic gradient has been restored, and the degraded aquifer water has been freshened by flushing with native or near native ground water.

Colorado River water, the only other known calcium sulfate water, is deficient in nitrate, the concentration being less than 2 ppm. Colorado River water would enter the study area as underflow, which is not consistent with the areal pattern of degradation. Sustained underflow of Colorado River water since 1962 would have resulted in an increase, not a decrease, in calcium and sulfate. And finally, wells tapping the same aquifer and closer to the Santa Ana River Spreading Basin should exhibit a greater concentration of calcium and sulfate, assuming Colorado River water to be the source. This is not shown by data for Bolsa aquifer wells 5S/11W-14A4, -22B3, and -27H4, plotted on Figure 12. Well -14A4 is located 8,500 feet inland of well -22B3, and well -22B3 lies 3,700 feet inland of well -27H4.

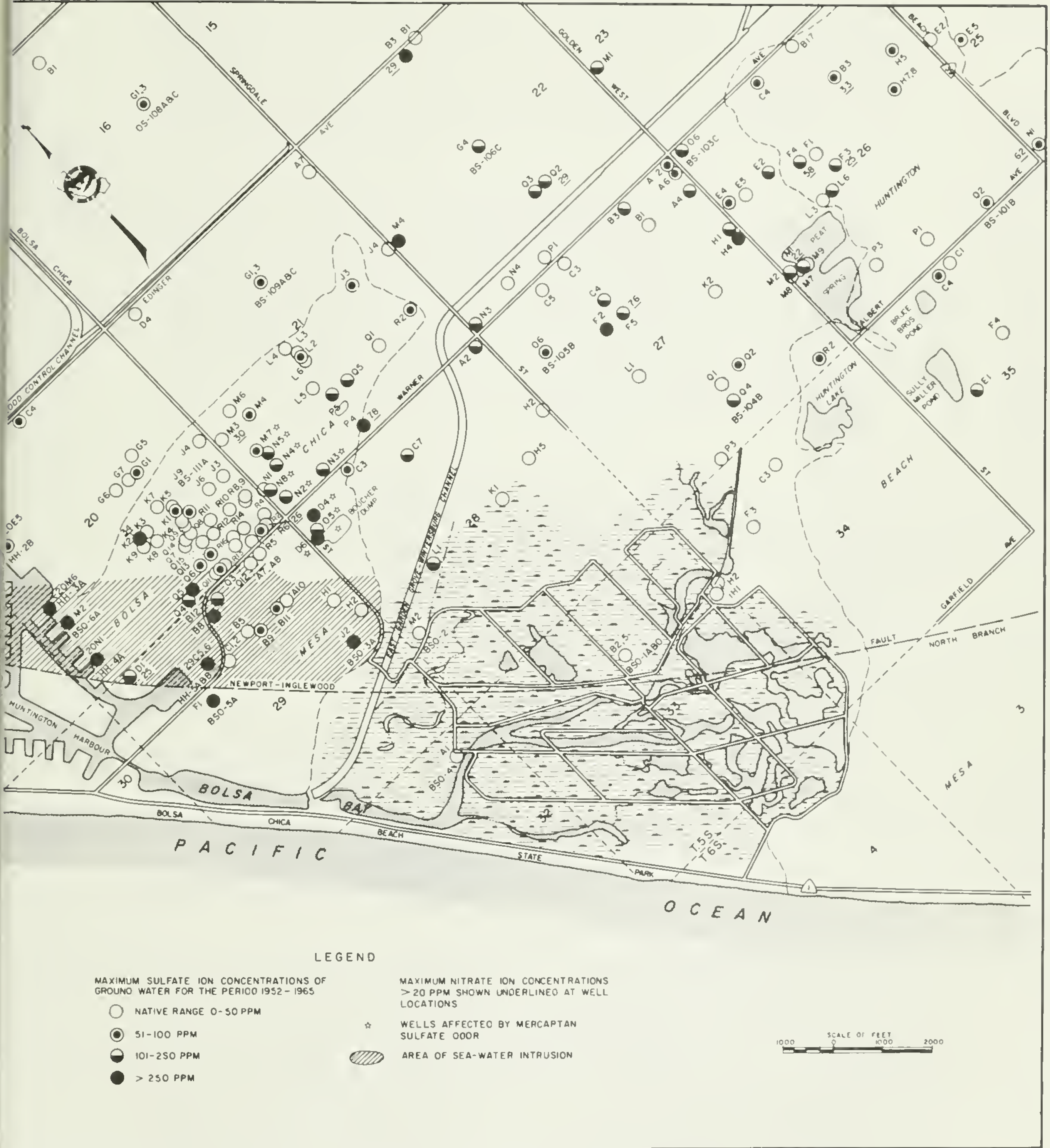


Figure 11 - DEGRADATIONAL EFFECTS OF SEMIPERCHED WATER

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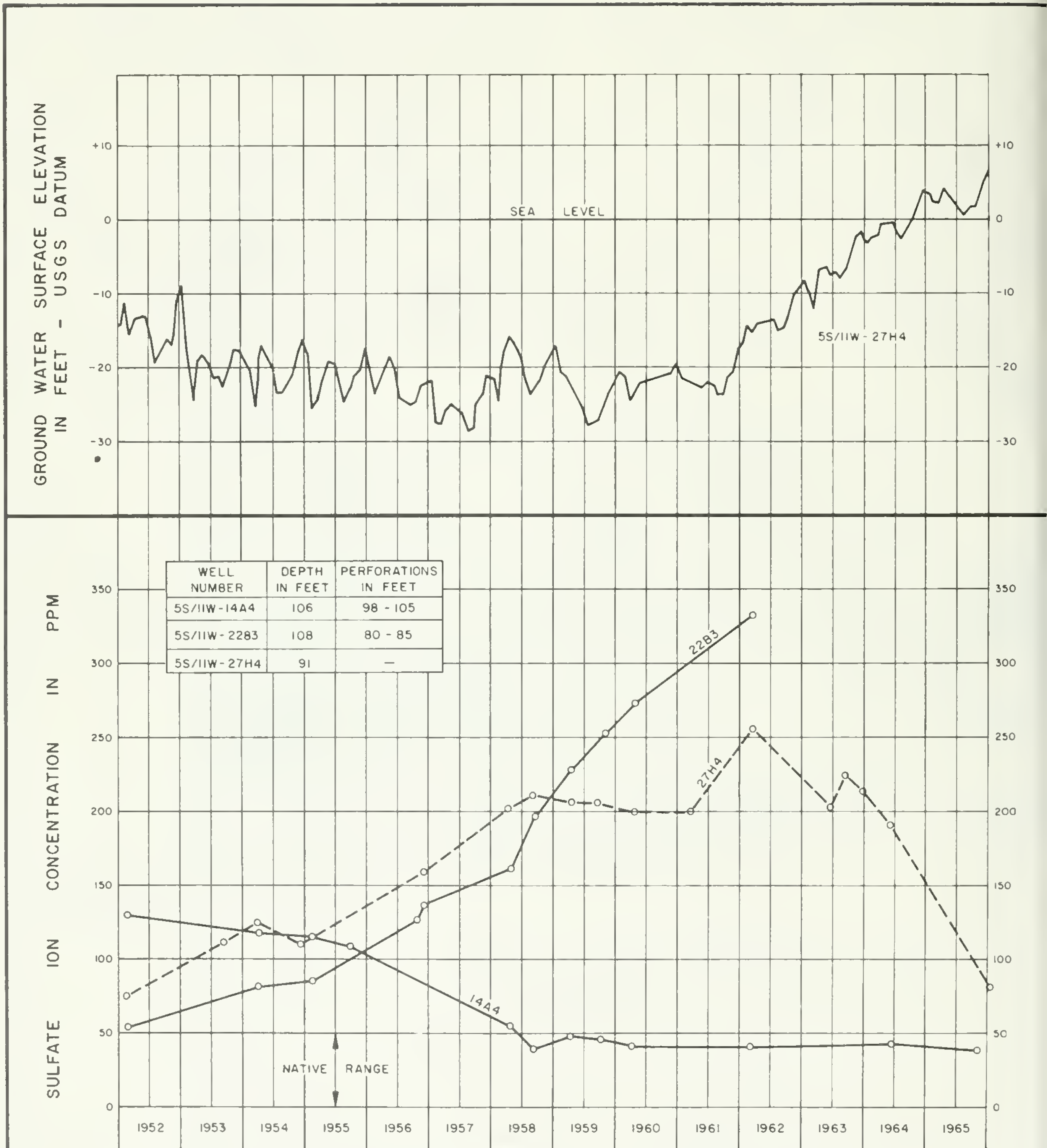

WELL NUMBER	DEPTH IN FEET	PERFORATIONS IN FEET
5S/11W-14A4	106	98 - 105
5S/11W-22B3	108	80 - 85
5S/11W-27H4	91	—

Figure 12 — INLAND SULFATE ION TRENDS — BOLSA AQUIFER

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The deleterious effects of semiperched water influx include an increase in sulfate, nitrate, total dissolved solids and hardness. Nine wells have yielded water containing more than 250 ppm sulfate or 45 ppm nitrate. The maximum concentrations recorded are 796 ppm sulfate and 1,472 ppm total solids (5S/11W-28D4), 78 ppm nitrate (5S/11W-21P4), and 833 ppm total hardness (5S/11W-26F4).

Among the four water quality effects previously cited, only nitrate is critical to health. Concentrations in excess of 45 ppm may cause methemoglobinemia, a nitrate poisoning which can be fatal to young children up to several months old. All fresh ground waters within the study area are characteristically deficient in nitrate, the concentrations ranging from 0 to 4 ppm. Any ground waters with nitrate concentrations from 5 ppm to 10 ppm indicate slight degradation and those in excess of 20 ppm are sufficiently great to warrant investigation.

Downward movement of semiperched water can occur by natural means, in the gravel-pack envelope of rotary drilled holes, and by well casings which have deteriorated with age, were improperly abandoned below the water table, or are otherwise open to the influx of shallow ground water. Which of these alternatives has been the principal flow route of semiperched water is uncertain. Each probably has contributed to the problem. However, semiperched water transmitted by wells can and should be corrected.

Minimal well construction procedures should include placing a cement grout seal above the perforated interval within the annulus between the casing and the wall of the bore hole. The grout should abut silt or clay beds separating the semiperched water body and the fresh ground water reservoir. In no case should a gravel-pack envelope extend upward through these silt and clay beds and into the semiperched zone. Grout plugs can be easily installed and would amount to only a fraction of the total well cost.

The abandonment of a well should follow a minimal procedure which would seal the casing to the vertical transmission of water between the semiperched zone and underlying aquifers. Preferably, the casing should be backfilled between ground surface and the top of the fresh ground water body by cement grout. The top of the casing should be cut off below ground surface and encased in concrete. In no instance should a well casing be left open to public access. Such wells are frequently used as waste disposal pipes and thus increase the possibility of pollution. They also attract children.

Unfortunately, well abandonment practices, except where enforced, are seldom properly conducted, even by original owners. And where urban development replaces farmland, this work is essentially a nuisance to builders unaware of local water problems and the consequences of "dozing it over". In view of the increasing importance of ground water, the indulgence of such practices is no longer justified.

CHAPTER V. SEA-WATER INTRUSION

Sea-water intrusion is the major qualitative problem threatening the ground water supply of Orange County. At Alamitos and Santa Ana Gaps, where it is most critical, intrusion has advanced freely in Recent aquifers to underlying Pleistocene aquifers. In the Bolsa-Sunset area, conditions are different. Intrusion is virtually undeveloped in the Recent Bolsa aquifer. Rather, salt water has encroached chiefly in upper Pleistocene aquifers, forming an irregular front up to 2,800 feet inland from the Newport-Inglewood fault. Further, there has been little vertical intrusion from one aquifer to the next. This chapter presents a review of the fundamentals of sea-water intrusion and examines the scope of the intrusion problem within each of the aquifers in the Bolsa-Sunset area. The effects of present and future marina construction are also evaluated.

Fundamentals of Sea-Water Intrusion

Sea-water intrusion, the inflow of ocean water into a freshwater aquifer, is dependent upon two physical conditions. First, the aquifer must be in hydraulic continuity with the ocean. That is, it must be exposed to the ocean floor or be accessible to sea water due to unconformities with overlying or underlying aquifers. Secondly, the pressure head of sea water, commonly taken as mean sea level, must exceed that of the fresh ground water within the aquifer. When this occurs, a reverse, or landward, hydraulic gradient is developed and sea water moves inland until this gradient is dissipated or a geologic boundary is intercepted. The freshwater head of most coastal aquifers declines when the available ground water supply is withdrawn in excess of replenishment over a sustained period of time.

Due to its greater concentration of dissolved solids, approximately 36,000 ppm, sea water weighs 1.025 times as much as an equal volume of fresh ground water. When the two waters come into contact within permeable media, the lighter fresh water tends to float upon the heavier sea water. Ionic diffusion of the two liquids is impeded by the aquifer sediments. Archimedes' Law of Bouyancy states that any floating object will displace its own weight of the surrounding fluid medium. Thus, a greater freshwater head is required to offset an equivalent volume of sea water. The hydrostatic equilibrium between fresh water and salt water is referred to as the Ghyben-Herzberg relationship. The freshwater-saltwater ratio of 1 to 1.025 is converted algebraically to the equation $h = 1/40H$ where h is the elevation of the freshwater head above sea level and H is the depth to the salt water interface below sea level. From this it is apparent that the deeper the base of an aquifer below sea level, the higher its freshwater head must be to preclude sea-water intrusion. The ratio $h = 1/40H$ is valid under both unconfined and confined aquifer conditions.

When sea-water intrusion occurs within an aquifer, the inmoving salt water forms a wedge pointing inland. This is referred to as the sea-water wedge and its inland extremity is called the toe. Advance or retreat of the sea-water wedge in response to changes in the hydraulic gradient begins at the toe. Due to the greater density of sea water, the toe of the wedge moves along the base of a permeable bed in contact with an impervious bed. Under most field conditions, the theoretical position of the saltwater-freshwater interface is modified by the cyclic flow of salt water within the intrusion wedge. Because of this, the depth to the saltwater interface is greater and the landward advance of intrusion is less than expressed by the Ghyben-Herzberg relationship, which assumes static conditions.

Sea-water intrusion can be prevented or controlled by the regulation of pumping within the basin; by artificial recharge; by the operation of a freshwater injection barrier or a saltwater pumping trough, separately or in combination; by the construction of an impermeable cutoff wall; or by a combination of these procedures. The emplacement of an impermeable cutoff wall is most applicable to shallow depths and for relatively short distances. Methods involving the manipulation of the hydraulic gradient are commonly employed for basinwide protection and to depths in excess of 50 feet.

Conditions Affecting Sea-Water Intrusion Within the Bolsa-Sunset Area

Three bodies of saline water exist within the study area. With respect to their location and route of flow into the freshwater aquifers, they are classified as follows:

1. Upper waters of the ocean, the tidal sloughs and the semiperched zone. Movement of these waters into the freshwater aquifers would occur as downward percolation through the upper aquiclude.

2. Coastal ground waters of the Recent and Pleistocene aquifers seaward of the Newport-Inglewood fault. Intrusion of these waters would occur laterally across that barrier.

3. Connate water of the underlying Tertiary deposits. Upward movement of these waters is sufficiently remote to preclude further consideration. However, as oil field brines they have percolated downward to the freshwater aquifers.

Each of these saline waters produces similar degradation of fresh ground water as measured by the ions commonly reported in chemical analyses. Their differentiation as a degradent is best determined by trace element analysis, by iodide-bromide analysis, or, in some instances, by organic compound analysis. Lacking these data, conclusions must be drawn by comparing the character of degradation with the geohydrologic conditions governing flow. With this procedure, however, it is sometimes difficult to fix the true source.

Geologic Conditions

Geologic barriers limit but do not prevent sea-water intrusion within the Bolsa-Sunset area. For the most part, the aquifers are interbedded with aquicludes of low permeability, which limit vertical percolation. Lateral hydraulic continuity of the aquifers to salt water is impeded by the Newport-Inglewood fault. Discontinuity of the fine-grained sediments and relatively permeable portions of the fault plane provide major routes for saltwater encroachment. Of the two, the effective permeability of the fault plane is the more critical.

The impedance rendered by the Newport-Inglewood fault to ground water flow has long been recognized. Early references to this geologic structure used the work "dike" to imply a steeply inclined rock wall. Subsequent geologic investigation has determined that the barrier property of the fault zone results from a combination of the following:

1. The displacement of beds.

2. Structural traps - the offset of permeable beds against essentially impermeable beds.

3. Fault gouge - the altered and rearranged sedimentary particles of the fault zone.

4. Plastic flow of clays within the zone of shearing.

5. The deposition of chemical precipitates in numerous irregular fissures. These precipitates include calcium carbonate, iron oxide, gypsum, and silica.

6. Intense folding of beds adjacent to the fault.

Because of its extreme heterogeneity and its concealment below ground surface, the barrier properties of the fault zone are practically impossible to explore. However, several basic conclusions can be drawn. First, vertical offset of aquifers is generally incomplete; water-bearing sediments remain stratigraphically opposed across the fault trace. The plane or zone of shearing must therefore constitute the major portion of the barrier. Variation in the permeability of such a barrier is inherent. Secondly, the fault zone becomes increasingly less permeable with depth, due to the progressively greater structural deformation of older sediments. Thus, intrusion is a lesser threat in deeper aquifers. Thirdly, the ability of the fault barrier to limit ground water flow is not constant but varies with the hydraulic differential imposed across it. Inflow of salt water at new portions of the barrier can be expected if the reverse hydraulic gradient is increased beyond historic conditions. No aquifer within the study area can be considered absolutely safe from sea-water intrusion, although the Main aquifer and underlying zones are least susceptible.

Hydrologic Conditions

For the most part, fresh ground waters of the area are held under artesian pressure in multiple confined aquifers and have limited hydraulic continuity with overlying or coastal saline waters. Due to erosion or facies change of aquicludes, the five upper aquifers are sufficiently interconnected to be grouped as an upper hydraulic system. The Main aquifer and deeper permeable zones are not interconnected with the upper aquifers and are grouped as a lower hydraulic system. Both the upper and lower aquifer systems are in hydraulic continuity with the inland basin and their piezometric surfaces fluctuate according to the replenishment-discharge of water within that basin.

Because pumping of ground water exceeded recharge to the basin, the piezometric surface of both aquifer systems was lowered entirely below sea level during the period 1948-64. A reverse hydraulic gradient was imposed landward across the Newport-Inglewood fault and downward across the uppermost aquiclude, causing saline waters to move into the upper aquifers, principally as underflow across the fault.

Sea-Water Intrusion by Aquifers

Sea-water intrusion within the area is identified primarily by the increasing concentration of chloride in excess of 50 ppm, the maximum limit among native fresh ground waters. Although 50 ppm is taken as the threshold of intrusion, ground waters containing up to 250 ppm chloride are entirely suitable for human consumption. Above the 250 ppm concentration, the maximum recommended limit established by the United States Public Health Service, the sodium chloride salt taste is detectable by most people. The maximum chloride ion concentration for which the California State Board of Public Health will issue a temporary water supply permit is 500 ppm. At this concentration, the salt taste is objectionable to most people. Water containing more than 500 ppm chloride is also impaired by excessive hardness and total dissolved solids. For irrigation, water containing more than 350 ppm chloride is rated as Class 3, injurious to unsatisfactory, because such concentrations generally cause subnormal growing rates and burning of leaves. However, these effects will vary according to crops, soils, climatological conditions, and irrigation practices.

Bolsa Aquifer

In contrast to highly intruded Recent aquifers in Alamitos and Santa Ana Gaps, there has been little or no direct sea-water intrusion into the Recent Bolsa aquifer, despite the sustained lowering of its piezometric surface to as much as 28 feet below sea level. These differences are due primarily to the relative faulting of the three stream channel deposits, the Bolsa aquifer being the only one displaced by the Newport-Inglewood fault. What little intrusion that may have developed landward within the Bolsa aquifer is obscured by the earlier influx of oil field brines or the later encroachment of intruded ground water from flanking upper Pleistocene aquifers.

Increasing chloride ion concentrations caused by oil field brines were evident in the Bolsa aquifer in the early 1940's at wells 5S/11W-26M1, -26M2, and -33H1. At seaward well -33H1, salty water was reported in the Bolsa aquifer during drilling of the well bore in 1940. Presumably this condition was determined by taste, which would have required a chloride ion concentration of 250 ppm or more. Thus, brines had encroached northerly more than 1,600 feet within the coastal reach of the aquifer prior to the sustained lowering of its piezometric surface below sea level. Continued encroachment of the brine front after 1940 was monitored at inland wells.

A landward hydraulic gradient developed within the aquifer in 1948, and persisted until late 1964. Available water quality data in the coastal fresh water portion of the aquifer and a hydrograph of the piezometric surface are compared in Figure 13. The locations of the wells are shown on Plate 1.

The chloride data on Figure 13 do not indicate sea water to be the principal degradent. There is no marked increase in

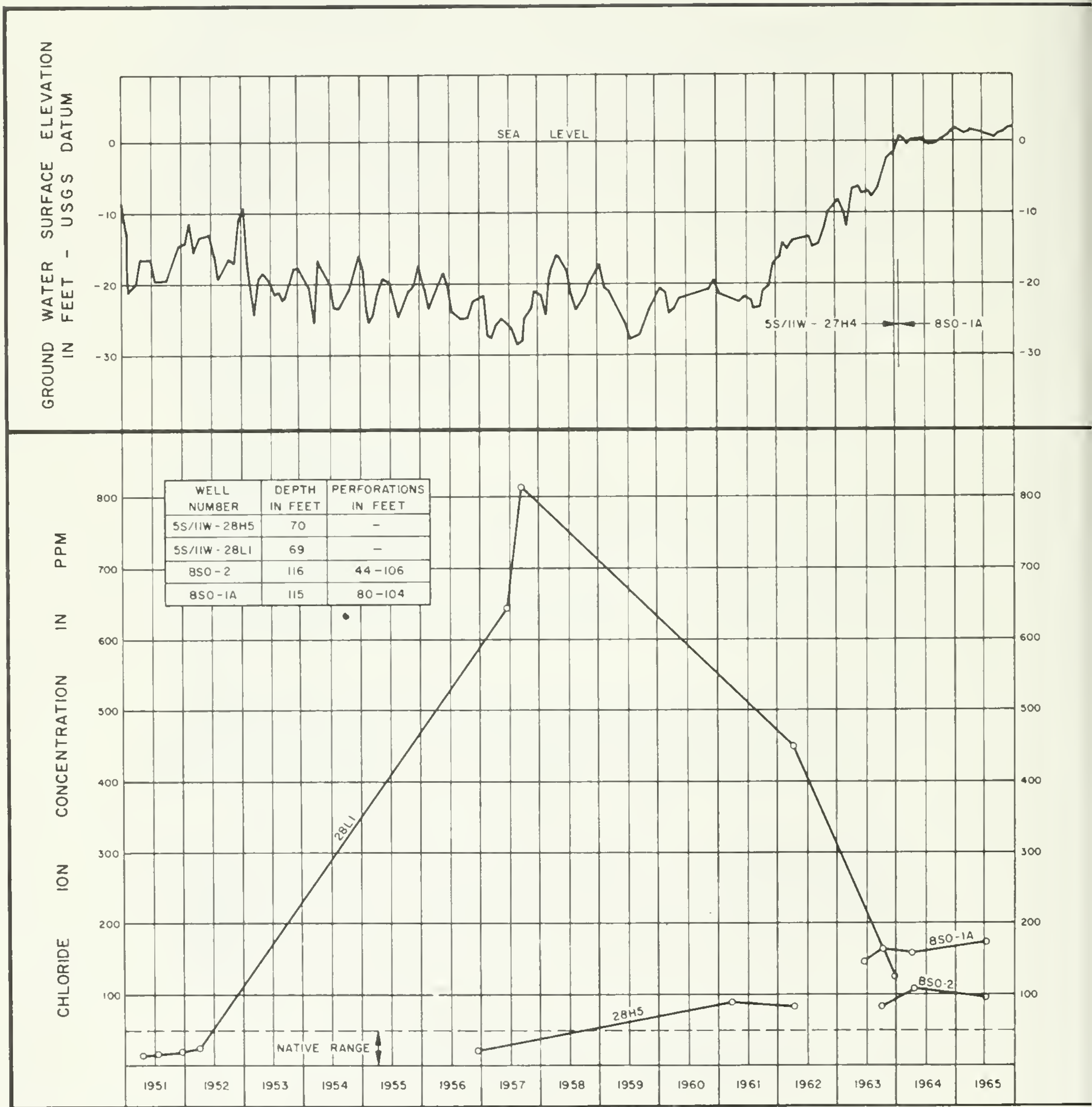

Figure 13 — COASTAL CHLORIDE ION TRENDS — BOLSA AQUIFER

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chlorides progressing seaward or downward within the aquifer. Both trends would be evident if an intrusion wedge had developed.

The chloride trend for well -28L1 is attributable to downward movement of semiperched water. Well -28L1 is an old steel cased well, 54 or 69 feet deep, that was constructed in the early 1930's. It is located within an area of saline semiperched water. The abrupt rise in chlorides suggests vertical influx of semiperched water via a leak in a deteriorated casing more than 20 years old. The decrease in chlorides, accompanying the rise of the piezometric surface, reflects a flushing of the degraded water. These chloride changes occurred in the top of the aquifer, about 1,400 feet inland of well BSO-2. Figure 13 shows that well BSO-2, located nearer the ocean, yielded water with equivalent chlorides from the entire aquifer in 1963-64. Whether this slight degradation resulted from inland flow across the fault or lateral flow from Bolsa Chica Mesa is uncertain.

That sea-water intrusion has not been significant in the Bolsa aquifer is indicated by two other factors. Chlorides have increased slightly at well BSO-1A and have remained stabilized at BSO-2 since 1963. This conflicts with the prevailing decrease in chlorides of the intruded Alpha and Beta aquifers at Bolsa Chica Mesa since 1962-63. Secondly, some evidence is provided by the sulfate ion concentration. At well BSO-1A, sulfates have ranged between 0 and 2 ppm and have exhibited no increase with chloride. In contrast, intruded water of the Alpha aquifer has exhibited an increase in both ions during the advance of the intrusion front. However, sulfates at well BSO-1 may have been reduced; hence this ion is not an absolute indicator. Nevertheless, the extremely low concentration is consistent with the influx of oil field brines.

Summarizing, the available data for wells BSO-1A, BSO-2, 5S/11W-28H5 and -28L1 indicate a fairly widespread chloride ion concentration of 100 to 220 ppm in the Bolsa aquifer near the Newport-Inglewood fault during 1963-65. These concentrations resulted primarily from the northern encroachment of oil field brines and locally by the downward movement of semiperched water. Lateral encroachment of intruded waters from Bolsa Chica and Huntington Beach Mesas has probably also occurred. The approximate limit of this degradation front is shown on Plate 9. The lack of a pronounced saltwater wedge toward the coast indicates little or no inland intrusion. Based on these limited data, it appears that the fault is a relatively effective hydraulic barrier within the Bolsa aquifer for differential heads up to nearly 30 feet.

Alpha Aquifer

Sea-water intrusion within the Bolsa-Sunset area has been most pronounced within the Alpha aquifer. The approximate areal extent of intrusion as of 1963-65 is shown on Plate 10; the vertical range of chloride is shown on the geologic sections, Plates 3A and 3B. At Sunset Gap, Landing Hill, and Huntington Beach Mesa, the extent of intrusion is indeterminable due to a lack of monitoring wells. At Huntington Beach Mesa, differentiation of sea-water intrusion is further complicated by the earlier influx of oil field brines. However, electric logs for test holes AE-11 and AE-12 at Landing Hill and for oil wells at Huntington Beach Mesa clearly show a sea-water intrusion wedge in these areas.

From the data presently available, intrusion within the Alpha aquifer is greatest in three areas: (1) in the vicinity of Hog Island, (2) from the middle of Huntington Harbour southeast across Bolsa Chica Mesa, and (3) at Huntington Beach Mesa. In areas 1 and 2, maximum chloride ion concentrations in 1963 were 9,280 ppm and 16,700 ppm, respectively.

Analytical data are unavailable for Huntington Beach Mesa. Electric logs show a marked increase in salinity (decrease in apparent resistivity) in the Alpha and Beta aquifers toward the Newport-Inglewood fault. In Section 34, T5S, R11W, electric logs run between October 1949 and October 1954 show a basal decrease in apparent resistivity to 4 ohm meters. This compares with an apparent resistivity of more than 40 ohm meters recorded on electric logs run between March 1941 and August 1944. These data indicate that a substantial increase in salinity to approximately 6,000 ppm total dissolved solids occurred at Huntington Beach Mesa as sea-water intrusion was advancing and when the land disposal of brines had been essentially curtailed.

Based upon the areal and vertical range in salinity within the aquifer and the vertical range in salinity within the overlying aquiclude, the principal route of intrusion has been inflow of sea water as a basal wedge through permeable portions of the Newport-Inglewood fault. Support for this is given by the following.

There is historic and current evidence that the Newport-Inglewood fault is a leaky hydraulic barrier. Pockets of fresh ground water once existed within the Alpha aquifer seaward of the fault at Hog Island and at the southwest corner of Huntington Beach Mesa. The origin of these two fresh ground water lenses within the coastal belt of native salt water has been attributed to subsurface outflow through the fault plane in response to historic seaward hydraulic gradients (Piper and Garrett, 1953). Seaward movement of fresh ground water through the fault is now evident at Bolsa Chica Mesa. At piezometer BSO-5A, constructed in the merged upper Pleistocene aquifers, the water level has risen to 1 foot above sea level and chlorides have diminished by 1,180 ppm since July 1963. The hydrograph for piezometer BSO-5A (Plate 8) suggests a slight seasonal rise and fall. These changes are consistent with the outflow of fresh water due to the present (1965) seaward hydraulic gradient of the aquifer.

Within the intrusion area landward of the fault, differentiation between lateral inflow across the Newport-Inglewood fault and downward movement of salt water through the aquiclude is complicated by the fact that both waters are saline and chloride in anion character. However, semiperched water native to upper Pleistocene beds is locally insufficiently saline to have caused the underlying degradation of the aquifer. Further, the resultant distribution of chlorides within the aquifer will differ for the two processes. In the case of lateral inflow, a saltwater wedge would develop along the base of the aquifer according to the Ghyben-Herzberg relationship and chlorides would decrease upward. In the case of downward movement, salt water would penetrate the aquiclude very slowly, enter the top of the aquifer, and then sink due to its greater density. Chlorides would eventually be distributed irregularly throughout the aquifer due to its anisotropy but would be greatest at its top.

Chloride ion concentrations for wells within the sea-water intrusion area at Bolsa Chica Mesa and representative hydrographs are shown in Figure 14. The well locations are shown on Plate 1. The data point out the following:

1. A focus of sea-water intrusion at the Newport-Inglewood fault, wells 5S/11W-29C4 and -29D1.

2. A landward advance of the saltwater front of about 400 feet per year in response to the declining elevation of the piezometric surface.

3. A rapid increase in chlorides during 1950-1962.

4. A decrease in chlorides at the inland perimeter of the intrusion area, wells 5S/11W-20Q5, -29B8, and -29B12, since early 1962.

5. An inland boundary to sea-water intrusion between well 5S/11W-20Q3 and wells -20Q6 and -20Q12. The depths of these wells are given below.

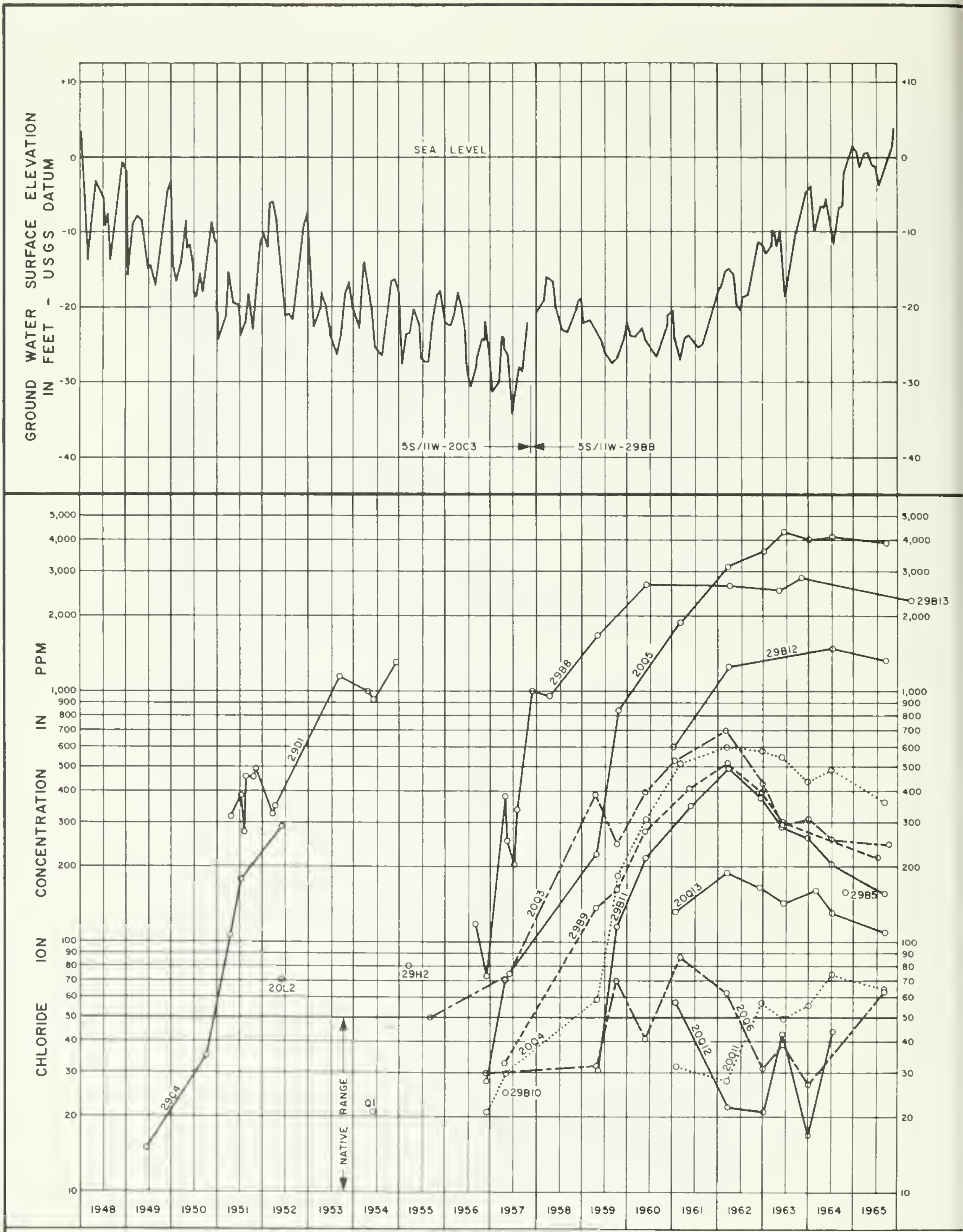

Figure 14 - CHLORIDE ION TRENDS IN INTRUDED UPPER AQUIFERS — BOLSA CHICA MESA

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Well Number	Depth in Feet
5S/11W-20Q3	120
5S/11W-20Q6	125
5S/11W-20Q12	120

6. A basal increase in chlorides between well pairs 5S/11W-20Q3 and -20Q11 and 5S/11W-29B5 and -29B9. The depths of these wells are given below:

Well Number	Depth in Feet
5S/11W-20Q11	100
5S/11W-20Q3	120
5S/11W-29B5	111
5S/11W-29B9	120

From the 1950-51 data for wells 5S/11W-29C4 and -29D1, the previous artesian conditions at these wells, and the log of nearby well -29C2, Garrett (1952) concluded that the cause of increasing chlorides was inflow of salt water across the Newport-Inglewood fault. This early conclusion is substantiated by the 6 points listed above, which describe (1) a focus of sea-water intrusion at the fault, (2) a saltwater wedge moving inland along the lower portion of the aquifer, causing a rapid increase in chlorides accompanying a decline in the freshwater head, (3) interruption of the inland advance of the saltwater wedge at a vertical boundary between closely spaced wells, and (4) a frontal decrease in chlorides since early 1962 due to (5) fresh water erosion of the toe of the saltwater wedge resulting from a recovery of the freshwater head.

