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PRELIMINARY CHEMICAL QUALITY STUDY IN
THE MANHATTAN BEACH AREA, CALIFORNIA

United States Geological Survey
Water Resources Division
Quality of Water Branch



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Quality of Water Branch

PRELIMINARY CHEMICAL-QUALITY STUDY IN THE
MANHATTAN BEACH AREA, CALIFORNIA

By Robert Brennan

Prepared in cooperation with the California
Department of Water Resources

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CONTENTS

	<u>Page</u>
Introduction	2
Acknowledgments	9
Description of the area	9
Chemical relations in the water	15
Summary	32
References	34

ILLUSTRATIONS

Figure 1	Location of wells in the Manhattan Beach project area, Manhattan Beach, California	4
2	Geologic profile through the "C" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth	11
3	Geologic profile through the "G" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth	12
4	Geologic profile through the "K" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth	13
5	Water-level contours for 1903-04 and 1945 in the Manhattan Beach area	14
6	Trilinear plot of selected analyses from the Manhattan Beach area	17
7	Calcium, magnesium, and chloride concentrations in the leach of core material from the Silverado water-bearing zone with a sodium chloride solution and sea water	19

TABLES

Table 1	Mineral constituents and related physical measurements of the ground water of the Silverado water-bearing zone in the Manhattan Beach area, selected samples of oil field brines and ocean water, California	5
2	Calculated mixtures of native water with ocean water and oil field brines for selected analyses from the municipal well 8, Manhattan Beach, California	22
3	Calculated mixtures of native water and ocean water for selected analyses from the "C" line of wells, Manhattan Beach, California.	26
4	Calculated mixtures of native water and ocean water for selected analyses from the "G" line of wells, Manhattan Beach, California	27
5	Calculated mixtures of native water and ocean water for selected analyses from the "K" line of wells, Manhattan Beach, California	28

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INTRODUCTION

In 1904 Mendenhall (1905) made a survey of the ground water conditions in southern California. At the time of his survey the piezometric surface in the area was above sea level, but since that time water levels have declined. During the 1920's, years of rapid development, the water levels declined at an increasing rate. However, because of decreased pumping during the depression years of the 1930's, the levels tended to recover somewhat. During the war years of the 1940's, a large expansion of industry occurred in the area, and ground water withdrawals greatly increased. By 1945 water levels in some areas had declined as much as 70 feet below sea level. In the coastal region this heavy withdrawal and the ensuing dry years rapidly lowered the ground water levels, reversing the normal seaward flow of the underground water to a landward flow.

In 1940 a definite increase in the salinity of the ground water was noticed at the Manhattan Beach municipal well field. The salinity increased over the years until most of the original wells of the field had to be abandoned. In 1947 Poland, Garrett, and others (1959) made studies of the contamination of the ground water in the Manhattan Beach area and concluded that the contaminating agent was most likely ocean water.

The State of California with its many coastal basins has been most conscious of the value of its ground-water supplies. The possibility of sea-water encroachment into these underground reservoirs has been recognized, and means to prevent it have been and still are being sought. In 1950 the California State Legislature appropriated \$750,000 for the experimental work connected with the study of this problem. The Manhattan Beach area was selected as the site for experiments to study the feasibility of creating a fresh-water barrier close to the coast to prevent sea-water encroachment. The work of this project was carried out by the Los Angeles County Flood Control District under contract with the State Water Resources Board and under the supervision of the California Division of Water Resources.

The study involved the injection of Colorado River water from the Metropolitan Water District into a line of wells roughly parallel to the coast and tapping only the main confined aquifer, thereby building up a "pressure ridge". In the course of this work, nine 12-inch injection wells and thirty-six 8-inch observation wells were drilled. Figure 1 is a map of the area showing the location of the wells.

As a part of this investigation, 166 samples of the ground water were obtained from the wells prior to the injection of the fresh water and were analyzed by the U. S. Geological Survey. In addition, as each well was developed chloride, conductance, and density determinations were made in the field by the Los Angeles County Flood Control District. Many analyses of water from the Manhattan Beach municipal wells also were available. Table 1 presents the analyses of the ground water of the area and selected analyses of ocean water and oil-field brines.

- LEGEND
- 12" Injection well
 - 8" Observation well
 - Manhattan Beach Municipal well
 - △ 2" Test hole

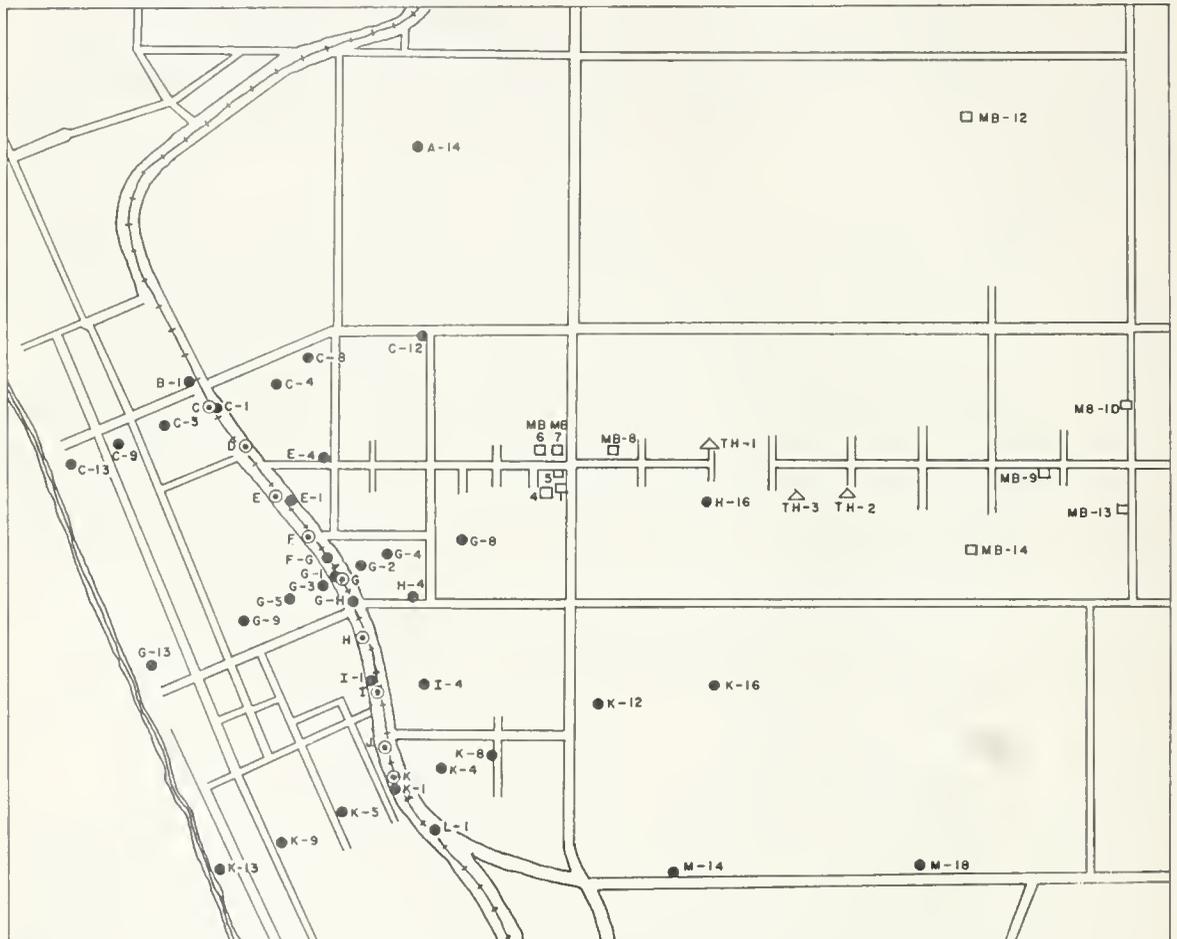
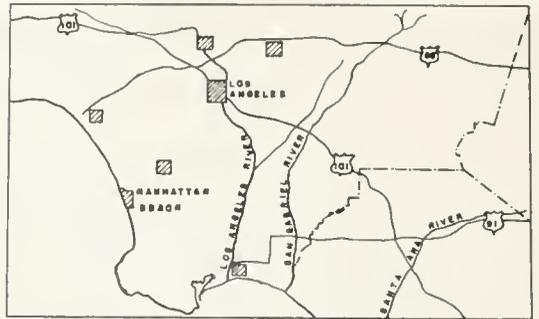


Figure 1 -- Location of wells in the Manhattan Beach Project, Manhattan Beach, California

Table 1 — Mineral constituents and related physical measurements of the ground water of the Silverado water-bearing zone in the Manhattan Beach area, selected samples of oil field brines, and ocean water, California.

