HYDROGEOLOGY OF THE BONNEVILLE SALT FLATS, UTAH

by

L. J. Turk

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UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
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CONTENTS

Appendix

ILLUSTRATIONS

Figure

HYDROGEOLOGY OF THE BONNEVILLE SALT FLATS, UTAH

by L. J. Turk[1]

INTRODUCTION

The investigation was undertaken to help evaluate the immediate and long-term potential of potash production at the Bonneville Salt Flats. The report includes a description of the hydrologic system of the salt flats, theories on its possible origin and predictions concerning the future of the system.

The Bonneville Salt Flats are located near the Utah-Nevada border in the west part of the Great Salt Lake Desert, where they occupy the west edge of a large flat playa (figures 1 and 2; Nolan, 1927).

The Salt Flats Desert, which had an average yearly precipitation of 4.74 inches from 1912 to 1967, is on the down-dropped side of a Basin and Range border fault with as much as 5,000 feet vertical displacement. Paleozoic limestones and dolomites and Tertiary volcanic rocks are exposed in the Silver Island Mountains to the northwest (figure 3; Schaeffer and Anderson, 1960). Shell Oil Company Well Salduro No. 1, drilled on the west edge of the desert (figure 2), reached an eroded volcanic surface under 1,375 feet of sediments and penetrated nearly 1,400 feet of volcanic rock before reaching Cretaceous (?) basic intrusive rock (Heylmun, 1965, p. 28). The basin overlying the volcanic rocks was filled with fluvial and later lacustrine sediments of Plio-Pleistocene age. Bedding in the upper sediments can be traced for thousands of feet with dips seldom exceeding 2 or 3 feet per mile (figure 4a and b).

Some of the younger sediments were removed by wind erosion when they were exposed by the dropping of the level of Lake Bonneville (Eardley, 1962, p. 18-23). Upward isostatic rebound has since raised the east side of the Bonneville Basin more than the west side. The salt crust, originally deposited in the center of the drying basin, was gradually shifted to the west until it came to rest in its present position at the foot of Silver Island Mountains.

The lacustrine sediments include claystone, gypsum, oolitic limestone and siltstone, mainly of silt- and clay-sized particles. Interbedded thin discontinuous lenses of sand-sized particles are composed chiefly of brine shrimp fecal pellets. The most common minerals are aragonite (more than 60 percent) and halite. Minor to trace amounts of calcite, quartz and dolomite occur in nearly all the samples; feldspar, illite and stilbite may or may not be present. Montmorillonite is the most abundant clay, followed by kaolinite (Christiansen and Thorne, 1960; Nielson and others, 1960a and b; Christiansen and others, 1962, and Christiansen and Thorpe, 1963). Table 1 indicates the range of particle size and mineral composition; locations of the six samples are shown on figure 2.

The salt crust, which occupies approximately 150 square miles, is lens-shaped in cross section (figure 5) and ranges in thickness from a feather edge to nearly 5 feet in the center. In wet seasons a shallow lake is formed from the runoff from Silver Island Mountains and the small surface drainage from the surrounding playa. The sediments underlying the salt crust are saturated with sodium chloride brine.

A second playa about 15 miles north of the Bonneville salt crust occupies a small basin between Silver Island and Pilot Mountain and has a small salt crust in its northwest corner.

The brine is collected by a system of ditches and transferred to solar evaporation ponds where potassium chloride salts are precipitated and harvested and magnesium chloride brines are collected as a byproduct (Turk, 1970).

THE HYDROLOGIC SYSTEM

Introduction

Three natural categories of aquifers in the Bonneville Salt Flats area are based on differences in occurrence, movement and recharge of the water and chemical composition of the water:

1. An alluvial fan aquifer containing fresh to brackish water;

2. A deep, stratified aquifer holding low-grade brine recoverable by deep wells, and

3. A shallow aquifer of lacustrine sediments containing high-grade brine which is harvested for its potassium chloride content.

Data from more than 130 wells were used in the study of the aquifers (Appendix A). Twenty-seven "fresh water wells" are designated FW on the location map (plate 1); 13 deeper brine wells are designated

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Table 1. Composition of playa sediments[1] (reprinted from Turk and others, 1973).

Particle size		Sample number[2]				
		1	2	3	4	5
		Weight percent of total[3]				
Sand		–	–	–	–	–
Silt		21.3	71.3	13.0	13.3	76.5
Clay		78.7	28.7	87.0	86.7	23.5
		Calcium carbonate,[4] weight percent of size fraction				
Sand		–	–	–	–	–
Silt		50.6	57.2	68.8	76.8	91.8
Clay		74.7	82.7	77.7	78.3	87.0
Total sample		69.6	64.5	76.5	78.1	90.7
	Mineral[5]	Weight percent of size fraction				
Sand	Aragonite	–	–	–	–	–
	Quartz	–	–	–	–	–
	Montmorillonite[6]	–	–	–	–	–
Silt	Aragonite	50.6	57.2	67.3	76.8[7]	91.8[7]
	Calcite	–	–	1.5		
	Quartz	49.4	26.2	–	21.4	3.8
	Gypsum	–	16.6	–	–	2.2
	Montmorillonite	–	–	31.2	–	2.2
	Illite	–	–	–	1.8	–
Clay	Aragonite	74.7[7]	75.2	77.7[7]	78.3[7]	87.0[7]
	Calcite		7.5			
	Quartz	24.1	2.6	17.6	16.3	13.0
	Gypsum	–	6.1	–	–	–
	Montmorillonite	–	6.0	4.7	5.4	–
	Illite	–	2.6	–	–	–
	Stilbite	1.2	–	–	–	–
Total sample	Aragonite	69.6[7]	62.4	76.5[7]	78.1[7]	90.7[7]
	Calcite		2.1			
	Quartz	29.5	19.5	15.4	17.0	5.9
	Gypsum	–	13.6	–	–	1.7
	Montmorillonite	–	1.7	8.1	4.7	1.7
	Illite	–	0.7	–	0.2	–
	Stilbite	0.9	–	–	–	–