Chloride ion concentrations for observation wells and piezometers at Huntington Harbour are shown on Plate 11; the locations of the well sites are shown on Plate 1. The chloride data and electric logs for sites BS-6, BS-7, HH-1, and HH-4 substantiate that intrusion has developed by lateral flow across the fault plane.

Sites HH-3, HH-4, HH-5, and BSO-6 are located within an area of highly intruded water. Plate 11 shows that in this area, chlorides are greatest in the bottom of the aquifer and decrease upward. At HH-3, the vertical range in salinity is from native fresh water at the top of the aquifer to intruded water containing more than 10,000 ppm chloride at the bottom.

Electric logs for BS-6 (Appendix C) and HH-4 show that the saltwater interface lies 10 to 15 feet below the top of the aquifer, with fresher water occupying the upper interval. The electric logs also show a top-to-bottom increase in apparent resistivity within the aquiclude, which is equivalent to a decrease in salinity of the contained formation water. At BS-6, a 10-foot-thick freshwater sand is evident in the bottom of the aquiclude. These data indicate that highly saline semiperched water has not penetrated downward through the aquiclude.

Except at sites HH-3, HH-4 and piezometer HH-5C, the chloride ion concentration of semiperched water contained in upper Pleistocene beds is less than 3,000 ppm. Concentrations of less than 1,000 ppm chloride were found at seeps 5S/11W-20ES2 and -20MS1 discharging from excavated channels. Based on these data, the maximum chloride concentration of native semiperched water contained in upper Pleistocene deposits beneath Huntington Harbour is probably less than 3,000 ppm. This concentration is insufficient to have produced the greater chloride concentrations of the Alpha aquifer south-southeast of and including site HH-3.

The high chloride ion concentrations of upper Pleistocene semiperched water at sites HH-3 and HH-4 (Plate 11) resulted from sea-water intrusion into the exposed semiperched beds at preexisting and partially to completed flooded marina channels prior to the construction of the piezometers in August 1964. Plate 11 shows that this intrusion is reaching piezometer BSO-6D and has replaced less saline water at piezometer BSO-7F, which drained south to excavated channels.

Finally, the data at Huntington Harbour and at Bolsa Chica Mesa show a focus of sea-water intrusion toward the Newport-Inglewood fault in the vicinity of sites HH-4 and HH-5, which flank the sea-water intrusion discovery wells 5S/11W-29C4 and -29D1. This areal trend in salinity is shown on Plate 10.

Data for site BSO-8 at Hog Island indicate that intrusion there has occurred both laterally across the fault and downward from the semiperched zone. Previous study (Piper and Garrett, 1953) established that the fault plane was permeable to the seaward flow of fresh water and that artesian flow of fresh water existed at a natural spring. Due to the subsequent decline of the inland piezometric surface, flow was reversed, being inland and downward.

Chloride data for piezometers at site BSO-8 are listed in Table 4. The data show only a slight downward increase in salinity within the aquifer, which would be expected from combined horizontal and vertical intrusion. The electric log (Appendix C) shows no significant change in apparent resistivity from the semiperched zone downward through the upper

TABLE 4

CHLORIDE ION CONCENTRATIONS IN THE ALPHA AQUIFER AND THE SEMIPERCHED ZONE - SITE BSO-8

Piezometer	Aquifer	Perforations in feet	Chlorides in ppm	Date
BSO-8A	Semiperched zone	21-41	13,758	8-28-63
			16,180	10-18-63
			17,910	2-20-64
			15,775	7-02-65
BSO-8B	Alpha	61-81	8,200	9-11-63
			8,830	3-03-64
			2,850	7-02-65
BSO-8C	Alpha	86-151	9,282	8-26-63
			7,180	10-18-63
			9,500	2-20-64
			7,550	7-02-65

20 feet of the aquifer, indicating vertical intrusion. Below a depth of 90 feet, the electric log shows an abrupt increase in apparent resistivity, and then downward, a progressive decrease in apparent resistivity. This indicates a saltwater wedge formed by horizontal intrusion in the lower 75 feet of the aquifer.

At the northern portion of Huntington Harbour (sites HH-1, HH-2, and BSO-7), conditions differ from those previously explained. Intrusion has been relatively minor and chlorides are higher in the top of the aquifer. Also, the aquifer is separated by silt and clay beds into an upper and lower zone. Chloride data on Plate 11 show that semiperched water is sufficiently saline to have caused the degradation in the aquifer. Vertical intrusion is indicated by the upward increase in chloride. The higher concentrations at site HH-1 suggest intrusion from a source inland or northerly of site BSO-7. However, electric logs for BS-7 and HH-1 show an increase in apparent resistivity to the native range for silt and clay progressing downward within the upper aquiclude. Further, the electric log for BS-7 shows thin freshwater sands in the aquiclude above the aquifer. Based on these data, it is doubtful that vertical intrusion has been the principal route of flow. It is more plausible that differential horizontal intrusion occurred within the upper and lower portions of the aquifer.

Differential horizontal intrusion across the fault is evident at site BSO-9. The electric log run in September 1961 (Appendix C) shows a basal saltwater wedge in the lower part of the aquifer and a slight increase in salinity within the upper part of the aquifer. These two salty wedges are separated by a silt and clay bed.

By August 1963, when piezometers were constructed, the highly saline water in the lower part of the aquifer had been substantially flushed. Chloride data are given below in Table 5.

TABLE 5

CHLORIDE ION CONCENTRATIONS IN THE ALPHA AQUIFER AND THE SEMIPERCHED ZONE - SITE BSO-9

Piezometer	Aquifer	Perforations in feet	Chlorides in ppm	Date
BSO-9B	Semiperched zone	10-24	4,264	9-12-63
			12,482	11-01-63
			19,500	2-21-64
BSO-9C	Alpha	56-101	312	9-11-63
			116	11-01-63
			92	2-20-64
			114	7-01-65
BSO-9D	Alpha	115-162	255	9-09-63
			376	10-31-63
			105	2-21-64
			67	5-01-64
			23	7-01-65

In the fall of 1963, chlorides were approximately the same in both the upper and lower portions of the aquifer but have since decreased due to freshwater flushing. In the upper part of the aquifer, however, the data indicate a late arrival of higher-chloride water from an inland source.

Current study (Wall and others, 1966) has determined that inland of site BSO-9, particularly along Bolsa Avenue, the upper aquiclude is missing and vertical hydraulic continuity exists in predominantly sandy deposits from ground surface to a depth of 100 feet. The slight 1964-65 increase in chlorides at BSO-9C suggests that inland water degraded by vertical intrusion has been shifted seaward due to the rising piezometric surface.

Summarizing, slight to intense sea-water intrusion, developed principally by horizontal flow across the Newport-Inglewood fault, is distributed in the Alpha aquifer across the study area. Intrusion is greatest in (1) Sunset Gap around Hog Island, (2) from the middle of Huntington Harbour southeast across Bolsa Chica Mesa, and (3) at Huntington Beach Mesa. At Bolsa Chica Mesa, and possibly at Huntington Beach Mesa, the intrusion front extends inland about 2,800 feet. The inland extent of intrusion elsewhere in the area is indeterminable at present.

Horizontal intrusion began in 1949 at Bolsa Chica Mesa under a landward hydraulic differential of less than 10 feet across the Newport-Inglewood fault. Intrusion advanced inland at a rate of about 400 feet per year as the piezometric surface declined to 35 feet below sea level. Encroachment landward of the Bolsa-Fairview fault has been locally impeded by that structure. Since 1962, the intrusion wedge has retreated or has been flushed in its upper reach due to the recovery of the freshwater head to 5 feet above sea level.

Vertical intrusion is evident locally at site BSO-8, inland of site BSO-9, and inland or northerly of site BSO-7. Except for site BSO-8, data show that the aquiclude, where greater than 10 feet thick, has effectively limited or prevented vertical intrusion.

Beta-Lambda Aquifer

Because the Beta and Lambda aquifers are merged or are separated by a very thin aquiclude within most of the intrusion area, they were considered as one permeable zone for well construction. There has been only slight intrusion, however, in the lower or Lambda portion of the merged aquifer. In the upper or Beta portion, intrusion has ranged from slight to intense, and is greatest in (1) Sunset Gap, (2) the south portion of Bolsa Chica Mesa, and (3) at Huntington Beach Mesa. The approximate areal extent of intrusion applicable to the Beta range is shown on Plate 12. Except for Sections 20 and 29, T5S, R11W, the inland boundary of the intrusion front cannot be accurately determined due to the lack of monitoring wells. The generalized vertical range in chloride is shown on the geologic sections, Plates 3A and 3B.

From data provided by observation wells, intrusion has been most pronounced in the vicinity of site BSO-9 in Sunset Gap. Chlorides at well BSO-9A have exceeded 6,825 ppm, the maximum recorded value, because the well is also perforated in 22 feet of underlying freshwater-bearing deposits. This also applies to chloride data for sites BSO-7 and BSO-8.

Although analytical data are unavailable for Huntington Beach Mesa, sea-water intrusion in that area is evident from the available shallow electric logs. In 1954, a pronounced saltwater wedge was apparent at wells 5S/11W-34Rb and -34Ja, but not at inland wells 5S/11W-35Ec and -35Mb. Electric logs of the latter two wells indicate slight to moderate brine degradation in the Alpha aquifer but native fresh water in the Beta aquifer. Electric logs run prior to 1949 at wells 5S/11W-34Jb,

-34Jc, -34La, and -34Ka also show fresh water in the Beta aquifer. From these data, it is concluded that brine degradation of the Beta aquifer in the vicinity of these wells has been negligible, and that as of 1954, an intrusion wedge had advanced inland greater than 2,700 feet but less than 3,900 feet.

Sea-water intrusion into the Beta-Lambda aquifer has occurred principally as lateral flow across the Newport-Inglewood fault. At Bolsa Chica Mesa the zone merges with the Alpha aquifer; however, this one aquifer has been intruded in a similar way. Intrusion at Landing Hill, evident at wells -12P1 and -12P3 (now destroyed), was also attributed by Piper and Garrett (1953) to the same cause.

The most striking evidence for horizontal intrusion is given by data for BSO-9. The electric log (Appendix C) shows a basal saltwater wedge in the Beta aquifer, 230 to 260 feet, and an increase in apparent resistivity for the overlying silt and clay aquiclude. This and the chloride data listed in Table 6 show that intrusion progressed laterally and not vertically from the Alpha aquifer. The intrusion wedge in both the Alpha and Beta aquifers ends abruptly at their contact with underlying silt and clay, the bed underlying the Beta wedge being only 5 feet thick, 258 to 263. Almost identical conditions are shown by the electric log for site BSO-7.

TABLE 6

CHLORIDE ION CONCENTRATIONS IN THE
ALPHA AND BETA-LAMBDA AQUIFERS - SITE BSO-9

Aquifer	Perforations in feet	Chlorides in ppm	Date
Alpha	115-162	225	9-63
		376	10-63
		105	2-64
		67	5-64
		23	7-65
Beta-Lambda	195-285	4,769	9-63
		6,810	2-64
		7,287	5-64
		6,825	7-65

The lack of vertical intrusion originating from the Alpha aquifer is also apparent on electric logs for sites BSO-6 and BSO-8 (Appendix C). An abrupt increase in apparent resistivity occurs in the separating silt and clay bed between the highly intruded Alpha aquifer and the slightly to moderately intruded Beta aquifer. Chloride data for sites BSO-6 and BSO-7 (Plate 11) show no relationship in salinity between the Alpha and Beta aquifers. In August 1963, chlorides were slightly higher (15 ppm) in the Beta aquifer at site BSO-7. In contrast, chlorides in the Alpha aquifer at BSO-7 were 96 ppm, while at site BSO-6 they were 10,960 ppm.

Meadowlark Aquifer

As shown by Plate 13 and Section A-A', Plate 3A, only localized and relatively slight sea-water intrusion has developed within the Meadowlark aquifer inland of the Newport-Inglewood fault. No intrusion has occurred at sites AE-12, BSO-8, BSO-6, BSO-3, and BSO-1 or at Huntington Beach Mesa as indicated by electric logs. However, an intrusion wedge is definitely shown in the Meadowlark aquifer (I Zone) on the electric log for AE-11, located about 2,000 feet inland of the fault at Landing Hill. Based upon the low apparent resistivity of 18 ohm meters, intrusion has been greatest in that vicinity. Undoubtedly, encroachment to AE-11 has been south from Alamitos Gap, where the I Zone is in hydraulic continuity with the highly intruded unnamed Recent aquifer.

The degree of intrusion at sites BSO-7 and BSO-9 is given by data in Table 7 below. Retreat of the saltwater wedge is evident at both sites, but at BSO-9, chlorides have fluctuated erratically. Whether this is due to seasonal changes in piezometric levels or from the seaward movement of inland intruded water is uncertain.

TABLE 7

CHLORIDE ION CONCENTRATIONS IN THE MEADOWLARK AQUIFER - SITES BSO-7 AND BSO-9

Piezometer	Perforations in feet	Chloride in ppm	Date
BSO-7	270-355	92	8-63
		35	4-64
		16	7-65
		14	10-65
BSO-9	340-435	259	8-63
		566	10-63
		121	2-64
		254	5-64
		71	7-65

Intrusion into the Meadowlark aquifer at sites BSO-9 and BSO-7 has occurred as horizontal flow across the Newport-Inglewood fault due to a maximum inland head differential of 35 to 40 feet. At both sites, fresh water occupies the lower part of the overlying merged Beta-Lambda aquifer as shown by electric logs (Appendix C). The effectiveness of the aquiclude in limiting vertical intrusion is best demonstrated at site BSO-3. There, a 5-foot bed of clayey silt and fine sand separates 30 ppm chloride water in the Meadowlark aquifer from overlying 4,000 ppm chloride water.

From the data presently available, the Newport-Inglewood fault is a relatively effective hydraulic barrier to the Meadowlark aquifer. Only localized intrusion has breached the fault plane in response to head differentials of 35 to 40 feet. Vertical intrusion from overlying aquifers has not been evident, despite thinning of the aquiclude to 5 feet.

Main Aquifer

Sea-water intrusion has not developed within the Main aquifer as shown by Plate 14 and Section A-A', Plate 3A, despite maximum head differentials of 50 feet landward across the Newport-Inglewood fault and 40 feet downward across the overlying aquiclude. However, water level data for AE-13 indicate underflow of fresh water has occurred across the fault at Alamitos Gap. Some intrusion has occurred vertically via wells 5S/11W-29H2 and 5S/12W-12P3, which were perforated both in intruded Pleistocene aquifers and in the Main aquifer. Vertical intrusion also existed temporarily at well 5S/11W-29C2 when the casing developed a leak at a depth of 100 feet (Alpha aquifer range) in 1957. This leak was plugged with a liner, and the well has since yielded fresh water. Oil field brines have been transmitted downward by wells 5S/11W-27R2 and -35L1, which were multiperforated in upper degraded aquifers and in the Main aquifer.

For all practical purposes, intrusion into the Main aquifer, either vertically or horizontally, may be considered only a slight hazard. The Newport-Inglewood fault is obviously an effective barrier for head differentials up to 50 feet. Ground water in the Main aquifer seaward of the fault is not saline; chloride ion concentrations at BSO-4 and BSO-5B are less than 1,000 ppm and at AE-13 are less than 100 ppm. Hence, the Ghyben-Herzberg relationship does not apply. The hydraulic base level for intrusion is further lowered because the pressure head of the coastal water in the Main aquifer is about 14 feet below sea level. If horizontal intrusion of this brackish water were to occur, degradation of the inland fresh water would be within an acceptable range for a considerable time. Intruding waters would have to completely replace more than 20 percent of the aquifer to cause a 250 ppm chloride concentration in blended water drawn from the entire aquifer. Due to diffusion of fresh and intruding waters, complete reoccupation would probably not occur; thus a greater proportion of the aquifer would have to be invaded.

Vertical intrusion to the Main aquifer is impeded by an aquiclude that has an average thickness of about 80 feet. Overlying saline waters seaward of the fault have not penetrated significantly into this relatively impervious boundary as shown by the electric logs for BS-4 and BSO-5 (Appendix C). This, despite a downward hydraulic head differential of 14 feet that has existed for some time. Inland of the fault, the overlying Bolsa and Meadowlark aquifers have been only slightly degraded by sea water. Intrusion would first have to become highly developed in these aquifers and then penetrate 80 feet of aquiclude, an inherently slow process.

Effects of Marina Construction at Huntington Harbour

The Huntington Harbour Corporation is presently constructing a residential marina in the coastal, southwest portion of Sunset Gap, as shown on Plate 2. Construction began in April 1961 in the area west of the Newport-Inglewood fault and by early 1963 had progressed to the landward side. When completed, the development will comprise 249 acres of excavated saltwater channels and 630 acres of residential and commercial land, much of which will be built up of excavated materials. The development is sited principally within a former area of shallow sloughs and salt marshes subject to inundation from tidal water.

The excavation of marina channels will cause no significant change in the sea-water intrusion regimen on the coastal side of the Newport-Inglewood fault. In this area, saline waters are native to all water-bearing deposits downward to the bottom of the Meadowlark aquifer. The hydraulic head of these waters is virtually at sea level. Excavation of marina channels to a maximum depth of 12.8 feet below mean sea level has occurred principally within Recent deposits and, to a lesser extent, in upper Pleistocene deposits. Both are in hydraulic continuity with tidal water. Thus, the hydraulic head and salinity of water in the coastal area will not be modified by the marina development.

Construction of the marina inland of the Newport-Inglewood fault has and will effect a substantial increase in the salinity of semiperched water. Excavation of saltwater channels to a maximum depth of 12.8 feet below sea level has taken place in both Recent and upper Pleistocene deposits. Stratigraphically, the deepest excavation has been into the upper part of the Pleistocene semiperched zone, which contains native water of brackish to slightly saline quality. Data on Plate 8 and Plate 11 show that channel excavation and flooding have directly affected water levels and have caused intrusion of semiperched waters. Ultimately, an upper intrusion wedge may be developed inland at least 3,000 feet from the fault as a consequence of channel excavation.

Pacific Air Industries

View northeast of tidal sloughs and marshes, February 1955.

Pacific Air Industries

View northeast of marina development as of February 1966.

Warner Avenue crossing tidal channel (bottom) and layout of the Naval Weapons Station - Seal Beach (top) provide reference points between the photographs.

HUNTINGTON HARBOUR — BEFORE AND AFTER

With respect to the freshwater aquifers, the excavation of marina channels inland of the fault will probably cause little, if any, change in vertical intrusion. Excavation will not extend into the principal aquiclude overlying the Alpha aquifer, nor even to the base of the semiperched zone. Hydraulic heads in the semiperched zone will probably be maintained at sea level due to marina development. However, it is reasonable to expect that they would be in that general range naturally. Any increase in hydraulic head attributable to channel excavation is estimated to be on the order of several feet.

As previously explained, very little, if any, vertical intrusion has reached the Alpha aquifer beneath Huntington Harbour. The principal intrusion route has been horizontal flow across the leaky fault barrier. This intrusion has highly advanced before the excavation of marina channels was started. Considering that (1) marina development will not effect an appreciable change in head differentials across the aquiclude, (2) such development will not cut into the principal aquiclude, (3) little if any vertical intrusion has occurred naturally through the aquiclude, and (4) the Alpha aquifer is subject to and has been highly intruded by underflow across the Newport-Inglewood fault, it is concluded that Huntington Harbour development does not constitute a practical threat to underlying fresh ground waters. Differentiation between horizontal and vertical intrusion that may develop in the future can be determined by the existing observation well net.

Effects of Future Marinas and Small Craft Harbors

Consideration is being given to the future development of marinas or small craft harbors in the tidal marsh portions of Sunset and Bolsa Gaps. In general, construction of salt-water channels no deeper than 15 feet below mean sea level into Recent deposits will not materially change the sea-water intrusion regimen where these shallow deposits contain saline water. However, any such proposed construction should be preceded by exploration to yield data on (1) the permeability and areal and vertical limits of stratigraphic units, (2) the salinity of shallow ground water, and (3) the hydraulic continuity of the shallow water-bearing deposits to the tidal prism and to underlying ground water aquifers.

CHAPTER VI. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The principal findings, conclusions, and recommendations of this investigation are as follows:

Findings

1. Native fresh ground waters containing less than 50 ppm chloride occur landward of the Newport-Inglewood fault in multiple, predominantly confined sand and gravel aquifers of moderate to high permeability. In descending order these are: the Bolsa aquifer (lower Recent); the Alpha, Beta, and Lambda aquifers (upper Pleistocene); the Meadowlark and Main aquifers, and the Lower Zone (lower Pleistocene); and undifferentiated aquifers of the upper Pico Formation (upper Pliocene), which are below the present reach of wells.

2. The upper five aquifers are locally interconnected, principally at Bolsa Gap and Huntington Beach Mesa, due to unconformities and discontinuities of aquicludes commonly less than 30 feet thick. Piezometric levels among these aquifers are therefore approximately the same elevation. Vertical head differentials across separating aquicludes are generally less than 1 foot. Because of these conditions, these five aquifers form an upper aquifer system.

3. The Main aquifer is overlain by a continuous aquiclude commonly more than 80 feet thick. Its piezometric surface, and that of the Lower Zone, differ in elevation from that of the upper aquifers when freshwater heads are reduced. Downward head differentials of 15 to 40 feet were developed across the aquiclude in 1957 and 1959. These deeper aquifers form a lower aquifer system.

4. Native saline waters containing up to 18,800 ppm chloride predominate seaward of the Newport-Inglewood fault within Recent and Pleistocene deposits to the base of the Meadowlark aquifer. The hydraulic head of these waters is stable and approximately at sea level. Ground water in the Main aquifer ranges downward from fresh to brackish, the more saline waters containing less than 1,000 ppm chloride. Fresh water containing less than 100 ppm chloride occurs throughout the Main aquifer beneath the south limit of Alamitos Gap. The piezometric surface of the Main aquifer seaward of the fault is essentially stable at 13 to 15 feet below sea level.

5. The Newport-Inglewood fault - North Branch - extends across the study area, partially displaces the Bolsa aquifer and all older aquifers, and forms a hydraulic barrier causing

abrupt discontinuities in piezometric levels and water quality. This barrier is not uniformly or absolutely watertight, areally or vertically. In general, it is progressively less permeable with depth. The fault does not affect ground water flow in shallow Recent deposits which contain brackish to saline semi-perched water at least 3,500 feet inland of its trace.

6. The inferred Newport-Inglewood fault - South Branch extends southeast from Bolsa Gap across Huntington Beach Mesa, apparently displaces Pleistocene aquifers, and may form a hydraulic barrier separating fresh and brackish water in the Main aquifer. Its effect on piezometric levels is indeterminable.

7. The Bolsa-Fairview fault extends southeast from Bolsa Chica Mesa across Huntington Beach Mesa and displaces Pleistocene aquifers and probably the Bolsa aquifer also. It forms a localized hydraulic barrier limiting sea-water intrusion in upper Pleistocene aquifers at Bolsa Chica Mesa but does not appear to offset piezometric levels.

8. Pumping of ground water in excess of recharge basinwide caused a decline in freshwater piezometric levels of the upper and lower aquifer systems during 1945-57. Recharge of imported water to the basin forebay and reduced extractions caused piezometric levels to recover during 1959-65. Piezometric levels were below sea level for nearly 17 years (1948-64), reaching lowest average levels of minus 30 feet in the upper aquifers and minus 50 feet in the Main aquifer during 1957 and 1959, respectively.

9. Landward head differentials of less than 10 feet caused inland horizontal intrusion of saline ground waters across relatively permeable portions of the Newport-Inglewood fault into the Alpha and Beta aquifers.

10. Intrusion advanced from 1949 until early 1962, reaching inland a maximum distance of 2,800 feet at Bolsa Chica Mesa and Huntington Beach Mesa. Since the spring of 1962, the intrusion front has retreated or has been partially eroded in most areas due to the rise in freshwater heads.

11. Separate intrusion wedges causing slight to intense degradation are irregularly distributed in the Alpha, Beta, and Lambda aquifers along most of their coastal reach. Local intrusion causing slight degradation has developed in the Meadowlark aquifer in Sunset Gap. No intrusion is evident in the Main aquifer, but underflow of fresh water across the Newport-Inglewood fault is evident at Alamitos Gap.

12. Very little, if any, inland intrusion has developed in the Bolsa aquifer, and if so, cannot be currently differentiated from the earlier northern encroachment of oil field

brines from Huntington Beach Mesa, or the later encroachment of intruded water from flanking upper Pleistocene aquifers at Bolsa Chica and Huntington Beach Mesas.

13. Vertical intrusion of tidal and saline semiperched water has occurred locally in Sunset Gap, where the surface aquiclude is discontinuous. Vertical movement of brackish semiperched water has also occurred inland of the intrusion front via wells and discontinuities in the aquiclude.

Conclusions

1. The principal route of sea-water intrusion has been horizontal flow through the variable watertight plane or shear zone of the Newport-Inglewood fault. Vertical intrusion of tidal and semiperched water through the upper aquiclude has been secondary. Vertical movement of intruded water between aquifers, except at wells, has been negligible.

2. Horizontal sea-water intrusion is a major threat to the Alpha, Beta, and Lambda aquifers, and vertical intrusion is locally a major threat to the Alpha aquifer.

3. Intrusion has been minor in the Bolsa and Meadowlark aquifers, even though they are interconnected with and are therefore subject to intrusion from the Alpha, Beta, and Lambda aquifers.

4. Intrusion is a potential but relatively slight threat to the Main aquifer and if developed would probably not cause unacceptable salt concentrations for a considerable time.

5. Freshwater heads fluctuate directly with the extraction-replenishment of water within the entire basin. Therefore, the potential for further sea-water intrusion is dependent upon future recharge-extraction conditions throughout the coastal basin, and not merely upon local pumpage.

6. Artificial recharge, and to a lesser degree, reduction in pumpage have caused a sufficient rise in piezometric levels to effect an overall retreat in the intrusion front, a retreat in the oil field brine front, and a partial flushing of waters degraded by semiperched water.

7. The Huntington Harbour development has and will continue to cause intrusion in the upper Pleistocene semiperched zone but will not appreciably change the hydraulic head of this upper water body nor cut into the principal aquiclude overlying the Alpha aquifer. The development, therefore, does not appear to constitute a practical sea-water intrusion threat to underlying freshwater aquifers.

Recommendations

1. Monitoring of wells and piezometers in the sea-water intrusion area should be continued.

2. An expanded net of monitoring wells should be constructed in the Alpha, Beta, Lambda, and Meadowlark aquifers at Landing Hill and Sunset Gap to determine the lateral and vertical range of intrusion in these areas.

3. Monitoring wells in the stratigraphic range down to and including the Main aquifer should be constructed, and trace element analysis of ground water samples made to determine the relative threat of sea-water intrusion into Pleistocene aquifers at Huntington Beach Mesa.

4. Based on present information, on findings of studies proposed under items 2 and 3, and on projected water supply conditions, the engineering feasibility of and economic justification for constructing a coastal sea-water intrusion barrier in the Bolsa-Sunset area should be determined.

5. Excavation of marinas, small craft harbors, or other major saltwater channels should be preceded by hydrogeologic exploration and water quality sampling to determine the potential intrusion hazard posed by such work. Findings should be reported to the Orange County Water District, the Regional Water Quality Control Board, and the Department of Water Resources.

6. A well construction and destruction standards policy should be adopted and enforced by local agencies to prevent any further vertical movement of inferior waters via improperly constructed or abandoned wells.

APPENDIX A

BIBLIOGRAPHY

APPENDIX A

BIBLIOGRAPHY

Allen, D. R. and Hazenbush, G. C. "Sunset Beach Oil Field." California Department of Natural Resources, Division of Oil and Gas. Summary of Operations - California Oil Fields. Vol. 43, No. 2. July-December 1957.

Bailey, P. "Water Supply of Orange County." April 1946.

----. "Engineer's Report on Ground Water Conditions in the Orange County Water District." March 1954, March 1955, March 1957, March 1958, and March 1959.

Beard, A. A. "Engineer's Report on Ground Water Conditions in the Orange County Water District." March 1956.

Bookman and Edmonston, Consulting Civil Engineers. "Investigation of Ground Water Geology and Hydrology at Huntington Harbour, Orange County, California." July 1963.

Bowes, G. H. "Seal Beach Oil Field." California State Department of Natural Resources, Division of Mines. Bulletin No. 118, Chapter VIII, pp. 325-328. 1943.

California Department of Public Works, Division of Water Resources. "Investigation of Salt Water Intrusion along Orange County Coast. General Outline of Situation and Estimate of Cost of Drilling." Office Report. June 1931.

----. "South Coastal Basin Investigation, Quality of Irrigation Waters." Bulletin No. 40. 1933.

----. "South Coastal Basin Investigation, Detailed Analyses Showing Quality of Irrigation Waters." Bulletin No. 40-A. 1933.

----. "South Coastal Basin Investigation, Geology and Ground Water Storage Capacity of Valley Fill." Bulletin No. 45. 1934.

----. "Present Overdraft On, and Safe Yield From, the Ground Water of the Coastal Plain of Orange County." Office Report. June 1945.

----. "South Coastal Basin Investigation, Overdraft on Ground Water Basins." Bulletin No. 53. 1947.

California Department of Public Works, Division of Water Resources. "Investigation of Salt Water Intrusion along Orange County Coast. General Outline of Situation and Estimate of Cost of Drilling." Office Report. June 1931.

----. "Sea-Water Intrusion into Ground Water Basins Bordering the California Coast and Inland Bays." Office Report. December 1950.

----. "Survey of Oil Industry Wastes in Orange County (Project No. 52-8-1)." Office Report and Appendixes prepared for the Santa Ana Regional Water Pollution Control Board No. 8. February 1954.

California Department of Water Resources. "Investigation of Ground Water Pollution of Bolsa Chica Mesa-Sunset Beach, California." Office Report. January 1958.

----. "Sea-Water Intrusion in California." Bulletin No. 63. November 1958; Appendix B, March 1957; Appendixes C, D, and E, April 1960.

----. "Orange County Land and Water Survey, 1957." Bulletin No. 70. January 1959.

----. "Santa Ana River Investigation." Bulletin No. 15. February 1959.

----. "Santa Ana Gap Salinity Barrier, Orange County." Bulletin No. 147-1. December 1966.

Ferris, J. D., Knowles, D. B., Brown, R. H., and Stallman, R. W. "Theory of Aquifer Tests." United States Geological Survey Water-Supply Paper No. 1536-E. 1962.

Garrett, A. A. "Status of Salt-Water Contamination in the Coastal Part of Orange County, California, as of 1948-49." United States Geological Survey. Unpublished Release. August 1949. Similar Reports for 1950, April 1951 and 1951, August 1952.

----. "Summary Statement of Salt-Water Contamination in the Coastal Part of Orange County, California, as of 1952." United States Geological Survey. Unpublished Release. January 1953.

Hazenbush, G. C. and Allen, D. R. "Huntington Beach Oil Field." California Department of Natural Resources, Division of Oil and Gas. Summary of Operations - California Oil Fields. Vol. 42, No. 2. January-June 1958.

Los Angeles County Flood Control District. "Coastal Basins Barrier and Replenishment Investigation, Alamitos Barrier Project Geologic Investigation." May 1961.

----. "Report on Required Facilities for Replenishing and Protecting Ground Water Reserves in the Central and West Coast Ground Water Basins, Part II, Alamitos Barrier Project." January 1962.

----. "Alamitos Barrier Project Annual Report, July 1, 1964 to June 30, 1965." October 1965.

----. "Report on Alamitos Barrier Project 1965-66." October 1966.

Mendenhall, W. C. "Development of Underground Waters in the Central Coastal-Plain Region of Southern California." United States Geological Survey Water-Supply Paper and Irrigation Paper No. 138. 1905.

Nichols, D. W. "Well Water Age Dating by Carbon-14 Technique." Unpublished M. S. Thesis, University of California at Los Angeles. 1964.

Orange County Water District. "Statement Regarding the Present Condition of the Underground Water Basin of Orange County." August 1945.

Piper, A. M., Garrett, A. A., et al. "Native and Contaminated Ground Waters in the Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1136. 1953.

Poland, J. F. "Summary Statement of Ground-Water Conditions and Saline Contamination Along the Coast of Orange County, California." Orange County Water District - United States Geological Survey. Unpublished Release. September 1947.

Poland, J. F., Piper, A. M., et al. "Ground Water Geology of the Coastal Zone, Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1109. 1956.

Poland, J. F. and Sinnott, A. "Hydrology of the Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1471. 1959.

Stallman, R. W. "Type Curves for the Solution of Single-Boundary Problems" in "Shortcuts and Special Problems in Aquifer Tests." United States Geological Survey Water Supper Paper No. 1545-C. Pp. 45-47 and Plate 3. 1963.

Talbert, T. B. "My Sixty Years in California". Huntington Beach News Press. 1952.

Toups, J. M. "Engineers Report on Ground Water Conditions in the Orange County Water District." February 1963.

----. "Annual Report on Ground Water Conditions Within the Orange County Water District for the Year 1965-66." February 1967.

United States Department of Health, Education, and Welfare, Public Health Service. "Drinking Water Standards, 1962." Publication No. 956. May 1962.

Wall, J. R., Cordes, E. H., and Moreland, J. A. "Progress Report on Salt-Water Intrusion Studies, Sunset and Bolsa Gaps, Orange County, California." United States Geological Survey. Open-File Report. June 1966.

Yerkes, R. F., McCulloh, T. H., Schoelhamer, J. E., and Vedder, J. G. "Geology of the Los Angeles Basin California - an Introduction." United States Geological Survey Professional Paper 420-A. 1965.

APPENDIX B

DEFINITIONS

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DEFINITIONS

The following words and terms as used in this report are defined as follows:

Acre-foot - The volume of water required to cover one acre to a depth of one foot. (43,560 cubic feet or 325,851 gallons).

Anticline - An upward convex fold where strata dip in opposite directions from a common axis.

Apparent Resistivity - The recorded electrical resistivity in ohms-meters squared per meter measured by the long normal (64 inches) or lateral (18 feet 8 inches) curves of an electric log.

Artesian Water - Ground water that is under sufficient hydraulic pressure to rise above the level at which it is contained in a confined aquifer and flow naturally from a well or spring.

Aquiclude - A geologic formation or zone which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply to a well or spring. In the Bolsa-Sunset area, beds comprised chiefly of silt and clay which impede vertical flow within the zone of saturation. Synonymous with confining bed.

Aquifer - A geologic formation or zone that transmits water in sufficient quantity to supply a well or spring. In the Bolsa-Sunset area, beds comprised chiefly of sand and gravel. Aquifers, either confined or unconfined, form the principal ground water reservoir.

Artificial Recharge - The process of adding water to the ground water body through facilities primarily designed for that purpose, such as through spreading basins or injection wells.

Brackish Water - Water containing more than 1,500 but less than 5,000 parts per million total dissolved solids.

Confined Aquifer - An aquifer containing confined ground water.

Confined Ground Water - A body of ground water immediately overlain by material sufficiently impervious to sever free hydraulic connection with overlying water or the atmosphere, and moving under gradient or pressure caused by the differences in head between the intake or forebay area and the discharge area.

