

STATE OF CALIFORNIA
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Southern District

SECTION 9
ITEM # 3588a
DATE 8/74

3588a

**MATHEMATICAL MODELING OF WATER QUALITY
FOR WATER RESOURCES MANAGEMENT**

VOLUME II

**DEVELOPMENT OF HISTORIC DATA FOR THE VERIFICATION
OF THE GROUND WATER QUALITY MODEL OF THE SANTA CLARA-
CALLEGUAS AREA, VENTURA COUNTY**

The work covered by this completed research report was supported, in part, by funds provided by the U. S. Department of the Interior, Office of Water Resources Research, under P.L. 88-379, Grant Proposal Number C-3117, Agreement Number 14-31-0001-3733, Investigation Period—March 1, 1972 to June 30, 1974.

DISTRICT REPORT

August 1974

REFERENCE COLLECTION

**DEPARTMENT OF WATER RESOURCES
CENTRAL RECORDS, ROOM 338**

VOLUME II

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CHAPTER 1. INTRODUCTION

The Santa Clara-Calleguas area encompasses the major ground water basins of southwestern Ventura County. It has a surface drainage area of 1,700 square miles, or 1.1 million acres. The Santa Clara River Valley is the most important valley in the area. It trends in an east-west direction and is essentially controlled by geological structural features. It is a downfolded, faulted syncline between mountains to the north and south. The water-bearing area (underlain by ground water reservoirs) is 300 square miles, or 192,000 acres, and constitutes about 18 percent of the total area.

Its main population centers are Ventura, Oxnard, Santa Paula, Fillmore, Piru, and Moorpark (Figure 1). Population has been increasing steadily since 1930 when it was 49,000; by 1970, it was approximately 330,000.

Precipitation in Ventura County occurs chiefly during the winter and is produced mostly by storms originating in the north Pacific. Based on data from the water years 1936-37 to 1959-60, average annual precipitation is 15.05 inches.

From 1957 to 1967, the base period for the model study, urban land use increased from 18,000 acres to 27,000 acres and agricultural land use from 112,000 acres to 106,000 acres.

The area's principal water supply comes from ground water reservoirs. With mounting water demand, pumpage of ground water has not materially increased, though the Calleguas Municipal Water District has imported Colorado River water. Pumpage varied from a high 224,240 acre-feet during the 1956-57 water year to a low 186,880 in 1966-67. Average pumpage was 224,100 acre-feet during the 10-year base period. The area contains the Piru, Fillmore, Santa Paula, Mound, Oxnard Forebay, Oxnard Plain, Las Posas, Pleasant Valley, and Santa Rosa ground water basins (Plate 1, Volume I). The Piru, Fillmore, Santa Paula, Mound, and Oxnard Forebay basins are the major alluvial free-water aquifers. Besides alluvial aquifers, development of older confined aquifers has been important in the other basins. Because of the complex hydrogeologic systems of the study area, the mathematical model for part of the area is made up of two layers. The upper layer (Nodes 1-90) consists of the unconfined alluvial aquifers in the Piru, Fillmore, Santa Paula, Mound, and Oxnard Forebay subbasins and the confined Oxnard and Mugu aquifers in the Oxnard Plain. The lower layer (Nodes 91-158) consists of the Hueneme, Fox Canyon and Grimes Canyon confined aquifers in the Oxnard Plain, Las Posas, the Pleasant Valley basins and the unconfined aquifers in the Arroyo Santa Rosa basin.

Based on the hydrologic balance, the change in ground water storage (zone of saturation as a free body) amounted to 69,290 acre-feet during the 1956-57 water year and 265,560 acre-feet during 1966-67. The 11-year average annual increase in storage was 24,470 acre-feet.

The two main surface water systems in the model area are the Santa Clara River to the north and the Calleguas Creek to the south. For the Santa

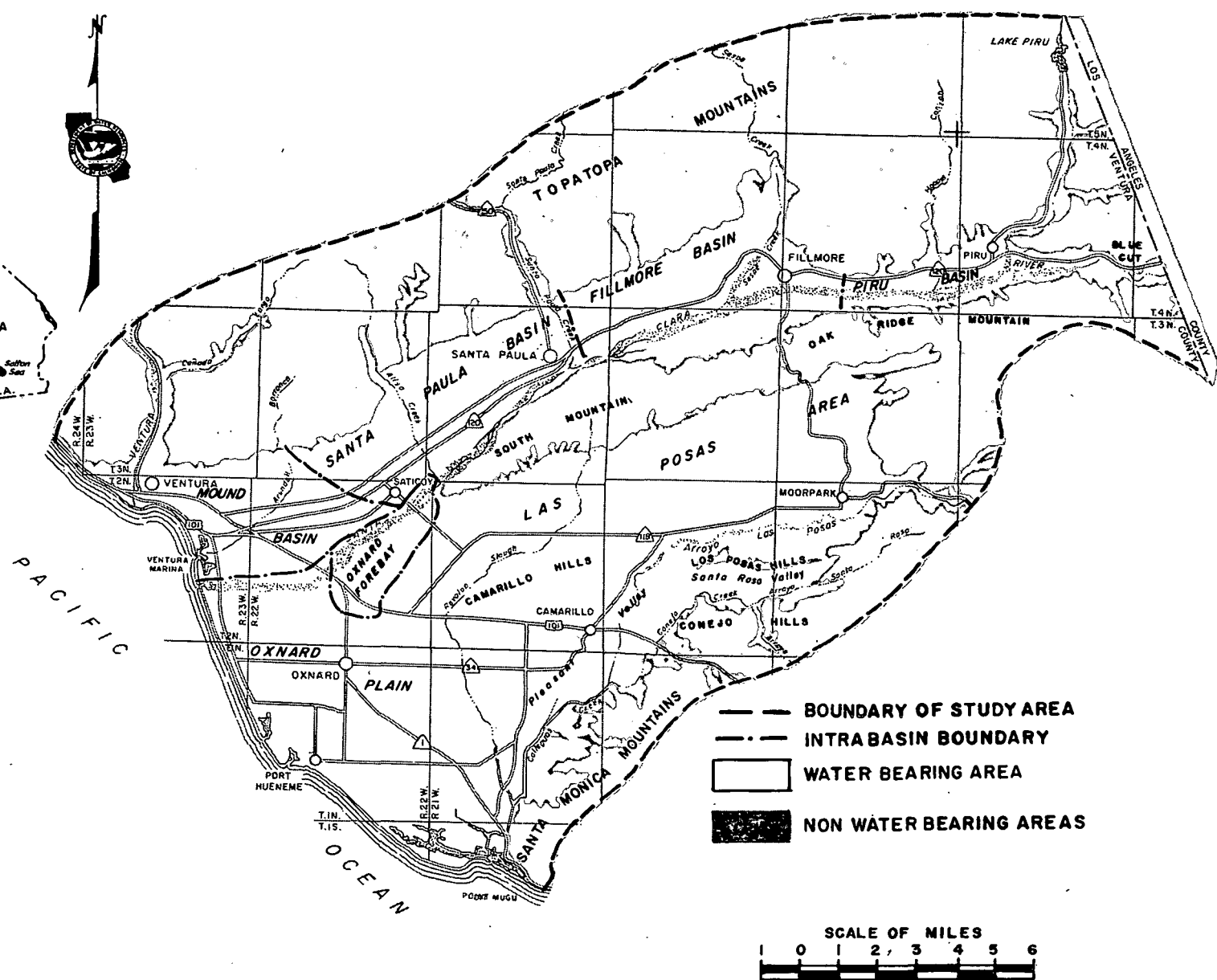


Figure 1 - STUDY AREA

Clara-Calleguas area, surface water runoff comes from the nonwater-bearing portions of the area and from the Upper Santa Clara River, which lies outside the study area. Average annual total inflow into the area, from the Upper Santa Clara River, from tributaries of the Santa Clara River, from Arroyo Simi, and from ungaged areas, was 201,030 acre-feet, with all surface water outflow to the ocean. Average annual outflow from the Santa Clara River from 1956-57 to 1966-67 was 79,700 acre-feet and from Calleguas Creek, 14,950 acre-feet.

For replenishment of the ground water basins, three artificial recharge facilities were in operation during the verification period at Piru, Saticoy, and El Rio. The only agency conducting spreading operations in the area is the United Conservation Water District (UCWD). Average annual rates of artificial recharge in the spreading basin were 4,780 acre-feet in Piru Creek at Piru, 16,950 acre-feet in the Santa Clara River at Saticoy, and 15,380 acre-feet in the Santa Clara River at El Rio.

Recharge of the free ground water basins is mostly from precipitation percolation, surface water percolation, subsurface inflows, irrigation return, and waste water discharges. Locally, subsurface inflows and percolation of rising water are additional sources of replenishment. The confined ground water basins are replenished mostly from subsurface inflows and leakage from overlying free aquifers.

Under natural conditions, ground water flow is predominantly seaward. Heavy pumping, however, has resulted in local flow inland from the ocean toward the pumping centers.

The factors that affect the mineral quality of ground water in the Santa Clara-Calleguas area are both natural and manmade. Soluble minerals in sediments above the saturated zone and in the water-bearing sediments are the sources of natural effects on the mineral quality of ground water. As water percolates through the unsaturated zone, the quality may change considerably, due to solution and deposition of minerals, ion exchange, oxidation-reduction, and other reactions. Changes in the total salt content (TDS) of water percolating beyond the root depth are relatively slight. Changes in the mineral quality in the saturated zone are normally much slower than changes in the unsaturated zone. Most of the change in quality in the saturated zone is due to long-term water contact with minerals.

Man's activities affect ground water quality adversely. Among their adverse effects are irrigation return with higher TDS than where applied, waste water percolation, and overdraft of ground water near the ocean, which has caused sea-water intrusion and which, in turn, has affected ground water quality in the Oxnard aquifer inland from the Port Hueneme and Point Mugu areas.

According to a 1968 DWR report, improper construction, destruction, and sealing of water wells may also allow the interchange of poor quality waters.

In the following pages, Chapter 2 describes the historic quality of ground water, surface water, domestic waste water, and industrial waste water;

Chapter 3 documents information on the effects of irrigated agriculture, significance of ion exchange, vertical zonation of quality, geochemical effects of sediments, and salt movement in ground water; Chapter 4 describes an inventory and distribution of water supplies; Chapter 5 documents sea-water intrusion in the Oxnard Plain; and Chapter 6 contains references. Because sea-water intrusion cannot be simulated by the developed quality model, a separate study examined relationships useful in future management of near-shore aquifers.

CHAPTER 2. HISTORICAL QUALITY OF GROUND WATER, SURFACE WATER, DOMESTIC AND INDUSTRIAL WASTE WATER IN SANTA CLARA-CALLEGUAS AREA

Historical Quality of Ground Water

The water supply of the Santa Clara-Calleguas area is obtained primarily from its ground water reservoir. But to utilize this source properly, it is important to understand all the factors that can affect its quality. For the quality model development, TDS has been selected to represent water quality.

Since TDS concentrations in ground water vary from one locality to another, isosalinity maps were drawn to show the spatial variations of TDS and help evaluate the cause of such variations. The maps were also used to calculate the historic nodal average TDS concentrations and analyze the temporal change in concentrations.

Procedures

In the development of the historical nodal average TDS concentrations for the water quality model, about 4,500 analyses of well water samples were used.

To develop historical nodal average TDS, isosalinity maps were constructed for selected years from 1956, 1960, and 1967 (Figures 2, 3, and 4). This was necessary because many wells have incomplete records of analyses and wells are not evenly distributed throughout the study area.

Isosalinity maps were used in the development of a historic weighted average TDS concentration, as mg/l for each node of the model. Values were calculated on the basis of area coverage between contour lines within the nodes. Table 1 shows the calculated historic nodal TDS concentrations from 1957 to 1967. Well water analyses were also used to estimate: (a) average nodal TDS concentration of ground water below the zone of mixed yield (quality interface) and (b) average TDS concentration of subflows into the area's boundary nodes.

Historic Quality of Ground Water in the Zone of Mixed Yield

Piru Ground Water Basin. The portion of the Santa Clara River Valley in Ventura County is divided into several ground water basins, of which Piru is the easternmost. Its eastern boundary is 1-1/2 miles west of the Ventura-Los Angeles County line and its western boundary is the Fillmore Basin. Its width near the town of Piru is 1-1/2 miles and its length, 9 miles.

In this Basin, only a few wells have a long, continuous historic record of ground water analyses. There are more wells with a shorter historic data record and there are some with incomplete records comprising only a few analyses during the study period.

In an unconfined ground water system, samples extracted from the ground water reservoir represent a mixture of water from different aquifer horizons, depending on the extent and depth of well perforations.

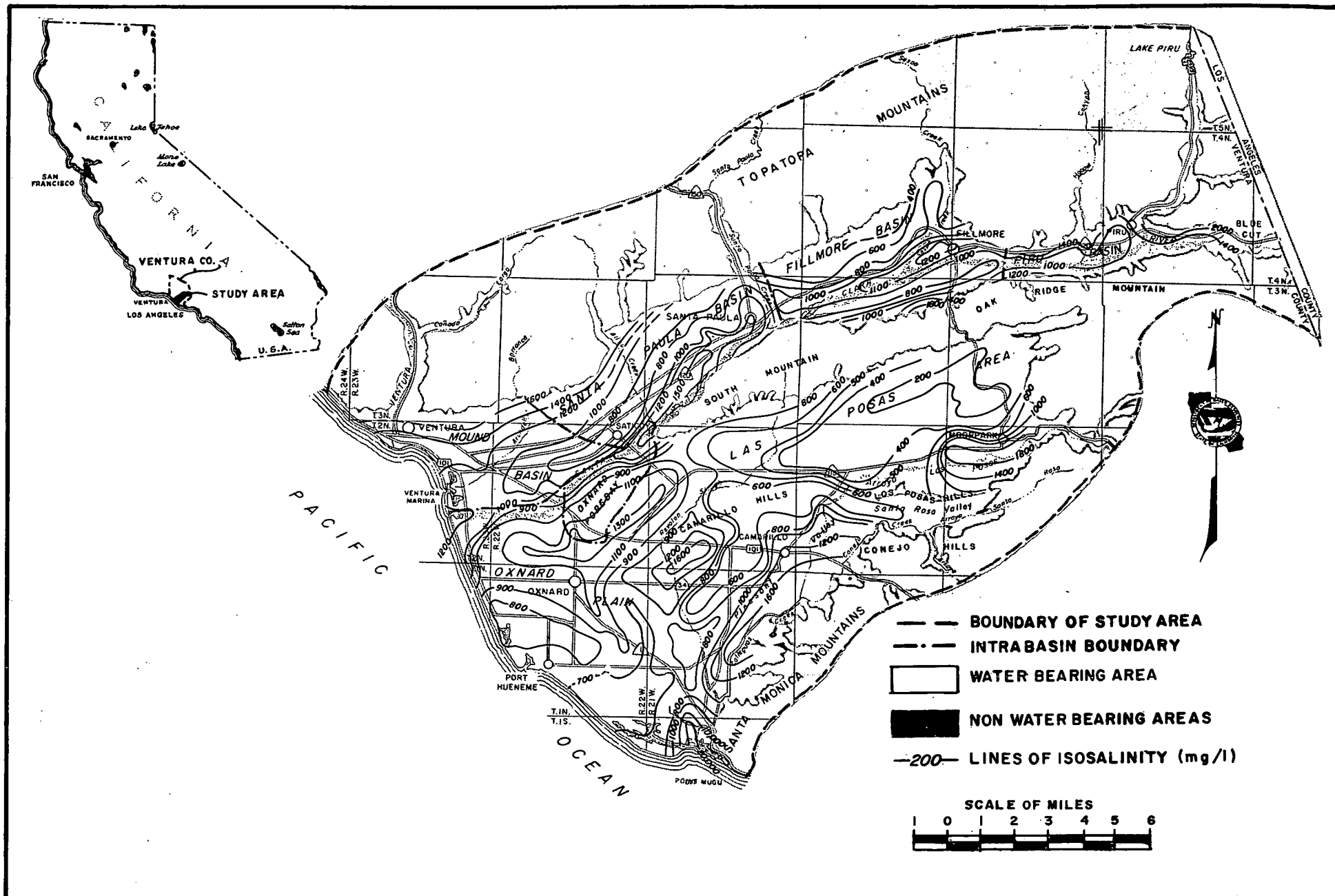
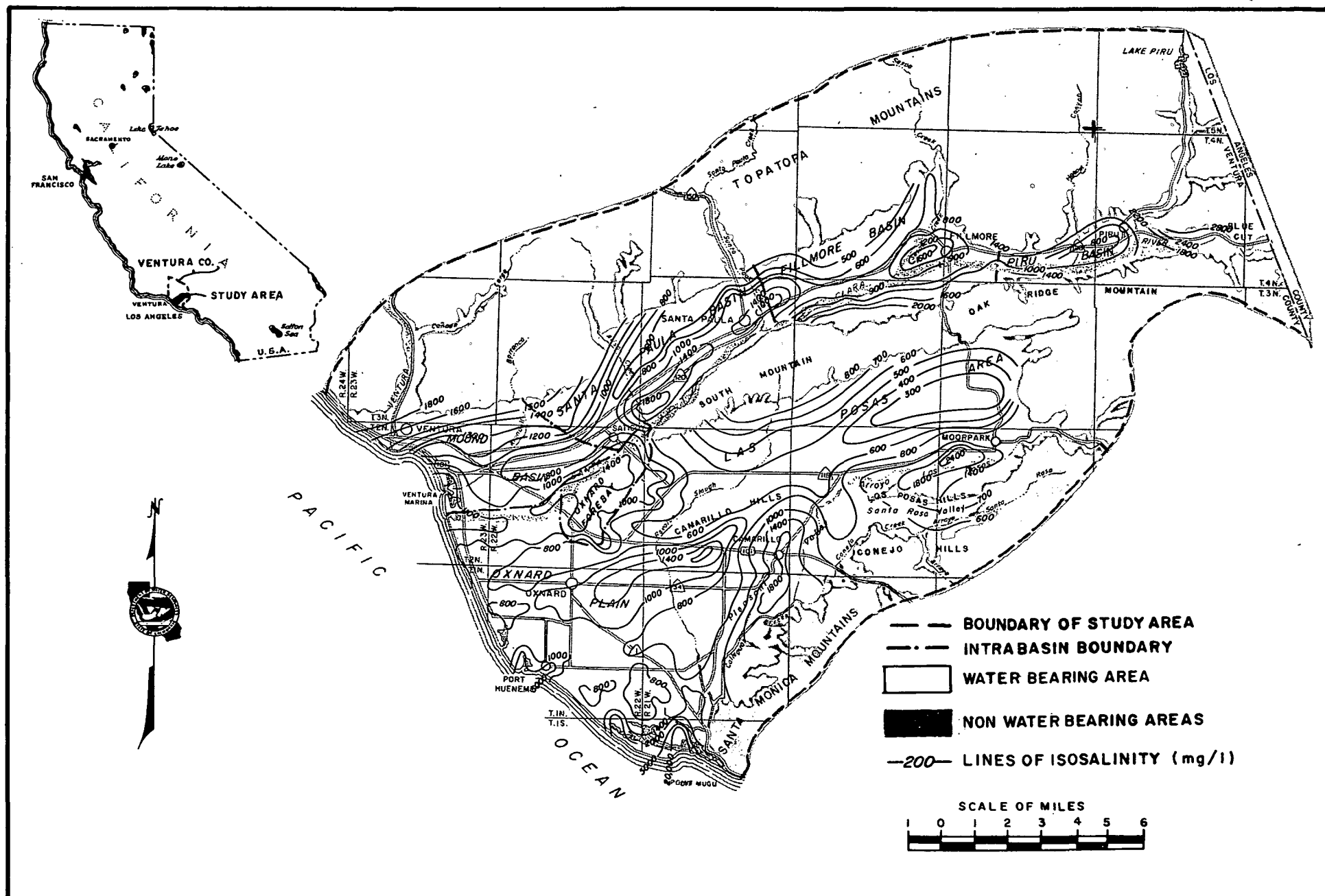


FIGURE 2- 1956 ISOSALINITY MAP OF EXTRACTED GROUND WATER IN THE
SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY



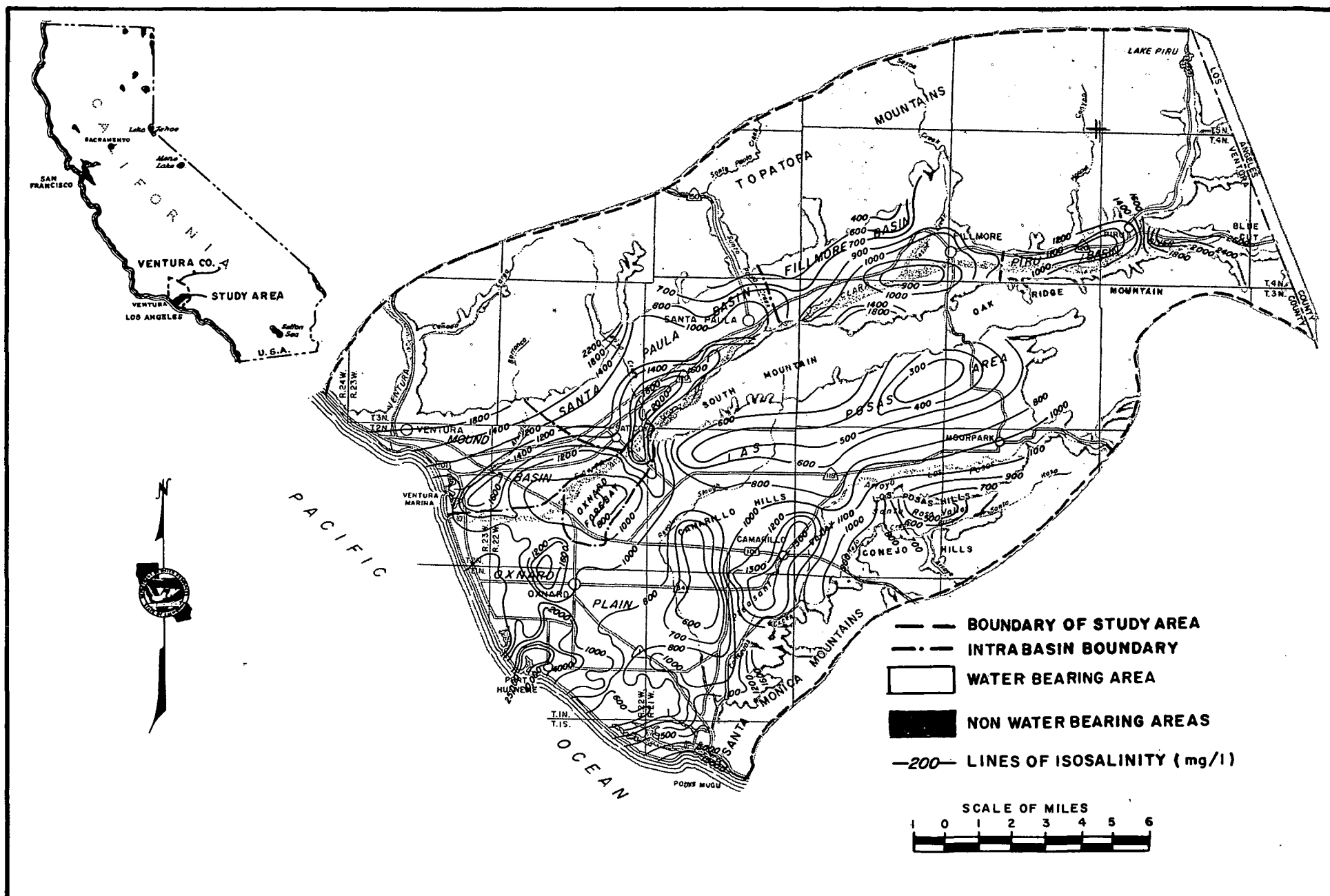


FIGURE 4—1966 ISOSALINITY MAP OF EXTRACTED GROUND WATER IN THE
SANTA CLARA—CALLEGUAS AREA, VENTURA COUNTY

TABLE 1
CALCULATED NODAL TDS VALUES FOR YEARS 1957 THROUGH 1967
(in mg/l)

NODE NUMBER	YEAR 1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	NODE NUMBER	YEAR 1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
1	2270	2230	2180	2400	2520	2300	2320	2600	2500	2400	2250	30	1250	1230	1250	1270	1300	1270	1195	1230	1235	1140	1100
2	1880	1820	1710	1900	1980	1800	1740	2200	2200	2100	1900	31	1280	1180	1170	1244	1380	1430	1370	1340	1365	1440	1380
3	1340	1370	1320	1420	1395	1225	1245	1500	1550	1450	1400	32	1050	1025	1050	1040	1005	1040	1070	1060	1045	1030	1080
4	1490	1450	1380	1460	1275	1350	1300	1500	1500	1450	1370	33	685	625	600	630	645	740	730	730	750	770	750
5	1185	1070	1040	1065	1120	1135	1095	1145	1180	1110	1000	34	1080	1025	1075	1165	1090	1085	1205	1250	1225	1200	1200
6	1100	1030	1030	1010	1060	1050	1025	1165	1145	1095	1020	35	850	825	775	655	795	920	900	970	950	940	900
7	1035	1000	980	890	920	990	1040	1050	1070	1020	1000	36	1215	1270	1245	1230	1260	1300	1370	1465	1368	1365	1340
8	1120	1100	1095	1040	1150	1200	1200	1185	1192	1060	1000	37	1250	1180	1260	1365	1465	1490	1525	1580	1620	1745	1700
9	1350	1350	1300	1290	1280	1260	1240	1370	1300	1280	1200	38	1300	1215	1200	1300	1385	1400	1335	1280	1400	1400	1410
10	1140	1230	1190	1200	1160	1150	1150	1220	1135	1095	1080	39	1175	1120	1060	1100	1190	1130	1380	1360	1365	1400	1370
11	1050	1010	980	1000	1070	1020	1030	1090	1065	1030	1020	40	950	880	890	880	980	1015	1130	1140	1174	1240	1220
12	1225	1230	1180	1165	1165	1150	1065	1175	1363	1070	1040	41	1005	945	1015	1160	1095	1150	1095	1135	1185	1230	1190
13	1030	1000	1040	1010	1085	1060	995	1040	1090	1050	1000	42	950	990	920	910	1040	1100	1045	1070	1178	1200	1210
14	990	880	1050	975	1100	1120	1087	1060	1040	990	910	43	1065	1035	845	980	1140	1040	1245	1210	1237	1230	1200
15	665	615	640	645	725	700	710	695	750	700	660	44	1050	850	925	870	1070	960	1175	1425	1477	1530	1320
16	1030	1000	1020	1040	1080	1040	945	990	990	990	920	45	1040	975	1070	1100	1045	1080	1088	1230	1235	1200	1160
17	1075	1140	1120	1035	1164	1245	1120	1150	1170	1170	1100	46	1110	1040	1090	1100	1105	1020	1080	1125	1185	1075	1130
18	1200	1150	1250	1300	1300	1250	1200	1260	1200	1170	1120	47	1055	1096	1070	1030	1075	1015	1010	1056	1105	1040	1100
19	975	950	970	950	986	950	950	965	980	980	935	48	1020	1090	1075	1140	1010	1075	1075	1050	1065	1055	1125
20	720	670	720	690	715	680	725	790	825	785	780	49	1225	1050	1090	1130	1075	1085	1100	1005	1087	1020	1010
21	705	640	635	685	650	690	735	755	765	750	760	50	1170	1155	1015	1060	1120	1150	1150	1225	1265	1280	1260
22	740	700	700	768	740	790	765	775	780	790	770	51	1050	1040	1010	1100	1162	1100	1070	1140	1085	1090	1070
23	845	900	920	850	910	940	900	900	920	915	890	52	1063	1100	1025	1110	1090	1085	1090	1070	1020	1035	1020
24	1120	1150	1200	1200	1234	1170	1160	1235	1180	1130	1150	53	1040	1015	1090	1050	1070	1080	1015	1040	1090	1045	1040
25	1110	1280	1200	1120	1180	1170	925	1145	1065	950	900	54	1015	950	1000	1060	1025	1060	975	1000	1065	1050	1000
26	815	950	980	900	1000	1000	900	960	935	900	850	55	965	970	885	895	1005	1050	812	910	1035	1120	1090
27	755	720	680	665	686	700	720	700	710	710	680	56	1035	1055	1045	1090	1095	1175	1125	1145	1115	1210	1200
28	735	655	650	645	700	740	700	680	710	710	700	57	1190	1070	1040	1145	1065	1160	1145	1270	1285	1290	1280
29	1020	1016	970	1090	1110	1100	1050	1020	1040	1020	1000	58	1274	1100	1175	1200	1230	1295	1225	1280	1290	1300	1290

TABLE 1
CALCULATED NODAL TDS VALUES FOR YEARS 1957 THROUGH 1967
(in mg/l)

10	NODE YEAR												NODE YEAR											
	NUMBER	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	NUMBER	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
	59	1096	1190	1190	1130	1060	1025	1055	1050	1075	1330	1280	88	840	860	840	885	835	845	850	865	855	865	900
	60	1020	1070	1130	1000	1020	1130	1140	1010	1140	1150	1125	89	860	865	860	896	885	896	870	865	870	865	870
	61	1350	1300	1310	1325	1325	1310	1290	1320	1325	1390	1380	90	950	945	965	950	945	1040	950	960	985	975	1000
	62	1465	1430	1470	1475	1440	1440	1480	1480	1465	1440	1500	91	380	375	380	405	400	375	400	425	430	420	400
	63	1060	1100	1130	1055	1120	1025	1120	1080	1020	1125	1100	92	800	790	800	840	940	950	1140	1120	1100	1180	1200
	64	1035	1010	1075	1045	1035	1060	1130	1030	1105	1100	1060	93	1160	1168	1190	1310	1447	1410	1520	1730	1830	1805	1760
	65	1065	1025	1030	1130	1120	1125	1100	1125	1115	1050	1050	94	300	290	330	345	345	340	335	300	300	340	345
	66	1034	1000	970	1080	1040	1070	1100	1075	1055	1010	1000	95	470	450	460	500	510	500	480	495	495	470	450
	67	1038	1000	1010	990	1000	1100	1035	1015	1035	1000	1020	96	380	390	360	375	350	390	420	365	380	435	425
	68	1055	1070	975	1065	945	1065	945	995	990	1015	1050	97	870	730	845	930	745	775	840	800	945	985	1000
	69	978	980	985	955	990	980	924	925	905	915	910	98	750	770	790	740	795	770	740	700	765	825	850
	70	1010	980	965	970	990	920	905	995	985	1045	1010	99	400	380	375	410	400	415	410	390	435	395	380
	71	1085	1050	1065	1070	1055	1135	1135	1065	1115	1070	1080	100	500	480	480	515	525	510	555	450	485	515	500
	72	1065	1100	1070	1050	1000	1050	1035	1045	1065	1210	1160	101	625	585	620	650	685	640	665	625	645	610	635
	73	1080	1035	990	870	900	1240	960	910	1030	1185	1175	102	670	670	700	700	750	705	700	645	635	625	610
	74	925	935	925	960	975	890	970	980	1000	1000	1000	103	575	590	590	545	595	595	645	610	625	615	620
	75	970	990	985	1010	935	950	975	995	975	975	960	104	650	610	620	650	640	610	705	700	700	715	700
	76	935	900	1020	1000	925	975	1050	1043	960	945	940	105	655	630	640	725	780	750	730	815	750	725	680
	77	1190	1200	1250	1140	1180	1175	1280	1265	1176	1190	1200	106	600	565	655	585	635	650	635	640	625	630	625
	78	1130	1140	1140	1090	1125	1170	1155	1260	1185	1205	1100	107	875	830	850	875	850	900	900	950	920	920	935
	79	1050	1000	975	1030	1050	1035	1050	1065	1087	1110	980	108	1240	1210	1225	1250	1290	1180	1230	1275	1240	1260	1270
	80	870	850	930	865	880	860	870	890	911	890	890	109	975	1000	940	950	950	940	930	1000	1020	1040	1020
	81	1020	1050	1030	1020	1025	1130	1050	1050	1035	1070	1050	110	640	590	605	635	690	655	610	610	680	680	700
	82	920	880	945	990	910	990	1000	970	950	945	940	111	625	625	640	650	675	610	600	625	655	635	600
	83	910	910	935	975	979	955	935	935	910	930	925	112	650	660	645	625	628	630	600	660	685	665	690
	84	930	915	915	960	935	925	915	970	910	945	930	113	810	825	835	840	840	855	855	850	800	825	840
	85	985	940	920	947	980	950	1100	1100	1045	1050	1050	114	840*	830*	790*	800*	860*	820*	840*	864*	850*	815*	820*
	86	885	990	945	935	965	935	945	1060	1127	1175	1170	115	825*	785*	800*	820*	835*	810*	830*	864*	875*	840*	815*
	87	1450	1600	1465	1540	1595	1575	1690	1745	1775	1800	1850	116	825	840	805	800	850	900	850	905	845	855	870

TABLE 1
CALCULATED NODAL TDS VALUES FOR YEARS 1957 THROUGH 1967
(in mg/l)

NODE NUMBER	YEAR 1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	NODE NUMBER	YEAR 1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
117	1050	950	965	970	1100	1050	1100	1120	1130	1095	1080	138	850*	865*	870*	890*	865*	840*	830*	810*	840*	855*	820*
118	1250	1215	1265	1225	1240	1270	1300	1220	1270	1300	1200	139	790*	780*	760*	770*	795*	794*	780*	790*	770*	800*	790*
119	1225	1180	1195	1230	1260	1240	1220	1200	1265	1275	1275	140	860*	890*	840*	880*	850*	845*	830*	870*	855*	890*	860*
120	850	785	855	850	900	880	900	865	888	810	820	141	1100*	1215*	1050*	1185*	1260*	1165*	1175*	1165*	1135*	1175*	1150*
121	1050	980	960	1130	1110	1025	1035	1030	1015	1000	950	142	845*	855*	830*	850*	825*	860*	870*	860*	835*	845*	830*
122	830*	850*	850*	845*	850*	850*	840*	820*	820*	810*	810*	143	760*	790*	760*	810*	740*	790*	780*	760*	780*	755*	740*
123	860*	885*	890*	890*	885*	865*	840*	840*	830*	830*	820*	144	780*	760*	775*	790*	765*	785*	780*	810*	790*	785*	780*
124	1000*	976*	960*	1000*	1010*	1017*	1000*	970*	1030*	980*	970*	145	800*	776*	780*	800*	780*	790*	800*	800*	820*	810*	800*
125	865*	860*	850*	865*	855*	880*	860*	840*	870*	870*	880*	146	860*	830*	860*	820*	815*	850*	830*	820*	840*	825*	835*
126	840*	810*	860*	850*	945*	865*	870*	850*	880*	945*	890*	147	880*	890*	880*	875*	910*	870*	870*	880*	880*	860*	870*
127	875*	850*	860*	860*	900*	850*	840*	840*	870*	900*	900*	148	945*	920*	930*	945*	965*	970*	950*	960*	940*	920*	930*
128	900*	860*	890*	910*	925*	920*	860*	860*	865*	925*	900*	149	1010*	1000*	1040*	1010*	1025*	1020*	1035*	1000*	1025*	1030*	1030*
129	910*	880*	900*	930*	930*	890*	875*	875*	880*	930*	940*	150	900*	890*	910*	900*	883*	890*	910*	915*	870*	880*	870*
130	920*	910*	930*	920*	955*	892*	900*	900*	900*	935*	920*	151	880*	895*	870*	885*	890*	860*	880*	890*	870*	870*	865*
131	980*	985*	960*	1005*	1015*	1020*	1000*	1010*	1005*	945*	930*	152	875*	870*	890*	845*	860*	880*	865*	870*	850*	890*	880*
132	1015*	996*	1000*	1035*	1040*	1030*	1010*	1040*	990*	990*	980*	153	870*	860*	900*	854*	845*	860*	840*	880*	870*	865*	870*
133	1000*	980*	960*	1040*	1030*	1020*	1070*	1050*	970*	975*	960*	154	850*	890*	860*	850*	865*	840*	815*	820*	840*	835*	820*
134	1030*	1020*	1010*	1030*	1000*	1040*	1060*	1090*	1020*	1020*	1030*	155	830*	840*	830*	855*	815*	818*	805*	789*	825*	840*	830*
135	950*	936*	920*	950*	970*	920*	960*	990*	970*	945*	960*	156	790*	822*	770*	810*	785*	797*	782*	790*	794*	810*	780*
136	950*	955*	936*	969*	970*	903*	937*	908*	934*	885*	900*	157	825*	816*	828*	842*	835*	820*	830*	798*	820*	810*	810*
137	880*	920*	920*	930*	870*	880*	880*	900*	870*	880*	900*	158	850*	840*	862*	870*	880*	860*	870*	820*	852*	850*	860

*Estimated TDS values from poor to insufficient data.

The character of ground water is affected by the chemical composition of the aquifer sediments and other sediments surrounding the basin, as well as by surface water inflow that percolates to the ground water table.

The major ionic constituents in ground water of the Piru Basin are calcium and sulfate. Less dominant ions are magnesium, sodium, potassium, bicarbonate, nitrate, chloride, boron, fluoride, and silica.

Analyses of ground water samples prior to 1956 showed that the water had a calcium-magnesium-sodium sulfate character, with magnesium and sodium varying in their relative concentrations.

In the eastern part of the Basin, above the confluence of Piru Creek and the Santa Clara River, TDS concentration in 1956 ranged from 2,200 to 2,600 mg/l (Figure 2). During the study period, the concentration has fluctuated only slightly. This fluctuation is apparently related to changes in the weather cycle when the volume of surface water entering or leaving the Basin varies. During wet years with high flows, TDS levels in surface water are generally low; during dry years with low flows, levels tend to be high. These surface water flows recharge the ground water basin, causing an increase or decrease in the concentrations in ground water, depending on the TDS levels of surface water. Additional effects result from irrigation return and subsurface inflow from the bordering sediments.

In the western part of the Basin, near the town of Piru, ground water is of better quality. Historically, TDS concentrations ranged from 900 to 1,400 mg/l. The lower concentrations occurred along the Santa Clara River, below the confluence of Piru Creek and the Santa Clara River. Farther westward, close to the boundary with the Fillmore Basin, the concentrations of TDS remained within the range of from 1,000 to 1,200 mg/l.

Toward the Piru Basin's southern border, the concentration increases and ground water is generally of poor quality. The tributary streams from Oak Ridge Mountain probably contribute runoff and subsurface flows of high salinity, which is probably one of the causes of the local high concentration of mineral constituents in ground water.

During the study period, TDS concentration in this Basin has remained almost unchanged from 1956 to 1967, except for an increase during 1960 and 1961 and again in 1964 and 1965. The increase during those years has been offset by percolation of surface water of low salinity in the intervals of high flows. Historic analyses show that the concentrations of nitrate and boron have increased 40 to 50 percent and 15 to 20 percent, respectively. The main sources of nitrate are irrigation return and septic tank effluents.

Fillmore Ground Water Basin. In the westerly course of the Santa Clara River, the next ground water basin is Fillmore. It is connected to the Piru Basin to the east and to the Santa Paula Basin to the west. The Basin is 4-1/2 miles wide and 9-1/2 miles long.

In this Basin, wells with records of water quality analyses are more evenly distributed. Also, there are a greater number of wells with continuous records of analysis during the study period. Most of the wells extract ground water from a depth of 300 feet or less, while the remainder extract from depths of 600 feet or less, with only a few descending to 1,000 feet or less.