[1] Analyses by J. A. Whelan, Utah Geological and Mineral Survey.
[2] Source of samples shown on figure 2.
[3] Determined by centrifuge.
[4] Weight loss in cold dilute hydrochloric acid.
[5] Determined by X-ray diffraction of whole and acid leached size fractions; quantities estimated from limited standards.
[6] Probably entrapped.
[7] Aragonite and calcite.

DBW and more than 90 shallow observation wells are designated K. Brine level recorders were installed in three shallow wells to study fluctuations in brine level.

Alluvial Fan Aquifer

Several alluvial fans along the southeast flank of the Silver Island Mountains are important aquifers which yield large volumes of brackish water needed for the daily operation of the potash plant. They are typical fanglomerates consisting of poorly sorted angular to rounded cobbles, pebbles, sand and silt, and they interfinger with lacustrine sediments near the margin of the salt flats (figure 6). According to Schaeffer and Anderson (1960, p. 113), the fans gained their greatest thickness before the advent of Lake Bonneville and their original geomorphology was altered as a result of later lacustrine and fluvial erosion and deposition.

Twenty-seven water wells, aligned near the edge of the present upper surface of the salt flats, were drilled for Bonneville, Ltd., during the 1940's and 1950's. James Phizacklea, a driller, remembers that alternating layers of sand, gravel, silt and clay persisted to depths of 80 to 220 feet (oral communcation, 1967). He reported that most of the wells were less than 100 feet deep and that all were completed in alluvium. Appendix B gives drillers' logs of three of the wells. Although called fresh water wells, the water produced is actually brackish.

Hydrologic Characteristics

The hydrologic characteristics of the fluvial deposits were first tested by Bonneville, Ltd., in 1966. Well FW9-A (plate 1) was pumped for eight hours at an estimated discharge of 1,650 gallons per minute (gpm). Drawdown was measured in wells FW9, 542 feet to the southwest and FW10, 553 feet to the northeast (figure 7). Jacob-Theis plots of the pumping test data are shown in figure 8.

The transmissivity was 385,000 gallons per day-per foot (gpd/ft) at FW9 and 185,000 gpd/ft at FW10. The storage coefficients were 0.00034 and 0.00014, respectively. Lateral variations of this magnitude are common in poorly sorted alluvium; thus, well yields can be expected to vary widely within a short distance.

In 1967 a 50-hour pumping test was run on FW9-A to better define the long-term potential of the aquifer. The longer-term test indicated that the alluvial fan functions as a leaky aquifer. A decrease in the rate of drawdown occurred after about 40 to 50 minutes of pumping, meaning that the contribution of water from the overlying confining layers became significant. The leaky aquifer analysis is important in predicting the long-term yield from a well because drawdown will be less than would be predicted by extrapolation of the early part of the Jacob-Theis curve.

Data were analyzed by both the Jacob-Theis method and the leaky aquifer modification of the standard Theis method. Type curves from Walton (1962) were used for the leaky aquifer analysis. Figure 9 shows a log-log plot of the pumping test data as well as calculations of transmissivity and storage coefficients. Table 2 summarizes the results of the pumping tests; field data are listed in Appendix C.

Transmissivities calculated by the Jacob-Theis method were 475,000 gpd/ft for FW9 and 200,000 gpd/ft for FW10, and by the leaky aquifer method were 412,000 and 159,000 gpd/ft, respectively. The slightly greater transmissivities measured in 1967 are the result of a difference of 150 gpm in estimated well discharge because the 1967 discharge was measured with a calibrated orifice and manometer which was considerably more accurate than the small weir used in 1966.

Storage coefficients calculated from the 1967 test ranged from 0.00023 and 0.00046, and indicate that the aquifer is confined.

Long-term Water-level Fluctuations

All the brackish water wells flowed as natural artesian wells when they were first drilled. Records of Bonneville, Ltd., indicate that several wells were still flowing as late as 1960. Table 3 is a summary of water-level measurements in eleven of the brackish water wells during the 3-year period 1965 to 1968.

Table 2. Summary of pumping tests on alluvial fan aquifer.

