EVALUATION OF WATER-QUALITY MONITORING IN THE ORANGE COUNTY WATER DISTRICT CALIFORNIA

OPEN-FILE REPORT

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division
Menlo Park, California, 1969
PREPARED IN COOPERATION WITH THE
ORANGE COUNTY WATER DISTRICT

Cal-143-C(1)

JLC	1	
RMB	2	
REM	3	
DEH		
WFH		
MWB		
GAM		
JJF		

Water Resources Division
District Office
855 Oak Grove Avenue
Menlo Park, California 94025

November 25, 1969

Mr. Langdon W. Owen, Secretary-Manager
Orange County Water District
1629 West 17th Street
Santa Ana, California 92706

Dear Mr. Owen:

Enclosed are 20 copies of our cooperatively prepared report, "Evaluation of Water-Quality Monitoring in the Orange County Water District, California," by J. A. Moreland and J. A. Singer, 1969. This report has been approved by the Director of the Survey for release to the public.

The report evaluates the efficiency and completeness of the water-quality monitoring network and suggests deletions from, additions to, and standards for the network. Of the 272 wells that are currently sampled, 22 are suggested for deletion, and 42 wells are suggested for addition to the network. The type and completeness of the chemical analysis of the water should be determined by the information that is wanted; complete chemical analyses are not always necessary. Sampling frequencies should be altered in some areas to more adequately monitor the water-quality changes. A central agency should probably be established to receive, store, and disburse the data; access to a computer would greatly assist the agency assuming this responsibility. In addition to the network evaluation and suggestions for changes in the network, this report also outlines the areas of poor-quality and potentially poor quality water, and an isochlor map indicates the 1967 conditions of sea-water intrusion in the shallow aquifers.

The Geological Survey is pleased to work with the Water District in this and other hydrologic studies of mutual interest.

Very truly yours,

R. Stanley Lord
District Chief

Enclosures (20)

cc w/encls (blind):

Chief, Garden Grove Subdistrict, WRD (20)
J. A. Moreland, WRD, Garden Grove, Calif. (3)
J. A. Singer, WRD, Garden Grove, Calif. (5)

to Chief, Garden Grove Subdistrict: Washington review copy is returned ... use and (or) disposal.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

EVALUATION OF WATER-QUALITY MONITORING IN THE ORANGE COUNTY WATER DISTRICT, CALIFORNIA

By

Joe A. Moreland and John A. Singer

Prepared in cooperation with the
Orange County Water District

OPEN-FILE REPORT
69-175

Menlo Park, California
August 4, 1969

CONTENTS

ILLUSTRATIONS

TABLES

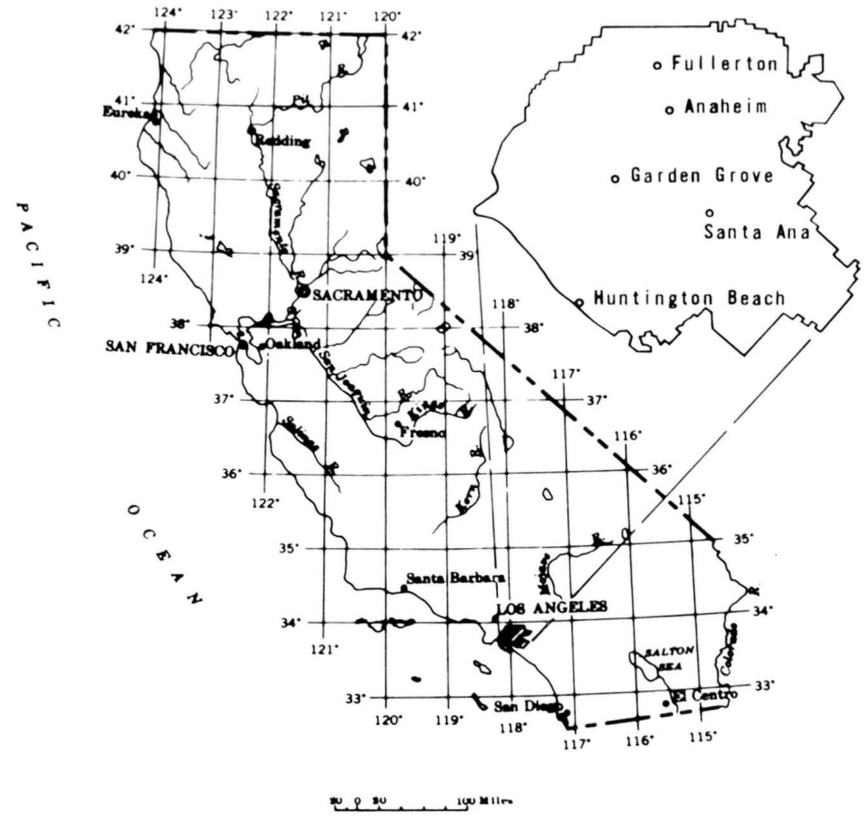


FIGURE 1.--Index map showing location of
Orange County Water District.

EVALUATION OF WATER-QUALITY MONITORING IN THE ORANGE COUNTY WATER DISTRICT CALIFORNIA

By Joe A. Moreland and John A. Singer

ABSTRACT

Water samples for chemical analysis are collected periodically from 272 wells in the Orange County Water District by 16 agencies. Many other wells are sampled at infrequent intervals by these and other agencies. This report evaluates the efficiency and completeness of the entire network and suggests additions to, deletions from, and standards for the network.

Of the regularly sampled wells, 22 are suggested for deletion from the water-quality monitoring network because of data duplication or because they are unused. For satisfactory surveillance of water quality, 42 wells are suggested for addition to the network. Most of these are in Sunset and Bolsa Gaps. Also, shallow wells, which penetrate only the upper few feet of the ground-water body, should be installed and monitored.

Complete chemical analysis of a water sample is not always necessary. Selective analyses suggested for obtaining specific types of data include: (1) Chloride determination and electrical conductivity measurements on samples from aquifers susceptible to intrusion of sea water; (2) sulfate, bicarbonate, and nitrate determinations on samples from aquifers underlying the forebay area; and (3) sodium, sulfate, chloride, and boron determinations and electrical conductivity measurements on samples from aquifers used as a source of irrigation water.

Sampling frequencies should be altered in some areas to adequately monitor quality changes. In the coastal gaps, samples should be collected quarterly to detect any landward movement of sea water. Nitrate determinations should be made monthly on water in the forebay region to monitor the extent of water containing nitrate concentrations in excess of U.S. Public Health Service standards.

A central agency should be established to receive, store, and disperse data collected throughout the district. To adequately handle the large mass of data collected, the central agency should have access to an electronic computer. All data should be stored on computer cards for ease in handling, retrieval, and analysis.

INTRODUCTION

The ground-water basin underlying the Orange County Water District (fig. 1) has been used extensively for many years. Continued use of the basin, both as a source of supply and as a means of storage and transmission of imported waters, depends on its proper management and protection.

The ground-water basin is large, and aquifers are generally continuous throughout. However, most pumping is from a few well fields rather than being evenly dispersed throughout the basin. Proper protection of the well fields requires intensive surveillance of water quality. If contamination is not detected and corrected before the contaminant has reached a well field, much time and money could be spent trying to alleviate the situation. To detect presence of a contaminant, long-term records of water-quality data from properly selected observation wells are essential. Changes in water quality must be detected and evaluated immediately so that action can be taken to retard or halt movement of the contaminant toward well fields that are heavily pumped.

The major water-quality problems that currently exist in Orange County are sea-water intrusion in the coastal gaps (fig. 2), high nitrate concentrations near Garden Grove, and high sulfate concentrations near Irvine.