The ground water system in the Fillmore Basin ranges from unconfined to partially confined. This condition probably affects the movement and diffusion of mineral ions, both vertically and laterally. Since most of the wells have their perforations at different intervals, the water in the sample is considered a mixture and thus reflects the quality of water from sediments surrounding the well.

The mineral quality of the ground water is affected by (a) the percolation of high and low flows of the Santa Clara River and its tributaries; (b) surface flows of Sespe Creek and its tributaries; (c) subsurface flows from the Piru Basin and adjacent highlands; and (d) irrigation return.

Analyses of ground water prior to 1956 indicate that the predominant ions are calcium and sulfate. The historic chemical character of the ground water north of the Santa Clara River is calcium-magnesium sulfate-bicarbonate. During the early study period, the concentration of sodium was higher than that of sodium. South of the Santa Clara River, the chemical character of ground water was calcium-sodium sulfate throughout the study period, with an increasing trend in nitrate concentration.

The 1956 isosalinity map (Figure 2) indicates that TDS concentrations in the Basin ranged from 400 to 1,800 mg/l. Generally, the concentration north of the Santa Clara River was less than 1,000 mg/l. Near Sespe Creek, ground water had TDS concentrations ranging from 400 to 800 mg/l. The lower TDS was probably due to the effect of surface water percolation from Sespe Creek, whose TDS ranged from 325 to 1,900 mg/l. The TDS concentrations of ground water north and south of the Santa Clara River ranged from 900 to 1,000 mg/l. Ground water of poor quality was found along the southern border of the Basin, where the concentration was above 1,700 mg/l. The concentrations near the Basin's eastern border with the Piru Basin were from 800 to 900 mg/l and from 900 to over 1,000 mg/l, near the western boundary with Santa Paula Basin.

The 1958 analyses indicate an increase in TDS concentration from 100 to 200 mg/l in most of the Basin, except where Sespe Creek enters the Valley. The data also show an increase in concentration from 400 to 600 mg/l in the western part of the Basin.

In 1960, there was an overall decrease in concentrations in most of the Basin, except along its southern border, where concentrations increased over 200 mg/l (Figure 3).

The 1962 analyses show an increase in concentration of from 150 to 200 mg/l throughout the Basin.

In 1964, there was a slight improvement in the quality. The decrease was in concentration over 100 mg/l along the southern border, as well as north of the confluence of Sespe Creek and the Santa Clara River.

The 1966 isosalinity map disclosed an improvement in quality in the western part of the Basin (Figure 4). There was a slight change in concentration from 1964 to 1966 in the rest of the Basin.

Santa Paula Ground Water Basin. The Santa Paula ground water basin lies between the Fillmore Basin on the east and the Mound and Montalvo Basins (Oxnard Forebay) on the west. It has an average width of 3-1/2 miles and a length of 10-1/2 miles.

Wells having records of water quality analyses are evenly distributed through the Basin. Most of them have been drilled to depths of 300 feet or less, some to depths of 600 feet or less, and a few to over 900 feet.

Ground water in this Basin is mostly unconfined. Wells drilled have been perforated at various depths so as to intersect both the confined and unconfined water-bearing sediments. Therefore, most of the water sampled is a mixture of water from the various aquifer horizons and the TDS concentration is representative of the quality of water in sediments adjacent to the well.

The mineral quality of the ground water is influenced by the percolation of high and low streamflow of the Santa Clara River and intermittent flow of small tributaries. At high and low flow, TDS ranged from 563 to 1,525 mg/l. Flow from Santa Paula Creek generally provided water of low TDS during periods of high flow, with an increase at low flow, ranging from 188 to 1,082 mg/l.

Prior to 1956, the chemical character of the ground water was calcium-sulfate and calcium-sodium sulfate, with calcium sulfate predominant. Toward the end of the study period, calcium sulfate predominated. Calcium sulfate ground water occurs in most of the Basin, except north of the Santa Clara River and southwest of the town of Santa Paula.

The 1956 isosalinity map showed that TDS in the eastern portion was less than 1,000 mg/l (Figure 2). TDS concentrations of ground water increased southwestward, along the Santa Clara River, where it was over 1,200 mg/l. Where the Wheeler and Aliso Creeks discharged water into the Valley, the quality of ground water deteriorated and TDS increased, the average being over 1,400 mg/l. During 1958, quality improved and TDS decreased through most of the Basin. The TDS decrease during 1956-58 ranged from 200 to 300 mg/l. In 1960, TDS increased near the River and toward the eastern boundary of the Basin (Figure 3). Elsewhere in the Basin, the change in TDS was slight. The 1962 analyses show an increase in TDS of 200 mg/l through most of the Basin. However, the largest increase occurred in the eastern part, where concentrations ranged from 1,200 to 1,400 mg/l. This increase in salinity occurred above and below the confluence of Santa Paula Creek and the Santa Clara River. In 1964, data showed a small decrease through most of the Basin, with the largest decrease north of the City of Santa Paula.

In 1966, a slight increase in TDS was found near Santa Paula (Figure 4). Further southwestward, near the Santa Clara River, TDS increased approximately 100 mg/l and near the southern part of the Basin it increased approximately 200 mg/l. Isosalinity contours suggest that TDS in ground water inflow at the boundary with the Fillmore Basin was about 950 mg/l and the average TDS of ground water outflow in the Mound and Montalvo Basins ranged from 1,200 to 1,800 mg/l. This difference in TDS between the subsurface inflow and outflow suggest salt input by water percolations from tributaries of the Santa Clara River and irrigated agriculture.

Mound Ground Water Basin. Mound Basin is northwest of the Oxnard Plain. It is bounded on the east by the Santa Paula Basin, on the north by Sulphur Mountain, and on the west by the Pacific. It is separated from the Oxnard Plain Basin by an apparent extension of the Oak Ridge fault. The Santa Clara River traverses this Basin near its southern border.

Data on the historic quality of ground water in the Mound Basin are meager, due to the small number of wells sampled.

Wells occur mostly in the southern part of the Basin, next to the Santa Clara River. To the north, along the Mountain front, ground water is undeveloped and consequently, there are no wells. Hence, the historic quality of ground water is based on the wells in the southern part of the Basin.

Prior to 1956, the character of the ground water was calcium-sodium sulfate. Analyses from one well having a continuous data record showed that the calcium ions were more prevalent prior to 1926 and during the early part of the study period. Toward the end of the period, the difference between the concentrations of calcium and sodium ions was relatively slight and the chemical character of the water fluctuated from calcium-sodium to sodium-calcium sulfate.

In 1956, TDS in ground water north of the Santa Clara River was approximately 1,000 mg/l (Figure 2). It is probable that ground water increased in concentrations of TDS toward the north because of percolation of runoff from Sulphur Mountain in the Valley floor. The quality of ground water showed a slight degradation in 1958, with an increase in TDS ranging from 100 to 200 mg/l. In 1960, the quality improved, with a decrease in TDS (Figure 3). The 1962 data showed that the quality had not changed from 1960 to 1962. Further deterioration in water quality, with increases in TDS, was shown in the 1966 isosalinity map (Figure 4).

In the northern part of the Basin, it was not possible to determine changes in the quality of ground water, due to lack of data. However, few available analyses suggest that TDS concentration is directly related to surface water TDS.

Montalvo Ground Water Basin. The Montalvo Basin, referred to sometimes as the Oxnard Forebay, is northwest of the Oxnard Plain. It is bounded on the east by Santa Paula Basin; on the south and west by the Oxnard Plain, and separated from the Mound Basin by the Oak Ridge fault on the north.

In developing the mathematical ground water quantity model of the Santa Clara-Calleguas area, the Oxnard Plain was considered as containing two layers, the upper composed of the Oxnard and Mugu aquifers, the lower of the Hueneme, Fox Canyon, and Grimes Canyon aquifers. The Montalvo Basin is regarded as the recharge area for the Oxnard Plain aquifers.

Wells having records of water quality data are distributed rather evenly through the Basin, 40 percent having a continuous record of analyses covering the entire study period and 40 percent having perforated intervals between depths of 100 to 200 feet. Perforations of the other wells range from 50 to 450 feet in depth with only a few perforated from 500 to over 1,000 feet in depth. Consequently, most of the wells including those in the Oxnard and Mugu aquifers, are perforated in the upper layer. Wells perforated only below 500 feet down to 1,700 feet extract water from the lower layer, including Hueneme, Fox Canyon, and Grimes Canyon.

In this Basin, ground water is extracted from both the upper and lower zones of the water-bearing sediments. Historic TDS of ground water will be examined in the two separate layers.

Upper Aquifer Zone. The quality of ground water in the upper layer of the Montalvo Basin is affected by percolations of surface flow from the Santa Clara River and recharge area. It is also affected by subsurface flow from the Santa Paula and Mound Basins.

Prior to 1956, the character of the ground water was calcium-sodium sulfate. Toward the end of the study period, its predominant character was calcium sulfate.

The 1956 isosalinity map showed that TDS was approximately 900 mg/l south and adjacent to the Santa Clara River (Figure 2). Farther from the River, TDS increased to from 1,200 to 1,300 mg/l. 1958 quality data showed a slight increase in 100 mg/l TDS through most of the Basin. In 1960, the isosalinity map showed further deterioration in water quality, with an increase in TDS of about 150 mg/l throughout the Basin (Figure 3).

The 1962 data showed an increase in TDS north and south of the Santa Clara River. Farther from the River and toward the Basin's southern border, TDS decreased and was in the order of from 800 to 900 mg/l. Analyses of the 1964 samples showed that the TDS of ground water near the northern boundary increased by several hundred mg/l to a maximum of about 1,500 mg/l. TDS in the rest of the Basin ranged from 1,000 to 1,200 mg/l.

The 1966 isosalinity map showed an improvement in quality in 60 percent of the Basin, with TDS from 800 to 1,000 mg/l (Figure 4).

Lower Aquifer Zone. Data on TDS in ground water in the lower zone are based on a few wells that extract water from the deeper aquifers. TDS from this source has remained virtually unchanged during the study period, ranging from 900 to 1,000 mg/l. Because records cover only the later period, current data are insufficient to determine annual changes in TDS. As for the character of the ground water, it is calcium sulfate.

Oxnard Plain Ground Water Basin. The Oxnard Plain Basin is bounded on the north by the Mound and Montalvo Basins; on the east, by the Las Posas and Pleasant Valley Basins; and on the southwest by the Pacific. The Santa Clara River crosses the Basin at its northern sector, near its boundary with the Mound Basin, and Calleguas Creek crosses the southern sector of the Plain.

In the mathematical quantity model of the Santa Clara-Calleguas Basins, the Oxnard Plain is classed as a two-layer system; the upper is composed of the Oxnard and Mugu aquifers; the lower, of the Hueneme, Fox Canyon, and Grimes Canyon aquifers.

The ground water reservoir is considered a confined ground water system, consisting of five separate confined aquifers separated by clay layers ranging in thickness from 10 feet or less to over several hundred feet. The uppermost aquifer, the Oxnard, is covered by a confining layer of silt and clayey materials, forming a relatively impervious zone. This clayey layer is partially effective in preventing percolation that can influence the ground water quality in the Oxnard aquifer in most of the area. Above the clay cap lies a perched aquifer, which is not included in the model study. However, because leakage occurs from that perched aquifer into the modeled upper aquifer zone, data on its quality were evaluated and estimates were made of the historic

TDS concentration of leakage water. Table 2 shows average nodal TDS concentration of perched water in the Oxnard Plain.

TABLE 2
AVERAGE HISTORIC TDS CONCENTRATION OF WATER IN THE
PERCHED AQUIFER OF THE OXNARD PLAIN

Node	TDS (mg/l)	Node	TDS (mg/l)
69	4,600	70	3,660
71	3,250	72	4,536
73	4,230	74	3,500
75	2,570	76	2,810
77	2,650	78	2,940
79	2,460	80	3,065
81	3,390	82	3,160
83	3,190	84	3,260
85	3,610	86	3,414
87	3,600	88	2,682
89	3,386	90	3,486

Numerous water wells in the Oxnard Plain are drilled to various depths and are evenly distributed throughout the Basin. Prior to and during the study period, samples have been collected from these wells, the accumulated analyses being used to construct isosalinity maps for selected years of the study period.

Wells used in this study were perforated at various depths; consequently, samples from them are probably mixtures of water from several aquifers. Seventy percent of the data are from wells with perforated depth intervals ranging from less than 100 feet to less than 350 feet. The source of ground water in these wells is the upper layer, which includes the Oxnard and Mugu aquifers. Other wells included in the study are perforated from depths of less than 350 feet to 500 feet. Wells perforated only below 500 feet were considered to be extracting water from the lower layer, which includes the Hueneme, Fox Canyon, and Grimes Canyon aquifers.

Upper Aquifer Zone. In the early part of the study, the ground water in the upper layer could have been described as calcium-sodium sulfate in character. Toward the end of the period, however, its character was calcium sulfate.

The 1956 isosalinity map showed that TDS in the northern part of the Basin ranged from 1,000 to 1,200 mg/l (Figure 2). Quality improved toward the southern part where TDS ranged from 700 to 800 mg/l. Near the Ocean, it also ranged from 700 to 800 mg/l, except near Point Mugu, where it soared to over 10,000 mg/l, and at the boundary of the Pleasant Valley and Las Posas Basins it ranged from 600 to 1,600 mg/l.

In 1958, TDS increased by about 200 mg/l in the northern part of the Basin, while in the southern part the increase was less than in 1956. Near the eastern edge of the Basin, ground water quality improved, with a decrease in TDS concentration to an average of 800 mg/l.

The 1960 isosalinity map showed improved quality throughout the Basin, except where aquifers had been invaded by sea water (Figure 3).

In 1962, analyses of quality data showed degradation, with an increase in TDS throughout the Basin, except near the Pleasant Valley road. The TDS increase was as much as 300 mg/l in some localities. The 1964 data on water quality showed an overall improvement in quality over 1962 due to a decrease of several hundred mg/l in TDS, except for areas of sea-water intrusion.

The 1966 isosalinity map revealed that ground water quality in the Basin remained unchanged, save for south of its border with the Montalvo Basin, where one area showed an increase in TDS and another showed a decrease (Figure 4). This change was probably due to a localized effect that caused a TDS increase in a few wells.

Lower Aquifer Zone. The number of wells extracting water from the lower aquifers is small in relation to the number extracting from the upper aquifers.

Of the wells in the Oxnard Plain Basin having records of water quality analyses, only 11 percent have data on ground water quality in the lower aquifers. Those wells are perforated below 500 feet of ground surface. Because few have records of analyses prior to and during the study period and because many lack continuity of analysis, evaluation of ground water quality must be preliminary until more data are available for a complete analysis of water from these wells. However, available data from a few wells indicate that TDS ranges from 600 to 850 mg/l.

Because of meager data and incomplete data records, the yearly average TDS for the lower layer is merely an estimate. However, the few wells for which there is a long-time analysis record show slight fluctuations in TDS, with an increase over a period of time.

Sea-Water Intrusion. There are two localities in the Oxnard Plain where the Oxnard aquifer has been invaded by sea water -- Port Hueneme and Point Mugu.

Water quality data on wells near Port Hueneme showed that in the fall of 1953 concentrations of chloride were high, with TDS over 4,000 mg/l. Water quality analyses for other wells suggested a definite degradation by sea water in 1959, and a frontal wedge of sea water extruding into a larger area from 1960 through 1962.

Water quality data on the lower zone aquifers indicate that they have not been degraded by sea water.

Data on one well near the Point Mugu lagoon indicate definite degradation before the study period, with a high concentration of chloride in the fall of 1953 and it has increased since then. In the fall of 1963, data showed that TDS was over 25,000 mg/l.

Data on wells perforated in the lower aquifer zone did not reveal any sea-water intrusion. (A detailed discussion of sea-water intrusion is in Chapter 5).

Las Posas Ground Water Basin. This Basin is included in the Santa Clara-Calleguas Basin study and is a single confined aquifer system. It is bounded on the west by the Oxnard Plain; on the north by the South Mountain; on the east by the Oak Ridge Mountain; and on the southwest by the Las Posas Hills and Pleasant Valley.

The number of wells for which there is water quality data amounts to less than 40, and they are scattered throughout the Basin. The wells used in this water quality study penetrate the widespread Fox Canyon and Grimes Canyon aquifers.

The isosalinity maps of this Basin were based on a few wells; hence, interpretation was necessary in developing the maps. However, analysing data from the wells having complete records suggests that the TDS of ground water has remained relatively unchanged during the study period. The ground water is calcium-sodium bicarbonate in character, with TDS ranging from less than 200 to 450 mg/l.

The 1956 isosalinity map indicated that the average TDS in the eastern part of the Basin was about 200 mg/l, while in the western part TDS ranged from 300 to 700 mg/l (Figure 2). Ground water near the Arroyo Las Posas Creek was of poor quality, with TDS reaching 2,000 mg/l.

The 1958 data on water quality showed that TDS remained relatively unchanged throughout the Basin. The 1960 isosalinity map revealed a slight deterioration in water quality, with an increase of TDS in the eastern sector, while the rest of the Basin showed little change (Figure 3).

The 1962 analyses of water quality showed an improvement in water quality, with a reduction in TDS in most of the Basin, except near the Arroyo Las Posas.

The 1966 isosalinity map indicated that quality changed little from 1962 to 1966 (Figure 4). However, this map was based on less data; thus, the conclusion with respect to quality change since 1962 was not corroborated by the evidence.

Pleasant Valley Ground Water Basin. This Basin is bounded on the west by the Oxnard Plain; on the north, by Las Posas Basin; on the east, by the Santa Rosa Basin; and on the southeast, by the Santa Monica Mountains. It is a single confined aquifer system.

The number of wells for which there is water quality data is unevenly distributed throughout the Basin. They penetrate the deeper aquifers of the Fox Canyon and Grimes Canyon.

The 1956 isosalinity map disclosed that TDS near the western and northern edges of the Basin ranged from 600 to 800 mg/l, increasing near Calleguas Creek and the Santa Monica Mountains (Figure 2).

The 1958 analyses of water quality data showed that TDS decreased slightly throughout the Basin. The 1960 isosalinity map showed a TDS increase over 1958 by 100 to 150 mg/l (Figure 3). The 1962 data on water quality showed further deterioration in quality in the southern and eastern sectors of the Basin. The 1964 water quality data and 1966 isosalinity map revealed an improvement in quality, with a concomitant reduction in TDS of from 75 to 150 mg/l throughout most of the Basin (Figure 4).

Santa Rosa Ground Water Basin. The Santa Rosa Basin is bounded on the north by the Las Posas Hill; on the south and east, by the Conejo Hills and Mountcliff Ridge; and on the west, by the Pleasant Valley. The Basin is 1-1/4 miles wide and 4-1/2 miles long.

Only a few wells have a continuous record of ground water analyses, with many more having incomplete records because of intermittent water sampling. The geographical distribution of wells for which there are water quality analysis records is uneven, most of them being in the western and southern sectors of the Basin.

The bulk of the wells in the eastern sector have been drilled to depths from 200 to less than 600 feet. Toward the west, depths range from 200 to less than 1,000 feet. Seventy percent have been drilled to depths of 500 feet or more, most of them having perforated intervals ranging from 300 to 800 feet deep.

Analyses of ground water prior to 1956 indicated that its historic chemical character was predominantly magnesium-sodium bicarbonate. A few wells in the western part were predominantly sodium and calcium.

The 1956 isosalinity map showed that TDS ranged from 500 to 700 mg/l, with the highest concentration where Conejo Creek enters the Basin (Figure 2). This increase in ion concentration was probably due to stream percolation and solution of minerals from weathered volcanic sediments.

The 1958 analyses of ground water revealed that TDS has remained almost unchanged since 1956, while the 1960 isosalinity map revealed a slight decrease (Figure 3).

The 1962 data on water quality indicated an increase in TDS, particularly along the southern border adjacent to the volcanic sediments, the concentration ranging from 500 to 900 mg/l. Along the Las Posas Hills, TDS ranged from 500 to 600 mg/l. In 1962, along the southern border, TDS increased by 200 mg/l since 1960.

The 1964 analyses of ground water showed an improvement in quality with a decrease in TDS near the southern border. The 1966 isosalinity map (Figure 4) on the other hand showed a TDS increase in the western part, though in the rest of the Basin ground water quality had not changed since 1964. TDS ranged from 500 mg/l in the eastern part to 900 mg/l in the western in 1966.

Depth of Zone of Mixed Yield

Based on well depth data, average well depths (zone of mixed yield or face) were calculated for the free water aquifer nodes. Originally estimated elevations of the faces of the nodes were subject to change during the verification of the model. Final values of the verified model are shown in Table 3.

Historic Quality of Ground Water Below the Zone of Mixed Yield

Well water analyses were also helpful in estimating the average TDS of ground water below the zone of mixed yield in the free water nodes. Historic data of the deepest well were used to calculate TDS (Table 4).

TABLE 3

AVERAGE NODAL ELEVATION OF "FACE" OR THE BOTTOM
OF THE ZONE OF MIXED YIELD

Node	: Face elevation	:	Node	: Face elevation
:	(in feet)	:	:	(in feet)
1	350		35	-205
2	500		36	-70
3	-110		37	100
4	-40		38	-85
5	150		39	-125
6	185		40	20
7	125		41	-146
8	-60		42	-200
9	165		43	-40
10	160		44	-670
11	200		45	-180
12	210		46	-120
13	80		47	-185
14	100		48	-240
15	220		49	-320
16	200		50	-150
17	200		51	-245
18	180		52	-250
19	60		53	-255
20	220		54	-265
21	0		55	-155
22	70		56	-105
23	75		57	-35
24	75		58	-195
25	80		59	-250
26	100		60	-200
27	100		61	-230
28	-305		62	-780
29	-85		63	-600
30	-145		64	-270
31	35		65	-280
32	10		87	-350
33	-200		105	400
34	-50		106	-240

TABLE 4

AVERAGE HISTORIC TDS CONCENTRATION OF GROUND WATER
BELOW THE "FACE" FROM 1957 TO 1967

Node	:	TDS (mg/l)	:	Node	:	TDS (mg/l)
1		2,200		33		600
2		1,500		34		1,100
3		1,100		35		700
4		1,150		36		1,200
5		1,100		37		1,200
6		1,000		38		900
7		900		39		900
8		1,000		40		800
9		1,200		41		900
10		1,200		42		900
11		1,000		43		900
12		1,000		44		900
13		1,000		45		900
14		900		46		1,100
15		700		47		1,000
16		1,000		48		1,000
17		1,000		49		1,000
18		1,100		50		900
19		900		51		1,000
20		700		52		1,000
21		650		53		900
22		700		54		900
23		800		55		800
24		1,000		56		950
25		800		57		900
26		700		58		900
27		650		59		900
28		700		60		900
29		900		61		1,150
30		1,100		62		1,300
31		1,100		63		1,000
32		1,000				

Historic Quality of Subsurface Inflows

Historical TDS concentrations of subsurface inflows into the study area's boundary nodes were calculated from data of wells adjacent to those boundaries. This was necessary because of the lack of wells outside and adjacent to those boundaries. Table 5 lists TDS concentrations of subsurface flows into the boundary nodes.

Historical Quality of Surface Water

Surface flow in the area's streams, chiefly from rainfall, exhibited monthly and seasonal variations. Flow in all the water courses diminished greatly with the end of the winter rains, though some summer flow was maintained by effluent ground water (rising water) and irrigation return seepage into the streams.

Mineral quality and chemical character of surface water varied greatly with rate of flow, season, and location.

The major causes of salinity in surface water were: (1) leaching of minerals from watershed sediments, (2) evaporation and evapotranspiration, (3) irrigation return, (4) waste water discharges, and (5) repercolation of rising water.

The two main stream systems in the model area are the Santa Clara River in the north and the Calleguas Creek in the south. Locations of surface water sampling are shown on Figure 5.

The Santa Clara River System

During periods of high flows, the Santa Clara River and its main tributaries, Piru, Hopper, Sespe, Wheeler, Aliso, and Santa Paula Creeks, had TDS concentrations of less than 700 mg/l. However, during low flow, TDS was often more than 1,000 mg/l. In general, the chemical character of both high and low flows was calcium to calcium-sodium sulfate.

Historic data showed that the quality of surface water entering Ventura County via the Santa Clara River was high in TDS, ranging from 387 to 1,475 mg/l, calcium-sodium sulfate in character, containing high sulfate concentrations of from 211 to 641 mg/l, and from 261 to 690 mg/l total hardness (TH) as CaCO_3 . Boron (B) concentrations were generally less than 1.0 mg/l, an amount that can be tolerated by most crops.

Above its confluence with Piru Creek, the Santa Clara River received some flow from North Tapo-Canyon and Salt and Eureka Canyon Creeks. The flows had TDS from 4,086 to 8,539 mg/l and were calcium-sodium sulfate-bicarbonate in character. The effect of such flows was reflected in the quality of water in the Santa Clara River above Piru Creek. Based on limited data, TDS in the River ranged from 1,659 to 1,816 mg/l, with sulfate (SO_4) concentrations from 802 to 929 mg/l.

TDS in Piru Creek above Lake Piru ranged from 363 to 1,192 mg/l; SO_4 , from 125 to 638 mg/l; B, from 0.5 to 3.0 mg/l; and TH, from 241 to 673 mg/l as CaCO_3 .

Lake Piru had TDS ranging from 425 to 1,332 mg/l, averaging about 800 mg/l; SO_4 , from 218 to 720 mg/l; B, from 0.5 to 2.3 mg/l; and TH, from 280 to 745 mg/l.

TABLE 5

HISTORIC TDS CONCENTRATIONS OF SUBSURFACE INFLOWS
INTO BOUNDARY NODES

NODE NUMBER	YEAR 1956	YEAR 1958	YEAR 1960	YEAR 1962	YEAR 1964	YEAR 1966	NODE NUMBER	YEAR 1956	YEAR 1958	YEAR 1960	YEAR 1962	YEAR 1964	YEAR 1966
1	1800	1750	2000	1900	2000	2100	41	1200	1300	1250	1300	1350	1400
2	1600	1500	1800	1700	1900	2000	44	900	950	850	800	1000	1100
3	1700	1600	1700	1500	1650	1600	57	1200	1200	1300	1250	1300	1300
4	1400	1500	1600	1400	1500	1550	58	1250	1200	1300	1350	1400	1400
5	900	800	1000	900	950	1000	61	1200	1300	1400	1350	1400	1350
6	2000	2000	1800	1700	1600	1500	62	1300	1350	1350	1300	1450	1400
7	1000	1100	1200	1100	1100	1200	79	1200	800	900	1000	1000	1050
9	1800	1900	1850	1600	1500	1300	80	800	700	500	900	700	800
10	1200	1250	1300	1400	1300	1350	81	1500	700	1200	800	750	700
11	1100	1050	1200	1200	1100	1200	82	1400	900	1200	700	755	700
12	1100	1200	1300	1250	1200	1100	87	1100	1200	1300	1350	1200	1300
13	900	1100	1100	1000	1050	1000	89	800	700	800	950	700	650
14	1000	1200	1100	1000	1000	900	90	1100	1200	1100	1250	1000	1100
15	600	700	750	800	800	850	91	200	200	250	300	300	350
17	1150	1200	1300	1250	1200	1200	92	600	900	950	900	950	1000
18	1200	1300	1400	1500	1400	1400	93	900	750	800	1000	1100	1000
20	500	500	550	500	500	500	94	200	200	250	300	300	350
21	500	500	500	550	600	500	95	200	200	300	350	300	350
22	600	600	600	600	600	600	101	250	300	350	400	350	400
24	1200	1300	1300	1350	1400	1300	102	300	350	400	400	400	450
25	1200	1250	1200	1100	1000	1000	105	500	500	600	650	600	600
27	700	700	650	700	600	600	106	600	600	600	750	700	700
28	500	600	600	700	700	650	107	500	1000	900	1000	900	1000
30	900	1000	1000	1100	1050	1200	108	1100	1200	1300	1200	1100	1000
31	1100	1100	1200	1250	1200	1300	111	500	550	500	550	600	550
33	700	650	700	700	700	750	112	600	600	550	600	600	600
34	1300	1250	1300	1350	1400	1500	118	1200	1300	1400	1400	1250	1200
37	1100	1100	1200	1250	1200	1300	119	1200	1300	1400	1400	1300	1300
38	1100	1050	1200	1300	1250	1300	141	1200	1300	1200	1300	1200	1400
40	1200	1250	1300	1400	1350	1400							

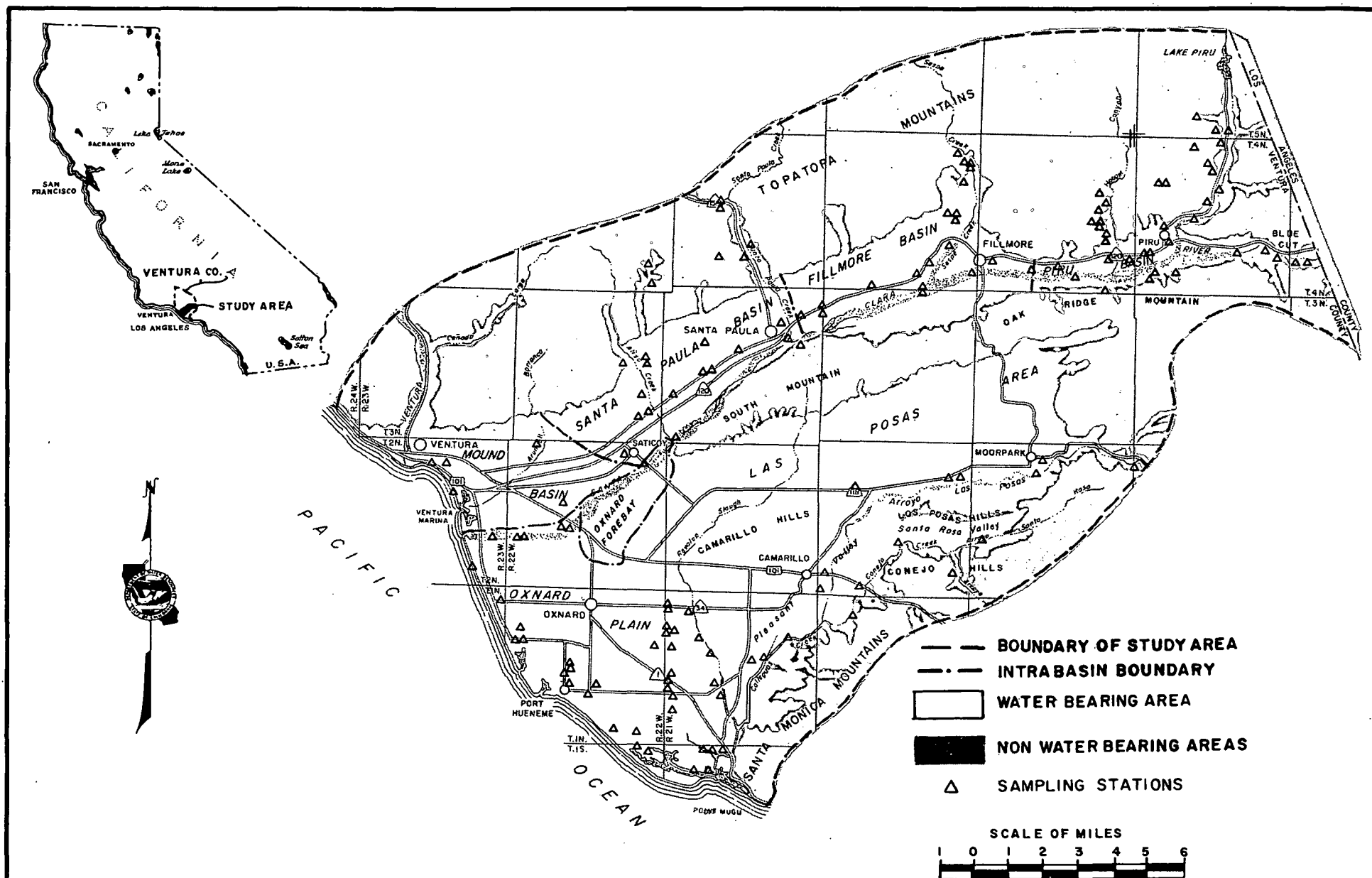


FIGURE 5—SURFACE WATER SAMPLING STATIONS IN THE
 SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

Below Santa Felicia Dam, Piru Creek had TDS ranging from 802 to 918 mg/l; SO_4 , from 404 to 480 mg/l; B, from 0.6 to 0.9 mg/l; and TH, from 479 to 550 mg/l.

Near its confluence with the Santa Clara River, Piru Creek, sampled at flows ranging from 5 to 75 cubic feet per second (cfs), had TDS ranging from 918 to 2,148 mg/l and was calcium-sodium sulfate in character. Sulfate concentrations ranged from 426 to 1,123 mg/l; TH, from 523 to 1,051 mg/l; and B, from 0.8 to 2.3 mg/l. Such water was not suitable for drinking or irrigation of such boron-sensitive crops as citrus.

Hopper Creek, a small tributary of the Santa Clara River, discharged calcium sulfate water, with TDS ranging from 274 to 2,270 mg/l for flows of from 191 to 0.7 cfs, respectively. At low flows, chemical character was sodium-calcium-magnesium sulfate. Farther upstream from its confluence with Santa Clara River, TDS ranging from 1,344 to 8,740 mg/l. The low flows were highest in TDS, sodium, sulfate, and chloride ion concentrations, and also high in boron -- from 0.2 to 8.3 mg/l.

The Santa Clara River above Sespe and below Hopper Creeks had TDS concentrations ranging from 528 to 1,710 mg/l at estimated flows from 5 to 10,000 cfs. The high flows were usually calcium sulfate in character and the low flows, calcium-sodium sulfate. Sulfate concentrations ranged from 271 to 880 mg/l; TH, from 328 to 1,068 mg/l; and B, from 0.4 to 1.1 mg/l. Beside flows from Hopper Creek, the Santa Clara received other surface flows from unnamed smaller canyons.

Sespe Creek, a major tributary of the Santa Clara River, discharged water containing relatively low TDS even during low flow, but with high B; SO_4 , from 88 to 361 mg/l; B, from 0.1 to 2.9 mg/l; and TH, from 123 to 456 mg/l. Contributing flows to the Sespe Creek were also from such smaller tributaries as Little Sespe Creek and Snow Creek.

Below Sespe Creek, TDS in the Santa Clara River ranged from 319 to 1,978 mg/l; SO_4 , from 112 to 981 mg/l; B, from 0.1 to 1.48 mg/l; and TH, from 175 to 970 mg/l, and its chemical character was calcium sulfate.

Santa Paula Creek, another major tributary of the Santa Clara River, discharged water of generally good quality during high flows; during low flows the quality was poorer, though of lower TDS in relation to the Santa Clara River above their confluence. TDS ranged from 188 to 1,082 mg/l; SO_4 , from 36 to 480 mg/l; B, from 0.0 to 10.4 mg/l; and TH, from 110 to 558 mg/l.

Sisar Creek, a tributary of Santa Paula Creek, discharged water of low TDS into the latter. On the other hand, Mud Creek discharged water of high TDS and poor quality into the Santa Paula Creek.

Below Santa Paula Creek's confluence with the Santa Clara River, the River had low TDS at high flows and high TDS at low flows; TDS ranged from 563 to 1,525 mg/l at flows from 300 to 16 cfs. Its chemical character ranged from calcium sulfate to calcium-sodium sulfate. Concentrations of SO_4 , ranged from 264 to 723 mg/l; B, from 0.5 to 0.9 mg/l; and TH, from 365 to 741 mg/l.

At the Santa Clara Diversion to El Rio Spreading Basin, TDS ranged from 511 to 1,745 mg/l.

Wheeler and Aliso Creeks, small tributaries of the Santa Clara River, discharged water of generally poor quality, with TDS ranging from 580 to 2,498 mg/l at flows from 450 to 0.3 cfs and its chemical character sodium-calcium sulfate to sodium sulfate.

Below Wheeler and Aliso Creeks, the River discharged water that was calcium-sodium sulfate in character, with TDS ranging from 400 to 2,049 mg/l. Concentrations of SO_4 ranged from 213 to 1,030 mg/l; B, from 0.1 to 1.5 mg/l; and TH, from 168 to 1,008 mg/l.

West of U. S. Highway 101, near the Pacific, flows of the Santa Clara River had TDS ranging from 345 to 1,903 mg/l at from 2,000 to 0.5 cfs and their chemical character ranged from calcium sulfate to sodium-calcium sulfate. Concentrations of SO_4 ranged from 183 to 1,038 mg/l; B, from 0.0 to 1.0 mg/l; and TH, from 128 to 1,305 mg/l.

The Calleguas Creek System

The Calleguas Creek system discharged relatively minor amounts of water; its flow usually continued only for short periods following rainfalls. For this reason, there were little data for evaluating surface water TDS in this system.

The main water course is designated differently from the Simi area southwestward towards the ocean. Arroyo Simi discharges its water into Las Posas Creek, which, in turn, flows into Calleguas Creek. The main tributaries of the Calleguas Creek system include Tapo, Coyote, Grimes Canyon, and Conejo Creeks. Revlon Slough discharges into Calleguas Creek near the latter's ocean outlet.

In the past, Arroyo Simi discharged water of excellent quality above its confluence with Tapo Creek. Its TDS content ranged from 186 to 365 mg/l and its chemical character was calcium bicarbonate-sulfate. Concentrations of SO_4 ranged from 24 to 139 mg/l; Cl, from 7 to 24 mg/l; NO_3 , from 3 to 20 mg/l; B, from 0.0 to 0.5 mg/l; and TH, from 88 to 197 mg/l.

Tapo Creek, a tributary of Arroyo Simi, discharged water of poor quality into Arroyo Simi, with TDS ranging from 719 to 4,122 mg/l, and, was calcium sulfate in character. Other constituents were SO_4 , from 338 to 1,427 mg/l; Cl, from 35 to 485 mg/l; B, from 0.1 to 4.3 mg/l; and TH, from 415 to 1,587 mg/l.

Below its confluence with Tapo Creek, Arroyo Simi had relatively poor quality. Its TDS ranged from 232 to 1,984 mg/l and its chemical character was calcium sulfate. Sulfate content ranged from 73 to 1,063 mg/l; Cl, from 7 to 180 mg/l; and TH, from 146 to 1,165 mg/l.

Las Posas Creek, near Moorpark, discharged water of poor quality, TDS ranging from 294 to 2,330 mg/l and its chemical character was calcium sulfate. SO_4 ranged from 107 to 1,268 mg/l; Cl, from 12 to 87 mg/l; B from 0.0 to 1.6 mg/l; and TH, from 90 to 1,408 mg/l.

Coyote and Grimes Canyon Creeks discharged good quality water into Las Posas Creek. It had low TDS at high flows (145 mg/l at 136 cfs) and higher TDS at low flows (680 mg/l at 2.5 cfs), its chemical character ranged from calcium bicarbonate at high flows to calcium sulfate at low flows. SO_4 ranged from 20 to 320 mg/l; Cl, from 5 to 42 mg/l; and TH, from 91 to 351 mg/l.

Below the confluence of Coyote and Grimes Canyons, Las Posas Creek discharged flows of good quality, with TDS ranging from 384 to 864 mg/l and calcium sulfate in character. Historical data revealed the following ranges: SO₄, from 104 to 514 mg/l; Cl, from 14 to 55 mg/l; TH, from 254 to 559 mg/l; NO₃, from 3 to 25 mg/l; and B, from 0.0 to 0.2 mg/l.