Well	Date	Depth to static water level (ft)	Distance to observation well, r (ft)	Pumping rate, Q (gpm)	Duration of pumping, t (min)	Maximum drawdown, s (ft)	Transmissivity, T, by Jacob-Theis method (gpd/ft)	Storage coefficient, S
FW9-A	6-30-66	9.193	–	1,650	480	–	–	–
FW9	6-30-66	11.671	541.7	–	–	2.065	385,000	0.00034
FW10	6-30-66	10.280	552.9	–	–	4.890	185,000	0.00014
FW9-A	8-28-67 to 8-30-67	–	–	1,800	3,023	–	–	–
FW9	8-28-67 to 8-30-67	7.767	541.7	–	–	2.485	475,000 (412,000)[1]	0.00041 (0.00046)[1]
FW10	8-28-67 to 8-30-67	6.178	552.9	–	–	5.397	200,000 (159,000)[1]	0.00017 (0.00023)[1]
FW8-A	8-28-67 to 8-30-67	6.531	1,048.0	–	–	1.891	–	–

[1] Analysis by standard Theis method modified for leaky aquifer (Walton, 1962).

Table 3. Water levels in brackish water wells, 1965 to 1968.

Date	Depth to water (ft)
FW2	
11-27-65	18.380
5-7-66	14.361
6-18-66	13.096
8-18-66	12.776
10-6-66	12.891
6-13-67	10.010
7-19-67	9.295
8-14-67	9.639
9-8-67	9.933
10-12-67	9.691
11-15-67	8.863
12-20-67	8.319
5-10-68	7.28
FW6	
11-27-65	19.648
5-7-66	13.260
6-18-66	11.718
8-18-66	12.532
10-6-66	13.362
FW6-A	
2-26-65	13.07
8-26-65	18.56
11-30-65	19.304
5-7-66	12.799
6-18-66	11.252
8-18-66	12.140
10-6-66	13.116
6-14-67	8.710
7-19-67	7.720
8-14-67	8.443
9-8-67	8.894
10-12-67	7.310
11-15-67	6.139
12-20-67	5.402
5-10-68	5.18
FW7	
11-27-65	17.936
5-7-66	11.602
6-18-66	10.045
8-18-66	10.830
10-6-66	11.721
FW7-A	
2-26-65	12.65
8-26-65	17.18
11-30-65	18.632
5-7-66	12.257
6-18-66	10.715
8-18-66	11.152
10-6-66	12.332
FW8	
2-26-65	13.92
8-26-65	19.32
11-30-65	19.887
5-7-66	13.582
6-18-66	11.982
8-18-66	12.083
10-6-66	13.521
FW8-A	
5-7-66	12.172
6-18-66	10.492
8-18-66	10.118
10-6-66	12.491
8-28-67	6.531
FW9	
6-30-66	11.671
8-18-66	11.452
10-6-66	14.549
6-13-67	8.240
7-19-67	7.481
8-4-67	7.425
8-14-67	7.597
8-28-67	7.767
9-8-67	7.885
10-12-67	7.562
11-5-67	6.661
12-20-67	6.019
5-10-68	4.62
FW9-A	
6-30-66	9.193
FW10	
6-30-66	10.280
8-18-66	9.848
10-6-66	17.857
8-28-67	6.177
FW12	
11-27-65	14.979
5-7-66	10.892
6-18-66	9.212
8-18-66	7.958
10-6-66	8.453
6-13-67	5.166
7-19-67	4.615
8-14-67	4.430
9-8-67	4.528
10-12-67	4.551
11-15-67	4.135
12-20-67	3.660
5-10-68	2.23

Hydrographs of four nonpumping wells are shown in figure 10. Note that sharp drops in the water levels occurred during the summer peak pumping season. Water levels dropped from above ground surface in 1960 to more than 19 feet below the surface in 1965; they have been rising since early 1966, probably because of the abnormally high rainfall in 1966 and 1967. Pumping wells naturally would have lower levels than the wells measured.

Brackish Water Characteristics

Chemical Composition

Water produced from the so-called fresh water wells is actually brackish as defined by Gorrell (1958). Five samples listed in table 4a contain about 6,800 to 8,200 milligrams per liter (mg/l) total dissolved solids. Table 4b gives a more complete analysis of water from FW5 plus two analyses of water from fault-line springs for comparison. The water is of the sodium chloride type, as shown on the Piper (1944) diagram (figure 11).

Temperature

Temperatures of the well waters are 26° to 43° F higher than the mean annual surface temperature of 52° F. Temperatures are similar to those found in fault-line springs along the east flank of the mountains which border the salt flats on the west, and are about the same as temperatures of brine from the deep brine wells. Table 5 lists temperatures from the brackish water wells, deep brine wells and two fault-line springs.

Origin and Recharge

Water in the alluvial fans is probably a mixture of waters from three sources:

1. Rainfall on the fans and runoff from adjacent slopes which infiltrate the upper part of the fans,

2. Brine from the playa, and

3. Upward leakage of warm water from the Paleozoic carbonate rocks to the west along the border fault beneath the fans.

The low rainfall precludes abundant recharge from precipitation, although it supplies a definite contribution to the aquifer. The increase of salt content over the years indicates a lateral or vertical contribution from the playa brines or a greater contribution from the fault. The high temperature of the water is the principal evidence that some of the water has experienced deep circulation, probably to a depth of 1,000 to 2,000 feet, or approximately the same depth as the deep brine wells.

Table 4a. Composition of brackish water (analyses by Bonneville, Ltd.).