Well number	Date	Well Depth (in feet)	Sampling Depth (in feet)	Temperature (°F)	Silica (SiO ₂) (Mn)	Magnesia (Mg)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Bromide (Br)	Iodide (I)	Nitrate (NO ₃)	Nitrite (NO ₂)	Iron (Fe)	Hardness (CaCO ₃)		Specific conductance (micro-mhos at 25°C)		
																				Sum	Calcium		Magnesium	Percent
A-1	1-29-53	3402 P	206	72	27	0.33	58	114	97	4.8	114	27	195	0.1	1.0	—	0.04	32	0.12	—	235	117	17	1,100
"	"	6420 P	206	72	30	0.08	295	150	673	16	350	222	1,600	1.1	5.2	—	0.01	39	0.25	—	1,200	117	17	1,100
"	"	9420 P	206	72	30	0.04	352	154	780	20	350	268	1,930	1.1	6.9	—	0.02	39	0.25	—	1,200	117	17	1,100
"	1-30-53	12120 A	206	72	29	0.50	364	129	780	20	356	268	1,930	1.1	7.0	—	0.02	39	0.25	—	1,200	117	17	1,100
"	"	11106 A	223	71	26	1.5	1,160	440	2,980	62	187	982	7,110	2	25	—	0.95	24	1.17	—	4,770	58	54	20,300
"	"	11115 A	202	71.5	30	0.00	60	112	109	4.8	112	27	210	1.1	1.5	—	0.02	33	0.10	—	236	120	17	1,040
"	"	11119 A	184	71.5	26	0.00	52	122	109	4.8	122	27	210	1.1	1.8	—	0.02	33	0.25	—	208	108	17	941
B-1	1-12-53	9412 A	197	68	6.7	410	1,080	9,040	313	413	121	2,400	16,700	6	56	—	0.00	7.4	1.1	—	5,160	77	144,000	
"	"	2430 P	197	70	25	1.0	719	994	7,870	255	151	2,200	15,100	6	48	—	0.00	7.4	1.1	—	5,160	77	144,000	
"	"	2415 P	180	68.5	21	0.53	422	1,190	9,770	342	124	2,550	17,900	4	67	—	0.00	5.4	0.71	—	5,810	77	165,000	
"	"	2450 P	266	71.5	27	1.0	1,310	661	4,940	116	177	1,450	10,500	4	42	—	0.00	9.5	0.58	—	5,990	61	28,800	
C-13	2-2-53	2-20 P	93	—	0.7	335	1,160	9,820	354	65	65	2,450	17,600	9	60	—	0.01	17	2.8	—	31,800	5,610	78	151,200
C-9	12-18-52	9412 A	305	65	11	1.2	310	1,350	10,100	477	124	2,590	18,300	1.4	60	—	1.0	11	3.5	—	33,200	6,350	76	17,800
"	"	11145 A	113	66	12	0.1	338	1,360	10,100	477	125	2,590	18,300	1.2	61	—	1.0	13	3.4	—	33,300	6,440	76	17,500
"	"	12100 N	195	66	13	0.64	456	1,310	9,810	441	130	2,560	18,200	1.2	62	—	1.0	13	3.3	—	33,300	6,420	75	17,300
"	"	12110 P	117	66	9.8	0.00	314	1,330	10,100	499	125	2,590	18,400	1.1	60	—	1.0	15	3.1	—	33,300	6,250	75	17,400
C-5	1-5-53	9412 A	297	66.5	10	0.16	388	1,230	10,200	468	123	2,560	18,500	1.6	64	—	0.02	7.5	4.2	—	33,500	6,020	77	16,400
"	"	11137 A	129	67	14	0.37	384	1,230	10,400	463	124	2,560	18,500	1.6	60	—	0.03	7.2	3.8	—	33,700	5,920	77	15,100
"	"	11147 A	117	67	20	0.16	403	1,150	9,480	420	124	2,420	17,400	1.6	60	—	0.03	7.2	4.3	—	33,700	6,120	77	16,300
"	"	11147 A	116	68	15	1.6	410	1,240	10,400	452	118	2,560	18,600	1.5	59	—	0.00	8.7	4.5	—	33,600	6,020	77	16,300
"	"	11154 A	178	69.5	14.8	0.15	381	1,230	10,400	452	118	2,570	18,500	1.5	59	—	0.00	8.7	4.5	—	33,600	6,020	77	16,300
C-1	6-11-52	—	381	69	18	—	397	1,310	10,200	471	124	2,600	19,300	5	66	—	1.0	—	3.6	—	34,400	6,380	76	18,400
C	12-15-52	8456 A	228	69	18	0.57	412	1,300	9,340	330	120	2,460	17,400	3	61	—	1.0	17	3.8	—	31,300	6,370	75	15,600
"	"	9410 P	180	69	26	0.86	338	1,360	10,100	435	120	2,600	18,500	3	62	—	1.0	13	3.4	—	33,400	6,440	76	17,800
"	"	9412 P	180	68	15	0.13	392	1,220	9,610	389	124	2,500	17,800	5	63	—	0.09	8.8	8.8	—	32,000	6,000	76	16,900
"	"	12120 P	176	68	19	0.21	407	1,230	9,610	389	122	2,510	17,900	5	64	—	0.08	11	3.2	—	32,200	6,070	76	16,900
"	"	12125 P	186	68	18	0.39	388	1,240	9,800	389	122	2,530	18,100	5	63	—	0.01	7.8	3.1	—	32,500	6,070	76	17,200
"	"	12130 P	197	69	19	0.25	393	1,230	9,810	389	124	2,530	17,900	5	64	—	0.01	7.8	3.1	—	32,300	6,040	77	17,400
C-4	6-5-52	—	281	71	19	—	793	1,000	7,270	112	121	2,000	13,300	0	50	—	0.00	14	4.2	—	25,600	6,090	72	36,400
"	"	1412 P	206	71	1.9	798	1,050	8,120	110	138	114	2,130	15,700	0	53	—	0.00	14	4.2	—	26,000	6,310	73	40,900
"	"	3435 P	213	71.5	22	2.2	734	1,080	8,340	142	114	2,220	16,200	3	54	—	0.00	18	4.0	—	28,800	6,270	74	42,400
"	"	3440 P	189	70.5	19	3.9	646	892	6,710	79	110	1,760	12,800	3	42	—	0.11	15	3.5	—	23,000	5,280	73	34,200
C-8	5-28-52	—	387	72	19	—	829	964	6,840	79	158	1,820	13,300	0	51	—	1.0	—	2.9	—	23,900	6,030	71	35,400
"	"	1432 P	276	70	14	1.5	702	711	5,560	71	131	1,540	11,000	2	35	—	7.33	20	1.8	—	19,700	4,800	71	30,100
"	"	3418 P	276	71	18	1.9	844	954	7,420	97	154	2,000	14,400	3	47	—	7.33	22	2.4	—	25,800	6,030	72	38,000
"	"	3428 P	231	71	23	0.02	35	17	115	4.1	122	51	241	1	1.0	—	0.09	50	0.40	—	656	158	70	1,270
C-12	6-18-52	—	315	74	24	—	739	301	1,390	36	160	535	4,000	0	18	—	10	18	0.70	—	7,120	3,080	49	12,200
"	"	9412 A	211	73	19	0.83	1,060	395	1,850	35	166	743	5,330	2	24	—	10	14	0.44	—	9,530	4,270	48	15,700
"	"	1448 F	219	73.5	28	1.0	1,475	513	2,230	60	223	905	6,840	1	29	—	10	9.9	9.9	—	12,200	5,790	45	19,200
"	"	1453 P	204	73	20	0.77	1,000	350	1,700	35	208	653	4,810	2	17	—	0.07	31	1.1	—	8,710	3,930	48	14,300
"	"	1459 P	179	73.5	12	0.02	29	17	119	4.2	88	48	222	2	1.1	—	0.07	31	1.1	—	556	142	70	1,110
"	"	8416 A	254	68	26	3.1	333	1,300	9,800	435	133	2,550	18,100	3	60	—	1.0	20	3.6	—	32,600	6,180	76	17,100
"	"	6420 P	232	69	26	3.3	338	1,310	9,810	425	131	2,550	18,200	3	61	—	1.0	16	3.4	—	32,800	6,350	76	17,000
"	"	6425 P	232	68	26	3.2	358	1,320	9,800	435	131	2,550	18,100	3	59	—	1.0	14	4.0	—	32,700	6,320	76	17,000
"	"	1422 P	186	70	17	0.83	388	1,260	10,200	426	118	2,610	18,600	3	63	—	0.01	14	2.5	—	33,500	6,150	76	18,100
"	"	3400 P	186	69.5	20	1.3	415	1,250	10,200	436	127	2,660	18,600	3	61	—	0.06	17	2.8	—	33,700	6,180	77	18,400
"	"	3404 P	208	70	22	2.5	447	1,200	9,640	394	130	2,540	17,800	3	62	—	0.06	17	2.3	—	32,100	6,050	76	16,500
E-1	7-29-52	—	233	70	12	—	668	1,130	8,450	275	126	2,270	16,500	1	57	—	1.0	—	3.8	—	29,400	6,310	73	43,300
E	12-5-52	1411 P	239	69	27	1.5	350	998	7,240	201	148	1,890	13,400	3	46	—	1.0	19	2.5	—	24,200	4,960	75	36,000
"	"	6430 P	170	69.5	28	2.5	468	1,010	7,440	210	148	1,860	13,000	3	48	—	1.0	20	2.5	—	25,200	5,320	74	37,500
"	"	9437 A	170	68	25	0.02	431	1,000	7,530	267	146	2,000	14,000	2	4									

Table 1 --- Mineral constituents and related physical measurements of the ground water of the Silverado water-bearing zone in the Manhattan Beach area, selected samples of oil field brines, and ocean water, California.---Cont'd

Well No.	Casing	Depth (feet)	Temperature (°C)	Salinity (‰)	Wardner (‰)	Calcium (ppm)	Magnesium (ppm)	Sulfate (ppm)	Chloride (ppm)	Fluoride (ppm)	Bromide (ppm)	Iodide (ppm)	Nitrate (ppm)	Nitrite (ppm)	Boron (ppm)	Horncastle (ppm)		Specific Conductance (micro-mhos/cm at 25°C)		
																Calcium	Magnesium			
F	2-7-55	294	69	22	1.36	452	1,200	9,810	17,900	0.1	55	---	0.01	15	3.0	32,500	6,100	6,000	76	46,800
"	12-10-55	211	65	25	1.65	461	1,200	9,650	17,600	0.2	58	---	0.02	16	3.1	32,200	5,980	5,980	76	46,500
"	3-25-55	211	69	24	1.25	460	1,200	9,960	17,900	0.2	58	---	0.03	17	2.8	32,000	6,080	6,080	77	46,500
"	8-27-55	177	69	24	1.11	460	1,200	9,640	17,900	0.3	56	---	0.03	17	3.1	33,000	6,000	6,010	76	47,000
"	12-15-55	202	69	25	1.96	402	1,110	9,800	16,500	0.2	52	---	0.02	16	2.7	30,200	5,800	5,700	75	44,000
"	12-15-55	303	65	21	2.69	568	1,310	9,090	16,500	0.2	52	---	0.02	16	2.7	30,200	5,800	5,700	75	44,000
G	2-9-53	167	71	20	6.6	635	1,070	8,700	15,600	0.3	45	---	0.03	20	2.0	28,100	5,980	5,880	76	40,700
"	3-31-53	154	70	19	6.4	625	1,080	8,690	15,600	0.3	45	---	0.03	20	2.1	28,100	6,000	5,880	76	41,500
"	3-19-53	172	70	21	5.6	635	1,080	8,460	15,700	0.3	47	---	0.02	20	2.1	28,300	6,030	5,900	75	41,900
"	3-19-53	192	70	20	6.5	644	1,070	8,460	15,500	0.3	46	---	0.03	20	2.1	28,300	6,010	5,900	75	40,700
G	11-20-52	119	67	11	0.2	383	1,250	9,480	17,500	1.4	60	1.0	---	15	3.9	31,500	6,100	6,000	76	46,300
"	11-18-52	117	67	11	0.2	383	1,300	10,100	18,300	1.4	60	1.0	---	13	3.0	33,200	6,370	6,270	76	47,900
"	11-13-52	130	67	11	0.3	392	1,310	10,100	18,300	1.4	60	1.0	---	16	3.0	33,200	6,360	6,260	75	47,700
G	12-9-52	254	68	11	0.25	286	1,000	7,340	13,600	0.5	50	1.0	---	28	2.7	24,600	4,830	4,740	75	37,100
"	3-10-52	254	69	11	1.7	431	1,340	10,300	18,400	0.5	61	1.0	---	11	3.2	33,500	6,590	6,490	76	47,800
G	9-20-52	241	69	11	0.22	161	1,340	10,100	18,400	0.4	65	1.0	---	31	2.8	33,200	6,660	6,560	76	47,700
"	2-16-52	185	69.5	27	3.3	538	1,260	9,410	17,100	0.5	63	1.0	---	30	2.7	30,800	6,500	6,390	75	44,500
"	2-18-52	197	70	28	3.7	598	1,250	9,180	17,000	0.5	63	1.0	---	16	3.0	30,800	6,430	6,320	75	44,500
"	2-18-52	185	69.5	33	0.5	441	1,340	10,300	18,400	0.5	66	1.0	---	33	3.0	33,400	6,610	6,510	77	47,900
G	9-12-52	184	70	19	6.0	598	1,130	9,220	16,500	0.3	58	---	0.04	22	2.1	30,000	6,110	6,020	76	42,700
"	12-11-52	180	70.5	22	4.9	570	1,130	9,210	16,500	0.3	63	---	0.06	22	2.8	30,000	6,160	6,110	76	42,700
"	12-11-52	180	71	21	6.1	602	1,120	9,210	16,500	0.3	67	---	0.02	26	3.0	29,800	6,110	5,990	76	42,700
G	8-5-53	193	69	20	6.5	627	1,030	8,240	15,300	0.3	59	---	0.11	12	2.6	27,500	5,680	5,680	75	40,100
"	11-13-53	205	70	22	6.0	617	1,040	8,240	15,300	0.3	58	---	0.09	12	2.6	27,700	5,820	5,820	75	40,700
"	11-17-53	161	70	21	2.8	567	1,100	8,700	16,000	0.2	57	---	0.02	11	2.9	28,900	5,940	5,940	75	40,300
"	11-17-53	161	70	20	1.8	825	1,131	3,290	7,120	0.1	28	---	0.20	29	1.2	12,800	3,630	3,730	65	26,400
G	8-15-52	304	72	25	3.3	709	1,030	7,780	14,900	0.3	55	1.0	---	16	2.8	26,700	6,000	5,900	73	39,800
"	8-5-53	234	71.5	25	3.3	515	1,220	9,500	17,900	0.3	64	---	0.16	11	3.1	32,200	6,230	6,230	76	46,900
"	11-13-52	205	71.5	25	3.3	535	1,210	10,100	18,300	0.3	63	---	0.11	11	3.2	33,000	6,310	6,310	76	47,000
"	11-13-52	218	71.5	25	4.4	653	1,010	8,010	15,100	0.2	51	---	0.02	22	2.8	27,100	5,780	5,680	75	40,300
"	11-15-52	175	71.5	27	0.35	111	1,15	258	5,522	0.1	3.0	---	0.02	18	1.60	1,190	162	320	51	2,230
G	8-10-52	206	72.5	26	2.5	450	1,243	1,250	3,000	0.0	12	1.0	---	11	1.78	5,190	2,120	2,020	56	9,390
"	11-20-52	206	71	27	2.2	38	12	70	130	0.1	6	---	---	52	0.60	416	1,111	1,62	53	171
"	10-00-52	296	71	27	1.1	320	161	666	2,500	0.1	7.1	---	---	71	0.38	4,120	1,510	1,660	57	7,100
"	11-21-52	296	71	27	1.1	320	161	666	2,500	0.1	7.1	---	---	52	0.38	4,120	1,510	1,660	57	7,100
"	11-21-52	296	71	27	1.1	320	161	666	2,500	0.1	7.1	---	---	52	0.38	4,120	1,510	1,660	57	7,100
"	11-23-52	296	71	27	2.0	338	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
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"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
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"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900
"	11-23-52	296	72.5	27	2.4	608	1,030	3,400	7,200	0.1	13	---	---	58	0.40	4,680	2,660	2,660	60	12,900

Table 1 — Mineral constituents and related physical measurements of the ground water of the Silverado water-bearing zone in the Manhattan Beach area, selected samples of oil field brines, and ocean water, California.—Cont'd.