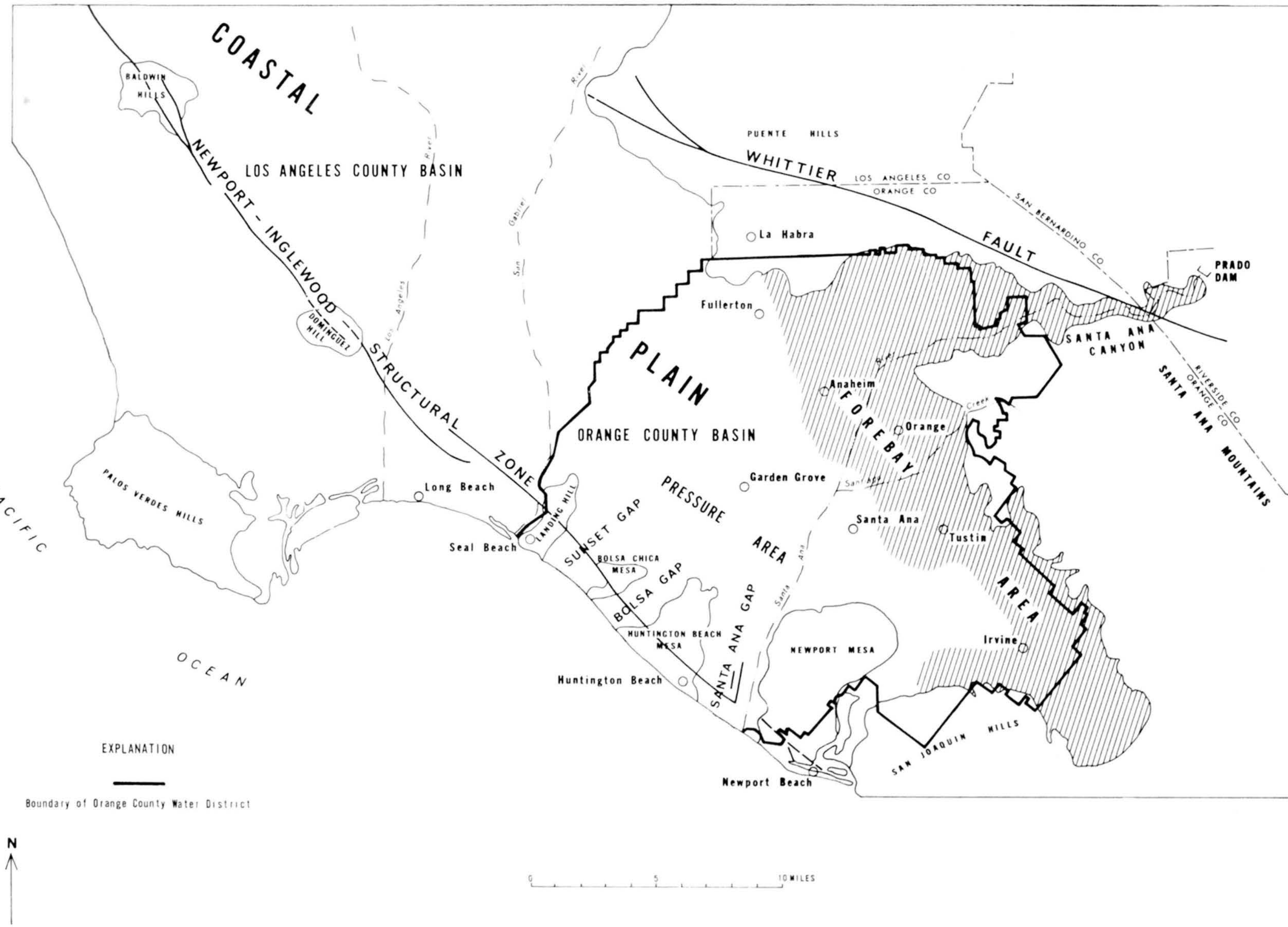


FIGURE 2.--Part of the coastal plain showing major physiographic and structural features.

Purpose and Scope

Many Federal, State, county, city, and private agencies are monitoring quality of ground water within the boundaries of the Orange County Water District. The lack of coordination of activities among these various agencies has resulted in duplication of effort in some areas and incomplete coverage in others.

The purpose of this investigation is to evaluate ground-water-quality monitoring as it is currently done within the Orange County Water District and to suggest additions to and deletions from the monitoring coverage. The agencies involved were asked to supply information about their sampling programs including sampling frequency, well locations, well depths, perforated intervals, drillers' logs, analyzing laboratory, sampling techniques, and water-quality analyses.

This report summarizes the results of the investigation listing the wells currently sampled, wells that should be added to the coverage, and wells that could be deleted. The suggested additions and deletions should result in a more meaningful monitoring of water quality in Orange County.

Thirty-three observation wells constructed in Bolsa and Sunset Gaps by the U.S. Geological Survey were sampled in September 1966 and January and April 1967. The information obtained from the samples collected in April 1967 was used to determine the extent of sea-water intrusion in that area.

This report was prepared by the U.S. Geological Survey, Water Resources Division, under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict.

Acknowledgments

This investigation was aided by the following agencies concerned with water-quality surveillance:

- Bastanchury Water Co.
- California Department of Water Resources
- California Domestic Water Co.
- California Water Resources Control Board
- City of Anaheim
- City of Buena Park
- City of Fullerton
- City of Garden Grove
- City of Huntington Beach
- City of La Habra
- City of Long Beach
- City of Orange
- City of Santa Ana
- City of Westminster
- Costa Mesa County Water District
- Holly Sugar Corp.
- The Irvine Co.
- Lemon Heights Mutual Water Co.
- Orange County Flood Control District
- Orange County Water District
- Orange County Water Pollution Department
- Pepsi-Cola Bottling Co. of Santa Ana
- Santa Ana Heights Water Co.
- Southern California Water Co.
- Sparkletts Drinking Water Corp.
- Tustin Water Works

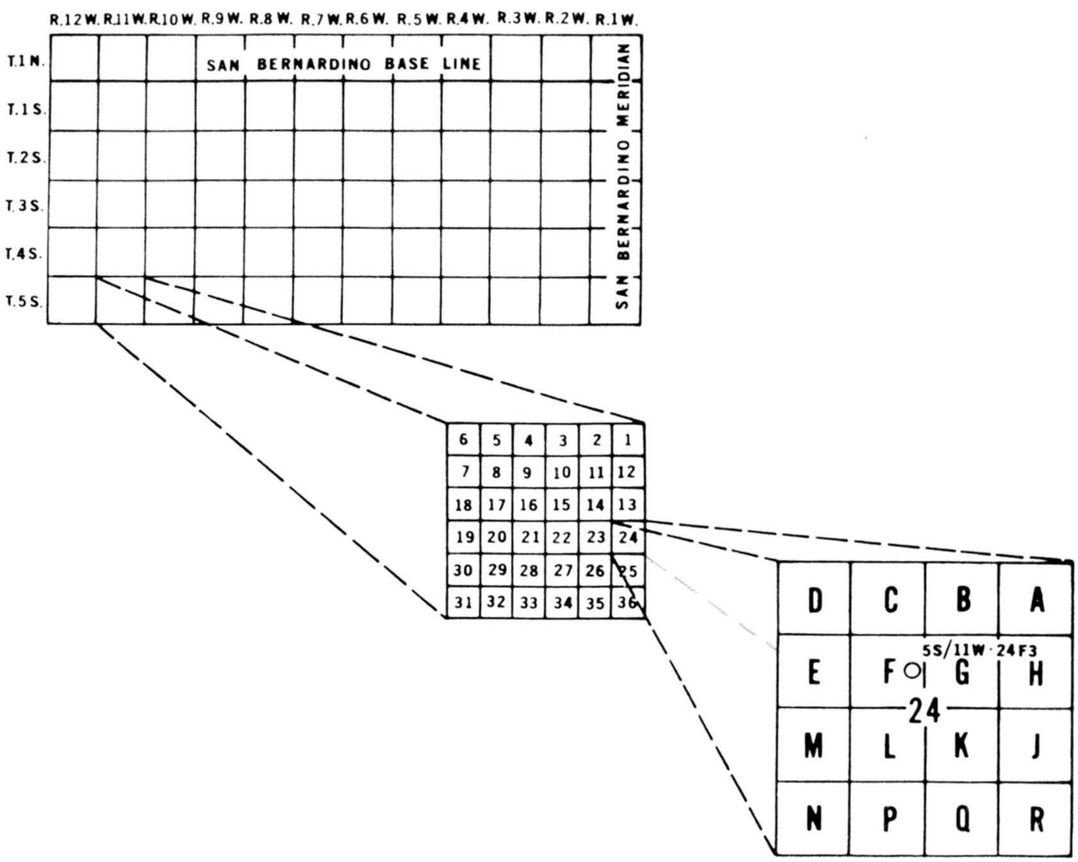
Well-Numbering Systems

There are nearly as many well-numbering systems in Orange County as there are agencies concerned with water. Because each agency has its own system, a single well often has several numbers. This causes confusion in relating data from different agencies.

The two most widely used numbering systems are those of the Orange County Water District and the California Department of Water Resources. In this report each well has been identified with a State well number.