Confining Bed - See aquiclude.

Connate Water - Ground water entrapped in the interstices of sediments at the time they were deposited. In this report, applied to saline waters of Tertiary deposits and synonymous with oil field brines.

Contamination - Defined in Section 13005 of the California Water Code: ". . . an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which creates an actual hazard to public health through poisoning or through the spread of disease ...." Jurisdiction over matters regarding contamination rests with the California Department of Public Health and local health officers.

Deterioration - An impairment of water quality.

Drawdown - The lowering of the water table or piezometric surface due to the pumping of ground water.

Electric Log - The log obtained by lowering electrodes in a bore hole and measuring continuous changes in electrical resistivity and spontaneous potential (SP) of geologic formations as the electrodes are withdrawn. Changes in resistivity and SP result principally from differences in lithology and ground water salinity.

Equivalents Per Million (epm) - Chemically equivalent weights of solute contained in one million parts by weight of solution. Parts per million (ppm) divided by the combining weight of an ion.

Fault - A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture. The displacement may be a few inches or many miles.

Fault Zone - Instead of one single fracture, numerous interlacing small faults or a confused zone of gouge or breccia of varying width.

Foraminifera - A subdivision of the phylum protozoa with skeletons known as tests, which are usually microscopic in size.

Forebay Area - An area of the ground water basin having essentially free hydraulic continuity from ground surface to the zone of saturation, where ground water is recharged and from which subsurface flow supplies ground water to a pressure area.

Fresh Water - Water containing less than 1,500 parts per million total dissolved solids.

Ground Water - Subsurface water occurring in the zone of saturation and moving under control of the water table or piezometric gradient.

Ground Water Basin - An area underlain by one or more permeable formations containing and capable of furnishing a substantial water supply.

Ground Water Storage - That stage of the hydrologic cycle during which water occurs below ground surface in the zone of saturation.

Hydraulic Gradient - Under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the slope of the profile of the piezometric surface.

Impairment - A change in quality of water which makes it less suitable for beneficial use.

Impermeable-Impervious - Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Industrial Waste - Defined in Section 13005 of the California Water Code: ". . . any and all liquid or solid waste substance, not sewage, from any producing, manufacturing or processing operation of whatever nature."

Oil Field Brines - Saline connate waters extracted by oil wells and discharged as industrial wastes.

Parts Per Million (ppm) - One part per million by weight solute to one million parts solution at a temperature of 20° centigrade.

Percolation - The movement, or flow, of water through interstices of porous media.

Permeability - The capacity of a porous media for transmitting a fluid. The degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Permeability, Coefficient of - The rate of flow of water in gallons per day through a cross-sectional area of one square foot under a hydraulic gradient of one foot per foot at a temperature of 60° F.

Permeability, Field Coefficient of - The amount of water moving through a unit area of aquifer per unit time under unit hydraulic gradient at the natural temperature. It is usually expressed in gallons per day per square foot.

Piezometer - A small-diameter observation well used to monitor the positive pressure exerted by a water table or pressure aquifer or to obtain ground water samples for chemical analysis.

Piezometric Surface - The surface to which confined ground water will rise in wells under full aquifer head.

Pollution - Defined in Section 13005 of the California Water Code: ". . . an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which does not create an actual hazard to the public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation." Regional water quality control boards are responsible for prevention and abatement of pollution.

Porosity - The ratio of the volume of voids of a given soil mass to the total volume of the soil mass, usually stated as a percentage.

Pressure Area - An area of the ground water basin underlain by confined ground waters which are not in free hydraulic continuity with ground surface or semiperched ground waters and which are recharged by underflow from a forebay area.

Saline Water - Salt Water - Water containing more than 5,000 parts per million total dissolved solids.

Saltwater Wedge - The inland pointing saltwater body which develops and advances along the bottom of an aquifer subject to saline intrusion, by virtue of the greater specific gravity of saline water compared to fresh water.

Sea Water - Ocean water and tidal water containing approximately 36,000 parts per million total dissolved solids. Also, for this report, native saline ground waters located seaward of the Newport-Inglewood fault.

Sea-Water Intrusion - The encroachment of ocean water, tidal water or native saline ground water into fresh water aquifers under a landward or downward hydraulic gradient.

Semiperched Ground Water - Shallow ground water within the zone of saturation having a different hydraulic head and commonly a different chemical quality than underlying confined ground waters, from which free hydraulic continuity is interrupted by an aquiclude.

Storage, Coefficient of - The volume of water released from storage in each vertical column of aquifer having a base one foot square when the water level declines one foot. In an unconfined aquifer the storage coefficient approximates specific yield; in a confined aquifer it is related to the elasticity of the aquifer and usually is very small.

Syncline - A downward concave fold where strata dip toward a common axis.

Total Dissolved Solids (TDS) - The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Transmissibility, Coefficient of - The rate of flow of water at the prevailing water temperature in gallons per day, through each vertical strip of the aquifer one foot wide, extending the full saturated height of the aquifer, under a hydraulic gradient of 100 percent.

Unconfined Aquifer - An aquifer containing a water table which is at atmospheric pressure and above which, water can, in most cases, percolate freely to the zone of saturation.

Unconfined Ground Water - Ground water whose upper surface forms a water table at atmospheric pressure and in which hydraulic pressure is equal to the depth from that water table to the point in question. Moves under gravity according to the slope of the water table.

Unconformity - A surface of erosion or nondeposition, usually the former, that separates younger strata from older rocks.

Water Table - The surface of ground water at atmospheric pressure in an unconfined aquifer. Forms the upper limit of the zone of saturation.

APPENDIX C

EXPLORATION DRILLING AND WELL CONSTRUCTION

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EXPLORATION DRILLING AND WELL CONSTRUCTION

During the early phase of the investigation, it became evident that exploration drilling and the construction of observation wells were necessary. Existing wells for monitoring ground water levels and water quality were unavailable in much of the sea-water intrusion area. For those wells suitably located, logs and construction records were generally inferior, incomplete, or unavailable.

Exploration Drilling - 1961

After evaluating the distribution of available subsurface geologic data, eight exploration drill sites were selected along the Newport-Inglewood structural zone between Bolsa and Sunset Gaps. Temporary land use permits were negotiated without cost from private owners and from the United States Navy. Exploration drilling was performed by light rotary equipment during July-September 1961. Contract expenditures amounting to $13,925 were paid to the Bowline Drilling Company. An additional $3,860.50 was paid to the Lane Wells Company and the Schlumberger Well Surveying Corporation for electric logging services.

The 7-inch rotary-drilled holes were logged continuously by Department geologists. To optimize obtaining representative logs, drilling speed was curtailed and the holes were circulated clean after each new penetration of drill rod (about 22 feet). After an electric log was run, the holes were backfilled with a heavy slurry of bentonite clay and drill cuttings to preclude the vertical exchange of ground water between aquifers.

At site BS-4, 5S/11W-32A1, a 2-inch piezometer was constructed in the Main aquifer. The construction of a 1-inch piezometer in the Bolsa aquifer was thwarted by the relatively large discharge of gas which disrupted emplacement of the cement grout plug above the gravel pack envelope. The cement became a froth, which worked its way through the gravel pack and into the piezometer.

The locations of the eight BS exploration holes are shown on Plate 2. The field number, state well number, and depth of these holes are shown in Table 8. Well logs and electric logs follow this text. Data on the 2-inch piezometer installed at BS-4 is included in Table 9.

TABLE 8

EXPLORATION DRILLING SITES - 1961

Field number	State well number	Depth of hole, in feet
BS-1	5S/11W-28J3	298
BS-2	5S/11W-33B1	500
BS-3	5S/11W-28P1	700
BS-4	5S/11W-32A1	700
BS-5	5S/11W-29J1	558
BS-6	5S/11W-20M1	298
BS-7	5S/11W-19B1	1,000
BS-8	5S/12W-13A1	1,010

Well Construction - 1963

Eight sites were selected for the construction of observation wells and piezometers. Of these eight sites, five were located at or near the exploration sites of 1961. Sites BSO-2, BSO-5 and BSO-8 were new. Right-of-way permits with a life of five years were negotiated from landowners without cost. The owner could cancel the permit at any time by giving 90 days advance written notice to the Department, but as of January 1967, all permits were in force.

Drilling and well construction were performed during June-September 1963, under contract to the Bowline Drilling Company at a cost of $28,385.42. The Lane Wells Company was paid $2,002.04 for electric logs run at sites BSO-5 and BSO-8.

According to the terms of the contract, 17 piezometers were constructed in nine 7-inch diameter rotary-drilled holes. The piezometers were 2-inch ID, schedule 80, type II polyvinyl chloride pipe, which is resistant to corrosion. The 20-foot sections of pipe were joined by Ventura Flush Modified Acme threads, providing a strong, watertight connection. Perforations were made in the field by an electric drill.

To obtain maximum use of construction expenditures, two piezometers were commonly installed within one bore hole. The deeper piezometer was run into the hole and the annulus filled with a well-rounded 1/4-inch gravel pack to several feet above the top of the aquifer. Portland cement grout with a 2 percent by weight calcium chloride additive was then pumped into the well annulus on top of the gravel pack. After the cement plug had set, the shallower piezometer was run into the hole. Gravel packing and emplacement of another cement plug proceeded as explained above.

The remaining or unused portion of the hole was filled with pea gravel in aquifers, and cement grout plugs in aquicludes. The uppermost 20 to 25 feet of the hole were filled with concrete.

The six observation wells of 6-3/8-inch ID steel casing were installed in separate 14-inch diameter rotary-drilled holes. The 21- to 23-foot sections of casing were joined by overlapping collars which were welded watertight. Perforations were machine-milled, 2-inch vertical keystone slots, 100-mesh. After installation of the casing, the hole was gravel-packed to several feet above the top of the aquifer and a cement grout plug was installed. The remaining portion of the hole was backfilled with pea gravel, cement grout, and concrete, as described previously.

Six 1-inch piezometers of steel and polyvinyl chloride pipe were also installed to monitor ground water zones not otherwise explored by the terms of the contract. The materials for these 1-inch piezometers were provided by the Orange County Water District. The 20-foot sections of pipe were connected by API threaded collars or glued plastic collars. Perforations were made in the field with an electric drill.

Table 9 lists data on the one piezometer constructed in 1961 and the 30 piezometers constructed in 1963. These wells and piezometer locations are shown on Plate 1. Well and electric logs for BSO-2, BSO-5, and BSO-8 follow the text.

Well Construction - 1965

During May-June 1965, 10 exploration holes were drilled and 26 piezometers were constructed in the inland portion of the study area from the south edge of Sunset Gap to Huntington Beach Mesa. This work was funded under the Department's Porter-Dolwig Ground Water Basin Protection Program as the first phase of a sea-water intrusion barrier study. High ground water pressure levels and reduction in program funds have caused further barrier studies to be deferred. Rotary drilling and well construction were performed by McCalla Brothers, for a contract price of $20,558. Welex and the Lane Wells Company were paid $3,445.40 for electric logging services. Data on the 26 one-inch diameter piezometers are presented in Table 10. The locations of the piezometers are shown on Plate 1.

TABLE 9

OBSERVATION WELLS AND PIEZOMETERS - 1963

Field number	State well number	Depth of hole, in feet	Length of casing, in feet	Diameter of casing, in inches	Depth of perforations, in feet	Aquifer
BSO-1A	5S/11W-33B2	113	115	6	80-104	Bolsa
BSO-1B	5S/11W-33B3	360	30	2	10-26	Semiperched
BSO-1C	5S/11W-33B4	360	55	2	31-50	Semiperched
BSO-1D	5S/11W-33B5	360	357	2	245-335	Meadowlark
BSO-2	5S/11W-28M2	115	116	6	44-106	Bolsa-Meadowlark
BSO-3A	5S/11W-29J2	125	124	6	57-120	Alpha-Beta
BSO-3B	5S/11W-29J3	155	155	2	125-150	Meadowlark
BSO-4	5S/11W-32A1	500	500	2	268-498	Main
BSO-5A	5S/11W-29F1	741	198	2	60-178	Alpha-Beta
BSO-5B	5S/11W-29F2	741	625	2	407-605	Main
BSO-6A	5S/11W-20M2	150	151	6	85-135	Alpha
BSO-6B	5S/11W-20M3	305	220	2	160-215	Beta-Lambda
BSO-6C	5S/11W-20M4	305	305	2	235-295	Meadowlark
BSO-6D	5S/11W-20M5	150	38	1	21-38	Semiperched
BSO-7A	5S/11W-19B2	257	256	6	187-248	Beta-Lambda
BSO-7B	5S/11W-19B3	177	115	2	80-110	Alpha
BSO-7C	5S/11W-19B4	177	175	2	140-170	Alpha
BSO-7D	5S/11W-19B5	575	365	2	271-355	Meadowlark
BSO-7E	5S/11W-19B6	575	575	2	446-565	Main
BSO-7F	5S/11W-19B7	257	41	1	21-41	Semiperched
BSO-8A	5S/11W-18N3	288	41	1	21-41	Semiperched
BSO-8B	5S/11W-18N4	288	81	1	61-81	Alpha
BSO-8C	5S/11W-18N5	288	156	2	81-151	Alpha
BSO-8D	5S/11W-18N6	288	214	1	174-209	Beta-Lambda
BSO-8E	5S/11W-18N7	288	289	2	249-281	Meadowlark
BSO-9A	5S/12W-13A2	285	285	6	195-285	Beta-Lambda
BSO-9B	5S/12W-13A3	285	24	1	10-24	Semiperched
BSO-9C	5S/12W-13A4	624	101	1	56-101	Alpha
BSO-9D	5S/12W-13A5	285	169	2	115-162	Alpha
BSO-9E	5S/12W-13A6	445	445	2	340-434	Meadowlark
BSO-9F	5S/12W-13A7	624	620	2	520-615	Main

TABLE 10

OBSERVATION PIEZOMETERS - 1965

Field number	State well number	Depth of hole, in feet	Length of casing, in feet	Depth of perforations, in feet	Aquifer
BS-101A	5S/11W-26Q1	505	252	229-247	Lower Rho
BS-101B	5S/11W-26Q2	505	167	126-157	Lambda
BS-102A	5S/11W-26H7	551	347	304-335	Lower Rho
BS-102B	5S/11W-26H8	551	235	176-225	Lambda
BS-103A	5S/11W-26D4	484	215	184-205	Lambda
BS-103B	5S/11W-26D5	484	145	98-135	Alpha-Beta
BS-103C	5S/11W-26D6	484	88	43- 78	Bolsa-Alpha
BS-104A	5S/11W-27Q3	349	271	245-260	Main
BS-104B	5S/11W-27Q4	349	90	32- 82	Bolsa
BS-105A	5S/11W-27D5	394	207	150-197	Lambda-Meadowlark
BS-105B	5S/11W-27D6	394	133	105-123	Beta
BS-105C	5S/11W-27D7	394	95	69- 85	Bolsa-Alpha
BS-106A	5S/11W-22G2	556	265	213-255	Lambda
BS-106B	5S/11W-22G3	556	163	111-153	Alpha-Beta
BS-106C	5S/11W-22G4	556	102	50- 92	Bolsa
BS-107A*	5S/11W-15G1	738	451	398-441	--
BS-107B	5S/11W-15G2	738	316	285-306; 254-268	--
BS-107C	5S/11W-15G3	738	202	117-192	Alpha
BS-108A	5S/11W-16G1	640	375	312-365	Lambda
BS-108B	5S/11W-16G2	640	300	206-290	Beta
BS-108C	5S/11W-16G3	640	195	90-185	Alpha
BS-109A	5S/11W-21G1	595	360	287-350	Meadowlark
BS-109B	5S/11W-21G2	595	263	226-253	Lambda
BS-109C	5S/11W-21G3	595	195	132-185	Alpha-Beta
BS-110**	--	--	--	--	--
BS-111A	5S/11W-20J9	483	215	184-205	Lambda
BS-111B	5S/11W-20J10	483	170	128-160	Alpha-Beta

*Site BS-107 located outside study area.
**Site BS-110 not drilled.

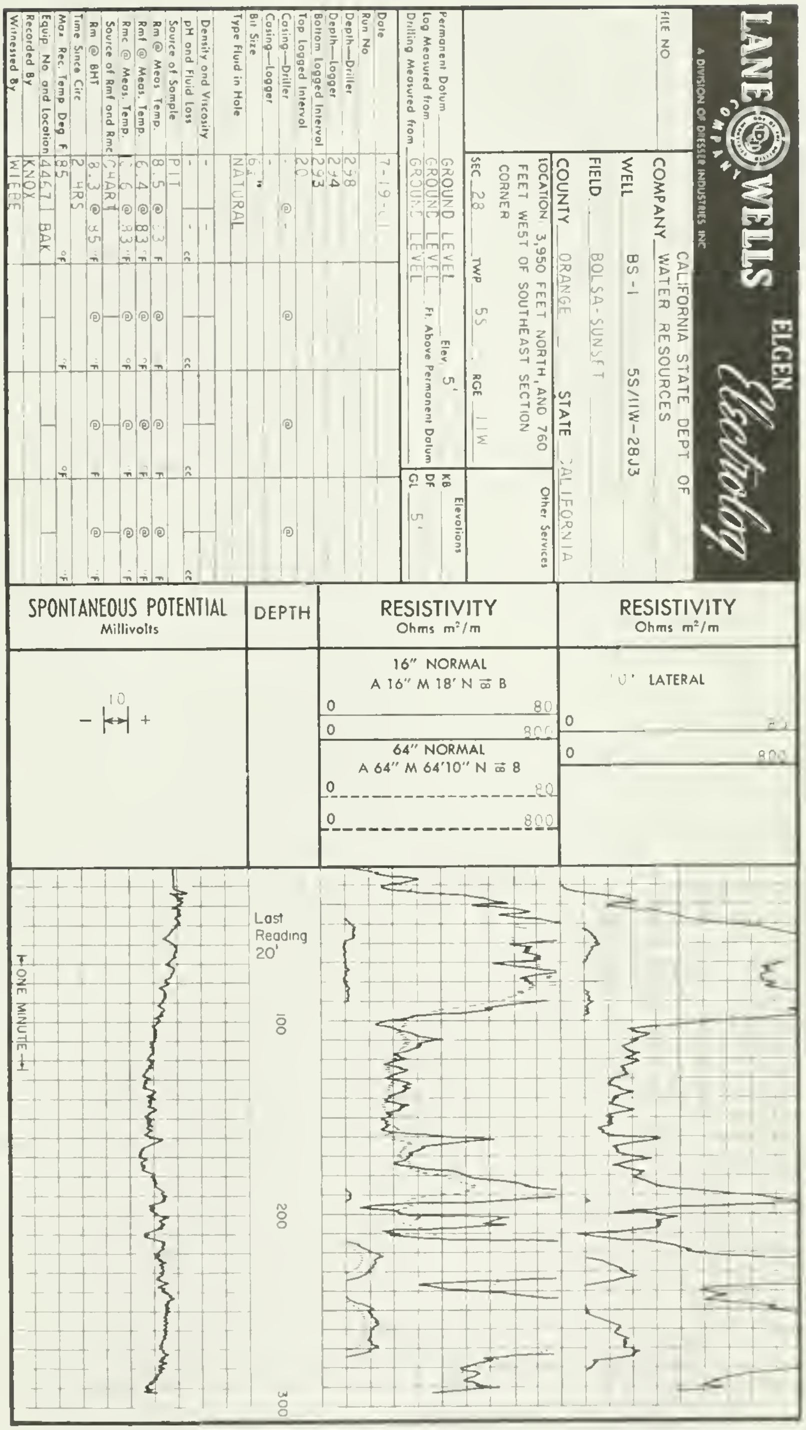
WELL LOG

Drilling Site No. BS–1
Drilling Method: Rotary
Ground Surface Elevation: 5 feet

State Well No. 5S/11W–28J3
Diameter: 7 inches
Depth: 298 feet

Depth in Feet	Material
0– 12	Clay and Sand.
12– 30	Clay: Gray, fine to medium sandy clay with granules and shell beds.
30– 39	Clay: Black and gray fine sandy clay with a few shells.
39– 74	Sand: Gray, fine to coarse silty sand with shells and wood fragments, and medium to very coarse sand, granules, fine gravel and a few shells.
74– 84	Sand and Clay: Medium to coarse sand, and clay with much wood and shells.
84– 98	Silt and Sand: Organic silt with fine sand, much wood and shell fragments.
98–165	Clay: Gray coarse sandy clay with wood and shell fragments.
165–211	Silt and Clay: Fine sandy silt and clay with shell fragments and thin sand stringers.
211–258	Sand: Gray, fine to very coarse sand with silt and fine stringers of very fine gravel and unweathered rock chips.
258–270	Sand and Gravel: Medium to very coarse sand, granules and gravel (fragments of 1 – 2-inch rock).
270–298	Clay: Dark gray, coarse sandy, silty clay with imbedded granules, wood fragments and shells.

ELECTRIC LOG BS-1



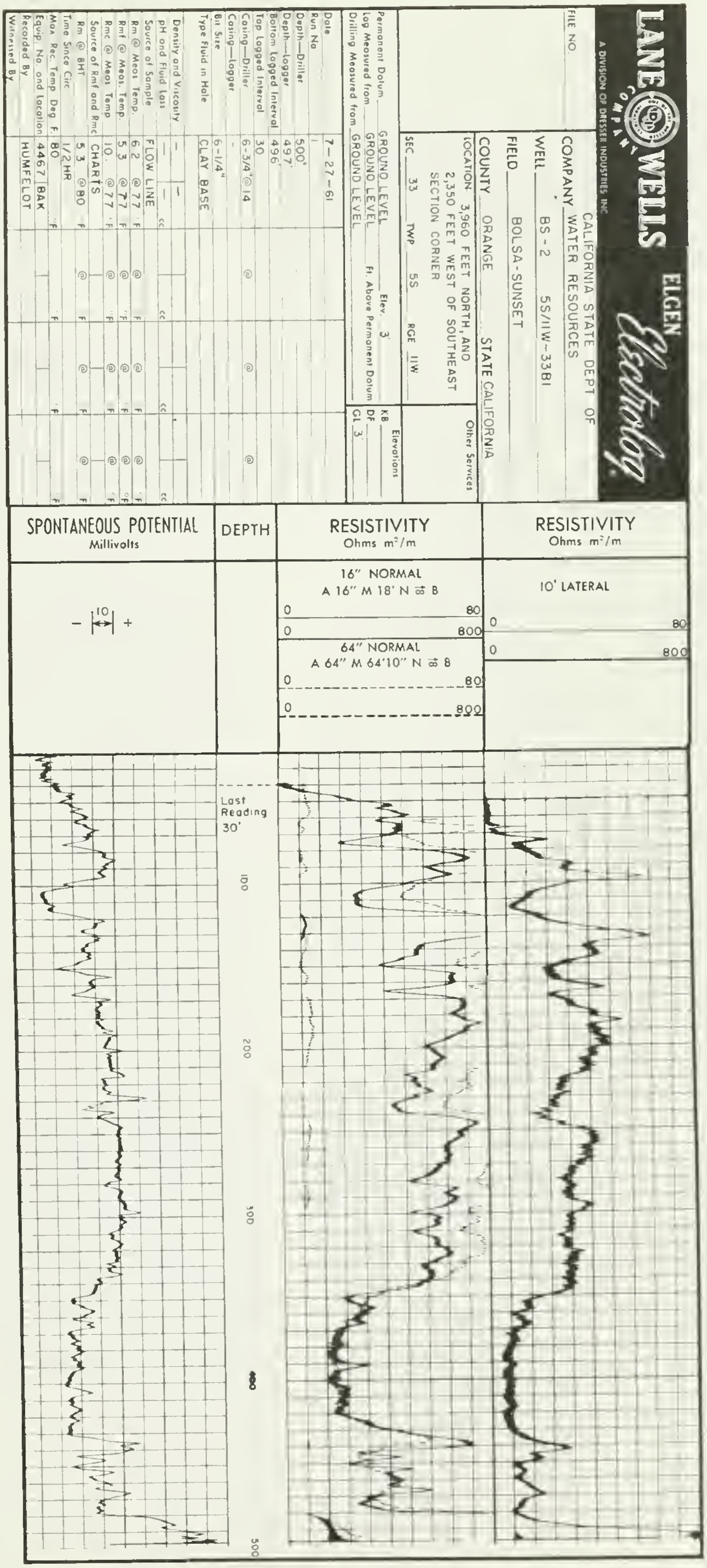
WELL LOG

Drilling Site No. BS–2 (BSO–1)
Drilling Method: Rotary
Ground Surface Elevation: 3 feet

State Well No. 5S/11W–33B1
Diameter: 7 inches
Depth: 500 feet

Depth in Feet	Material
0– 3	Fill: Silty sand.
3– 9	Clay: Dark gray, fine sandy clay with large shells.
9– 26	Sand: Dark blue, very fine to fine silty sand with shells.
26– 30	Sand and Clay: Dark blue, very fine to fine sand with clay. Large shells.
30– 40	Sand: Gray, very fine to fine sand with organic silt and shells.
40– 46	Silt: Dark gray clayey silt with fine to medium sand and shell fragments.
46– 49	Sand: Black, fine to coarse silty organic sand.
49– 70	Clay: Light blue-gray silty clay with fine sand. Medium to coarse sand streaks 64 – 69 feet.
70– 81	Sand and Clay: Gray sandy clay (71 – 76 feet, and 80 – 81 feet) and medium to very coarse sand with granules.
81–100	Sand: Fine to very coarse clean sand with granules.
100–119	Clay: Brown coarse sandy clay with embedded granules and gravel to 1/4 inch.
119–150	Sand: Fine to very coarse sand with granules and rock chips. Gravel streaks and shell fragments.
150–154	Clay: Gray, medium to very coarse sandy, silty clay.
154–190	Sand: Brown, fine to coarse sand with granules and shell fragments.
190–208	Sand: Brown, fine to coarse sand with silt and clay. Organic matter abundant.
208–218	Sand: Fine to medium quartzose sand with organic matter.
218–365	Sand: Brown to blue silty sand with some coarse particles. Shell fragments.
365–385	Silty Sand: Fine sand with some medium to coarse particles and some clay.
385–399	Sandy Silt: Blue gray, very fine to fine sandy silt with minor clay.
399–425	Clayey Silt: Dark gray clayey silt.
425–440	Sandy Silt: Gray, fine sandy silt with shell fragments.
440–481	Sand: Gray, fine silty sand.
481–493	Sandy Clay: Gray sandy clay with abundant medium sand granules.
493–500	Sand: Gray to white, medium to coarse sand.

ELECTRIC LOG BS-2



WELL LOG

Drilling Site No. BS–3
Drilling Method: Rotary
Ground Surface Elevation: 1 foot

State Well No. 5S/11W–28P1
Diameter: 7 inches
Depth: 700 feet

Depth in Feet	Material
0– 17	Sand and Silt: Very fine to fine silty sand and clayey silt with large shells.
17– 46	Clay: Dark gray silty clay with fine to coarse sandy silt. Large shells.
46– 80	Sand and Gravel: Very fine to fine sand with granules and gravel to 1/2 inch. Few small shells and clay stringers between 67 – 70 feet.
80–102	Clay: Medium to coarse sandy clay with granules and gravel to 1/2 inch.
102–144	Clay: Dark gray, fine to medium sandy clay. Shell fragments and sand stringers at 140 – 143 feet.
144–187	Silt and Clay: Very fine sandy clay, and clayey silt with a few shells. Fine sand stringers at 153 – 187 feet.
187–221	Sand: Fine to very coarse silty sand with some granules and wood fragments.
221–248	Sand and Gravel: Medium to very coarse sand with granules and gravel to 1/4 inch. Wood and shell fragments.
248–251	Clay: Gray coarse sandy clay with embedded granules.
251–273	Sand: Fine to very coarse sand with granules. Clay and fine sand stringers at 261 – 273 feet.
273–344	Sand: Medium to very coarse sand with granules and gravel to 1/2 inch. 1 – 2-inch gravel at 320 – 333 feet, and thin clay streaks at 333 – 341 feet.
344–366	Clay: Dark gray silty clay with some embedded granules.
366–436	Sand: Very fine to very coarse sand with granules and fine gravel. Shell fragments and clay stringers at 400 to 411 feet.
436–482	Clay: Gray silty clay with some coarse sand and granules. Thin sand stringers at 443 – 447 and 461 – 479 feet.
482–549	Sand: Fine to very coarse sand with granules and shell fragments. Clay stringers at 506 – 508 and 532 – 549 feet.
549–605	Silt: Gray clayey silt with very fine to coarse sand and a few granules and shell fragments.
605–674	Silt and Clay: Alternating beds of fine to coarse sandy, clayey silt, and silty clay, and silt. Some thin sand streaks.
674–700	Clay: Fine to very coarse sandy silty clay with embedded granules.

ELECTRIC LOG BS-3

LANE WELLS COMPANY — A DIVISION OF DRESSER INDUSTRIES INC

ELGEN Electrolog

FILE NO. ______

COMPANY: CALIFORNIA STATE DEPT OF WATER RESOURCES

WELL: BS-3 5S/11W-28P1

FIELD: BOLSA-SUNSET

COUNTY: ORANGE STATE: CALIFORNIA

LOCATION: 780 FEET NORTH, AND 1,580 FEET EAST OF SOUTHWEST SECTION CORNER

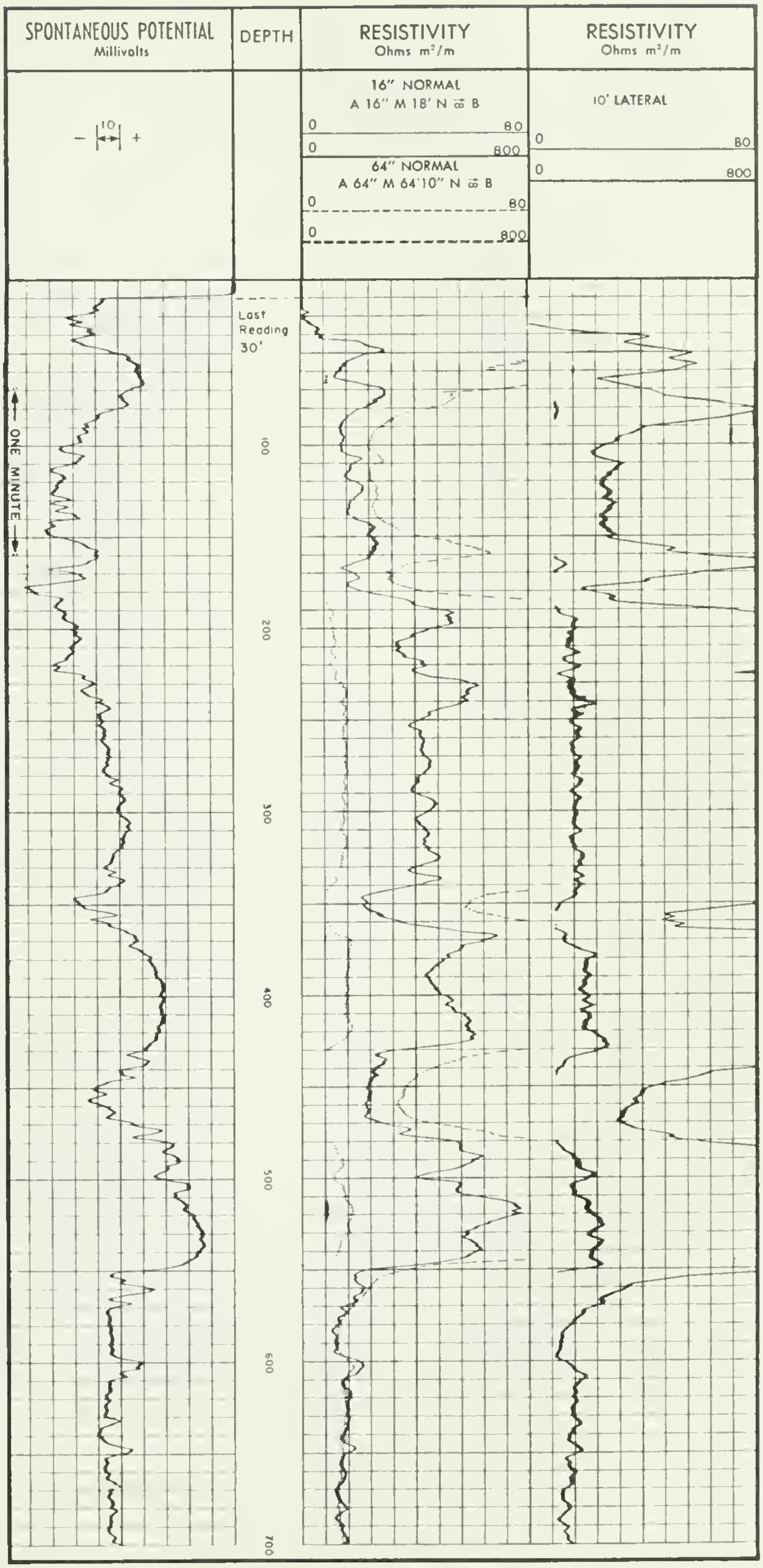
SEC 28 TWP 5S RGE 11W

Other Services

Permanent Datum: GROUND LEVEL Elev 1'
Log Measured from: GROUND LEVEL Ft Above Permanent Datum
Drilling Measured from: GROUND LEVEL

Elevations: KB —; DF —; GL 1'

Date	8-4-61			
Run No	1			
Depth—Driller	700			
Depth—Logger	700			
Bottom Logged Interval	700			
Top Logged Interval	30			
Casing—Driller	6-3/4" @ 14	@	@	@
Casing—Logger	—			
Bit Size	6-1/4"			
Type Fluid in Hole	CLAY BASE			
Density and Viscosity	— —			
pH and Fluid Loss	— — cc	cc	cc	cc
Source of Sample	MUD PIT			
Rm @ Meas Temp	4.5 @ 75 °F	@ °F	@ °F	@ °F
Rmf @ Meas Temp	3.66 @ 75 °F	@ °F	@ °F	@ °F
Rmc @ Meas Temp	6.5 @ 75 °F	@ °F	@ °F	@ °F
Source of Rmf and Rmc	CHARTS			
Rm @ BHT	4.2 @ 82 °F	@ °F	@ °F	@ °F
Time Since Circ.	1 HR			
Max Rec. Temp Deg F	82 °F	°F	°F	°F
Equip No and Location	4474 PARA			
Recorded By	HUMFELDT			
Witnessed By	CARL WIEBE			



WELL LOG

Drilling Site No. BS–4 (BSO–4)
Drilling Method: Rotary
Ground Surface Elevation: 2 feet

State Well No. 5S/11W–32A1
Diameter: 7 inches
Depth: 700 feet

Depth in Feet	Material
0– 33	Sand: Very fine silty sand with thick shell zones.
33– 46	Clay: Gray soft silty clay with fine sand.
46– 62	Silt and Sand:
62– 96	Sand: Very fine to coarse sand with granules and gravel to 1/2-inch; shells, and wood fragments.
96–102	Silt: Fine to coarse sandy, clayey silt with shells.
102–107	Clay and Gravel: Gray sandy clay with embedded gravel to 1/4 inch.
107–113	Sand and Silt: Very fine sand and sandy silt with shells.
113–151	Clay: Fine to coarse sandy, silty clay with embedded granules. Lenses of silty medium sand.
151–170	Sand: Medium to very coarse silty sand.
170–177	Sand and Silt: Very fine to coarse silty sand and fine sandy silt with shell fragments.
177–205	Silt: Fine to very coarse sand, clayey silt, with embedded granules. Wood and shells present.
205–274	Clay: Gray, fine to very coarse sandy, silty clay with shell and wood fragments. Sand stringers 255 – 260, and 269 – 273 feet.
274–306	Sand: Gray, very fine to coarse sand with shell and wood fragments.
306–340	Sand and Gravel: Fine to very coarse sand with granules and gravel. Shell and wood fragments. Lenses of brown sandy clay.
340–387	Sand: Fine to very coarse sand with granules and fine gravel. Wood and shell fragments. Beds of 1/4 – 1/2-inch gravel at 353 to 378 feet.
387–445	Sand and Gravel: Fine to very coarse sand with granules and gravel to 1/4 inch.
445–509	Sand: Fine to coarse sand with gravel lenses. Shell fragments.
509–700	Sand: Very fine to coarse sand with some clay and shell fragments.