(Analytical results in parts per million except as indicated)

Well Number	Date	Time	Well Depth	Sampling Depth	Temperature of	Silica (SiO ₂)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Bromide (Br)	Iodide (I)	Nitrite (NO ₂)	Nitrate (NO ₃)	Iron (Fe)	Hardness (as CaCO ₃)			Specific Conductance (micro-mhos at 25°C)		
																					Sum	Calcium	Non-Calcium			
1-1	7-7-52		266	207	73	21	--	892	1,200	8,830	90	132	2,400	17,400	0.0	63	1.0	--	--	3.2	30,900	7,160	7,050	73	14,700	7.3
1	2-4-53	9:50 A	267	224	70	21	5.11	588	1,140	8,680	162	138	2,350	16,600	.3	54	--	0.01	1.3	2.7	29,600	6,150	6,040	75	13,600	6.9
"	"	12:30 P	"	224	70.5	22	3.90	615	1,100	8,450	178	138	2,370	16,200	.1	52	--	.01	1.3	2.6	28,900	6,020	5,900	75	12,700	7.0
"	"	5:00 P	"	224	69	23	5.85	642	1,090	8,310	168	140	2,290	16,100	.1	52	--	.00	8.1	2.6	28,700	6,050	5,930	74	12,500	7.1
1-4	7-3-52		314	285	73	22	--	1,090	836	5,930	85	140	1,630	12,300	.1	48	1.0	--	2.4	--	22,000	6,160	6,040	67	32,000	7.2
"	1-19-53	9:57 A	"	219	70.5	25	6.3	1,140	917	6,900	105	142	1,910	11,500	.2	47	--	.00	17	3.5	25,400	6,520	6,500	69	37,200	7.1
"	"	2:11 P	"	209	72	25	5.0	1,010	780	5,930	83	158	1,600	11,500	.2	39	--	.29	22	3.2	21,100	5,730	5,600	69	31,900	7.3
"	"	2:40 P	"	186	72	28	1.13	274	82	395	14	168	157	1,100	.2	3.8	--	.15	36	1.5	2,170	1,020	883	45	3,910	7.5
"	"	2:42 P	"	265	73.5	23	4.1	1,130	933	7,090	108	144	1,930	14,100	.3	48	--	.00	18	3.8	25,700	6,560	6,510	69	37,100	7.2
"	"	2:43 P	"	285	72	22	6.1	1,130	932	6,910	102	138	1,970	14,100	.2	48	--	.00	1.3	2.0	25,200	6,550	6,510	69	37,100	7.0
J	1-24-53	9:05 A	252	224	71	23	1.7	544	1,010	8,110	234	142	2,080	14,900	.2	56	--	.02	10	2.7	27,000	5,510	5,390	75	10,000	7.2
"	"	1:02 P	"	224	71	24	1.8	517	1,030	8,110	234	144	2,080	15,000	.2	56	--	.01	12	2.6	27,100	5,520	5,410	75	10,100	7.2
"	2-2-53	1:57 P	"	179	71	12	.96	470	1,160	9,210	303	144	2,380	16,800	.2	66	--	.02	8.5	3.2	30,400	5,940	5,950	76	11,400	7.1
"	"	3:30 P	"	189	71.5	22	2.2	571	1,020	7,980	218	144	2,050	14,700	.2	66	--	.03	10	2.7	26,700	5,620	5,500	75	39,100	7.3
"	"	3:37 P	"	156	71	22	.61	475	1,200	9,200	319	126	2,420	17,300	.2	66	--	.10	10	3.2	31,000	6,120	6,020	75	14,900	7.3
K-9	12-15-52	9:17 A	295	115	66	13	.04	1.0	2.4	200	9.2	248	117	88	1.8	.4	1.0	--	1.1	.30	556	12	0	95	946	8.2
"	"	3:47 P	"	126	67	11	.00	304	1,280	9,660	461	130	2,620	17,900	1.4	65	1.0	--	1.3	3.3	32,300	6,020	5,920	76	15,900	7.2
"	"	3:53 P	"	99	67	13	.03	3.0	5.7	345	16	251	142	332	1.8	1.8	1.0	--	.6	.39	984	31	0	94	2,590	8.2
K-5	11-18-52	12:52 P	212	121	70.5	22	1.5	423	1,180	8,930	275	164	2,290	16,000	.3	49	1.0	--	15	3.0	29,100	5,910	5,770	75	12,900	7.3
"	"	3:17 P	"	125	70	24	1.0	426	1,330	9,800	373	155	2,590	18,300	.3	59	1.0	--	12	3.2	32,900	6,530	6,400	75	17,700	7.5
"	"	3:30 P	"	112	70	21	1.9	374	1,140	8,690	270	171	2,300	15,900	.3	52	1.0	--	13	3.2	28,800	5,620	5,480	76	12,200	7.1
K-1	6-13-52		432	197	73	25	--	1,080	738	5,390	65	180	1,480	10,800	.0	40	1.0	--	1.0	1.0	19,800	5,730	5,580	67	29,600	7.6
Z	1-12-53	9:27 A	329	294	71.5	25	5.2	1,190	753	6,130	65	188	1,750	12,400	.2	45	--	.05	--	1.5	22,400	6,070	5,910	68	33,300	7.3
"	"	12:45 P	"	294	71.5	26	4.1	1,010	676	5,210	55	194	1,500	10,600	.2	35	--	.06	19	1.4	19,200	5,300	5,210	68	29,200	7.3
"	"	4:15 P	"	294	72	27	3.8	986	618	4,880	54	198	1,390	9,910	.2	35	--	.09	16	1.3	18,000	5,000	4,810	68	27,500	7.3
K-4	6-6-52		256	213	72	25	--	688	1,130	8,600	110	144	2,190	15,700	.0	58	1.0	--	3.2	28,600	6,360	6,240	74	13,700	7.5	
"	1-20-53	9:22 A	"	198	70	24	4.3	734	8,220	142	75	2,210	16,200	.2	56	--	.00	17	1.5	28,600	6,230	6,170	74	12,300	6.8	
"	"	11:00 A	"	206	72	24	4.8	656	1,110	8,960	155	141	2,270	16,800	.3	57	--	.00	17	1.1	30,100	6,090	6,090	75	13,500	7.2
"	"	11:11 A	"	187	71.5	19	4.8	765	845	6,520	79	138	1,730	12,600	.3	42	--	.00	1.3	3.3	22,500	5,380	5,270	72	34,000	7.2
K-6	6-20-52		356	254	73	24	--	1,010	826	6,320	77	157	1,720	12,500	.0	46	1.0	--	2.1	22,600	5,920	5,790	70	34,000	7.1	
"	"	9:37 A	"	266	72.5	23	3.3	927	948	7,120	91	131	1,900	13,800	.2	45	1.0	--	1.2	1.7	24,900	6,210	6,100	71	36,100	7.0
"	"	1:04 P	"	253	73	27	3.5	949	849	6,460	86	156	1,750	12,500	.2	40	1.0	--	1.8	1.5	22,700	5,860	5,730	70	33,500	7.2
K-12	6-16-52		430	311	75	25	--	885	302	966	32	179	428	3,400	.1	36	1.0	--	24	.53	6,150	3,450	3,300	38	10,600	7.6
"	12-10-52	9:17 A	"	302	72	30	.2	40	16	74	4.7	136	31	107	.3	2.1	1.0	--	45	1.0	115	166	54	48	736	7.6
"	"	2:35 P	"	311	73.5	28	1.5	1,310	403	1,520	44	134	673	5,230	.1	21	1.0	--	17	.32	9,320	4,930	4,780	40	15,000	7.3
"	"	2:42 P	"	282	72.5	29	.2	40	16	74	4.7	134	35	109	.3	.8	1.0	--	15	.09	419	166	54	48	743	7.1
K-17	12-5-52	9:07 A	470	266	70	23	.2	56	20	71	5.5	213	51	107	.2	1.7	1.0	--	9.8	.09	448	222	47	40	911	7.5
"	"	3:31 P	"	306	73.5	19	1.1	98	36	116	7.1	209	71	300	.2	2.2	1.0	--	7	.06	751	392	221	39	1,440	7.7
"	"	3:39 P	"	256	73	29	.2	544	177	500	23	223	230	1,980	.1	1.7	1.0	--	11	.09	3,600	2,080	1,900	34	6,330	7.5
L-1	11-21-52	9:17 A	377	128	69.5	15	1.7	311	852	6,430	101	173	1,670	11,600	.4	44	1.0	--	3.3	1.8	21,100	4,330	4,190	76	31,400	7.5
"	"	12:03 P	"	128	71	16	2.0	515	1,260	9,620	126	131	2,460	17,200	.5	61	1.0	--	26	2.6	31,300	6,360	6,240	76	14,700	7.2
"	"	12:30 P	"	226	72	16	1.7	500	1,250	9,620	145	130	2,430	17,100	.5	62	1.0	--	26	2.7	31,200	6,390	6,280	76	14,900	7.2
M-11	7-10-52		535	265	74	27	--	280	89	448	17	213	163	1,220	.1	5.0	1.0	--	4.7	.18	2,320	1,060	890	46	4,370	7.4
"	12-4-52	10:02 A	"	271	72	25	.7	404	121	469	20	204	201	1,560	.1	7.1	1.0	--	7.9	.13	2,610	1,510	1,340	40	4,270	7.5
"	"	1:11 P	"	309	74	13	.5	329	117	449	20	104	161	1,460	.1	5.4	1.0	--	8.3	.11	1,900	1,220	1,120	42	4,660	7.1
"	"	1:45 P	"	285	73	30	.7	377	144	492	20	206	201	1,500	.1	5.7	1.0	--	8.6	.14	2,810	1,410	1,220	42	4,180	7.6
"	"	2:10	"	235	73	26	.6	344	106	456	16	190	198	1,360	.1	5.0	1.0	--	9.2	.13	2,630	1,290	1,210	43	4,860	7.4
M-18	12-22-52	9:22 A	498	212	70.5	27	.10	443	39	116	7.9															

Table 1 -- Mineral constituents and related physical measurements of the ground water of the Silverado water-bearing zone in the Manhattan Beach area, selected samples of oil field brines, and ocean water, California.--Cont'd.

Well Number	Date	Time	Well Depth (in feet)	Sampling Depth (in feet)	Temperature of	Silica (SiO ₂) (M)	Magnesia (Mg)	Calcium (Ca)	Magnesium (Mg)	Sulfate (SO ₄) (S)	Chloride (Cl) (F)	Fluoride (F)	Bromide (Br)	Iodide (I)	Nitrate (NO ₃) (N)	Nitrite (NO ₂) (N)	Boron (B)	Hardness (CaCO ₃)			Specific conductance (micro-mhos of 25°C)
																		Sum	Calcium	Non-carbonate magnesium	
MANHATTAN BEACH MUNICIPAL WELL 8																					
a 10-20-38			Est. 350					55		262	67										
b 3-21-44							20 b	57		252	111									220	
c 6-15-44					36		19 b	73		220	172									240	
d 9-25-44					36		26 b	86		212	212									278	
e 10-29-44					30		86	112		212	212									329	
f 3-9-48					25		77 b	95		210	303									715	
g 1-3-49					28		77 b	164		261	644									908	
h 2-15-49					19		72 b	217		249	760									1,590	
i 5-27-52					25		70 b	187		231	829									1,002	
j 1-2-53					74		177	198		208	1,150									1,450	
					74		218	313		208	1,520									1,650	
					22		0.39													1,280	
								197												1,680	
PACIFIC OCEAN WATER, NORTH DRAKES BAY, MARTIN COUNTY																					
								383		136	2,950									6,110	
								1,260		10,400	18,600									6,920	
CONNATE WATERS FROM THE ROSEGRANS OIL FIELD																					
d 4-24-44			4,946				151 b	11,150		208	6.1									2,117	
e 4-29-40							112	8,682		3,532	1									2,122	
CONNATE WATER FROM THE TORRANCE OIL FIELD																					
a 4-10-21			3,514				202 b	11,052		632	18									2,360	
GROUND WATER FROM WELLS BETWEEN MANHATTAN BEACH AND ROSEGRANS OIL FIELD																					
a 10-1-45			527				15 b	65		306	2.4									169	
a 9-17-45			710				50	53		250	41									187	
a 4-23-45			397				51	45		224	58									189	
GROUND WATER FROM WELLS BETWEEN MANHATTAN BEACH AND TORRANCE OIL FIELD																					
f 1-4-45			449				16 b	59		219	44									206	
g 10-21-44			260				b 18			262	50									142	

a Analyses by Smith-Energy Co.
 b Calculated.
 c Analyses by Carl Wilson Chemical and Biological Laboratories.
 d Analyses by Union Oil Co.
 e Includes equivalent of 116 parts per million of carbonate (CO₃).
 f Analyses by California Water Service.