The Orange County Water District well-numbering system is based upon the tax assessor's book. In the number 76-05-2A, the first two numbers refer to the book, the next two numbers refer to the page in that book, and the final numbers and letter refer to the parcel of land and corresponding wells on that page.

The well-numbering system used by the Department of Water Resources is based upon a rectangular coordinate system for the subdivision of public land. In the number 5S/11W-24F3, the part preceding the slash is the township (T. 5 S.), the part between the slash and the hyphen is the range (R. 11 W.), the number between the hyphen and the letter is the section (sec. 24), and the letter (F) is the 40-acre subdivision of the section as shown by the diagram below. Within the 40-acre tract, wells are numbered serially by the final digit.



Location and Extent of the Area

Orange County Water District lies wholly within Orange County. The boundary of the ground-water basin underlying Orange County approximates the water district boundary. The basin is terminated on the north, east, and southeast by the nearly impermeable rocks of the Puente Hills, Santa Ana Mountains, and San Joaquin Hills, respectively. With the exception of the coastal gaps, the basin is bordered on the southwest by the impermeable Newport-Inglewood structural zone. The Los Angeles-Orange County line, although political rather than physical, is the western boundary.

GROUND-WATER RECHARGE

Recharge to the ground-water basin underlying Orange County comes from several sources and varies in quality. The present major sources of water are imported Colorado River water, surface inflow, precipitation, irrigation return, and subsurface inflow.

Imported Colorado River Water

Colorado River water was first delivered to Orange County by the Metropolitan Water District of Southern California in 1941. From 1941 to 1949 all imported water was softened and delivered in surface lines for direct use. In 1949 Orange County Water District began purchasing unsoftened water for ground-water recharge. During the 1966 water year (October 1, 1965-September 30, 1966) 88,796 acre-feet of softened water was delivered to the consumer for direct use, and 85,609 acre-feet of unsoftened water was delivered for recharge to the ground-water system. Unsoftened Colorado River water is sodium calcium sulfate in character. Historically, the dissolved-solids concentration has ranged from 500 to 800 mg/l (milligrams per liter). Currently, the concentration is approximately 750 to 800 mg/l. Imported water enters the ground-water system primarily through infiltration in the Santa Ana River channel and Crill pit spreading grounds (fig. 3). Smaller quantities are spread in Rattlesnake Canyon and Santiago Creek.

Surface Inflow

Streamflow in the Santa Ana River is gaged below Prado Dam and at the Fifth Street Bridge in Santa Ana (fig. 3). Streamflow that passes the Fifth Street Bridge is probably lost to the ocean. The amount of water entering the ground-water system between the two gaging points is computed regularly. Total annual natural flow in the Santa Ana River at Prado Dam has been declining over the past years from 174,400 acre-feet in the 1941 water year to 26,950 acre-feet in the 1961 water year. In the 1966 water year the flow increased to 74,840 acre-feet--the first substantial increase from the record low. Quality of the surface flow in the Santa Ana River is monitored monthly by the California Department of Water Resources. The water is generally calcium sodium bicarbonate chloride in character and often has a high coliform count, a bacteria group associated with domestic sewage. Because of changes in flow, biological activity, evaporation, waste discharges, and other parameters, the water quality is highly variable.

Precipitation

Ground-water recharge from precipitation is limited largely to the forebay or recharge area (fig. 2). Precipitation in the pressure or artesian area is discharged to the ocean as runoff or lost by evapotranspiration. In computing recharge from precipitation consideration was given to the size of storms and the topography, vegetation, and soil cover of the receiving area. In recent years recharge from precipitation has ranged from about 22,000 acre-feet in 1961 to about 53,000 acre-feet in 1964. The quality of rainwater is dependent on soluble materials present in the atmosphere. Bicarbonate commonly is the dominant anion. Although analyses of rainwater are not available for the Orange County area, sulfate and chloride may be significant because of smog and the nearness of the ocean. The concentrations of dissolved solids in rain is commonly in the range from a few to a few tens of milligrams per liter.

Irrigation Return

About 80 percent of the irrigation water applied in the forebay area is used consumptively. The remaining 20 percent of the water, an average of 15,600 acre-feet per year, enters the ground-water system as irrigation return. Additional data such as vertical permeabilities and storage coefficients of the confining material, vertical pressure gradients, and water quality in the confining material are needed to estimate the quantity and quality of irrigation return in the pressure area.

The quality of irrigation return is dependent on several factors including: leaching, evaporation, transpiration, ion exchange, filtration, heat transfer, precipitation of salts, biochemical activity, nature of the soil, method of irrigation, types of crops irrigated, application of fertilizers, pesticides and weed killers, and the quantity and quality of the irrigation water applied (Sylvester and Seabloom, 1963).

AREAS OF POOR WATER QUALITY

Ground-water quality in Orange County changed significantly over the period 1954-66 (fig. 4). Although historically ground-water quality was good in most areas of Orange County, some degradation has occurred in nearly every part of the system. Piper (Piper, Garrett, and others, 1953, p. 50) defined waters of inferior quality as "those which contain more than about 600 ppm of dissolved solids." Using this criterion, the present extent of water of inferior quality includes most of the forebay area, almost all of the area northeast of Irvine, and the entire coastal front. However, the dissolved-solids content of Colorado River water, used as recharge in the forebay area during 1967, is as much as 800 mg/l. In this report water of poor quality is defined as water that is undesirable for its intended or probable use (fig. 3).

Figure 3 outlines areas which are presently underlain by water of poor quality and areas which may become degraded in the future. These latter areas include: The inland margins of Sunset and Bolsa Gaps, the area near the proposed Santa Ana Gap injection barrier, the area adjacent to the Santa Ana River above Fifth Street Bridge, the Irvine area, and the forebay area north of Tustin.

The most significant water-quality problem in Orange County has been the intrusion of sea water into the coastal aquifers. In 1965 the California Department of Water Resources (1966) completed a detailed study of Santa Ana Gap. The report of that study outlined the extent of intrusion in that area. An isochlor map of Sunset and Bolsa Gaps (fig. 5) was constructed from chloride analyses of water samples collected from U.S. Geological Survey observation wells during 1967.

Nitrate concentrations in excess of 45 mg/l have been detected in the upper aquifers in the northeastern part of Garden Grove and in Tustin. Although high concentrations of nitrate have been present in this area for several years, the condition was not studied until water from public-supply wells contained nitrate concentrations approaching or exceeding the limit recommended by the U.S. Public Health Service (1962). The primary source of nitrate has been attributed to the agricultural use of nitrogen-base fertilizers (written commun., Orange County Water District, 1967).