ELECTRIC LOG BS-4

LANE WELLS COMPANY *Electrolog*

FILE NO

COMPANY: CALIFORNIA STATE DEPT OF WATER RESOURCES

WELL: BS-4 5S/11W-32A1

FIELD: BOLSA - SUNSET

COUNTY: ORANGE STATE: CALIFORNIA

LOCATION: 650 FEET WEST AND 275 FEET SOUTH OF NORTHEAST SECTION CORNER

Other Services

SEC 32 TWP 5S RGE 11W

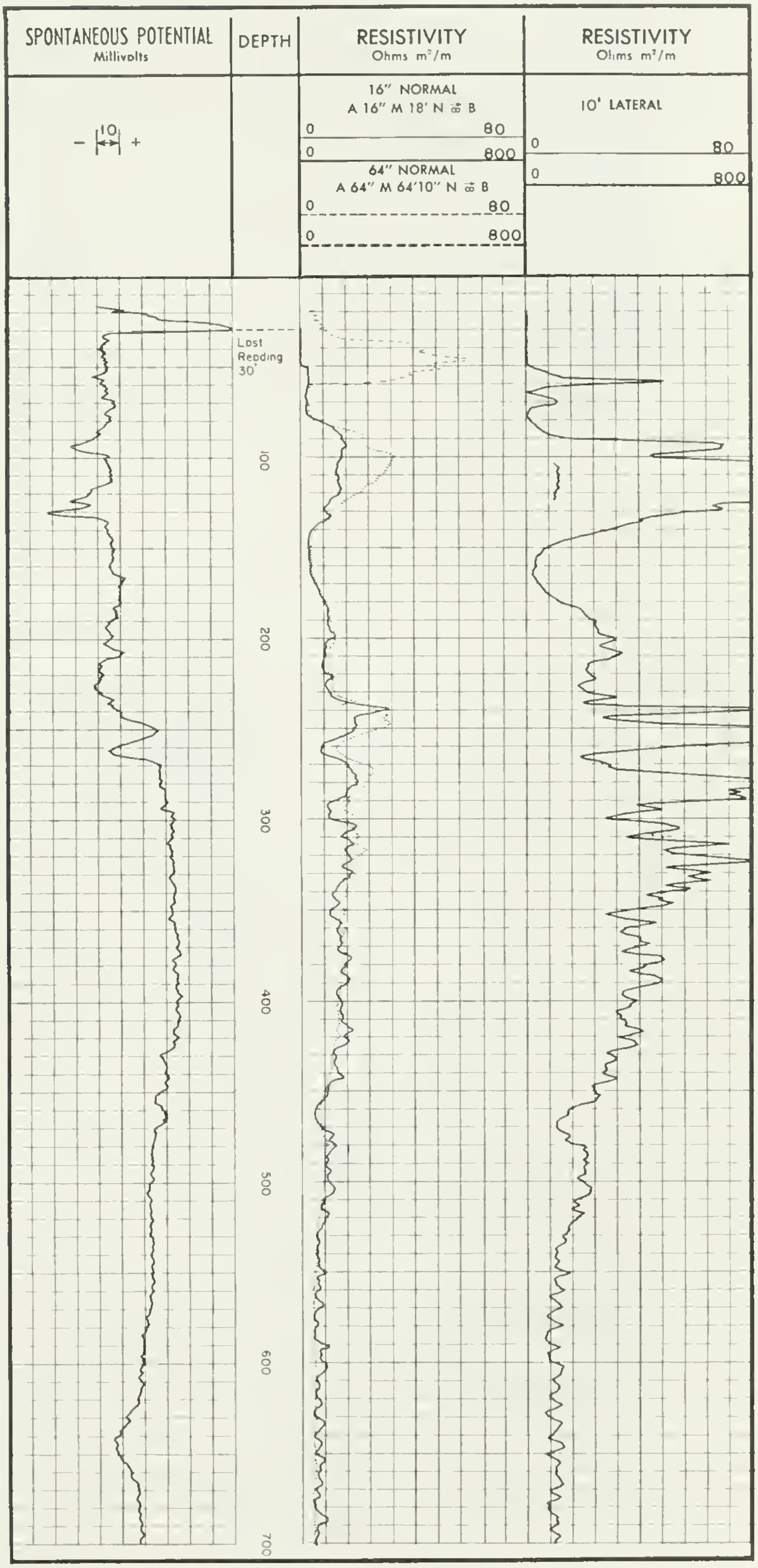
Permanent Datum: GROUND LEVEL Elev 2'

Log Measured from: GROUND LEVEL Ft Above Permanent Datum

Drilling Measured from: GROUND LEVEL

Elevations: KB DF GL 2'

Date	8-12-61			
Run No	1			
Depth—Driller	700'			
Depth—Logger	700'			
Bottom Logged Interval	69[illegible]			
Top Logged Interval	30'			
Casing—Driller	8 5/8" @ 30	@	@	@
Casing—Logger	30			
Bit Size	7"			
Type Fluid in Hole	CLAY BASE			
Density and Viscosity	NR NR			
pH and Fluid Loss	NR NR cc	cc	cc	cc
Source of Sample	MUD PIT			
Rm @ Meas. Temp.	3.9 @ 75 °F	@ °F	@ °F	@ °F
Rmf @ Meas. Temp.	2.35 @ 100 °F	@ °F	@ °F	@ °F
Rmc @ Meas. Temp.	[illegible] @ 100 °F	@ °F	@ °F	@ °F
Source of Rmf and Rmc	CHARTS			
Rm @ BHT	3.4 @ 83 °F	@ °F	@ °F	@ °F
Time Since Circ.	2 HRS			
Max. Rec. Temp. Deg. F	83 °F	°F	°F	°F
Equip. No. and Location	4474 PARA.			
Recorded By	WATSON			
Witnessed By	WEHE			



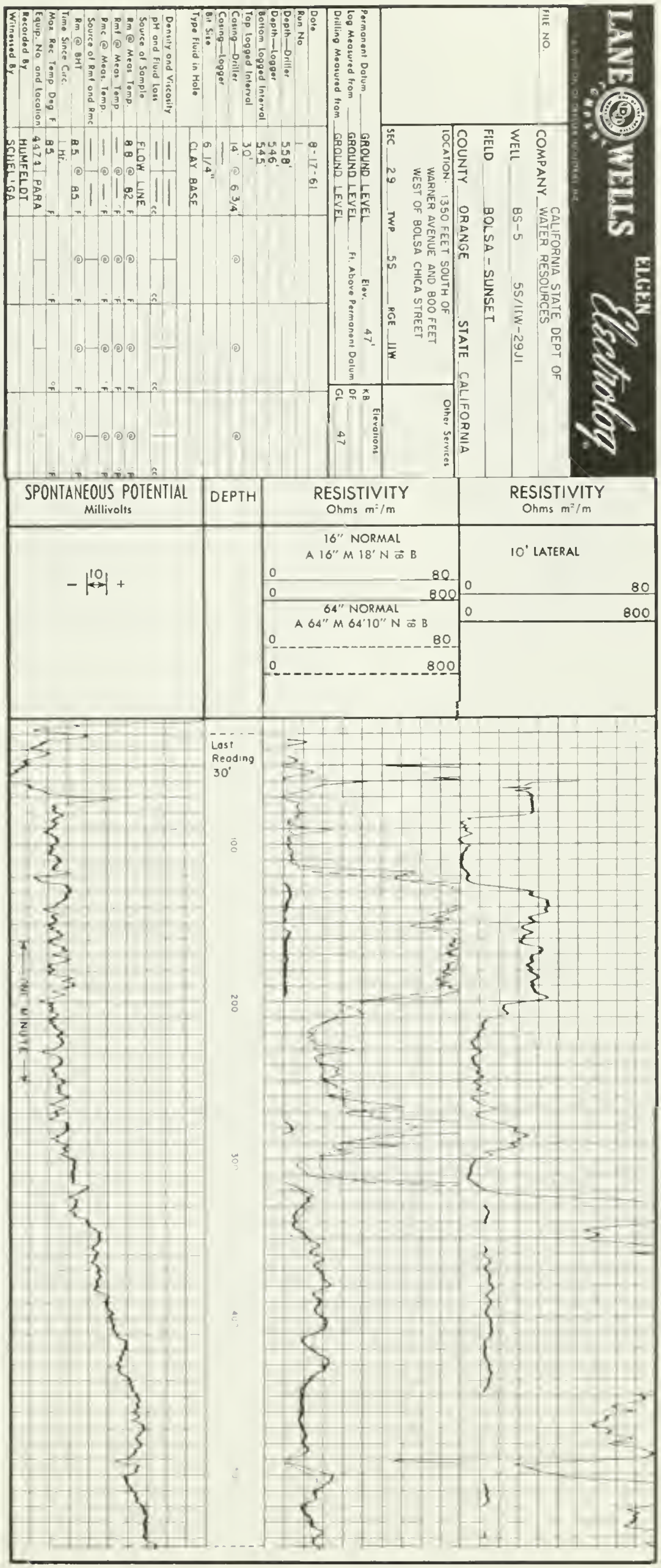
WELL LOG

Drilling Site No. BS–5 (BSO–3)
Drilling Method: Rotary
Ground Surface Elevation: 47 feet

State Well No. 5S/11W–29J1
Diameter: 7 inches
Depth: 558 feet

Depth in Feet	Material
0– 30	Clay: Brown to gray-green clay with silty, clayey sands. Some fine sand lenses.
30– 35	Clay: Gray firm clay.
35– 81	Sand: Brown, fine to coarse sand with clay stringers and shells.
81– 83	Clayey Sand: Gray sand.
83– 97	Sand: Brown, fine to coarse sand.
97–109	Sand and Gravel: Medium to coarse sand with gravel.
109–125	Sand: Fine to coarse sand with shells.
125–154	Sand: Dark gray fine sand with shells.
154–204	Sand and Silt: Very fine sand with silt and shell fragments.
204–212	Silt
212–275	Clay: Gray-blue silty clay with granules and shells.
275–288	Sand and Silt: Gray fine sand with silt and shells.
288–316	Silty Clay: Alternating fine sand, silt and clay stringers.
316–452	Sand and Gravel: Medium to coarse sand with abundant gravel.
452–464	Sand: Medium to coarse sand.
464–494	Sand and Silt: Medium to fine sand with silt and some clay.
494–532	Silt: Brown clayey silt with medium to coarse sand streaks.
532–558	Sand: Fine to coarse sand with some gravel.

ELECTRIC LOG BS-5



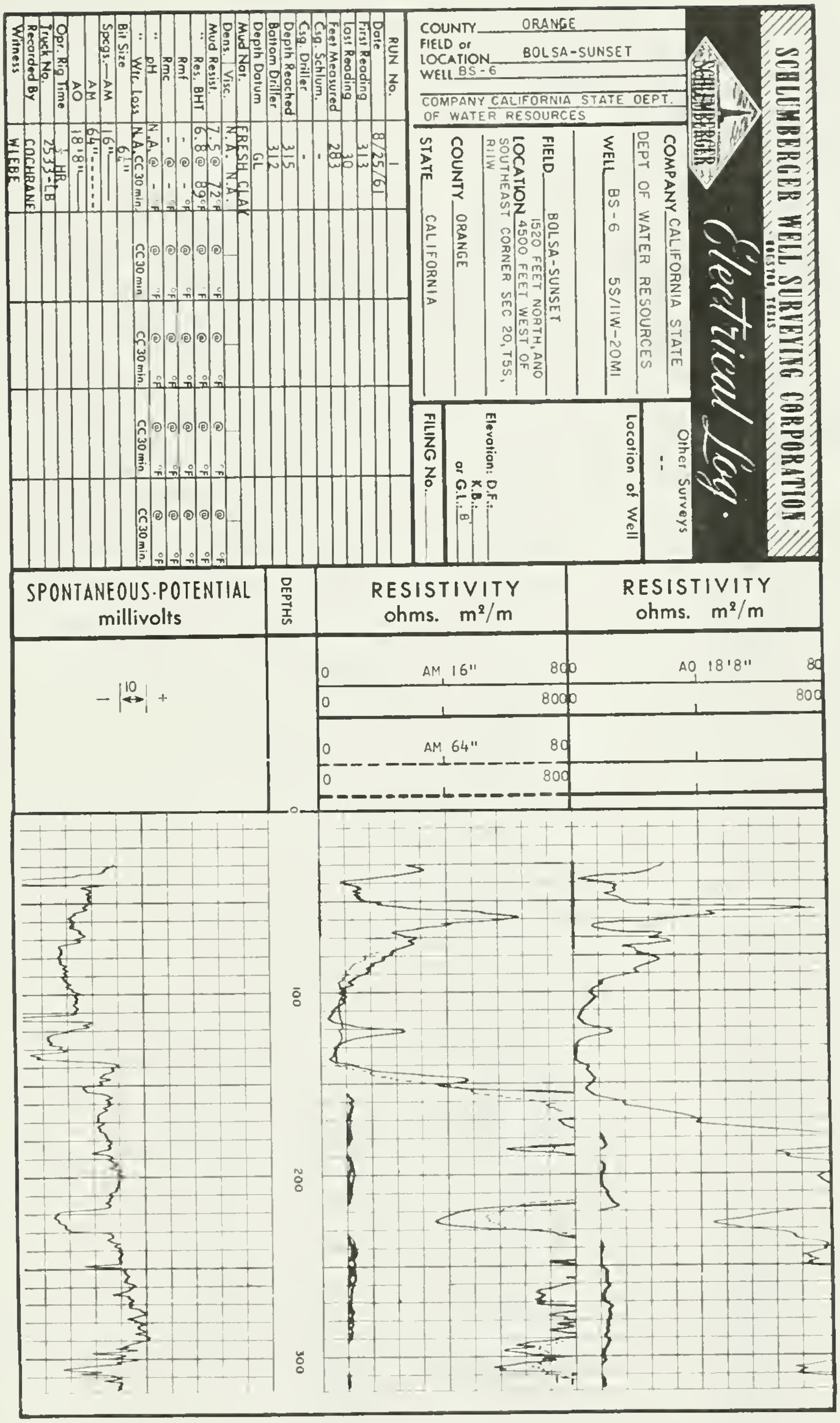
WELL LOG

Drilling Site No. BS–6 (BSO–6)
Drilling Method: Rotary
Ground Surface Elevation: 8 feet

State Well No. 5S/11W–20M1
Diameter: 7 inches
Depth: 300 feet

Depth in Feet	Material
0– 20	Clay: Brown, fine to medium sandy silty clay with wood fragments.
20– 24	Sand: Medium to coarse weathered sand with wood.
24– 29	Clay: Brown, coarse sandy, silty clay.
29– 40	Sand: Brown, fine to coarse sand with wood.
40– 59	Silt and Clay: Blue-gray, medium sandy silt and gray silty clay. Shell fragments and sand lenses.
59– 66	Silt: Gray, very fine to medium sandy silt.
66– 98	Sand and Clay: Gray, sandy, silty clay with fine to coarse sand. Shell fragments.
98–111	Sand: Fine to coarse sand with granules and shell fragments. Some clay lenses.
111–121	Silt: Dark gray, fine to very coarse sandy, clayey silt.
121–135	Sand: Medium to very coarse sand with granules and some gravel.
135–157	Silt and Clay: Dark gray, fine to medium sandy, silty clay with hard fine sandy silt. Embedded gravel and wood fragments. Sand lenses between 154 – 156 feet.
157–190	Sand: Fine to very coarse sand with granules and gravel to 1/4 inch. Embedded wood and shell fragments.
190–216	Sand and Clay: Fine to very coarse sand with interbedded coarse sandy clay.
216–240	Silt: Fine sandy, clayey silt with embedded granules and wood fragments and other organic debris. Shells at 217 – 218 feet.
240–300	Sand: Very fine to very coarse sand with granules and lenses of silt and clay. Some wood fragments.

ELECTRIC LOG BS-6



WELL LOG

Drilling Site No. BS–7 (BSO–7)
Drilling Method: Rotary
Ground Surface Elevation: 3 feet

State Well No. 5S/11W–19B1–7
Diameter: 6–1/4 inches
Depth: 1,000 feet

Depth in Feet	Material
0– 5	Fill: Gray–brown silty clay with shells.
5– 13	Sand: Gray, very fine to fine silty micaceous quartzose sand. Some wood and shells.
13– 17	Sand and Clay: Gray, very fine to fine silty sand and clay.
17– 43	Clay and Sand: Tan soft clay with very fine to fine micaceous sand. Embedded calcareous granules and wood and weeds.
43– 58	Clay: Blue–gray soft silty clay with some fine micaceous sand. Some wood.
58– 63	Sand: Gray, very fine to fine silty micaceous sand.
63– 69	Sand and Clay: Blue–gray silty sand with very fine to fine micaceous sand.
69– 73	Sand and Shells: Very fine to coarse sand with abundant shells.
73– 78	Clay: Dark gray sandy clay with shell fragments.
78– 83	Sand and Clay: Very fine to medium sand with gray sandy clay and some shells.
83–116	Sand: Very fine to coarse sand with stringers of silty clay.
116–121	Clay: Blue–gray soft sandy clay with abundant thin pelecypods.
121–126	Sand: Gray, very fine to fine micaceous sand with shell fragments.
126–139	Clay: Blue–gray clay with very fine sand. Wood and shell fragments.
139–164	Sand: Very fine to coarse sand with granules and some thin clay lenses. Few shells and wood.
164–169	Sand and Clay: Gray, very fine to coarse sand with silty clay.
169–179	Clay: Dark gray silty clay with some very fine sand.
179–188	Sand: Gray, very fine to fine silty sand. Some wood.
188–206	Sand and Gravel: Fine to coarse weathered sand with granules and gravel to ½ inch. Some wood and shells.
206–212	Clay and Gravel: Gray silty clay with embedded granules and gravel to 1/4 inch.
212–245	Sand and Gravel: Fine to coarse subrounded weathered sand with granules and gravel to 1/4 inch. Some minor clay streaks.
245–250	Sand and Shells: Very fine to coarse micaceous sand with abundant shells. Small amount of gray clay.
250–256	Clay and Shells: Gray, soft sandy silty clay and abundant shells. Streaks of embedded granules.
256–303	Clay, Sand and Gravel: Green–brownish gray, silty clay with fine to coarse sand and gravel to 1/4 inch.
303–315	Sand and Gravel: Fine to coarse subangular sand with granules and gravel to 1/4 inch. Minor stringers of green silty clay.
315–338	Sand and Granules: Fine to coarse subangular sand with numerous granules. Some gray silty clay.
338–354	Clay and Sand: Gray soft silty clay with very fine to medium sand and few granules.
354–448	Clay: Gray soft silty clay. Few shell fragments and wood.
448–472	Sand: Gray, fine to coarse silty sand with some silty clay.
472–478	Clay: Gray silty clay with some very fine sand.
478–511	Sand and Gravel: Fine to very coarse sand with 1/8 to 1/4 inch gravel.
511–543	Clay: Dark gray, weak silty clay with very fine sand and some embedded fine to coarse sand. Some wood fragments.
543–569	Sand and Clay: Greenish–gray, very fine to coarse subangular sand with granules, and soft silty clay.
569–600	Clay and Sand: Gray sandy clay with embedded fine to coarse sand and some gravel to 1/8 inch.
600–620	Sand: Fine to medium sand with some gray silty clay.
620–650	Clay: Dark gray silty clay with minor lenses of fine to medium sand.
650–660	Sand and Clay: Gray, very fine to medium silty sand with gray soft clay.
660–865	Clay: Dark gray silty clay with alternating lenses of very fine to medium sand.
865–895	Sand: Medium to coarse sand with granules.
895–905	Clay: Dark gray soft silty clay.
905–915	Sand: Fine to coarse silty sand with stringers of silty clay.
915–922	Clay: Dark gray sandy clay.
922–950	Sand: Fine to medium sand with granules. Silty clay present near bottom of interval.
950–962	Clay: Dark gray sandy clay.
962–980	Sand: Very fine to medium sand with granules and streaks of gray clay.
980–1000	Clay: Dark gray soft silty clay.

ELECTRIC LOG BS-7

LANE WELLS COMPANY — A DIVISION OF DRESSER INDUSTRIES INC

ELGEN Electrolog

FILE NO ____

COMPANY CALIFORNIA STATE DEPT OF WATER RESOURCES

WELL BS-7 5S/11W-1981-7

FIELD BOLSA-SUNSET

COUNTY ORANGE STATE CALIFORNIA

LOCATION 1220 FEET SOUTH, AND 1600 FEET WEST OF NORTHEAST SECTION CORNER

SEC 19 TWP 5S RGE 11W

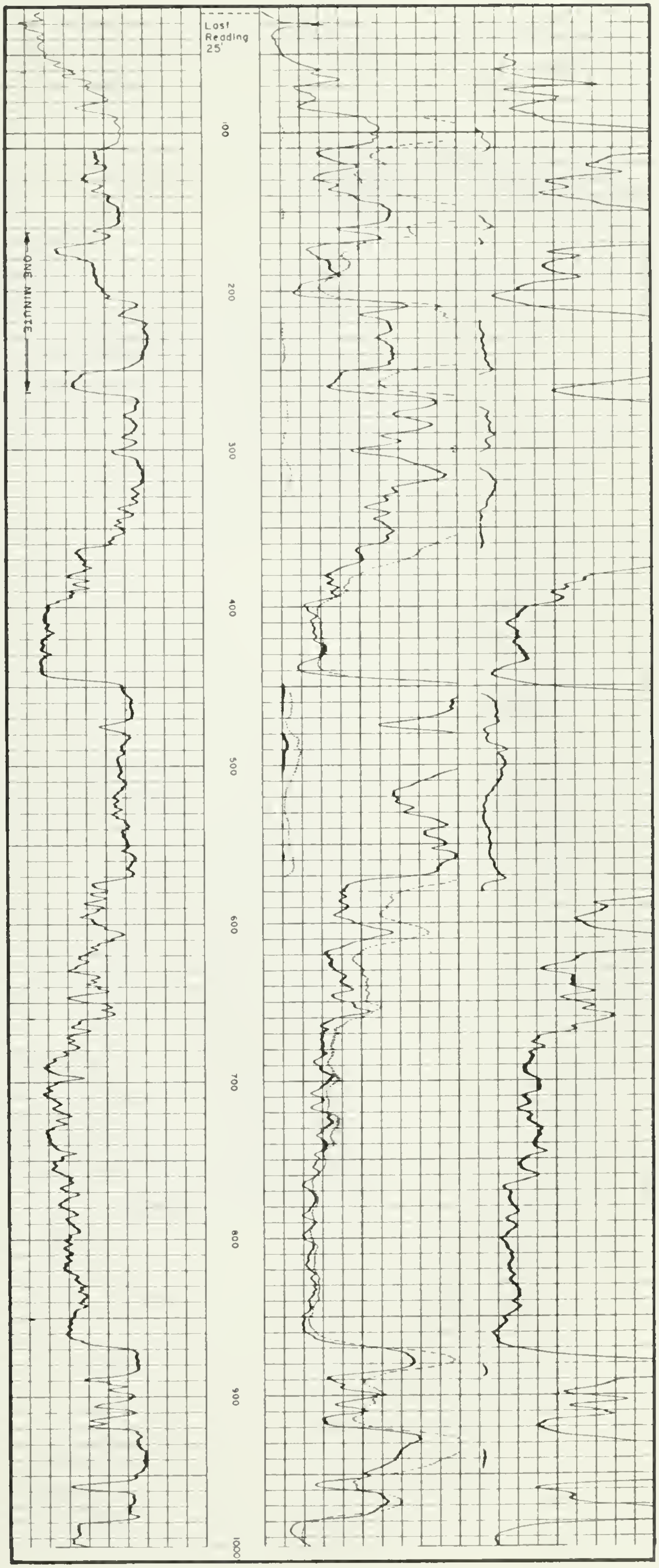
Other Services

Permanent Datum GROUND LEVEL Elev 3'
Log Measured from GROUND LEVEL Ft Above Permanent Datum
Drilling Measured from GROUND LEVEL

Elevations: KB —, DF —, GL 3'

Date	8-31-61			
Run No	1			
Depth—Driller	1000'			
Depth—Logger	996'			
Bottom Logged Interval	995'			
Top Logged Interval	25'			
Casing—Driller	— @ —	@	@	@
Casing—Logger	—			
Bit Size	6-1/4"			
Type Fluid in Hole	CLAY BASE			
Density and Viscosity	— —			
pH and Fluid Loss	— — cc	cc	cc	cc
Source of Sample	MUD PIT			
Rm @ Meas Temp	2.8 @ 74 °F	@ °F	@ °F	@ °F
Rmf @ Meas Temp	2.26 @ 75 °F	@ °F	@ °F	@ °F
Rmc @ Meas Temp	3.5 @ 75 °F	@ °F	@ °F	@ °F
Source of Rmf and Rmc	CHARTS			
Rm @ BHT	2.5 @ 104 °F	@ °F	@ °F	@ °F
Time Since Circ.	1 HR			
Max Rec. Temp Deg F	104 °F	°F	°F	°F
Equip. No and Location	4474 PARA			
Recorded By	HUMFELDT			
Witnessed By	J LO BUE			

SPONTANEOUS POTENTIAL Millivolts	DEPTH	RESISTIVITY Ohms m²/m	RESISTIVITY Ohms m²/m
− ⊢10⊣ +		16" NORMAL A 16" M 18 N ≡ 8; 0–80; 0–800	10 LATERAL A 32" B 16 8 N 50 10" M; 0–80; 0–800
		64" NORMAL A 64" M 64 10' N ≡ 8; 0–80; 0–800	



WELL LOG

Drilling Site No. BS–8 (BSO–9)
Drilling Method: Rotary
Ground Surface Elevation: 5 feet

State Well No. 5S/12W–13A1–7
Diameter: 7 inches
Depth: 1,010 feet

Depth in Feet	Material
0– 5	Fill: Road construction material.
5– 21	Clay: Dark gray, silty, sticky clay. Few shells and weeds.
21– 37	Clay and Shells: Dark gray silty clay and very fine to fine silty sand. Abundant pelecypods (pectens) and small gastropods.
37– 45	Clay: Gray-green, very fine micaceous sandy clay with shell fragments.
45– 47	Sand: Very fine to medium sand.
47– 54	Clay: Black-greenish clay with abundant weeds and organic debris.
54– 76	Sand: Very fine to coarse subrounded sand with 10 – 25 percent black-green silty clay.
76– 88	Clay and Sand: Black-green sandy clay with interbeds of fine to coarse sand.
88–106	Sand: Fine to coarse sand with granules.
106–113	Clay: Gray clay with granules and some gravel to 1/4 inch.
113–161	Sand: Very fine sand with clay lenses and abundant shell fragments.
161–196	Clay: Dark gray-brown silty clay with lenses of fine to medium sand.
196–212	Sand: Very fine to medium sand with shell fragments.
212–226	Clay: Gray, very fine micaceous sandy, silty clay with wood and shell fragments.
226–228	Sand: Fine to medium quartzose sand.
228–231	Clay: Dark gray clay.
231–287	Sand: Fine to medium, well sorted, subangular sand with granules and some gravel to 1/8 inch.
287–294	Clay: Gray-green soft silty clay with wood and shell fragments.
294–316	Silt and Sand: Gray soft silt with very fine micaceous sand. Few small peleycypod shells.
316–329	Clay: Gray, very fine micaceous sandy clay with few shell fragments.
329–343	Silt and Sand: Gray clayey silt with very fine sand. Some wood and weeds present.
343–364	Sand: Very fine to coarse, silty, micaceous sand. Shell and wood fragments.
364–375	Silt and Clay: Gray, very fine micaceous sandy silt with clay. Few shells and wood.
375–385	Clay and Sand: Gray, very fine micaceous, sandy, silty clay with medium to coarse sand.
385–422	Sand: Fine to coarse sand with very fine micaceous sandy silt.
422–435	Clay: Gray, very fine sandy, silty clay with fine to medium sand.
435–523	Clay: Gray, silty, sticky clay. Few shell fragments.
523–538	Sand: Gray-green, fine to coarse sand with silty clay.
538–545	Sand and Clay: Gray-green, fine to coarse sand and gray silty clay.
545–559	Clay: Green, silty, very fine micaceous sandy silt.
559–585	Sand: Gray, very fine to coarse sand with granules. Some silty, micaceous, sandy clay and few shells.
585–593	Silt and Sand: Gray, clayey, very fine, sandy silt, and very fine to medium sand.
593–615	Silt: Gray, soft, clayey silt with very fine to coarse sand. Some shell fragments.
615–642	Clay: Dark gray clay with some very fine sand. Lenses of medium to very coarse sand and granules.
642–837	Clay: Dark gray clay with some sand and shell fragments.
837–876	Clay: Dark gray clay with stringers of medium to coarse sand.
876–880	Clay: Dark gray-greenish clay.
880–1010	Clay: Dark gray silty clay.

ELECTRIC LOG BS-8

LANE WELLS COMPANY — ELGEN *Electrolog*

FILE NO

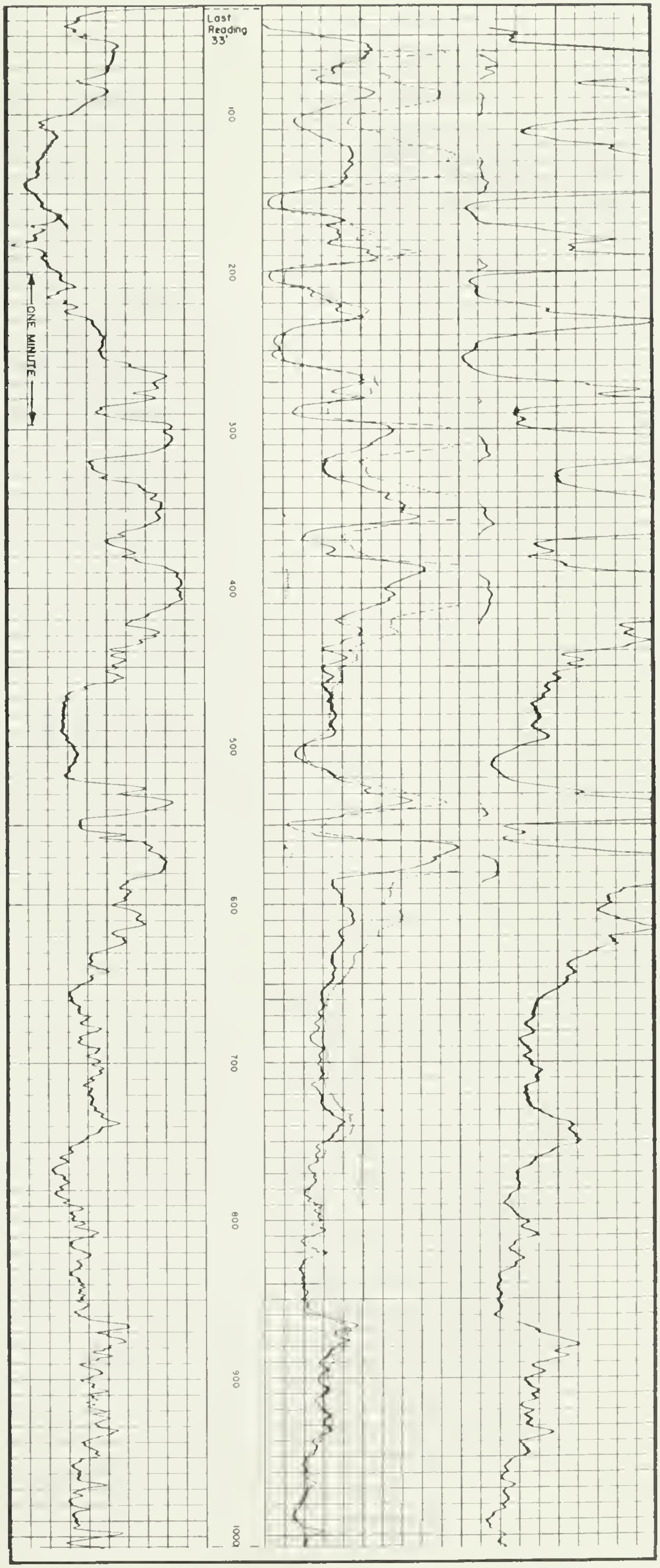
COMPANY: CALIFORNIA STATE DEPT OF WATER RESOURCES
WELL: BS-8 5S/12W-13A1-7
FIELD: BOLSA-SUNSET
COUNTY: ORANGE STATE: CALIFORNIA
LOCATION: 4170 FEET NORTH AND 750 FEET WEST OF SOUTHEAST SECTION CORNER
SEC 13 TWP 5S RGE 12W
Other Services

Permanent Datum: GROUND LEVEL Elev 5'
Log Measured from: GROUND LEVEL Ft Above Permanent Datum
Drilling Measured from: GROUND LEVEL

Elevations: KB — DF — GL 5

Date	9-12-61			
Run No	1			
Depth—Driller	1010'			
Depth—Logger	1007'			
Bottom Logged Interval	1006'			
Top Logged Interval	33'			
Casing—Driller	6 3/4" @	@	@	@
Casing—Logger	—			
Bit Size	6 1/4"			
Type Fluid in Hole	CLAY BASE			
Density and Viscosity	N.R. N.R.			
pH and Fluid Loss	N.R. N.R. cc	cc	cc	cc
Source of Sample	FLOW LINE			
Rm @ Meas. Temp.	1.82 @ 75 °F	@ °F	@ °F	@ °F
Rmf @ Meas. Temp.	1.45 @ 100 °F	@ °F	@ °F	@ °F
Rmc @ Meas. Temp.	1.72 @ 100 °F	@ °F	@ °F	@ °F
Source of Rmf and Rmc	CHARTS			
Rm @ BHT	1.61 @ 85 °F	@ °F	@ °F	@ °F
Time Since Circ.	1½ HRS			
Max. Rec. Temp. Deg. F	85 °F	°F	°F	°F
Equip. No. and Location	4474 PARA			
Recorded By	HUMFELDT			
Witnessed By	J. LaRUE			

SPONTANEOUS POTENTIAL Millivolts	DEPTH	RESISTIVITY Ohms m²/m	RESISTIVITY Ohms m²/m
− 10 +		16" NORMAL A 16 M 18 N ≥ B; 0–80; 0–800; 64" NORMAL A 64" M 64 10" N ≥ B; 0–80; 0–800	10' LATERAL A 32" B 16 8' N 50'10" M; 0–80; 0–800



WELL LOG

Drilling Site No. BSO–2
Drilling Method: Rotary
Ground Surface Elevation: 2 feet

State Well No. 5S/11W–20M2
Diameter: 14 inches
Depth: 115 feet

Depth in Feet	Material
0– 7	Clay: Gray and sticky clay.
7– 19	Clayey Sand: Gray soft clay and fine silty micaceous sand. Numerous large pectens.
19– 28	Sand: Fine to medium micaceous sand. Numerous shells.
28– 43	Sandy Clay: Gray soft clay with fine sand. (Shell bed 37 – 38 feet.)
43– 53	Sand and Gravel: Medium to coarse sand and gravel. Minor amounts gray-green sandy clay. Few shells.
53– 60	Sand and Gravel: Medium to coarse sand and fine gravel. Few shells.
60– 80	Sand: Fine to coarse sand with fine gravel. Shells.
80– 87	Sand and Clay: Gray soft clay and fine to coarse sand. Small gastropods.
87–103	Clayey Gravel: Gray soft clay and coarse sand to 1/4 inch gravel. Numerous turritellas.
103–106	Clayey Gravel: As above with wood fragments.
106–115	Clay: Gray soft fine sandy clay.