From geologic and hydrologic evidence it was concluded by Poland and others (1959) that ocean water was encroaching into the water-bearing zone in the Manhattan Beach area, and model studies have been made at the University of California, Experimental Station, Richmond, California, which show that the encroaching water probably enters the zone in the shape of a wedge. It is the purpose of this report to review the chemical-quality data obtained in the Manhattan Beach area and to determine whether these data lend support to these conclusions.

ACKNOWLEDGMENTS

The study described in this report was made by the United States Geological Survey at the request of and in cooperation with the California State Department of Water Resources. It was under the supervision of I. W. Walling, District Chemist, Sacramento, California.

Water samples analyzed by the U.S. Geological Survey were collected by personnel of the California State Department of Water Resources and Los Angeles County Flood Control District.

Density, conductance, and chloride data made in the field by the Los Angeles County Flood Control District and well logs were supplied by the California State Department of Water Resources.

DESCRIPTION OF THE AREA

The hydrologic data for this section of the report as well as Figure 5 have been abstracted from the report by Poland (1959) on this area.

The Manhattan Beach area discussed in this report lies within the West Basin in Los Angeles County. The principal aquifer, known as the

Silverado water-bearing zone, is composed of sandy and gravelly phases of beach and marine deposits of Pleistocene age. Except in the reaches adjacent to the present shoreline, this aquifer is confined under artesian pressure in the Manhattan Beach area. The confining bed consists of clay on top of the aquifer. The aquifer also is underlain by clay. The Silverado zone is said to be "merged" in this area because the several distinct aquifers present in the zone inland have converged to form a single aquifer in hydrologic continuity with the inland aquifers. Figures 2, 3, and 4 show the extent of the Silverado zone in the report area.

Recharge of fresh water into this aquifer comes mainly from the intake areas inland from the Newport-Inglewood uplift, but some local penetration of rainfall also recharges the aquifer.

The Newport-Inglewood fault zone, which forms the eastern edge of the West Basin, acts as a partial barrier to fresh-water recharge to the aquifer. Lowering the piezometric surface west of the faults will increase the flow across the faults, and conversely, lowering the piezometric surface east of the faults will reduce the recharge to the West Basin.

At the time of Mendenhall's work the water level in the West Basin was above sea level and that east of the fault zone was still higher. The ground water flowed across this fault zone and discharged into the ocean. Figure 5 shows the water level for 1903-04 from the data of Mendenhall as modified by Poland. Since the time of Mendenhall's work, withdrawal of the ground water in the West Basin has increased, and the water level has declined as shown by the water level in the area for 1945 (Figure 5). The recharge of fresh water across the Newport-Inglewood

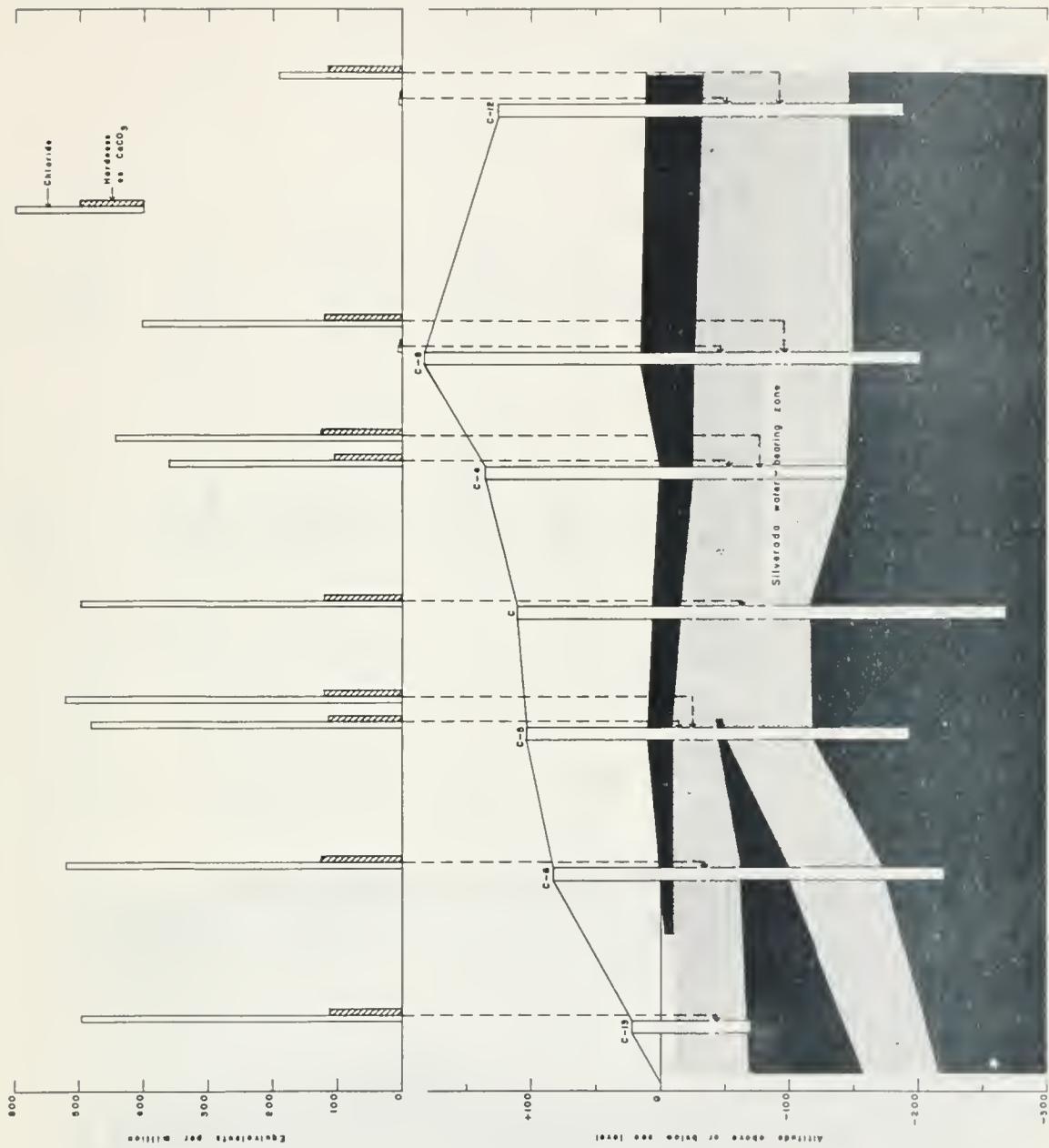


Figure 2 -- Geologic profile through the "C" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth

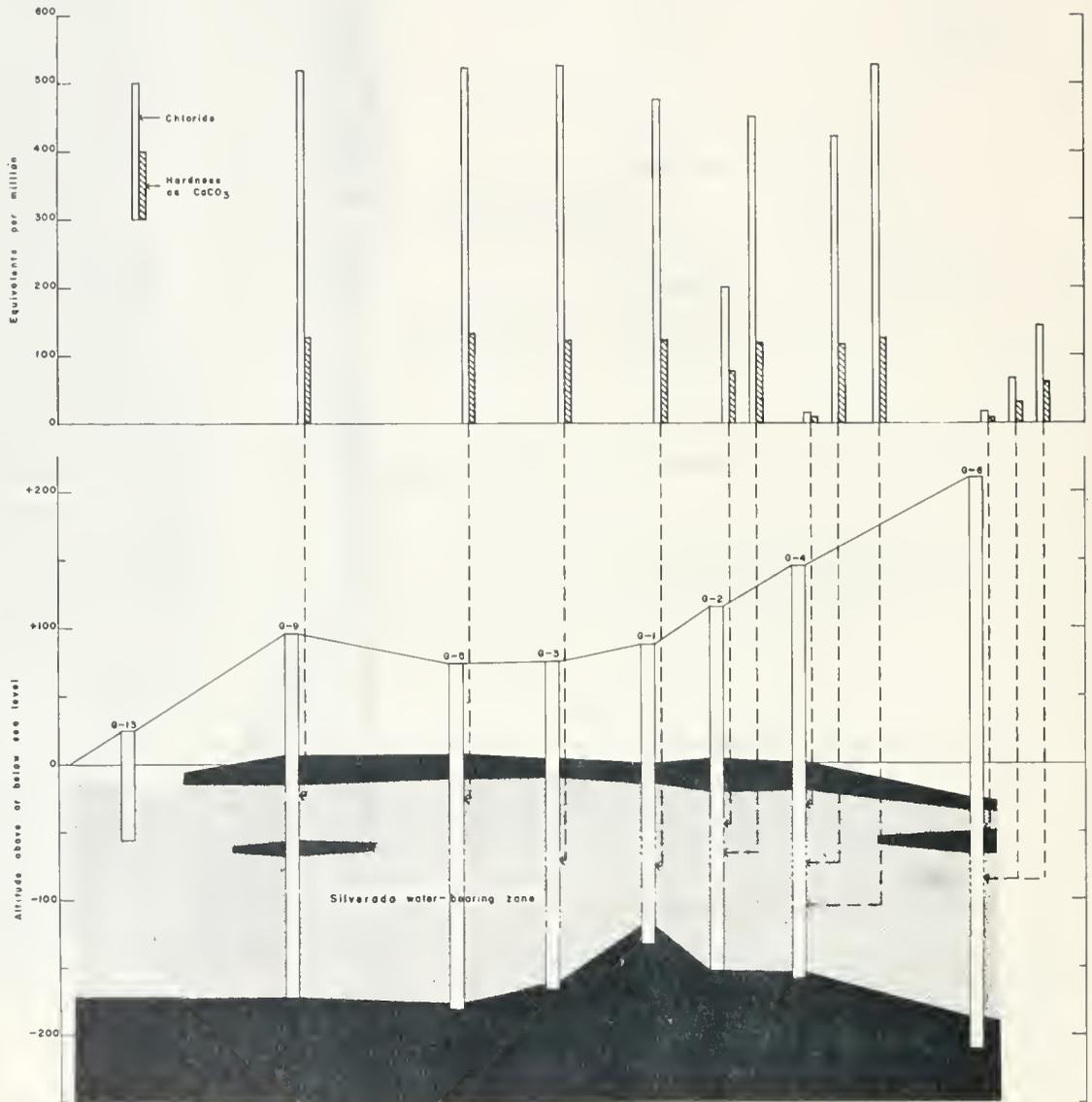


Figure 3--Geologic profile through the "G" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth

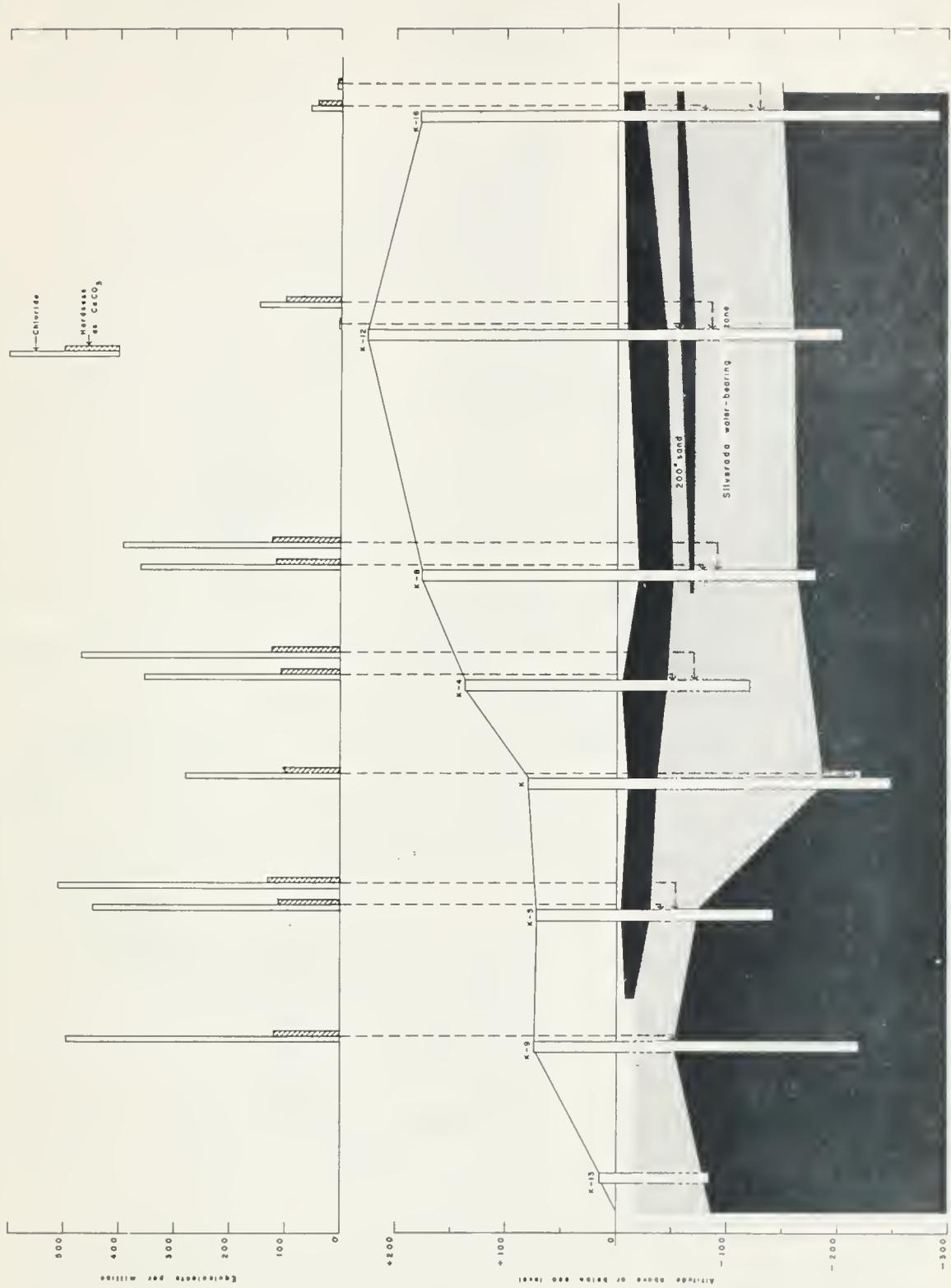


Figure 4--Geologic profile through the "K" line of wells showing the extent of the Silverado water-bearing zone and variation of chloride and total hardness with sampling depth

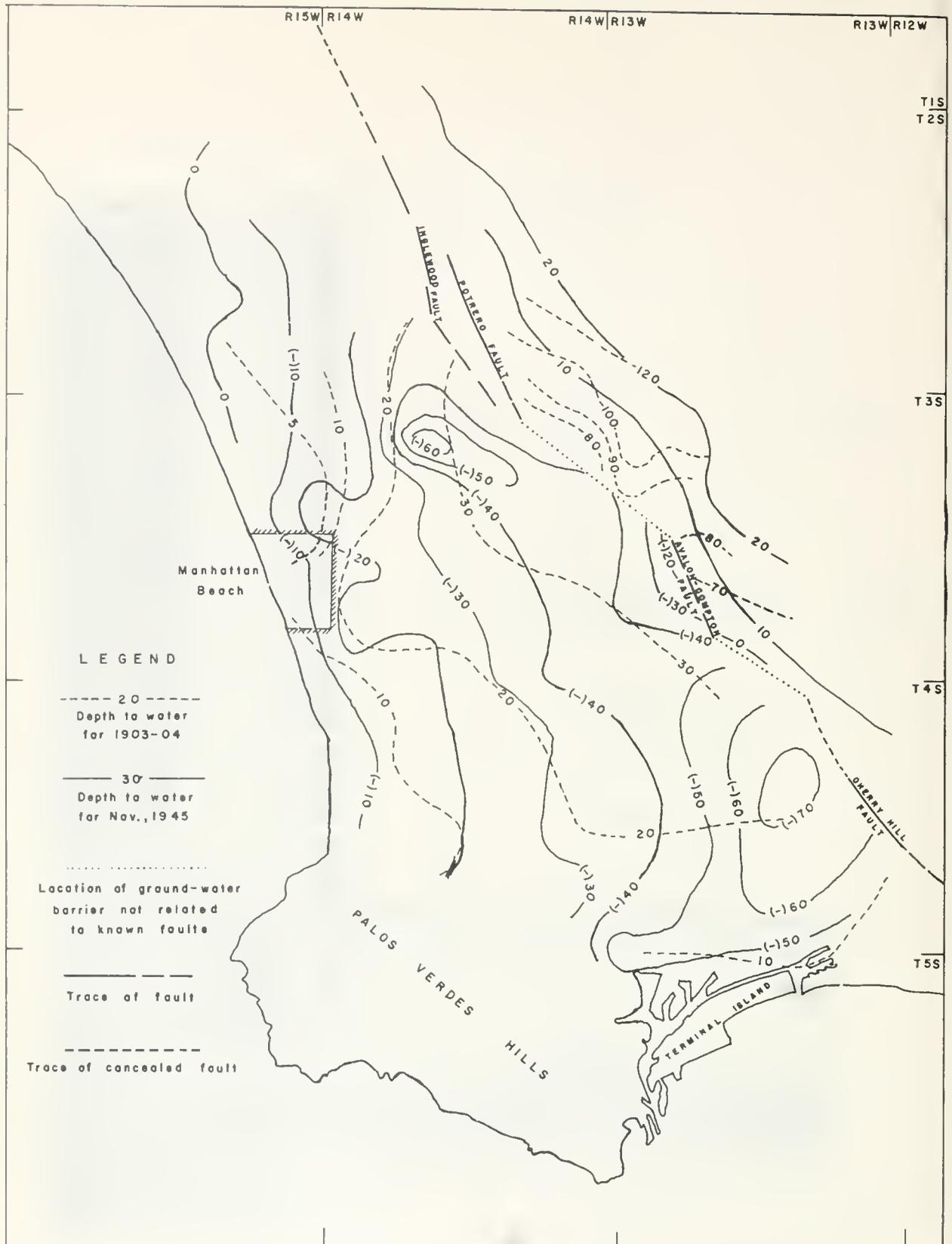


Figure 5 -- Depth to water for 1903-04 and 1945 in the Manhattan Beach Area, California

fault zone also has decreased, owing to the lowering of the water level inland from the faults. A depression in the piezometric surface has formed in the West Basin east of the Manhattan Beach area. This depression inland from the ocean has reversed the normal seaward gradient in the coastal area and allowed sea water to more inland.

CHEMICAL RELATIONS IN THE WATER

The earliest chemical-quality data available for the ground water in the Manhattan Beach area are from the Manhattan Beach municipal well field. These analyses show that the water as of 1938 was of the calcium and magnesium bicarbonate type. In this report the analysis of the water from the Manhattan Beach municipal well 8 for October 1938 is considered as water native to the Silverado water-bearing zone prior to the present saline contamination. The concentrations of the ions in this water are used in all calculations involving native water. It is not to be construed that the concentration of a single analysis adequately represents all the water of the aquifer; however, large errors will not be introduced by using a single analysis because, generally, the chemical quality of ground water at a selected sampling point does not undergo marked changes with time unless contaminated, and the total dissolved mineral concentration of the native water is very small compared to the saline contaminant in this area.

The word contamination is used in this report in the broad sense to cover deterioration in chemical character of the water without regard to concentration or source of the contamination. This broad usage should not be confused with the established usage of the word in the California Water Code (Water Code of 1949, Division 7, Chapter 2, Definitions).

Figure 6 is a trilinear plot of selected analyses of the ground water from the Manhattan Beach area. This plot shows the changes in chemical

character of the ground water in the area from 1938 to 1953 and also the change in character of the water coastward from the Manhattan Beach municipal well field. The principles involved and the procedures used in plotting the chemical character of waters on this type of plot have been described by Piper (1945).

Chemical data for the water of the municipal well field in 1938 plots just to the left of center in the central diamond of the figure, and later analyses of water from the same well plot away from the native water approximately in a straight line and toward the top of the diamond. The total dissolved mineral content of the water has increased and the percentage concentration of the ions expressed in equivalents per million has changed. Percentage changes in the cations of analyses 1 through 10 shown in the left-hand triangle have been small. The calcium and magnesium have increased by approximately 10 percent and the percent sodium has decreased by an equal amount. The anion percentages, as shown in the right-hand triangle, have undergone large changes. The bicarbonate-type water originally present has progressively changed to a chloride-type water. The sulfate percentage has remained relatively constant, producing a straight-line plot in the triangle. Plotting analyses of water from project wells closer to the ocean produces a new plot in the diamond. These analyses plot in a line along the edge of the diamond, descending downward from the apex to a point which represents essentially undiluted sea water. Generally, as the locations of the wells approach the ocean, the analyses of these well waters approach that of sea water.

No	Well	Date	ppm Cl
1	M-8	Oct 20, 1938	87
2	"	Mar. 31, 1944	111
3	"	Aug. 15, 1944	172
4	"	Sept. 25, 1944	212
5	M-18	Dec. 22, 1952	365
6	M-8	Oct. 29, 1944	303
7	"	Mar. 9, 1948	644
8	"	Jan. 3, 1949	780
9	"	Feb. 15, 1949	829
10	"	May 27, 1952	1,150
11	"	Jan. 2, 1953	1,880
12	K-12	June 16, 1952	3,400
13	C-12	Jan. 16, 1953	8,640
14	"	"	6,330
15	"	"	4,640
16	0-8	June 10, 1952	3,000

No	Well	Date	ppm Cl
17	0-8	Nov. 20, 1962	2,200
18	"	"	3,600
19	"	Nov. 21, 1962	4,200
20	"	"	5,070
21	0-1	Jan. 12, 1963	10,800
22	1-4	Jan. 18, 1963	14,400
23	6-4	June 4, 1952	14,800
24	"	Jan. 9, 1953	15,100
25	0-3	Dec. 17, 1952	17,100
26	6-5	Dec. 9, 1952	18,400
27	0-4	Jan. 9, 1953	18,100
28	Ocean	Oct. 29, 1953	18,800
29	Rosecrans	Apr. 24, 1924	18,610
30	Tarrence	Apr. 10, 1924	18,332
A	33/14W-22A	Sept. 17, 1945	41
B	33/14W-32A	Jan. 4, 1945	58