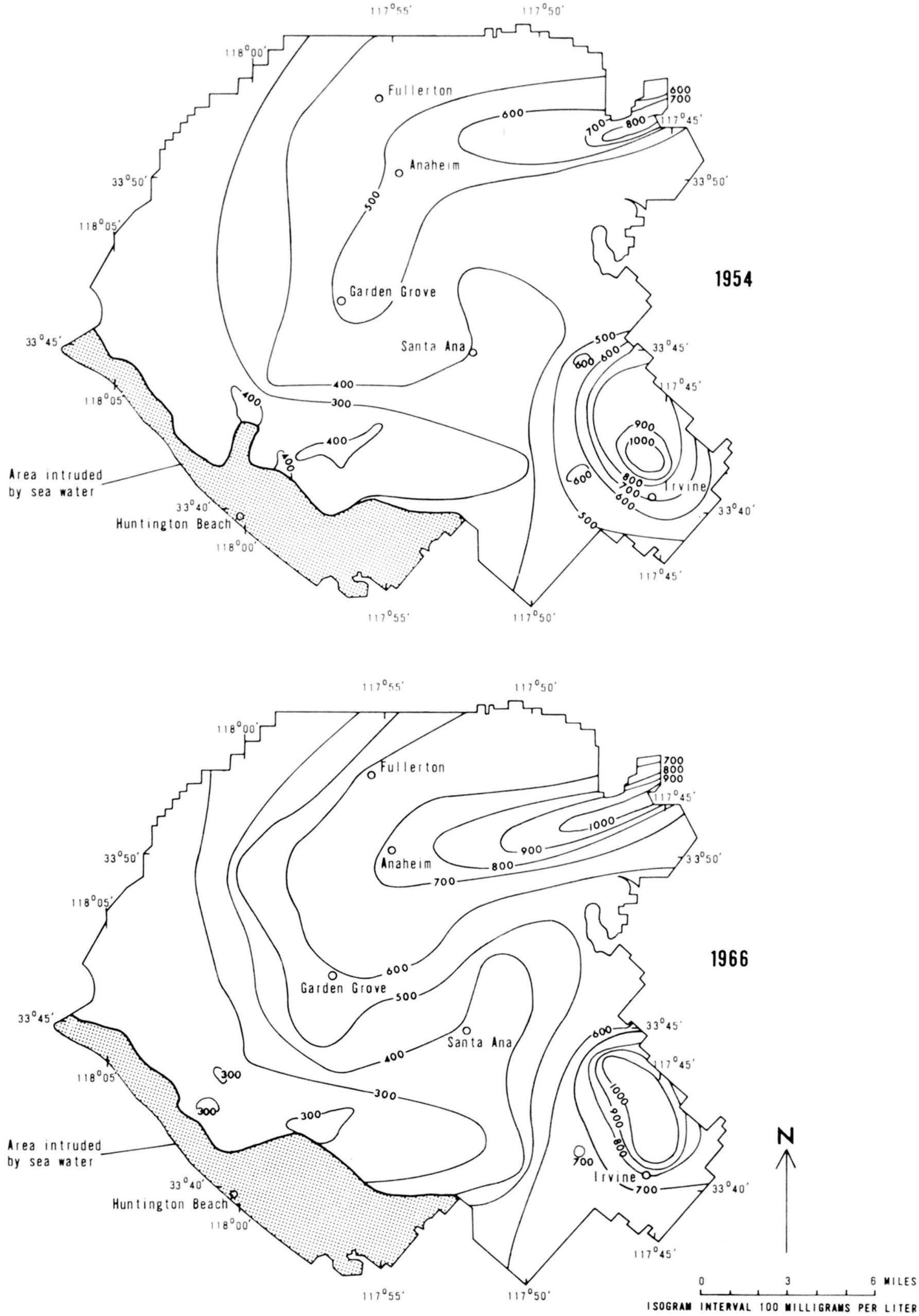


FIGURE 4.--Dissolved-solids content of ground water, 1954 and 1966.

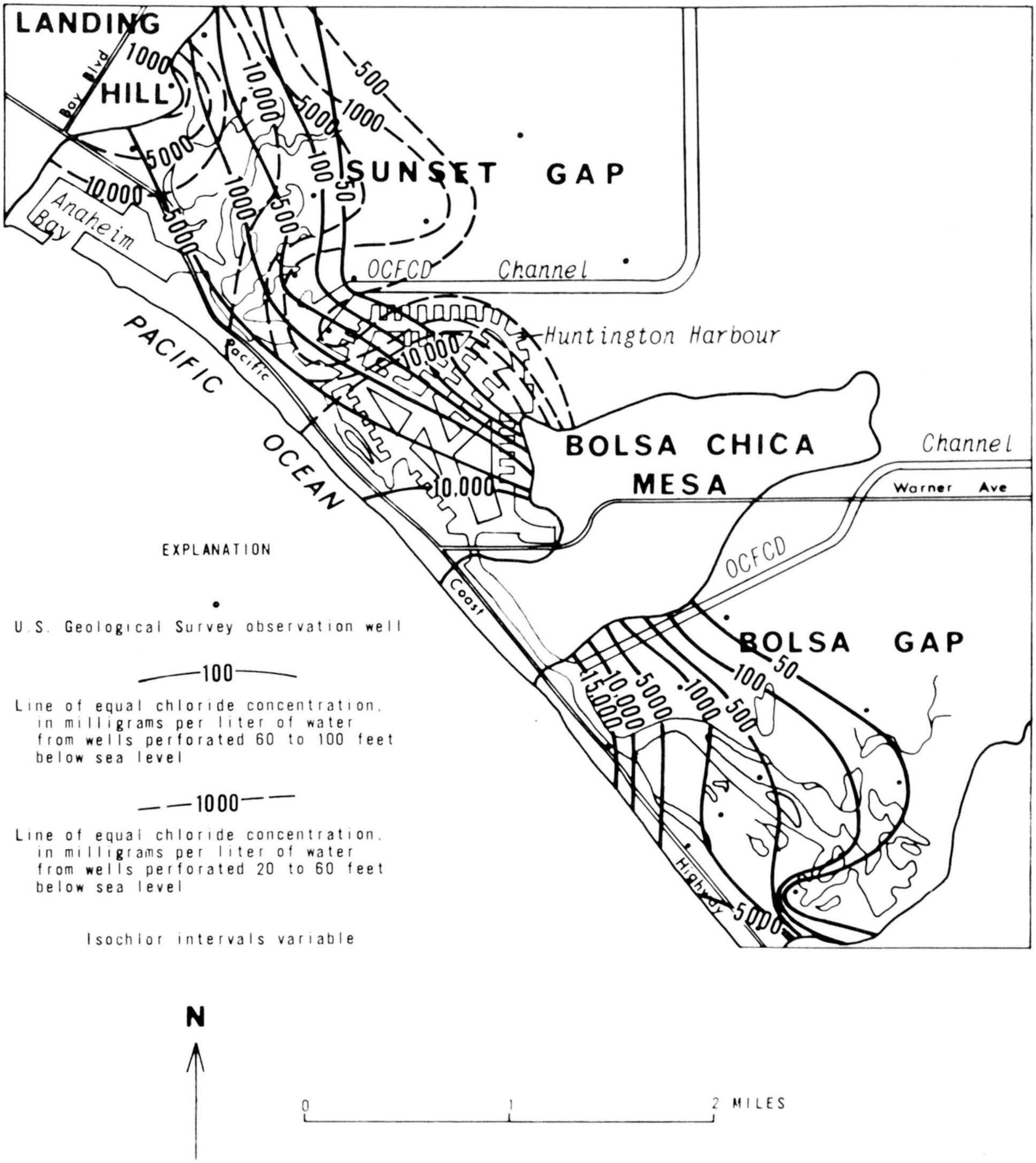


FIGURE 5.--Chloride concentration in Sunset and Bolsa Gaps, 1967.

Water of inferior quality as defined by Piper, Garrett, and others (1953, p. 55) is native to parts of the area surrounding Irvine. High concentrations of sulfate, about 400 mg/l, which occur in this area are probably derived from sodium sulfate water native to the rocks of the Santa Ana Mountains. In the upper aquifers, the sulfate concentrations have been greatly increased through the practice of addition of gypsum to the soil. Irrigation return and sewage disposal have contributed to the high dissolved solids in the area.

In the lower Santa Ana Canyon area, high concentrations of dissolved solids are a result of downward percolation of Santa Ana River water, imported Colorado River water, and irrigation return.

Aquifer units that are deeply buried in the inland areas of the water district have been brought close to ground surface by movement along the Newport-Inglewood structural zone. Water from these lower units is commonly amber colored due to organic material. Although much of the water has low concentrations of dissolved solids, the amber color detracts considerably from its utility. The water is undesirable for domestic use without treatment to remove the color. Mixing, filtering, and bleaching are methods that can be used, but further study is needed to determine the most economical and practical means of decoloring the water.

CURRENT WATER-QUALITY MONITORING

During 1967 samples of water were collected periodically for chemical analysis by 16 agencies in the Orange County Water District. The 272 wells sampled by these agencies are shown in figure 3 and listed in table 1. The frequency of sampling, as shown in table 1, ranges from monthly to every 24 months depending on the agency collecting the sample.

In addition to regularly sampled wells, which are listed in this report, many other wells have been sampled at the time of installation or at intervals ranging from 2 to 5 years. Although the infrequently sampled wells cannot be employed in a monitoring network, they supply much valuable data. Sampling of this type is performed by agencies such as the California State Health Department, city of Yorba Linda, Irvine Ranch, Southern California Water Co., and many private industrial firms.

Investigations of water-quality problems, such as intrusion of sea water, furnish specialized data. Although those investigations generally span only a short interval and cover a small area, the data collected are invaluable in defining the water-quality problems in that specific area.

TABLE 1.--*Wells currently sampled*

OCWD & owner number: The first number given is the Orange County Water District number. Other numbers are given by owners. Symbols: Anah - Anaheim; CM - Costa Mesa; Full - Fullerton; Full Hts - Fullerton Heights; GG - Garden Grove; Hunt Beach - Huntington Beach; OCWD - Orange County Water District; SA - Santa Ana; SB - Seal Beach; SAHWC - Santa Ana Heights Water Co.; West - Westminster.