Well BSO—2 was not electric logged due to its shallow depth

WELL LOG

Drilling Site No. BSO–5
Drilling Method: Rotary
Ground Surface Elevation: 13 feet

State Well No. 5S/11W–29F1–2
Diameter: 7 inches
Depth: 740 feet

Depth in Feet	Material
0– 8	Silt: Brown, fine to medium sandy and clayey silt.
8– 30	Sand: Brown, fine to medium sand.
30– 36	Clay: Buff clay.
36– 41	Sand: Brown, fine to medium sand.
41– 61	Sand and Clay: Buff-light tan clay and interbedded fine to medium sand. Beds 1 – 2 feet thick.
61– 66	Clayey Sand: Buff-light tan clay and fine to medium sand.
66– 87	Sand: Brown, fine to medium sand.
87–103	Sand: Medium to coarse sand with shells.
103–124	Sand: Fine to medium sand.
124–126	Gravel and Sand: 1/4-inch well rounded gravel, and fine to medium sand.
126–153	Sand: Fine to medium sand with stringers of fine gravel.
153–164	Sand and Granules: Medium to coarse sand with granules. Shell fragments.
164–187	Sand: Medium to coarse sand with shells.
187–245	Silty Sand and Gravel: Gray silt, and medium to coarse sand with granules. Shells and wood.
245–285	Sandy and Gravelly Silt: Gray weak silt, shells, wood with 20 – 30 percent medium to coarse sand and gravel.
285–360	Silt: Gray clayey and fine sandy silt. Wood and shells.
360–380	Sand and Silt: Gray silt with fine micaceous sand – 10 percent medium to coarse sand.
380–389	Silty Sand: Gray silt with fine to coarse sand.
389–397	Sand and Silt: Soft clayey silt with fine to coarse sand. Wood fragments.
397–411	Sand: 10 percent gray clayey silt and fine to coarse sand.
411–429	Sand and Gravel: Gray, fine to coarse sand with gravel to ½ inch. Wood fragments and shells.
429–438	Sand: Gray, fine to coarse silty sand with minor 1/4-inch gravel. Wood fragments and shells.
438–458	Sand and Gravel: Gray, fine to coarse sand and gravel to 1/4 inch. Few shells.
458–505	Sand: Gray, fine to coarse sand (coarse size predominant). Few shells.
505–515	Gravel: Gray, fine to coarse sand and gravel. Wood fragments.
515–524	Sand and Gravel: Gray, medium to coarse sand and gravel to 1/2 inch.
524–541	Sand: Fine to coarse sand, poorly sorted with gravels to 1/8 inch.
541–558	Gravel and Sand: Medium to coarse sand with gravels to 1/8 inch, and granules.
558–573	Gravel: 1/2-inch gravel with granules and coarse sands.
573–608	Gravelly Sand: Gray, fine to coarse sand with granules and gravel to 3/8 inch.
608–637	Sandy Gravel: Gray, fine to coarse sand with granules and gravel to 3/8 inch.
637–660	Gravelly Sand: Gray, fine to coarse sand with granules and gravel to 1/4 inch.
660–663	Gravel: Coarse gravel.
663–684	Gravelly Sand: Gray, fine to coarse sand with granules and gravel to 1/4 inch.
684–730	Gravel and Sand: Gray, fine to coarse sand with granules and gravel to 3/8 inch.
730–740	Clay and Gravel: Gray, soft sandy clay and embedded gravel to 3/8 inch.

ELECTRIC LOG BSO-5

LANE WELLS COMPANY — A DIVISION OF DRESSER INDUSTRIES INC

ELGEN Electrolog

FILE NO

COMPANY CALIFORNIA STATE DEPT OF WATER RESOURCES

WELL BSO-S 5S/11W-29F1-2

FIELD BOLSA-SUNSET

COUNTY ORANGE STATE CALIFORNIA

LOCATION 350 FEET SOUTH OF WARNER AVENUE AND 1000 FEET WEST OF ALGONGUIN STREET

SEC 29 TWP 5S RGE 11W

Other Services

Permanent Datum GROUND LEVEL Elev 13'
Log Measured from GROUND LEVEL 0 Ft Above Permanent Datum
Drilling Measured from GROUND LEVEL

Elevations: KB -; DF -; GL 13'

Date	6/28/63			
Run No	ONE			
Depth—Driller	740'			
Depth—Logger	740'			
Bottom Logged Interval	739'			
Top Logged Interval	80'			
Casing—Driller	- @ -	@	@	@
Casing—Logger	-			
Bit Size	7" TO 485, 6 5/8" TO T.O.			
Type Fluid in Hole	AQUANGLE & WATER			
Density and Viscosity	- -			
pH and Fluid Loss	- - cc	cc	cc	cc
Source of Sample	FLOWLINE			
Rm @ Meas. Temp	10.0 @ 77 °F	@ °F	@ °F	@ °F
Rmf @ Meas. Temp	8.3 @ 75 °F	@ °F	@ °F	@ °F
Rmc @ Meas. Temp	11.1 @ 75 °F	@ °F	@ °F	@ °F
Source of Rmf and Rmc	MEAS MEAS			
Rm @ BHT	8.7 @ 83 °F	@ °F	@ °F	@ °F
Time Since Circ.	1 HR			
Max Rec Temp Deg F	83 °F	°F	°F	°F
Equip No and Location	L4474 PARA			
Recorded By	MOSES			
Witnessed By	MR CUMMINGS			

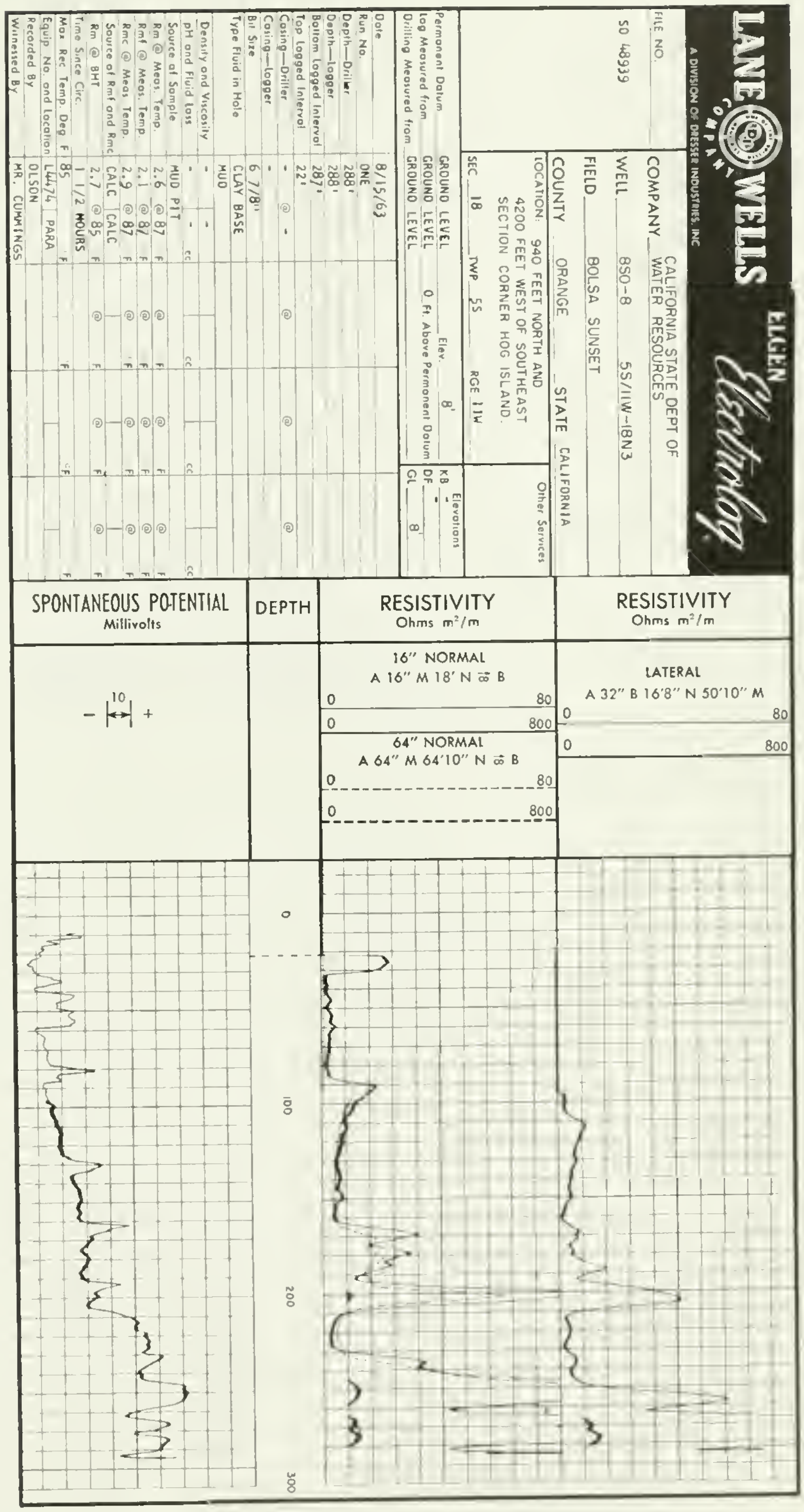
WELL LOG

Drilling Site No. BSO–8
Drilling Method: Rotary
Ground Surface Elevation: 8 feet

State Well No. 5S/11W–18N3
Diameter: 7 inches
Depth: 288 feet

Depth in Feet	Material
0– 13	Sandy Clay: Tan to light brown fine sandy clay.
13– 14	Sand: Fine to medium sand.
14– 21	Sandy Clay: Tan to light brown fine sandy clay.
21– 35	Sand: Brown, medium to coarse sand with some granules. Minor streaks of clay.
35– 42	Clayey Sand and Gravel: Brown, soft clayey medium to coarse sand and gravel to 1/4 inch.
42– 48	Gravelly Clay: Blue micaceous clay with embedded gravel to 1/4 inch. Minor amounts of brown sandy-silty clay.
48– 59	Clay: Blue-gray micaceous clay.
59– 72	Sand: Fine to medium sand with shells and streaks of blue-gray clay.
72– 80	Sand with Gravel: Fine to coarse sand and fine gravel. Streaks of gray micaceous clay.
80– 83	Clay and Gravel: Gray-blue micaceous clay with gravel to 1/4 inch.
83– 87	Sandy Clay: Gray, fine to coarse sand with clay.
87–107	Sand: Gray, fine to coarse sand with minor amounts of clay. Some shells.
107–118	Sand: As above with wood fragments.
118–128	Sand: Gray, fine to coarse sand.
128–134	Clay: Gray soft clay.
134–152	Sand: Gray, fine to medium sand.
152–162	Sand and Granules: Gray, fine to coarse sand with granules and some fine gravel.
162–166	Sandy Clay: Gray, fine to coarse sandy clay.
166–202	Sandy Gravel: Gray, fine to coarse sand with granules and gravel to ½ inch. Streaks of gray-tan sandy clay.
202–219	Gravelly Sand: Fine to coarse sand with gravel.
219–230	Silty Sand and Gravel: Tan to rust silt and fine to coarse sand with gravel to 1/4 inch (shells at 230 feet).
230–247	Silt: Dark gray clayey silt with shells.
247–257	Silty Sand: Brown, fine to medium sand with gray-rust micaceous clayey silt.
257–264	Silt: Gray-rust micaceous clayey silt.
264–270	Sand and Silt: Gray-rust micaceous clayey silt and fine to medium sand.
270–276	Sand: Gray, fine to coarse sand with streaks of gray to green clay.
276–281	Gravelly Sand: Fine to coarse sand with gravel to 1/4 inch. Some streaks of gray to green clay.
281–286	Sandy Clay: Green, fine sandy clay with some rust clay.
286–288	Sand: Gray, fine to coarse sand.

ELECTRIC LOG BSO-8



APPENDIX D

WATER QUALITY CRITERIA AND CHEMICAL ANALYSES OF WATERS

APPENDIX D

WATER QUALITY CRITERIA AND CHEMICAL ANALYSES OF WATERS

This appendix contains (1) water quality criteria as adopted by the Department of Water Resources for irrigation, municipal, and domestic uses, (2) an explanation of the state well and spring numbering system and (3) chemical analyses of ground and surface waters.

Water Quality Criteria

The suitability of a given water for a particular use is dependent upon its bacteriological, chemical, physical and radiological character. Only the chemical aspect of water quality will be emphasized here.

Due to a high solvent capacity, naturally occurring water available for man's use contains dissolved mineral salts dissociated into positively charged cations and negatively charged anions. These dissolved ions are generally ranked as major and trace constituents. A complete chemical analysis lists the relative concentrations by weight of the major cations (calcium, magnesium, sodium and potassium), the major anions (carbonate, bicarbonate, sulfate, chloride and nitrate) and generally silica, boron and fluoride. Also listed are the pH (hydrogen ion concentration), temperature, electrical conductance, total dissolved solids, total hardness and percent sodium. The relative concentrations or values of these chemical and physical parameters determine the suitability of a water for particular uses. Standards are those values established by a regulatory agency as obligatory limits beyond which water is rejected for a particular use. Criteria are general guidelines, not obligatory, for judging water quality.

Domestic and Municipal Use

Water used for drinking and culinary purposes should be clear, colorless, odorless, pleasant tasting, and free from toxic salts. It should not contain excessive amounts of dissolved minerals and must be free from pathogenic organisms. In addition to these requirements, certain qualifications are generally placed on chemical quality, by a regulatory agency or for comparative grading of different waters.

The 1962 Drinking Water Standards of the United States Public Health Service are the most recent in a series started in 1914 to serve as guides for protecting the health of the traveling public. Since 1914, they have been revised several times in the light of increasing medical and engineering knowledge. The Drinking Water Standards are legally applicable only to drinking water and water supply systems used by interstate carriers and others subject to Federal quarantine regulations. Table 11 presents the standards; the recommended values are those which should not be exceeded in a water supply if other more suitable supplies are or can be made available. The mandatory values are those which, if exceeded, constitute grounds for rejection of the supply.

TABLE 11

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962

Substance	Recommended limits of concentrations, in mg/l	Mandatory limits of concentrations, in mg/l
Alkyl benzene sulfonate (ABS)	0.5	--
Arsenic (As)	0.01	0.05
Barium (Ba)	--	1.0
Cadmium (Cd)	--	0.01
Carbon chloroform extract (CCE)	0.2	--
Chloride (Cl)	250	--
Chromium (hexavalent) (Cr^{+6})	--	0.05
Copper (Cu)	1.0	--
Cyanide (CN)	0.01	0.2
Fluoride (F)	**	**
Iron (Fe)	0.3	--
Lead (Pb)	--	0.05
Manganese (Mn)	0.05	--
Nitrate (NO_3)*	45	--
Phenols	0.001	--
Selenium (Se)	--	0.01
Silver (Ag)	--	0.05
Sulfate (SO_4)	250	--
Total dissolved solids (TDS)	500	--
Zinc (Zn)	5	--

*In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

**See Table 12.

The standards for fluoride are related to the annual average maximum daily air temperatures based on a minimum five-year record. The average concentration should not exceed the appropriate upper limit in Table 12. The presence of fluoride in average concentrations greater than twice the optimum values constitutes grounds for rejection of the supply. The standards further state that where fluoridation is practiced the average fluoride concentration shall be kept within the upper and lower control limits.

TABLE 12

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962 -- FLUORIDE

Annual average of maximum daily air temperatures, in degrees Fahrenheit	Recommended control limits -- fluoride concentrations, in mg/l		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

In California, the State Board of Public Health issues water supply permits in accordance with its "Interim Policy on Mineral Quality of Drinking Water", as adopted September 4, 1959, and in accordance with "Policy Statement and Resolutions by the State Board of Public Health with Respect to Fluoride Ion Concentrations in Public Water Supplies", as approved August 22, 1958. The interim policy on mineral quality is presented as follows:

"1. Water supply permits may be issued for drinking and culinary purposes only when the Public Health Service Drinking Water Standards of 1946 1/ and the State Board of Public Health policy on fluorides are fully met.

"2. In view of the wide variation in opinion in this field, the uncertainty as to the long-time health effects, the uncertainty of public attitude concerning various mineral levels, and the obvious need for further study, temporary permits may be issued for drinking water supplies failing to meet the Drinking Water Standards if the mineral constitutents do not exceed those listed under the heading 'Temporary Permit' in the following table:*

UPPER LIMITS OF TOTAL SOLIDS** AND SELECTED MINERALS IN DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit
Total Solids	500 (1,000)***	1,500 parts per million
Sulphates	250 (500)***	600 " " "
Chlorides	250 (500)***	600 " " "
Magnesium	125 (125)	150 " " "

1/ Author's Note: It is assumed, in the absence of any later proclamation, that the 1962 Drinking Water Standards now apply.

*This interim policy relates to potable water and is not intended to apply to a secondary mineralized water supply intended for domestic uses other than drinking and culinary purposes.

**Waters having less than 32 milliequivalents per liter of dissolved minerals or 1,600 micromhos electrical conductance will usually have less than 1,000 parts per million total solids.

***Numbers in parentheses are maximum permissible, to be used only where no other more suitable water is available in sufficient quantity for use in the system.

"3. Exception: No temporary permit for drinking water supplies in which the mineral constituents exceed those listed under the heading 'Temporary Permit' as set forth in No. 2 above may be issued unless the Board determines after public hearing:

(a) The water to be supplied will not endanger the lives or health of human beings; and

(b) No other solution to meet the local situation is practicable and feasible; and

(c) The applicant is making diligent effort to develop, and has reasonable prospect of developing a supply of water which will warrant a regular permit within an acceptable period of time.

The burden of presenting evidence to fulfill the requirements as set forth in (a), (b), and (c) above is upon the applicant."

With respect to fluoride concentrations, the State Board of Public Health has defined the maximum safe amounts of fluoride ion in relation to mean annual temperature as shown in Table 13.

TABLE 13

CALIFORNIA STATE BOARD OF PUBLIC HEALTH
MAXIMUM FLUORIDE ION CONCENTRATIONS

Mean annual temperature, in degrees Fahrenheit*	Mean monthly fluoride concentration, in parts per million
50	1.5
60	1.0
70 - above	0.7

*For temperature values between those shown in the table, the fluoride ion concentrations may be obtained by interpolation.

The State Board of Public Health's policy on fluoride ion further states that:

"1. The concentration of the fluoride ion in public water systems, whether added or naturally occurring, should not exceed the fluoride ion concentrations stated in the above table.

"2. In the development of new public water systems used for drinking and culinary purposes the above fluoride ion concentrations shall not be exceeded.

"3. In existing public water systems used for drinking and culinary purposes in which the above fluoride ion concentrations are exceeded the fluoride ion concentration shall be reduced to a safe level by the use of methods acceptable to the State Department of Public Health. Exception: In cases where the Department determines after investigation that it is not practicable and feasible to reduce the fluoride ion concentration in the entire supply to a safe level, special methods acceptable to the State Department of Public Health, shall be provided by the applicant to furnish water of suitable fluoride ion concentration to all children 10 years of age or under."

Another common criteria for judging the suitability of water for domestic use is hardness, a measure of the soap-consuming power of the water. In general, hardness results from the presence of cations, principally calcium and magnesium, which form insoluble compounds with soap. For purposes of classification, the following definitions of relative total hardness are used in this report:

1. Soft - waters containing less than 100 ppm of total hardness.

2. Moderately hard - waters containing 101 to 200 ppm of total hardness.

3. Hard - waters containing more than 200 ppm of total hardness.

Agricultural Use

The major criteria for judging the suitability of water for irrigation are chloride concentration, specific electrical conductance (presented as EC x 10^6 at 25° C), boron concentration, and percent sodium.

Chlorides are present in nearly all waters. They are not necessary to plant growth, and in high concentrations cause subnormal growing rates and burning of leaves.

Electrical conductance indicates the total dissolved solids, and furnishes an approximate indication of the overall mineral quality of the water. For most waters, the total dissolved solids measured in parts per million (ppm), may be approximated by multiplying the electrical conductance by 0.7. As the amount of dissolved salts in irrigation water increases, the crop yields are reduced until at high concentrations (the value depending on the plant, type of soil, climatological conditions, and amount of water applied) plants cannot survive.

Boron is never found in the free state but occurs as borates or boric acid. This element is essential in minor amounts for the growth of many but not all plants. It is, however, extremely toxic to most plants in high concentrations. Limits of tolerance for most irrigated crops vary from 0.5 to 2.0 ppm. Citrus crops, particularly lemons, are sensitive to boron in concentrations exceeding 0.5 ppm.

The percent sodium, as reported in analyses, is 100 times the proportion of the sodium cation to the sum of all cations, all expressed in equivalents per million (epm). Water containing a high percent sodium has an adverse effect upon the physical structure of soils that contain clay by dispersing the soil colloids. This reduces soil permeability, thus, retarding the movement of water and the leaching of salts, and makes the soils difficult to work. The effect of potassium in water is similar to that of sodium.

Because of the diverse climatological conditions, crops, soils, and irrigation practices in California, criteria which may be set up to establish the suitability of water for irrigation must necessarily be of a general nature, and judgment must be used in applying these criteria to individual cases.

Based on results of studies by Dr. L. D. Doneen, Professor of Irrigation at the University of California at Davis, three general classes of irrigation water have been established.

Class 1 Excellent to Good. Regarded as safe and suitable for most plants under any condition of soil or climate.

Class 2 Good to Injurious. Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 Injurious to Unsatisfactory. Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Limiting values for concentrations of chloride, boron, specific electrical conductance, and percent sodium for these three classes of irrigation water have been established and are shown in Table 14.

TABLE 14

CRITERIA FOR IRRIGATION WATERS

Factors	Class 1 - Excellent to good	Class 2 - Good to injurious	Class 3 - Injurious to unsatisfactory
Specific electrical conductance $EC \times 10^6$ at 25°C	Less than 1,000	1,000-3,000	More than 3,000
Boron, ppm	Less than 0.5	0.5-2.0	More than 2.0
Chloride, ppm	Less than 175	175-350	More than 350
Percent sodium	Less than 60	60- 75	More than 75

Well and Spring Numbering System

For convenience in recording wells and springs and pertinent data, the following systems have been used.

Water Wells

Wells from which samples of water or measurements of depth to ground water have been obtained are assigned state well numbers. These wells are referenced by the United States Public Land Survey System. The well number consists of the township, range, and section numbers, a letter to indicate the 40-acre lot in which the well is located and a number to identify the particular well in the 40-acre lot. A terminal letter to indicate the base and meridian in question has been deleted because all references in the study are for the San Bernardino Base and Meridian.

Sections are subdivided into 40-acre lots as shown below. For example, well 4S/11W-20N3 denotes the third well to be assigned a number in Lot N of Section 20 of Township 4 South, Range 11 West.

D	C	B	A
E	F	G	H
M	L	K	J
N3 ● N	P	Q	R

Observation wells and piezometers constructed within the area were also referred to by arbitrarily assigned field numbers. Multiple wells and piezometers at one site were assigned a site number and were differentiated by a letter prefix. For example, at site BSO-1, there is well BSO-1A (Bolsa aquifer), piezometers BSO-1B and -1C (semiperched zone) and piezometer BSO-1D (Meadowlark aquifer). The following abbreviated terms denote the agency or private firm which has constructed observation wells or piezometers.

HH - Huntington Harbour Corporation

AE - Los Angeles County Flood Control District

BS and BSO - Department of Water Resources

GS - United States Geological Survey

Springs

Springs are assigned state well numbers on the same basis as water wells, but the letter S is inserted immediately after the lot identification. For example, 4S/11W-20MS1 is the first spring assigned a number in Lot M of Section 20 of Township 4 South, Range 11 West.

Chemical Analyses of Surface and Ground Waters

Chemical analyses of surface waters within the study area are listed below in Table 15. Table 16 lists representative chemical analyses of ground waters.

TABLE 15

CHEMICAL ANALYSES OF SURFACE WATERS

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Chemical constituents in parts per million, equivalents per million, percent reactance value: Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Chemical constituents in parts per million: Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C Evap 105°C Computed	Total hardness as $CaCO_3$
PACIFIC OCEAN AND TIDAL SLOUGHS																	
PACIFIC OCEAN SEAL BEACH PIER																	
05S/12W-14M	76	8.0	50000	411	1317	10257	381	0	143	2616	18828	0	0.6	4.60	--	35989	6446
6- 4-57				20.51	108.31	445.97	9.74		2.34	54.47	530.95						
				4	19	76	2			9	90					33886	
PACIFIC OCEAN SURF																	
5S/11W-32R	--	7.9	45455	408	1460	9890	--	0	146	2550	19250	0	--	3.82	--	36070	7027
8-23-51				20.36	120.07	430.02			2.39	53.09	542.85						
				4	21	75				9	91					33634	
TIDAL SLOUGH																	
5S/11W-29C	--	7.1	63000	424	1372	11213	41	0	257	2724	20210	0	1.0	4.00	1	37500	6705
6- 5-57				21.16	112.83	487.54	1.05		4.21	56.71	569.92						
				3	18	78			1	9	90					36116	
LAKES, PONDS, SPRINGS AND FLOOD CONTROL CHANNELS																	
POND																	
5S/11W-22M	--	8.0	2291	382	81	97	--	0	199	1180	44	68.8	--	0.20	--	1949	1287
3-25-52				19.06	6.66	4.22			3.26	24.57	1.24	1.11					
				64	22	14			11	81	4	4				1951	
PEAT SPRING																	
5S/11W-26M	68	8.0	2800	461	101	198	21	0	407	1090	379	17	0.8	0.90	--	2626	1567
1-26-65				23.00	8.31	8.61	0.54		6.67	22.69	10.69	0.27					
				57	21	21	1		17	56	27	1				2469	
FLOOD CONTROL CHANNEL																	
5S/11W-28H	--	8.2	2620	270	112	300	13	0	263	1221	185	29	1.8	0.35	--	2214	1135
1-21-65				13.47	9.21	13.04	0.33		4.31	25.42	5.22	0.47					
				37	26	36	1		12	72	15	1				2261	
POND BOUCHER DUMP																	
5S/11W-28D	--	7.1	5860	16	94	1200	34	0	232	1814	65	10.5	2.4	3.25	0	4099	427
9- 5-55				0.80	7.73	52.18	0.87		3.80	37.77	1.83	0.17					
				1	13	85	1		9	87	4					3353	
HUNTINGTON LAKE																	
5S/11W-34R	--	8.0	5950	386	110	1375	13	--	231	760	1710	11	--	6.00	--		1417
1-30-64				19.26	9.05	59.79	0.33		3.79	15.82	48.22	0.18					
				22	10	68			6	23	71					4485	
BRUCE BROS. POND																	
5S/11W-35C	--	7.9	755	56	13	97	3	0	138	65	129	6	--	0.35	--		193
1-29-64				2.79	1.07	4.22	0.08		2.26	1.35	3.64	0.10					
				34	13	52	1		31	18	50	1				437	

CHEMICAL ANALYSES OF GROUND WATERS

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Chemical constituents in parts per million, equivalents per million, percent reactance value: Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Chemical constituents in parts per million: Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
									SEMIPERCHED								
5S/11W-18N 3 S	62	7.7	33000	1032	1058	8650	240	0	271	2464	16810	0.0	0.2	3.50	11	36472	6931
10-18-63				51.50	87.01	376.10	6.14		4.44	51.30	474.04						
850-8A				10	17	72	1		1	10	89					30402	
	64	7.2	40000	1076	1035	8100	221	0	298	2145	15775	13	1.6	3.10	--	30670	6946
7- 2-65				53.69	85.12	352.19	5.65		4.88	44.66	444.86	0.21					
				11	17	71	1		1	9	90					28516	
5S/11W-18H 7 S	--	10.9	8100	497	36	1325	33	15	0	255	2766	0.0	0.1	0.17	6	6100	1389
8-15-63[a]				24.80	2.96	57.61	0.84	0.50		5.31	78.00						
850-7F				29	3	67	1	1		6	93					4935	
	65	7.6	29000	1186	806	6000	17	0	183	1919	12410	0.0	0.2	0.65	--	26040	6279
5-13-64				59.18	66.29	260.88	0.43		3.00	39.95	349.96						
				15	17	67			1	10	89					22429	
5S/11W-19B11 S	--	8.0	6000	697	131	385	11	0	169	136	2046	0.0	0.1	0.35	--	4282	2279
8- 3-64				34.78	10.77	16.74	0.28		2.77	2.83	57.70						
HH-1D				56	17	27			4	4	91					3489	
	68	7.1	4808	480	114	330	10	0	198	156	1420	17	0.5	0.20	--	2900	1668
7-12-65				23.95	9.38	14.35	0.26		3.25	3.25	40.04	0.27					
				50	20	30	1		7	7	86	1				2625	
5S/11W-20E52 S	--	7.1	1891	197	57	123	2	0	191	295	345	86	0.8	0.15	22	1616	727
8- 3-64[b]				9.83	4.69	5.35	0.05		3.13	6.14	9.73	1.39					
				49	24	27			15	30	48	7				1222	
5S/11W-20E 4 S	--	8.2	2300	64	167	240	3	0	542	281	436	0.0	0.1	0.22	--	1682	847
7-29-64				3.19	13.73	10.44	0.08		8.88	5.85	12.30						
HH-2C				12	50	38			33	22	46					1458	
5S/11W-20K 2 S	--	7.6	2100	251	60	96	2	0	289	211	455	30	0.2	0.12	21		873
2- 1-61				12.52	4.93	4.17	0.05		4.74	4.39	12.83	0.48					
				58	23	19			21	20	57	2				1268	
	--	7.6	2900	378	39	245	6	0	403	259	714	7.4	0.1	0.50	22		1104
6-20-63				18.86	3.21	10.65	0.15		6.61	5.39	20.13	0.12					
				57	10	32			20	17	62					1869	
	--	8.0	2300	218	92	157	5	0	336	213	523	14.0	0.1	0.24	--	1614	923
7-20-64				10.88	7.57	6.83	0.13		5.51	4.43	14.75	0.23					
				43	30	27	1		22	18	59	1				1388	
5S/11W-20M51 S	--	7.9	3250	90	27	620	1	0	291	270	805	7.1	0.4	0.59	16	1886	336
6-11-64				4.49	2.22	26.96	0.03		4.77	5.62	22.70	0.11					
				13	7	80			14	17	68					1980	
5S/11W-20M 5 S	--	8.8	1860	235	9	110	4	6	24	96	511	0	0.6	0.12	14	1290	624
8-15-63[a]				11.73	0.74	4.78	0.10	0.20	0.39	2.00	14.41						
850-6D				68	4	28	1	1	2	12	85					998	
5S/11W-20M 8 S	--	7.3	36000	4541	1138	5350	35	0	69	1047	18950	0.0	0.2	0.47	--	31740	
7-16-64				226.60	93.59	232.62	0.89		1.13	21.80	534.39						
HH-3C				41	17	42				4	96					31096	
	66	7.0	42918	5037	1510	4300	34	0	190	1522	18700	13	1.6	0.10	--	33720	8792
7- 9-65				251.35	124.18	186.96	0.87		3.11	31.69	527.34	0.21					
				45	22	33			1	6	94					31211	
5S/11W-20N 3 S	--	7.4	30000	1186	608	6800	20	0	326	1667	12730	0.0	0.2	2.24	--	24000	5463
7-14-64				59.18	50.00	295.66	0.51		5.34	34.71	358.99						
HH-4C				15	12	73			1	9	90					23174	
	--	7.2	36030	1333	907	7590	39	0	353	1940	15260	8.7	1.0	2.40	--	29800	7061
3- 2-65				66.52	74.59	330.01	1.00		5.79	40.39	430.33	0.14					
				14	16	70			1	8	90					27255	
5S/11W-20N 4 S	--	7.6	48750	823	1264	12140	289	0	355	2849	22270	14	1.1	5.00	--	41800	7257
3- 2-65				41.07	103.95	527.85	7.39		5.82	59.32	628.01	0.23					
HH-4D				6	15	78	1		1	9	91					39830	
5S/11W-22E	--	--	219	321	82	125	--	--	192	1077	62	13	--	--	--		1139
2-15-32				16.02	6.74	5.44			3.15	22.42	1.75	0.21					
LA BOLSA DRAIN				57	24	19			11	81	6	1				1774	
5S/11W-29C 7 S	--	7.2	17000	1114	263	2970	15	0	184	581	6700	0.0	0.2	2.50	--	13220	3864
7-22-64				55.59	21.63	129.14	0.38		3.02	12.10	188.94						
HH-5C				27	10	62			1	6	93					11736	
	--	7.2	16950	1251	320	2550	21	0	207	576	6500	7.0	0.9	7.20	--	12330	4441
3- 2-65				62.42	26.32	110.87	0.54		3.39	11.99	183.30	0.11					
				31	13	55			2	6	92					11335	
5S/11W-29C 8 S	--	11.2	2300	130	12	410	5	17	0	187	546	5.0	0.2	0.50	--	1310	374
7-22-64[a]				6.49	0.99	17.83	0.13	0.57		3.89	15.40	0.08					
HH-5D				26	4	70	1	3		20	77					1313	