Well no.	Date	Specific gravity (at 20° C)	Percentage by weight				Temperature	
			KCl	$MgCl_2$	NaCl	SO_4	(°C)	(°F)
FW3	8-4-67	1.0040	0.05	0.11	0.64	0.02	35	95
FW5	8-4-67	1.0039	0.05	0.08	0.57	0.02	31	88
FW9-A	8-4-67	1.0037	0.05	0.11	0.50	0.02	25.5	78
FW11	8-4-67	1.0037	0.05	0.11	0.50	0.02	25.5	78

Table 4b. Composition of brackish water and water from fault-line springs (analyses by Kaiser Chemicals, San Leandro, California).

Sample no.	Source	Constituents in parts per million						
		Ca	Mg	Na	Li	K	SO_4	Cl
1.16	FW5	100	80	2,100	1.2	100	300	3,700
1.17	Spring 1[1]	200	50	1,400	1.4	100	200	2,600
1.18	Spring 2[1]	270	50	2,000	1.7	130	100	3,400

[1] See figure 3 for locations of springs.

Table 5. Temperatures of water from brackish water wells, deep brine wells and fault-line springs.

Source of sample	Date	Temperature		Remarks
		°C	°F	
FW3	8-4-67	35	95	
FW5	8-4-67	31	88	
	9-8-67	31	88	
FW9-A	8-4-67	25.5	78	
FW11	8-4-67	25.5	78	
DBW6	7-24-67	27	80	
	8-14-67	27	80	
	9-13-67	27	80	
DBW7	6-16-67	24.5	76	
	7-24-67	25	77	
	8-14-67	24.5	76	
	9-13-67	24.5	76	
DBW8	6-16-67	28	82	
	7-24-67	28	82	
	8-14-67	28	82	
	9-13-67	28	82	
DBW10	6-16-67	25	77	Temperature fluctuation probably the result of short pumping time before sample was collected
	7-24-67	27	80	
	8-14-67	24.5	76	
	9-13-67	23	73	
DBW13	7-25-67	22	71	
	8-14-67	24	75	Same as above
	9-13-67	24.5	76	
Spring No. 1, Blue Lake	9-14-67	29	84	
Spring No. 2, Pilot Valley	7-23-67	24.5	76	

Deep Brine Aquifer

Thirteen wells were drilled near the west edge of the playa to depths of from 1,070 to 2,069 feet between 1939 and 1951 (Appendix B and plate 1). Water from the wells currently is used to maintain the hydraulic head in the seal ditches above the brine level of the evaporation ponds to minimize seepage loss of valuable brines. It is also a source of additional brine which, if purposely recharged, could significantly extend the productive life of the potash deposit.

Hydrologic Characteristics

Table 6 summarizes data from a long-term production test on DBW1 (plate 1) run during the period January 21 to April 17, 1948. The data include almost all the existing hydrologic information about the deep aquifer. Brine levels were measured during the test with an air line equipped with a pressure gauge. Pump discharge was monitored with a vertical manometer or standpipe mounted between the pump and a 6-inch orifice on the discharge pipe. Before the beginning of the test, the orifice was calibrated by discharging brine into a tank of known volume. Brine levels and discharge were measured only once a day and times of measurement were not recorded.

Pumping rates varied from 400 to 765 gpm, but interruptions in pumping rendered data unsuitable for a complete step-drawdown analysis. Examination of the specific capacity data on table 6 shows that the well was extremely inefficient; its specific capacity (Q/s, where Q = discharge in gallons per minute, and s = drawdown in feet) ranged from 52.4 gpm/ft at 765 gpm after pumping for about one-half day to 11.5 gpm/ft at 670 gpm after pumping for almost three

Table 6. Production test data, Well No. DBW1 (from files of Bonneville, Ltd.).

Date[1] (1948)	Depth to brine[2] (ft)	Draw-down (ft)	Dis-charge (gpm)	Specific capacity (gpm/ft)	Remarks
January					
21	26.0 (est)	0	–	–	Approx. static brine level
21	40.6	14.6	765	52.4	Assume pumping time = 8 hours
22	61.5	35.5	706	19.9	Temp. = 41° C
23	63.6	37.6	662	17.6	Temp. = 42° C
24	64.7	38.7	662	17.1	Temp. = 42° C
25	64.7	38.7	672	17.1	Temp. = 42° C
26	67.8	41.8	662	15.8	Temp. = 42° C
27	67.8	41.8	657	15.7	Temp. = 42° C
28	68.3	42.3	650	15.4	Temp. = 43° C
29	68.3	42.3	645	15.2	Temp. = 43° C
30	68.3	42.3	642	15.2	Temp. = 43° C
31	–	–	635	–	Air line broke
					Air line repaired, pump started Feb. 4 (in afternoon)
February					
4	26.0	0	–	–	
4	–	–	745	–	Start pump
5	–	–	698	–	
6	–	–	677	–	
7	73.3	47.3	672	14.2	
8	73.3	47.3	662	14.0	
9	71.2	45.2	645	14.3	
10	71.6	45.6	642	14.1	
11	–	–	662	–	Pump was down for a few hours
12	71.2	45.2	650	14.4	
13	71.8	45.8	642	14.0	
14	71.8	45.8	637	13.9	
15	71.8	45.8	637	13.9	
16	71.8	45.8	635	13.9	
17	71.8	45.8	637	13.9	
18	71.8	45.8	637	13.9	
19	72.2	46.2	627	13.8	
20	71.8	45.8	637	13.9	
21	71.8	45.8	642	14.0	
21	46.0	20.0	–	–	Pump down–leveling pipe
22	72.2	46.2	642	13.9	
23	73.3	47.3	642	13.6	
24	72.2	46.2	635	13.7	
24	70.1	44.1	504	11.4	Pump slowed down
25	64.9	38.9	523	13.4	
26	62.8	36.8	504	13.7	
27	62.5	36.5	504	13.8	
28	62.8	36.8	504	13.7	
29	62.8	36.8	504	13.7	
March					
1	62.8	36.8	504	13.7	
2	62.8	36.8	504	13.7	
3	62.8	36.8	504	13.7	
4	62.8	36.8	504	13.7	
5	62.8	36.8	504	13.7	