Conejo Creek, a tributary of Calleguas Creek, discharged water of excellent quality at high flows and of poor quality at low flows, its character ranging from calcium-magnesium bicarbonate-sulfate to magnesium-calcium sulfate. TDS, ranged from 110 to 1,965 mg/l; SO₄, from 14 to 808 mg/l; TH, from 53 to 1,149 mg/l; Cl, from 7 to 224 mg/l; NO₃, from 1.0 to 15 mg/l; and B, from 0.1 to 0.8 mg/l.

Below Conejo Creek, TDS in Calleguas Creek ranged from 264 mg/l at 75 cfs to 2,870 mg/l at 1.0 cfs. SO₄ ranged from 54 to 1,070; Cl, from 19 to 475 mg/l; TH, from 131 to 1,406 mg/l; NO₃, from 1.2 to 16.0 mg/l; and B, from 0.0 to 7.4 mg/l.

Three miles inland from its outlet to the Ocean, Calleguas Creek receives seepage flows from Revlon Slough, which is used chiefly as a waterway for the disposal of irrigation drainage from the Oxnard Plain and Pleasant Valley ground water basins.

In the past, water transported by the Slough had TDS ranging from 3,022 to 11,400 mg/l and was sodium sulfate in character. Sulfate ranged from 1,667 to 6,270 mg/l; Cl, from 168 to 910 mg/l; TH, from 995 to 2,748 mg/l; NO₃, from 1.9 to 17.0 mg/l.

Near its outlet to the Ocean and below its confluence with Revlon Slough, Calleguas Creek discharged water of very poor quality, with TDS ranging from 2,875 to 15,993 mg/l. Chemical character ranged from sodium sulfate to sodium chloride. SO₄ ranged from 1,577 to 2,399 mg/l; Cl, from 277 to 7,304 mg/l; TH, from 970 to 3,460 mg/l; NO₃, from 43 to 66 mg/l; and B, from 1.9 to 3.5 mg/l.

Salinity of Nodal Surface Water Percolation

Evaluation of surface water salinity at different sampling locations was necessary prior to estimating the historic nodal TDS of stream percolation. Table 6 shows the estimated average TDS concentration of stream percolations in the nodes traversed by surface water drainage from 1957 to 1967.

Surface Water Diversions to Spreading Basins

Three spreading basins received surface water diversions during the verification period 1957 - 1967. Historic TDS concentrations of the recharge water to these basins is shown in Table 7.

Historic Quality of Domestic Waste Water

Most of the domestic waste water in the study area is sewered and treated prior to disposal. However, small amounts are discharged to septic

TABLE 6

AVERAGE HISTORIC NODAL TDS CONCENTRATION
OF STREAM PERCOLATION (1957 - 1967)

Node	TDS (mg/l)	Node	TDS	Node	TDS
1	1,400	2	1,200	3	1,200
4	1,000	6	900	7	800
10	1,100	11	1,000	12	1,100
13	1,100	14	1,150	15	600
16	700	17	750	18	750
19	750	20	800	21	700
22	700	23	800	24	800
26	600	27	600	28	400
30	900	31	900	32	1,250
33	1,250	34	2,000	35	2,000
36	1,100	37	1,000	39	1,000
40	1,000	41	800	42	1,300
43	1,000	46	1,000	47	1,000
52	1,000	55	1,300	57	1,300
58	1,650	59	1,650	61	1,650
62	800	63	800	64	1,700
65	750	66	750	67	750
68	2,000	86	27,000	87	27,000
92	450	93	350	105	230
106	270				

TABLE 7

HISTORIC TDS CONCENTRATION OF RECHARGE WATER
(in milligrams per liter)

Spreading Basin	:	Node	:	Year	:	TDS Concentration	:
Piru	:	45	:	1957	:	1,214	:
				1958		1,075	
				1959		1,065	
				1960		1,302	
				1961		1,536	
				1962		871	
				1963		1,079	
				1964		1,041	
				1965		890	
				1966		950	
				1967		760	
El Rio	:	49	:	1957	:	507	:
				1958		511	
				1959		618	
				1960		916	
				1961		1,643	
				1962		1,037	
				1963		1,531	
				1964		1,557	
				1965		1,276	
				1966		1,090	
				1967		869	
Saticoy	:	44	:	1957	:	500	:
				1958		731	
				1959		780	
				1960		1,000	
				1961		1,770	
				1962		1,213	
				1963		1,531	
				1964		1,557	
				1965		1,276	
				1966		1,090	
				1967		869	

tanks and cesspools, especially in the rural portions of the Piru, Oxnard, and El Rio areas. Discharges to septic tanks and cesspools were small in volume and were included in input data for verification of the quality model.

Disposal of domestic waste water, with its abundant solids, in cesspools and septic tanks results in anaerobic digestion and reduction of its soluble and insoluble organic and inorganic matter. Effluent percolating from septic tanks through the unsaturated zone probably contains more TDS than treatment plant effluent TDS if the same waste water were to be sewered. Because of early screening of solids in treatment plants, there is less TDS pickup from domestic use.

Based on data in DWR's reports (1959, 1968, and 1969) and in SWRCB's report (1971), it has been estimated that salt pickup due to domestic use ranges from 300 to 500 mg/l.

In the verification of the quality model, the historic TDS of treatment plant effluents was used. In employing the model for future estimates of ground water quality, 400 mg/l TDS should be added to the TDS content of the water supply to arrive at the TDS concentration of domestic waste water.

Fourteen waste water treatment plants served the study area from 1956 to 1967. Effluents from these plants were disposed of either to the ocean, to permeable stream channels, to spreading basins, to farmland, to oxidation-percolation ponds, or to a combination of those mentioned. Because some of the treatment plants receive industrial waste water at irregular times, analyses show wide variations of quality from one year to the other; not because of a true change of effluent's quality, but mainly because of irregular monitoring and sampling. Judgment was exercised in selecting representative domestic waste water TDS concentrations presented in Table 8. The table gives information about TDS of effluents, their disposal, and source of supply to sewered areas for the 14 treatment plants serving the area. Locations of the plants are shown in Figure 6.

In the past, effluents from four treatment plants in the City of Fillmore, City of Santa Paula, Saticoy Sanitary District, and City of Thousand Oaks percolated to ground water.

Historic Quality of Industrial Waste Water

Industry in Ventura County is diversified, though it consists chiefly of local agricultural products, ocean resources, or oil exploration and exploitation. The principal sources of waste water are citrus washing and packing, vegetable canning, meat and fish processing, chemical plating, and manufacturing. Some high TDS waste water produced by these industries is hauled to impermeable Class I landfills or discharged to the ocean via outfalls. The remainder is discharged to sewers (reaching domestic waste water treatment plants) or evaporation-percolation ponds, cesspools, or streams.

Dependable data are incomplete on historic locations of industrial waste water discharges and TDS concentrations in the waste water. Data on waste water from citrus-packing plants are more dependable.

Citrus-packing Plant Waste Water

The source of information about waste water from citrus-packing plants is the Fruit Growers Laboratory, Inc. report (Table 9). Plate 1 shows their locations.

TABLE 8
DOMESTIC WASTE WATER TREATMENT PLANTS
AND HISTORIC TOTAL DISSOLVED SOLIDS CONTENT OF THEIR EFFLUENTS
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No.:Treatment:Node:Disposal:Reuse:Type of :Source of:							Total Dissolved Solids in Mg/l											
:Plant*	:	:	:	: Waste	: Supply	:	1956	57	58	59	60	61	62	63	64	65	66	67
1	Montalvo Municipal Improve- ment District	66	Santa Clara River	None	Domestic & Industrial	Local Wells	2,260	3,180	2,100	2,458	2,950	2,024	2,038	2,049	1,700	1,756	2,159	2,421
2	Moorpark County Sani- tation District	93	Perco- lation adjacent to Las Posas Arroyo	Irrig.	Domestic	Wells												
3	City of Oxnard, Ormond Beach Treatment Plant	85	Ocean outfall	None	Domestic & Industrial	Wells, Colorado River	1,610	1,604	1,473	2,208	1,987	1,730	1,771	2,360	1,910	2,685	--	--
4	Port Hueneme Sanitary District	85	Ocean outfall	None	Domestic & Industrial	Wells	1,775	1,832	1,650	2,105	1,818	1,728	1,545	1,615	1,503	1,590	2,022	--
5	City of Santa Paula Sani- tation Plant	31	Santa Clara River	Irrig. 25%	Domestic & Industrial	Wells	1,515	1,430	1,490	1,741	1,535	1,390	1,293	1,300	1,616	1,510	1,787	1,491

* For location see Figure 6

TABLE 8 (Continued)
DOMESTIC WASTE WATER TREATMENT PLANTS
AND HISTORIC TOTAL DISSOLVED SOLIDS CONTENT OF THEIR EFFLUENTS
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No.:Treatment:Node:Disposal:Reuse:Type of:Source of:							Total Dissolved Solids in Mg/l											
:Plant	:	:	:	:	: Waste	: Supply	: 1956	57	58	59	60	61	62	63	64	65	66	67
6	Saticoy Sanitary District	46	Perco- lation adjacent to Santa Clara River	None	Domestic	Wells	3,555	1,806	1,636	1,770	1,765	1,800	--	2,018	1,690	1,775	2,100	--
7	U.S. Naval Station, Point Mugu (Pacific Missile Range)	87	Mugu Lagoon, then to ocean	None	Domestic	Wells	--	--	1,600	5,800	2,585	--	--	2,980	--	1,332	--	--
8	U.S. Naval Construction Battalion Center, Port Hueneme	74	Ocean outfall	None	Domestic	Wells	2,576	--	3,200	--	2,325	--	--	3,850	1,318	--	--	--
9	City of Ventura (Eastside Plant)	63	Santa Clara River 70% Golf Course 30%	Irrig.	Domestic & Industrial	Ventura River, Wells	--	--	--	--	--	1,611	1,555	1,465	1,760	1,977	--	--

TABLE 8 (Continued)
DOMESTIC WASTE WATER TREATMENT PLANT
AND HISTORIC TOTAL DISSOLVED SOLIDS CONTENT OF THEIR EFFLUENTS
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No.	Treatment Plant	Node	Disposal	Reuse	Type of Waste	Source of Supply	Total Dissolved Solids in Mg/l											
							1956	57	58	59	60	61	62	63	64	65	66	67
10	City of Ventura (Seaside Plant)	62	Ocean	None	Domestic & Industrial	Ventura River Wells	1,719	2,325	1,320	1,340	1,872	1,812	1,253	1,380	1,409	1,755	--	--
11	Camarillo Sanitary District	--	Conejo Creek 17%	Irrig. 83%	Domestic	Wells, Colorado River	--	--	1,500	1,726	1,655	1,498	1,455	1,469	1,165	1,164	1,330	1,330
12	Camarillo State Hospital	141	Land	Irrig.	Domestic	Wells							1,260	1,430	1,370	1,610	1,605	1,460
13	City of Fillmore	16	Perco-lation Adjacent to Santa Clara River	None	Domestic	Wells	1,320	1,880	1,687	2,240	1,728	1,795	1,714	1,668	1,570	1,475	1,575	1,670
14	City of Thousand Oaks	105 106	Arroyo Conejo	None	Domestic & Industrial	Wells	--	--	--	--	--	1,260	1,355	1,167	1,095	1,090	1,120	1,075

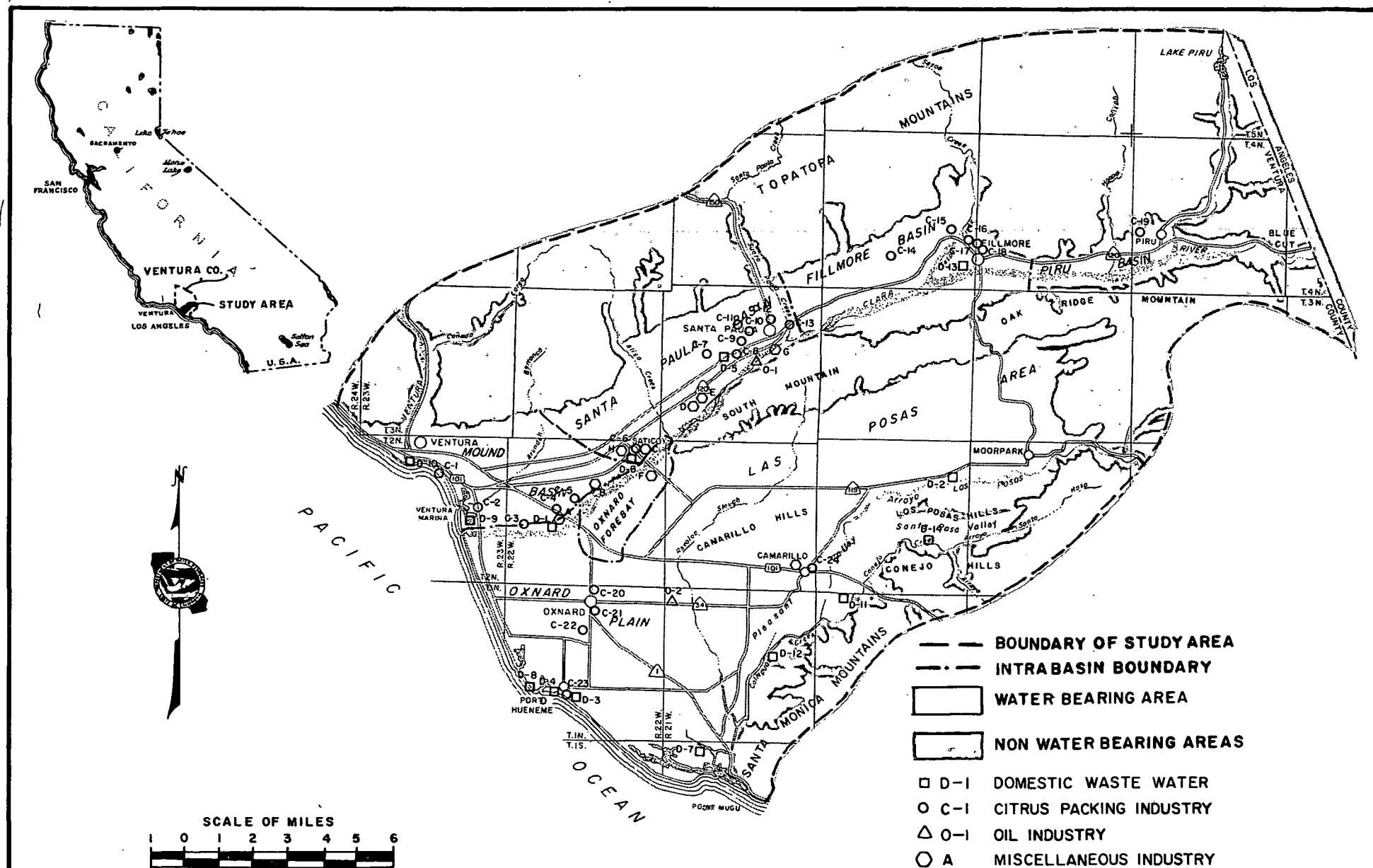


FIGURE 6-SOURCES OF DOMESTIC AND INDUSTRIAL WASTE WATER IN THE
SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

TABLE 9
CITRUS PLANT WASTE WATERS^{1/}
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No. on Figure 6	Industry	Node	Vol. of: Wash Water : ac-ft/yr.	TDS mg/l.	Vol. of : Rinse Water: gallons/hr : ac-ft/yr :	TDS mg/l	Waste Disposal
1.	Ventura Coastal Lemon Ass'n	62	0.007	--		--	Ocean
2.	Ventura County Citrus Ass'n, Ventura	63	0.3	--	$\frac{300}{0.9}$	--	Ocean
3.	Mutual Orange Distributors, Fillmore	64	0.3	15,470-15,501	$\frac{450}{1.4}$	2,077-2,381	Surface
4.	Ventura Pacific Company	65	0.3	16,376	$\frac{486}{1.5}$	1,580	Surface
5.	Saticoy Lemon Ass'n	53	0.2	15,062-16,423	$\frac{450}{1.4}$	1,898	Surface
6.	Culbertson Lemon Ass'n	55	0.2	21,807-25,656	$\frac{264}{1.8}$	1,542-1,758	City Sewer
7.	Lemoneira Company	32	0.2	21,349-24,328	$\frac{1,000}{3.1}$	6,558	Surface
8.	Briggs Lemon Ass'n	31,32	--	21,807-25,656	$\frac{500}{1.5}$	1,542-1,758	Sewer
9.	Mupu Citrus Ass'n	32	0.02	26,104-26,603	$\frac{450}{1.4}$	1,966	City Sewer
10.	American Fruit Growers, Inc.	29	0.1	68,077	$\frac{450}{1.4}$	1,153-3,596	City Sewer
11.	Santa Paula Citrus Fruit Ass'n	29	0.3	17,658	$\frac{450}{1.4}$	5,890	City Sewer

TABLE 9 (Continued)
CITRUS PLANT WASTE WATERS^{1/}
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No. on Figure 6:	Industry	Node	Vol. of		TDS mg/l.	Vol. of:		TDS mg/l.	Waste Disposal
			Wash Water:	ac-ft/yr		Rinse Water:	ac-ft/yr		
12.	Santa Paula Orange Ass'n	29	0.1	15,062-16,423		$\frac{450}{1.4}$		1,898	City Sewer
13.	Teaque McKeveatt Ass'n	30	0.2	11,613-20,424		$\frac{450}{1.4}$		1,005-2,409	Surface
14.	Rancho Sespe	21	0.7	14,239-15,873		$\frac{900}{2.8}$		733	Surface
-37- 15.	Mutual Orange Distributors, Fillmore	14	0.1	23,859		$\frac{450}{1.4}$		3,510-3,668	Cesspool
16.	Fillmore Citrus Ass'n	14	0.4	10,395		$\frac{900}{2.8}$		1,654-1,862	Surface
17.	Fillmore Lemon Ass'n	14	0.2	15,470-15,501		$\frac{1,000}{3.1}$		2,077-2,381	Surface
18.	Ventura County Citrus Ass'n Fillmore	14	0.1	9,941-15,146		$\frac{300}{0.9}$		1,706-1,896	Cesspool
19.	Piru Citrus Ass'n	5	0.2	2,717		$\frac{600}{1.8}$		1,460-2,588	Surface
20.	Seaboard Lemon Ass'n	72	0.2	--		$\frac{450}{1.4}$		--	Ocean
21.	Somis Lemon Ass'n	75	0.1	17,070		$\frac{250}{0.7}$		1,294-1,568	Ocean

TABLE 9 (Continued)
CITRUS PLANT WASTE WATERS^{1/}
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

No. on Figure 6:	Industry	Node	Vol. of: Wash Water ac-ft/yr	TDS mg/l.	Vol. of Rinse Water: gallons/hr ac-ft/yr	TDS mg/l.	Waste Disposal
22.	Santa Clara Lemon Ass'n	75	0.2	--	$\frac{450}{3.1}$	--	Ocean
23.	Oxnard Citrus Ass'n	85	0.7	--	$\frac{1,000}{3.1}$	--	Ocean
24.	Camarillo Citrus Ass'n	108	0.1	19,319	$\frac{1,025}{3.1}$	<u>1,069-1,285</u>	Dry Stream

^{1/} From Fruit Growers Laboratory, Inc. (1953)

Citrus-packing plants generally use three chemicals for washing and disinfecting fruit: (a) sodium hypochlorite; (b) borax-boric acid; and (c) soda ash. However, use of borax-boric acid has decreased because of the unfavorable effects of boron-rich waste water on water resources. Table 10 lists examples of analyses of packing-plant wastes (Fruit Growers Laboratory, Inc. 1953).

TABLE 10
ANALYSIS OF CITRUS-PACKING WASTE WATER
(Ingredients in mg/l, except pH)

a. Sodium Hypochlorite

Ingredient	Wash Water	Rinse Water
PH	10.06	9.54
Calcium	18	20
Magnesium	10	25
Sodium	23,980	987
Carbonate	9,820	447
Bicarbonate	--	--
Chloride	13,695	736
Sulfate	594	246
Borate (B_4O_7)	14,960	447
TDS	68,077	2,858

b. Borax-boric Acid

Ingredient	Wash Water	Rinse Water
PH	8.23	8.48
Calcium	18	101
Magnesium	49	38
Sodium	4,230	251
Carbonate	--	136
Bicarbonate	--	477
Chloride	169	119
Sulfate	503	148
Borate	14,350	--
TDS	19,319	1,285

c. Soda Ash

Ingredient	Wash Water	Rinse Water
PH	10.98	8.23
Calcium	2	12
Magnesium	17	8
Sodium	10,830	530
Carbonate	13,060	14
Bicarbonate	726	432
Chloride	273	110
Sulfate	744	648
Borate	12	3
TDS	25,656	1,758

Oil Industry Waste Water

One of the major industries in Ventura County is exploration and exploitation of oil. Brines extracted with the oil are disposed of to the ocean, injection wells, and/or sumps in the nonwater-bearing bedrock areas, although in the past some brines were discharged into stream channels. Table 11 shows available data on oil waste water (DWR, 1959). Figure 6 shows the location of the oil fields referred to in Table 11.

TABLE 11
OIL FIELD BRINE WASTES^{1/}

No. on Figure 6	1	2
Oil Field	South Mountain	Oxnard
Location State No.	3N/21W-22A	1N/21W-6L
Node	31	82.83
No. of Active Sumps	46	15
Area of Unlined Sumps (ft ²)	93,900	58,600
No. of Unconfined Sumps	5	1
Brine Produced July '51 - June '52 (Barrels)	226,500	30,600
Salts in Brine Produced (tons)	809	50
TDS mg/l	18,866	3,290
Date of Analysis	1952	1952
Effects on receiving waters	No apparent threat of pollution	No threat of pollution

^{1/} From DWR, Bulletin 75, 1959.

Miscellaneous Industrial Waste Waters

Table 12 contains data on other types of industry and their waste water TDS. For locations of these industries, see Figure 6.

TABLE 12
MISCELLANEOUS INDUSTRIAL WASTE WATER*
IN THE SANTA CLARA-CALLEGUAS AREA
VENTURA COUNTY

Location on: Figure 6 :	Industry	: Location :(state No.):	:Location: (node)	Quantity: :ac-ft/yr:	Date of : Analysis:	TDS mg/l	: :	Disposal
A	United Celery Growers, Oxnard	2N/22W-21	65	9	1972	1,512		Santa Clara River
B	Southern Pacific Milling	2N/22W-15	54	4	1969	Max. 1,500**		Sumps and Santa Clara River
C	Southern Pacific Milling	2N/22W-1	42,43	1	1969	Max. 1,500**		Sumps and Santa Clara River
D	Saticoy Food Co., Santa Paula	3N/21W-30	37	2	--	1,940		Santa Clara River
E	W. Atlee Burpec, Santa Paula	3N/21W-29	37	4	1968	2,350		Santa Clara River
F	Industrial Asphalt Co., Saticoy	2N/22W-12	45	-	1968	1,570		Santa Clara River
G	Southern Pacific Mill Co., Santa Paula	3N/21W-14	30	-	--	Max. 1,500**		Sumps and percolation
H	Upton and Williams, Inc.	2N/22W-2J	55	-	--	2.8T/yr***		Percolation and discharge to roadside ditch
I	Saticoy Walnut Growers Ass'n	2N/22W-2J	55	-	--	4.2T/yr***		Discharge to ravine
J	Walnut Growers Ass'n	2N/21W-36B	(108)	-	--	2.8T/yr***		Ponds

* From DWR, Bulletin No. 75, (1959) and Regional Water Quality Control Board, Los Angeles Region's files.

** Requirement by California Regional Water Quality Control Board, Los Angeles Region.

*** TDS in tons per year

CHAPTER 3. FACTORS AFFECTING THE MINERAL QUALITY OF GROUND WATER IN SANTA CLARA-CALLEGUAS AREA

The foregoing chapter contained information on the major salt input to the Santa Clara-Calleguas area ground water basins from subsurface inflows, surface water percolation, rising water repercolation, artificial recharge, domestic, and industrial waste water discharges. In addition, the following factors could have a significant effect on ground water quality in the study area and were therefore investigated for possible inclusion in the quality model: (1) irrigated agriculture; (b) ion exchange; (c) vertical zonation of salinity in ground water; (d) geochemical effects of sediments, and (e) salt movement in ground water.

Effect of Irrigated Agriculture on Ground Water

Irrigated agriculture is the most significant land use that can produce extensive deep percolation of the ground water basins. It constitutes the largest beneficial use in the study area.

The two principal effects of agriculture that cause degradation are concentration of salts in irrigation return and leaching of minerals from applied fertilizers and soil conditioners. Irrigation water that is not consumed by evapotranspiration and plant uptake becomes irrigation return waste water. Irrigation efficiency is the ratio of the amount of consumptive use or evapotranspiration to the amount of applied irrigation water. Hence, low irrigation efficiencies lead to large amounts of return drainage water and high efficiencies lead to small amounts.

Crops and Water Use

The principal crops are citrus, avocados, beans, walnuts, and truck crops. Minor crops include deciduous fruits, sugar beets, and irrigated pasture.

On the basis of similar water demands, irrigated agriculture falls into six groups: alfalfa, pasture, deciduous fruits and walnuts, citrus, truck crops, and grapes. Nodal acreages within these groups have been obtained from DWR land-use studies in 1950, 1961, and 1969.

Based on the unit consumptive water-use values of the different crops (Table 13) and their irrigation efficiencies, each crop unit irrigation return value was calculated (DWR, 1970). Historic irrigation efficiency was estimated at 67 percent, calculated from consumptive use and applied water.

Table 14 shows the estimates of average seasonal unit values of applied and return water for irrigated agriculture.

Concentration of Salts

Most of the water applied to irrigated crops is consumed by evapotranspiration; only negligible amounts of dissolved solids are lost thereby. As a result, the portion of applied water that percolates below the root zone

TABLE 13

ESTIMATES OF AVERAGE SEASONAL UNIT VALUES OF CONSUMPTIVE USE OF
WATER BY IRRIGATED AGRICULTURE IN THE SANTA CLARA-CALLEGUAS AREA

Category	Consumptive use of water, in feet
Alfalfa	2.2
Pasture	2.3
Deciduous fruits and walnuts	1.4
Citrus	1.4
Truck crops	1.2
Grapes	1.0

TABLE 14

ESTIMATES OF AVERAGE SEASONAL UNIT VALUES OF APPLIED AND
RETURN WATER FOR IRRIGATED AGRICULTURE IN THE SANTA CLARA-
CALLEGUAS AREA
(in feet)

Category	Applied water	Return water
Alfalfa	3.3	1.1
Pasture	3.4	1.1
Deciduous fruits and walnuts	2.1	0.7
Citrus	2.1	0.7
Truck crops	1.8	0.6
Grapes	1.5	0.5

contains a higher concentration of dissolved salts than does the applied water. Irrigation efficiency and concentration of TDS in applied water provide the data needed to calculate the concentration of TDS in the percolating water, e.g., if irrigation efficiency is 67 percent and TDS of applied water is 1,000 mg/l, then the TDS of the percolating water is

$$1,000 \times \frac{100}{(100-67)} = 3,030 \text{ mg/l}$$

Such data will be included as input to the quality model.

The quality of the water ultimately reaching the saturated zone will vary, depending on the amount of salts that dissolve from the soil medium, the amount of salts that precipitate in the soil from the percolating water, and the amount of salts removed in the harvested crop. To determine such factors, an extensive, detailed salt balance of the soils would be necessary.

Information to produce a detailed soil salt balance is not available. Moreover, in healthy, irrigated, well-drained soil, the amount of salt dissolved from or precipitated in the soil and the amount removed in the crop are small. Hence, it was assumed that the total amount of TDS in applied irrigation water will be percolated in the irrigation return.

Thus,
$$\frac{\text{volume of applied water}}{\text{volume of drainage water}} = \frac{\text{TDS of drainage water}}{\text{TDS of applied water}}$$

The basic assumption was that water leaving the root zone carries the salts and continues to move downward with them, so salt imbalance in the soil will not occur.

Fertilizer Minerals

Besides the salts in the applied water, irrigation return also transports residual fertilizer minerals to the saturated zone. Fertilizers do not contribute appreciably toward increasing the salinity of drainage water or ground water because fertilizer salts in excess of plant uptake are small compared to quantities already in the applied water. However, the contribution of nitrates by fertilizers causes an increase in the concentration of nitrate in ground water.

Of the three major plant nutrients (nitrogen, phosphorus, and potassium) in fertilizers, only nitrogen can percolate in appreciable amounts to the saturated zone (phosphorus becomes immobilized in the soil and potassium is fixed by clays or taken up by crops). Consideration was accordingly given only to the nitrogen fertilizers. Some nitrogen is also added to the soil by fixation from the atmosphere by symbiotic bacteria from legumes and some of it is leached by the percolating water. Not all nitrogen in fertilizers applied to irrigated agriculture is available for leaching because of such factors as volatilization, fixation, and uptake of nitrogen by plants.

In an aerobic soil, nitrogen fertilizers are oxidized to the nitrate form by biochemical reactions in the soil medium. The nitrate anion combines with an equivalent amount of available cations in the soil medium. Because soils of the study area are calcareous, it was assumed that calcium is leached with the nitrate ions. Nitrogen fertilizers were applied, mainly ammonia, urea, and ammonium nitrate.

The minerals available for leaching from irrigated agriculture were calculated by using an approach developed by Hassan (1972) and rates of fertilizer application obtained from Ventura County fertilizer companies, farm advisors, and Dr. Wang* of the Fruit Growers Laboratory (1973) (Table 15).

*Personal communication with Dr. Ming Y. Wang of the Fruit Growers Laboratory, Inc., Santa Paula, California, 1973.

Other Contributions

Besides the effect that irrigated agriculture has on the quality of ground water, native vegetation and phreatophytes consume ground water and take up minimum amounts of salt, thereby increasing TDS in the ground water. Unit seasonal consumptive use of water by native vegetation or phreatophytes was calculated at 1.1 feet per acre.

TABLE 15

FERTILIZER MINERALS AVAILABLE FOR LEACHING FROM IRRIGATED AGRICULTURE

(in pounds per acre per year)

Item	: :Alfalfa: :	: :Pasture: :	: :Deciduous fruits : and walnuts :	: :Citrus: :	: :Truck : crops :	: :Grapes :
N applied	200 ^a	100 ^b	100	200 ^c	180	60
Volatilization (15%)	--	-15	-15	-30	-27	-9
Fixation (10%)	-20	-10	-10	-20	-18	-6
Uptake	-140	-70	-20	-70	-100	-15
Remainder	40	5	55	80	35	30
Equivalent Ca (NO ₃) ₂	235	29	322	470	203	175
Total salts available	235	29	322	470	203	175

a. N fixed from the atmosphere.

b. Pasture is usually mixed with legumes.

3. Average for all citrus (more N is applied to lemons than to oranges).

In urban and suburban areas, irrigated lands consist mainly of lawns, shrubs, and vegetable gardens. Water supplied for irrigation is normally part of the municipal supply. Based on a land-use inventory and an irrigation efficiency of 80 percent, unit applied, consumptive, and irrigation return per acre of residential land were determined (Table 16).

Beside the concentration of salts in irrigation return, fertilizers applied to residential areas also add some salts. Salts contributed by fertilizers were estimated at the rate of 100 pounds of nitrogen applied per acre (Table 17).

Values Used in The Model

Table 18 shows the fertilizer salt input used in the verification of the quality model.

TABLE 16

ESTIMATES OF AVERAGE SEASONAL UNIT VALUES OF APPLIED, CONSUMPTIVE USE,
AND RETURN IRRIGATION WATER IN RESIDENTIAL AREAS

Type of land use	In feet			
	Percent of	Applied	Consumptive	Return water
	land irrigated	water	use	
Residential, single	57	1.8	1.4	0.4
Residential, multiple	10	0.4	0.3	0.1
Residential, rural	50	0.9	0.7	0.2
Unclassified*	20	0.5	0.4	0.1

*Includes schools, parks, cemeteries, and golf courses.

TABLE 17

FERTILIZER MINERALS AVAILABLE FOR LEACHING IN RESIDENTIAL AREAS

(in pounds per acre per year)

Item	Residential single	Residential multiple	Residential rural	Unclassified
N applied	100	100	100	100
Net N applied*	57	10	50	20
Plant uptake and losses**	-42	-8	-37	-15
Remainder	15	2	13	5
Equivalent $\text{Ca}(\text{NO}_3)_2$	87	12	75	29
Total salts available for leaching	87	12	75	29

*Using percentage of land irrigated as shown in Table 16.

**Uptake, volatilization, denitrification, and other losses were assumed to be 75 percent of applied N.

TABLE 18

FERTILIZER SALT INPUT CONTRIBUTED BY AGRICULTURE
IN TONS PER ACRE PER YEAR

Crop	Tons	Crop	Tons
Alfalfa	0.12	Grapes	0.09
Pasture	0.01	Residential, single	0.04
Deciduous fruits and walnuts	0.16	Residential, multiple	0.01
Citrus	0.24	Residential, rural	0.04
Truck	0.23	Unclassified	0.01

Ion Exchange and Its Importance
in Modeling TDS

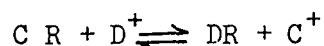
Ion exchange is only one of the reactions that take place within the unsaturated zone. Others are solution of minerals from the sediments, deposition of salts from the percolating water, and oxidation and reduction. As the result of these reactions, the quality of the water reaching the saturated zone may be completely different from that when it began percolating.

Water carries salts in a dissociated ionized state. These ions are cations and anions present in balanced equivalent weights. Among the major ions in water are the positively charged (cations) calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), and potassium (K^+), and the negatively charged ions (anions) carbonate (CO_3^{--}), bicarbonate (HCO_3^{--}), sulfate (SO_4^{--}), and chloride (Cl^-).

Under the reaction, known as ion exchange, ions from the water are exchanged for others in the exchange medium or in the soil's exchange complex. Ion exchange in the soil is mainly an activity of the soil's exchange complex, which is largely composed of colloids, clays, and, to a lesser extent, silt. The adsorptive power of soil particles increases with their fineness in size, reaching a maximum in the colloidal range because of the particles' high specific surface.

Both cation (or "base exchange") and anion exchange are included in ion exchange. However, in the soil's exchange complex and in clayey sediments, most of the exchange is cationic because most of the exchange surfaces are negatively charged. Just a few mineral surfaces, such as those of iron oxides, are positively charged. Therefore, only base exchange has been considered because it is more significant than anion exchange.

Ion exchange reactions are stoichiometric and reversible. They are true equilibrium reactions and can be represented as:

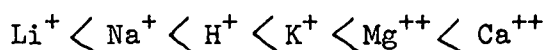


where R represents cation exchanger, C and D are the exchangeable cations in solution. Because cation exchange is a surface reaction, it proceeds just as fast as ions from the solution that come in contact with the exchange material.

Factors Affecting Ion Exchange

Many factors affect ion exchange, the following being the most important (Hassan, 1963):

1. Concentration of Ions. With constant amounts of exchange material and exchange solution, generally the more concentrated the solution, the greater the amount of exchange. Kelley and Cummins (1921) found that the replacement of Ca^{++} and Mg^{++} ions by Na^+ ions increased as the concentration of the sodium in the soil solution increased.
2. Temperature. The effect of temperature on cation exchange is generally small. High temperature causes a small increase in the rate of ion exchange.
3. Relative Replacing Power of Cations. In the exchange material, the relative replacing power of cations generally follows the order $\text{M}^+ < \text{M}^{++} < \text{M}^{+3}$, where the order of relative replacing power is related to the valence. Ross (1943) gave the following order:



The relative replacing power of cations is influenced by many factors, including the relative concentrations of cations in solution and the cation exchange capacity (CEC) of the exchange material. CEC of the exchange material is defined quantitatively as the total exchangeable cations adsorbed by the exchange material in milliequivalents per 100 grams of the material.

4. Salts in the Medium. Two of the important factors in the mineral composition of the exchange solution are the amounts and types of salts found in the exchange medium. In the soil, these may be soluble salts, as Na_2CO_3 , CaCl_2 , MgCl_2 , Na_2SO_4 , and CaSO_4 or less soluble salts such as CaCO_3 and $\text{Ca}_3(\text{PO}_4)_2$.

5. Rate of Movement of Water. Because chemical equilibrium is approached only after a finite time, the velocity of the movement of the solution governs how near to equilibrium the exchange reactions approach.

Soils are not homogeneous in pore size. Thus, water moves at different velocities throughout the system. When the structure of the soil changes, pore size and distribution change, and so too does the movement of water through the soil. An example of this is the effect of Na^+ on the soil. Na^+ disperses clay minerals; hence, the resulting structure will not have as large pores as the original soil and the rate of movement of water will be reduced.

6. Changes in the CEC. During mechanical and chemical weathering, soil minerals are broken down into ever finer particles, culminating in particles of colloidal size. Thus, the adsorptive power of the soil exchange material may increase with time.

The CEC of soil also increases as the result of an increase in the organic content of the soil, which comes from the addition of manure and soil

conditioners. However, according to Pratt (1957), "Cation exchange capacity of sandy loam soils of granitic origin is not affected by urea, phosphate or potassium applied individually or collectively. Only the treatment that included manure affected the exchange capacity and then only in the surface soil (0" - 6")".

These six factors govern the composition of the equilibrium solution that would result if a solution were allowed to remain in contact with soil colloids until no further change occurred in the resulting solution. However, to analyze the role of ion exchange in changing the TDS of water percolating to the water table, a thorough knowledge of the soils of the area is necessary.

Soils of the Study Area

Soils of the study area have developed on in-place parent material. The three main groups are: (a) soils developed on alluvial plains and in river basins; (b) soils developed on old terraces and alluvial fans; and (c) soils developed on the upland areas (U. S. Department of Agriculture, 1970).

Soils in the first group are well drained, loamy sands to silty clay loams developed on alluvial fans and plains, plus poorly drained, loamy sands to silty clay loams in basins. Such soils are classified further into four associations: (1) Pico-Metz-Anacapa; (2) Mocho-Sorrento-Garretson; (3) Camarillo-Hueneme-Pacheco; and (4) river wash -- sandy alluvial land -- coastal beaches association.

Under the Pico-Metz-Anacapa Association are soils in the Las Posas, Pleasant, Santa Rosa, and Santa Clara River Valleys (Figure 7). These soils are deep (60 inches or more), well drained, calcareous sandy loams.

Under the Mocho-Sorrento-Garretson Association are soils in the Las Posas and Santa Clara River Valleys. Soils are deep (60 inches or more), well drained, calcareous loams to silty clay loams.

Under the Camarillo-Hueneme-Pacheco Association are soils mainly in the Oxnard Plain. These soils are deep (60 inches or more), poorly drained, calcareous sandy loam to sandy clay loam. Because of the poor drainage conditions, most of the area under irrigation is artificially drained.

Under the Fourth Association are soils mainly in the Santa Clara Riverbed and along the coast (coastal beaches and tidal flats). These soils are well drained, sandy loam to loamy sand.

Soils in the second group are developed on terraces and older alluvial fans; they are well to moderately drained, both shallow and deep, calcareous sandy loams to silty clay loams. These soils occur in the Las Posas, Santa Rosa, and Santa Clara River Valleys.

Soils in the third group are developed in the upland areas; they are well drained, both shallow and deep, calcareous shaley loam. These soils are found on the uplands north and south of the Santa Clara River Valley.