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million, equivalents per million, percent reactance value									Chemical constituents in parts per million				
SEMIPERCHED (Continued)																	
5S/11W-29C 8 S	--	7.8	7463	201	127	1300	16	0	59	430	2375	12.0	0.9	0.80	--	4810	1024
3- 2-65				10.03	10.44	56.52	0.41		0.97	8.95	66.98	0.19					
88-50				13	13	73	1		1	12	87					4492	
5S/11W-33R 3 S	69	6.5	14970	344	171	2800	113	0	32	604	4950	31	1.1	0.50	--	9500	1563
7- 6-65				17.17	14.06	121.74	2.89		0.52	12.58	139.59	0.50					
850-18				11	9	78	2			8	91					9030	
5S/11W-33R 4 S	64	7.3	1452	94	27	132	19	0	204	7	338	0.8	0.3	0.02	--	982	346
7- 6-65				4.69	2.22	5.74	0.49		3.34	0.15	9.53	0.01					
850-1C				36	17	44	4		26	1	73					718	
5S/12W-13A 3 S	--	7.5	29500	1536	565	5800	11	0	62	1222	12482	0.0	0.1	0.60	12	23844	6161
11- 1-63				76.65	46.47	252.18	0.28		1.02	25.44	351.99						
850-98				20	12	67				7	93					21659	
	--	7.3	36000	1884	1308	8625	120	0	516	872	19500	0.0	0.4	1.52	14	38080	
2-21-64				94.01	107.57	375.02	3.07		8.46	18.16	549.90						
				16	19	65	1		1	3	95					32579	
BOLSA AQUIFER																	
5S/11W-22H 3 S	--	7.8	500	71	13	35	3	0	246	57	32	3.9	0.6	0.04	--		231
2-27-52				3.54	1.07	1.52	0.08		4.03	1.19	0.90	0.06				326	
				57	17	24	1		65	19	15	1				336	
	--	7.4	1182	178	25	48	3	--	276	333	69	--	--	0.05	--	947	547
3-26-62				8.88	2.06	2.09	0.08		4.52	6.93	1.95						
				68	16	16	0		34	52	14						
5S/11W-22G 4 S	69	11.3	1186	105	2	77	9	24	0	224	53	1	0.5	0.06	--	560	270
6-15-65[a]				5.24	0.16	3.35	0.23	0.80		4.66	1.49	0.02					
85-106C				56	2	37	3	11		67	21					496	
5S/11W-22N 3 S	--	7.9	620	67	21	42	3	0	232	129	13	0.0	0.2	0.10	17	420	254
12-31-63				3.34	1.73	1.83	0.08		3.80	2.69	0.37						
				48	25	26	1		55	39	5					406	
5S/11W-22P 1 S	--	8.2	450	39	21	36	3	0	226	43	19	0.0	0.4	0.14	16	318	184
12-31-63				1.95	1.73	1.57	0.08		3.70	0.90	0.54						
				37	32	29	2		72	18	11					289	
5S/11W-26D 6 S	66	10.8	871	90	2	63	6	19	0	216	34	17	0.5	0.09	--	515	233
6-22-65[a]				4.49	0.16	2.74	0.15	0.63		4.50	0.96	0.27					
85-103C				60	2	36	2	10		71	15	4				448	
5S/11W-27A 4 S	--	7.6	1190	152	24	50	4	0	236	139	181	7.5	0.4	0.22	20	770	478
4- 4-62				7.58	1.97	2.17	0.10		3.87	2.89	5.10	0.12					
				64	17	18	1		32	24	43	1				694	
	--	8.2	620	71	17	40	3	0	217	70	66	4.4	0.2	0.17	17	406	247
12-31-63				3.54	1.40	1.74	0.08		3.56	1.46	1.86	0.07					
				52	21	26	1		51	21	27	1				395	
5S/11W-27D 7 S	69	8.0	376	28	9	36	3	0	142	43	21	1	0.6	0.09	--	215	107
6- 5-65				1.40	0.74	1.57	0.08		2.33	0.90	0.59	0.02					
85-105C				37	20	41	2		61	23	15	1				211	
5S/11W-27H 4 S	--	7.8	842	105	19	42	--	--	218	75	110	3.7	0	0	--	578	340
2-28-52				5.24	1.56	1.83			3.57	1.56	3.10	0.06					
				61	18	21			43	19	37	1				462	
	--	7.4	2747	192	58	280	9	0	299	201	616	--	--	--	--		718
3-21-61				9.58	4.77	12.17	0.23		4.90	4.18	17.37						
				36	18	45	1		18	16	65						
	--	8.3	825	90	13	56	4	7	203	82	97	3.0	0.5	0.23	--	505	276
1-27-66				4.49	1.07	2.43	0.10	0.23	3.33	1.71	2.74	0.05					
				56	13	30	1	3	41	21	34	1				453	
5S/11W-27P 3 S	--	8.2	376	25	3	53	3	0	215	0	16	--	--	0.05	--	220	75
10-17-61				1.25	0.25	2.30	0.08		3.52		0.45						
				32	6	59	2		89		11						
5S/11W-27Q 4 S	69	8.1	575	36	7	74	5	0	124	119	30	14.6	0.3	0.16	--	416	119
6-14-65				1.80	0.58	3.22	0.13		2.03	2.48	0.85	0.24					
85-104B				31	10	56	2		36	44	15	4				347	
5S/11W-28C 7 S	66	7.9	530	62	8	36	2	0	189	44	46	3.1	0.4	0.05	19	314	188
2-20-61				3.09	0.66	1.57	0.05		3.10	0.92	1.30	0.05					
				58	12	29	1		58	17	24	1				313	
5S/11W-28H 5 S	--	7.9	437	46	4	35	2	0	207	16	21	1.2	0.7	0.16	--		132
12- 5-56				2.30	0.33	1.52	0.05		3.39	0.33	0.59	0.02				263	
				55	8	36	1		78	8	14					228	
	--	7.2	618	62	11	53	3	0	211	18	83	0	0.4	0.06	16	435	200
4- 8-62				3.09	0.90	2.30	0.08		3.46	0.37	2.34						
				49	14	36	1		56	6	38					352	

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million / equivalents per million / percent reactance value									Chemical constituents in parts per million				
BOLSA AQUIFER (Continued)																	
5S/11W-28L 1 S	--	7.7	1825	122	9	242	2	0	143	87	459	0.0	0.3	0.14	15	1370	342
4- 8-62				6.09	0.74	10.52	0.05		2.34	1.81	12.94						
				35	4	60			14	11	76					1007	
	--	7.9	660	38	4	103	2	0	162	35	125	0.0	0.4	0.13	11	396	112
12-31-63				1.90	0.33	4.48	0.05		2.66	0.73	3.53						
				28	5	66	1		38	11	51					398	
5S/11W-28M 2 S	67	8.2	540	22	8	85	2	0	168	22	83	0.0	0.2	0.09	11	312	88
10-10-63				1.10	0.66	3.70	0.05		2.75	0.46	2.34						
850-2				20	12	67	1		50	8	42					316	
	67	8.2	622	38	3	81	2	0	170	20	96	0	0.4	0.05	--	335	108
7- 6-65				1.90	0.25	3.52	0.05		2.79	0.42	2.71						
				33	4	62	1		47	7	46					324	
5S/11W-33H 2 S	--	8.0	760	52	25	67	3	0	207	1	145	0.0	0.4	0.19	18	480	233
6-24-63				2.59	2.06	2.91	0.08		3.39	0.02	4.09						
B50-1A				34	27	38	1		45		55					413	
	65	7.9	904	94	14	58	4	0	209	1	173	0	0.4	0.06	--	626	292
7- 6-65				4.69	1.15	2.52	0.10		3.43	0.02	4.88						
				55	14	30	1		41		59					447	
ALPHA AQUIFER																	
5S/11W-16G 3 S	--	8.4	360	47	6	43	5	14	150	59	19	0.0	0.4	0.05	--	268	142
7-13-65[a]				2.35	0.49	1.87	0.13	0.47	2.46	1.23	0.54						
85-108C				49	10	39	3	10	52	26	11					267	
5S/11W-18N 4 S	63	7.7	19500	998	430	4400	55	0	99	1062	8830	0.0	0.1	0.85	10	17460	4261
2-20-64				49.80	35.36	191.31	1.41		1.62	22.11	249.01						
850-88				18	13	69	1		1	8	91					15835	
	66	9.2	8850	446	94	1361	25	9	7	331	2850	9	0.4	0.24	--	6144	1501
7- 2-65[a]				22.26	7.73	59.18	0.64	0.30	0.11	6.89	80.37	0.15					
				25	9	66	1			8	92					5129	
5S/11W-18N 5 S	62	7.4	17000	649	435	3600	103	0	250	1061	7180	0.0	0.2	1.70	15	15562	3411
10-18-63				32.39	35.77	156.53	2.63		4.10	22.09	202.48						
850-8C				14	16	69	1		2	10	89					13168	
	64	7.4	20096	695	478	3655	98	0	254	973	7550	11	0.8	1.00	--	16360	3702
7- 2-65				34.68	39.31	158.92	2.51		4.16	20.26	212.91	0.18					
				15	17	68	1		2	9	90					13587	
5S/11W-19H 3 S	70	8.1	900	68	15	104	3	0	201	67	155	0.0	0.4	0.10	17	540	231
8-14-63				3.39	1.23	4.52	0.08		3.29	1.39	4.37						
850-7B				37	13	49	1		36	15	48					528	
	65	8.4	489	45	13	40	3	5	207	36	28	1	0.7	0.04	--	270	166
7- 8-65				2.25	1.07	1.74	0.08	0.17	3.39	0.75	0.79	0.02					
				44	21	34	2	3	66	15	15					273	
5S/11W-19H 4 S	70	7.9	720	64	11	71	3	0	192	75	96	0.0	0.4	0.10	17	450	205
8-14-63				3.19	0.90	3.09	0.08		3.15	1.56	2.71						
850-7C				44	12	43	1		42	21	37					432	
	68	8.2	438	46	10	37	3	0	212	34	16	0	0.6	0.05	--	260	156
7- 8-65				2.30	0.82	1.61	0.08		3.47	0.71	0.45						
				48	17	33	2		75	15	10					251	
5S/11W-19H 8 S	--	8.0	650	32	24	69	4	0	212	49	74	0.0	0.4	0.11	--	370	179
9- 8-64				1.60	1.97	3.00	0.10		3.47	1.02	2.09						
88-1A				24	30	45	1		53	16	32					357	
5S/11W-19H 9 S	--	8.0	850	49	25	95	4	0	221	62	143	0.0	0.4	0.04	--	552	226
9- 8-64				2.45	2.06	4.13	0.10		3.62	1.29	4.03						
88-1B				28	24	47	1		40	14	45					487	
5S/11W-19H10 S	--	7.9	1300	58	84	73	4	0	202	68	305	0.0	0.2	0.04	--	732	490
8- 3-64				2.89	6.91	3.17	0.10		3.31	1.42	8.60						
88-1C				22	53	24	1		25	11	65					692	
5S/11W-20F 5 S	--	8.1	671	25	45	42	3	0	261	63	40	0.0	0.2	0.07	--	376	248
7-29-64				1.25	3.70	1.83	0.08		4.28	1.31	1.13						
88-2B				18	54	27	1		64	19	17					347	
5S/11W-20E 6 S	--	8.2	460	51	9	38	3	0	222	41	13	0.0	0.6	0.50	--	266	164
7-28-64				2.54	0.74	1.65	0.08		3.64	0.85	0.37						
88-2A				51	15	33	2		75	17	8					265	
5S/11W-20G 7 S	--	7.9	440	49	10	33	3	0	214	36	14	0.0	0.2	0.08	15	244	164
1- 7-64				2.45	0.82	1.43	0.08		3.51	0.75	0.39						
				51	17	30	2		75	16	8					265	
5S/11W-20K 9 S	--	7.6	415	44	7	37	2	0	197	34	16	0.0	0.6	0.07	16	268	139
2- 1-61				2.20	0.58	1.61	0.05		3.23	0.71	0.45						
				50	13	36	1		74	16	10					253	

State well number Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C Evap 105°C Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million / equivalents per million / percent reactance value									Chemical constituents in parts per million				
ALPHA AQUIFER (Continued)																	
55/11W-20M 2 S 8- 6-53 BSO-6A	--	7.5	29500	1804 90.02 26	608 50.00 14	4700 204.36 59	40 1.02	0	284 4.65 1	1340 27.90 8	10860 306.25 90	0	0.1	0.50	13	21600 19505	7007
 7- 9-65	65	7.2	18109	1227 61.23 31	394 32.40 16	2360 102.61 52	27 0.69	0	140 2.29 1	725 15.09 8	6325 178.37 91	1 0.02	0.6	0.25	--	12088 11129	4685
55/11W-20M 6 S 7-16-64 HH-3A	--	7.2	27000	2340 116.77 33	664 54.61 16	4100 178.27 51	40 1.02	0	230 3.77 1	1013 21.09 6	11330 319.51 93	0.0	0.1	0.36	--	23140 19600	8576
55/11W-20M 7 S 7-16-64 HH-3B	--	8.1	530	26 1.30 24	26 2.14 40	42 1.83 34	3 0.08 1	0	209 3.43 65	34 0.71 13	40 1.13 21	0.0	0.6	0.17	--	286 274	172
55/11W-20N 1 S 7-14-64 HH-4A	--	7.5	37000	810 40.42 8	987 81.17 16	8700 378.28 75	110 2.81 1	0	244 4.00 1	2267 47.20 10	15710 443.02 90	0.0	0.2	3.90	--	29200 28708	6084
55/11W-20N 2 S 7-14-64 HH-4B	--	7.2	5600	677 33.78 56	148 12.17 20	320 13.91 23	12 0.31 1	0	142 2.33 4	163 3.39 6	1911 53.89 90	0.0	0.2	0.17	--	4250 3301	2299
55/11W-20Q 3 S 9-15-55	--	7.7	513	52 2.59 53	8 0.66 14	34 1.48 30	6 0.15 3	0	195 3.20 59	35 0.73 14	50 1.41 26	3 0.05 1	0.3	0.10	--	 306 284	163
 3-30-62	--	7.4	2320	265 13.22 55	36 2.96 12	175 7.61 32	5 0.13 1	0	175 2.87 12	81 1.69 7	695 19.60 81	0	0.1	0.15	22	1952 1365	810
 9-23-65	--	8.0	1190	121 6.04 53	22 1.81 16	77 3.35 30	4 0.10 1	0	193 3.16 28	58 1.21 11	241 6.80 61	0	0.5	0.11	--	879 618	393
55/11W-20Q 5 S 12- 5-56	--	7.9	459	--	--	--	--	0	198 3.25	--	28 0.79	--	--	--	--		
 6-24-63	--	7.4	11000	1526 76.15 60	270 22.20 18	645 28.04 22	15 0.38	0	146 2.39 2	31 0.65 1	4308 121.49 98	0	0.1	0.20	14	6882 6881	4921
 9-23-65	--	7.4	11280	1417 70.71 57	266 21.88 18	699 30.39 25	16 0.41	0	133 2.18 2	467 9.72 8	3872 109.19 89	115 1.85 2	0.6	0.15	--	8720 6918	4633
55/11W-20Q 6 S 3-21-61	--	7.4	592	72 3.59 57	12 0.99 16	38 1.65 26	3 0.08 1	0	180 2.95 47	37 0.77 12	87 2.45 39	3.1 0.05 1	0.6	0.05	21	342 362	229
 9-23-65	--	8.1	586	60 2.99 51	13 1.07 18	39 1.70 29	3 0.08 1	0	199 3.26 56	39 0.81 14	63 1.78 30	1 0.02	0.5	0.04	--	316 316	203
55/11W-20Q11 S 3-29-62	--	7.8	470	51 2.54 52	12 0.99 20	30 1.30 27	2 0.05 1	0	206 3.38 71	29 0.60 13	28 0.79 17	0	0.4	0.04	24	 278	177
 9-23-65	--	8.3	602	67 3.34 54	11 0.90 15	43 1.87 30	3 0.08 1	8 0.27 4	197 3.23 53	38 0.79 13	65 1.83 30	1 0.02	0.6	0.10	--	398 334	212
55/11W-20Q12 S 2- 3-61	--	7.6	540	77 3.84 58	12 0.99 15	39 1.70 26	3 0.08 1	0	214 3.51 63	22 0.46 8	58 1.64 29	0	0.4	0.10	14	 338 331	242
 9-23-65	--	7.9	540	55 2.74 51	10 0.82 15	41 1.78 33	3 0.08 1	0	208 3.41 62	38 0.79 14	45 1.27 23	0	0.5	0.02	--	301 295	178
55/11W-21L 6 S 7-22-64	--	7.8	460	54 2.69 52	11 0.90 17	34 1.48 29	3 0.08 2	0	215 3.52 70	34 0.71 14	28 0.79 16	0.0	0.4	0.08	--	274 270	180
55/11W-21N 7 S 7-20-64	--	8.1	545	53 2.64 45	17 1.40 24	39 1.70 29	3 0.08 1	0	212 3.47 60	54 1.12 19	41 1.16 20	0.0	0.2	0.10	--	314 312	202
55/11W-21P 4 S 3-26-52	--	7.9	--	60 2.99 54	12 0.99 18	33 1.43 26	3 0.08 1	0	210 3.44 64	47 0.98 18	32 0.90 17	3.9 0.06 1	0.4	0.04	--	 306 295	199
 4- 2-62	--	7.4	1330	198 9.88 66	33 2.71 18	50 2.17 15	4 0.10 1	0	217 3.56 23	459 9.56 61	42 1.18 8	78 1.26 8	0.6	0.19	23	 1002 994	630

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million / equivalents per million / percent reactance value									Chemical constituents in parts per million				
ALPHA AQUIFER (Continued)																	
5S/11W-22G 3 S	69	9.3	369	9	5	58	5	22	37	62	29	14	0.6	0.13	--	250	43
6-15-65[a]				0.45	0.41	2.52	0.13	0.73	0.61	1.29	0.82	0.23					
85-1068				13	12	72	4	20	17	35	22	6				223	
5S/11W-22M 4 S	--	8.0	500	69	12	33	3	0	220	84	22	3.4	0.6	0.60	--		222
3-27-52				3.44	0.99	1.43	0.08		3.61	1.75	0.62	0.05					
				58	17	24	1		60	29	10	1				336	
	--	7.6	1320	166	55	95	6	0	249	576	37	0.0	0.1	0.25	11	1130	641
12-31-63				8.28	4.52	4.13	0.15		4.08	11.99	1.04						
				48	26	24	1		24	70	6					1069	
5S/11W-25E 5 S	--	7.5	494	62	12	34	3	0	205	70	22	0	0.6	0.07	16		204
11-28-61				3.09	0.99	1.48	0.08		3.36	1.46	0.62					288	
				55	18	26	1		62	27	11					320	
5S/11W-25N 1 S	--	7.9	782	96	12	35	4	--	214	118	51	24	0.3	0.24	18		289
5- 8-56				4.79	0.99	1.52	0.10		3.51	2.46	1.44	0.39				503	
				65	13	21	1		45	32	18	5				464	
	--	7.8	977	122	20	44	3	0	220	86	148	--	--	0.04	--	633	387
9-18-61				6.09	1.64	1.91	0.08		3.61	1.79	4.17						
				63	17	20	1		38	19	43						
	68	7.9	550	61	11	36	3	0	226	58	26	3.0	0.4	0.08	--	318	197
6-17-64				3.04	0.90	1.57	0.08		3.70	1.21	0.73	0.05					
				54	16	28	1		65	21	13	1				310	
5S/11W-26B 3 S	--	7.7	780	79	12	58	7	0	240	85	56	33	0.5	0.14	16		247
1-23-62				3.94	0.99	2.52	0.18		3.93	1.77	1.58	0.53				448	
				52	13	33	2		50	23	20	7				465	
5S/11W-26D 5 S	66	8.8	350	20	6	43	2	12	81	54	21	1	0.7	0.07	--	200	75
7-14-65[a]				1.00	0.49	1.87	0.05	0.40	1.33	1.12	0.59	0.02					
85-1038				29	14	55	1	12	38	32	17	1				200	
5S/11W-27C 5 S	--	8.0	430	45	7	34	2	0	202	20	18	0.0	0.3	0.12	20	234	142
4- 5-62				2.25	0.58	1.48	0.05		3.31	0.42	0.51						
				52	13	34	1		78	10	12					246	
5S/11W-28D 4 S	--	6.7	1753	248	74	91	6	--	227	831	30	--	--	0	--	1444	924
3-29-60				12.38	6.09	3.96	0.15		3.72	17.30	0.85						
				55	27	18	1		17	79	4						
	--	8.3	845	98	27	45	4	12	198	220	26	0.9	0.4	0.09	--	593	356
1-28-66				4.89	2.22	1.96	0.10	0.40	3.25	4.58	0.73	0.01					
				53	24	21	1	4	36	51	8					531	
5S/11W-28D 6 S	--	7.7	990	126	32	47	3	0	203	328	35	0.0	0.2	0.15	--	694	446
12-18-64				6.29	2.63	2.04	0.08		3.33	6.83	0.99						
				57	24	18	1		30	61	9					671	
5S/11W-29A 8 S	--	7.9	495	45	7	34	2	0	185	42	20	0	0.4	0.07	20	286	142
4- 6-62				2.25	0.58	1.48	0.05		3.03	0.87	0.56						
				52	13	34	1		68	20	13					261	
5S/11W-29B 8 S	--	7.8	1660	166	33	95	5	0	189	58	388	0.0	0.2	0.10	7	960	550
5- 8-57				8.28	2.71	4.13	0.13		3.10	1.21	10.94						
				54	18	27	1		20	8	72					845	
	--	7.3	7400	777	152	685	23	0	94	280	2606	0	0.1	0.55	15		2566
4- 6-62				38.77	12.50	29.78	0.59		1.54	5.83	73.49					4798	
				47	15	36	1		2	7	91					4585	
5S/11W-29B 9 S	72	8.1	470	36	6	53	2	0	189	33	33	0	0.4	0	15	312	115
5- 8-57				1.80	0.49	2.30	0.05		3.10	0.69	0.93						
				39	11	50	1		66	15	20					271	
	--	7.5	1975	214	33	111	5	0	135	64	517	0	0.2	0.14	17		670
4- 6-62				10.68	2.71	4.83	0.13		2.21	1.33	14.58					1152	
				58	15	26	1		12	7	80					1028	
	--	8.2	979	98	16	68	3	0	173	41	195	1.5	0.4	0.09	--	700	311
9-23-65				4.89	1.32	2.96	0.08		2.84	0.85	5.50	0.02					
				53	14	32	1		31	9	60					508	
5S/11W-29B11 S	--	8.2	414	27	5	51	3	0	149	32	31	0.0	0.8	0.27	19	294	88
5-18-59				1.35	0.41	2.22	0.08		2.44	0.67	0.87						
				33	10	55	2		61	17	22					242	
	--	7.5	1700	203	29	100	4	0	126	64	491	0	0.4	0.17	17		626
4- 6-62				10.13	2.38	4.35	0.10		2.07	1.33	13.85						
				60	14	26	1		12	8	80					970	
	--	8.0	832	76	11	67	3	0	159	37	155	1	0.5	0.10	--	521	235
9-23-65				3.79	0.90	2.91	0.08		2.61	0.77	4.37	0.02					
				49	12	38	1		34	10	56					429	

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million / equivalents per million / percent reactance value									Chemical constituents in parts per million				
ALPHA AQUIFER (Continued)																	
5S/11W-29C 5 S	--	7.3	39000	882	1030	9300	120	0	193	2349	16840	0.0	0.2	3.90	--	34180	6441
7-22-64				44.01	84.71	404.36	3.07		3.16	48.91	474.89						
HH-5A				8	16	75	1		1	9	90					30620	
5S/11W-29C 6 S	--	7.4	24000	1283	503	5300	40	0	197	1342	10640	0.0	0.2	1.33	--	20440	5274
7-22-64				64.02	41.37	230.44	1.02		3.23	27.94	300.05						
HH-5B				19	12	68			1	8	91					19206	
5S/11W-35E 1 S	70	6.9	11200	657	151	1532	17	0	607	123	3599	18.8	0.4	3.23	--	7405	2262
12-14-56				32.78	12.42	66.61	0.43		9.95	2.56	101.49	0.30					
				29	11	59			9	2	89					6400	
	69	7.3	6800	475	113	1080	16	0	628	26	2447	0.0	0.1	5.20	21	5020	1651
12-31-63				23.70	9.29	46.96	0.41		10.29	0.54	69.01						
				29	12	58	1		13	1	86					4492	
5S/12W-13A 4 S	--	7.7	1200	77	13	178	6	0	149	68	312	0.0	0.4	0.11	17	824	246
9-11-63				3.84	1.07	7.74	0.15		2.44	1.42	8.80						
850-9C				30	8	60	1		19	11	70					745	
	65	8.2	769	60	14	75	4	0	209	39	114	0	0.6	0.02	--	388	207
7- 1-65				2.99	1.15	3.26	0.10		3.43	0.81	3.21						
				40	15	43	1		46	11	43					409	
5S/12W-13A 5 S	--	7.8	960	48	10	153	5	0	82	58	255	0.0	0.4	0.08	18	604	161
9- 9-63				2.40	0.82	6.65	0.13		1.34	1.21	7.19						
850-90				24	8	67	1		14	12	74					588	
	66	7.8	446	40	7	45	3	0	190	39	23	0	0.7	0.05	--	250	129
7- 1-65				2.00	0.58	1.96	0.08		3.11	0.81	0.65						
				43	13	42	2		68	18	14					251	
BETA AQUIFER																	
5S/11W-16G 2 S	67	8.0	350	42	5	47	5	0	191	41	18	0.0	0.3	0	--	284	126
6-28-65				2.10	0.41	2.04	0.13		3.13	0.85	0.51						
85-1088				45	9	44	3		70	19	11					252	
5S/11W-18N 6 S	68	8.0	5400	190	78	1045	11	0	123	254	1968	0.0	0.1	0.48	11	1840	795
12-19-63				9.48	6.41	45.44	0.28		2.02	5.29	55.50						
850-80				15	10	74			3	8	88					3618	
	66	7.8	4647	134	56	736	6	0	141	186	1320	11	0.5	0.20	--	2930	565
7- 2-65				6.69	4.61	32.00	0.15		2.31	3.87	37.22	0.18					
				15	11	74			5	9	85					2519	
5S/11W-19B 2 S	70	8.1	755	63	20	66	3	0	160	38	145	0	0.4	0.13	16	488	239
8- 9-63				3.14	1.64	2.87	0.08		2.62	0.79	4.09						
850-7A				41	21	37	1		35	11	55					430	
	69	8.2	530	48	10	47	3	0	161	36	66	0	0.6	0.04	--	300	161
7- 8-65				2.40	0.82	2.04	0.08		2.64	0.75	1.86						
				45	15	38	1		50	14	35					290	
5S/11W-20G 6 S	69	8.0	454	50	9	40	2	0	195	36	37	2.9	0.7	0.02	23	227	162
3-14-61				2.50	0.74	1.74	0.05		3.20	0.75	1.04	0.05					
				50	15	35	1		63	15	21	1				296	
5S/11W-20J10 S	69	8.7	450	33	8	50	3	10	134	42	42	0	0.6	0.07	--	260	116
6-26-65[a]				1.65	0.66	2.17	0.08	0.33	2.20	0.87	1.18						
85-1118				36	14	48	2	7	48	19	26					254	
5S/11W-20M 3 S	--	8.2	760	73	12	62	3	0	177	54	128	0	0.4	0.08	16	468	232
8- 5-63				3.64	0.99	2.70	0.08		2.90	1.12	3.61						
850-6B				49	13	36	1		38	15	47					435	
	66	8.0	655	62	12	53	3	0	181	41	91	0.0	0.6	0.06	--	385	204
7- 9-65				3.09	0.99	2.30	0.08		2.97	0.85	2.57						
				48	15	36	1		46	13	40					352	
5S/11W-20Q 4 S	--	7.8	510	47	10	40	5	0	210	36	30	0	0.6	0.06	17	326	159
5- 8-57				2.35	0.82	1.74	0.13		3.44	0.75	0.85						
				47	16	35	3		68	15	17					289	
	--	7.5	2175	380	45	93	5	0	169	188	589	0	0.1	0.09	18		1134
3-29-62				18.96	3.70	4.04	0.13		2.77	3.91	16.61					1550	
				71	14	15			12	17	71					1401	
	--	8.1	1524	171	30	75	4	0	185	62	352	0	0.5	0.09	--	1314	550
9-23-65				8.53	2.47	3.26	0.10		3.03	1.29	9.93						
				59	17	23	1		21	9	70					785	
5S/11W-20R12 S	--	7.8	695	62	8	41	3	0	198	39	56	0	0.3	0.14	17		188
6- 8-61				3.09	0.66	1.78	0.08		3.25	0.81	1.58					286	
				55	12	32	1		58	14	28					324	
	--	8.2	490	48	11	39	3	0	203	32	36	0	0.2	0.12	11	286	165
6-24-63				2.40	0.90	1.70	0.08		3.33	0.67	1.02						
				47	18	33	2		66	13	20					280	

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Chemical constituents in parts per million / equivalents per million / percent reactance value									Chemical constituents in parts per million				
				Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
BETA AQUIFER (Continued)																	
5S/11W-20R16 S	--	7.4	435	49	8	33	2	0	195	36	25	4.3	0.4	0.06	19	231	156
3-21-61				2.45	0.66	1.43	0.05		3.20	0.75	0.71	0.07					
				53	14	31	1		68	16	15	1				273	
5S/11W-21G 3 S	69	10.2	451	18	4	63	5	31	0	51	55	2	0.5	0.09	--	260	62
6-23-65[a]				0.90	0.33	2.74	0.13	1.03		1.06	1.55	0.03					
85-109C				22	8	67	3	28		29	42	1				230	
5S/11W-21L 5 S	--	8.2	430	40	11	38	4	0	189	38	23	0.0	0.2	0.08	--	246	145
7-22-64				2.00	0.90	1.65	0.10		3.10	0.79	0.65						
				43	19	35	2		68	17	14					247	
5S/11W-21N 5 S	--	8.2	590	60	21	43	3	0	215	104	29	0.0	0.2	0.12	--	422	236
7-21-64				2.99	1.73	1.87	0.08		3.52	2.17	0.82						
				45	26	28	1		54	33	13					366	
5S/11W-26R17 S	69	7.5	415	47	12	26	2	0	198	38	15	0	0.4	0.05	17		167
1-25-62				2.35	0.99	1.13	0.05		3.25	0.79	0.42					298	
				52	22	25	1		73	18	9					255	
5S/11W-26F 4 S	--	7.7	391	52	9	30	3	0	212	28	18	3.4	0.5	0.02	--		167
3-31-52				2.59	0.74	1.30	0.08		3.47	0.58	0.51	0.05				264	
				55	16	28	2		75	13	11	1				248	
	68	7.5	2580	309	50	110	6	0	250	96	652	6.6	0.4	--	--		977
12- 6-56				15.42	4.11	4.78	0.15		4.10	2.00	18.39	0.11				1775	
				63	17	20	1		17	8	75					1353	
5S/11W-26H 5 S	--	7.9	470	59	6	27	3	0	193	52	19	1.8	0.4	0.06	18		172
1-24-62				2.94	0.49	1.17	0.08		3.16	1.08	0.54	0.03				360	
				63	10	25	2		66	22	11	1				281	
5S/11W-26M 1 S	--	7.7	2888	195	44	340	11	--	293	172	698	--	--	--	--		668
10- 2-56				9.73	3.62	14.78	0.28		4.80	3.58	19.68					1708	
				34	13	52	1		17	13	70						
5S/11W-26M 2 S	--	7.6	2535	176	29	320	12	0	282	172	580	13	0.5	0.90	--		558
5-17-58				8.78	2.38	13.91	0.31		4.62	3.58	16.36	0.21				1607	
				35	9	55	1		19	14	66	1				1442	
5S/11W-27D 6 S	69	8.3	422	30	9	43	4	2	120	53	36	0	0.6	0.08	--	240	112
6- 5-65				1.50	0.74	1.87	0.10	0.07	1.97	1.10	1.02						
85-1058				36	18	44	2	2	47	26	25					237	
5S/11W-27F 4 S	--	8.1	610	63	27	43	3	0	220	120	27	10.0	0.6	0.14	12	454	268
12-31-63				3.14	2.22	1.87	0.08		3.6	2.50	0.76	0. 6					
				43	30	26	1		51	36	11	2				414	
5S/11W-27R 2 S	--	7.5	5730	365	75	720	14	0	390	95	1670	0.9	0.2	3.80	19	3160	1220
6-15-54				18.21	6.17	31.31	0.36		6.39	1.98	47.09	0.01					
				32	11	56	1		12	4	85					3155	
5S/11W-28C 3 S	--	8.0	495	51	7	45	2	0	205	42	30	0.8	0.4	0.12	20	282	156
4- 3-62				2.54	0.58	1.96	0.05		3.36	0.87	0.85	0.01					
				50	11	38	1		66	17	17					299	
	--	8.2	494	48	11	44	2	0	193	77	15	1.8	0.5	0.06	--	297	165
7-23-64				2.40	0.90	1.91	0.05		3.16	1.60	0.42	0.03					
				46	17	36	1		61	31	8	1				294	
5S/11W-29A10 S	--	8.0	420	39	7	43	2	0	181	30	25	0.0	0.4	0.15	14	250	127
11-21-63				1.95	0.58	1.87	0.05		2.97	0.62	0.71						
				44	13	42	1		69	14	17					249	
5S/11W-29F 1 S	--	7.7	46000	556	1137	10250	200	0	156	2498	18484	0.0	0.1	0.22	14	34440	6067
7-11-63				27.74	93.51	445.67	5.11		2.56	52.01	521.25						
850-5A				5	16	78	1			9	91					33216	
	--	7.0	40240	683	1102	9545	66	0	168	2362	17300	3.1	1.9	3.00	--	33630	6240
4-16-64				34.08	90.63	415.02	1.69		2.75	49.18	487.86	0.05					
				6	17	77			1	9	90					31149	
5S/11W-29J 2 S	--	7.4	13100	982	280	1700	25	0	189	1282	3998	0.0	0.1	0.47	18	10320	3604
6-25-63				49.00	23.03	73.92	0.64		3.10	26.69	112.74						
850-3A				33	16	50			2	19	79					8378	
5S/11W-35C 1 S	--	7.6	3800	431	85	391	11	0	311	46	1390	6.8	0.3	1.30	24	2915	1426
1-29-62				21.51	6.99	17.00	0.28		5.10	0.96	39.20	0.11					
				47	15	37	1		11	2	86					2539	
5S/12W-13A 2 S	--	7.2	14800	1097	204	1865	23	0	184	615	4769	0.0	0.1	0.20	16	10294	3579
9-12-63				54.74	16.78	81.09	0.59		3.02	12.80	134.49						
850-9A				36	11	53			2	9	89					8680	
	66	7.2	19880	947	426	3100	35	0	242	927	6825	15	0.8	0.60	--	13790	4118
7- 1-65				47.26	35.03	134.79	0.89		3.97	19.30	192.47	0.24					
				22	16	62			2	9	89					12395	