Sampling agency: Anah - city of Anaheim; Bastanchury - Bastanchury Water Co.; Cal WRC - California Water Resources Control Board; CM - Costa Mesa County Water District; DWR - California Department of Water Resources; Full - city of Fullerton; GG - city of Garden Grove; Holly Sugar - Holly Sugar Corp.; Hunt Beach - city of Huntington Beach; OCWP - Orange County Water Pollution Department; Orange - city of Orange; Pepsi-Cola - Pepsi-Cola Bottling Co. of Santa Ana; SA - city of Santa Ana; Sparkletts Water - Sparkletts Drinking Water Co.; Tustin WW - Tustin Water Works; West - city of Westminster.

Use: The use of the well is indicated by the following symbols: A - agriculture; D - domestic; I - industrial; M - municipal; U - unused.

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
3S/8W-31E2	85-041-11A	OCWP	6	93	13-83	A,D
3S/9W-19B2	75-25-2B	OCWP	6	276		D
21D1	65-14-4A	OCWP	6	161	154-160	D
21D2	65-13-9A	OCWP	6	180		A
21M1	76-05-2B	OCWP	6	274	74-274	I,D
21M2	76-05-2A	OCWP	6	294		D
28L2	77-02-7A	OCWP	6	212	112-200	D
32H3	77-10-2A	OCWP	6	330		I,D
32K6	74-27-9A Anah 30	Anah	6	479		M
32K7	74-27-7C Anah 31	Anah	6	472		M
32P3	74-27-10A Anah 27	Anah	6	295	240-282	M
32P4	74-27-10B Anah 28	Anah	6	379		M
33H1	77-182-11A	OCWP	6	90	85-90	U
33K1	77-13-16A	OCWP	6	395	90-340	A
34G1	77-20-3A	OCWP	6	452		I
34H1	77-20-11A	OCWP	6	190	75-110	U
34M1	77-19-22A	OCWP	6	250	90-213	I,D
35Q1	77-23-13A	OCWP	6	96	20-60	D
3S/10W-28G1	28-24-17A Full Hts	Full	6	3,100	180-700	M
29D1	28-03-26A Coyote 1	Bastanchury	6	477	162-368	D
30B1	28-03-1A Coyote 2	Full	6	700	275-676	M
32F1	30-29-5A Basque well	Full	6	240	147-232	M
35K1	33-270-14A Fire Station	Full	6	454	351-419	M
35N1	73-11-6A Kimberly 1	Full	6	610	339-572	M
35R1	73-12-13A Kimberly 2	Full	6	652	320-626	M
4S/9W-1C1	85-03-12B	OCWP	6	100	45-100	D
1E2	85-03-12A	OCWP	6	100		A
4M2	77-15-8A	OCWP	6	308	190-280	A
6G2	74-22-6A	OCWP	6	515	211-510	A
7P1	84-01-1C Orange SAVI 8	Orange	6	506		M
7Q5	84-04-1H	OCWP	6	1,061		A
18B1	84-09-2B Batavia 2	Orange	6	502		M
18B2	84-09-2A Orange 1	Orange	6	500		M
27C1	93-07-5A Orange 10	Orange	6	784	260-761	M
27F1	40-24-14A	OCWP	6	1,006	416-792	A
31B1	41-11-4A Orange 6	OCWP & Orange	6	667	276-651	M
32B1	42-11-5A Orange 4	Orange	6	726	320-711	M
32B2	42-11-5B Orange 5	Orange	6	751	156-723	M
32K1	94-01-2A	OCWP	6	975	199-766	A
33J1	94-07-4A LaVeta	Tustin WW	24	535	240-400	M
4S/10W-1F1	74-01-4B Anah 26	Anah	6	411	266-383	M
3P1	35-01-5A Anah 6	Anah	6	638	310-610	M
3P2	35-01-5B Anah 7	Anah	6	642	324-608	M

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
4S/10W-4Q1	34-31-18A Anah 11	Anah	6	400		M
4Q2	34-32-12A Anah 20	Anah	6	418		M
4R1	34-01-12B Full 3	Full	6	408	340-408	M
4R2	34-01-12D Full 1	Full	6	424	310-410	M
4R3	34-01-12C Full 4	Full	6	422	314-405	M
4R4	34-01-12F Full 6	Full	6	430	340-401	M
4R5	34-01-12E Full 5	Full	6	440	350-400	M
4R6	34-01-12A Full 2	Full	6	420	318-408	M
4R7	34-01-12G Full 7	Full	6	434	300-410	M
5E1	72-02-5A Christlieb well	Full	6	324		M
6P1	71-06-23A	DWR	6	670	650-670	A,D
7E1	71-08-4A Anah 12	Anah	6	510	450-498	M
7Q4	71-11-1B Golf Course	Anah	6	491	452-473	A
8C2	72-05-8A Anah 9	Anah	6	380		M
8N5	72-08-4A Anah 16	Anah	6	420	384-414	M
9B2	34-09-1B Anah 14	Anah	6	450	309-425	M
9B3	34-09-1C Anah 23	Anah	6	467	354-408	M
11Q2	82-01-11A Anah 29	Anah	6	400		M
12C1	83-03-6A Anah 17	Anah	6	367	240-360	M
14D2	37-121-4A Anah 22	Anah	6	446	368-421	M
14H2	82-04-7A Anah 15	Anah	6	638	400-536	M
14M1	82-07-6A Anah 25	Anah	6	423	269-403	M
15B5	37-04-3E Anah 34	Anah	6	411	277-392	M
15C1	36-15-2A Police Bldg	Anah	6	394	304-344	M
17H1	81-05-4A Anah 35	Anah	6	425		M
17J2	81-08-8A Anah 10	Anah	6	389		M
17L2	81-07-7A Anah 18	Anah	6	576	425-480	M
18K1	80-12-3B Anah 105	Anah	6	616	538-593	M
18P1	80-141-4B Anah 122	Anah	6	490		M
19H1	80-22-10A Anah 111	Anah	6	250		M
19L2	80-31-8A Anah 136	Anah	6	620		M
19R3	80-33-1A Anah 112	Anah	6	558	462-551	M
20N1	81-26-1A Anah 113	Anah	6	265		M
20N2	81-26-1B Anah 114	Anah	6	172		M
21N2	81-28-3A Anah 117	Anah	6	222	155-175	M
23B2	82-15-1A Anah 19	Anah	6	351		M
24D2	83-21-4A	OCWP	6	525		A
24J1	92-08-15A Orange 8	OCWP & Orange	6	870	570-850	M
24J2	92-08-15B Orange 9	Orange	6	910	546-888	M
25F1	83-28-2A Anah 33	Anah	6	478	240-447	M
26N1	91-21-6A Orange 3	Orange	6	216	207-216	M
26P1	91-21-7A Orange 7	Orange	6	729	175-692	M
27N2	91-04-5A GG 56	GG	12	203		M
28R1	90-22-6A GG 51	GG	12	243		M
29K1	89-15-1B GG 19	GG	12	942		M
29M1	89-02-11A	DWR	6	276		D,A
30A2	88-27-2A GG 79	GG	12	251		M
30B1	88-27-1B GG 76	GG	12	400		M
30F3	88-25-3A GG 19L	GG	12	165		M
30M1	88-23-2A GG 26	GG	12	175		M
30N1	88-23-4A GG 25	GG	12	168		M
30P2	88-24-7A GG 27	GG	12	180	142-166	M
30R1	88-30-8A GG 32	GG	12	764	250-745	M