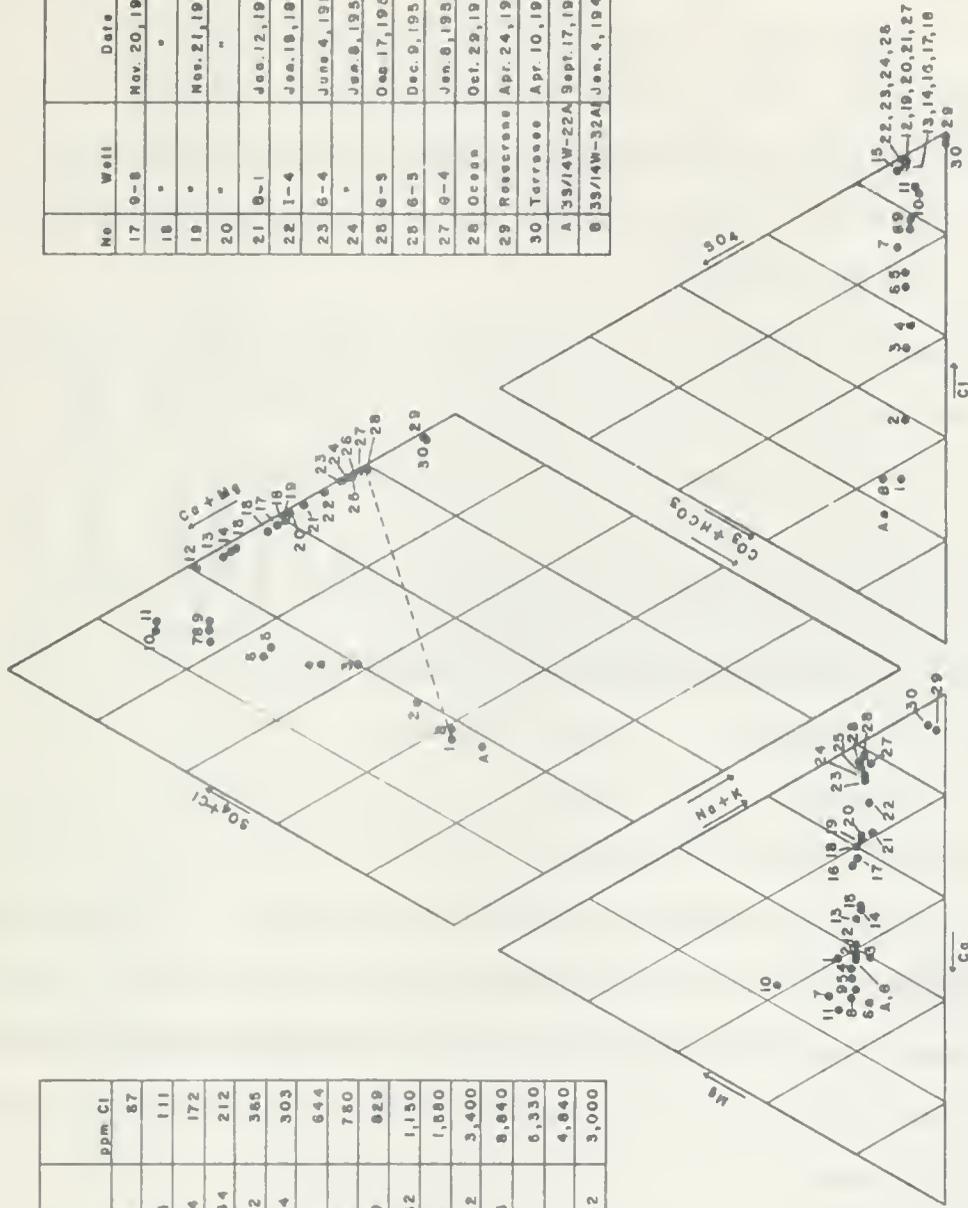


Figure 6 -- Trilinear plot of selected analyses from the Manhattan Beach Area

Simple mixing of the native water with sea water or an oil-field brine would give a series of plots approximating a straight line joining the native water and the sea water or brine. Obviously, simple mixing of sea water or a brine with the native water has not taken place. No single type of water will produce a double-line plot such as this by simple admixture of two waters. The chemical change may be that of cation exchange. This type of change requires that ion-exchange materials be present in the Silverado zone.

Several core samples of the Silverado water-bearing zone were obtained from wells H-13 and H-16 and tested for exchange materials. The sediment samples were obtained from three different depths in each well and thoroughly mixed. The dry material was placed in a column and leached with distilled water until most of the soluble material was removed, as indicated by a decrease in hardness of the leachate to 100 ppm. A liter of sodium chloride solution of approximately the concentration of sea water was introduced into the column. When the silver nitrate test indicated the presence of chloride in the leach, samples of leach were collected and analyzed for calcium, magnesium, and chloride. Figure 7a shows the results of these analyses. Maximum ion exchange apparently took place in about two hours and then steadily decreased with time. The maximum exchange noted (between 9 and 11 hours) was slightly less than the concentration of sodium in the solution added.

The core material was regenerated with a calcium chloride solution and again rinsed with distilled water until the rinse leachate had a total hardness of approximately 100 ppm. A liter of sea water was then introduced at the top of the column and samples of leach collected and

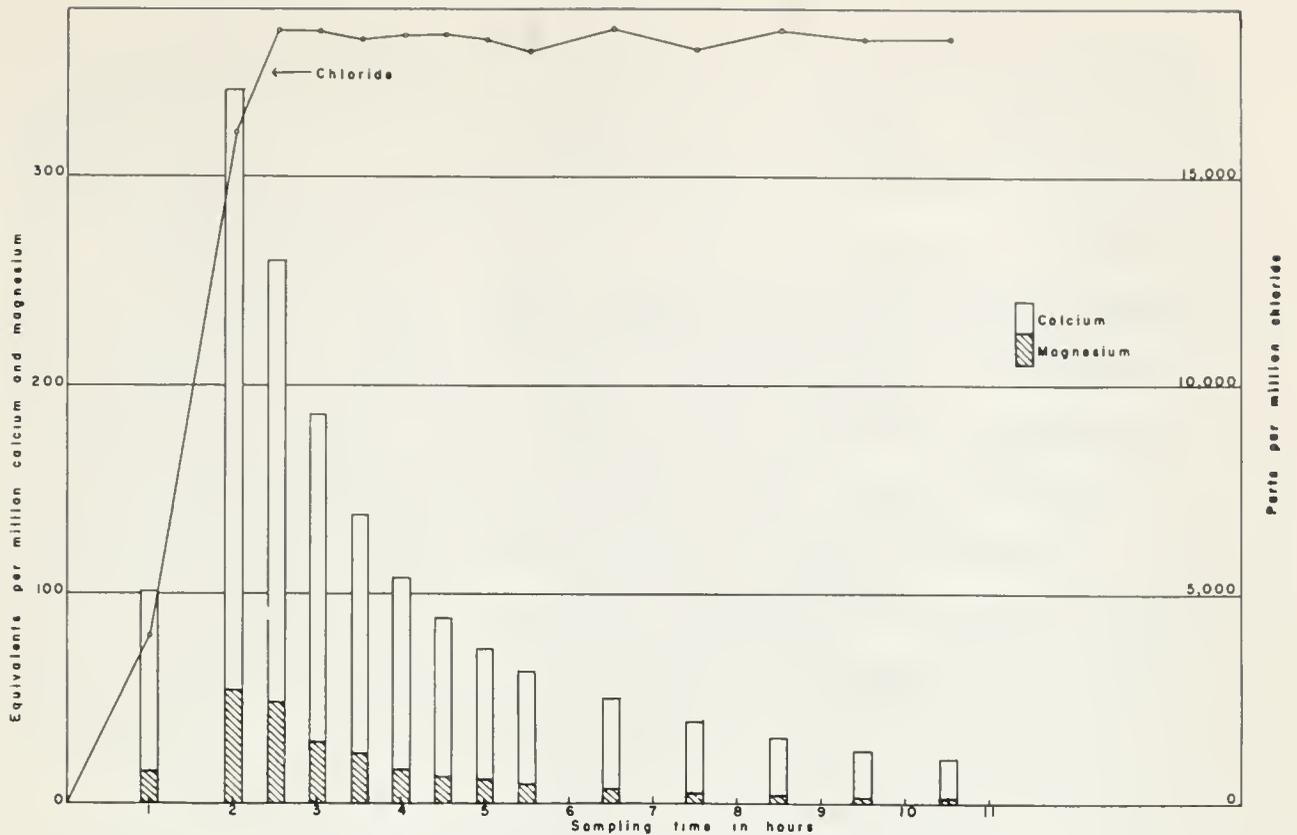


Figure a-- Calcium, magnesium, and chloride concentrations in the leach from the Silverado water-bearing zone core material leached with a sodium chloride solution

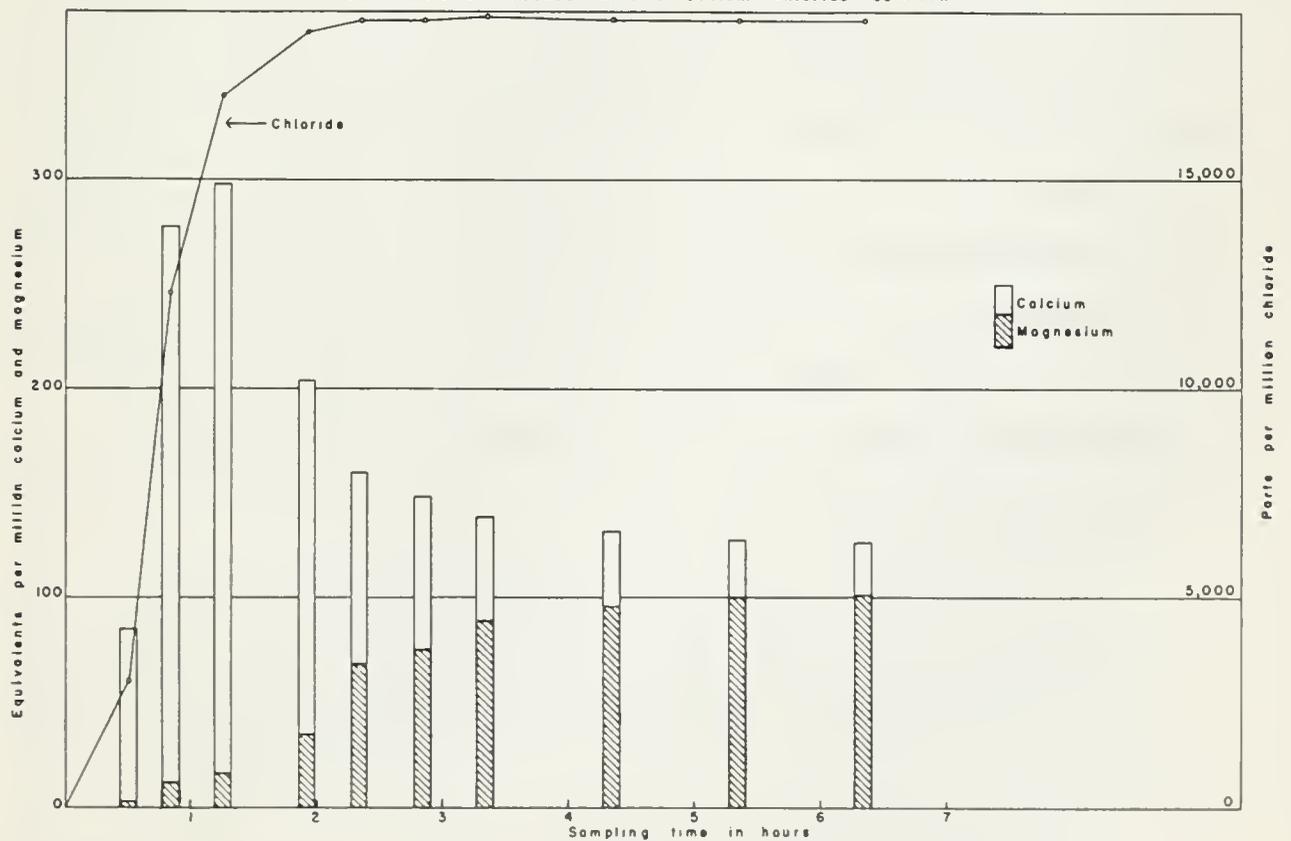


Figure b-- Calcium, magnesium, and chloride concentrations in the leach from the Silverado water-bearing zone core material leached with sea water

analyzed as before. The flow through was faster during this second run. Figure 7b shows the results of these analyses. As with the sodium chloride solution, ion exchange took place rapidly increasing to a maximum and then decreasing. After about five hours, the leach attained a calcium and magnesium concentration of the sea water added. Because the column was regenerated with a calcium chloride solution, it should not be inferred from the sea-water data that the magnesium of the sea water exchanges for the calcium of the soil. This aspect of ion exchange was not investigated; only the possibility of ion exchange was sought. The postulation that ion exchange is the mechanism by which the observed chemical phenomena can be explained is supported by these tests showing that minerals capable of entering into ion-exchange reactions are present in the Silverado water-bearing zone.

The double-line plot of the trilinear diagram can be explained on the basis of ion exchange coupled with simple mixture. The contaminating water, as it moves through the Silverado zone, undergoes cation exchange. In the resulting mixture of native and contaminating water the percentage of calcium plus magnesium will remain constant or increase to a maximum if the inflow of contaminating water steadily increases. When this maximum point is reached, the high sodium content of the contaminating water causes the percentage of sodium to increase in the mixture until the contaminating water constitutes 100 per cent of the mixture.