[1] Time of measurement not listed.

[2] Depth measured from pump discharge elevation, about 3 feet above ground surface.

Table 6 (continued)

Date[1] (1948)	Depth to brine[2] (ft)	Drawdown (ft)	Discharge (gpm)	Specific capacity (gpm/ft)	Remarks
6	62.8	36.8	495	13.5	
7	62.8	36.8	495	13.5	
8	62.8	36.8	504	13.7	
9	62.8	36.8	504	13.7	
10	62.8	36.8	504	13.7	
11	62.8	36.8	504	13.7	
12	62.8	36.8	504	13.7	
13	62.8	36.8	495	13.5	
14	62.8	36.8	504	13.7	
15	62.8	36.8	504	13.7	
15	–	–	400	–	Pump slowed down
16	54.4	28.4	422	14.9	
17	52.3	26.3	400	15.2	
18	52.3	26.3	400	15.2	
19	50.2	24.2	405	16.7	
20	50.2	24.2	400	16.5	
21	50.2	24.2	400	16.5	
22	–	–	685	–	Pump speeded up
23	–	–	–	–	Pump down
24	73.3	47.3	657	13.9	
25	77.5	51.5	685	13.3	
26	80.6	54.6	672	12.3	
27	82.7	56.7	672	11.9	
28	82.7	56.7	672	11.9	
29	82.7	56.7	685	12.1	
30	82.7	56.7	672	11.9	
31	82.7	56.7	672	11.9	
April					
1	–	–	–	–	Pump down–engine trouble
2	–	–	–	–	
3	82.7	56.7	677	11.9	
4	–	–	–	–	No record
5	–	–	–	–	No record
6	80.1	54.1	667	12.3	
7	82.7	56.7	662	11.7	
8	84.3	58.3	677	11.6	
9	83.8	57.8	672	11.6	
10	83.8	57.8	672	11.6	
11	83.8	57.8	672	11.6	
12	83.8	57.8	672	11.6	
13	83.8	57.8	662	11.5	
14	82.7	56.7	672	11.9	
15	83.8	57.8	662	11.5	
16	83.8	57.8	–	–	Pump shut down in early morning
Recovery data					Recovery, ft
17	48.0	22.0	–	–	35.8
18	31.2	5.2	–	–	52.6
19	29.2	3.2	–	–	54.6
20	28.2	2.2	–	–	55.6
21	28.1	2.1	–	–	55.7
22	28.1	2.1	–	–	55.7
22	–	–	–	–	Pumping resumed

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[1] Time of measurement not listed.

[2] Depth measured from pump discharge elevation, about 3 feet above ground surface.

months. The most useful values of specific capacity can be obtained by using data from the period when the pumping level was nearly stabilized and the system was in quasi-equilibrium.

The only other pumping test data on the deep aquifer are from two production tests on DBW8 (drillers' logs, Appendix B). The well produced 1,270 gpm and 1,000 gpm, with 85 and 70 feet of drawdown respectively. Duration of the pumping was not recorded.

Long-term Brine-level Fluctuation

Detailed brine-level measurements are lacking. In 1948 the brine level stood about 25 feet below the surface as listed in the pumping record of DBW1. Measurements in DBW9 and DBW12 during 1966 and 1967 indicated that the brine level was about 44 to 50 feet below the surface (table 7). This represents an average decline in head of a little more than one foot per year since 1948.

Deep Brine Characteristics

Chemical Composition

Concentrations of potassium chloride and magnesium chloride in the deep brine are about one-third to one-half the concentrations of the shallow brine. The $Cl^-/SO_4^=$ ratio is 12.3 or about the same as in water from the alluvial fans, but the absolute amount of $SO_4^=$ is much greater in the deep wells and hydrogen sulfide odor is evident around the wells. Table 8a lists partial chemical analyses of brines from five deep brine wells with more complete analyses of two samples listed in table 8b.

The composition of the brine is relatively constant throughout the aquifer, although salinity increases slightly toward the north. Water deeper than 1,900 feet, however, is much more dilute than that at slightly shallower depths. The electric log of Shell Oil Company's well south of Salduro indicates dissolved solids content of 10,000 to 12,000 mg/l, one tenth that at 1,500 feet in DBW13 (table 8b).