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
4S/10W-31F1	88-182-3A GG 6	GG	12		137-155	M
31H1	88-31-30A GG 69	GG	12	960	250-856	M
31M1	88-371-3A GG 11	GG	12		154-214	M
32A3	89-243-12A GG 42	GG	12	350		M
32Q1	89-092-17B GG 3	GG	12	3,100	435-800	M
33C1	90-272-8A GG 77	GG	12	204		M
33F1	90-08-2A GG 9	GG	12	236	154-214	M
34A2	91-12-9A GG 88	GG	12	187		M
34B1	91-11-1A GG 60	GG	12	237		M
34K1	91-10-2A GG 59	GG	12	303		M
34R2	91-09-10B, GG 64	GG	12	452	417-432	M
4S/11W-8P2	68-07-8A	DWR	6	300		A
9A1	68-22-5C	DWR	6	154	146-153	D
12M1	70-14-3A	DWR	6			D
12R1	70-16-6A	DWR	6	541	485-525	A,D
13A3	80-02-19A	DWR	6	129		A
13A4	80-02-18A	DWR	6	118		U
13D3	80-08-8A Anah 106	Anah	6	580	540-560	M
13P1	80-16-13A Anah 107	Anah	6	360		M
14H1	79-06-6A Anah 108	Anah	6	582		M
14Q4	79-16-1A Anah 128	Anah	6	210		M
15M1	79-11-1A	DWR	6	293		D
16E1	78-13-3A	DWR	6	89		D
24A1	80-19-11D Anah 129	Anah	6	668	542-585	M
24P1	80-38-2A GG 111	GG & DWR	6	236	118-225	M
25K1	88-03-3A, GG 17	GG	12	450		M
33L1	87-02-9C,D GG 16N,S	GG	12	864	354-860	M
34C4	87-14-8B GG 15	GG	12	502		M
36A1	88-06-5A GG 91	GG	12	150		M
36A2	88-05-2A GG 85	GG	12	600		M
36N1	87-301-2A	DWR	6	568	500-546	D
5S/8W-31K1	104-11-15A Irvine 37	OCWP	6	1,560		A
32L1	104-11-15B Irvine 64	OCWP	6	830	310-540	A
5S/9W-4C1	102-03-8A Yorba well	Tustin WW	24	863	385-850	M
4J1	102-03-2A Prospect well	Tustin WW	24	730	270-630	M
5R1	102-20-26A Tustin well	Tustin WW	24	827	306-776	M
9H1	62-21-11A Livingston well	Tustin WW	24	617	300-617	M
10L1	102-25-11A Newport well	Tustin WW	24	375	234-267	M
14Q2	104-04-8B Irvine 99	OCWP	6	692		D
15J1	104-04-11A Irvine 72	OCWP	6	1,151	160-897	A
16B2	62-082-9D Old well	Tustin WW	24	600	270-600	M
16B5	62-082-9F New well	Tustin WW	24	607	307-607	M
21B1	104-06-10A Irvine 77	OCWP	6	997	397-995	A
22C4	103-31-6A Panky well	Tustin WW	24	614	323-614	M
24H1	104-04-55A Irvine 67	OCWP	6	902	245-900	A,D
25E1	104-10-5A Irvine 53	OCWP	6	1,296	285-1,296	A
30G1	16-15-8B Main well	Holly Sugar	1	1,010		I
32A1	120-04-18A Irvine 92	OCWP	6	1,032	360-1,010	A
34J1	120-04-2A Irvine 82	OCWP	6	1,145	410-1,001	A
34J2	120-04-14B Irvine 14	OCWP	6	1,026	30-1,010	D
34Q1	120-04-14A Irvine 78	OCWP	6	1,103	410-690	A
36B1	104-11-1A Irvine 41	OCWP	6	1,603	266-1,570	A

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
5S/10W-1E1	1-12-1A SA 14	SA	6	1,050	236-622	M
1E2	1-12-1B SA 18	SA	6	654	245-623	M
2B2	101-05-3A	OCWP	6	142		D
2E1	101-04-6A GG 90	GG	12	180		M
2E2	101-03-9A GG 55	GG	12	190		M
3K2	101-09-3A GG 104	GG	12	167		M
4E1	100-09-4A GG 8	GG	12		145-246	M
4L1	100-11-9A GG 47	GG	12	385	144-216	M
5R2	99-15-12C GG 96	GG	12	212	130-180	M
7C1	98-10-6A West 23	West	12	201		M
7D4	98-10-1B West 22	West	12	168		M
7G1	98-14-5A GG 14	GG	12	174	128-157	M
7L1	98-17-1B West 6	West	12	694	176-660	M
8D1	99-18-1A GG 12	GG	12	145		M
8P1	99-19-6A West 4	West	12	624	130-610	M
9C1	100-18-9A GG 48	GG & DWR	6	380	310-360	M
9C2	100-19-24B	Sparkletts Water	12	246	154-212	D
9H3	100-21-5A GG 49	GG	12	428		M
11R1	7-082-4A	Pepsi-Cola	1	520		I
12L3	8-02-1A SA 16	SA	6	978	305-950	M
13B3	8-153-1A SA 7	SA & DWR	6	960	426-907	M
13B7	8-153-1B SA 13	SA	6	950	294-906	M
13C1	8-144-17A SA 15	SA	6	1,140	214-1,042	M
16B2	108-27-17B SA 21	SA	6	986	127-560	M
16B3	108-27-17A SA 20	SA	6	981	390-940	M
16L1	108-15-2A GG 105	GG	12	172		M
16M2	108-14-4A GG 71	GG	12	165		M
16N1	108-14-5A SA 19	SA	6	175		M
16P1	108-15-2B GG 84	GG	12	216	110-146	M
18L1	107-29-1B West 5	West	12	360	130-330	M
22E3	108-31-3E	DWR	6	145		D
28H2	113-01-5B	DWR	6	250	96-210	D
29P4	112-20-9A	DWR	6	115	80-90	D,A
32F4	112-24-15A	Cal WRC	6	100		D
32J1	112-25-9A	Cal WRC & DWR	6	300		D
33D1	112-25-2A	DWR	6	568	506-529	A
34F2	113-08-1B CM 6	CM	12	900		M
34Q2	113-08-1A CM 5	CM	12	458	205-458	M
35K1	113-09-4A CM 7	CM	12	779		M
5S/11W-1A2	97-26-17A GG 21	GG	12	186		M
1E2	97-03-1A GG 16L	GG	12	650		M
1H1	97-26-19A GG 7	GG	12			M
1H2	87-19-14A GG 20	GG	12	960		M
1L1	97-03-8A West 13A	West	12	145		M
2B2	96-27-2A West 89	West	12	500		M
2D4	96-01-6A West 106	West	12	500		M
2J1	96-29-1A West 83	West	12	490		M
2L1	96-04-4A West 10	West	12	400		M
2N1	96-07-8A West 01	West & DWR	6	438	397-432	M
2Q6	96-23-3A West OC2	West	12	435		M
3H4	95-16-2A West 75	West	12	500		M
4A2	95-04-2B	DWR	6	135		D
4D1	95-04-4A West 124	West	12	528		M

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
5S/11W-4Q1	95-04-5A West 122	West	12	810	720-810	M
7C1	95-02-2A SB 6	DWR	6	802	548-655	M
7C2	95-02-2B SB 7	DWR	6	674	580-654	M
7L1	95-02-2D Navy 2	DWR	6	796		M
8C1	95-02-2C Navy 1	DWR	6	915	633-870	M
10C12	95-10-4A West 9	West	12	385		M
10D6	95-07-3A West 8	West	12	455	130-330	M
10J4	95-20-14A West 99	West	12	371		M
12H1	97-32-14A West 86	West	12	164		M
12K1	97-33-1A West 107	West	12	176		M
13A2	107-20-1A West 1	West	12	764		M
13A4	107-20-1C West 2	West	12			M
13L5	107-21-5A West 113	West	12	410		M
14A4	107-14-4A	DWR	6	106	98-105	D
14A9	107-14-21A	DWR	6			D
14A10	107-01-9B West 95	West	12	852		M
14H3	107-01-9A West 63	West	12	114		M
15D3	106-27-4C Hunt Beach 1	Hunt Beach	12	306		M
16R1	106-27-11A Hunt Beach 2	Hunt Beach	12	820	359-705	M
20G1	106-14-34A	DWR	6	100		D
20J4	106-16-2A	DWR	6	288	253-288	A
20K9	106-171-10A	DWR	6	145		D
20Q4	106-19-1A	DWR	6	165		A
20Q13	106-19-7A	DWR	6	136		D
20R3	106-21-1F	DWR	6	130	119-129	D
21M3	106-23-6A	DWR	6	231	203-228	D
21N2	106-22-8A	DWR	6	197		D
21Q1	106-25-3A	DWR	6	537	475-525	A
21Q5	106-25-3D	DWR	6	310	292-300	D
23A3	107-03-4B Hunt Beach 3	Hunt Beach	12	904		M
23M1	107-04-1B	DWR	6	1,021		D
23R1	107-04-4B	DWR	6	252	160-250	D
24F3	107-22-3C West 3	West	12	365	285-365	M
26E5	111-01-4A	DWR	6	460	420-460	D
26M7	111-01-21C Hunt Beach GW 3	Hunt Beach & DWR	6	515	342-470	M
26M8	111-01-21D Hunt Beach GW 4	Hunt Beach & DWR	6	515	342-486	M
26M9	111-01-21E Hunt Beach GW 5	Hunt Beach & DWR	6	647	336-597	M
26P1	111-01-26A	DWR	6	510	475-510	I,A
26P3	111-01-24A	DWR	6	577	448-548	I
27F5	110-08-8C	DWR	6	192	92-99	D,A
27H4	110-10-6B	DWR	6	93		D
28D4	110-06-12A	DWR	6	130	124-129	D
28K1	110-07-8A	DWR	6	917	292-848	A
29B11	110-032-20A	DWR	6	125		D
29C1	106-12-1B SB E2	DWR	6	450	333-416	M
29C2	106-12-1A SB W1	DWR	6	630	460-614	M
29H1	110-01-10A	DWR	6	500	338-466	A,D
33H1	110-01-20A	DWR	6	368	330-360	I
34F3	110-01-20C	DWR	6	773	464-773	I
35F4	111-071-10A	DWR	6	205	190-205	I,D
36B2	112-10-7A	DWR	6	136		D
36C1	112-07-12A Dyke 1	Hunt Beach & DWR	6	206	170-190	M