Sea water and oil-field brines are two possible sources of contamination in the Manhattan Beach area. Hydrologic evidence favors sea water, and if this is valid, chemical-quality data also should support this conclusion.

There are oil wells north, west, and southwest of the Manhattan Beach area. Samples of brines from these fields (Table 1) are lower in sulfate and higher in carbonate than sea water and plot below sea water in the trilinear diagram.

Selected analyses from the Manhattan Beach municipal well eight were compared with hypothetical mixtures of native water and sea water and native water and oil-field brines. These hypothetical mixtures were calculated by determining the percentages of contaminating water and native water required to produce a water whose chloride content in equivalents was equal to the equivalents of chloride of the water actually analyzed. Table 2 compares the analyses with the hypothetical mixtures of native water with sea water and oil-field brines.

These data show that the sum of the equivalents of calcium and magnesium in the natural well water exceeds the sum of these ions in the hypothetical mixtures, and this difference increases as the total dissolved mineral concentration increases. Similarly, the equivalents of sodium in the natural well water is less than the equivalents of sodium in the hypothetical mixtures in all instances, and this difference is approximately equal to that for the calcium and magnesium. This indicates that ion exchange has taken place as well as simple mixture.

The hypothetical mixtures of sea water and native water indicate that the loss of sodium and potassium ions is slightly larger than the gain of the calcium and magnesium ions and that this difference is equal to the loss of the anions bicarbonate and sulfate. This loss can be explained as precipitation of salts from solution. If the sodium ions of sea water exchange for calcium, barium, strontium, etc. of the soil and any of the ions later precipitate from solution as the carbonates or sulfates, the apparent loss would be in sodium carbonate and sulfate.

The hypothetical mixtures of native water and brine indicate that the gain of the alkaline-earth ion is larger than the loss of alkali ions and that the difference is almost equal to the gain of sulfate ions. The solution of calcium sulfate from gypsum deposits in the Silverado zone would provide an explanation of this gain. That this has not been the case is evidenced by the net loss of sodium carbonate in the less contaminated water and not a gain of calcium sulfate, and by the low sulfate concentration in the native water. This would not be expected if gypsum deposits were common in the Silverado zone. For this reason sea water seems the more logical contaminating agent.

The project wells, which are nearer the ocean than well eight, yield more highly concentrated water than do wells farther away. The selected analyses plotted in Figure 6 show that sea-water character is approached with decreasing distance from the well to the ocean. Analyses A and B are from waters in wells that tap the Silverado zone in the area between the Manhattan Beach municipal well field and the Rosecrans and Torrance oil fields.

These analyses do not show increased contamination and, in fact, are similar to native water in concentration and character. This gives further indication that in the Manhattan Beach area sea water is the saline contaminant.

The ratio of chloride to bromide also gives evidence that the contaminant is sea water. The ratio of chloride to bromide in sea water is about 290 to 1. Most of the water samples collected in the Manhattan Beach area have a chloride-to-bromide ratio between 270 and 310 to 1. The less concentrated waters show larger deviations from the sea-water ratio. This probably is due mainly to the error of the bromide determination. In

the waters of low concentration the relative error is larger than in those of high concentration.

A review of the manganese content of the waters introduces some interesting facts. The greatest concentration of manganese is found in waters from wells along the injection line and just inland from this line in the vicinity of the "G" injection well. The manganese content decreases seaward and landward from this line of high concentration. Generally, the manganese content increases with depth within a particular well.

This increase in manganese content probably is brought about by ion-exchange phenomena. The sodium ions of the sea water are exchanging for manganese ions in the materials of the Silverado zone. The greatest manganese concentration seems to occur when the magnesium content is equal to or just exceeds the calcium content.

Sea-water contamination of fresh-water bodies is not unique to California. Many coastal areas and island provinces have the same problem. In working with these problems over the years, hydrologic data have shown that the heavier sea water enters an aquifer at the bottom and does not mix completely. Some island countries obtain fresh water which overlies sea water and, if the pumping is not too heavy, contamination can be prevented.

As a part of the study of the Manhattan Beach project a model of a confined aquifer was built by the University of California Experimental Station at Richmond to furnish hydrologic data for a body of sea water trapped inland from the injection line as a fresh-water pressure ridge was being built up. In addition to these data, the model studies also showed that the sea water first would enter the basal deposits of the aquifer and then advance inland as a sloping wedge until it completely filled the

confined zone. Project wells situated in the frontal portion of the intruding sea water provided sampling opportunities which aided in the proof of the wedge theory.

Three concepts can be postulated about the behavior of a wedge of saline water moving against a body of fresh water in an aquifer:

(1) The depth to sea water below a horizontal plane should be less near the coast than inland; (2) any fresh water remaining in the aquifer will be found in the uppermost part of the aquifer; and (3) a zone of mixed sea water and fresh water should be encountered at the sea water-fresh water interface.

To obtain the best data on the shape and extent of the intruded body of sea water a static situation would be desirable. However, in practice this is impossible to attain, because pumping the wells disturbs the balance between the saline water and the fresh water causing the waters to mix. Pumping also disturbs the rate of movement of the wedge in the vicinity of the well.

Samples of water were collected from the many project wells at different depths as they were developed. These data lend themselves to some proof of the wedge concept. Three lines of observation wells were drilled roughly perpendicular to the line of injection wells and extending inland from the coast about half a mile. Figures 2, 3, and 4 show the chloride content and total hardness of selected samples from the "C", "G", and "K" lines of wells as of February, 1953. The water from the more inland wells had lower chloride concentration and the concentration increased with depth in any particular well. The relative amounts of hardness increased inland, indicating greater ion exchange at the saline front. Where the aquifer was saturated with sea water, the ion-exchange

Table 3 — Calculated mixtures of native water and ocean water for selected analyses from the "C" line of wells, Manhattan Beach, California.

	Well C-13 Depth 66'		Mixture 94.05% ocean 5.95% native		Well C-9 Depth 117'		Mixture 98.75% ocean 1.25% native		Well C-5 Depth 117'		Mixture 91.84% ocean 8.16% native		Well C-5 Depth 129'		Mixture 98.76% ocean 1.24% native		Well C Depth 176'		Mixture 94.24% ocean 5.76% native		Well C-4 Depth 189'		Mixture 68.21% ocean 31.79% native		
	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm												
Calcium	16.72	17.99	15.67	18.75	20.11	17.63	19.16	17.63	19.16	17.63	18.75	20.11	17.63	19.16	17.63	18.75	20.11	20.31	18.03	32.24	13.81				
Magnesium	95.59	97.55	109.37	102.24	94.57	95.29	101.15	102.36	101.15	94.57	102.36	101.15	95.29	101.15	102.36	97.74	73.36	42.19	97.74	73.36	71.23				
Sodium	427.01	429.17	439.19	446.61	442.82	445.53	443.54	446.65	443.54	442.82	446.65	443.54	445.53	443.54	446.65	449.18	291.78	9.95	426.32	291.78	309.38				
Potassium	9.05	9.39	12.76	9.86	10.23	9.17	11.87	9.86	10.23	10.23	9.86	11.87	9.86	11.87	9.86	9.86	2.02	2.02	9.44	2.02	6.81				
Total ^a	548.27	550.40	576.99	577.56	537.14	537.62	575.82	577.62	575.82	537.14	577.62	575.82	577.62	575.82	577.62	551.50	399.10	551.50	551.50	399.10	401.24				
Bicarbonate	1.07	2.36	2.06	2.95	2.04	2.10	2.01	2.95	2.01	2.04	2.95	2.01	2.95	2.01	2.95	2.35	2.29	1.97	2.35	2.29	2.88				
Sulfate	50.98	51.93	54.11	54.10	50.61	50.71	52.92	54.50	52.92	50.61	54.50	52.92	54.50	52.92	54.50	52.03	36.59	51.16	52.03	36.59	37.86				
Chloride	496.12	496.13	520.81	520.83	484.49	484.51	520.89	520.88	520.89	484.49	520.88	520.89	520.88	520.89	520.88	497.13	360.52	497.15	497.13	360.52	360.50				
Total ^e	548.17	550.42	576.98	577.57	537.14	537.62	575.82	577.63	575.82	537.14	577.63	575.82	577.63	575.82	577.63	551.51	399.10	551.51	551.51	399.10	401.24				
Alkaline earth (Ca + Mg) loss or gain	-3.43																					+20.56			
Alkali (Na + K) loss or gain	+1.20																					-22.39			
Difference	-2.23																					-1.83			
Anion loss or gain	-2.25																					-1.81			
																						-0.93			

	Well C-4 Depth 213'		Mixture 84.22% ocean 15.78% native		Well C-8 Depth 276'		Mixture 76.11% ocean 23.89% native		Well C-12 Depth 179'		Mixture 0.93% ocean 99.07% native		Well C-12 Depth 219'		Mixture 36.16% ocean 63.84% native	
	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	epm	
Calcium	36.63	16.10	1.75	2.91	42.12	15.09	1.45	2.89	73.60	8.61						
Magnesium	88.82	87.53	1.40	2.73	78.15	79.29	1.40	2.58	42.19	38.52						
Sodium	362.66	381.26	7.61	7.28	322.65	344.92	6.48	6.66	96.97	165.11						
Potassium	3.63	8.11	2.10	1.1	2.48	7.60	1.1	1.09	1.53	3.61						
Total ^a	491.74	493.60	10.86	13.03	445.70	446.90	9.44	12.22	211.29	215.85						
Bicarbonate	2.30	2.56	2.21	4.26	2.49	2.72	1.56	4.27	3.63	3.55						
Sulfate	44.56	46.57	1.17	1.25	41.22	42.17	1.09	1.17	18.71	20.38						
Chloride	444.18	444.18	7.50	7.51	401.99	402.01	6.79	6.77	191.91	191.92						
Total ^e	491.74	493.61	10.88	13.02	445.70	446.90	9.44	12.21	211.28	215.85						
Alkaline earth (Ca + Mg) loss or gain	+21.52															
Alkali (Na + K) loss or gain	-23.38															
Difference	-1.86															
Anion loss or gain	-1.87															

^a The cation and anion imbalance of water samples has been proportionally distributed to obtain a balance.

Table 4 — Calculated mixtures of native water and ocean water for selected analyses from the "G" line of wells, Manhattan Beach, California.

	Well G-9 Depth 119'	Mixture 98.43% ocean 1.57% native	Well G-5 Depth 98'	Mixture 99.38% ocean .62% native	Well G-3 Depth 145'	Mixture 99.22% ocean .08% native	Well O-1 Depth 164'	Mixture 90.01% ocean 9.99% native	Well O-2 Depth 160'	Mixture 37.86% ocean 62.14% native	Well O-2 Depth 181'	Mixture 85.71% ocean 14.29% native
Calcium	20.56	18.70	21.30	18.86	22.01	18.94	29.84	17.34	41.17	8.85	28.29	16.64
Magnesium	106.91	102.02	109.11	102.99	110.20	103.54	92.93	93.43	35.44	40.04	90.46	89.04
Sodium	439.19	445.17	443.46	449.45	447.88	451.87	400.92	407.30	143.06	171.85	178.31	187.96
Potassium	9.28	9.82	6.99	9.92	4.12	9.97	2.10	8.98	1.38	3.76	4.32	8.55
Total ^a	575.94	575.71	580.85	581.22	581.21	584.32	526.09	527.05	221.50	224.50	501.18	502.19
Bicarbonate	2.09	2.26	2.02	2.25	2.06	2.23	2.34	2.44	1.97	3.51	2.13	2.52
Sulfate	54.66	54.31	54.67	54.83	55.18	55.13	48.86	49.73	19.26	21.20	46.74	47.39
Chloride	519.17	519.15	524.16	524.14	526.96	526.98	474.89	474.90	199.81	199.80	452.30	452.30
Total ^a	575.92	575.72	580.85	581.22	581.20	584.34	526.09	527.07	221.04	224.51	501.17	502.21
Alkaline earth (Ca + Mg) loss or gain	+6.75		+8.56		+9.73		+12.00		+27.72		+13.07	
Alkali (Na + K) loss or gain	-6.52		-8.92		-9.84		-12.96		-31.17		-24.08	
Difference	+2.23		+2.36		+2.11		+2.96		-3.45		-1.01	
Anion loss or gain	+2.20		+2.37		+2.14		+2.98		-3.47		-1.04	
Calcium	5.54	3.16	32.58	15.68	26.60	18.91	4.59	3.20	15.07	4.69	30.34	7.15
Magnesium	3.70	4.29	83.06	83.02	92.51	103.30	3.62	4.53	14.88	13.92	30.10	29.40
Sodium	11.22	14.17	348.31	361.38	452.23	450.79	12.22	15.24	42.01	56.62	100.45	124.90
Potassium	.13	.26	2.79	7.96	3.33	9.95	.19	.28	.43	1.20	.97	2.72
Total ^a	20.59	21.88	466.74	468.04	581.67	582.95	20.62	23.25	73.29	76.43	161.86	164.17
Bicarbonate	3.01	4.24	2.01	2.65	1.51	2.23	1.85	4.23	1.81	4.04	2.13	3.73
Sulfate	2.03	2.08	43.46	44.17	54.46	54.99	1.93	2.22	6.30	7.23	14.81	15.51
Chloride	15.55	15.55	421.27	421.25	525.70	525.72	16.84	16.82	65.18	65.16	144.92	144.94
Total ^a	20.59	21.87	466.74	468.07	581.67	582.94	20.62	23.27	73.29	76.43	161.86	164.18
Alkaline earth (Ca + Mg) loss or gain	+1.79		+16.94		+3.90		+4.48		+12.24		+23.89	
Alkali (Na + K) loss or gain	-3.08		-18.24		-3.11		-3.11		-15.38		-26.20	
Difference	-1.29		-1.30		-1.28		-2.63		-3.14		-2.31	
Anion loss or gain	-1.28		-1.33		-1.27		-2.65		-3.14		-2.32	

^a The cation and anion imbalance of well samples has been proportionally distributed to obtain a balance.