The characteristics that are important in evaluating ion exchange:

1. Soils that vary from neutral to mildly alkaline, with pH values ranging from 6.5 to 8.5.
2. Soils that are calcareous, strongly effervescent with the application of dilute hydrochloric acid; they contain calcium carbonate and sulfate (gypsum) in abundance.
3. Soils that are sandy to silty clay loams, allowing water infiltration readily; hence, most of the soils are well drained.
4. Clay minerals, which are the main soil exchange material in soils of the area, are mostly mixed and montmorillonitic varieties.

Figure 7 is a general soil map of the study area. For detailed soil information, see the U. S. Department of Agriculture report (1970).

Exchange Reactions in Soils of the Area

Water percolating through the soils of the area includes precipitation, stream percolation, applied irrigation water, septic tank effluents, and ponded domestic and industrial waste water. This water varies in its TDS and in cationic makeup. However, as it percolates to the water table, its TDS and cationic makeup will change markedly.

If ion exchange were the only process that causes chemical change in percolating water, predicting the final composition of water reaching the saturated zone would be less difficult. However, besides ion exchange, many other reactions are involved, the most important being:

1. Precipitation of salts from water: Evapotranspiration results in the concentration of salts in percolating water. Under some conditions, where applied water is relatively high in TDS, as in the study area, evapotranspiration causes the concentration of certain salts to exceed their solubility limit. As a result, precipitation of some of the salts occurs.

Salts precipitating in the soils of the study area include calcium carbonate and sulfate. This disproportionate precipitation of salts causes a change in the cationic composition of the water, which appears to be an effect of ion exchange.

2. Dissolution of salts in soil: Soils of the area are calcareous, containing calcium carbonate, magnesium carbonate, and sulfates. Water percolating through these soils, especially rain water that is slightly acidic and low in TDS, will dissolve calcium and magnesium salts and other minerals. Therefore, the water will eventually reach the water table at a higher concentration of TDS and at a different cationic composition than rain water.

Information is not available on the ion exchange capacities of soils in the study area. However, on the basis of the mechanical composition of these soils, ion exchange capacities are thought to be low (less than 30 milliequivalents per 100 grams of soil). Therefore, ion exchange activities would not have

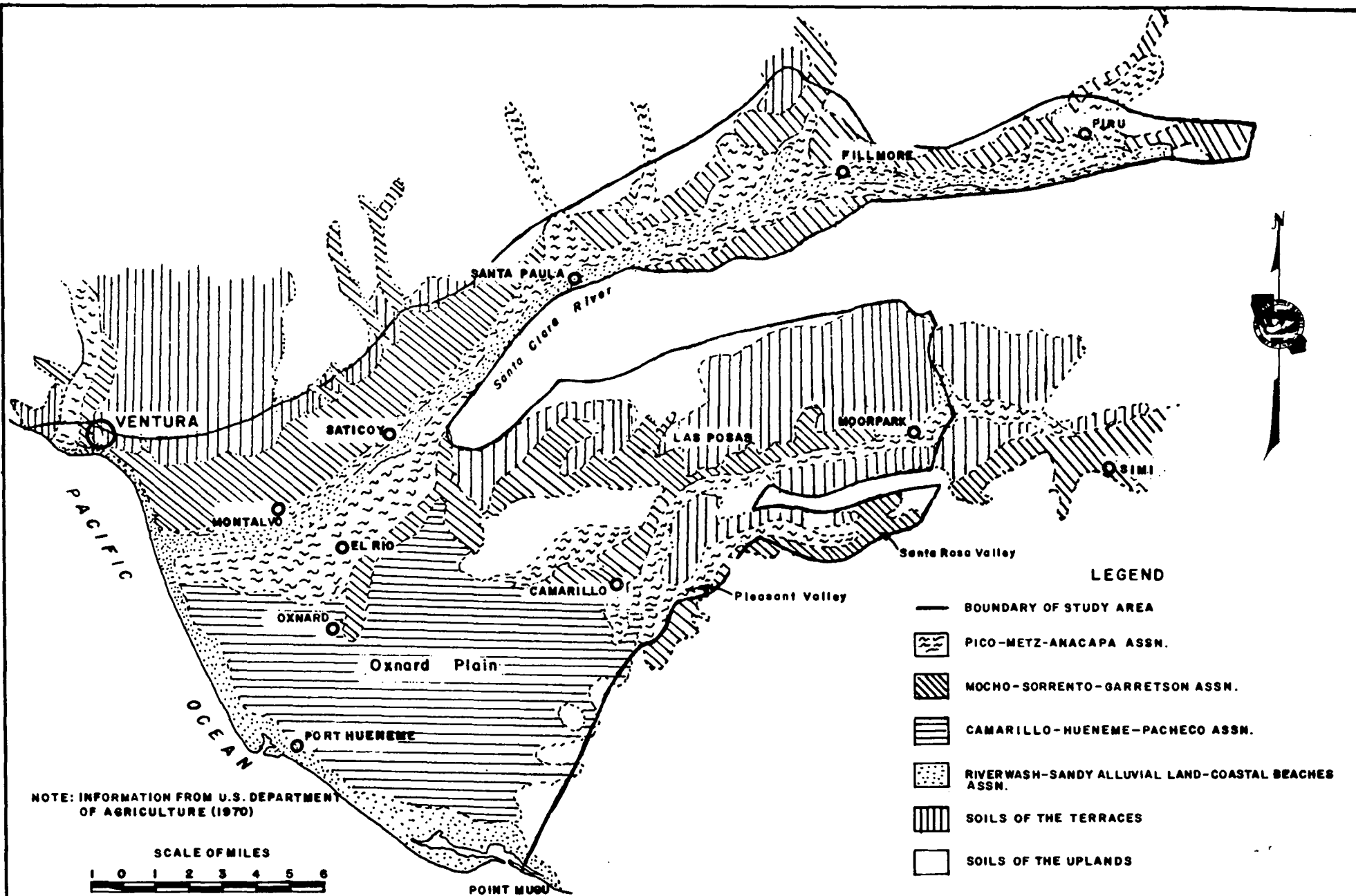


Figure 7 - GENERAL SOIL MAP OF THE SANTA CLARA-CALLEGUAS AREA

a significant effect on the chemistry of the percolating water when compared with precipitation and solution reactions.

In other words, because of the prevalence of calcium salts, especially gypsum in the soils, surface water, and applied ground water, ion exchange reactions are of minor importance in changing the cationic composition and the TDS of percolating water. Accordingly, ion exchange will be overlooked in the development of the mathematical water quality model of that area.

Vertical Zonation of Salinity in Ground Water Aquifers

In the past, when developing ground water quality models or applying the total ground water basin salt balance approach, the assumption has generally been made that complete mixing of salts takes place in a ground water basin. Such an assumption was found necessary because data were not at hand to describe the vertical distribution of salts in different segments of those basins.

Successive studies over the years have defined the areal distribution of salts in the Santa Clara-Calleguas ground water basins, but scant attention has been given to vertical distribution of salts. Knowledge of such vertical variations in salinity would provide insight into:

1. The rate and mechanics of the mixing of percolating salt-laden water with ground water in the zone of saturation.
2. The rate of movement and areal extent of the different water quality zones.
3. The volumes of water of specific salt concentrations.

Such factors, if determined, would have helped in the development of the quality model and in the management and control of the ground water system.

Conduct of the Study

To determine the variation in salinity at different depths, the best process would be to collect and analyze samples from isolated aquifer intervals from existing wells. Isolation of these intervals could be accomplished by special packer equipment that can be installed in the well.

Because such elaborate field experimentation is more than this study encompassed, a study of available water quality data was undertaken as the best alternative. To determine if significant vertical variations in ground water salinity exist, data on wells at different depths and perforation intervals were analyzed. TDS concentrations of well water during 1962 were plotted against depths of wells within each township of the Santa Clara-Calleguas area. (Locations of wells in the study area are shown on Plate 1.)

Results of the Study

Contrary to expectations, TDS of water from shallow and deep wells in single aquifer systems show minor, insignificant differences. This may be seen

in township 2N/19W where wells extract water from the confined Fox Canyon and Grimes Canyon aquifer system (Figure 8). It is also clearly shown in those townships adjacent to the Santa Clara River, where wells pump water from unconfined alluvial sediments (Figure 9).

However, some variations were found where wells are pumping water from multiaquifer systems (Figures 10 and 11). In townships 1N/22W, 2N/21W, and 2N/22W, where three aquifer systems occur, data show three water quality zones. These zones are: (1) the shallow (less than 200 feet deep) perched aquifer of TDS ranging from 800 to 8,000 mg/l; (2) the confined Oxnard and Mugu aquifer system of uniform quality (less than 2,000 mg/l TDS), except where it is intruded by sea water (TDS as high as 33,488 mg/l); and (3) the confined Hueneme, Fox Canyon, and Grimes Canyon aquifer system of TDS similar to that of the Oxnard and Mugu aquifer system (less than 2,000 mg/l).

Based on the evaluation of TDS in wells of different depths, vertical variation of quality was found to be insignificant, except in the Oxnard Plain area which has three separate aquifer systems.

In the Oxnard Plain area, the shallow perched aquifer is not being modeled in either the quantity or quality model. Leakage from the perched aquifer is an input to the upper layer nodes of the model. The Oxnard-Mugu aquifer system and the Hueneme, Fox Canyon, and Grimes Canyon system are modeled as separate layers of specific water quality values.

In those areas where water is extracted from unconfined alluvial sediments, the water pumped from the aquifer will be assumed to be a weighted mixture from the water table to the bottom of the well. This part of the unconfined aquifer is termed "zone of mixed yield" and the water quality to be verified represents that of the zone of mixed yield, rather than that of the whole aquifer thickness.

Therefore the vertical zonation of water quality in the saturated zone was not considered in developing the water quality model.

Geochemical Effects of Sediments

To determine the geochemical effect of sediments, it is necessary to study the geology of the study area. Plate 2 is an areal geology map showing the main lithologic formations in the study area. Table 19 shows water occurrences and types of aquifers in the ground water basins of the area.

The Santa Clara-Calleguas area is in the Transverse Range geomorphic province (DWR, 1953). Mountains and valleys trend nearly east-west. The Santa Clara River Valley is the most prominent valley in the area. It is a downfolded and faulted trough between mountains to the north and south.

South of the Santa Clara River Valley are the Las Posas upland and Simi Valley. The Las Posas upland extends eastward from the Oxnard Plain almost to Simi Valley, which extends westward into the Arroyo Las Posas and Calleguas drainage area. The Oxnard Plain was formed by deposition of sediments from the Santa Clara and Calleguas Creek drainage systems.

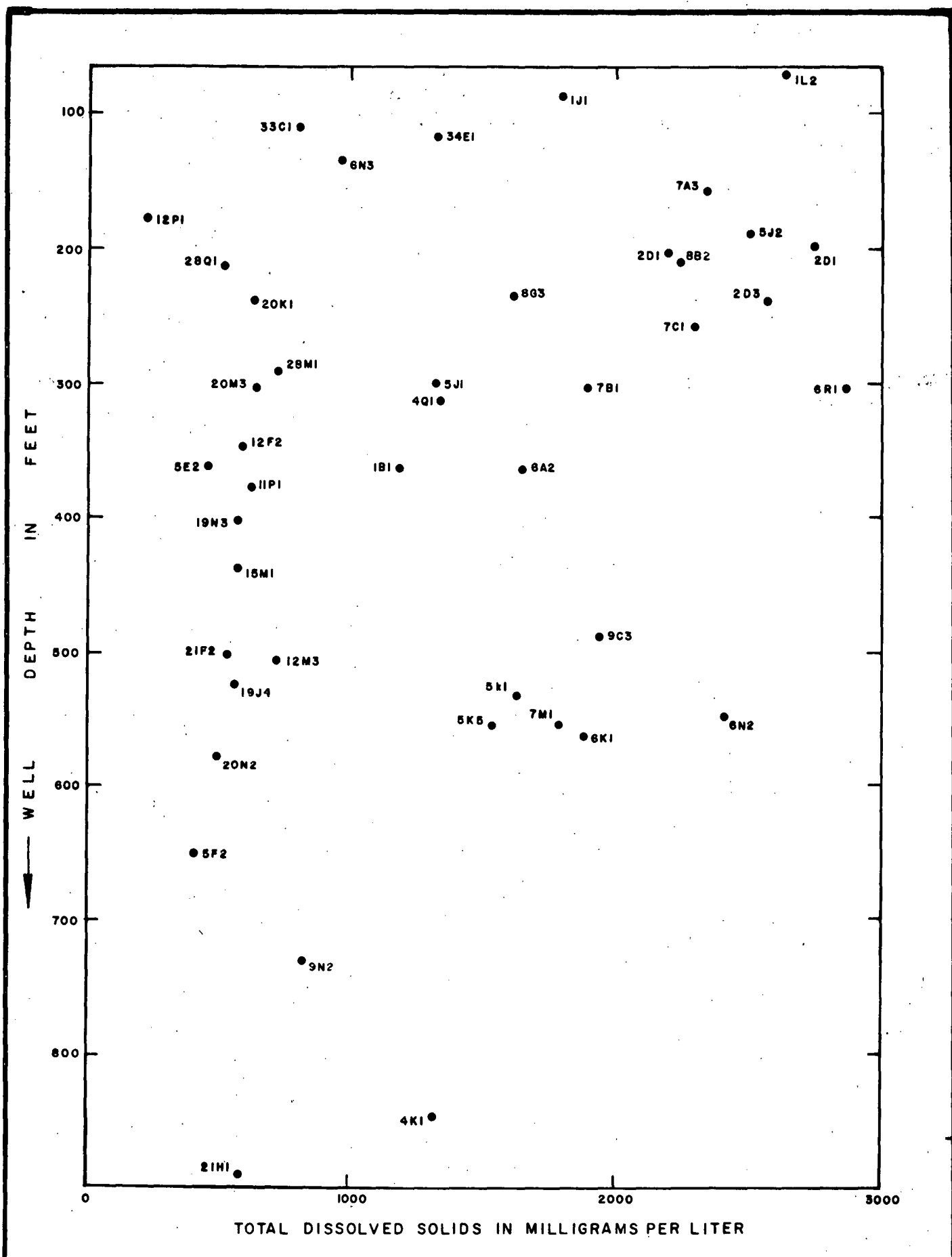


Figure 8— WELL DEPTH AND TOTAL DISSOLVED SOLIDS CONCENTRATION
IN TOWNSHIP 2N/19W OF THE SANTA CLARA CALLEGUS AREA

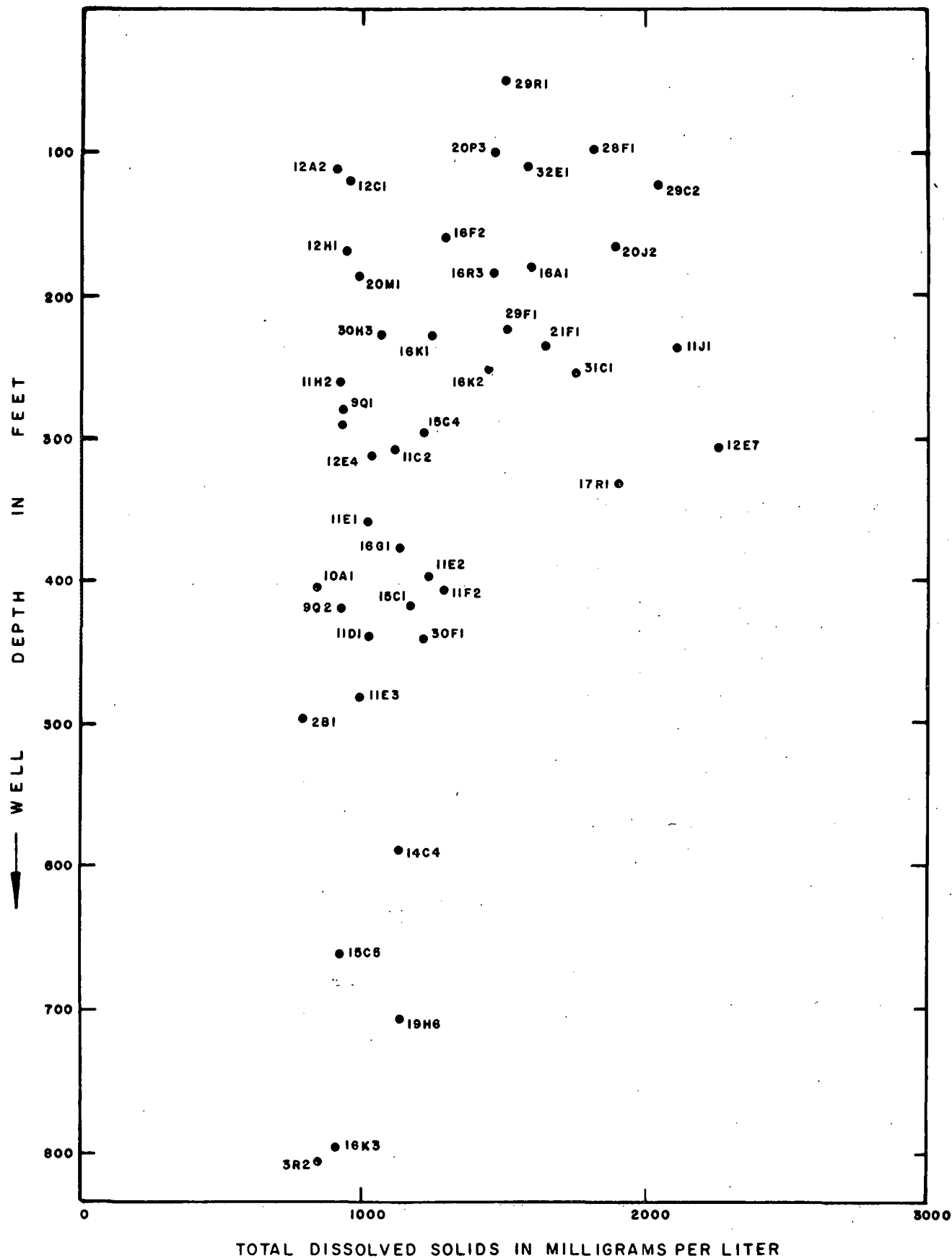


Figure 9— WELL DEPTH AND TOTAL DISSOLVED SOLIDS CONCENTRATION
IN TOWNSHIP 3N/2W OF THE SANTA CLARA CALLEGUS AREA

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1974

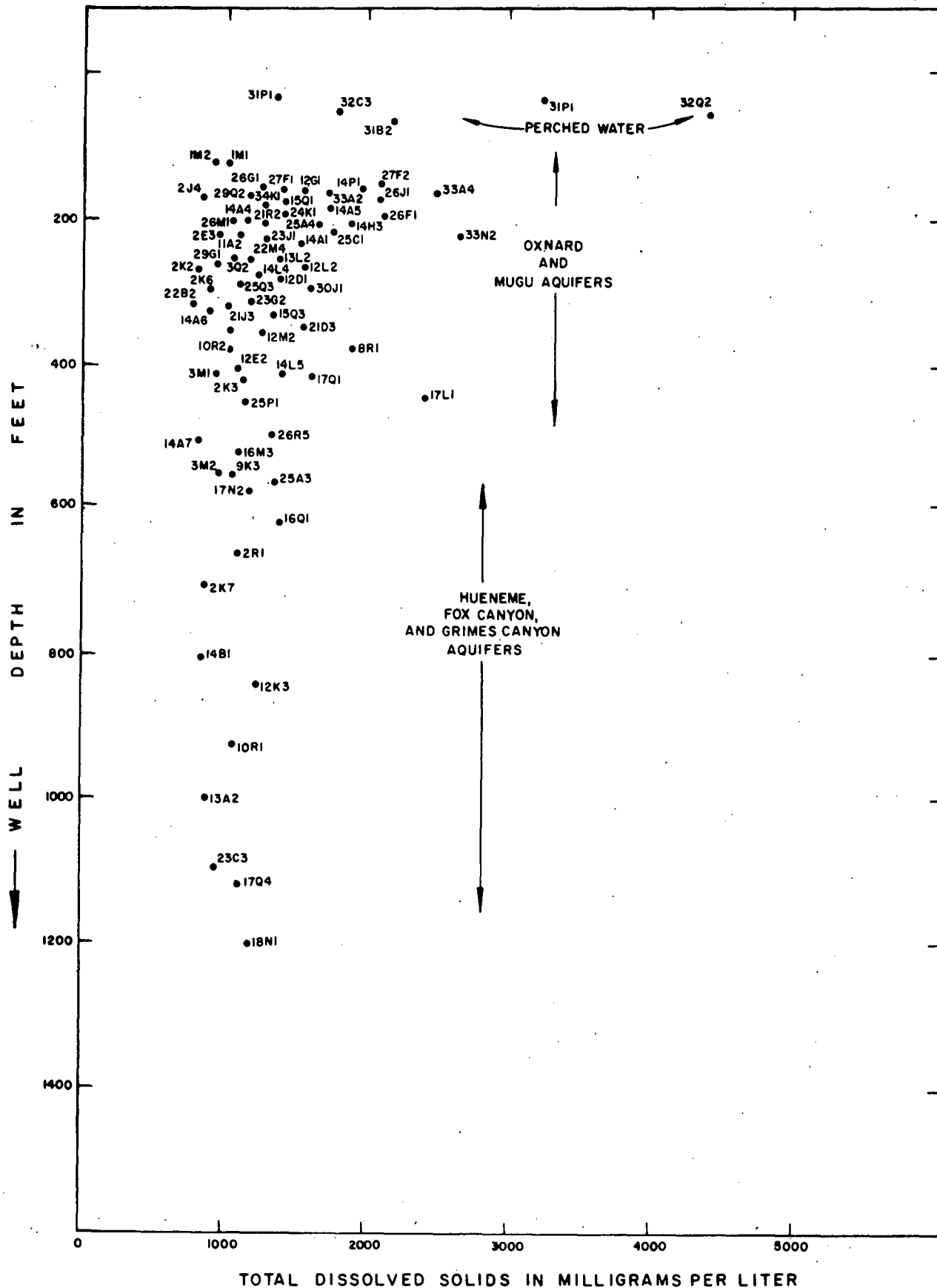


Figure 10- WELL DEPTH AND TOTAL DISSOLVED SOLIDS CONCENTRATION
IN TOWNSHIP 2N/22W OF THE SANTA CLARA CALLEGUS AREA

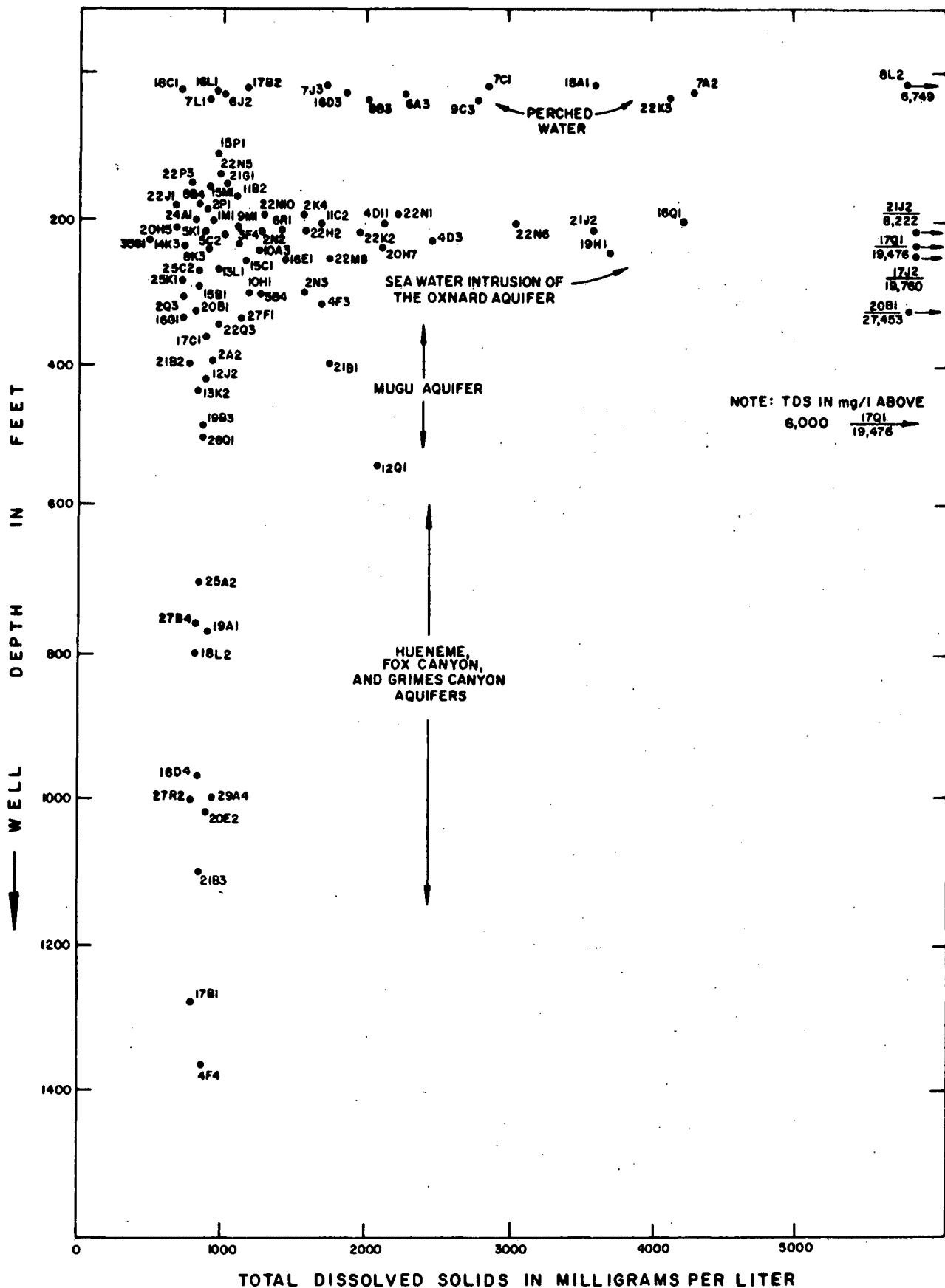


Figure II— WELL DEPTH AND TOTAL DISSOLVED SOLIDS CONCENTRATION IN TOWNSHIP IN/22W OF THE SANTA CLARA CALLEGUAS AREA

Sediments that may affect the chemical composition of surface and ground water are discussed below.

TABLE 19*

GROUND WATER BASINS IN THE SANTA CLARA-CALLEGUAS AREA

Ground water basins	formations	Principal aquifers	Condition of occurrence of ground water
Piru	Recent and Pleistocene alluvium	Sand and gravel beds	Unconfined
	San Pedro formation	Sand and gravel beds	Unconfined
Fillmore	Recent and Pleistocene alluvium	Sand and gravel beds	Unconfined
Santa Paula	Recent and Pleistocene alluvium	Lenses of permeable sediments	Essentially unconfined
	San Pedro formation	Lenses of permeable sediments	Essentially unconfined
Mound	San Pedro formation	Lenses of permeable sediments near top	Confined
Oxnard Forebay Area	Recent and Pleistocene alluvium	Most of the formations	Unconfined
Oxnard Pressure Area	Recent alluvium	Semiperched water-bearing zone Oxnard aquifer	Unconfined Confined
	Upper Pleistocene alluvium	Mugu aquifer	Confined
	San Pedro	Hueneme aquifer Fox Canyon aquifer	Confined

*From: California Department of Water Resources, 1968.

GROUND WATER BASINS IN THE SANTA CLARA-CALLEGUAS AREA
(continued)

Ground water basins	Water-bearing formations	Principal aquifers	Condition of occurrence of ground water
Pleasant Valley	Recent and Pleistocene alluvium	Permeable lenses not connected with Oxnard aquifer	Essentially confined
	San Pedro formation	Fox Canyon aquifer	Essentially confined
East and West Las Posas	Recent and Pleistocene alluvium	Lenses of permeable sediments	Unconfined
	San Pedro formation	Epworth gravels	Essentially confined
		Fox Canyon aquifer	Confined except near outcrop
	Santa Barbara formation	Grimes Canyon aquifer	Confined except near outcrop

Paleocene and Eocene sediments outcrop north and south of the Santa Clara River Valley. These sediments vary from nonmarine to marine sandstones, conglomerates, gypsiferous clays, and shale. Surface water derived from areas where the gypsiferous sediments outcrop is generally of calcium sulfate character.

The Oligocene Sespe Formation also outcrops north and south of the Santa Clara River. Surface water derived from the areas where these outcrops are found is generally of a calcium bicarbonate-sulfate character.

Miocene marine and nonmarine sediments composed of sandstone, conglomerate, and shale are exposed north and south of the Santa Clara River Valley and in other locations in the study area (Plate 2). Surface water derived from the marine formations is generally a sodium-calcium-magnesium sulfate type. Runoff from areas of Miocene continental beds is generally a calcium sulfate type.

Pliocene marine and nonmarine sediments outcrop on both sides of the Santa Clara River Valley and in other areas also. Surface water from these formations is generally a sodium sulfate type. The nonwater-bearing Pliocene Pico Formation lies deep underneath the more recent water-bearing deposits of the ground water basins.

Sediments of the lower Pleistocene series form some of the important water-bearing formations of the study area. Sands and gravels of the Grimes Canyon member of the Santa Barbara Formation are water-bearing and supply some wells in the Las Posas area and Pleasant Valley. This member contains fresh water of good quality. The Santa Barbara Formation also outcrops next to the Santa Clara River Valley.

The San Pedro Formation, which is another lower Pleistocene formation, outcrops throughout the study area. It underlies the important upper Pleistocene and Recent water-bearing formations. A prominent member is the Fox Canyon, which lies beneath the Las Posas area and extends into Pleasant Valley and the Oxnard Plain. The San Pedro Formation also occurs at greater depth in the Santa Clara River Valley. This formation yields water to wells in the Santa Clara Valley and in the Las Posas area, Oxnard Plain, and Pleasant Valley. The water produced from the Fox Canyon member in the last three areas is generally low in TDS.

Surface runoff from these lower Pleistocene formations is generally of calcium sulfate character.

Sediments of the upper Pleistocene include the principal aquifer in the Oxnard Plain, which is the Oxnard aquifer. It consists of stream-deposited sand and gravel. The upper Pleistocene occurs also in Pleasant Valley and the Las Posas area. Most of the alluvium of the Santa Clara River Valley is also upper Pleistocene (Table 19).

The main aquifers of the Oxnard Plain extend offshore also. The extent of these offshore aquifers has been investigated by the U. S. Geological Survey (Greene et al., 1971).

Recent alluvium is thin over most of the study area (probably no more than 60 to 70 feet thick) where it is found.

Hydrogeochemistry

The origin and distribution of dissolved ions and the means by which ground water acquires its chemical character include: (a) differential solubility of the minerals present in outcropping sediments, in the zone of aeration and in the aquifers (Table 20); (b) ion exchange; and (c) mixing of water from more than one source within the ground water basin.

Ground water in the study area generally moves in a westerly and south-westerly direction, except in localized regions where the flows are influenced by local geohydrologic conditions. Replenishment of the ground water basins comes from percolation of precipitation, surface runoff, artificial recharge, applied water, discharged treated waste water, and subsurface inflow.

The effects of percolation of the different waters vary, depending on the rate of percolation, quality of the percolates, and rate of mixing of the percolates with ground water. Mixing is controlled by convection (movement described by Darcy's law), hydrodynamic dispersion (movement through interconnected pores), and ionic diffusion (movement of ions under concentration gradients). The quality of the percolate will depend on the original

TABLE 20
SOLUBILITY OF SOME COMMON MINERALS

Mineral	:	mg/l
Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)	:	2,080 at 25°C
Calcite (CaCO_3)	:	14 at 25°C
Magnesite (MgCO_3)	:	106 at 18°C
Fluorite (CaF_2)	:	16 at 18°C
Sylvite (KCl)	:	347,000 at 20°C
Halite (NaCl)	:	357,000 at 0°C

quality of the source water (precipitation, surface water, or waste water) and the reactions that take place as the water travels to the ground water system.

There is no doubt that the initial dissolution of salts occurs on the ground surface where evaporites and minerals are subject to chemical attack. Most of the reactions above ground are: hydration (water absorption in mineral lattices); hydrolysis (reaction of water with minerals whereby acids and bases are formed); carbonation (reaction with CO_2 forming carbonates or bicarbonates); oxidation (reaction with atmospheric O_2); solution (dissociation of minerals into ions); and ion exchange (where ions from water are exchanged for others on mineral surfaces or the reverse).

Where sands and gravels immediately underlie the surface of a ground water basin, deep percolation to the underlying water table is unrestricted. Where clayey sediments occur, water moving downward from the ground surface is stored in perched aquifers and the main aquifers are confined underneath. The perched water in the Oxnard Basin is of very poor quality, TDS averaging 5,000 mg/l or higher. However, even where near-surface layers of low permeability exist, limited quantities of water may percolate (by leakage) to the underlying confined aquifers.

Surface water flows in the study area are seldom less than 500 mg/l and, for the most part, are calcium sulfate in character, reflecting the geochemical effects of the gypsiferous marine clays that are found in the older sediments bordering the alluvial basins. Because of the natural occurrence of gypsum in the upper Pleistocene and Recent alluvium and the replenishment of the ground water basins with runoff waters containing CaSO_4 , which has been dissolved from prealluvial parent sediments, the ground water is normally CaSO_4 in character. Because of evaporation of water and resultant deposition of calcium sulfate (gypsum) over the years in the soils and in the unsaturated zone, most of the soils of the study area are rich in gypsum and calcium carbonate.

Precipitation water percolating through the soils will normally dissolve CaSO_4 and carry it to the ground water basin, thus maintaining the predominant CaSO_4 character of the ground water.