State well number	OCWD & owner number	Sampling agency	Sample frequency (months)	Total depth (feet)	Overall perforated interval (feet)	Use
5S/12W-12C1	95-01-4A	DWR	6	705	417-473	I
6S/8W-5E2	104-11-5C Irvine 61	OCWP	6	762	240-762	A
7Q1	120-15-2A Irvine 168	OCWP	6	894	210-403	A,D
6S/9W-1L1	120-04-4A Irvine 35	OCWP	6	1,503	263-1,503	A
2D1	120-04-13A Irvine 76	OCWP	6	1,120	395-795	A
3C1	120-04-19A Irvine 75	OCWP	6	868	400-820	A
5A1	120-04-38A Irvine 103	OCWP	6	1,127		A,D
6S/10W-1E5	113-143-6B SAHWC	OCWP & DWR	6	976	720-968	M
1L1	113-144-12A	DWR	6	460	160-460	A,D
3D2	113-12-5A CM 4	CM	12	550	300-550	M
4D1	113-10-3A CM 3	CM	12	200		M
5B3	114-01-16B	DWR	6	218	125-180	I
6B2	114-01-1A	DWR	6	100		D
11G1	113-21-6B CM 2	CM	12	725	254-407	M
12E3	120-06-2A CM 1	CM	12	465	335-465	M
6S/11W-1N2	114-02-8A	DWR	6	700		D,A
3J1	23-18-1A	DWR	6	235	75-212	A
3R2	23-10-1A	DWR	6	279	180-279	A
13F4	114-08-12A	DWR	6	200	164-184	I

Surface-water samples are collected throughout the county by personnel of the Orange County Water Pollution Department and the Orange County Flood Control District. Samples are collected from flood-control channels, drainage ditches, streams, and collection basins. The frequency and location of sample collection are variable because of intermittent flow.

The California Department of Water Resources maintains a sampling station on the Santa Ana River below Prado Dam from which samples are collected at regular intervals. However, to monitor water-quality parameters that change rapidly and continuously, the U.S. Geological Survey has installed at Prado Dam an automatic water-quality monitor which will record pH, temperature, conductivity, turbidity, dissolved oxygen, and stage.

IDEAL MONITORING NETWORK

Suggested Alterations

Many of the wells listed in table 1 are sampled by municipal water departments or industrial firms. The wells are sampled for a specific reason and are therefore assumed to be continuing sources of water-quality data. For this reason, the wells are not considered in the following suggested alterations.

Data collected from wells that tap more than one aquifer and from wells whose perforated intervals are unknown are often misleading. Care should be taken when analyzing data from such wells to insure against erroneous conclusions. Ideally, water-quality samples should be collected from wells that are perforated in only one aquifer and effectively sealed against mixing with water from other sources.

Deletions

Wells that are suggested for deletion from the water-quality monitoring network (table 2) were selected principally because of data duplication. Although only a few wells currently are being sampled by more than one agency, much duplication occurs in sampling adjacent wells that tap the same aquifer. Some wells were deleted because they are unused.

TABLE 2.—*Suggested deletions of wells currently sampled*

State well No.	Sampling agency[1]	Reason for deletion
3S/9W-21D2	OCWP	Nearby well is sampled.
32H3	OCWP	Do.
33H1	OCWP	Not in use.
4S/9W-1C1	OCWP	Nearby well is sampled.
4S/10W-6P1	DWR	Do.
4S/11W-13A4	DWR	Not in use.
36N1	DWR	Nearby well is sampled.
5S/9W-34J2	OCWP	Do.
5S/10W-13B3	DWR	Sampled by city of Santa Ana.
32J1	DWR	Sampled by Cal WRC.[2]
5S/11W-2N1	DWR	Sampled by city of Westminster.
7C1	DWR	Nearby well is sampled.
14A4	DWR	Do.
20G1	DWR	Do.
26E5	DWR	Do.
26M7	DWR	Sampled by city of Huntington Beach.
26M8	DWR	Do.
26M9	DWR	Do.
26P3	DWR	Nearby well is sampled.
36C1	DWR	Sampled by city of Huntington Beach.
6S/9W-3C1	OCWP	Nearby well is sampled.
6S/10W-1E5	DWR	Sampled by OCWP.[1]

[1]OCWP, Orange County Water Pollution Department; DWR, California Department of Water Resources.

[2]Cal WRC, California Water Resources Control Board.

Additions

With more than 270 wells currently monitored by various agencies within the boundaries of the Orange County Water District, few areas lack adequate water-quality surveillance. The wells suggested for addition to the monitoring network (table 3) will provide the data needed for comprehensive coverage of water-quality conditions throughout the area. The observation wells listed, like all unpumped wells, should be sampled by airlift or bailed to insure a representative sample.

Although few wells currently are sampled in Santa Ana Gap, that area was not considered in the compilation of suggested additions to the water-quality monitoring network. The Orange County Water District has formulated extensive plans for surveillance of water movement and quality changes caused by the salinity barrier (fig. 3) that will soon be in operation across the gap. Any attempt to establish a water-quality monitoring network in that area before the implementation of this system would be meaningless.

Additional wells that tap only the upper few feet of the ground-water reservoir are needed for sampling water that moves downward from the land surface. The chemical quality of irrigation return and other surface sources must be known to predict quality changes in the reservoir. Although shallow wells have been drilled in the past, most have been destroyed.

TABLE 3.—*Suggested additions to wells currently sampled*

State well No.	Other No.	Depth (feet)	Perforated interval (feet)	Owner	Use
4S/9W-16L2	84-29-5A	400	([1])	D. Hein	Domestic
22M4	Owner No. 2 92-31-13A	435	([1])	Serrano Irrigation Dist.	Agriculture
4S/11W-4G3	Hocker 68-01-9A	250	([1])	La Palma	Municipal
19Q3	Cherry No. 2 78-322-16A	632	([1])	So. Cal. Water	Do.
23L3	Lowell 79-31-6A	564	140-560	do.	Do.
28B1	87-13-3A	500	([1])	H. Van Ruitan	Agriculture
30M5	Baskerville 87-01-4F	500	386-416	So. Cal. Water	Municipal
31P1	Yellowtail 87-01-8E	812	250-800	do.	Do.
5S/10W-14N1	Clara 109-091-49A	199	([1])	do.	Do.
26P1	113-02-13A	1,018	([1])	Marshburn	Agriculture
29D2	112-20-1B	280	([1])	G. M. Holstein	Agriculture and domestic
5S/11W-17D2	USGS SGO-19	60	50-60	U.S. Navy	Observation[2]
17D3	USGS SGO-20	100	90-100	do.	Do.[2]
17Q2	USGS SGO-21	30	20-30	do.	Do.[2]
17Q3	USGS SGO-22	100	90-100	do.	Do.[2]
18K1	USGS SGO-17	60	50-60	do.	Do.[2]
18K2	USGS SGO-18	100	90-100	do.	Do.[2]
18L1	USGS SGO-12	130	98-130	do.	Do.[2]
18L2	USGS SGO-11	75	52-75	do.	Do.[2]
19C1	USGS SGO-15	40	30-40	do.	Do.[2]
19C2	USGS SGO-16	100	90-100	do.	Do.[2]