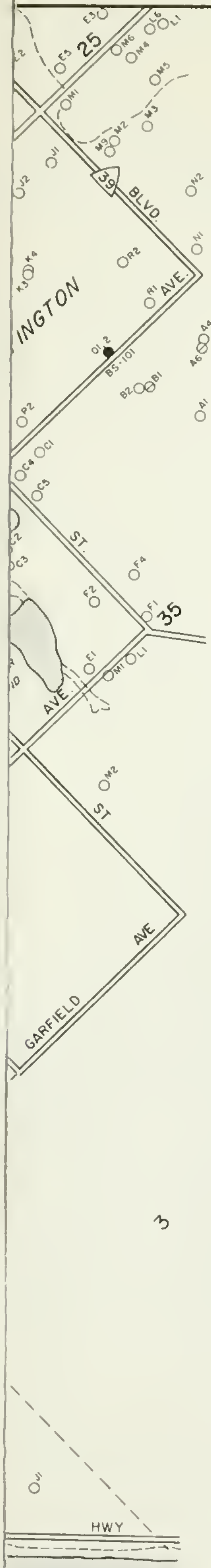
State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C Evap 105°C Computed	Total hardness as $CaCO_3$
				Chemical constituents in parts per million, equivalents per million, percent reactance value									Chemical constituents in parts per million				
LAMBDA AQUIFER																	
5S/11W-16G 1 S	67	9.7	330	13	2	55	6	8	79	66	20	0.0	0.3	0.01	--	223	41
6-28-65[a]				0.65	0.16	2.39	0.15	0.27	1.29	1.37	0.56						
8S-108A				19	5	71	4	8	37	39	16					209	
5S/11W-20C 4 S	--	7.5	480	40	5	54	1	0	168	62	33	0	0.3	0.08	14		121
1-31-61				2.00	0.41	2.35	0.03		2.75	1.29	0.93					290	
				42	9	49	1		55	26	19					292	
5S/11W-20J 9 S	69	8.6	549	44	7	66	3	10	186	51	46	0	0.7	0.07	--	320	139
6-26-65[a]				2.20	0.58	2.87	0.08	0.33	3.05	1.06	1.30						
8S-111A				38	10	50	1	6	53	18	23					319	
5S/11W-21G 2 S	69	8.8	425	40	9	41	3	14	166	37	16	0	0.4	0.09	--	250	137
6-23-65[a]				2.00	0.74	1.78	0.08	0.47	2.72	0.77	0.45						
8S-109B				43	16	39	2	11	62	17	10					242	
5S/11W-21M 3 S	--	7.9	380	25	2	54	1	0	167	38	15	0.0	0.2	0.08	--	224	71
6-19-64				1.25	0.16	2.35	0.03		2.74	0.79	0.42						
				33	4	62	1		69	20	11					217	
5S/11W-21N 2 S	--	7.9	462	50	2	43	6	--	186	52	20	3	0.3	0.10	--		133
9- 2-55				2.50	0.16	1.87	0.15		3.05	1.08	0.56	0.05				270	
				53	3	40	3		64	23	12	1				268	
	--	7.8	549	58	10	58	3	--	187	156	19	--	--	0	--		186
4-13-59				2.89	0.82	2.52	0.08		3.06	3.25	0.54					340	
				46	13	40	1		45	47	8						
5S/11W-22G 2 S	69	8.4	481	41	11	47	3	12	173	51	26	0	0.6	0.13	--	285	148
6-15-65				2.05	0.90	2.04	0.08	0.40	2.84	1.06	0.73						
8S-106A				40	18	40	2	8	56	21	15					277	
5S/11W-22N 4 S	--	7.9	410	45	7	34	2	0	195	24	17	0	0.4	0.10	16		142
4- 3-62				2.25	0.58	1.48	0.05		3.20	0.50	0.48					226	
				52	13	34	1		77	12	11					241	
5S/11W-26D 4 S	67	8.6	472	47	8	46	2	20	172	44	22	0	0.6	0.07	--	273	151
6-22-65[a]				2.35	0.66	2.00	0.05	0.67	2.82	0.92	0.62						
8S-103A				46	13	40	1	13	56	18	12					274	
5S/11W-26F 4 S	--	7.9	508	70	12	32	3	0	215	56	31	8.8	0.6	0.05	--		224
3-31-52				3.49	0.99	1.39	0.08		3.52	1.17	0.87	0.14				362	
				59	17	23	1		62	21	15	2				319	
	--	7.6	1473	198	33	30	3	0	211	124	282	58	0.3	0.15	--		630
9-25-57				9.88	2.71	1.30	0.08		3.46	2.58	7.95	0.94					
				71	19	9	1		23	17	53	6				832	
5S/11W-26H 8 S	68	8.0	513	41	6	55	5	0	175	57	32	0.8	0.3	0.04	--	360	127
6- 2-65				2.05	0.49	2.39	0.13		2.87	1.19	0.90	0.01					
8S-102B				41	10	47			58	24	18					283	
5S/11W-26Q 2 S	68	8.2	580	63	10	55	5	11	139	84	60	7.5	0.6	0.05	--	396	198
5-25-65				3.14	0.82	2.39	0.13	0.37	2.28	1.75	1.69	0.12					
8S-101B				48	13	37	2	6	37	28	27	2				364	
5S/11W-27D 6 S	69	8.3	422	30	9	43	4	2	120	53	36	0	0.6	0.08	--	240	112
6- 5-65				1.50	0.74	1.87	0.10	0.07	1.97	1.10	1.02						
8S-105A				36	18	44	2	2	47	26	25					237	
MEADOWLARK AQUIFER																	
5S/11W-18N 7 S	--	8.3	355	15	1	64	2	3	170	19	17	0	0.2	0.05	9	222	42
8-26-63				0.75	0.08	2.78	0.05	0.10	2.79	0.40	0.48						
8SO-8E				20	2	76	1	3	74	11	13					214	
	70	7.7	386	13	3	61	2	0	173	16	14	0	0.6	0.10	--	225	45
7- 2-65				0.65	0.25	2.65	0.05		2.84	0.33	0.39						
				18	7	74	1		80	9	11					195	
5S/11W-19H 5 S	70	8.1	620	32	3	102	2	0	147	58	92	0.0	0.2	0.10	14	374	93
8-14-63				1.60	0.25	4.43	0.05		2.41	1.21	2.59						
8SO-7D				25	4	70	1		39	19	42					376	
	71	8.6	342	15	3	59	2	10	134	30	14	0	0.5	0.06	--	200	50
7- 8-65				0.75	0.25	2.57	0.05	0.33	2.20	0.62	0.39						
				21	7	71	1	9	62	18	11					199	
5S/11W-20J 4 S	--	8.3	480	43	12	45	2	2	218	49	22	0.0	0.4	0.10	--	300	157
6-19-64				2.15	0.99	1.96	0.05	0.07	3.57	1.02	0.62						
				42	19	38	1	1	68	19	12					283	
5S/11W-20M 4 S	--	8.4	360	25	1	52	2	3	148	31	13	0.0	0.2	0.08	12	208	67
8- 1-63				1.25	0.08	2.26	0.05	0.10	2.43	0.65	0.37						
8SO-6C				34	2	62	1	3	68	18	10					212	
	59	8.1	360	23	3	53	2	0	160	30	16	1	0.4	0.06	--	206	70
7- 9-65				1.15	0.25	2.30	0.05		2.62	0.62	0.45	0.02					
				31	7	61	1		71	17	12	1				207	

State well number / Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Chemical constituents in parts per million, equivalents per million, percent reactance value: Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Chemical constituents in parts per million: Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
MEADOWLARK AQUIFER (Continued)																	
5S/11W-21G 1 S	69	8.3	572	44	3	83	5	19	151	68	53	0	0.4	0.05	--	332	123
6-25-65				2.20	0.25	3.61	0.13	0.63	2.47	1.42	1.49						
BS-109A				36	4	58	2	10	41	24	25					350	
5S/11W-21N 3 S	--	7.8	774	86	14	42	2	0	217	165	20	3.7	0.5	0.03	18	450	272
3-21-61				4.29	1.15	1.83	0.05		3.56	3.44	0.56	0.06					
				59	16	25	1		47	45	7	1				456	
	--	8.2	390	30	13	37	2	0	193	31	20	0.0	0.2	0.10	--	242	129
1-25-65				1.50	1.07	1.61	0.05		3.16	0.65	0.56						
				35	25	38	1		72	15	13					228	
5S/11W-21Q 5 S	--	8.3	647	80	9	38	13	--	204	67	50	1.6	0.3	0	19		237
5-15-56				3.99	0.74	1.65	0.33		3.34	1.39	1.41	0.03				400	
				59	11	25	5		54	23	23					378	
	72	7.9	919	109	19	56	4	0	233	146	89	9.0	0.4	0.08	--	585	350
11-10-65				5.44	1.56	2.43	0.10		3.82	3.04	2.51	0.15					
				57	16	25	1		40	32	26	2				547	
5S/11W-21R 2 S	--	8.1	420	41	7	36	3	0	191	29	13	0	0.4	0.04	14	246	132
6-24-63				2.05	0.58	1.57	0.08		3.13	0.60	0.37						
				48	14	37	2		76	15	9					237	
5S/11W-22B 1 S	--	7.9	407	44	9	33	3	--	195	34	12	--	--	0.07	--	277	147
3-26-62				2.20	0.74	1.43	0.08		3.20	0.71	0.34						
				49	17	32	2		75	17	8						
5S/11W-29J 3 S	--	8.4	420	21	0	56	1	2	153	23	14	0.0	0.2	0.14	12	212	53
7- 9-63				1.05		2.43	0.03	0.07	2.51	0.48	0.39						
BSO-3B				30		69	1	2	73	14	11					205	
5S/11W-33B 5 S	--	8.0	450	36	6	42	2	0	188	29	14	0.0	0.6	0.17	18	232	115
6-24-63				1.80	0.49	1.83	0.05		3.08	0.60	0.39						
BSO-1D				43	12	44	1		76	15	10					240	
5S/11W-35F 4 S	--	8.9	255	12	--	66	2	16	150	14	13	--	--	0.06	--	255	30
3- 9-62				0.60		2.87	0.05	0.53	2.46	0.29	0.37						
				17		82	1	15	67	8	10						
5S/12W-13A 6 S	--	7.8	1100	76	8	155	4	0	148	67	259	0.0	0.4	0.08	13	722	223
8-31-63				3.79	0.66	6.74	0.10		2.43	1.39	7.30						
BSO-9E				34	6	60	1		22	13	66					655	
	70	8.1	542	24	5	84	2	0	159	35	71	0	0.5	0.08	--	330	81
7- 1-65				1.20	0.41	3.65	0.05		2.61	0.73	2.00						
				23	8	69	1		49	14	37					300	
MAIN AQUIFER																	
5S/11W- 7C 1 S	77	8.2	399	34	8	44	2	--	186	34	12	0.0	0.4	0.04	16	210	118
10- 9-63				1.70	0.66	1.91	0.05		3.05	0.71	0.34						
				39	15	44	1		74	17	8					242	
5S/11W- 8C 1 S	--	8.5	372	18	3	59	2	7	159	32	12	--	--	0.02	--	211	58
10- 1-62				0.90	0.25	2.57	0.05	0.23	2.61	0.67	0.34						
				24	7	68	1	6	68	17	9						
5S/11W-16R 1 S	--	8.1	404	38	9	39	5	0	198	41	12	0	0.7	0.08	17		132
7- 9-63				1.90	0.74	1.70	0.13		3.25	0.85	0.34						
				43	17	38	3		73	19	8					259	
5S/11W-19B 6 S	70	8.7	335	8	1	69	1	9	143	10	18	0.0	0.8	0.12	14	216	24
8-15-63				0.40	0.08	3.00	0.03	0.30	2.34	0.21	0.51						
BSO-7E				11	2	85	1	9	70	6	15					201	
	75	8.4	301	5	1	66	1	7	146	9	17	1	0.7	0.10	--	160	17
7- 8-65				0.25	0.08	2.87	0.03	0.23	2.39	0.19	0.48	0.02					
				8	2	89	1	7	72	6	15	1				180	
5S/11W-21J 4 S	68	7.9	310	6	1	69	1	0	128	43	14	6.8	0.2	0.07	15	187	19
3-21-61				0.30	0.08	3.00	0.03		2.10	0.90	0.39	0.11					
				9	2	88	1		60	26	11	3				219	
5S/11W-21Q 1 S	--	7.9	368	8	0	77	0	0	153	31	15	1.5	0.5	0.18	--	196	20
6-22-64				0.40		3.35			2.51	0.65	0.42	0.02					
				11		89			70	18	12	1				208	
5S/11W-26M 7 S	--	7.7	436	16	1	88	1	0	246	7	13	0.6	0.7	0.17	--	261	44
4-20-65				0.80	0.08	3.83	0.03		4.03	0.15	0.37	0.01					
				17	2	81	1		88	3	8					248	
5S/11W-26P 1 S	--	6.5	380	4	1	81	1	3	178	20	13	0.0	0.6	0.15	--	244	14
6-17-64				0.20	0.08	3.52	0.03	0.10	2.92	0.42	0.37						
				5	2	92	1	3	77	11	10					211	
5S/11W-27K 2 S	69	8.1	350	7	1	82	1	0	189	12	17	1.8	0.6	0.28	13	242	22
1- 7-64				0.35	0.08	3.57	0.03		3.10	0.25	0.48	0.03					
				9	2	89	1		80	8	12	1				229	

State well number Date sampled	Temp. when sampled in °F	pH	Specific conductance (micromhos at 25°C)	Chemical constituents in parts per million / equivalents per million / percent reactance value: Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Chemical constituents in parts per million: Fluoride F	Boron B	Silica SiO_2	TDS Evap 180°C / Evap 105°C / Computed	Total hardness as $CaCO_3$
							MAIN AQUIFER (Continued)										
5S/11W-27Q 3 S 6-14-65[a] 85-104A	69	8.9	370	10 0.50 11	0	88 3.83 87	3 0.08 2	28 0.93 20	183 3.00 65	0	23 0.65 14	0.8 0.01	0.6	0.13	--	364 243	25
5S/11W-28A 1 S 3-21-61	75	8.1	305	18 0.90 25	2 0.16 4	57 2.48 69	1 0.03 1	0	159 2.61 74	24 0.50 14	14 0.39 11	2.9 0.05 1	0.3	0.08	13	 210	53
5S/11W-29C 2 S 12- 5-56	--	8.5	330	6 0.30 9	0	71 3.09 90	1 0.03 1	3 0.10 3	168 2.75 79	12 0.25 7	14 0.39 11	0	0.8	0.05	--	 201 190	15
5-29-57	74	7.3	37800	704 35.13 10	735 60.45 18	5520 240.01 71	62 1.59	0	217 3.56 1	1522 31.69 10	10550 297.51 89	0	0	0.90	17	20300 19218	4783
8- 8-57	--	7.6	327	7 0.35 10	1 0.08 2	70 3.04 84	6 0.15 4	0	165 2.70 80	11 0.23 7	13 0.37 11	4 0.06 2	0.1	0.07	--	 204 193	22
5S/11W-29F 2 S 10-11-63 850-5H	--	7.9	2650	71 3.54 12	19 1.56 5	527 22.91 81	15 0.38 1	0	287 4.70 17	8 0.17 1	823 23.21 83	0.0	0.2	1.03	13	1624 1618	255
4-16-64	--	8.0	3011	85 4.24 15	18 1.48 5	506 22.00 79	4 0.10	0	285 4.67 17	1 0.02	815 22.98 82	20.0 0.32 1	0.3	1.50	--	1673 1591	286
5S/11W-29H 1 S 6-22-64	--	8.1	347	11 0.55 15	0	70 3.04 84	1 0.03 1	0	173 2.84 82	6 0.12 3	17 0.48 14	0.5 0.01	0.6	0.15	--	215 191	28
5S/11W-32A 1 S 10- 6-61	72	7.8	2950	66 3.29 12	21 1.73 6	536 23.39 82	5 0.13	0	348 5.70 20	37 0.77 3	780 22.00 77	0	0.8	1.80	13	1622 1634	251
4-16-64	71	8.0	2820	75 3.74 14	18 1.48 5	499 21.70 80	6 0.15 1	0	337 5.52 21	0	738 20.81 79	5.0 0.08	0.3	1.30	--	1498 1508	261
5S/11W-33H 1 S 6-19-64	72	7.4	354	8 0.40 10	2 0.16 4	75 3.26 85	1 0.03 1	0	203 3.33 86	0	20 0.56 14	0.0	0.6	0.14	--	211 207	28
5S/12W-12C 1 S 6-19-64	--	8.2	330	2 0.10 3	1 0.08 2	73 3.17 94	1 0.03 1	0	157 2.57 79	15 0.31 9	14 0.39 12	0.0	0.6	0.10	--	210 184	9
5S/12W-13A 7 S 8-27-63 850-9F	--	8.0	360	8 0.40 11	1 0.08 2	70 3.04 86	1 0.03 1	0	179 2.93 85	0	18 0.51 15	0.0	0.8	0.11	14	226 201	24
7- 1-65	72	8.0	341	2 0.10 3	4 0.33 9	70 3.04 87	1 0.03 1	0	178 2.92 84	1 0.02 1	18 0.51 15	1 0.02 1	0.9	0.16	--	220 186	22
							LOWER ZONE										
5S/11W-28K 1 S 6-22-64	--	7.4	528	11 0.55 9	2 0.16 3	117 5.09 87	1 0.03 1	0	303 4.97 88	1 0.02	22 0.62 11	2.5 0.04 1	0.4	0.44	--	446 306	36
5S/11W-34F 3 S 6-19-64	83	7.8	609	7 0.35 5	2 0.16 2	142 6.17 92	2 0.05 1	0	371 6.08 91	0	21 0.59 9	0.7 0.01	0.6	0.80	--	388 359	26

a. Sample chemically affected by curing of cement grout plug
Ca CO_3, HCO_3 and pH not representative of native quality

b. ABS 0.15 ppm



LEGEND

A1 ○	WATER WELL. STATE WELL NUMBER SHOWN BESIDE THE WELL.
A1 ⊖	ABANDONED OR DESTROYED WATER WELL.
B2-5 ● BSO-1	OBSERVATION WELL OR PIEZOMETERS. FIELD SITE NUMBER SHOWN BELOW THE WELL. AE DENOTES ALAMITOS EXPLORATION, LOS ANGELES COUNTY FLOOD CONTROL DISTRICT, 1959 BSO DENOTES BOLSA-SUNSET OBSERVATION, DEPARTMENT OF WATER RESOURCES, 1963 HH DENOTES HUNTINGTON HARBOUR CORPORATION, 1964 BS DENOTES BOLSA-SUNSET, DEPARTMENT OF WATER RESOURCES, 1965
E1 ◒	ABANDONED OBSERVATION WELL, UNITED STATES GEOLOGICAL SURVEY, 1941
G1 △	ABANDONED OR DESTROYED OBSERVATION PIEZOMETER LESS THAN 30' DEEP, UNITED STATES GEOLOGICAL SURVEY, 1941-42.
ES1 ○	SEEPS ASSOCIATED WITH MARINA EXCAVATION

3

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

SEA-WATER INTRUSION: BOLSA-SUNSET AREA, ORANGE COUNTY

WELL LOCATION MAP

SCALE OF FEET
1000 0 1000 2000 3000

1967

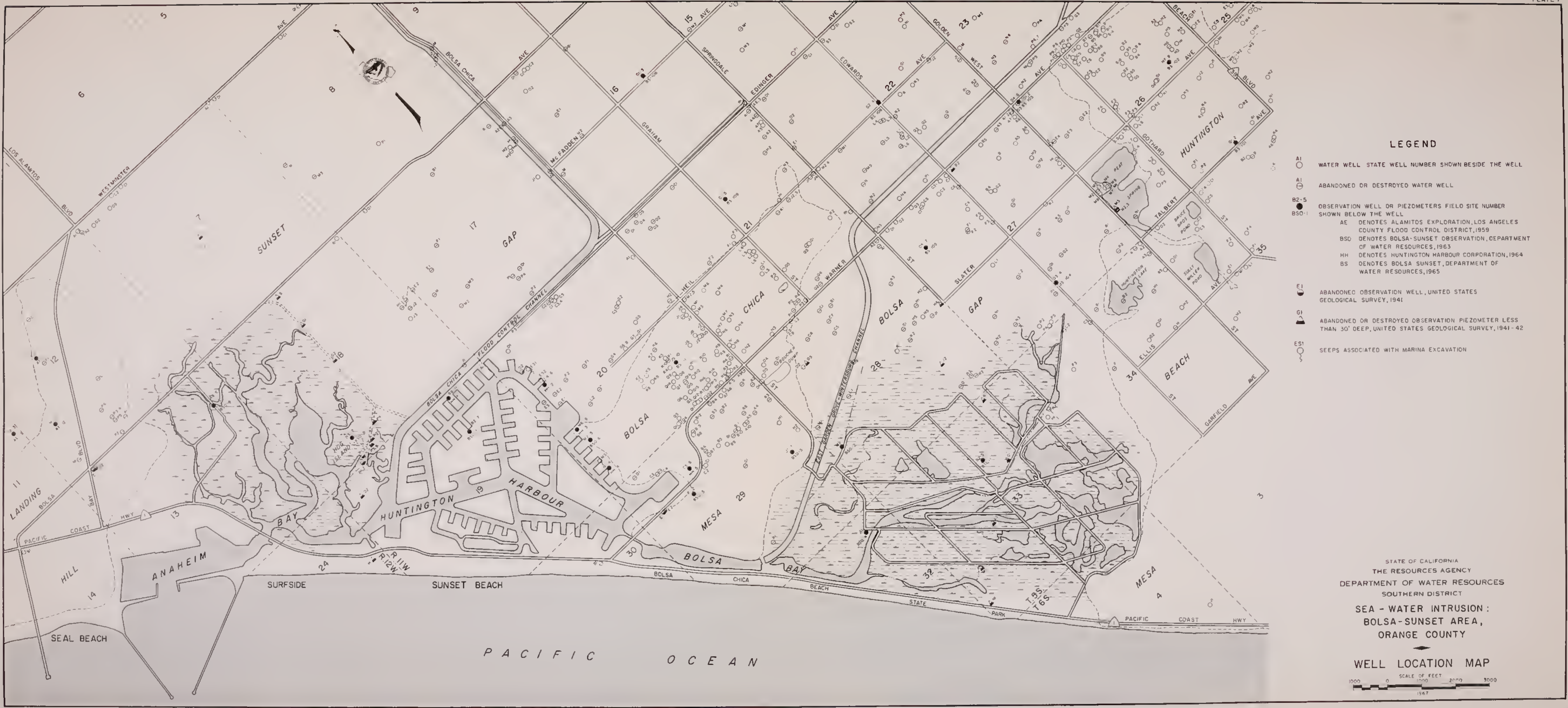
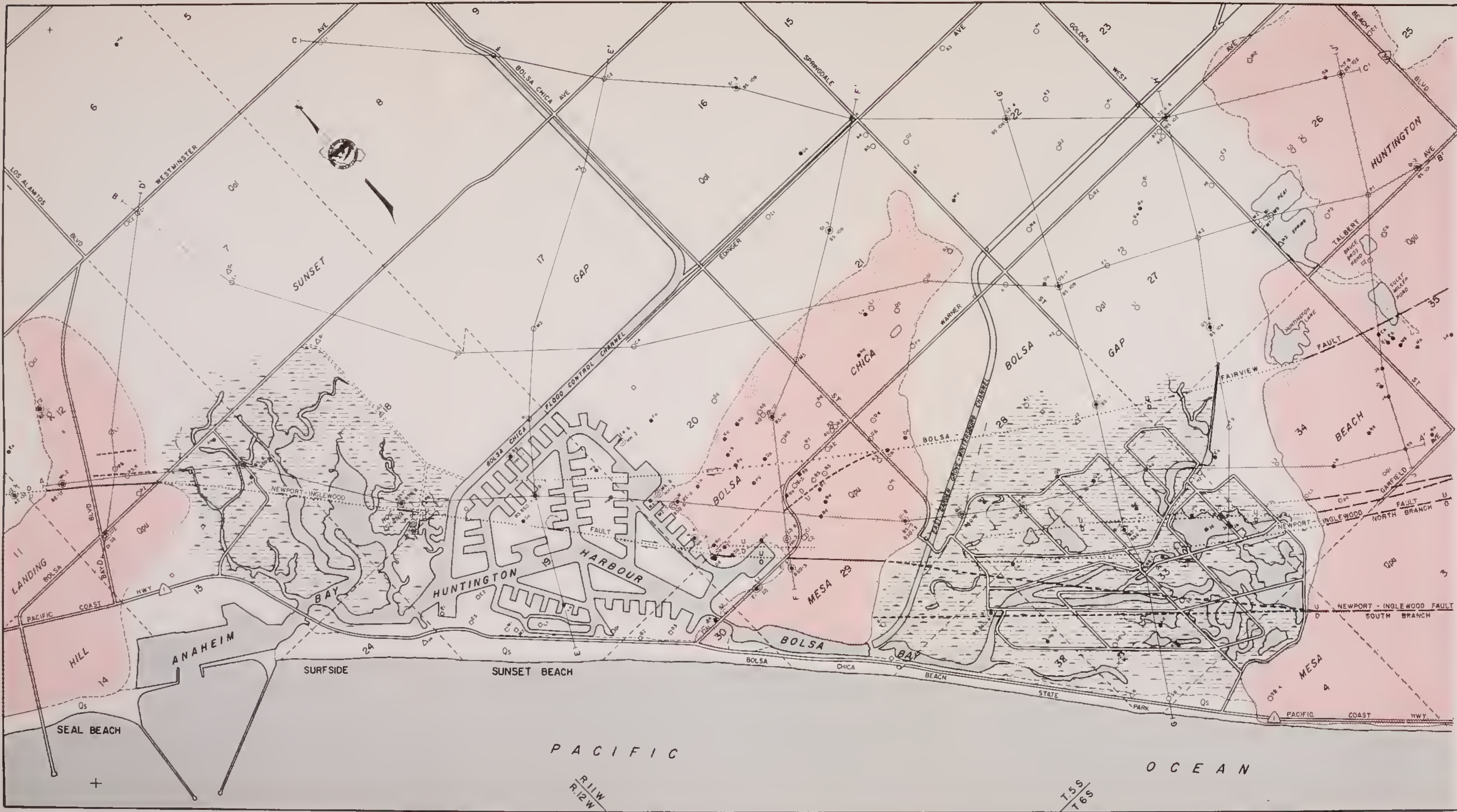

LEGEND
WATER WELL STATE WELL NUMBER SHOWN BESIDE THE WELL
ABANDONED OR DESTROYED WATER WELL
OBSERVATION WELL OR PIEZOMETERS FIELD SITE NUMBER SHOWN BELOW THE WELL
AE DENOTES ALAMITOS EXPLORATION, LOS ANGELES COUNTY FLOOD CONTROL DISTRICT, 1959
BSO DENOTES BOLSA-SUNSET OBSERVATION, DEPARTMENT OF WATER RESOURCES, 1963
HH DENOTES HUNTINGTON HARBOUR CORPORATION, 1964
BS DENOTES BOLSA SUNSET, DEPARTMENT OF WATER RESOURCES, 1965
ABANDONED OBSERVATION WELL, UNITED STATES GEOLOGICAL SURVEY, 1941
ABANDONED OR DESTROYED OBSERVATION PIEZOMETER LESS THAN 30' DEEP, UNITED STATES GEOLOGICAL SURVEY, 1941-42
SEEPS ASSOCIATED WITH MARINA EXCAVATION
SUNSET GAP
BOLSA CHICA
BOLSA GAP
BOLSA MESA
HUNTINGTON BEACH MESA
LANDING HILL
HUNTINGTON HARBOUR
ANAHEIM BAY
BOLSA BAY
SURFSIDE
SUNSET BEACH
SEAL BEACH
PACIFIC OCEAN
PACIFIC COAST HWY
BOLSA CHICA BEACH STATE PARK
BOLSA CHICA FLOOD CONTROL CHANNEL
EAST GARDEN GROVE-WINTERSBURG CHANNEL
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA-WATER INTRUSION: BOLSA-SUNSET AREA, ORANGE COUNTY
WELL LOCATION MAP
SCALE OF FEET
1967

PLATE 2



LEGEND

QUATERNARY	RECENT	Qs — BEACH AND DUNE DEPOSITS SAND
		Qal — ALLUVIUM UNDIFFERENTIATED CONTINENTAL AND LAGOONAL SAND, SILT AND CLAY
	UPPER PLEISTOCENE	Qpu — LAKEWOOD FORMATION CONTINENTAL AND MARINE GRAVEL, SAND, SILT AND CLAY

CONTACT DASHED WHERE APPROXIMATELY LOCATED

KNOWN FAULT DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED U UPTHROWN SIDE, D DOWNTHROWN SIDE ARROWS INDICATE RELATIVE LATERAL MOVEMENT

INFERRED FAULT, APPROXIMATELY LOCATED AND CONCEALED

A — A' LINE OF GEOLOGIC SECTION SECTIONS ARE SHOWN ON PLATES 3A AND 3B

LOCATION OF WELLS AND TEST HOLES WITH LOGS USED IN THIS REPORT

A1 WATER WELL OR BACKFILLED TEST HOLE WITH DRILLER'S LOG
NB-1 AND SB-1 TO 4 SIGNAL OIL AND GAS COMPANY TEST HOLES

J3 / BS-1 OBSERVATION WELL OR BACKFILLED TEST HOLE WITH GEOLOGIST'S LOG
BS AND BSO - DEPARTMENT OF WATER RESOURCES
GS - UNITED STATES GEOLOGICAL SURVEY

J1 / BS-3 AS ABOVE WITH ELECTRIC LOG
AE - LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
HH - HUNTINGTON HARBOUR CORPORATION

OIL WELL WITH DRILLER'S LOG

Aa OIL WELL WITH ELECTRIC LOG

G1 SHALLOW OBSERVATION WELL WITH GEOLOGIST'S LOG

SOIL BORING LOG

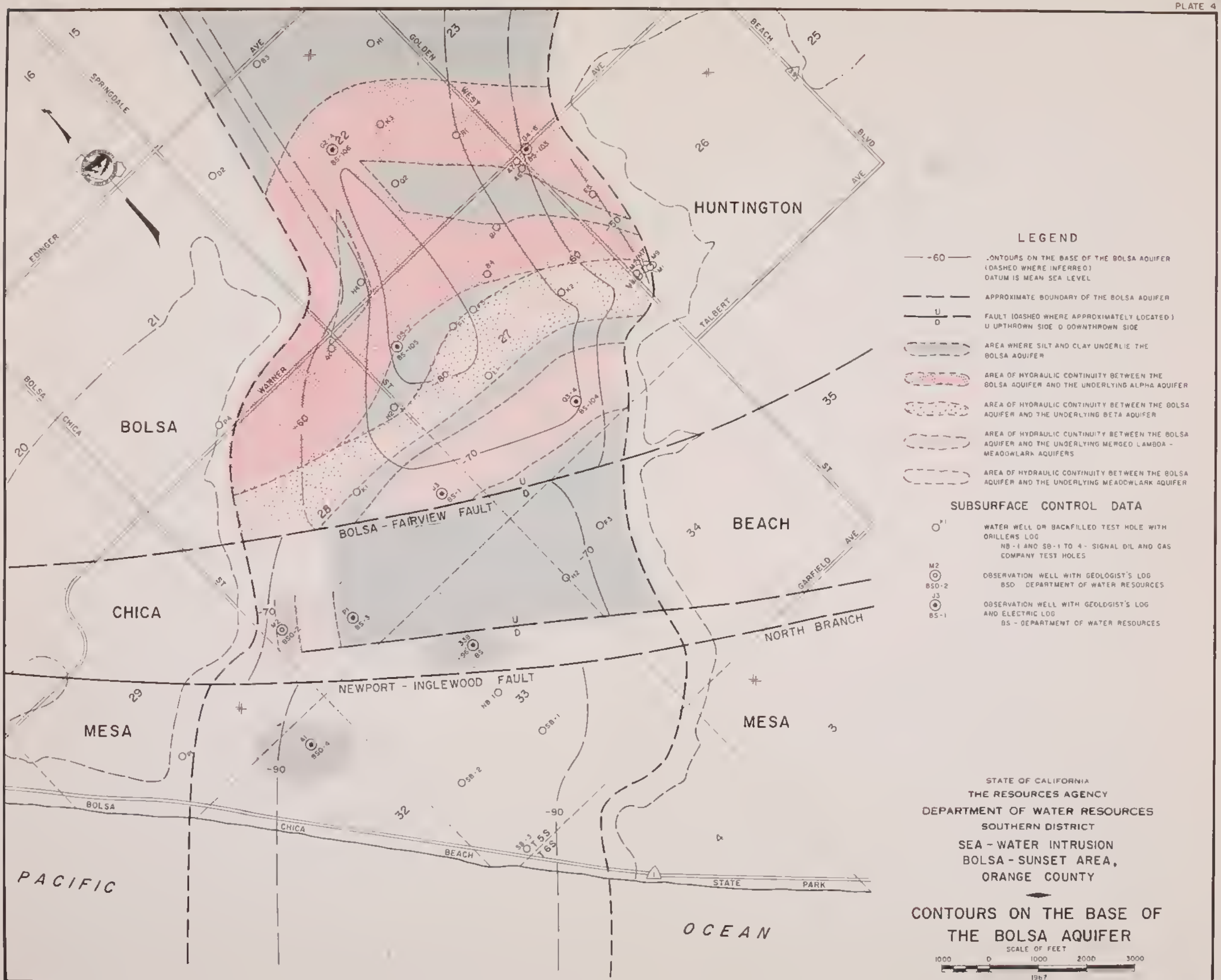
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

SEA - WATER INTRUSION: BOLSA-SUNSET AREA, ORANGE COUNTY

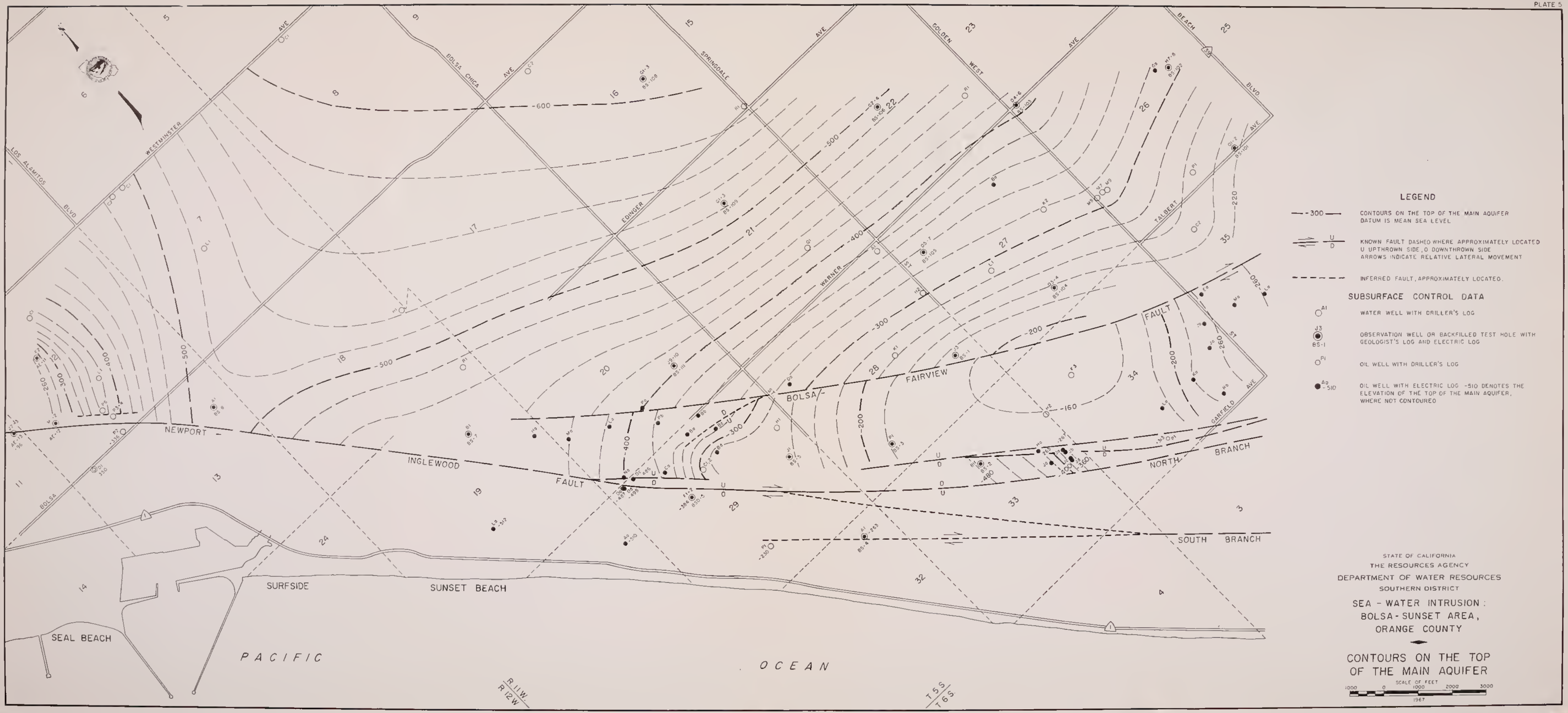
AREAL GEOLOGY

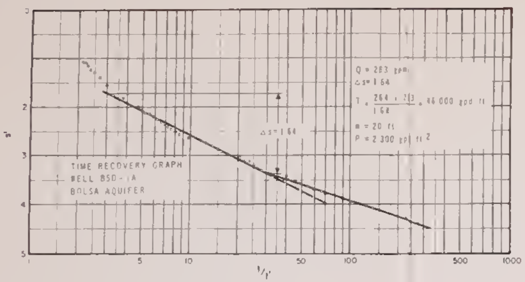
SCALE OF FEET
1000 0 1000 2000 3000
1967