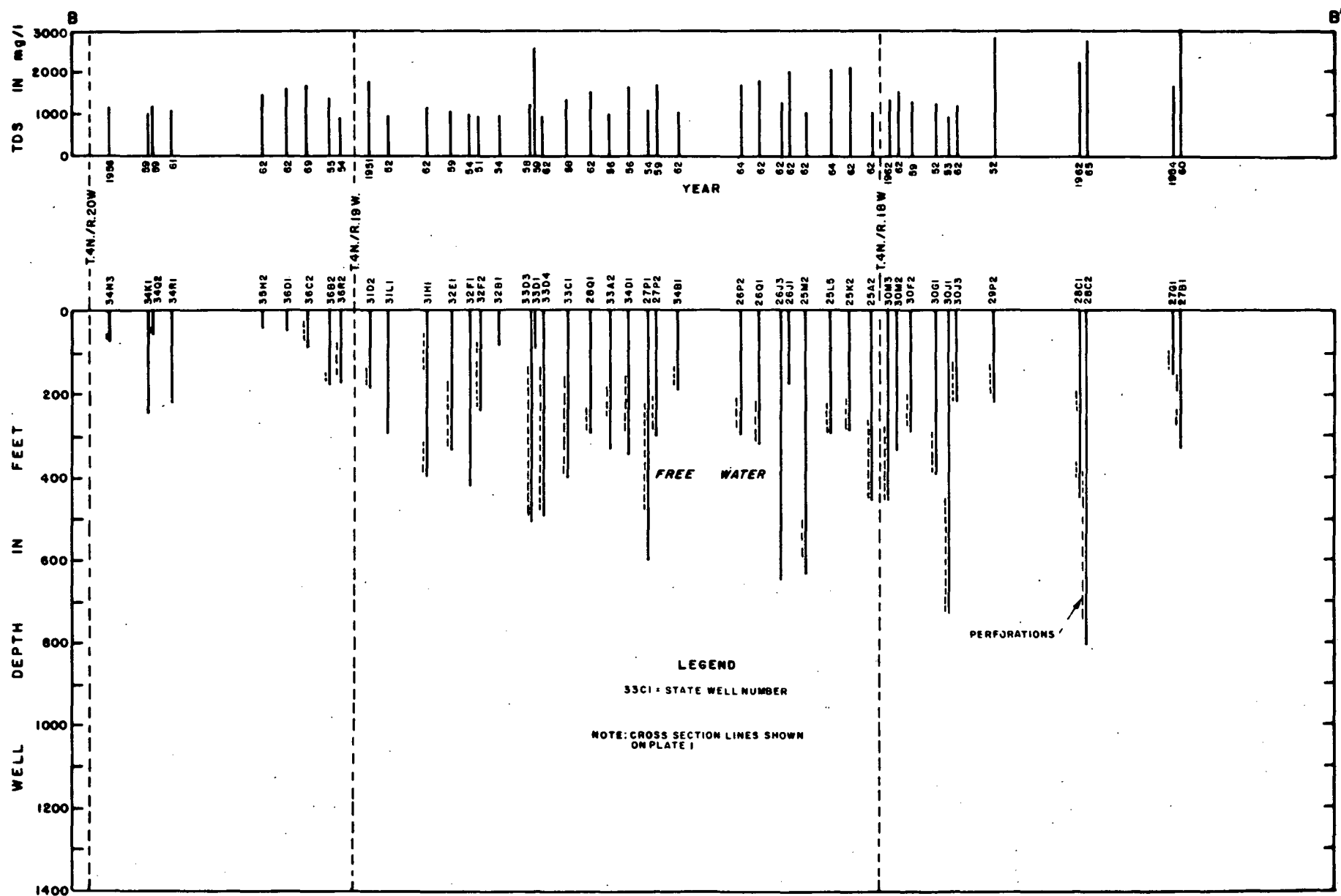


Figure 13 - CROSS SECTION B-B' SHOWING WELLS AND TOTAL DISSOLVED SOLIDS CONCENTRATION IN THE SANTA CLARA-CALLEGUAS AREA

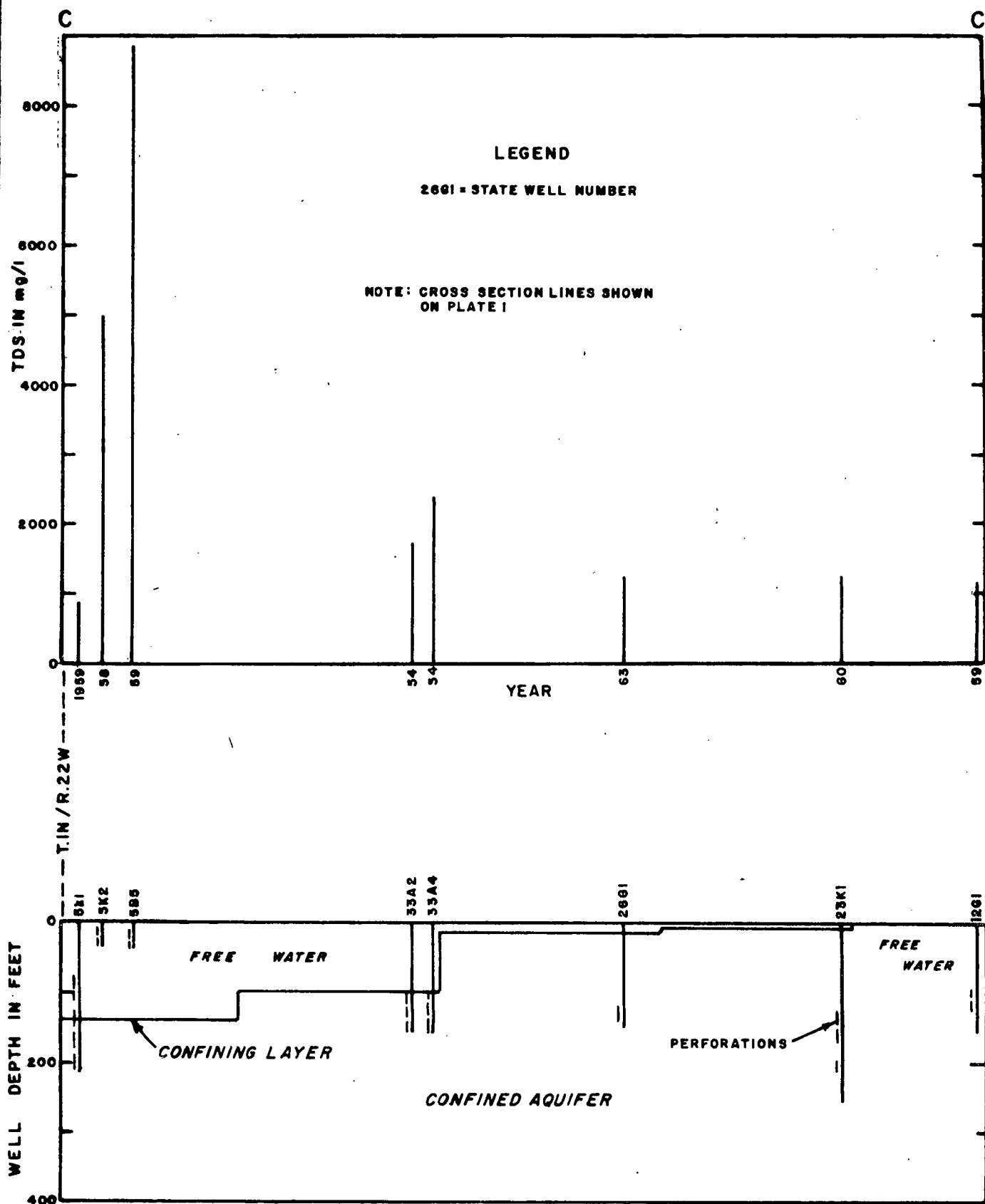


Figure 14 - CROSS SECTION C-C' SHOWING WELLS AND TOTAL DISSOLVED SOLIDS CONCENTRATION IN THE SANTA CLARA-CALLEGUAS AREA

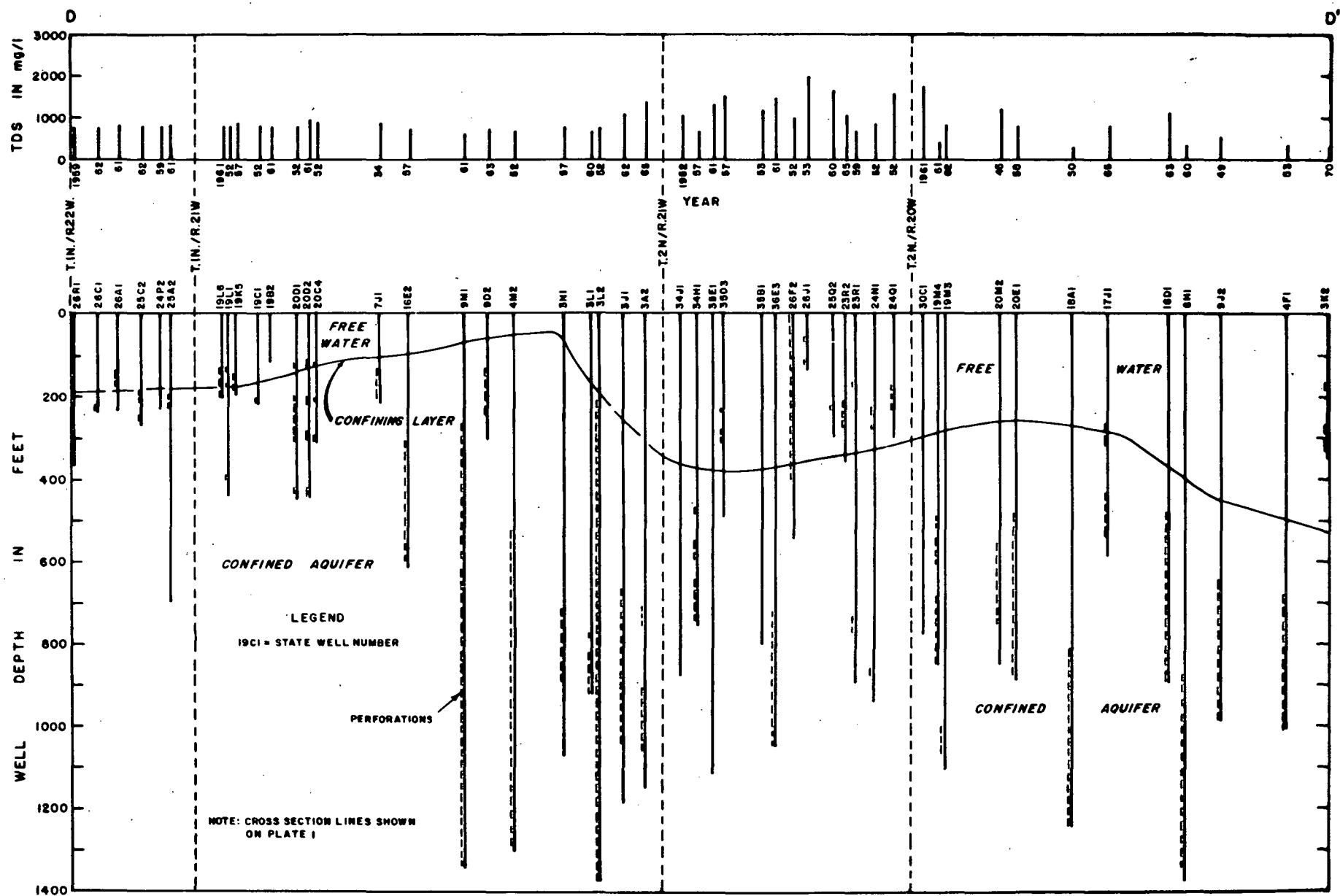


Figure 15 - CROSS SECTION D-D' SHOWING WELLS AND TOTAL DISSOLVED SOLIDS CONCENTRATION IN THE SANTA CLARA-CALLEGUAS AREA

Sespe and Piru Creeks receive small flows of water with high boron concentrations, originating from past mining operations. Boron concentrations above 1.0 mg/l are common at low flows. Analyses showed a concentration of boron of 3.9 mg/l in Sespe Creek on September 20, 1963.

Beside these natural factors that affect the chemical composition of surface and ground water, man's activities, such as extensive pumping, disposal of waste water, irrigation of crops, and importation of water, cause other changes in the chemical quality of ground water. Extensive pumping reversed the hydraulic gradient near the Pacific Ocean; thus, ocean water intruded the Oxnard aquifer, increasing the NaCl content of the ground water. Disposal of domestic waste water increases salinity, especially nitrate levels. The effect of the consumptive use of water applied to irrigated crops and of fertilizers is normally the percolation of more saline drainage water to the ground water basin.

Use of Colorado River water, which is of sodium-calcium sulfate character and thus of a different chemical composition from that of the native ground water, also causes some modification in the quality of ground water.

To investigate areal variations of TDS in the ground water basin, isosalinity contours were constructed (Figures 2, 3, and 4). To determine if depth is a factor in quality variation, cross sections showing well locations, depth, perforations, and TDS were constructed (Figures 12, 13, 14, and 15).

The TDS contour maps show significant areal variations in TDS within the ground water basins; however, vertical variations are less significant. Vertical zonation is more significant where more than one aquifer occurs, e.g., in the Oxnard Plain, the semiperched water is high in TDS--sulfates and nitrates, in particular; the confined Oxnard aquifer has relatively lower TDS, except where it has been intruded by sea water; and the Fox Canyon aquifer has a similar TDS content to the unintruded Oxnard aquifer.

Quality of Water in the Basins

The chemical reactions discussed, which are dependent on the geochemical makeup of the sediments, played a major role in the chemical composition of ground water in Santa Clara-Calleguas Area.

The following is an evaluation of the quality of extracted ground water in the different ground water basins of the study area:

Piru Basin. Based on concentrations of TDS, the quality of extracted ground water is poorer close to the northern and southern border of the Basin. This is mainly due to the effect of irrigation return and subsurface flows received from the bordering sediments. The quality is improved in the portion adjacent to the Santa Clara River Channel. The quality improves also west of the confluence of Piru Creek and the Santa Clara River. Sulfate and boron are the main constituents that cause quality impairment.

Fillmore Basin. Generally, ground water derived from that portion of the Basin north of Santa Clara River and west of Sespe Creek is low in TDS

and is of the calcium bicarbonate type. Water in the southern portion of the Basin is relatively high in TDS. TDS is generally high in those parts receiving deeply percolated irrigation return. Nitrate and boron are problem constituents.

Santa Paula Basin. Runoff and subsurface flows of high TDS content cause high TDS in ground water next to the hills flanking the north and south sides of the Basin. Ground water extracted from the eastern portion of the Basin, near the mouth of Santa Paula Creek, is low in TDS from percolation from that Creek.

Mound Basin. Ground water extracted from the portion of the Basin north of the Santa Clara River is high in TDS. TDS is highest at the northern boundary of the Basin and decreases southward toward the Santa Clara River.

Montalvo (Oxnard Forebay) Basin. The quality deteriorates southwestward as ground water moves away from the Santa Clara River, which is the main source of recharge for the Basin.

Oxnard Plain Basin (Pressure Area). Most of the water pumped is from the Oxnard aquifer. Some water is also pumped from the Fox Canyon aquifer. Semiperched ground water is found above the Oxnard aquifer. The semiperched aquifer is high in TDS (5,000 mg/l and higher) because it receives irrigation return and other wastes. Oxnard aquifer water improves westward and southeastward because of the spreading of water of higher salinity in relation to the native ground water in the Oxnard Forebay area. Near Port Hueneme, the aquifer has been intruded by ocean water, hence, its water is locally high in TDS.

Pleasant Valley Basin. Ground water derived from the northern and eastern portions of the Basin is generally lower in TDS than water extracted from the central and southwestern parts.

East and West Las Posas Basins. Water is extracted mainly from the Fox Canyon and Grimes Canyon aquifers. Most of the water in these Basins is low in TDS, with relatively high percentages of magnesium, which indicates the effects of the volcanic formations that form the eastern border of the Basins.

Values Used in Modeling

The information herein is mainly based on geology, hydrology, surface and ground water quality, and soil minerals. Quantitative information is unavailable about the mineral quality of precipitation and runoff water at the source, the amount of minerals dissolved by runoff in different parts of the Basin, and the amount of salts dissolved from the zone of aeration. Because time and funds do not permit field and laboratory tests, the measured historic quality of surface water will be used in the model for that of percolating surface water. Such water already contains salts dissolved from the outcropping sediments, man's waste discharges, and irrigation return.

For precipitation percolated to the ground water basin, a TDS value of 200 mg/l will be assumed. This value is reasonable since the TDS of ground water in the Las Posas Basin, which is mainly recharged by precipitation percolation,

is similar. Such a value will be subject to change in the verification of the mathematical ground water quality model.

Salt Movement in Ground Water

Until now, a gross assumption has been used to estimate the future quality of ground water in areas receiving waste water and other recharge water, namely: instantaneous mixing of the percolates in the entire ground water basin. Although this procedure can still be used in small sections of basins that directly receive waste water, it is erroneous when used for whole basins or for larger sections unless the percolation of waste water is widespread (diffused source).

Changes in the mineral quality of ground water are generally slow. Waste water discharges or recharge water percolate to the water table and mix with ground water gradually. The rate of dispersion of these percolates and the resultant changes in ground water quality depend on seepage velocity.

Seepage velocity varies with the porosity of the aquifer and the density and viscosity of the moving fluid. Movement of ground water as described by the Darcy's Law ($V = Q/A = K \frac{dh}{dL}$), in which laminar flow is through a total cross section of the aquifer, falls short of describing the actual movement of the water. Actually, water and salts move through an intricate system of connected aquifer voids under a changing hydraulic gradient -- affected by recharges or discharges.

Water Quality Models

Quantity models are normally developed prior to verification of quality models. In the DWR quantity models, water movement is described by its general transmissibility through the cross section of an aquifer.

Such a model can be used to describe salt movement as being dissociated in water with reasonable error where water percolations are diffused in the basin and not localized. Where waste water is discharged from local point sources, the rate of salt movement and the dispersion process of the percolating water in the ground water reservoir becomes more complex.

Ground water quality models until now were based on: (a) conservation of mass (salts in $\pm$ salt storage); and (b) movement of salts and water uniformly mixed from one area to another. WRE, in cooperation with DWR, devised the following equation to calculate the concentration of dissolved solids in subsurface flow from one node to another (1969):

$$C_{ij} = C_i \delta + (1-\delta) C_j$$

where:

C_i is salt concentration in node i

C_j is salt concentration in node j

δ is an interpolation factor

The interpolation factor employed by WRE in the water quality model developed for the Upper Santa Ana River Basin was 0.75.

DWR applied a simpler procedure in the development of a water quality model for the Riverside Ground Water Basin (April 1971). In that model the quality of subsurface flow was considered the same as that of the source node. Thus, $C_{ij} = C_i$ and $C_{ji} = C_j$.

In these models, ground water flow is described by its movement under particular hydraulic gradients. However, many investigators have recognized that quality models should be based on an approach that considers the true movement of water and salts (Weber and Hassan, 1972). Such an approach should enable one to calculate concentrations of dissolved salts as they move away from their source area. Water quality computations without considering dispersion of salts in the ground water do not represent the actual physical processes.

Dispersion

The movement of salts in water through the pores of the saturated aquifers is controlled by three mechanisms: convection, dispersion, and diffusion.

Convection

Convective flow (hydraulic diffusion) is described by Darcy's equation ($V = k \frac{dh}{dx}$). The convective term is the flow of the salts = VC: where V is the average velocity of flow and C is the concentration of salts in the medium.

Dispersion

Dispersion (hydrodynamic dispersion) is a mixing process of two fluids resulting primarily from the mechanical variations that take place when the fluids are in motion within the geometrically complex pore channels of the medium. As a result, the fluid elements become mixed and the salts become dispersed in the medium. The size and shape of the pores and the magnitude of the seepage velocity control the amount of dispersion that occurs.

According to Bruch and Street (1967), the character and size of the dispersion pattern is dependent on the size of the salt input area, the average seepage velocity, the average diameter of the medium (d_{50}), and the kinematic viscosity of the fluid. Dispersive flux = $D \frac{dC}{dX}$, where D is the dispersion coefficient, X is distance, and $\frac{dC}{dX}$ is the concentration gradient.

Dispersion occurs in both the longitudinal (parallel to the direction of flow) and the transverse (perpendicular to the flow) directions. Harlemen and Rumer (1963) determined the relative magnitude of both coefficients from experiments using a model containing isotropic porous materials. Their results showed that, for a Reynolds number equal to 0.1, the ratio of

$\frac{\text{longitudinal dispersion}}{\text{transverse dispersion}} = 5.8$ and for a Reynolds number equal to 1.0,

$\frac{\text{longitudinal dispersion}}{\text{transverse dispersion}} = 12.3$. Thus, the ratio increases with increasing seepage velocity.

The dispersion coefficient is essentially a function of the average rate of flow and the geometry of the medium. Experimenting with Ottawa sand of median effective size of 0.45 mm and average porosity of 39.5 percent, Rifai and others (1956) reported on the variations in the coefficient of dispersion with the variations in the average velocity of flow (Table 21).

TABLE 21
VARIATIONS IN THE COEFFICIENT OF DISPERSION WITH THE
AVERAGE VELOCITY OF FLOW

Average velocity ($V \times 10^4$ cm/sec)	Coefficient of dispersion ($D \times 10^5$ cm ² /sec)
5	3
10	6
20	10
40	20
50	22
212	150
636	380
1,060	600
1,600	850

Harleman and others (1963) reported on the variations in the coefficient of dispersion with the variations in the geometry of the medium, mainly grain size (Table 22).

Diffusion

Diffusion is the result of molecular action in the fluids. Diffusion flux is therefore proportional to the concentration gradient. Diffusive flux = $D_m \frac{dC}{dx}$, where D_m is the molecular diffusion coefficient.

It was reported that in the case of fluid flowing within the range of Darcy's Law, molecular diffusion decreases as velocity increases. Beran (1955) and Rumer (1962) reported that the average velocity at which molecular diffusion starts to be of some importance is about 1 cm/hour.

TABLE 22*

VARIATIONS IN THE COEFFICIENT OF DISPERSION WITH
VARIATIONS IN PARTICLE SIZE AND SEEPAGE VELOCITY

Particle size (cm)	Coefficient of dispersion ($D \times 10^4 \text{ cm}^2/\text{sec}$)	Seepage velocity ($V \times 10^3 \text{ cm/sec}$)
0.14	6.5	8
0.14	30	30
0.14	55	50
0.14	85	70
0.14	120	90
0.092	5	9.5
0.092	16	25
0.092	37	46
0.092	55	70
0.092	75	90
0.045	2	9
0.045	9	30
0.045	11	40
0.045	22	62
0.045	37	95

*Harleman and others, 1963.

Total Transport

The total transport resulting from the three mechanisms of convection, dispersion, and diffusion can be expressed by an equation suggested by Cearlock (1966):

$$\left[C v_{x1} - D \frac{dC}{dx_1} - D \frac{dC}{dx_1} \right] dx_2 dx_3$$

The negative sign appears before the diffusive and dispersive flux because $\frac{dC}{dx}$ is negative. x_1 , x_2 , and x_3 are the directions of input and output from an elemental cube.

Theoretical studies and experimentations of ideal conditions using homogeneous isotropic media led researchers to develop the following equation to calculate the concentration of water at some known distance from the source front (Rifai and others, 1956):

$$\frac{C}{C_0} = 1/2 \left[1 + \operatorname{erf} \frac{Z-Vt}{2\sqrt{Dt}} \right]$$

Where C = concentration at Z , C_0 = initial concentration at source

Z = any direction, V = average velocity of flow,

t = time, D = longitudinal dispersion, and erf = error function.

Using a lucite column filled with saturated Ottawa sand, Kulp (1961) measured the dispersion rate of potassium chloride (KCl) in the sand. He developed a procedure for calculating the approximate dispersion coefficient of that sand. In developing the procedure, he modified the above equation. The dispersion equation in a coordinate system fixed to the column is:

$$\frac{dC}{dt} = D \frac{d^2C}{dx^2}$$

The solution of the above equation for the following boundary conditions

(a) $C(X,0) = 0 \quad x > 0$

The concentration at X when $t = 0$ is zero.

(b) $C(0,t) = C_0 \quad t > 0$

The initial concentration when $X = 0$ is C_0 at any time greater than zero

(c) $C(\infty,t) = 0 \quad t > 0$

Where x is infinite, the concentration is zero.

is $1 - \frac{2C}{C_0} = \operatorname{erf} \frac{X}{2\sqrt{Dt}}$

let $u = \frac{X}{2\sqrt{Dt}}$

Therefore $1 - \frac{2C}{C_0} = \operatorname{erf} \frac{X}{2\sqrt{Dt}} = \operatorname{erf} u$

and $D = \frac{x^2}{4tu^2}$

where: x is the distance from the interface measured positively in the direction of decreasing concentration.

By plotting the values of the error function, $\text{erf } u$, versus those of u on log-log paper, plotting the absolute values of x (distance from interface) versus the absolute values of $1-2C/C_0$ on another log-log paper, and then matching the two curves developed, a matching point can be selected (Kulp, 1961). Using the values corresponding to the matching point at a determined t and substituting in the above equation for u and x , Kulp calculated the dispersion coefficient D of Ottawa sand (Figure 16).

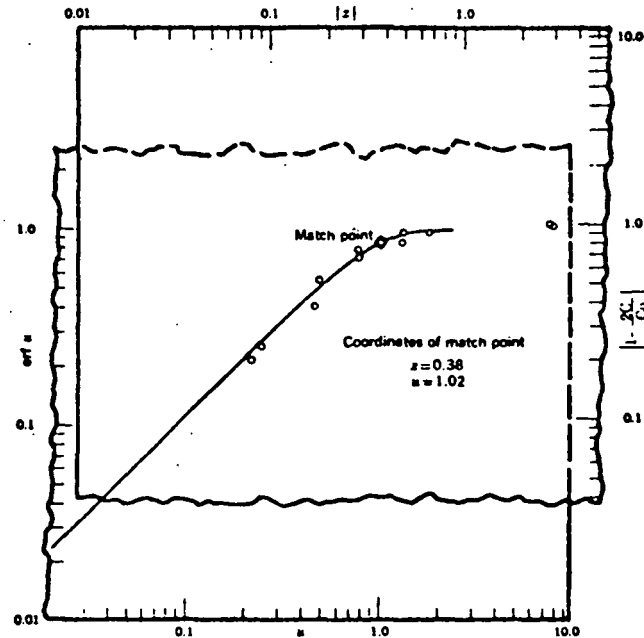


Figure 16. Matching of Absolute Values of X vs. Absolute Values of $1-2C/C_0$ and u vs. $\text{erf } u$. (From Kulp, 1961)

Data Required to Apply the Dispersion Theory

To apply the dispersion equations to the quality model equations the following data are required: (1) dispersion coefficients of the aquifer materials; (2) areas of point source discharges and their projections on the water table; (3) rate of discharge to these disposal sites and TDS concentrations of the discharged water; (4) historic data for verification of the salt dispersion into the ground water reservoir; and (5) defining the areal picture of the developing plumes.

Such data were not available anywhere in the Santa Clara-Calleguas area. Accordingly, the effects of local point source waste discharges were

more or less diffused into nodal weighted TDS concentrations. Dispersion of salts from one node to the next was handled empirically using a dispersion factor that describes the TDS concentration of subsurface flow into or out of a node. This was discussed in the water quality model chapter of Volume I.

CHAPTER 4. THE ALLOCATION OF WATER SUPPLY IN THE SANTA CLARA-CALLEGUAS AREA

In an investigation whose objective is the modeling of the quality of ground water, data must be collected and developed to describe the mineral composition of the water supply. This chapter summarizes the method employed to obtain data relating to the allocation of the water supply for the Santa Clara-Calleguas area during the study period, 1956-1967. The data base program calculates the weighted TDS concentration of supply water to the nodal areas.

Basic Data

The following was necessary to inventory the sources, destination and uses of water:

1. A list of water purveyors in Ventura County which was provided by the County Planning Department (Table 23).
2. A map showing the areal boundaries of water purveyors in the County, also provided by the Planning Department (Figure 17). Some boundary modifications had to be made after consulting water agencies.
3. A map of the study area's nodal network, which was designed for the ground water quantity model of Santa Clara-Calleguas (Plate 1, Volume I).
4. A map showing the location of water wells (Plate 1).
5. A list of calculated historical nodal average TDS concentrations of ground water for selected years (Table 1).

Inventory of Water Purveyors

A canvass of water purveyors was made to obtain information about their sources of water, including ground, surface, imported, and reclaimed water. It was essential to determine if the source of supply was ground water alone or some proportion of ground water, surface water diversion, and/or imported water. It was also essential to obtain data on the percentage of supply from each source in relation to the total for each year from 1956 to 1967, e.g., 60 percent ground water and 40 percent imported water. Information was also sought about the location of such supply sources as water wells (referenced to nodal areas), surface water diversions, and the source of imported water, which are utilized by the water purveyors.

Data were collected about domestic, agricultural, industrial, and commercial water uses, as well as the percentage allocated for domestic, agricultural, or industrial purposes, e.g., the annual water supply of Water Service Area No. 36 is 5 percent domestic and 95 percent irrigated agriculture (based on the average for 1956-1967).

TABLE 23

WATER PURVEYORS IN THE SANTA CLARA-CALLEGUAS AREA

CASITAS MUNICIPAL WATER DISTRICT

16.* City of Ventura Water Department

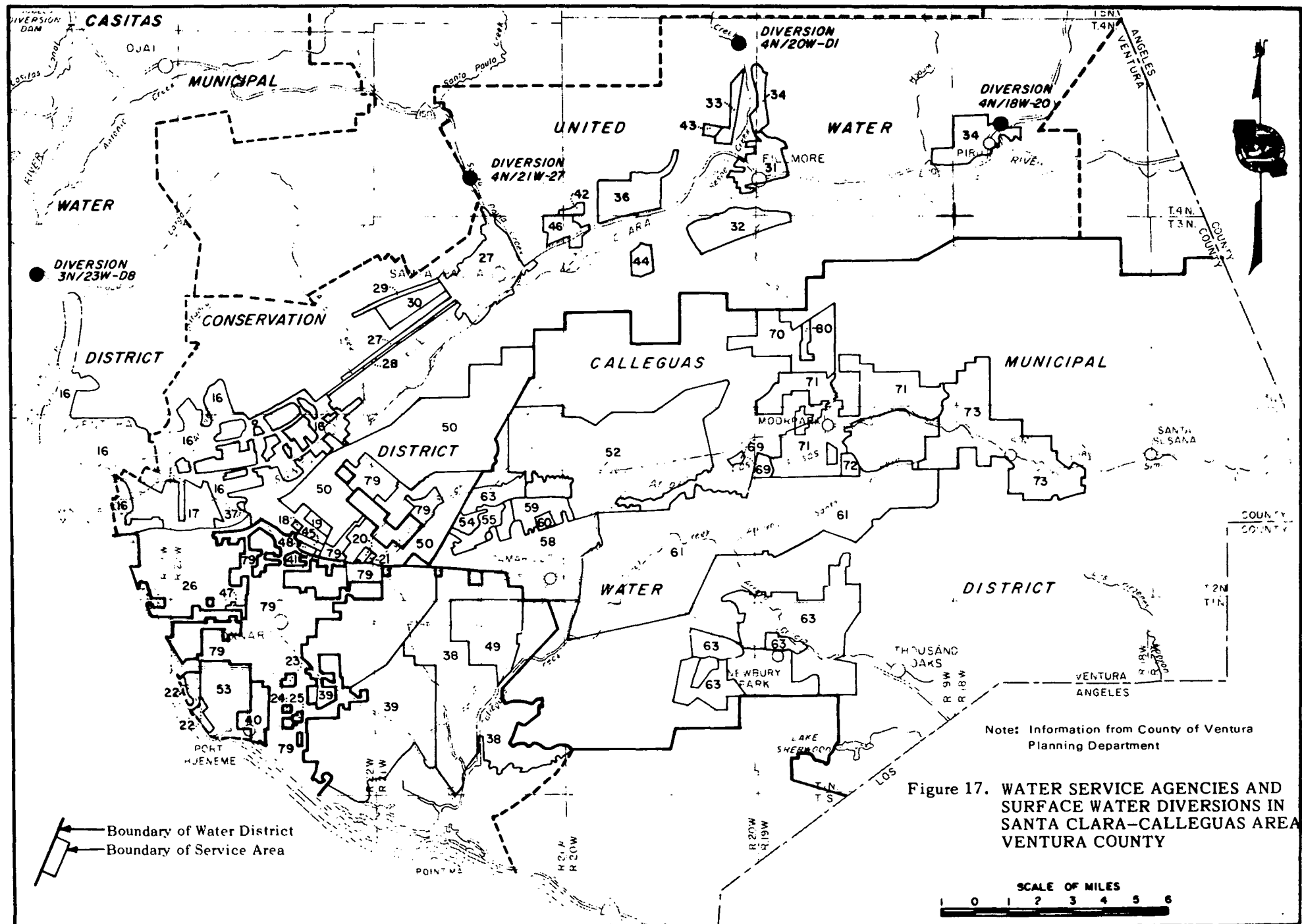
UNITED WATER CONSERVATION DISTRICT

17. Montalvo Mutual Water Company (Irrigation)
18. El Rio Mutual Water Company
19. Rio Plaza Water Company
20. Nyeland Acres Mutual Water Company
21. Garden Acres Mutual Water Company
22. Channel Islands County Water District
23. Dempsey Road Mutual Water Company
24. Saviers Road Mutual Water Company
25. Cypress Mutual Water Company
26. Colonia Municipal Water District
27. Santa Paula Waterworks Ltd.
28. Farmers Irrigation Company
30. Middle Road Mutual Water Company
31. City of Fillmore Water Department
32. Southside Improvement Company
33. Fillmore Irrigation Company
34. Ventura County Waterwork District #16
36. San Cayetano Mutual Water Company
37. Sherwin Acres Water Company
38. Pleasant Valley County Water District
39. Ocean View Municipal Water Company
40. City of Port Hueneme
41. Rio Manor Mutual Water Company
42. Timber Canyon Mutual Water Co.
43. Brownstone Mutual
44. Stork Mutual Water Co.
45. Vineyard Avenue Acres Mutual Water Co.
46. Community Mutual Water Co.
47. Agee's Farms Mutual Water Co.
48. Cloverdale Mutual Water Co.
49. Oxnard Mutual Water Co.
50. Del Norte Municipal Water District
53. U. S. Navy, Port Hueneme
79. City of Oxnard

CALLEGUAS MUNICIPAL WATER DISTRICT

- 52.* Rancho Las Posas Water Company
- 54. Country Club Mutual Water Company
- 55. Crestview Mutual Water Company
- 56. Air Force Capehart Housing
- 58. City of Camarillo Water Department
- 59. Pleasant Valley Mutual Water Company
- 60. Ray Thomas Ranches Mutual Service Company
- 61. Camrosa County Water District
- 63. Cal-American Water Co.
- 69. Ventura County Waterworks District No. 11
- 70. Fairview County Water District
- 71. Ventura County Waterworks District No. 1
- 72. Peach Hill Mutual Water Company
- 80. Epworth Mutual Water Co.

*Please note that the numbers were assigned by Ventura County Planning Department. They refer to locations on Figure 17.



Changes in the sources of supply during 1956-1967 were also collected. This was necessary because some purveyors had used the same sources throughout the study period, while others had acquired alternative sources during part of the period. Information was obtained regarding water agency changes in service area boundaries by mergers or annexations.

Location of Water Source

The location of the source of supply in relation to the area's nodal network was determined from the well location map (Plate 1) and the nodal network map (Plate 1, Volume I).

The location of diversions of surface water and of delivered imported water were also determined in relation to the nodal areas.

Service Area Nodal Coverage

To determine the source and quality of supply water delivered to each nodal area, the percentage of nodal coverage within each agency boundary was estimated. This was necessary because some nodal areas receive water from more than one agency.

(Figure 16 shows the boundaries of the areas served by each water purveyor; Plate 1, Volume I, shows the nodal network used to estimate nodal coverage.)

Average TDS Concentration of Supply to Nodal Areas

To develop data on the average TDS concentration of water supply to nodal areas required information about: (a) the historic average TDS concentration of ground water in each nodal area; (b) the weighted TDS concentration of the service area supply; and (c) the percentage of the service area within each nodal area.

The San Cayetano Mutual Water Company Water Agency No. 36 shown in Figure 17 obtains its total supply from wells in nodal area 19. The annual average TDS of ground water extracted from nodal area 19 is assumed to be the TDS of the supply for this agency. Water for nodal areas outside the agency boundary comes from local ground water. Therefore, the average TDS of the total supply of the nodal area includes water supplied by the purveyor and water extracted locally from the ground water basin. Table 24 illustrates the results of these calculations.

TABLE 24

ESTIMATED TDS CONCENTRATION OF SUPPLY WATER
TO NODAL AREAS 19, 20, 21, 22 and 23 in 1956

Nodal Area	: Water Agency No. 36 :		Local ground water :		Average
	: Percent :	TDS	: Percent :	TDS	
					TDS of supply
19	6	1,010	94	1,010	1,010
20	9	1,010	91	630	664
21	55	1,010	45	690	866
22	17	1,010	83	665	723
23	13	1,010	87	655	701

A summary of the collected data on sources of supply, where the supply is delivered, and how the water is used is shown in Table 25.

ALLOCATION OF WATER SUPPLY IN THE SANTA CLARA-CALLEGUAS AREA FOR THE PERIOD 1956-67

Service	Date	Water Sources								Service Area Covered								Use		
Agency		Ground Water	U.W.C.D.	C.M.W.D.	Other Agencies	Surface	Location	Dom.	Irrig.	Other										
Number	From - To	Node	Node	Node	%	El Rio	%	M.W.D.	%	Agency	supply	Water	Source	Node	%	Node	%	Node	%	%
16	1956-1967	55	60	64	24	None		None		Casitas Reser- voir	25	51	3N/23W-08	41	4	42	2	46	2	38
		63												53	1	54	5	55	7	38
														56	4	58	12	59	4	7
														60	7	61	15	62	20	
														63	10	64	3	65	2	
														66	2					
17	1956-1967	64			100	None		None		None		None		60	5	61	4	63	57	100
														64	34					100
18	1956-1967	51			100	None		None		None		None		51	65	50	35			98
19	1956-1967	49			100	None		None		None		None		49	2	50	65	51	33	96
20	1956-1967	77			100	None		None		None		None		77	85	78	15			100
21	1956-1967	7				None		None		None		None		77	90	78	10			100
22	1956-1965	74			100	None		None		None		None		74	100					100
	1965-1967	74			90		10	None		None		None		74	100					100
23	1956-1964	84			100	None		None		None		None		85	100					100
	1965-1967	84			5		95	None		None		None		85	100					100
24	1956-1959	84			100	None		None		None		None		85	100					100
	1960-1967	84			10		90	None		None		None		85	100					100
25	1956-1957	85			100	None		None		None		None		85	100					100
	1958-1959	85			15		85	None		None		None		85	100					100
	1960-1967						100							85	100					100
26	1956-1967	71	70	67	100	None		None		None		None		63	6	64	7	66	2	5
														67	9	68	43	69	20	5
														70	13					5
27	1956-1967	28	29	32	62	None		None		None		38%	4N/21W-27	28	8	29	30	30	19	40
														31	14	32	21	36	4	60
														39	4					

TABLE 25 (Continued)

ALLOCATION OF WATER SUPPLY IN THE SANTA CLARA-CALLEGUAS AREA
FOR THE PERIOD 1956-67

Service	Date	Water Sources								Service Area Covered								Use		
Agency		Ground Water	U.W.C.D.	C.M.W.D.	Other Agencies	Surface	Location											Dom.	Irrig.	Other
Number	From - To	Node	Node	Node	%	El Rio	%	M.W.D.	%	Agency	supply	Water	Source	Node	%	Node	%	Node	%	%
28	1956-1967	32	29	36	100	None		None		None		None		32	16	36	35	39	35	100
29	1956-1967	29			25	None		None		28	75	None		41	14	34	3	35	71	100
30	1956-1967		None			None		None		27	100	None		32	30	35	65	36	5	100
31	1956-1967	14			100	None		None		None		None		13	8	14	80	16	12	100
32	1956-1967	12	13	17	100	None		None		None		None		13	15	17	80	18	5	100
33	1956-1967	14	15		60	None		None				40%	4N/20W-01	15	100					20
34	1956-1967	4	5		50	None		None		None		50%	4N/18W-20	4	30	5	40	8	10	50
36	1956-1967	19			100	None		None				None		9	20					50
37	1956-1958	65			100	None		None				None		19	6	20	9	21	55	95
38	1959-1967													22	17	23	13			5
38	1960-1967	None				100		None		None		None	3N/21W-31	65	100					97
39	1956-1967	None				None		None		79	100	None		87	12	89	22	90	30	100
40	1956-1967	74			49	51		None		None		None		118	5	119	8	121	2	95
41	1956-1967	50			100	None		None		None		None		140	8	141	13			5
42	1956-1967	23			100	None		None		None		None		83	3	84	10	85	12	98
43	1956-1967	15			100	None		None		None		None		86	17	87	2	88	50	
44	1956-1967	24			100	None		None		None		None		89	4	90	2			
45	1956-1967	50	51		100	None		None		None		None		74	85	85	15			95
46	1956-1967	25			100	None		None		None		None		50	80	72	20			100
47	1956-1967	73			100	None		None		None		None		22	15	23	40	26	45	95
														15	100					5
														18	55	24	45			95
														50	100					100
														25	24	26	64	23	12	100
														73	100					100

TABLE 25 (Continued)

ALLOCATION OF WATER SUPPLY IN THE SANTA CLARA-CALLEGUAS AREA
FOR THE PERIOD 1956-67

Service	Date	Water Sources								Service Area Covered								Use		
Agency		Ground Water	U.W.C.D.	C.M.W.D.	Other Agencies	Surface	Location											Dom.	Irrig.	Other
Number	From - To	Node	Node	Node	%	El Rio	%	M.W.D.	%	Agency	supply	Water	Source	Node	%	Node	%	Node	%	%
48	1956-1967	50			100	None		None		None		None		50	100			90	10	
49	1956-1961	120	119	121	100	None		None		None		None		89	6	119	17	117	1	99
	1962-1967	120	119	121	50		50	None		None		None		118	2	120	35	121	2	99
														140	32	141	5		1	99
50	1956-1967	112	114		100	None		None		None		None		111	53	112	19	113	15	80
														114	4	114	9			
53	1956-1959	74			100	None		None		None		None		74	96	85	4		90	10
	1960-1967	74			79		21	None		None		None		74	96	85	4		90	10
79	1956-1967	72	75	73	75		25	None		None		None		66	2	67	1	68	1	85
		85												69	5	70	2	71	2	
														72	6	73	7	74	9	
														75	9	76	3	77	4	
														78	4	79	3	80	4	
														81	1	82	2	84	8	
														85	8	86	1	88	1	
														45	4	49	1	50	3	
														110	1	114	4	115	4	
52	1956-1967	100	98	96	100	None		None		None		None		96	7	97	5	98	13	30
		99	95	96										99	19	100	14	102	11	70
														103	12	104	19			70
54	1956-1967	111			100	None		None		None		None		110	15	116	85		95	5
55	1956-1967	93	111		100	None		None		None		None		116	82	110	18		23	77
56	1956-1957	87	86		100	None		None		None		None		87	55	86	45		95	
	1958-1967	87	86		40		60	None		None		None		87	55	86	45		95	5 Indus
58	1956-1963	109	116	118	100	None		None		None		None		104	2	108	23	109	20	4 Indus
	1964-1967	109	116	118	50	None			50	None		None		115	1	116	12	117	23	2 Indus
														118	17	121	2		97	1
59	1956-1967	109	115		100	None		None		None		None		103	10	109	90		60	40
60	1956-1967	94			100	None		None		None		None		109	100				1	99
61	1956-1967	105	106		30				70	None		None		104	3	105	26	106	19	10 Indus
														107	31	108	21			

TABLE 25 (Continued)

ALLOCATION OF WATER SUPPLY IN THE SANTA CLARA-CALLEGUAS AREA
FOR THE PERIOD 1956-67

Service	Date	Water Sources								Service Area Covered								Use												
Agency	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:							
Agency	:	:	Ground Water	:	U.W.C.D.	:	C.M.W.D.	:	Other Agencies	:	Surface	:	Location	:	:	:	:	:	:	Dom.	:	Irrig.	:	Other						
:	:	:	:	:	Saticoy:	:	:	:	% of its	:	:	:	of	:	:	:	:	:	:	:	:	:	:							
Number	:	From - To:	Node:	Node:	Node:	%	El Rio	:	%	M.W.D.:	%	Agency	:	supply	:	Water	:	Source	:	Node:	%	Node:	%	Node:	%	%	:	%	:	%
63	:	1956-1967	93	111	:	100	None	:	None	:	None	:	None	:	103	30	:	110	:	70	:	100	:	:	:	:	:	:	:	:
69	:	1956-1964	93	:	:	100	None	:	None	:	None	:	None	:	93	56	:	97	:	44	:	40	:	:	:	:	:	:	:	60
:	:	1965-1967	:	:	:	:	None	:	:	:	100	:	None	:	93	56	:	97	:	44	:	:	:	:	:	:	:	:	:	:
70	:	1956-1967	94	91	:	100	None	:	None	:	None	:	None	:	91	50	:	92	:	8	:	94	:	42	:	2	:	:	:	98
71	:	1956-1964	92	:	:	100	None	:	None	:	None	:	None	:	92	35	:	93	:	38	:	94	:	5	:	80	:	:	:	20
:	:	1965-1967	92	:	:	83	None	:	:	:	17	:	None	:	92	35	:	93	:	38	:	94	:	5	:	80	:	:	:	20
72	:	1956-1965	93	:	:	100	None	:	None	:	None	:	None	:	92	12	:	93	:	18	:	:	:	:	:	:	:	:	:	100
:	:	1966-1967	:	:	:	:	None	:	:	:	100	:	None	:	92	12	:	93	:	18	:	:	:	:	:	:	:	:	:	100
80	:	1956-1967	91	:	:	100	None	:	None	:	None	:	None	:	91	100	:	:	:	:	:	5	:	:	:	:	:	:	:	95

CHAPTER 5. EVALUATION OF SEA-WATER INTRUSION OF OXNARD AND MUGU AQUIFERS IN THE OXNARD PLAIN, VENTURA COUNTY

Because the water quality model cannot be used to estimate the TDS concentration of ground water in the areas intruded by sea water, it was necessary to assess the problem and develop some relationships that can be used for future management of water resources in the near-shore aquifers.