State well No.	Other No.	Depth (feet)	Perforated interval (feet)	Owner	Use
5S/11W-19D3	USGS SGO-8	60	50-60	U.S. Navy	Observation[2]
19D4	USGS SGO-9	100	90-100	do.	Do.[2]
19F1	USGS SGO-13	60	50-60	Huntington Harbour Corp.	Do.[2]
19F2	USGS SGO-14	100	90-100	do.	Do.[2]
28M3	USGS BGO-1	80	70-80	Bolsa Corp.	Do.[2]
29R1	USGS BGO-2	80	70-80	do.	Do.[2]
32B1	USGS BGO-3	90	80-90	do.	Do.[2]
32J1	USGS BGO-4	90	80-90	do.	Do.[2]
33A1	USGS BGO-7	60	50-60	do.	Do.[2]
33F1	USGS BGO-6	80	70-80	do.	Do.[2]
33K1	USGS BGO-9	80	70-80	do.	Do.[2]
33M1	USGS BGO-5	80	70-80	do.	Do.[2]
33P1	USGS BGO-10	100	80-100	do.	Do.[2]
34E2	USGS BGO-8	80	70-80	do.	Do.[2]
5S/12W-12Q2	USGS SGO-4	30	28-30	U.S. Navy	Do.[2]
12Q3	USGS SGO-5	90	80-90	do.	Do.[2]
13A9	USGS SGO-7	120	67-120	do.	Do.[2]
13B1	USGS SGO-2	30	20-30	do.	Do.[2]
13B2	USGS SGO-3	90	80-90	do.	Do.[2]
13F1	USGS SGO-1	70	60-70	do.	Do.[2]
6S/11W-4C1	USGS BGO-11	90	80-90	Bolsa Corp.	Do.[2]

[1]Only wells with known perforated intervals should be used in the monitoring network. However, lack of data requires the use of some wells which have only a known depth.

[2]Observation wells should be sampled by airlift method to insure collection of representative sample.

Type of Analysis

Standard chemical analysis (sodium, calcium, magnesium, potassium, sulfate, chloride, carbonate, bicarbonate, nitrate, and fluoride), although helpful, often is not required for interpretation of water-quality conditions. Tracing the movement of a body of water possessing a specific chemical character can sometimes be accomplished more effectively with selective analyses from many wells than by more complete analyses of samples from a limited number of wells. If the general chemical character of the water sample is known from previous analyses of water from the well or from other wells in the area, concentrations of undetermined constituents can be estimated quite accurately from a selective analysis. A more detailed analysis is needed periodically to insure against unexpected quality changes and to check the accuracy of estimated concentrations.

In the shallow coastal aquifers in Sunset, Bolsa, and Santa Ana Gaps, frequent chloride analyses and electrical conductivity measurements will supply adequate data for determining the position of the fresh-water-salt-water interface. Standard chemical analyses are needed only every 2 years from wells in the areas unless major changes occur in chloride concentrations or electrical conductivity.

In the forebay area selective analyses that include sulfate, bicarbonate, and nitrate determinations are necessary to adequately monitor the movement of ground water. Because of high concentrations of nitrate found in several parts of the forebay area and near Garden Grove, nitrate determinations should be made on all samples collected from these areas. Detailed chemical analyses at intervals of not more than 2 years should be made to aid in detection of degradation from various sources.

In the Irvine area water is used primarily for irrigation. For chemical-quality data to be of value for that area, the analysis should include sodium, sulfate, chloride, and boron concentrations and electrical conductivity. Detailed chemical analysis should be made whenever possible to monitor the spread of poor-quality water that has been occurring in the area.

Frequency of Sampling

Because changes of water quality occur at infrequent intervals, it would be impractical to limit all observations to a predetermined schedule. In the coastal gaps threatened by sea-water intrusion, samples should be collected quarterly for chloride determination, particularly near the fresh-water-salt-water interface. Standard analyses should be made less often, probably every 2 years. Monthly samples for chloride analysis should be collected in Santa Ana Gap when the operation of the salinity barrier is begun. Nitrate determinations should be made monthly on water in the forebay region to monitor the extent of water containing nitrate concentrations in excess of U.S. Public Health Service (1962) standards. Because water quality in the northwestern part of the water district has changed little in recent years, annual samples from wells in that area should supply sufficient data to monitor the slow quality changes.

Many of the municipal water departments collect samples for chemical analysis only once a year. To obtain a more complete record from their wells, measurements of electrical conductivity taken between sampling periods would be desirable to supplement the chemical analyses. This might give indications of gross contamination that could otherwise go undetected for a full year.

Future Changes

As ground-water conditions in Orange County change, the water-quality monitoring must be altered to keep abreast of new situations. The wells sampled, types of analyses required, and frequency of sampling should all be adapted to changing water-quality conditions.

Because of the rapid urban development in Orange County, many wells become unused or are destroyed each year. When it is no longer possible to obtain a sample from a monitoring well, an attempt should be made to find a nearby replacement well so that the water-quality record will continue uninterrupted.

Cooperation of Agencies

To obtain the most effective and inexpensive water-quality monitoring network within the boundaries of the Orange County Water District, all agencies involved should cooperate fully in the exchange of data and coordination of sampling techniques. The most important feature of a coordinated program is the establishment of a central agency that will receive and store all chemical-quality data collected in the water district. The central agency would prevent duplication of effort by supplying available water-quality analyses to agencies that might otherwise have to collect samples to obtain needed data.

The time lapse between the actual collection of a water sample and the completion of the chemical analysis, often in excess of 3 months, contributes substantially to duplication of effort. To reduce this problem, the central agency should be notified immediately after samples have been collected. The information supplied would include the well number, date the sample was collected, sampling agency, type of analysis requested, analyzing laboratory, and estimated date of the analysis.

The central agency would provide an annual report to interested agencies on water-quality conditions within the water district. This report should include a tabulation of chemical analyses made during the year, a tabulation of samples collected but not yet analyzed, and a description of the water-quality changes which have occurred.

Automated Processing of Data

Water-quality data in laboratory-report form is invaluable to the hydrologist as an aid to a more complete understanding of the water-quality conditions in his area of interest. However, because of the large mass of data and the number of chemical constituents involved, water-quality data are best handled by use of electronic computers. The storage and retrieval of data would be a monumental task in itself without the aid of computers. When more detailed information is desired, such as probable proportions of various source waters contained in a specific sample, the computer is indispensable.

Many of the chemical-quality data available from wells within the water district have already been punched on cards by the California Department of Water Resources. Other data presently available should be converted to computer cards. Arrangements should also be made to receive and process new data as they become available. Only if the program is kept abreast with current data will the central agency be helpful to those agencies planning sample collections.

SELECTED REFERENCES

California Water Quality Control Board, 1963, Water quality criteria, 2d edition: State Water Quality Control Board, 548 p.

California Department of Water Resources, 1966, Santa Ana Gap salinity barrier, Orange County: Dept. Water Resources, Bull. 147-1, 178 p.

Eckis, Rollin, 1934, South coastal basin investigation; geology and ground-water storage capacity and valley fill: California Dept. Public Works, Div. Water Resources, Bull. 45, 273 p.

Moore, E. W., 1940, Progress report of the committee on quality tolerances of water for industrial uses: New England Water Works Assoc. Jour., v. 54, p. 271.

Piper, A. M., Garrett, A. A., and others, 1953, Native and contaminated ground waters in the Long Beach-Santa Ana area, California: U.S. Geol. Survey Water-Supply Paper 1136, 320 p.

Poland, J. F., 1959, Hydrology of the Long Beach-Santa Ana area, California, with special reference to the watertightness of the Newport-Inglewood structural zone: U.S. Geol. Survey Water-Supply Paper 1471, 257 p.

Poland, J. F., Piper, A. M., and others, 1956, Ground-water geology of the coastal zone, Long Beach-Santa Ana area, California: U.S. Geol. Survey Water-Supply Paper 1109, 162 p.

Sylvester, R. O., and Seabloom, R. W., Jr., 1963, Quality and significance of irrigation return flow, _in_ Jour. Irrig. and Drainage Div.: Ann Arbor, Michigan, Proc. Am. Society Civil Engineers, v. 89, no. IR3, Sept. 1963, pt. 1, p. 1-27.

Thomas, R. G., 1961, Planned utilization of the ground-water basins of the coastal plain of Los Angeles County: California Dept. Public Works, Div. Water Resources Bull. 104, 181 p.

U.S. Public Health Service, Drinking water standards, 1962: Pub. 956, 61 p.

Wall, J. R., Cordes, E. H., and Moreland, J. A., 1966, Progress report on salt-water intrusion studies, Sunset and Bolsa Gaps, Orange County, California: U.S. Geol. Survey open-file rept., 32 p.

Yerkes, R. F., McCulloh, T. H., Schoellhamer, J. E., and Vedder, J. G., 1965, Geology of the Los Angeles basin, California—an introduction: U.S. Geol. Survey Prof. Paper 420-A, p. A1-A57.

GPC 978-091