Temperature

Temperatures of the deep brines are shown on table 8a; along with temperatures of the shallower waters, they are plotted on the depth-temperature profile of figure 12. The temperature of brine from DBW3 while the hole was being drilled and from DBW1 shortly after its completion yielded temperatures considerably higher than would be expected from the geothermal gradient. The temperatures may have some relation with the warm waters found in the fault-line springs to the north.

Table 7. Brine levels in deep brine wells.

Date	Depth to brine (ft)	
	DBW9	DBW12
6-13-67	52.033	47.170
7-20-67	50.829	46.990
8-8-67	53.681	47.098
9-8-67	54.831	47.310
12-21-67	49.140[1]	48.195[1]
5-10-68	55.08 [1]	48.87 [1]

[1] Measurements by others—possibly from a different measuring point.

Origin

Whether the initial composition and concentration of dissolved solids in the deep brine have changed since the sediments were laid down is not known, but the water likely was originally fresh water which dissolved mineral solids from the sediments.

Recharge

Detailed pumping tests would be required to determine if the brine is squeezed from storage by compression of the aquifer or if there is a substantial recharge of relatively fresh water along the fault which borders the salt flats on the west.

Shallow Brine Aquifer

The shallow brine aquifer is the uppermost 25 feet of lacustrine sediments. Because the brine is harvested for its potash content, it has been explored in more detail than the rest of the hydrologic system. Ninety-two shallow wells (plate 1) were hand augered and tested with electric or gasoline pumps. The wells are 6 inches in diameter; most were cased with 4-inch slotted plastic casing and packed with gravel. Depths of test wells ranged from 10 to 30 feet, the most common depth being 23 feet.

Hydrologic Characteristics

Davis (1966, p. 9) found the average porosity of the shallow aquifer to be about 45 percent and the specific yield of the sediments to be about 10 percent.

Transmissivities of the playa sediments were determined from 62 pumping tests by C. P. Bingham of Kaiser Aluminum and Chemical Corp. (Davis, 1966, p. 14-15), 12 by engineers from Utah State University (Christiansen and others, 1960), and 8 by the author.

Table 8a. Composition and temperature of brine from deep wells (analyses by Bonneville, Ltd.).

Well no.	Date	Specific gravity	Percentage by weight				Temperature		Remarks
			KCl	$MgCl_2$	NaCl	SO_4	(°C)	(°F)	
DBW1	1-22-48	–	–	–	–	–	41	106	Continuous pumping
	1-23-48	–	–	–	–	–	42	108	
	1-24-48	–	–	–	–	–	42	108	
	1-25-48	–	–	–	–	–	42	108	
	1-26-48	–	–	–	–	–	42	108	
	1-27-48	–	–	–	–	–	42	108	
	1-28-48	–	–	–	–	–	43	109	
	1-29-48	–	–	–	–	–	43	109	
	1-30-48	–	–	–	–	–	43	109	
DBW3	–	–	–	–	–	–	56	133[1]	Depth 1,502 ft
	–	–	–	–	–	–	88	190[1]	Depth 1,636 ft
DBW6	7-24-67	1.0935	0.386	0.436	10.74	–	27	80	
	8-14-67	1.0940	0.36	0.54	10.68	0.52	27	80	
	9-13-67	1.0960	0.385	0.545	10.72	0.52	27	80	
DBW7	6-16-67	1.0940	0.367	0.504	10.66	0.52	24.5	76	
	7-24-67	1.0940	0.386	0.436	10.63	–	25	77	
	8-14-67	1.0940	0.38	0.47	10.71	0.52	24.5	76	
	9-13-67	1.0950	0.393	0.501	10.65	0.51	24.5	76	
DBW8	6-16-67	1.0960	0.370	0.537	10.75	0.55	28	82	
	7-24-67	1.0955	0.394	0.569	10.77	–	28	82	
	8-14-67	1.0945	0.38	0.50	10.77	0.55	28	82	
	9-13-67	1.0950	0.388	0.511	10.85	0.53	28	82	
DBW10	6-16-67	1.0950	0.376	0.487	10.73	0.52	25	77	
	7-24-67	1.0940	0.398	0.436	10.60	–	27	80	
	8-14-67	1.0940	0.38	0.54	10.68	0.51	24.5	76	
	9-13-67	1.0950	0.397	0.477	10.74	0.51	23	73	
DBW13	7-25-67	1.1040	0.47	0.69	11.58	0.58	22	71	
	8-14-67	1.0980	0.41	0.57	11.16	0.55	24	75	
	9-13-67	1.0995	0.426	0.543	11.33	0.55	24.5	76	

[1] Temperatures of mud bailed when drilling.

Table 8b. Composition of brine from deep wells (analyses by Kaiser Chemicals, San Leandro, California).

Sample no.	Source	Constituents in parts per million						
		Ca	Mg	Na	Li	K	SO_4	Cl
1.14	DBW8	1,600	1,400	41,400	16	1,800	6,000	70,000
1.15	DBW13	1,500	1,400	46,000	17	2,000	6,200	72,800

The pumping test data were analyzed by the nonequilibrium type curve method of Theis (1935) and the leaky aquifer modification of that method, as well as the Jacob-Theis semi-log method. Records of selected pumping tests are listed in Appendix C; table 9 summarizes results of all the tests made on the shallow aquifer.