The Coastal Plain of Ventura County extends 20 miles south of the Santa Clara River to the western part of the Santa Monica Mountains (Figures 18). It is relatively flat, with an elevation of 20 feet or less along the shore and reaches an elevation of 100 feet or more approaching the foothills of South Mountain. The sediments of the Plain also extend offshore from 5 to 10 miles along the Continental Shelf. Offshore, the sediments are incised by two large submarine canyons. Sea-water intrusion occurs in two locations: Port Hueneme and Point Mugu (Figure 18).

Previous Investigations

Because of sea-water intrusion in the Oxnard Plain and the threat of pollution of valuable ground water, DWR and other agencies have devoted considerable attention to this area, investigating and monitoring sea-water encroachment of its freshwater supply. In 1965, DWR published Bulletin No. 63-1, "Sea-Water Intrusion, Oxnard Plain of Ventura County", detailing the extent of the problem.

History of Sea-water Intrusion

Increased use of ground water combined with a period of dry years during the early 1930's caused water elevations to decline several feet below sea level in parts of the Oxnard Coastal Plain (Figures 19, 20, and 21).

In 1931, data on water quality in Well No. 1N/22W-8D1, near the head of the Hueneme submarine canyon (Plate 5), revealed a chloride ion (Cl) concentration of over 2,000 mg/l. By the end of 1933, the concentration decreased to less than 100 mg/l. The decrease near Port Hueneme was probably due to natural recharge and rising water levels. In the fall of 1931, water quality data on Well No. 1S/21W-8H1, near Point Mugu, revealed that Cl exceeded 500 mg/l and in March 1933, 2,000 mg/l. This increase was probably caused by factors other than sea-water intrusion, mainly percolations from the Mugu Lagoon.

From 1930 to 1945, the piezometric head of the Oxnard aquifer remained from 5 to 10 feet above sea level. This was due to above-normal annual precipitation during that period. In 1945, this wet period ended and the piezometric surface started to decline and, by 1949, levels had dropped to 30 feet below sea level. During this period of drought, a well-defined pumping trough also developed about 5 miles inland, causing a landward hydraulic gradient that increased sea-water encroachment.

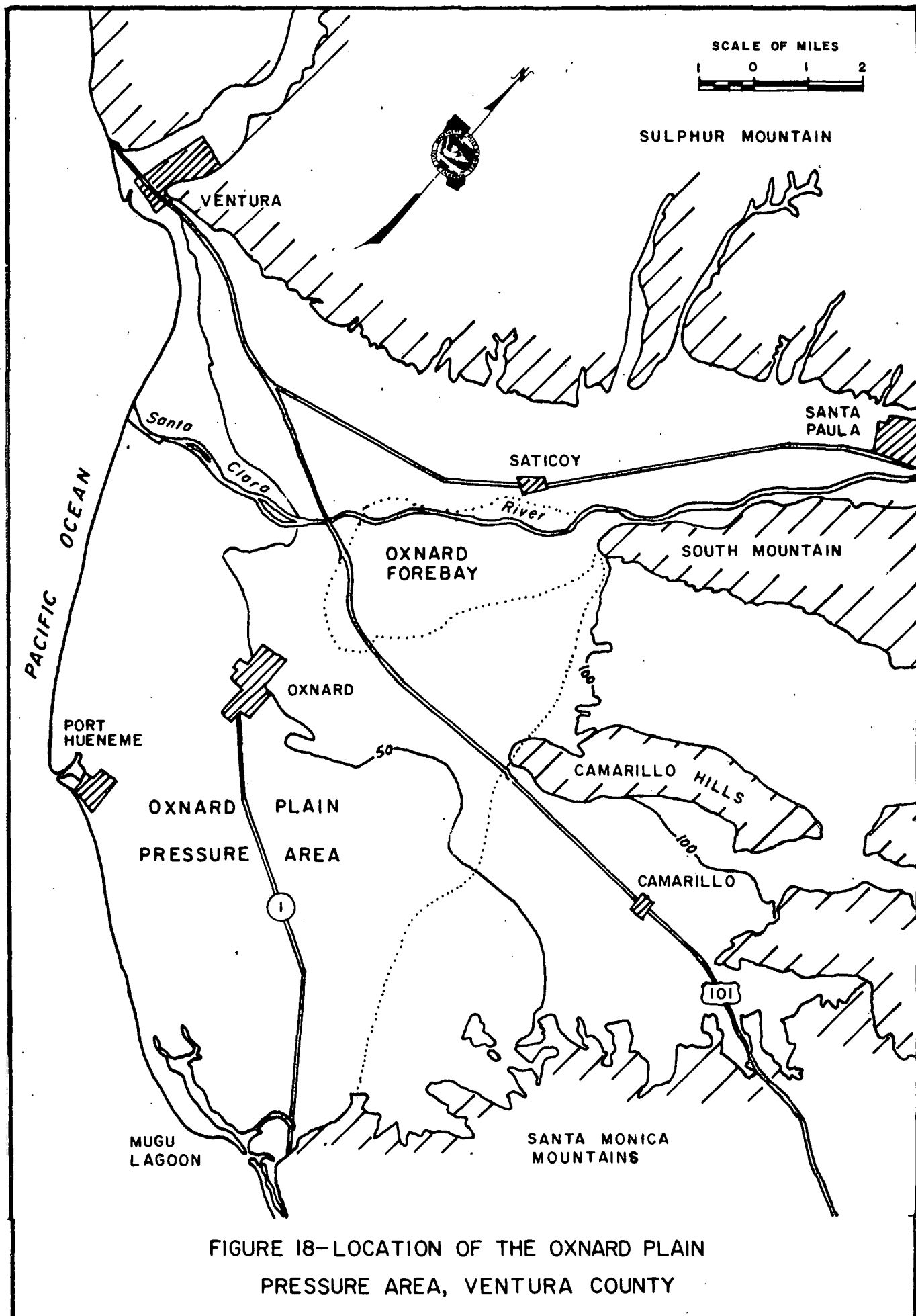


FIGURE 18-LOCATION OF THE OXNARD PLAIN
PRESSURE AREA, VENTURA COUNTY

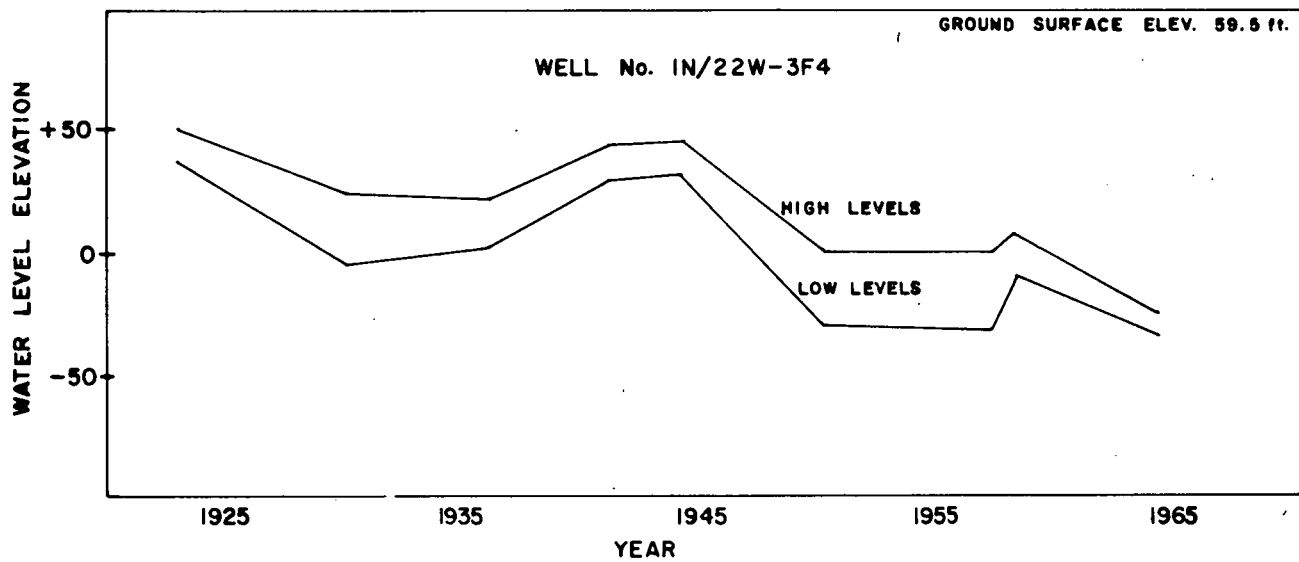
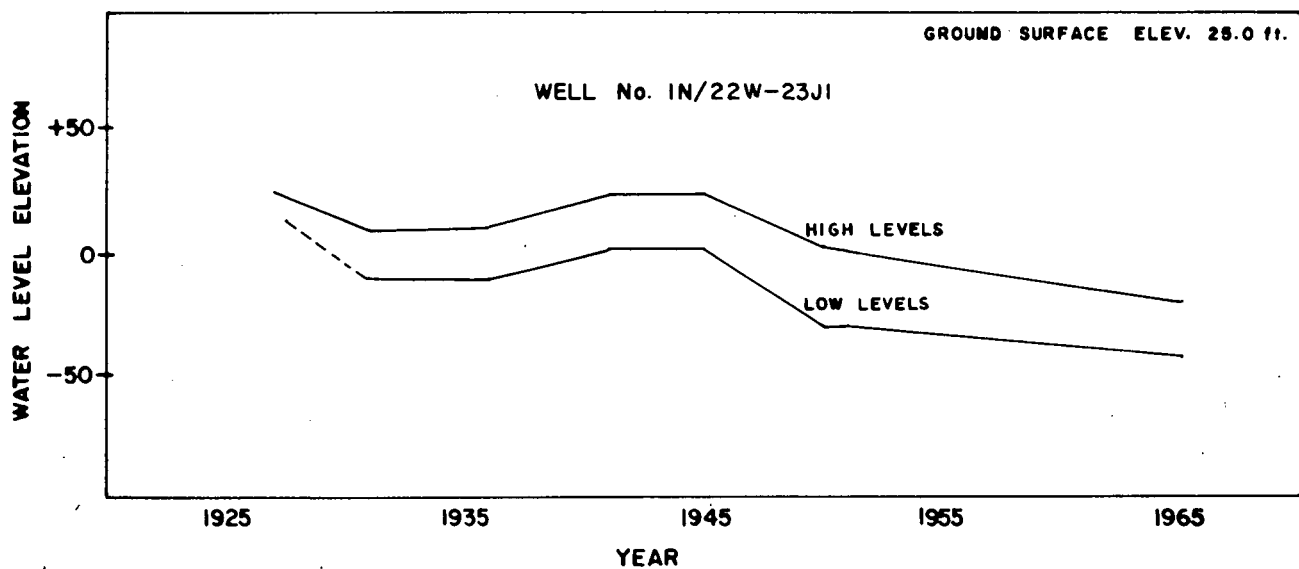
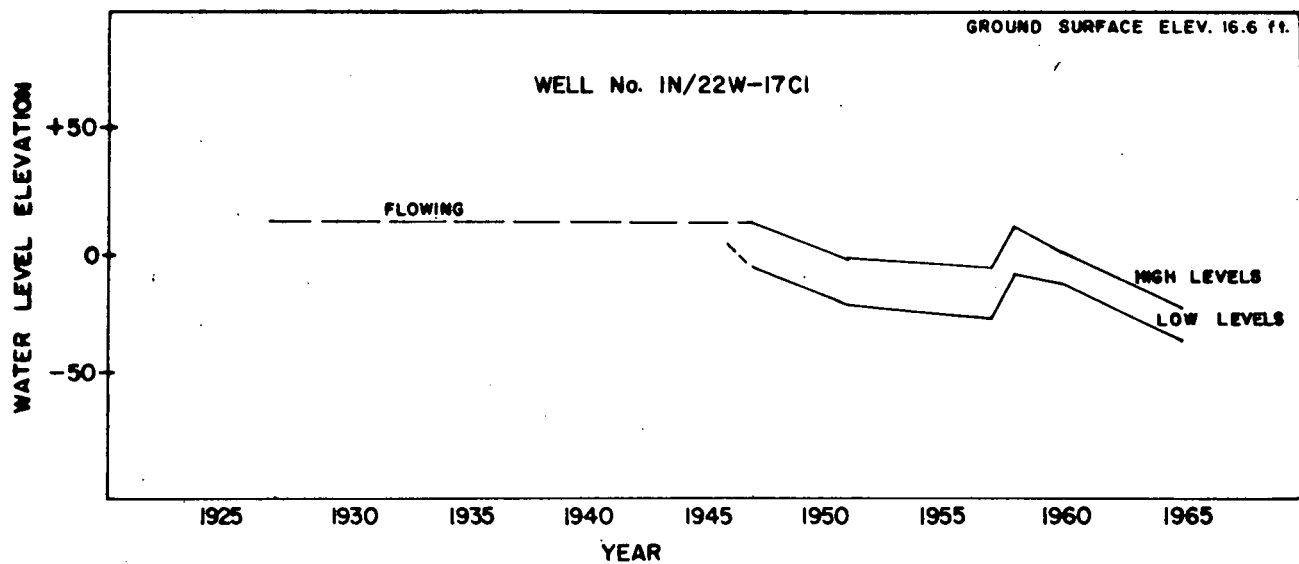


FIGURE 19—WELL HYDROGRAPHS SHOWING WATER LEVEL FLUCTUATIONS

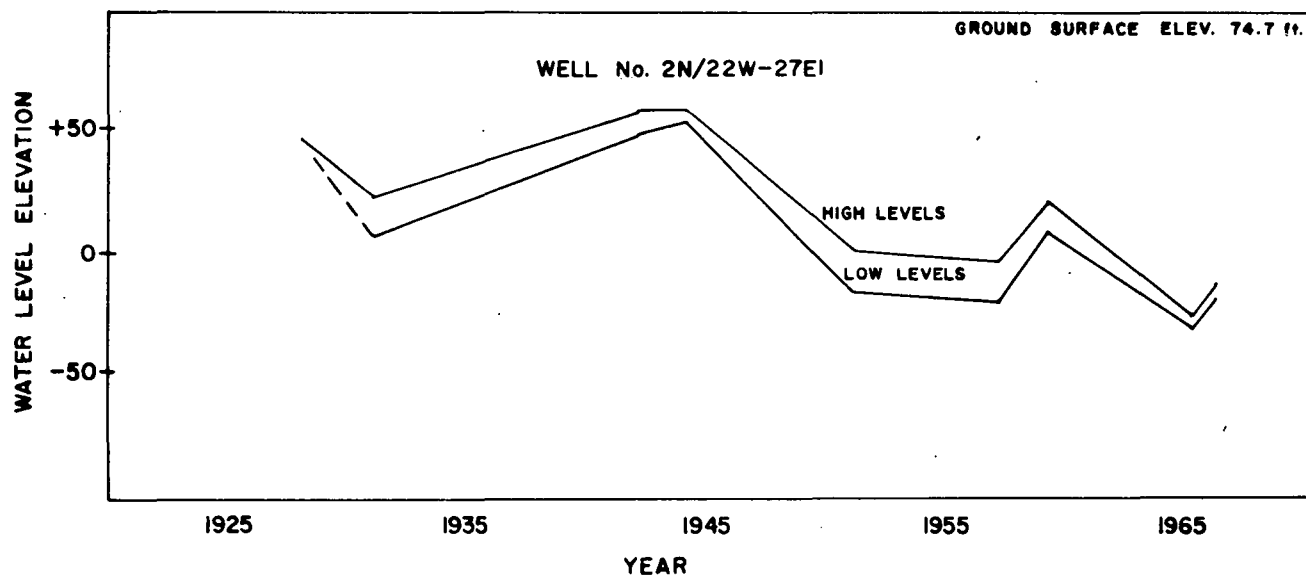
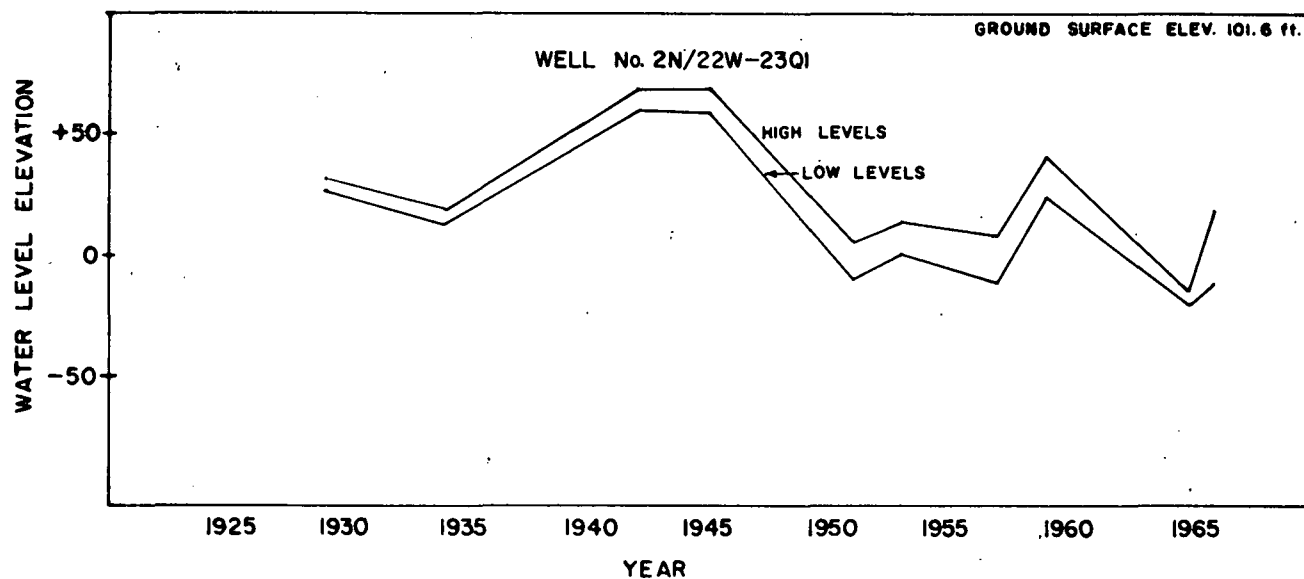


FIGURE 20-WELL HYDROGRAPHS SHOWING WATER LEVEL FLUCTUATIONS

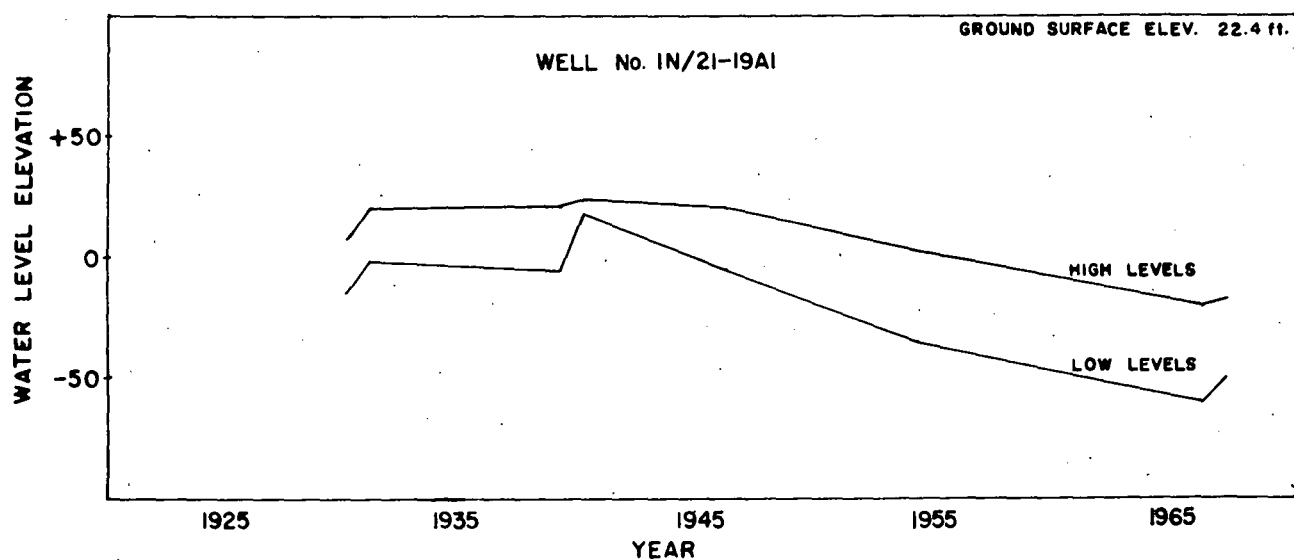
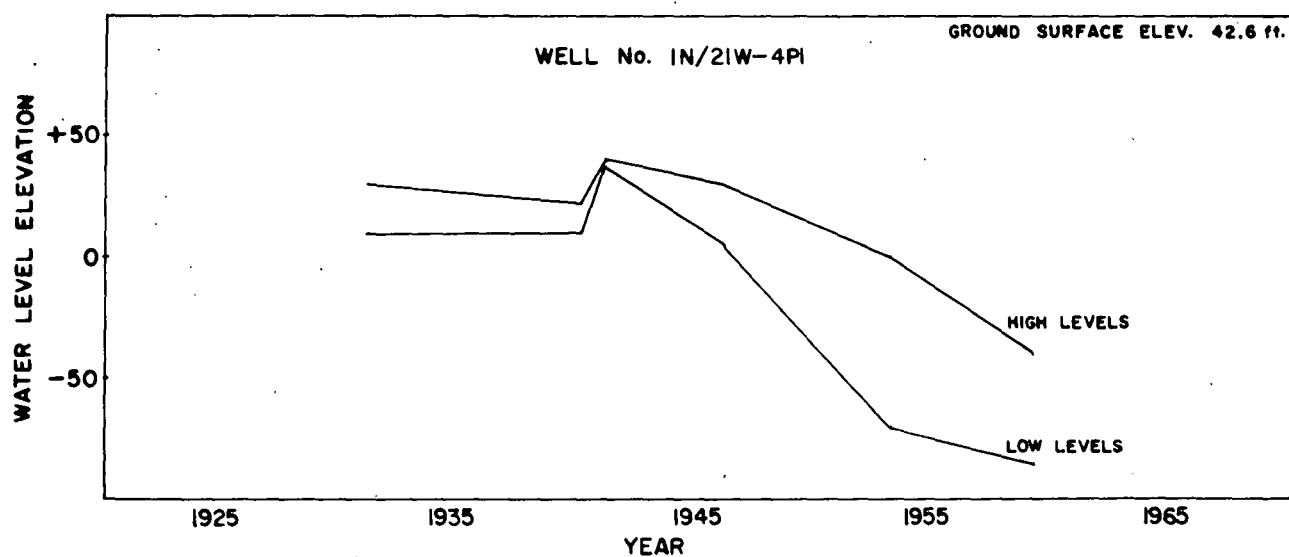
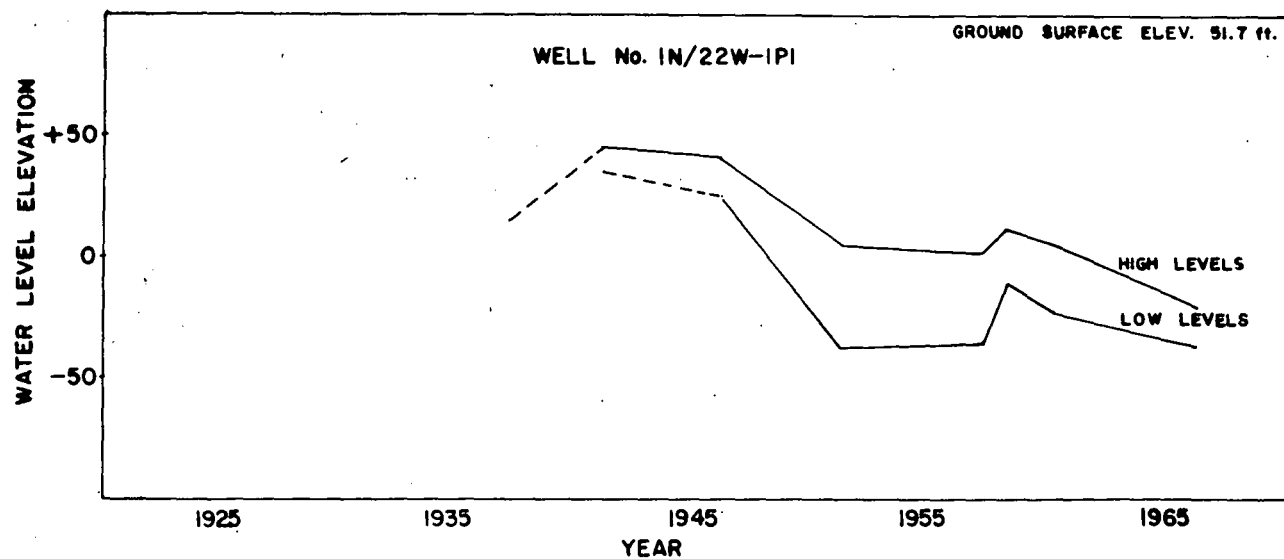


FIGURE 21.—WELL HYDROGRAPHS SHOWING WATER LEVEL FLUCTUATIONS

In 1952, samples from Wells Nos. 1N/22W-20R2 and -29C1, near the head of the Hueneme submarine canyon, showed Cl concentrations ranging from 1,000 to over 1,500 mg/l. Therefore, sea-water intrusion must have occurred before 1952.

In the Point Mugu area, water quality data on Well No. 1S/21W-5H1 indicate an increase in Cl concentration from less than 350 mg/l in 1949 to over 8,000 mg/l in 1954. This well is perforated at depths from 180 to 190 feet, which places it within the Oxnard aquifer. Water quality data on Well No. 1S/21W-5H3 show an increase from 5,000 mg/l Cl in 1953 to 13,000 mg/l in 1965. The perforated interval of this well is from 330 to 340 feet, probably within the Mugu aquifer. Water quality data support the conclusion that sea-water intrusion occurred during the early 1950's.

Geohydrology

The upper sequence of the freshwater-bearing sediments in the Coastal Plain are of Upper Pleistocene and Recent age. The Upper Pleistocene deposits include sands and gravels interbedded with silt and clay of a maximum thickness of about 500 feet. The Recent deposits consist of fluvial sands and gravels interbedded with silt and clay. These water-bearing sediments of the Coastal Plain also extend offshore to distances of from less than 5 miles to a maximum of 10 miles. They are separated from the Lower Pleistocene sediments by an unconformity.

Recent Deposits

The Recent sedimentary section includes a shallow sandy perched aquifer, a clay layer, and the confined Oxnard aquifer.

Perched Aquifer

A perched water zone overlies the Oxnard aquifer. It is underlain by a "clay cap" and is from 20 to 60 feet deep. According to lithologs, the clay cap varies in thickness and lateral extent. It is impermeable in most of the area, thus preventing perched water of poor quality from degrading the Oxnard aquifer. In some places, lenses of fine sandy silt occur in the clay cap, forming conduits for leakage of water from the perched zone to the Oxnard aquifer.

Oxnard Aquifer

The Oxnard aquifer extends over the entire Oxnard Plain, from the Santa Clara River to the north, easterly toward the Camarillo Hills and Santa Monica Mountains to the south (Figure 17). It is overlain by a clay to silty clay deposit, which forms the confining condition. The thickness of the aquifer along the coastal area ranges from 80 to 130 feet. The aquifer is interbedded locally with lenses of clay, silty clay, and silt. These localized aquicludes do not apparently affect the piezometric head or retard the vertical and horizontal movement of water in the aquifer. The general slope of the ground surface is toward the Ocean and the regional slope of the Oxnard aquifer is approximately 30 feet per mile.

Near Point Mugu, lithologs show that the overlying clay cap thins out or is totally absent. Thus, the Oxnard aquifer becomes unconfined and probably receives water from the Mugu Lagoon and other low-lying areas containing waters of high mineral concentration.

The Oxnard aquifer extends offshore as a confined aquifer. The offshore extension of the Oxnard Plain has been incised by the Hueneme and Mugu submarine canyons, which were formed by underwater erosion and expose the freshwater-bearing sediments in the canyon walls to sea water. Profiles of "Sparker Survey" (USGS, 1971) suggest that slumping or sliding in the canyons probably resulted in the exposure or disruption of the water-bearing sediments.

Upper Pleistocene Deposits

The Oxnard aquifer of Recent age is underlain by the Mugu aquifer of Upper Pleistocene. The Mugu aquifer is separated from the Oxnard by a clayey aquiclude.

Mugu Aquifer

The Mugu aquifer is composed of fine to coarse sand and gravel, with interbedded lenses of clayey silt. Its thickness ranges from under 50 to 200 feet. The seaward gradient is the same as the Oxnard aquifer. The top of the aquifer lies between 200 and 300 feet below sea level and its base, from 350 to 500 feet below sea level. The Mugu aquifer is separated from the Oxnard aquifer by a predominant clayey aquiclude, ranging from 10 to 100 feet thick. This clay bed was deposited in the Oxnard Plain at the end of the Pleistocene era. It appears to form an effective barrier to vertical movement of ground water from the Oxnard to the Mugu aquifer, which, like the Oxnard, extends offshore into the Continental Shelf.

Hydrology

The water-bearing sediments of the Oxnard Plain include five confining aquifers: the Oxnard, Mugu, Hueneme, Fox Canyon, and Grimes Canyon.

They are replenished by water percolating in the upstream recharge area, known as the Oxnard Forebay (Figure 17). The general gradient of the piezometric heads of the confining aquifers, except where sea-water encroachment occurs, is seaward, at a slope ranging from less than 3 to 10 feet per mile (Plate 6).

To solve the problem of sea-water intrusion, local changes in water levels in areas adjacent to the Pacific Ocean were carefully studied. Figures 18, 19, and 20 show the long-term trends in ground water elevations in wells having continuous records. Each graph shows the highest and lowest water levels in past years. The difference between the two values is the range of annual fluctuations in water levels due to seasonal recharge. These graphs show only long-term trends that reflect cycles of wet and dry years.

An example is the hydrograph of Well No. 1N/22W-3F4, which has continuous water level measurements from 1916 to 1964 (Figure 18). This well is 4 miles from Port Hueneme and within an 8-mile radius of Point Mugu (Plate 5). From 1916 to 1923, water levels remained almost 50 feet above sea level. From 1923 to 1930, levels declined almost 25 feet. From 1930 to 1936, high water levels remained stable at 20 to 25 feet above sea level and low levels fluctuated a few feet above and below sea level. From 1936 to 1941, levels rose to a high of 45 feet above sea level. From 1941 to 1944, they remained high, but from 1944 to 1950 declined to a few feet above sea level and the annual low was 30 feet below sea level. This condition prevailed until 1957, when levels rose to about 8 feet above and within 10 feet below sea level. The high levels shown in the graph resulted from recharge during periods of heavy rainfall and the declining levels occurred during the periods of light rainfall. In areas near the shore, when the piezometric head declined to elevations below sea level, an inland gradient developed, thus causing sea water to move inland.

Figure 19 shows long-term trends in hydrographs of two wells in the southwestern part of the forebay area. The wells' records began in 1928 and 1929 and continued through 1966. Hydrographs of Wells Nos. 2N/22W-23Q1 and -27E1 show similar water level fluctuations, though of dissimilar magnitude. A significant feature in both hydrographs is that water levels declined sharply from 1944 to 1951. This decline in the Oxnard Forebay and excessive pumping in the Oxnard Plain resulted in a drop in the piezometric head of the Oxnard aquifer and caused sea-water intrusion.

The Mugu aquifer, exposed in the seaward submarine canyon, was also probably intruded at the same time. However, definite proof is lacking, due to insufficient data. The decline in water levels, or piezometric head, may have been due to heavy pumping, in excess of the natural or artificial replenishment (Figure 20).

Sea-water Intrusion

Because the density of sea water is about 1.025 times that of fresh water, density is an important factor in the mechanics of sea-water intrusion. Hence, there is a tendency for fresh water to float on sea water when they come in contact in water-bearing sediments. This is the basis of the Ghyben-Herzberg Principle.

It has been assumed that the sea-water wedge has the shape of an inclined surface that always slopes landward. It responds to changes in the hydraulic gradient of the fresh water by either advancing or receding.

The advancing or receding wedge moves at the toe and upper end of the interface and remains in a fixed position at the shoreline until all the fresh water in that portion of the aquifer has been displaced by sea water. At that time, fresh water stops flowing to the ocean. A further decline in the piezometric head of the freshwater aquifer causes the entire sea-water wedge to advance inland.

The fresh-water-sea-water interface is a narrow zone containing mixed water. The width of this zone is dependent on the rate of mechanical and ionic dispersion of minerals. Its width can also vary, due to changes in the piezometric head of the freshwater aquifer. The changes result in the advance and retreat of the sea-water wedge.

Sea-water intrusion occurs in coastal ground water basins under certain conditions. When the water level or the piezometric head is lowered below sea level the pressure of sea water on fresh water increases and the interface moves slowly inland. It moves first into the offshore extension of the aquifers and then through the inland aquifers, causing degradation of the freshwater supply.

Port Hueneme Area

The landward encroachment of sea water at Port Hueneme probably started before 1952. In the fall of that year, an analysis of water from Well No. 1N/22W-29C1, about 500 feet from the shore, showed a Cl concentration over 1,000 mg/l. Data on the quality of perforated water wells only in the Oxnard aquifer were used to study the encroachment of sea water into the Oxnard aquifer. A few wells have continuous water quality data from 1952 to 1967. These key wells have at least one or more analyses per year. Such data were helpful in estimating the location of the frontal wedge of the encroaching sea water. The wells also fan out from Port Hueneme from 3 to 5 miles inland (Plate 5). Geologic cross sections were used to show the historic location of the advancing wedge of sea water (Plate 5). The sections also show the stratigraphic position of the Oxnard aquifer and wells whose perforations or entire depth are within the Oxnard aquifer.

Information about the location of wells and their historic Cl concentrations was used to determine the location of the sea-water wedge and the approximate rate of encroachment. The determination was based on the following:

1. Cl concentration of sea water in the aquifer is 18,900 mg/l (the value was based on Cl concentrations in wells in near-shore areas, where the Oxnard aquifer is completely inundated by sea water).

2. The thickness of the sea-water frontal wedge is a function of the Cl concentration of well water. It is calculated using the following equation:

$$\frac{\text{Cl of well water}}{\text{Cl of sea water (18,900 mg/l)}} = \frac{\text{thickness of sea-water wedge}}{\text{total aquifer thickness}}$$

3. In the intruded Oxnard aquifer, the Cl concentration of the well sample is assumed to be a representative mixture of sea water and fresh water and contains no leakage from the overlying perched aquifer.

4. The annual Cl concentration value calculated from two or more wells along cross section A-A' (Figure 22) is assumed to be adequate to show the approximate slope of the intruding sea-water wedge.

Figures 23 to 28 show historic changes in Cl concentrations of well water, fluctuations in ground water levels, and the effects of the long-term declining piezometric head on the Cl concentration.