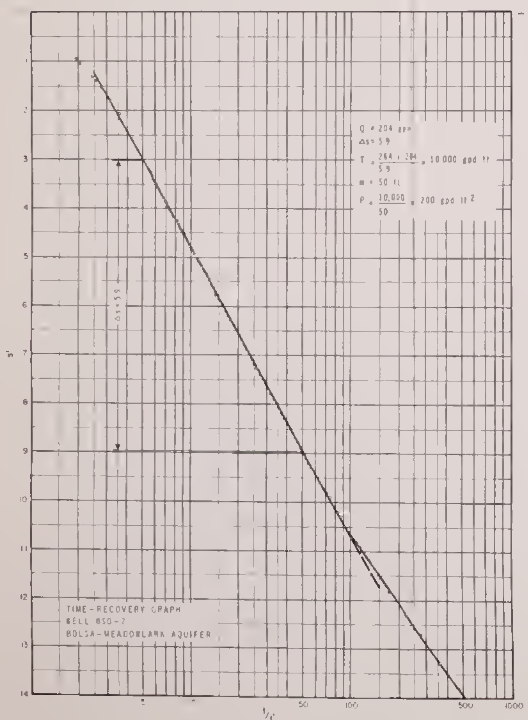
PLATE 4

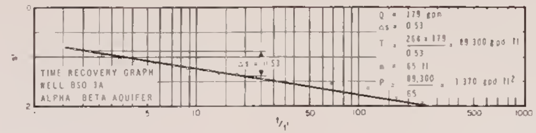


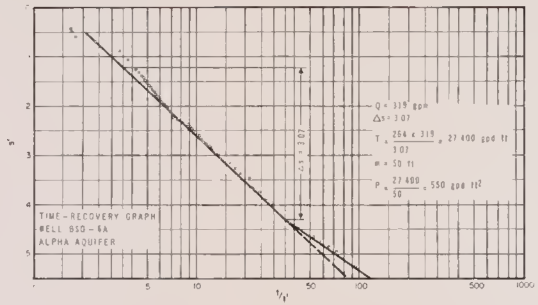
HUNTINGTON
BEACH
BOLSA
CHICA
MESA
MESA
PACIFIC
OCEAN
BOLSA - FAIRVIEW FAULT
NEWPORT - INGLEWOOD FAULT
NORTH BRANCH
GOLDEN WEST
WARNER AVE
SPRINGDALE
EDINGER
BOLSA CHICA ST
BEACH BLVD
TALBERT AVE
GARFIELD AVE
BOLSA CHICA BEACH STATE PARK
T5S
T6S
-60
-70
-80
-90
LEGEND
CONTOURS ON THE BASE OF THE BOLSA AQUIFER (DASHED WHERE INFERRED) DATUM IS MEAN SEA LEVEL
APPROXIMATE BOUNDARY OF THE BOLSA AQUIFER
FAULT (DASHED WHERE APPROXIMATELY LOCATED) U UPTHROWN SIDE D DOWNTHROWN SIDE
AREA WHERE SILT AND CLAY UNDERLIE THE BOLSA AQUIFER
AREA OF HYDRAULIC CONTINUITY BETWEEN THE BOLSA AQUIFER AND THE UNDERLYING ALPHA AQUIFER
AREA OF HYDRAULIC CONTINUITY BETWEEN THE BOLSA AQUIFER AND THE UNDERLYING BETA AQUIFER
AREA OF HYDRAULIC CONTINUITY BETWEEN THE BOLSA AQUIFER AND THE UNDERLYING MERGED LAMBDA - MEADOWLARK AQUIFERS
AREA OF HYDRAULIC CONTINUITY BETWEEN THE BOLSA AQUIFER AND THE UNDERLYING MEADOWLARK AQUIFER
SUBSURFACE CONTROL DATA
WATER WELL OR BACKFILLED TEST HOLE WITH DRILLERS LOG
NB - I AND SB - I TO 4 - SIGNAL OIL AND GAS COMPANY TEST HOLES
OBSERVATION WELL WITH GEOLOGIST'S LOG
BSD DEPARTMENT OF WATER RESOURCES
OBSERVATION WELL WITH GEOLOGIST'S LOG AND ELECTRIC LOG
BS - DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION
BOLSA - SUNSET AREA,
ORANGE COUNTY
CONTOURS ON THE BASE OF THE BOLSA AQUIFER
SCALE OF FEET
1000 0 1000 2000 3000
1967

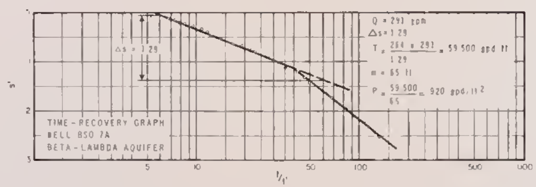

LEGEND
-300 CONTOURS ON THE TOP OF THE MAIN AQUIFER DATUM IS MEAN SEA LEVEL
U D KNOWN FAULT DASHED WHERE APPROXIMATELY LOCATED U UPTHROWN SIDE, D DOWNTHROWN SIDE ARROWS INDICATE RELATIVE LATERAL MOVEMENT
INFERRED FAULT, APPROXIMATELY LOCATED.
SUBSURFACE CONTROL DATA
A1 WATER WELL WITH DRILLER'S LOG
J3 BS-1 OBSERVATION WELL OR BACKFILLED TEST HOLE WITH GEOLOGIST'S LOG AND ELECTRIC LOG
P1 OIL WELL WITH DRILLER'S LOG
A0 -510 OIL WELL WITH ELECTRIC LOG -510 DENOTES THE ELEVATION OF THE TOP OF THE MAIN AQUIFER, WHERE NOT CONTOURED
NEWPORT - INGLEWOOD FAULT
BOLSA - FAIRVIEW FAULT
NORTH BRANCH
SOUTH BRANCH
WESTMINSTER
BOLSA CHICA AVE
SPRINGDALE
GOLDEN WEST
BEACH BLVD
EDINGER
WARNER AVE
TALBERT AVE
GARFIELD AVE
LOS ALAMITOS BLVD
BOLSA
SURFSIDE
SUNSET BEACH
SEAL BEACH
PACIFIC OCEAN
R 11 W
R 12 W
T 5 S
T 6 S
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION :
BOLSA - SUNSET AREA,
ORANGE COUNTY
CONTOURS ON THE TOP OF THE MAIN AQUIFER
SCALE OF FEET
1000 0 1000 2000 3000
1967

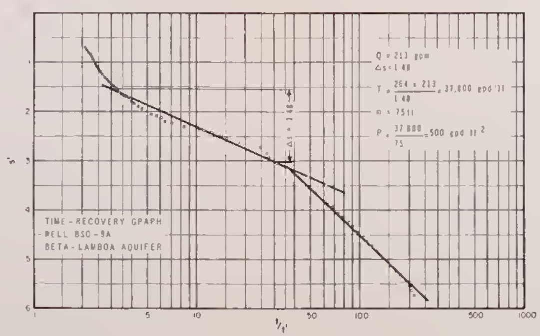


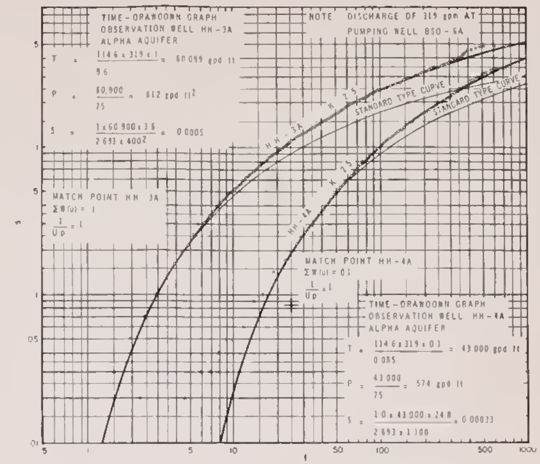












s DRAWDOWN OF THE PIEZOMETRIC SURFACE IN FEET

s' RESIDUAL DRAWDOWN (RECOVERY) OF THE PIEZOMETRIC SURFACE IN FEET

t ELAPSED TIME SINCE PUMPING OF WELL BEGAN IN MINUTES

t' ELAPSED TIME SINCE PUMPING OF WELL CEASED IN MINUTES

NOTE

1. ELAPSED PUMPING TIME FOR ALL WELLS APPROXIMATELY 32 HOURS
2. TYPE CURVES FROM U.S.G.S. W.S.P. NO. 1545C PLATE 3 1963

STATE OF CALIFORNIA
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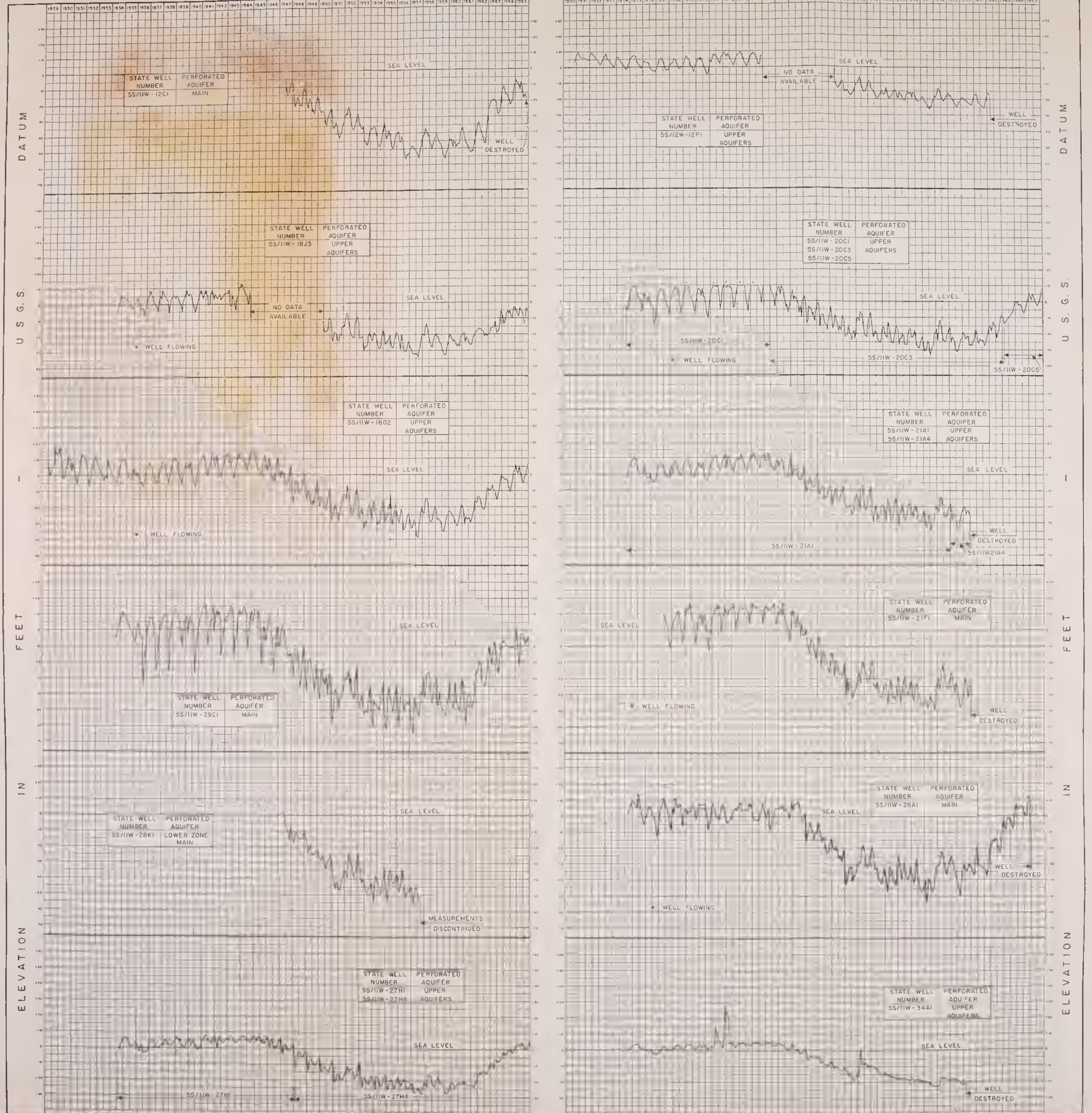
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

SEA - WATER INTRUSION
BOLSA - SUNSET AREA,
ORANGE COUNTY

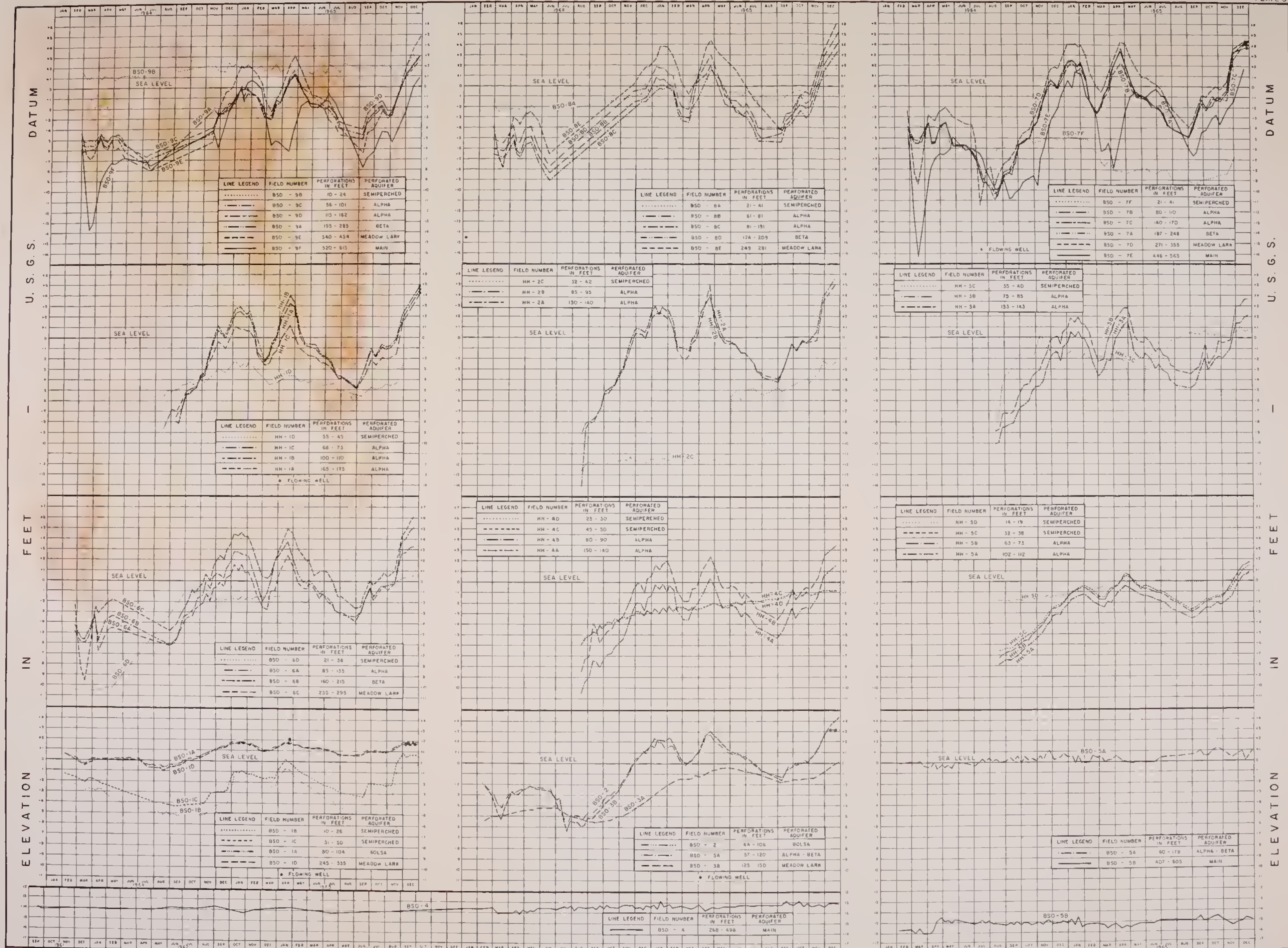
TIME-DRAWDOWN AND RECOVERY GRAPHS OF AQUIFER TESTS

1967



HYDROGRAPHS OF WATER WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967



HYDROGRAPHS OF OBSERVATION WELLS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

LEGEND

--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1961 - 63. DENOTES THE MAXIMUM EXTENT OF SALT WATER ENCROACHMENT

--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1965.

AREA OF OIL FIELD BRINE CONTAMINATION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 250 PPM, 1965.

AREA OF NATIVE SALT WATER WHERE CHLORIDE ION CONCENTRATIONS GENERALLY EXCEED 2000 PPM

FAULT, DASHED WHERE APPROXIMATELY LOCATED.

APPROXIMATE BOUNDARY OF BOLSA AQUIFER.

CONTROL DATA

A2 — WATER WELL WITH CHEMICAL ANAYSIS. WELLS CONSTRUCTED IN MERGED OR MULTIPLE AQUIFERS ARE NOTED ON THE MAP (ALPHA) DENOTES ASSOCIATED AQUIFER. RED WELLS DENOTE CHLORIDE ION CONCENTRATIONS >50 PPM.

C5 — WATER WELL WITH CHEMICAL ANALYSIS AQUIFER UNCERTAIN

NB-1 — TEST HOLE WITH CHEMICAL ANALYSIS

B2 BSO-1A — OBSERVATION WELL OR PIEZOMETER WITH CHEMICAL ANALYSIS. BS AND BSO - DEPARTMENT OF WATER RESOURCES.

32 A1 BS-4 — TEST HOLE WITH ELECTRIC LOG SHOWING SALTY WATER (>500 PPM CHLORIDE) IN THE BOLSA AQUIFER.

NOTE: CHEMICAL ANALYSES OF GROUND WATER WHERE COLLECTED DURING 1961 - 65, EXCEPT AS NOTED ON THE MAP

WELL ABANDONED OR DESTROYED AS OF 1965.

33H1 — SALTY WATER (>250ppm Cl) WAS REPORTED IN THE BOLSA AQUIFER WHEN THIS WELL WAS DRILLED IN 1940

STATE OF CALIFORNIA
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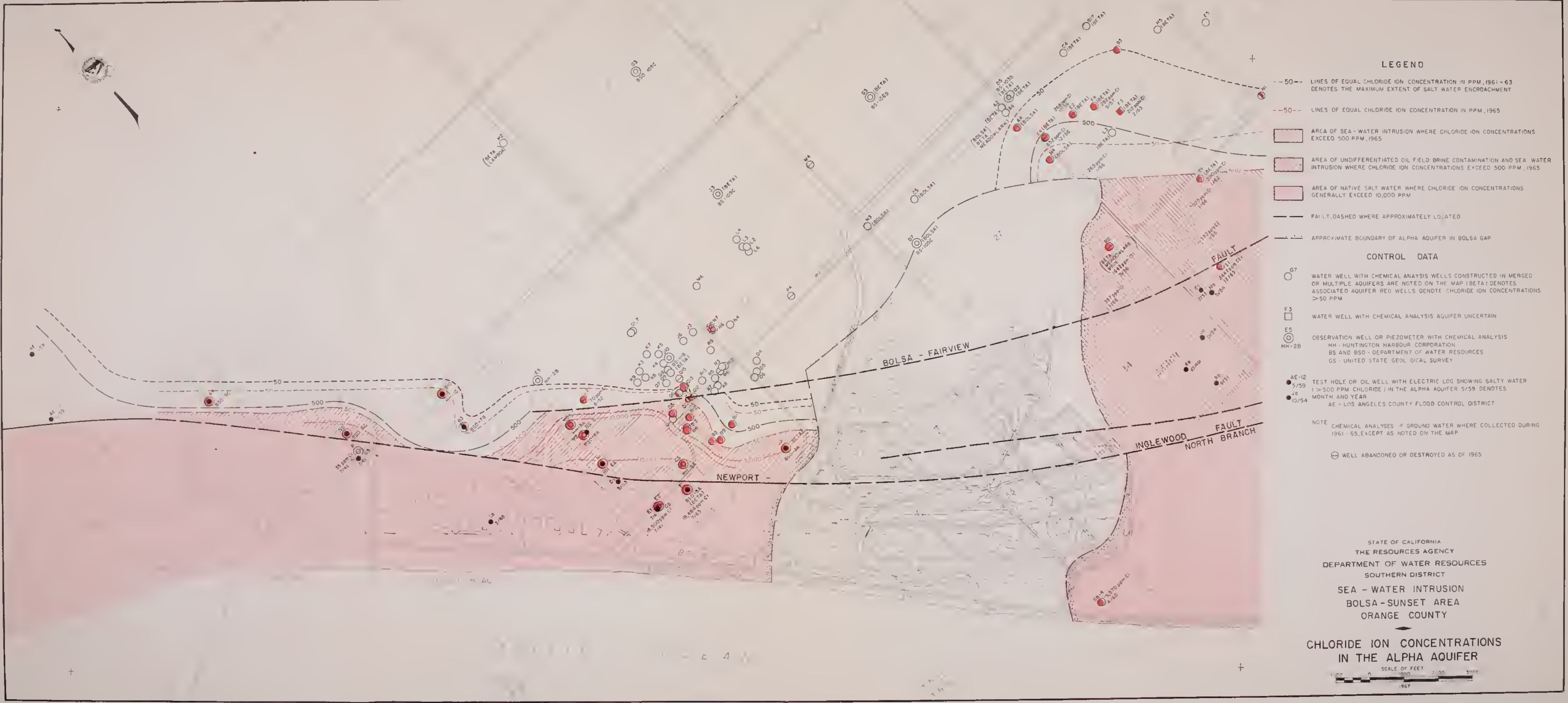
SOUTHERN DISTRICT

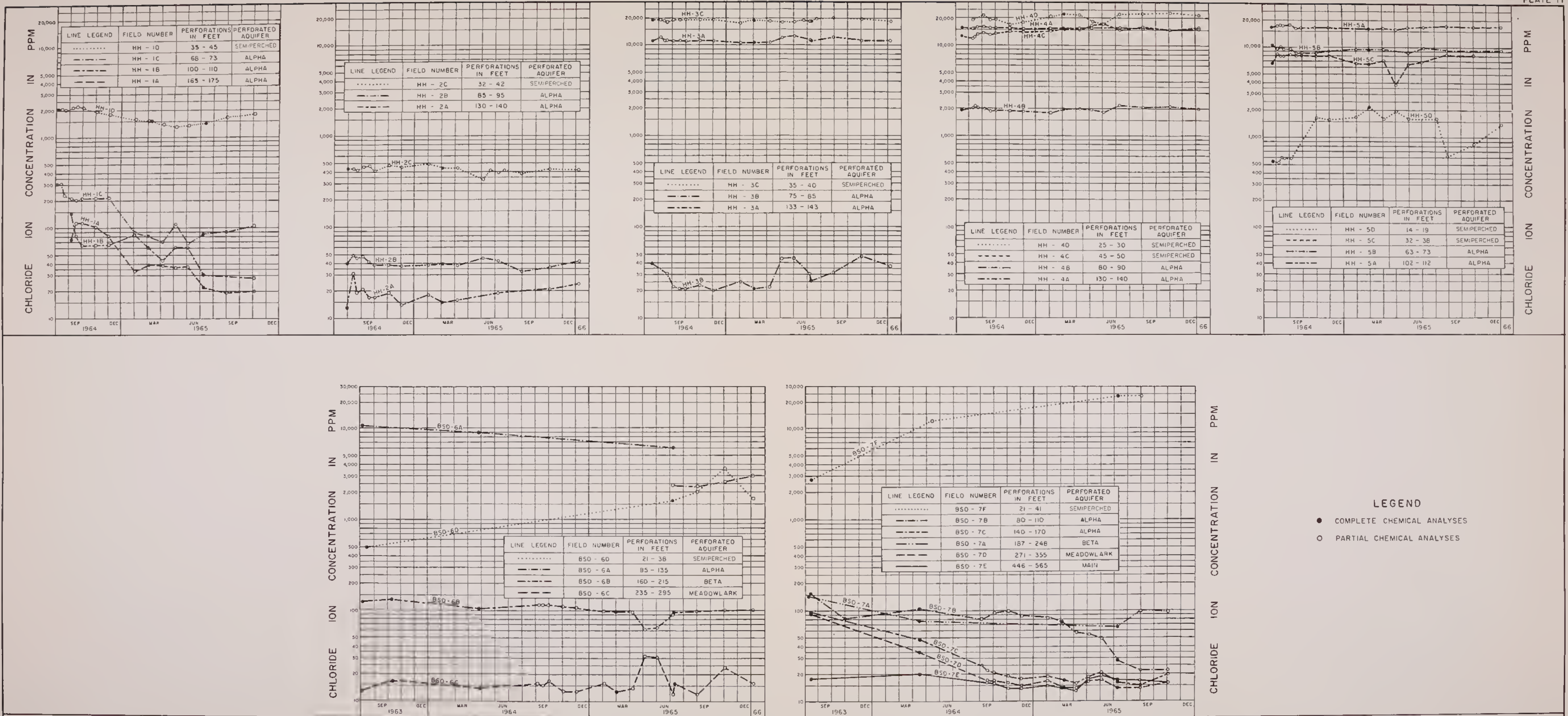
SEA - WATER INTRUSION :
BOLSA - SUNSET AREA
ORANGE COUNTY

CHLORIDE ION CONCENTRATIONS IN THE BOLSA AQUIFER

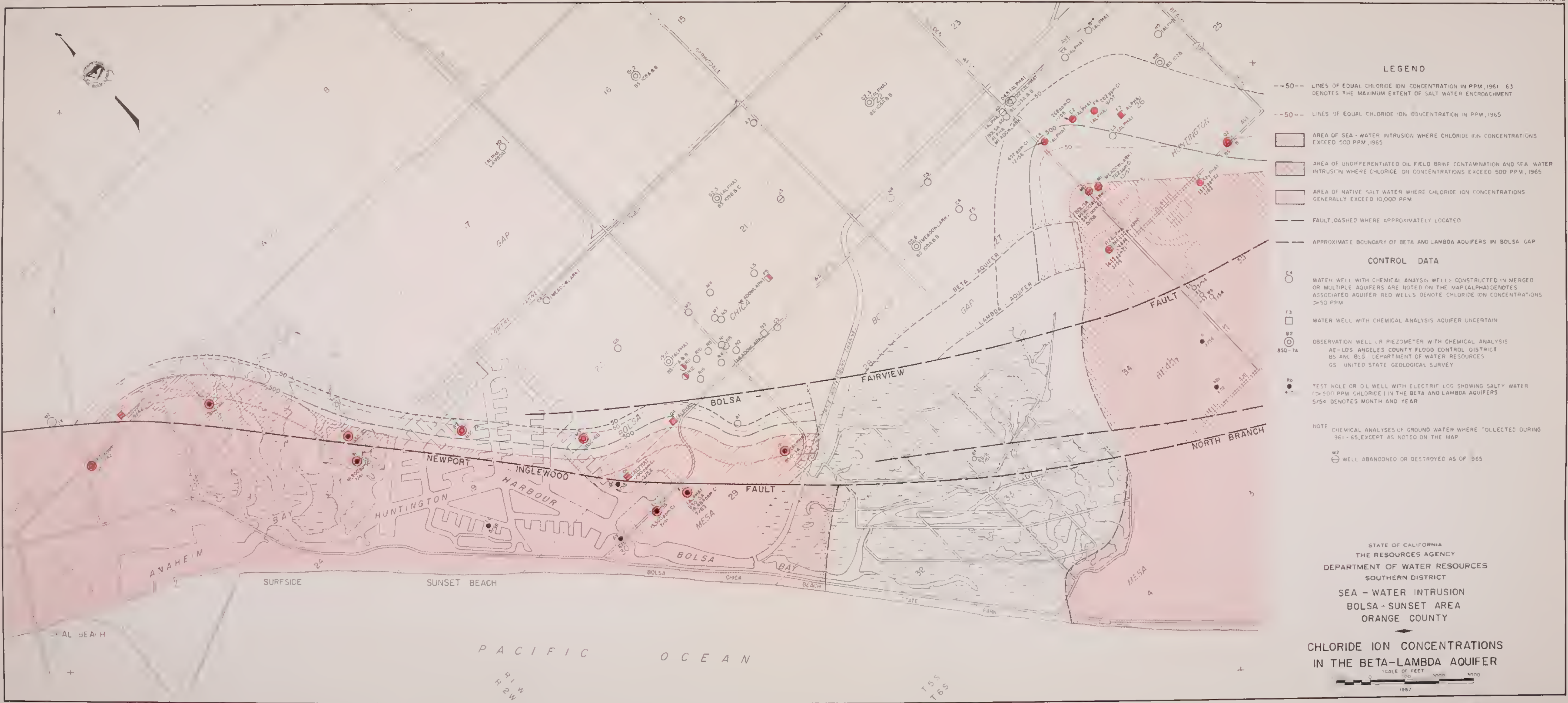
SCALE OF FEET
1000 0 1000 2000 3000

1967


LEGEND
--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1961 - 63 DENOTES THE MAXIMUM EXTENT OF SALT WATER ENCROACHMENT
--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1965
AREA OF SEA - WATER INTRUSION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 500 PPM, 1965
AREA OF UNDIFFERENTIATED OIL FIELD BRINE CONTAMINATION AND SEA WATER INTRUSION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 500 PPM, 1965
AREA OF NATIVE SALT WATER WHERE CHLORIDE ION CONCENTRATIONS GENERALLY EXCEED 10,000 PPM
FAULT, DASHED WHERE APPROXIMATELY LOCATED
APPROXIMATE BOUNDARY OF ALPHA AQUIFER IN BOLSA GAP
CONTROL DATA
G7
WATER WELL WITH CHEMICAL ANAYSIS WELLS CONSTRUCTED IN MERGED OR MULTIPLE AQUIFERS ARE NOTED ON THE MAP (BETA) DENOTES ASSOCIATED AQUIFER RED WELLS DENOTE CHLORIDE ION CONCENTRATIONS >50 PPM
F3
WATER WELL WITH CHEMICAL ANALYSIS AQUIFER UNCERTAIN
E5
HH-28
OBSERVATION WELL OR PIEZOMETER WITH CHEMICAL ANALYSIS
HH - HUNTINGTON HARBOUR CORPORATION
BS AND BSO - DEPARTMENT OF WATER RESOURCES
GS - UNITED STATE GEOLGICAL SURVEY
AE-12 5/59
Ja 10/54
TEST HOLE OR OIL WELL WITH ELECTRIC LOG SHOWING SALTY WATER (>500 PPM CHLORIDE) IN THE ALPHA AQUIFER 5/59 DENOTES MONTH AND YEAR
AE - LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
NOTE CHEMICAL ANALYSES OF GROUND WATER WHERE COLLECTED DURING 1961 - 65, EXCEPT AS NOTED ON THE MAP
WELL ABANDONED OR DESTROYED AS OF 1965
BOLSA - FAIRVIEW
NEWPORT -
INGLEWOOD FAULT
NORTH BRANCH
FAULT
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION
BOLSA - SUNSET AREA
ORANGE COUNTY
CHLORIDE ION CONCENTRATIONS
IN THE ALPHA AQUIFER
SCALE OF FEET
1967



CHANGES IN CHLORIDE ION CONCENTRATION AT HUNTINGTON HARBOUR AUGUST 1963 - JANUARY 1966


LEGEND
LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1961 63 DENOTES THE MAXIMUM EXTENT OF SALT WATER ENCROACHMENT
LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1965
AREA OF SEA-WATER INTRUSION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 500 PPM, 1965
AREA OF UNDIFFERENTIATED OIL FIELD BRINE CONTAMINATION AND SEA WATER INTRUSION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 500 PPM, 1965
AREA OF NATIVE SALT WATER WHERE CHLORIDE ION CONCENTRATIONS GENERALLY EXCEED 10,000 PPM
FAULT, DASHED WHERE APPROXIMATELY LOCATED
APPROXIMATE BOUNDARY OF BETA AND LAMBDA AQUIFERS IN BOLSA GAP
CONTROL DATA
WATER WELL WITH CHEMICAL ANAYSIS WELLS CONSTRUCTED IN MERGED OR MULTIPLE AQUIFERS ARE NOTED ON THE MAP (ALPHA) DENOTES ASSOCIATED AQUIFER RED WELLS DENOTE CHLORIDE ION CONCENTRATIONS >50 PPM
WATER WELL WITH CHEMICAL ANALYSIS AQUIFER UNCERTAIN
OBSERVATION WELL OR PIEZOMETER WITH CHEMICAL ANALYSIS
AE-LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
BS AND BSO DEPARTMENT OF WATER RESOURCES
GS UNITED STATE GEOLOGICAL SURVEY
TEST HOLE OR OIL WELL WITH ELECTRIC LOG SHOWING SALTY WATER (>500 PPM CHLORIDE) IN THE BETA AND LAMBDA AQUIFERS
5/54 DENOTES MONTH AND YEAR
NOTE CHEMICAL ANALYSES OF GROUND WATER WHERE COLLECTED DURING 1961-65, EXCEPT AS NOTED ON THE MAP
WELL ABANDONED OR DESTROYED AS OF 1965
NEWPORT INGLEWOOD FAULT
BOLSA FAIRVIEW
NORTH BRANCH
HUNTINGTON HARBOUR
BOLSA CHICA GAP
BOLSA BAY
HUNTINGTON BEACH MESA
BETA AQUIFER
LAMBDA AQUIFER
ANAHEIM BAY
SURFSIDE
SUNSET BEACH
PACIFIC OCEAN
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION
BOLSA - SUNSET AREA
ORANGE COUNTY
CHLORIDE ION CONCENTRATIONS
IN THE BETA-LAMBDA AQUIFER
SCALE OF FEET
1967


LEGEND
--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1961 - 63 DENOTES THE MAXIMUM EXTENT OF SALT WATER ENCROACHMENT
--50-- LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PPM, 1965
AREA OF SEA - WATER INTRUSION WHERE CHLORIDE ION CONCENTRATIONS EXCEED 500 PPM, 1965
AREA OF NATIVE SALT WATER WHERE CHLORIDE ION CONCENTRATIONS GENERALLY EXCEED 10,000 PPM
FAULT, DASHED WHERE APPROXIMATELY LOCATED
APPROXIMATE BOUNDARY OF MEADOWLARK AQUIFER IN BOLSA GAP
CONTROL DATA
C4
WATER WELL WITH CHEMICAL ANAYSIS WELLS CONSTRUCTED IN MERGED OR MULTIPLE AQUIFERS ARE NOTED ON THE MAP (LAMBDA) DENOTES ASSOCIATED AQUIFER RED WELLS DENOTE CHLORIDE ION CONCENTRATIONS >50 PPM
A1
WATER WELL WITH CHEMICAL ANALYSIS AQUIFER UNCERTAIN
A6
BSO-9E
OBSERVATION WELL OR PIEZOMETER WITH CHEMICAL ANALYSIS
BS AND BSO - DEPARTMENT OF WATER RESOURCES
GS - UNITED STATE GEOLOGICAL SURVEY
AE-11 5/59
Aa 6/51
TEST HOLE OR OIL WELL WITH ELECTRIC LOG SHOWING SALTY WATER (>500 PPM CHLORIDE) IN THE MEADOWLARK AQUIFER 5/59 DENOTES MONTH AND YEAR
AE - LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
GS - UNITED STATES GEOLOGICAL SURVEY
NOTE
CHEMICAL ANALYSES OF GROUND WATER WHERE COLLECTED DURING 1961 - 65, EXCEPT AS NOTED ON THE MAP
WELL ABANDONED OR DESTROYED AS OF 1955
NEWPORT
INGLEWOOD
FAULT
BOLSA
FAIRVIEW
FAULT
NORTH BRANCH
HARBOUR
MESA
BOLSA
BAY
SUNSET BEACH
BOLSA CHICA BEACH STATE PARK
O C E A N
CHICA
T5S
T6S
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION
BOLSA - SUNSET AREA,
ORANGE COUNTY
CHLORIDE ION CONCENTRATIONS
IN THE MEADOWLARK AQUIFER
SCALE OF FEET
1000 0 1000 2000 3000
1967


LEGEND
CONTROL DATA
NEWPORT
INGLEWOOD
FAULT
BOLSA
FAIRVIEW
FAULT
NORTH BRANCH
SOUTH BRANCH
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
SEA - WATER INTRUSION
BOLSA - SUNSET AREA,
ORANGE COUNTY
CHLORIDE ION CONCENTRATIONS
IN THE MAIN AQUIFER

262 [illegible]
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