Table 5 -- Calculated mixtures of native water and ocean water for selected analyses from the "W" lines of wells, Manhattan Beach, California.

	Well K-9 Depth 126'		Well K-5 Depth 112'		Well K-5 Depth 125'		Well K Depth 294'		Well K-4 Depth 181'		Well K-4 Depth 206'		Mixture	
	epm	Mixture 94.12% ocean 5.88% native	epm	Mixture 84.65% ocean 15.35% native	epm	Mixture 96.78% ocean 3.22% native	epm	Mixture 53.15% ocean 46.85% native	epm	Mixture 67.17% ocean 32.83% native	epm	Mixture 88.80% ocean 11.20% native	epm	Mixture
Calcium	15.17	18.01	16.17	16.66	21.26	18.14	49.20	11.36	38.17	13.64	32.73	17.15		
Magnesium	105.26	97.63	87.96	50.82	109.37	100.33	50.82	55.84	69.49	70.16	91.28	92.19		
Sodium	424.05	125.79	377.88	383.19	426.14	437.75	212.20	211.52	283.52	304.66	389.62	401.86		
Potassium	11.70	9.38	6.91	8.45	9.51	9.66	1.38	5.30	2.02	6.71	3.96	8.86		
Total ^a	552.27	550.82	497.20	496.07	566.31	566.18	313.60	314.02	393.20	395.17	517.59	520.06		
Bicarbonate	2.49	2.35	2.79	2.55	2.51	2.30	3.26	3.20	2.26	2.91	2.28	2.46		
Sulfate	53.65	51.97	47.70	46.80	53.33	53.41	29.12	29.63	35.98	37.28	46.74	49.07		
Chloride	96.52	486.50	446.71	446.73	510.46	510.48	281.22	281.20	354.96	354.98	468.56	468.54		
Total ^a	552.27	550.82	497.20	496.08	566.30	566.19	313.60	314.03	393.20	395.18	517.58	520.07		
Alkaline earth (Ca + Mg) loss or gain	+4.79		+7.98		+11.86		+11.86		+32.82	+23.80	+14.67			
Alkal. (Na + K) loss or gain	-3.34		-6.85		-11.73		-33.21		-25.83	-17.11	-2.47			
Difference	+1.45		+1.13		+1.13		-4.2		-1.97	-1.97	-2.47			
Anion loss or gain	+1.44		+1.12		+1.1		-4.3		-1.98	-1.98	-2.49			

	Well K-8 Depth 253'		Well K-8 Depth 266'		Well K-12 Depth 282'		Well K-12 Depth 311'		Well K-16 Depth 256'		Well K-16 Depth 306'		Mixture	
	epm	Mixture 60.23% ocean 31.77% native	epm	Mixture 74.61% ocean 25.39% native	epm	Mixture 0.29% ocean 99.71% native	epm	Mixture 27.92% ocean 72.08% native	epm	Mixture 10.23% ocean 89.77% native	epm	Mixture 1.22% ocean 98.78% native	epm	Mixture
Calcium	47.26	13.81	46.26	14.85	2.00	2.78	65.37	7.26	27.15	4.40	4.89	2.94		
Magnesium	59.82	71.22	77.26	77.73	4.32	1.94	33.14	30.11	14.56	12.07	2.96	2.88		
Sodium	280.91	309.34	309.61	338.04	3.22	3.77	66.10	128.04	21.74	18.18	5.04	7.96		
Potassium	2.20	6.81	2.33	7.45	.12	.03	1.13	2.79	.59	1.02	1.19	.42		
Total ^a	400.29	401.18	436.16	438.07	6.66	8.52	165.71	168.20	64.04	65.97	13.09	13.90		
Bicarbonate	2.62	2.88	2.18	2.75	2.44	4.29	3.02	3.71	3.64	4.08	3.36	4.27		
Sulfate	37.25	37.85	40.04	41.33	4.81	4.83	14.12	15.88	4.77	6.24	1.45	1.33		
Chloride	360.44	360.45	393.95	393.97	3.41	3.41	148.61	148.61	55.63	55.65	8.28	8.30		
Total ^a	400.31	401.18	436.17	438.05	6.66	8.53	165.75	168.20	64.04	65.97	13.09	13.90		
Alkaline earth (Ca + Mg) loss or gain	+32.15		+31.64		-1.40		+61.14		+25.24	+2.03	+2.03			
Alkal. (Na + K) loss or gain	-33.04		-33.55		-1.06		-63.60		-27.17	-2.85	-2.85			
Difference	-0.89		-1.91		-1.86		-2.46		-1.93	-1.93	-2.82			
Anion loss or gain	-0.87		-1.88		-1.87		-2.45		-1.93	-1.93	-2.81			

^a The cation and anion imbalance of well samples has been proportionally distributed to obtain a balance.

capacity of the materials was exceeded and no further evidence of ion exchange was apparent.

Tables 3, 4, and 5 present the chemical analyses for the water samples from the several wells and the hypothetical mixtures of native water and sea water having the same chloride content. The analyses from the "C" line of wells show that the water from wells C-9, C-5, and C-4 was essentially sea water. The water from well C-4 at 77 feet below sea level was approximately 87 per cent sea water with greater hardness than the more seaward wells. The water from 53 feet below sea level was approximately 68 per cent sea water and had a slightly higher hardness. Further inland at well C-8 the water from 47 feet below sea level was less than twice as concentrated as the designated native water, whereas the water from 95 feet below sea level was about 76 per cent sea water. The water from 52 feet below sea level in well C-12 was less concentrated than the dilute water from well C-8 and the water from 92 feet below sea level was only 36 per cent sea water compared to 68 per cent for water at that depth in well C-8. The calcium and magnesium percentage increased markedly in the water from well C-12.

The analyses of the water from the "G" line of wells show that the aquifer inland to well G-5 was essentially sea water for the total thickness. The water at 71 feet below sea level from well G-3 was about 92 per cent sea water but water from 123 feet below sea level was essentially sea water. The water at 76 feet below sea level from well G-1 was about 90 per cent sea water and showed increased hardness. A water sample from 45 feet below sea level in well G-2 was approximately 38 per cent sea water and relatively high in hardness, whereas the water from 66 feet below sea level was about 86 per cent sea water and exhibited a smaller percentage

of calcium and magnesium. Water from 30 feet below sea level in well G-4 was approximately three times as concentrated as native water but at 73 feet below sea level the water was 80 per cent sea water. Water at 105 feet below sea level in well G-4 was essentially sea water.

Water from 48 feet below sea level in well G-8 was approximately the same as water from 30 feet below sea level from well G-4. The water at 86 feet below sea level in well G-8 showed increased concentration with continued pumping. After four hours of pumping the water was about 12 per cent sea water, but after 20.5 hours it increased to 27 per cent. This illustrates the change in the rate of movement of the saline water under conditions of pumping.

The analyses of the water from the "K" line of wells show that the water in wells K-9 and K-5 was essentially sea water. The water from 40 feet below sea level in well K-5 was only 87 per cent sea water, indicating that the aquifer was not completely filled with sea water in the total thickness of the aquifer. The analysis of water from well "K" was obtained from 245 feet below sea level. This is apparently below the base of the Silverado water-bearing zone, and the mixture of water from the Silverado zone and a deeper, relatively uncontaminated aquifer probably accounts for the lower concentration. No water samples were obtained at lesser depths from this well.

The water from well K-4 at 50 feet below sea level was about 67 per cent sea water whereas the water from depth 69 feet below sea level was 89 per cent sea water. The relative hardness was greater in the less concentrated water at shallow depth. At 77 feet below sea level in well K-8 the water was 68 per cent sea water but at 90 feet below sea

level the water was 75 per cent sea water. The relative hardness of these waters was higher than for the waters from well K-4 and decreased with depth within the well.

The water from well K-12 at 56 feet below sea level came from the "200-foot sand", and was essentially native water. The upper water-bearing zone in Figure 4 is the "200-foot sand" which merges with the Silverado zone near the coast to form the single merged Silverado water-bearing zone. The water from 85 feet below sea level was obtained from the Silverado zone and was 28 per cent sea water. The relative hardness of this water was very high.

The analyses of water from well K-16 seem to show rather anomalous results. The water at 78 feet below sea level was about 10 per cent sea water whereas the water from 128 feet below sea level was only about twice the concentration of native water. The cause of this anomaly is not known.

The water samples collected from the wells in the "C", "G", and "K" lines show to a large extent that chemical-quality data do substantiate the hydrologic conclusions of an advancing wedge of saline water into the confined aquifer. More complete sampling in wells farther inland undoubtedly would provide better evidence of the existence of a saline wedge.

SUMMARY

Years of decreased rainfall and increased ground-water use have brought about a rapid lowering of ground-water levels in the West Basin of Los Angeles County. The lowering of water levels has reversed the normal seaward gradient of the ground water to a landward gradient in the West Basin thereby allowing sea water to encroach into the ground-water reservoir. In 1950 the California State Legislature appropriated \$750,000 for the study of means to prevent sea-water encroachment of ground-water basins. The Manhattan Beach area was selected as the site to study the feasibility of creating a pressure ridge of fresh water near the coast to hold back the sea water.

The chemical-quality data obtained from the project wells have been reviewed and interpreted. These data support the previous conclusions made from hydrologic evidence that sea water is the contaminant and that the relatively dense sea water will enter a zone in the shape of an advancing wedge.

Chemical-quality data from the Manhattan Beach municipal well eight indicate that the concentration of dissolved minerals in the water has increased over the years and that the chemical character of this water has approached the character of sea water. Comparison of the contaminated water with hypothetical mixtures of sea water and native water indicate that simple mixing has not taken place but that the sodium ions in the sea water have probably been exchanged for the calcium and magnesium in the sediments. The calcium and magnesium percentages are higher and the sodium percentage is lower than would be expected from simple mixture of native fresh water and sea water.

Core samples of material from the Silverado water-bearing zone were obtained and leached with a sodium chloride solution approximately the concentration of sea water and with a sample of sea water. These data show that minerals capable of entering into ion exchange reactions occur in the Silverado zone. Analyses of water from wells close to the ocean and oil fields show that contamination increases in the direction of the ocean and not in the direction of the oil fields, thereby substantiating other observations that the source of contamination is sea water.

Chemical-quality data of waters from wells normal to the coast show that the contamination increases with depth in the well. In most places essentially native fresh water was found in the upper part of the aquifer. The depth to the saline water body increased with increasing distance inland. This increase in depth to the saline water body in a landward direction indicates that saline water was entering the aquifer in the shape of a sloping wedge.

The chemical-quality data obtained in the Manhattan Beach area substantiate the previous conclusions of encroaching sea water and lend support to the hypothesis that sea water will enter a confined zone as an advancing wedge.

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