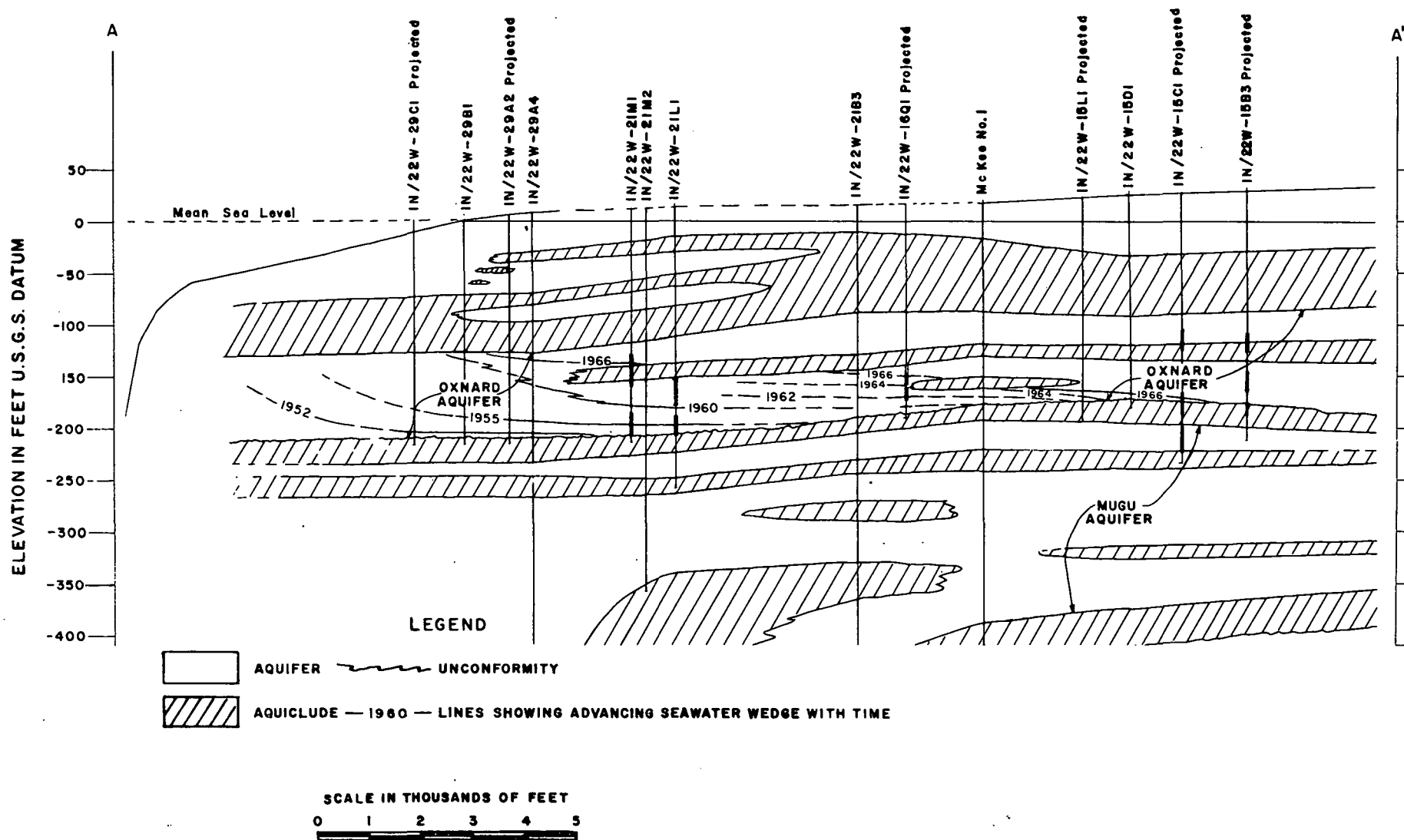


Figure 22- GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER-FRESHWATER INTERFACE IN THE OXNARD PLAIN, VENTURA COUNTY

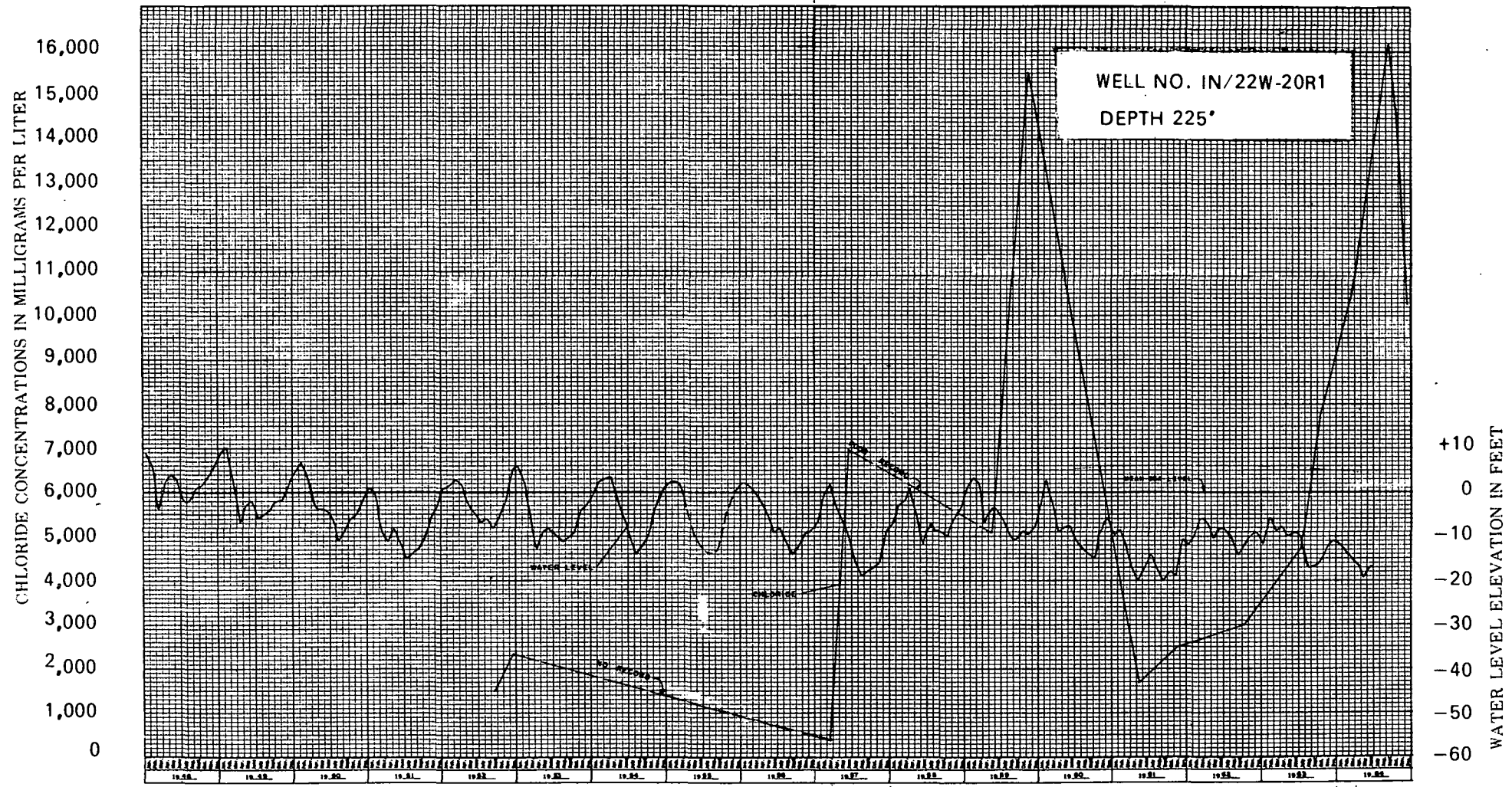


Figure 23. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE



Figure 24. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

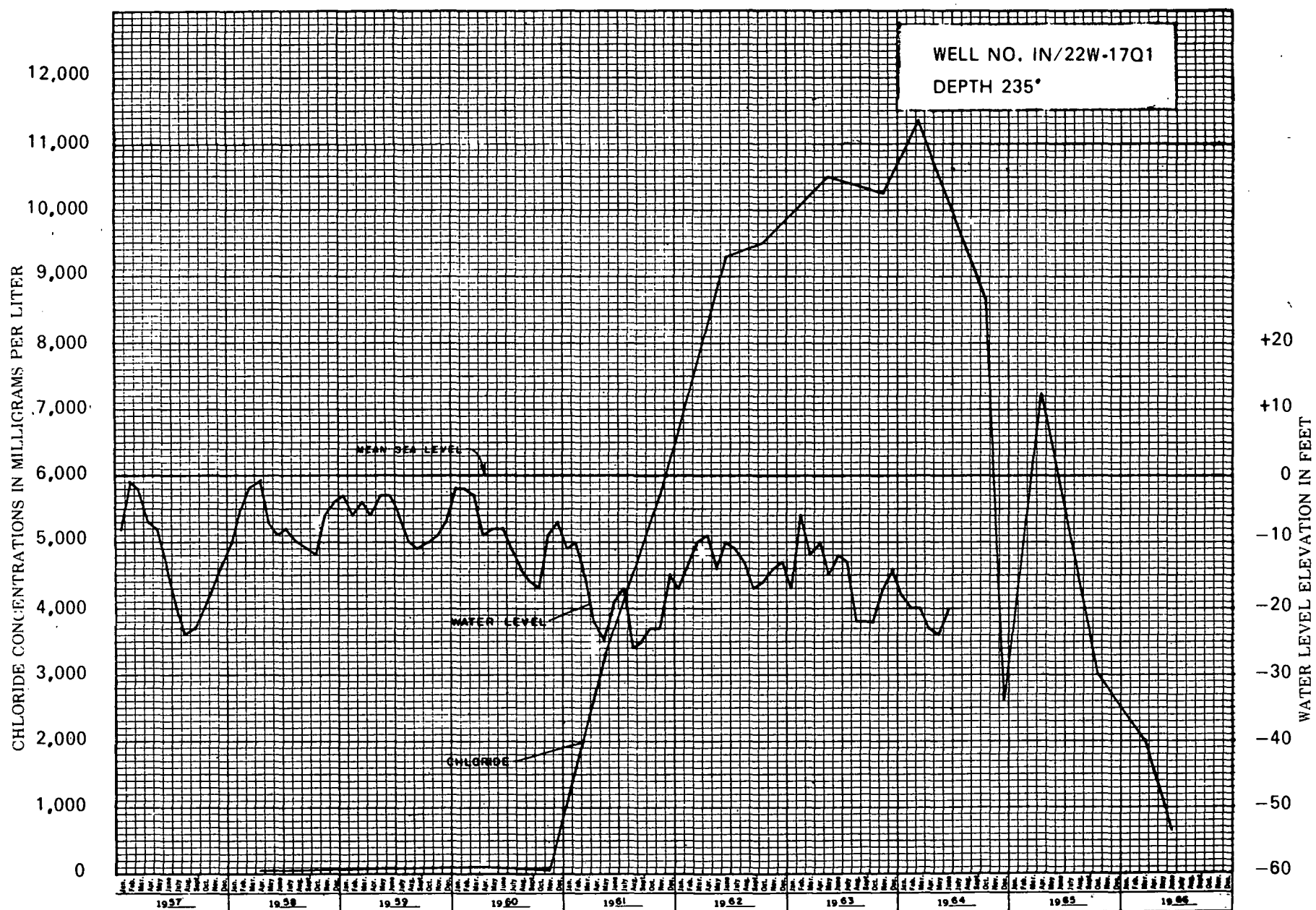


Figure 25. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

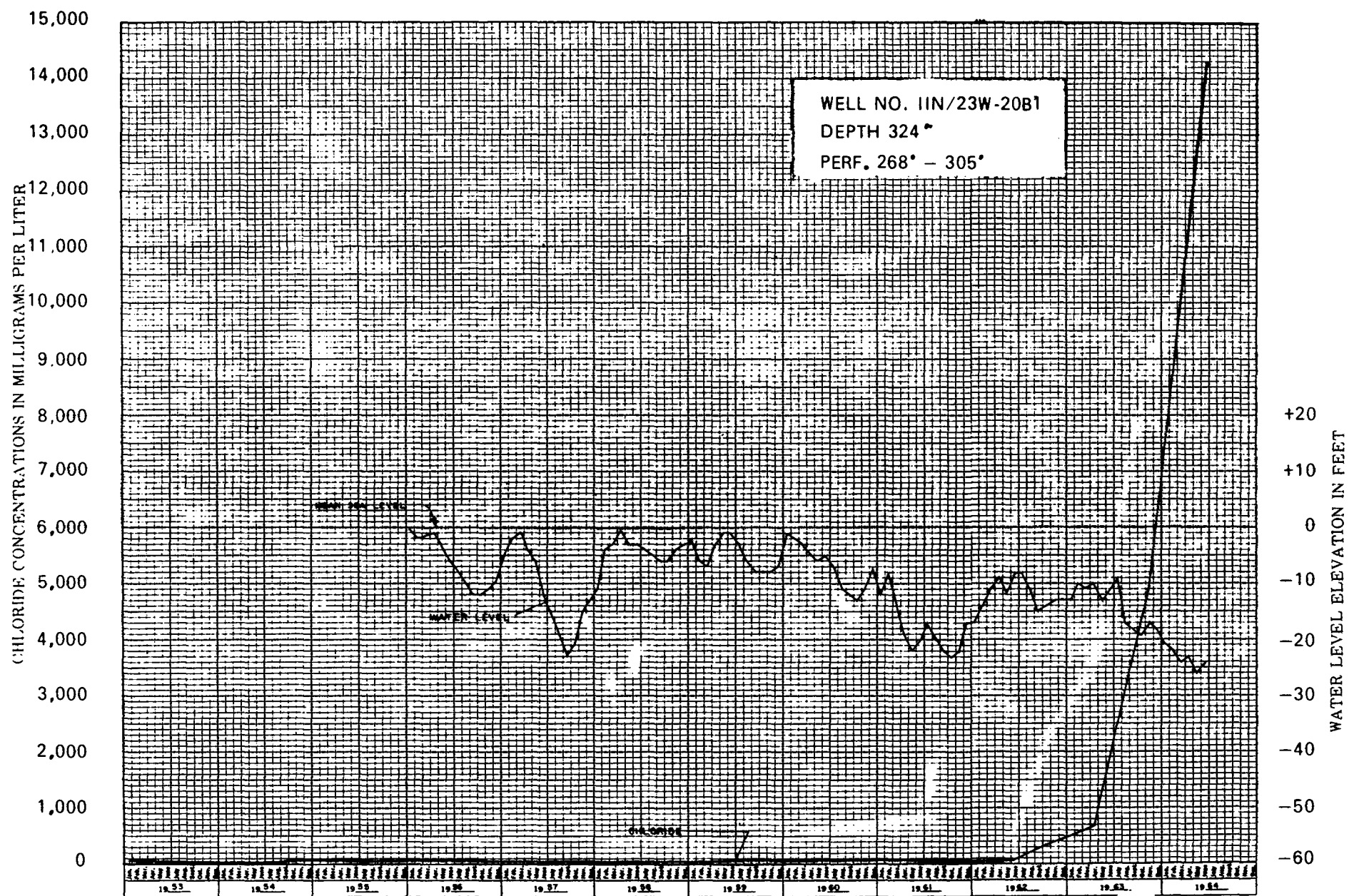


Figure 26. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

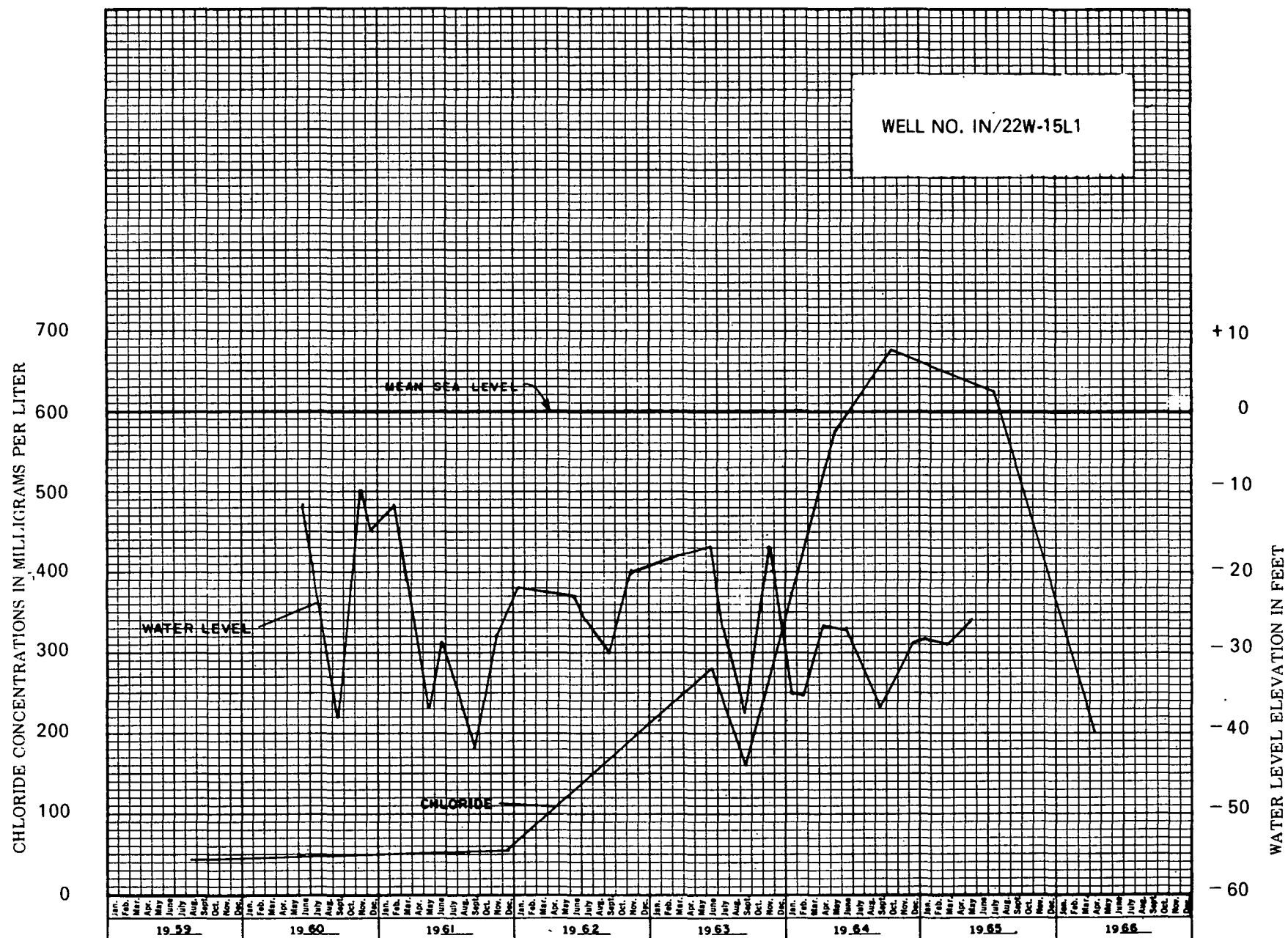


Figure 27. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

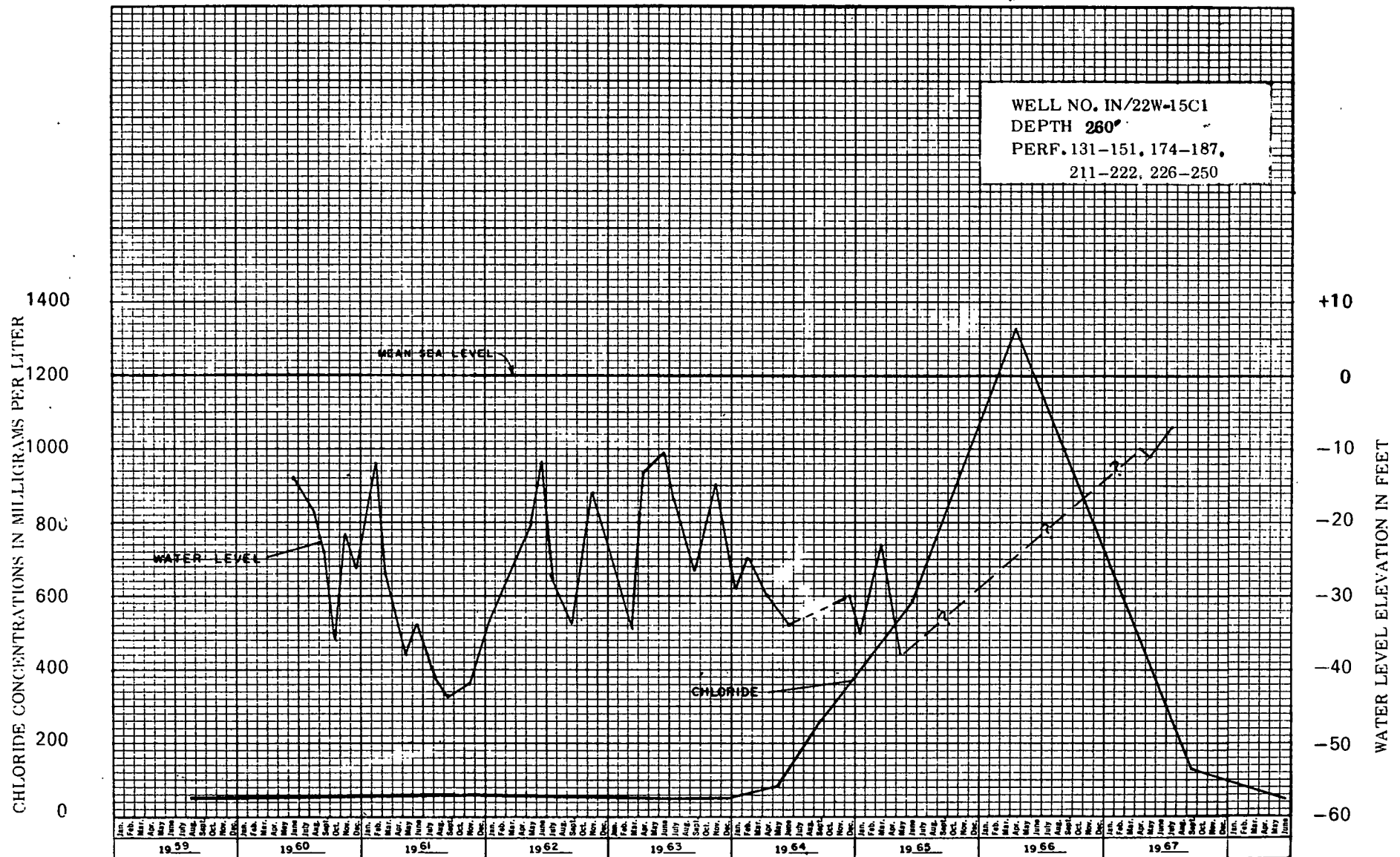


Figure 28. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

Plate 5 shows the location of the cross sections. Sections B-B' and C-C' run almost parallel to the shoreline (Figures 29 and 30). Sections A-A' and D-D' run almost perpendicular to the shoreline (Figures 22 and 31). Cross section D-D' extends from the head of the Hueneme submarine canyon 3 miles inland.

Figure 22 shows the extent of landward movement of the sea-water front along Section A-A'. By 1952, it had moved inland 1/2 mile. This section also shows subsequent landward advances of the sea-water wedge. The farthest encroachment was reached in 1966, 2.7 miles inland. Well No. 1N/22W-29B01, about 2,000 feet inland from the head of the submarine canyon, had a Cl concentration of 18,173 mg/l in the fall of 1960. It is possible that 80 to 90 percent of the Oxnard aquifer was displaced by sea water. By 1966, a well 4,000 feet from the submarine canyon had a Cl concentration of more than 19,000 mg/l.

Section D-D', Figure 31, which runs parallel to Section A-A', confirms the historic locations of the advancing sea-water wedge in the Oxnard aquifer, as shown in Section A-A'.

Section B-B', Figure 29, shows the lateral extent of sea-water intrusion of the Oxnard aquifer. Analyses of ground water indicate that in 1961 and 1963 intrusion of sea water reached the farthest lateral extension. Analyses of water from Well No. 1N/22W-28C1, 1 mile east of the head of Hueneme canyon, show degradation of fresh water from 1960 to 1966. However, Well No. 1N/22W-27F2, 1 mile southeast of Well No. 1N/22W-28C1 and perforated from top to bottom of the Oxnard aquifer, had no increase in chloride ion concentration during the same period. The farthest northeast extent of sea-water intrusion is probably between Wells Nos. 1N/22W-19B1 and 1N/22W1-8P1. Historic water analysis of the latter well showed no increase in Cl concentration. Section B-B' also shows that the maximum extent of intrusion occurred in 1964, when the displacement of fresh water in the Oxnard aquifer reached 85 to 90 percent. The farthest intrusion occurred opposite the head of the Hueneme submarine canyon. The sections also show that the sea-water wedge has advanced and receded several times from 1952 to 1966.

Section C-C', Figure 30, runs parallel to Section B-B' up to Well No. 1N/22W-21L1, then it turns eastward. The section shows that the farthest lateral extent of the sea-water wedge is bound northwesterly by Wells Nos 1N/22W-17M1 and -17M2, which showed no increase in Cl concentration. In the easterly direction, the farthest intrusion of sea water is bound by Well No. 1N/22W-23Q1. The farthest extent of the intrusion is 4 miles (Figure 29). Cl concentration in these wells suggests that the maximum displacement of fresh water by sea water occurred in 1966. Recent water quality data show a sharp decline in chloride ion concentration of the ground water.

Figures 23, 24, 25, 26, 27, and 28 show changes over a period of time in Cl concentration and ground water levels in wells near Port Hueneme. The increase in Cl concentration was due to the increased intrusion with time. Figure 22 shows the data on Well No. 1N/22W-20R1, which is 4,000 feet inland. It had a Cl concentration of over 2,000 mg/l in 1952. The sharpest increase in Cl concentration occurred in 1964, when it reached 16,121 mg/l.

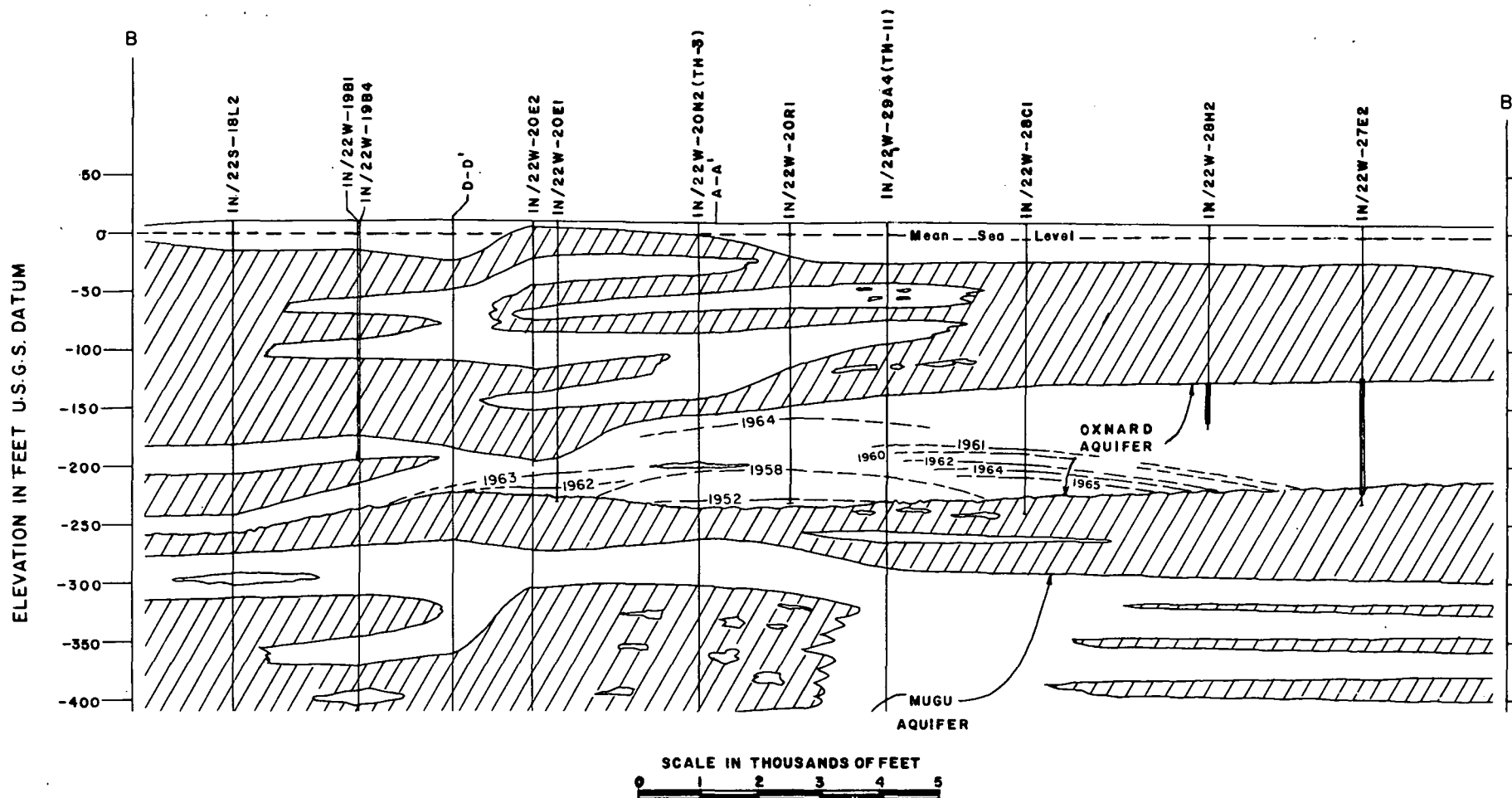
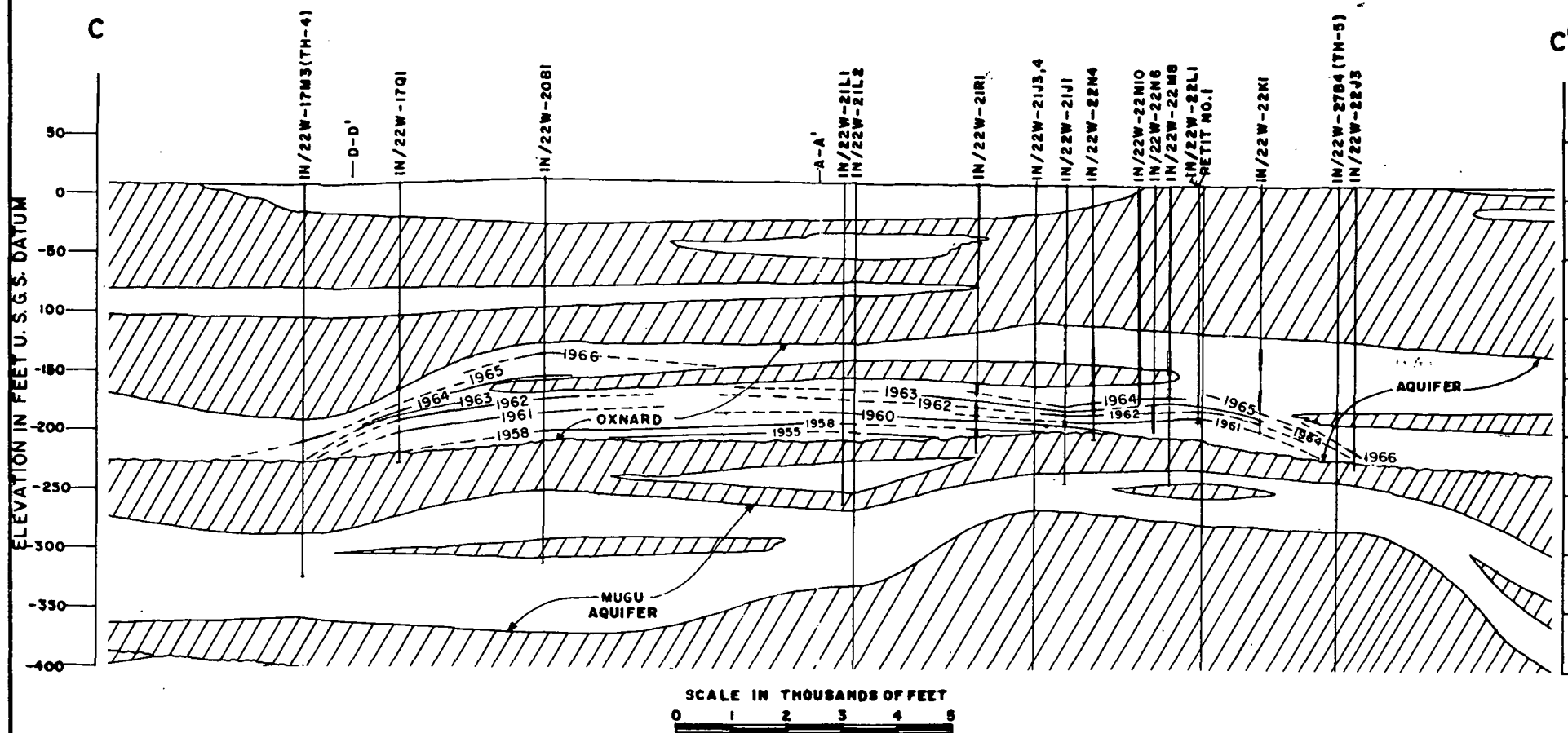


Figure 29—GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER—FRESHWATER INTERFACE IN THE OXNARD PLAIN, VENTURA COUNTY



**Figure 30— GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER—FRESHWATER INTERFACE
IN THE OXNARD PLAIN, VENTURA COUNTY**

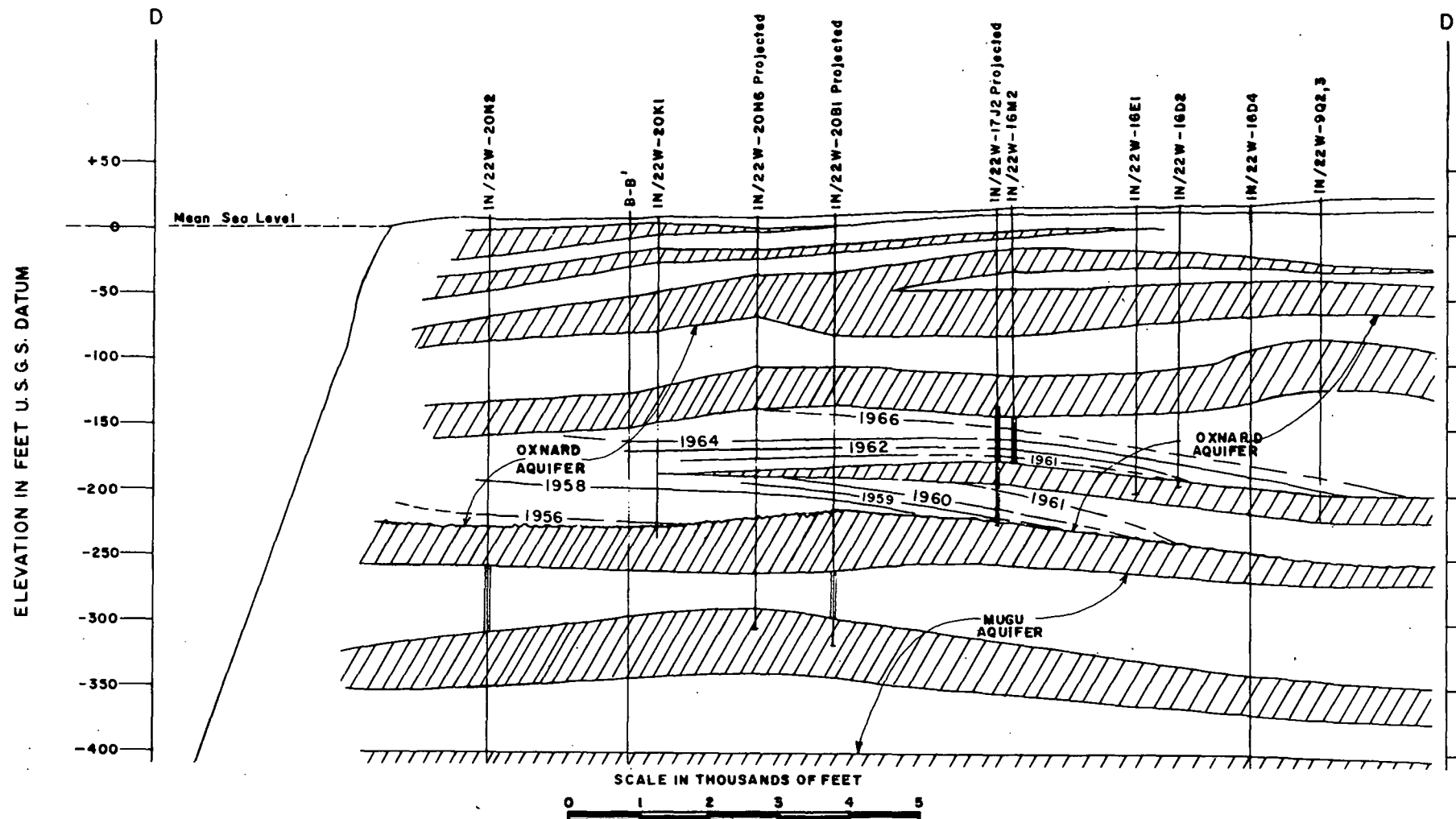


Figure 31—GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER—FRESHWATER INTERFACE IN THE OXNARD PLAIN, VENTURA COUNTY

Figure 24 shows data on Well No. 1N/22W-20E1, which is less than 1 mile from the head of the Hueneme submarine canyon. The graph indicates a Cl concentration of less than 100 mg/l from 1951 to 1955. Data are not available from 1956 to 1960. Cl concentration increased from 350 mg/l in the fall of 1960 to 6,200 mg/l in 1961 and reached a maximum of 9,400 mg/l in 1963. Water levels in this well declined from 1959 to 1964, coinciding with the increase in Cl concentration.

Figure 25 shows data on Well No. 1N/22W-17Q1, which is 8,000 feet inland. Cl concentrations from 1958 and 1959 and the spring of 1960 were less than 100 mg/l. From the fall of 1960 to the spring of 1961, Cl concentration increased from 100 mg/l to 3,000 mg/l. The highest concentration, 11,375 mg/l, occurred in 1964. The hydrograph also shows declining ground water levels during the same period of Cl increase.

Figure 26 shows data on Well No. 1N/22W-20B1, 1 mile inland. Concentration of Cl was about 50 mg/l between 1952 and 1962, except for a slight increase in 1961. From June 1962 to October 1963, Cl concentration increased to over 7,000 mg/l and reached a maximum of over 14,000 mg/l in 1964. The sharp increase in concentration coincided with declining water levels.

Figure 27 shows data on Well No. 1N/22W-15L1, which is 3 miles inland. Cl concentration was 54 mg/l or less from 1959 to 1961. From December 1961 to 1963, the concentration rose to 280 mg/l and reached 680 mg/l in 1964. Water levels declined 38 feet below sea level.

Figure 28 shows data on Well No. 1N/22W-15C1, 3 miles inland. Cl concentration increased to 257 mg/l, reaching a maximum of 1,328 mg/l in the spring of 1966. A general decline in ground water levels coincided with the sharp increase in Cl concentration.

Based on the data shown in the cross sections and hydrographs, Figure 32 was constructed to show the historic inland movement of the sea-water front along Section A-A' and the decline in the piezometric surface. The Figure shows that the distance traveled inland by the sea-water wedge is proportional to the rate of decline in the piezometric head of the Oxnard aquifer. This relationship can be used to estimate the location of the sea-water front under conditions similar to those in the past. The relationship cannot be used under different hydrologic conditions because the distance of sea-water advance inland is affected by other factors, such as the magnitude and duration of decline in the piezometric head.

Point Mugu Area

The conditions causing degradation of the freshwater supply at Point Mugu area are different from those of Port Hueneme for the following reasons:

1. The clay cap overlying the Oxnard aquifer thins out or is completely absent. Thus, locally, the Oxnard aquifer is totally unconfined and in continuity with the ground surface.

2. Ground water probably receives sea or brackish water from the Mugu Lagoon and tidal flats, which are near the shoreline.