Figure 13 shows the general distribution of transmissivity over the salt flats. Note that the area of highest transmissivity coincides almost perfectly with the axis of the salt flat where the salt is thickest. A contour map of the hydraulic conductivity (figure 14) shows the same pattern as figure 13.

The transmissivity varies from less than 500 gpd/ft in wells near the edge of the salt crust to 100,000 gpd/ft or more in some wells near the center of the crust. The exceptionally high transmissivities are due to flow of brine through highly permeable salt crust, to shrinkage fissuring of the sediments, or to thin layers of highly permeable fecal pellet sand (Turk and others, 1973). The areas of high transmissivity

Table 9. Results of pumping tests on the shallow aquifer.[1]

Well no.	Elevation (ft)	Date	Depth of well (ft)	Static water depth (ft)	Saturated thickness (ft)	Distance to observation well (ft)	Average pumping rate (gpm)	Pumping duration (min)	Maximum drawdown (ft)	Transmissivity (gpd/ft)	Average hydraulic conductivity (meinzers)	Storage coefficient	b′/k′	Reliability
K1	4,214.148	11-19-65	16	5.728	10.03	–	9.6	60	1.55	7.7 x 10^3	768	–	–	Good
K2	4,214.294	9-14-65	20	–	–	–	24.0	42	4.00	3.2 x 10^3	–	–	–	No good
K3	4,215.238	10-4-65	25	1.170	23.83	–	12.5	50	2.16	5.0 x 10^3	210	–	–	Good
K4	4,214.942	9-28-65	23	0.955	22.04	–	19.2	104	6.65	–	–	–	–	–
K4-A	4,214.959	9-28-65	23	–	–	–	–	–	0.50	17.0 x 10^3	771	1.07 x 10^{-2}	11.2	Very good
K5	4,215.248	10-4-65	25	1.194	23.81	–	10.5	36	2.56	20.0 x 10^3	840	–	–	Fair
K6	4,215.142	10-2-65	23	1.040	21.96	–	14.0	44	8.42	1.5 x 10^3	68	–	–	Poor
K7	4,215.127	6-17-65	25	1.156	23.84	–	11.1	88	8.20	–	–	–	–	–
K7-A	4,215.148	10-4-65	25	–	–	–	–	–	0.98	3.0 x 10^3	126	9.00 x 10^{-4}	3.6	Good
K8-B	4,215.504	11-7-65	23	1.634	21.362	–	7.6	121	7.04	–	–	–	–	–
K8-C	4,215.455	11-7-65	23	1.716	21.72	–	–	–	0.22	11.0 x 10^3	506	1.42 x 10^{-3}	3.8	Good
K9	4,215.279	9-30-65	25	1.508	23.49	–	6.4	50	5.00	3.0 x 10^3	128	–	–	Poor
K10	4,215.344	9-29-65	25	1.409	24.59	–	4.0	105	2.59	–	–	–	–	–
K10-A	4,215.289	9-29-65	23	1.310	21.69	–	–	–	0.38	3.0 x 10^3	138	1.16 x 10^{-3}	24.6	Very good
K11	4,215.247	9-28-65	25	1.235	23.77	–	4.0	105	7.36	–	–	–	–	–
K11-A	4,215.302	9-28-65	25	1.113	23.89	49.6	–	–	0.23	3.0 x 10^3	126	2.15 x 10^{-3}	2.6	Good
K12	4,215.135	11-15-65	25	1.898	23.10	–	4.9	60	8.30	2.0 x 10^2	9	–	–	Poor
K15	–	10-1-65	13	1.609	21.39	–	2.4	50	1.64	5.0 x 10^2	23	–	–	Fair
K16	4,215.288	9-30-65	25	1.596	23.40	–	11.7	50	4.75	6.0 x 10^3	256	–	–	Fair
K17	4,215.029	10-5-65	22	1.465	20.54	–	15.0	50	3.88	10.0 x 10^3	487	–	–	Fair
K18	4,215.270	11-16-65	23	2.032	20.97	–	4.8	60	1.55	1.0 x 10^3	48	–	–	Fair
K19	4,215.472	11-16-65	23	2.019	20.98	–	7.9	60	6.01	3.0 x 10^2	14	–	–	Fair
K20	4,215.077	11-16-65	23	1.736	21.26	–	6.1	60	3.45	5.0 x 10^2	24	–	–	Fair
K22	4,215.035	10-2-65	25	1.139	24.86	–	16.0	56	5.80	2.0 x 10^3	80	–	–	Fair
K23	4,215.970	11-16-65	25	1.210	23.79	–	7.8	60	5.90	–	–	–	–	–
K23-A	–	11-16-65	25	0.158	24.84	–	–	–	0.39	3.0 x 10^3	121	1.19 x 10^{-1}	–	Good
K24	4,215.193	11-7-65	23	1.464	22.79	–	–	–	0.47	1.1 x 10^4	483	2.11 x 10^{-2}	–	Very good
K24-A	4,215.924	11-7-65	19	1.254	17.65	–	9.5	57	8.30	–	–	–	–	–
K26	–	9-30-65	23	1.530	21.47	–	19.5	50	4.00	2.0 x 10^3	93	–	–	Poor
K27	–	11-8-65	27	1.431	21.57	49.9	–	–	0.04	1.0 x 10^5	4,640	4.06 x 10^{-2}	–	Good
K27-A	–	11-8-65	20	1.705	18.70	–	12.0	121	7.60	–	–	–	–	–
K28	–	9-30-65	23	1.272	21.73	–	21.5	50	3.30	5.0 x 10^3	230	–	–	Good
K29	–	10-1-65	23	1.355	21.65	–	19.2	50	2.71	5.0 x 10^3	222	–	–	Good
K30	4,214.216	9-9-65	22	3.125	18.50	–	25.5	32	2.20	5.0 x 10^4	2,700	–	–	Very good
K31	4,215.280	11-19-65	20	0.991	19.01	–	5.0	50	10.20	1.0 x 10^3	53	–	–	Good
K32	4,214.392	9-17-65	23	2.167	20.83	–	34.0	50	4.60	1.0 x 10^4	480	–	–	Fair
K33	4,214.340	11-17-65	23	6.891	17.11	–	12.0	119	2.53	–	–	–	–	–
K33-A	4,214.353	11-17-65	19	6.909	12.49	49.7	–	–	0.14	2.5 x 10^4	2,000	2.03 x 10^{-2}	–	Very good
K34	4,214.254	9-10-65	23	1.125	21.88	–	41.4	61	5.77	–	–	–	–	–
K34-A	4,214.482	9-10-65	23	1.416	21.58	–	–	–	0.16	1.26 x 10^5	5,840	5.25 x 10^{-3}		Very good
K35	4,214.195	10-1-65	23	0.950	22.05	–	17.2	50	5.70	7.0 x 10^3	317	–	–	Poor
K36	4,214.485	11-6-65	23	6.894	16.11	–	12.5	56	2.06	1.5 x 10^4	931	–	–	Fair
K37	4,214.457	11-4-65	23	4.392	18.61	–	16.7	61	1.80	3.3 x 10^4	1,770	–	–	Fair
K39	4,214.540	11-10-65	23	4.361	18.64	–	11.9	120	2.70	–	–	–	–	–
K39-A	4,214.301	11-10-65	23	4.139	18.86	–	–	–	0.37	1.6 x 10^4	848	1.12 x 10^{-3}	31.6	Very good
K40	4,214.229	11-10-65	23	5.867	17.13	–	6.3	61	4.33	1.0 x 10^4	583	–	–	Very poor
K41	4,214.714	9-21-65	23	1.540	21.46	–	2.4	55	8.60	1.5 x 10^2	7	–	–	Fair
K42	4,214.628	11-5-65	23	1.750	21.25	–	1.3	56	2.09	3.0 x 10^2	14	–	–	Good
K43	4,214.576	9-21-65	23	1.322	21.68	–	10.1	100	4.25	–	–	–	–	–