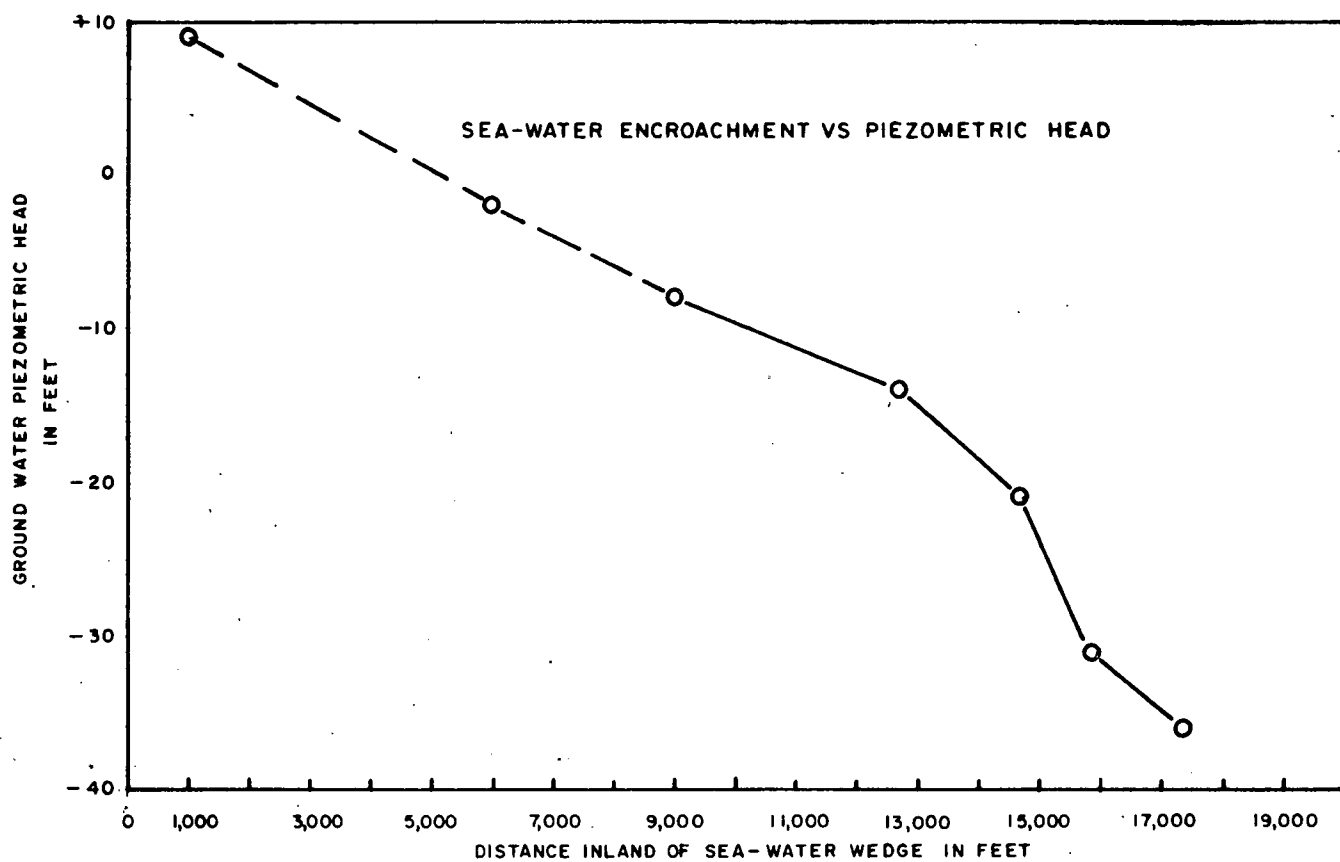
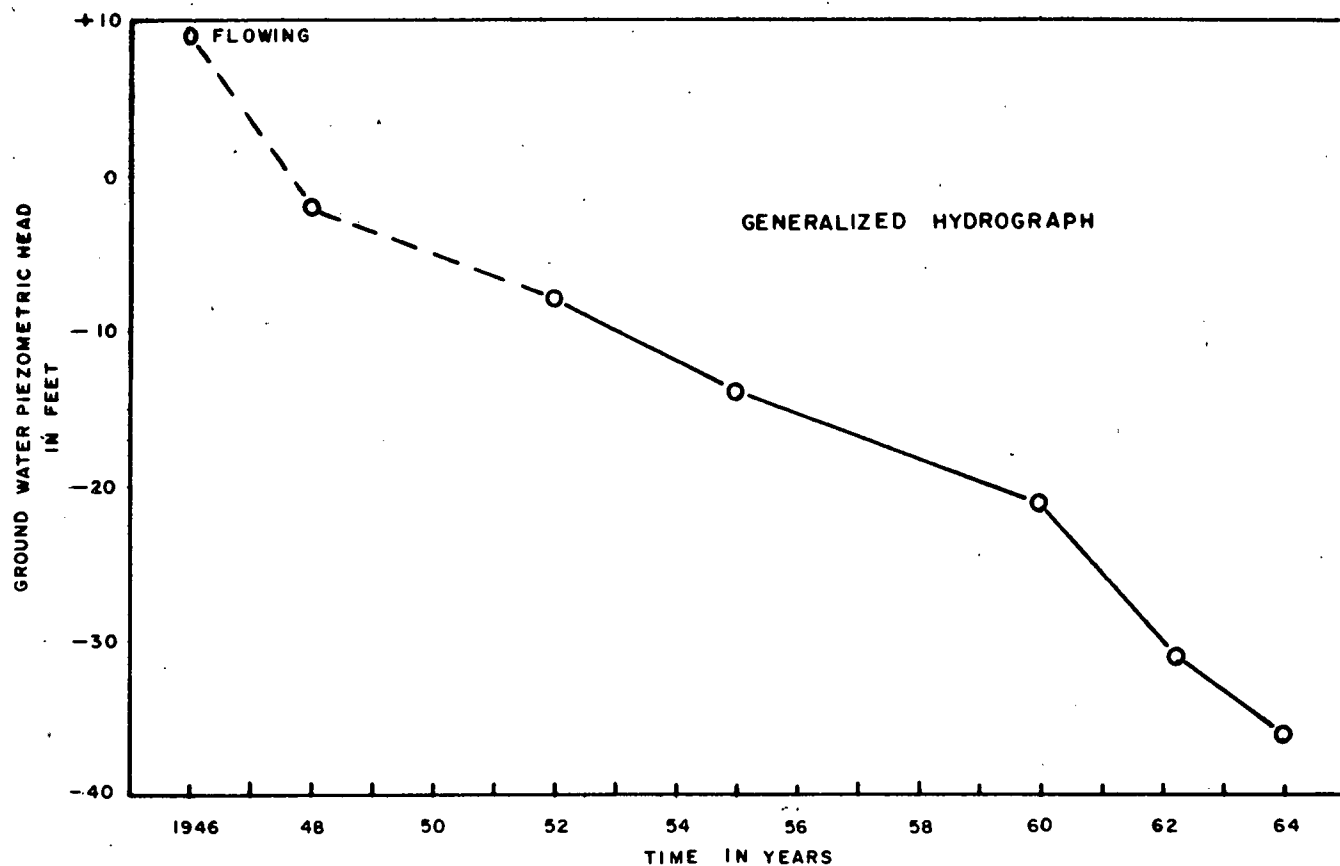


FIGURE 32—RELATION BETWEEN ADVANCE OF THE SEA-WATER WEDGE INLAND AND DECLINE OF PIEZOMETRIC HEAD ALONG SECTION A-A' IN THE OXNARD PLAIN, VENTURA COUNTY

3. Marshland surrounding the lagoon is subjected to flooding and may contribute poor quality water to the ground water.

Therefore, degradation of fresh water in the Oxnard aquifer in this area is probably due to the interaction of several factors, including sea-water intrusion. Also, evaluation of sea-water intrusion of the Mugu area was more difficult because of the relatively small number of wells that have long, continuous records. In some cases it is necessary to use data on ground water quality from one well and water level elevations from an adjacent well. Data include those representing conditions prior to sea-water intrusion, those showing effects of the intrusion, and those showing the farthest landward movement of the sea-water wedge.

Positive evidence of freshwater degradation occurred in 1949 when Well No. 1S/W21-4E1, less than 1 mile inland, had a Cl concentration of 300 mg/l. This increase in Cl concentration coincides with declining ground water levels near Point Mugu. Because water quality data prior to 1949 are lacking, it is difficult to establish the real cause of degradation. The increase in Cl concentration could have been caused by either deep percolation of sea or brackish water from the lagoons, or by sea-water intrusion, or by both.

Landward movement of the sea-water wedge is shown in two cross sections (Figures 33 and 34). Section E-E' (Figure 33) starts in the Mugu submarine canyon and extends inland and northward for 4 miles. The first well in this section, No. 1S/21W-5H1, is 1 mile inland and is perforated from 180 to 190 feet below the ground surface and within the Oxnard aquifer. Analysis of water from this well represents the quality of water in the aquifer at that location. Because water level data on this well are not available, it was difficult to determine the effects of declining levels on Cl concentration with time. Data on the quality of water in this well from 1953 to 1958 show that Cl concentration was due to the effects of the advancing wedge of sea water. Few of the analyses showed any decrease in Cl concentration, which was because of the receding sea-water wedge.

Data on Well No. 1N/21W-32L1, shown in Section E-E', show an increase in the concentration of Cl from 47 to 99 mg/l from 1962 to 1965. In 1967, Cl concentration increased to 725 mg/l and by 1969 it reached 1,050 mg/l. Based on the location of the well's perforations, thickness of the Oxnard aquifer, and the Cl concentration in 1949, it is estimated that the sea-water wedge occupied about 5 percent of the aquifer. It may have been that the front of the fresh-water-sea-water interface was farther inland, but it was not possible to determine the exact position due to the paucity of water-quality data. Data on wells in Section 29, 1 mile further inland from Well No. 1N/21W-32L1, show concentrations of Cl and sodium (Na) of 156 and 252 mg/l, which are slightly higher than background levels. This degradation could be due to other causes than sea-water intrusion.

Section F-F' (Figure 34) shows the approximate locations of the sea-water wedge in the Oxnard aquifer. Data on Well No. 1S/21S-8L2 show a Cl concentration over 10,000 mg/l in the spring of 1962. The well is 290 feet deep and is perforated from 170 to 270 feet. The well's Cl concentration increased from 10,035 mg/l in 1962 to 13,587 mg/l in 1965, then decreased to 12,600 mg/l in 1969. The advancing fresh-water-sea-water interface apparently

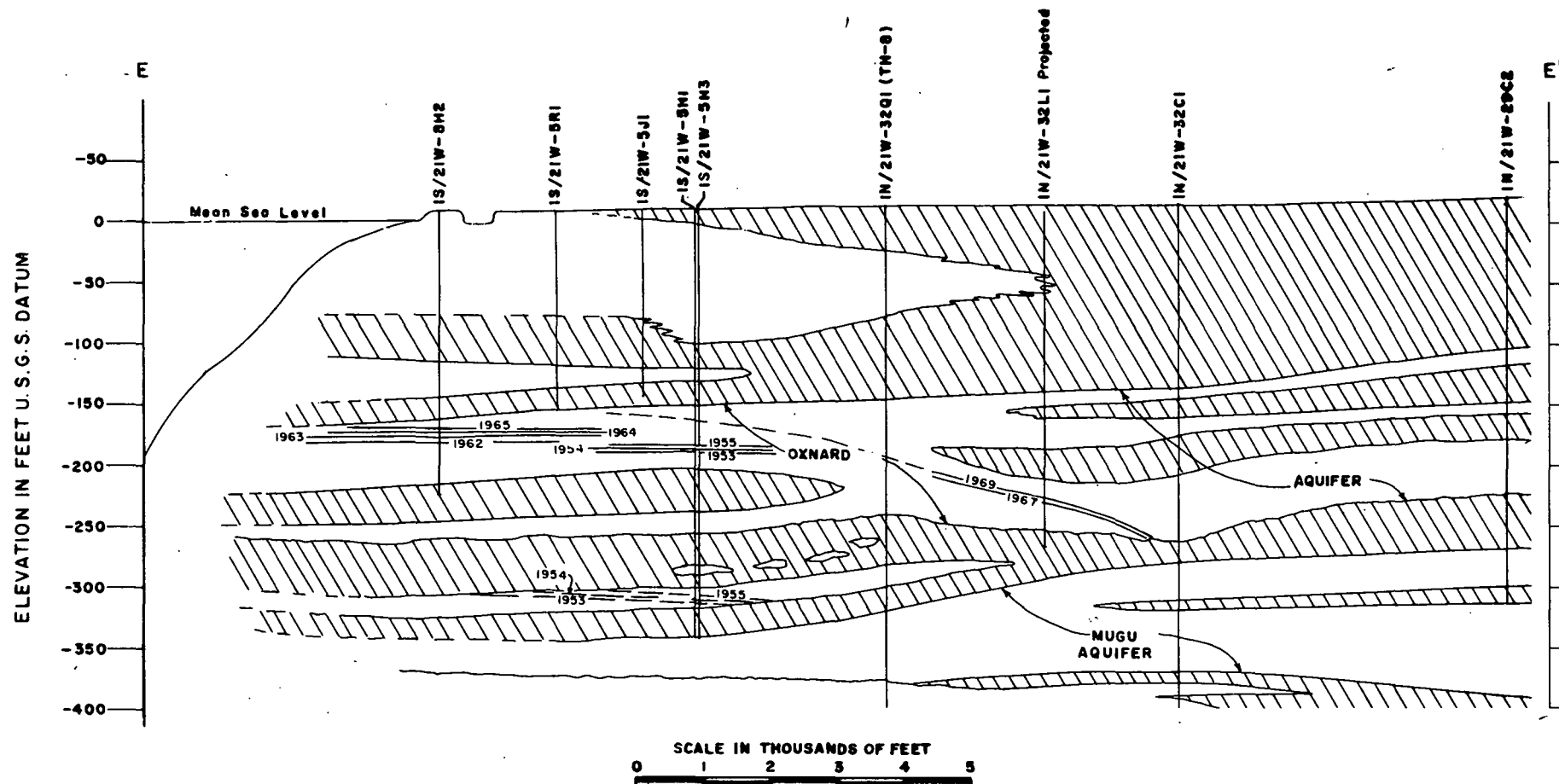


Figure 33—GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER—FRESHWATER INTERFACE IN THE OXNARD PLAIN, VENTURA COUNTY—

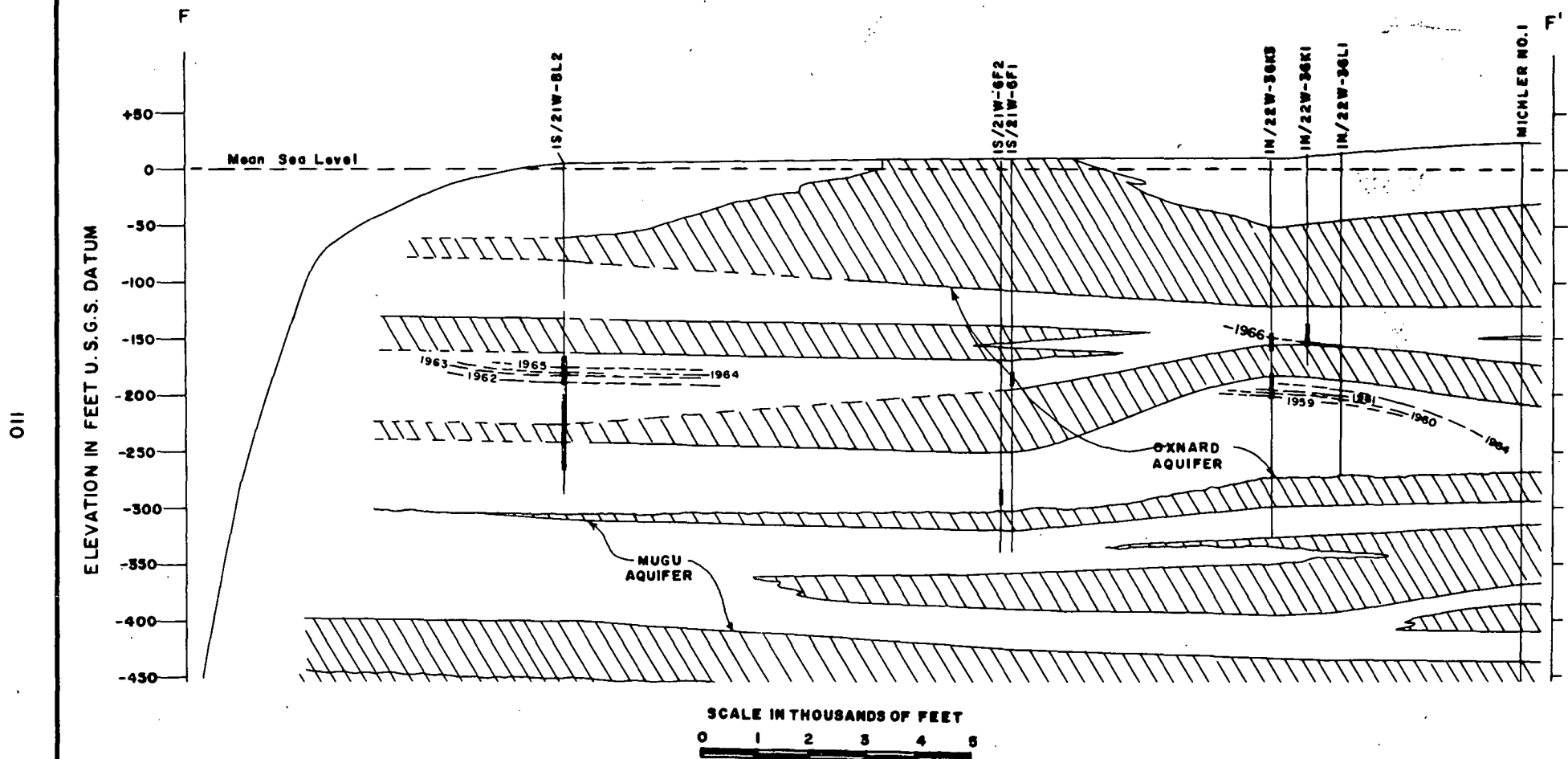


Figure 34— GEOLOGIC-SECTION SHOWING THE LOCATION OF THE SEAWATER—FRESHWATER INTERFACE
IN THE OXNARD PLAIN, VENTURA COUNTY

moved slowly inland, causing the small annual increases in Cl concentration. It was not possible to establish the exact position of the fresh-water-sea-water interface because the well's perforated interval intersects water-bearing sediments separated by an aquiclude. The analyses, therefore, represent a mixture of water from both sediments.

Quality data on Well No. 1S/21W-6F1, 1-1/2 miles inland, show virtually no increase in Cl concentration from the fall of 1952 to the spring of 1958, when the record ended. This well is 350 feet deep and is perforated from 190 to 200 feet below the ground surface and within the Oxnard aquifer zone. Well No. 1S/21W-6F2 is also 350 feet deep and is perforated between depths of 295 and 305 feet. Water quality data on this well show virtually no increase in chloride ion concentration from 1954 to 1955.

Hydrographs of other wells, 2-1/2 miles inland, are shown in Figure 29. Water quality data from 1952 to 1956 show small increases in Cl concentration, but increasing to more than 700 mg/l from 1957 to 1964. Well No. 1N/22W-36K3 showed a Cl concentration of more than 1,800 mg/l in late 1959. This indicates the landward advance of the fresh-water-sea-water interface after 1956. By early 1961, Cl concentration had reached values over 3,300 mg/l. The concentration of Cl decreased to less than 1,000 mg/l in 1963 and 1964.

Water level data on Well No. 1N/22W-36L1, which is the closest to the intruded area, was used to show the relationship between fluctuating water levels and Cl concentration in Wells Nos. 1N/22W-36K1 and -36K3. The hydrograph (Figure 35) shows the long-term declining water levels from 1952 to 1956. The well's perforated interval is not known, but the total depth of the well is 284 feet, and is within the Oxnard aquifer. It is possible that the toe of the fresh-water-sea-water interface extends farther inland from Well No. 1N/22W-36L1. Data on Well No. 1N/22W-25K1, 1 mile farther inland from Well No. 1N/22W-36L1, show no increase in the concentration of Cl from 1959 to 1962. Thus, the sea-water wedge was between the two referenced wells.

Conclusions

The following are the main conclusions of the sea-water intrusion study:

1. Based on the fluctuations of ground water levels and chloride concentrations in well water, it was possible to construct cross sections showing the sequential advance inland of the sea-water front into the Oxnard aquifer.
2. Generally, Cl concentrations increased as water levels declined.
3. Sufficient data were available in the Port Hueneme area to relate the inland advance of sea water into the Oxnard aquifer to the decline in water levels. Data were insufficient to develop the same relationship in the Point Mugu area.
4. Increase in the Cl concentration of ground water in the Point Mugu area may be due to sea-water intrusion and also to percolation of saline water from the ground surface.

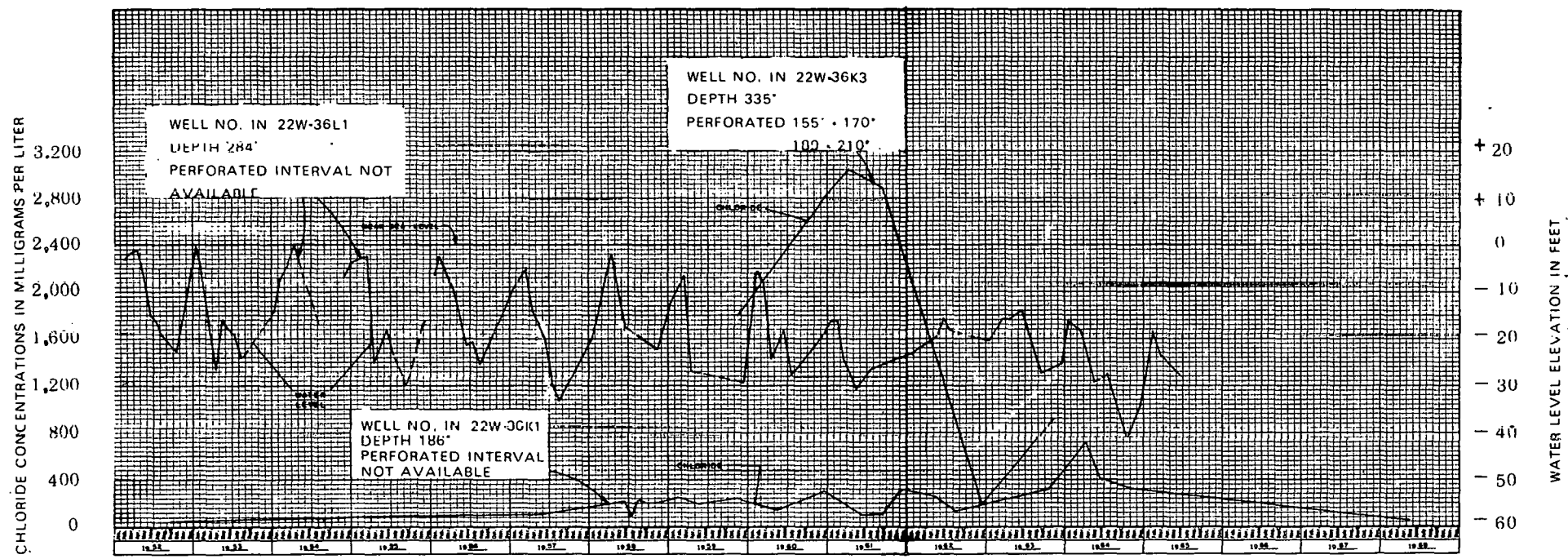


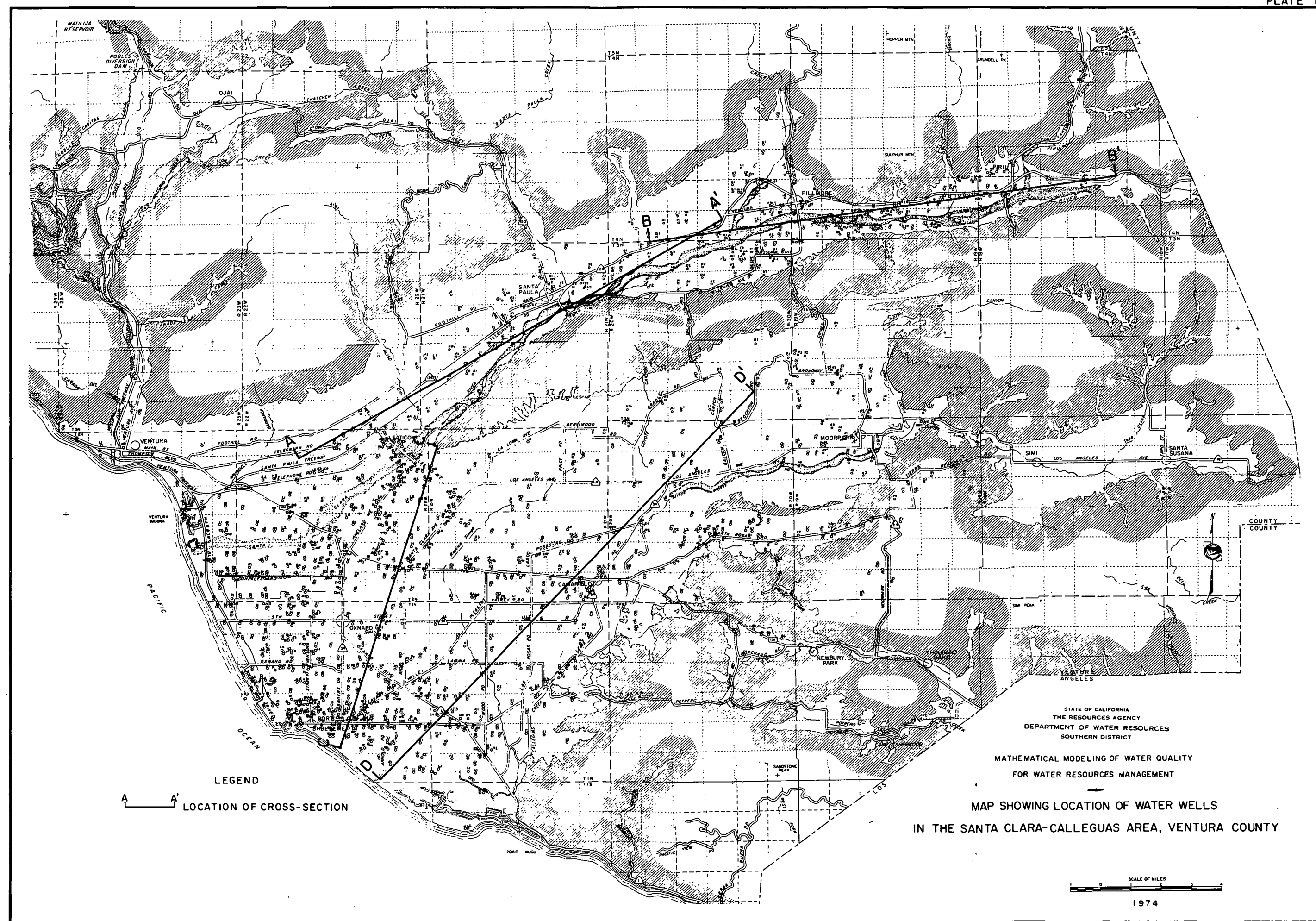
Figure 35. CHANGE IN GROUND WATER LEVELS AND CONCENTRATIONS OF CHLORIDE

APPENDIX I

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LEGEND
A A' LOCATION OF CROSS-SECTION

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
MATHEMATICAL MODELING OF WATER QUALITY
FOR WATER RESOURCES MANAGEMENT
MAP SHOWING LOCATION OF WATER WELLS
IN THE SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

SCALE OF MILES
1974



RECENT		Qal	ALLUVIUM SAND, GRAVEL AND CLAY IN STREAM CHANNELS AND FLOOD PLAINS. SUPPLIES MANY WELLS.
PLEISTOCENE		Qt	TERRACE DEPOSITS AND OLDER ALLUVIUM GRAVEL, SAND AND CLAY. GENERALLY HIGHLY PERMEABLE, SUPPLIES MANY WELLS.
		Qmc	SAN PEDRO FORMATION SAND, GRAVEL AND CLAY. MARINE AND CONTINENTAL. PERMEABLE ZONES SUPPLY MANY WELLS; INCLUDES FOX CANYON MEMBER WHICH YIELDS CONSIDERABLE WATER OF GOOD QUALITY IN THE LAS POSAS AND PLEASANT VALLEY AREAS.
		PQm	SANTA BARBARA FORMATION MARINE MUDSTONE, SHALE, SANDSTONE, SAND, GRAVEL AND CLAY. NONWATER-BEARING EXCEPT FOR GRIMES CANYON MEMBER WHICH SUPPLIES SOME WELLS IN THE LAS POSAS- PLEASANT VALLEY AREA.
PLIOCENE		PQc	SAUGUS FORMATION SAND, SLIGHTLY CEMENTED GRAVEL AND CLAY. CONTAINS MODERATELY PERMEABLE STRATA; YIELDS WATER TO FEW WELLS.
		Pm	PICO FORMATION MARINE SANDSTONE, SHALE, LENSES OF CONGLOMERATE. GENERALLY NONWATER-BEARING OR CONTAINS SALTY WATER.
		Pc	RIDGE BASIN GROUP AND MORALES FORMATION CONTINENTAL SHALE, SANDSTONE, CONGLOMERATE, GRAVEL AND SAND. CONTAINS UNDEVELOPED PERMEABLE ZONES.
MIOCENE		Mm	SANTA MARGARITA, MODELO, RINCON AND VAQUEROS FORMATIONS MARINE SANDSTONE AND SHALE, SOME CONGLOMERATE AND CLAY. GENERALLY NONWATER-BEARING OR CONTAINS BRACKISH WATER. LOCALLY PROVIDES LIMITED QUANTITIES OF FRESH WATER TO WELLS.
		Mc	MINT CANYON AND QUTAL FORMATIONS NON-MARINE SANDSTONE, CONGLOMERATE, GYPSIFEROUS CLAY AND SOME MARL. GENERALLY NONWATER-BEARING.
OLIGOCENE		Oc	SESPE, SIMMLER AND VASQUEZ FORMATIONS NON-MARINE SANDSTONE, CONGLOMERATE AND SHALE. GENERALLY NONWATER-BEARING OR CONTAINS BRACKISH WATER; SUPPLIES FEW WELLS LOCALLY.
EOCENE AND PALEOCENE		Em	UNDIFFERENTIATED EOCENE AND PALEOCENE FORMATIONS MARINE SANDSTONE, SHALE AND CONGLOMERATE. PERMEABLE ZONES YIELD LIMITED QUANTITIES OF VARIABLE QUALITY WATER.
		Ku	UNDIFFERENTIATED MARINE FORMATIONS SANDSTONE, SHALE AND LITTLE CONGLOMERATE. PERMEABLE ZONES IN SOME AREAS YIELD WATER OF VARIABLE QUALITY IN LIMITED AMOUNT.

IGNEOUS AND METAMORPHIC ROCKS

Tv	VOLCANIC FLOWS, PYROCLASTICS, AND SHALLOW INTRUSIVES YIELDS VARIABLE QUANTITIES OF WATER TO WELLS; IMPORTANT WATER SOURCE IN SANTA ROSA, TIERRA REJADA AND CONEJO AREAS.	} TERTIARY
bc	BASEMENT COMPLEX IGNEOUS AND METAMORPHIC ROCKS. NONWATER-BEARING EXCEPT FOR LIMITED QUANTITIES OF WATER DERIVED FROM FISSURES OR WEATHERED ZONES.	} PRE-CRETACEOUS

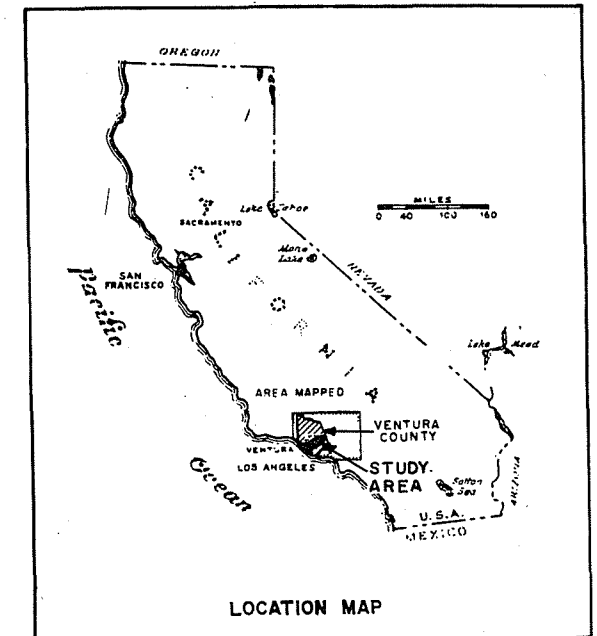
	FAULT, SURFACE TRACE	
	FAULT, BURIED OR INFERRED	
	AXIS OF ANTICLINE	} DASHED WHERE BURIED
	AXIS OF SYNCLINE	
	FORMATION CONTACT	

QUATERNARY

▶ TERTIARY

▶ TERTIARY

PRE-CRETACEOUS

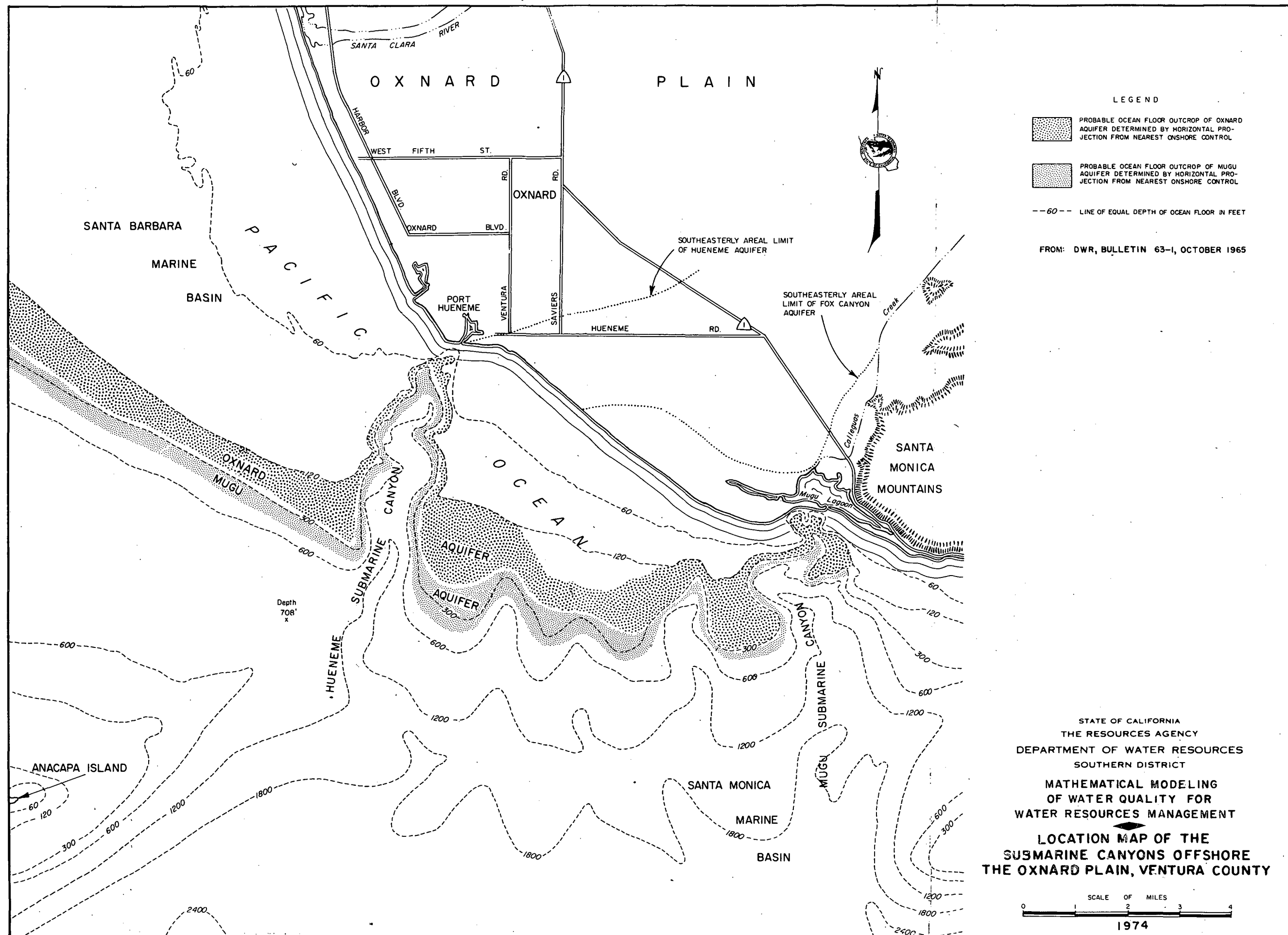


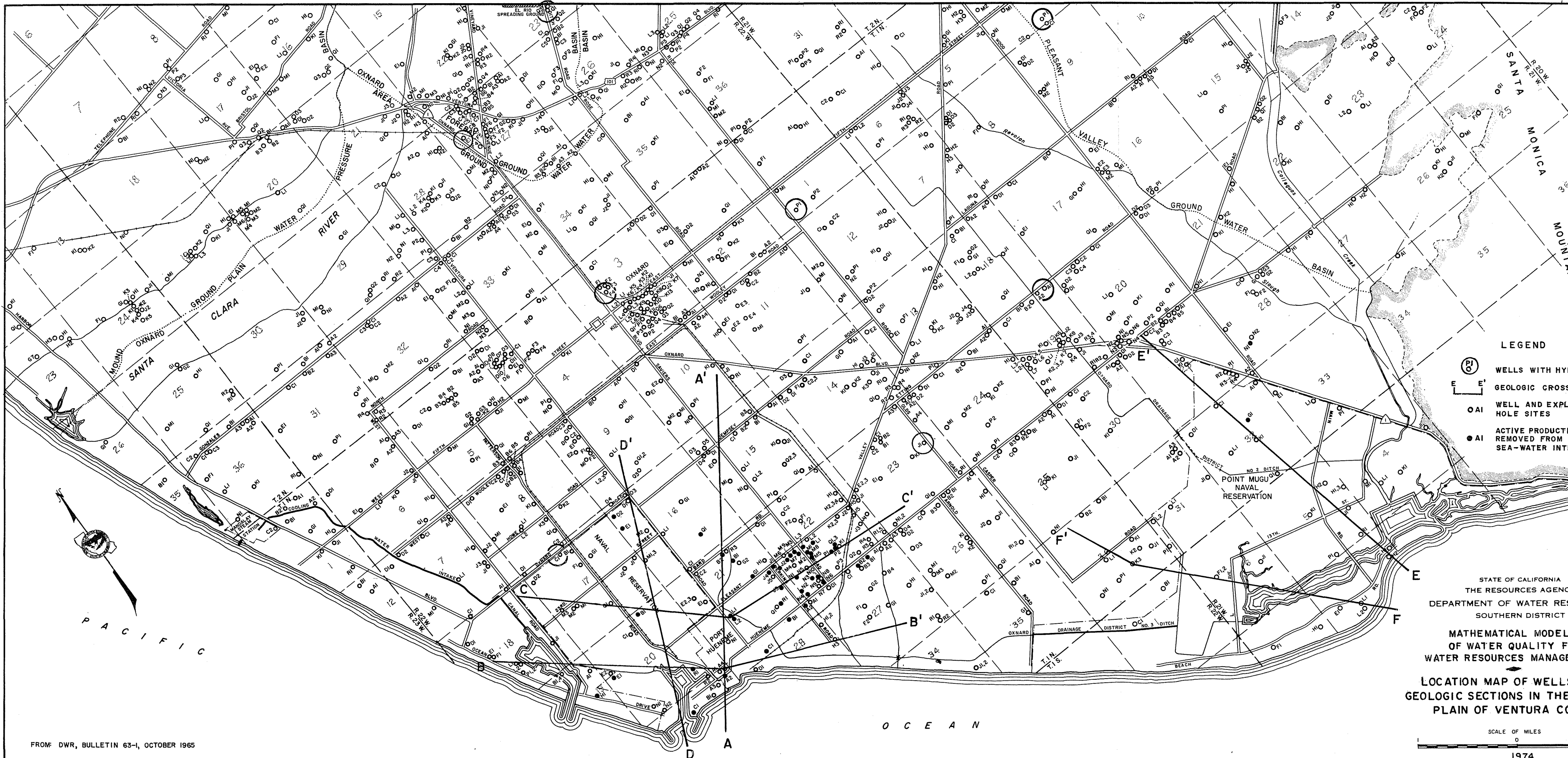
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THE RESOURCES AGENCY
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MATHEMATICAL MODELING
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AREAL GEOLOGY OF THE
SANTA CLARA-CALLEGUAS AREA, VENTURA COUNTY

0 1 2 3 4

1974





- LEGEND
- WELLS WITH HYDROGRAPHS
 - GEOLOGIC CROSS-SECTIONS
 - WELL AND EXPLORATORY HOLE SITES
 - ACTIVE PRODUCTION WELLS REMOVED FROM USE DUE TO SEA-WATER INTRUSION

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

MATHEMATICAL MODELING
OF WATER QUALITY FOR
WATER RESOURCES MANAGEMENT

LOCATION MAP OF WELLS, AND
GEOLOGIC SECTIONS IN THE OXNARD
PLAIN OF VENTURA COUNTY