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[1] Pumping tests in 1965 to 1966 were by C. P. Bingham of Kaiser Aluminum Corp. Pumping tests in 1967 were by L. J. Turk.

Table 9 (continued)

Well no.	Elevation (ft)	Date	Depth of well (ft)	Static water depth (ft)	Saturated thickness (ft)	Distance to observation well (ft)	Average pumping rate (gpm)	Pumping duration (min)	Maximum drawdown (ft)	Transmissivity (gpd/ft)	Average hydraulic conductivity (meinzers)	Storage coefficient	b'/k'	Reliability
K43-A	4,214.523	9-21-65	23	1.292	21.71	51.6	–	–	0.95	5.6×10^{3}	258	4.00×10^{-5}	191.0	Very good
K44	4,214.427	9-21-65	23	1.250	21.75	–	5.3	50	1.84	5.0×10^{3}	230	–	–	Fair
K45	4,214.426	11-5-65	23	2.258	20.47	–	7.5	60	2.33	9.0×10^{3}	439	–	–	Fair
K46	–	11-5-65	23	2.109	20.89	–	11.5	50	3.10	2.0×10^{4}	962	–	–	Fair
K47	–	11-5-65	19	1.593	18.41	–	7.4	60	7.32	1.0×10^{3}	54	–	–	Fair
K48	–	9-27-65	23	2.920	20.08	–	2.6	54	2.22	1.15×10^{3}	57	–	–	Good
K49	–	9-27-65	23	2.633	20.37	–	15.6	52	4.00	1.0×10^{4}	491	–	–	Fair
K50	–	9-27-65	23	1.505	21.50	–	10.8	52	2.15	1.6×10^{4}	744	–	–	Fair
K52	–	9-27-65	23	1.538	21.46	–	14.3	60	2.08	9.0×10^{3}	419	–	–	Fair
K53	–	9-23-65	23	3.000	20.00	–	17.9	50	4.72	1.1×10^{4}	550	–	–	Fair
K54	–	11-6-65	23	5.247	17.75	–	9.5	11	1.55	9.0×10^{3}	507	–	–	Fair
K55	4,214.000	11-11-65	18	4.633	13.37	–	13.4	60	1.90	2.0×10^{4}	1,500	–	–	Good
K56	–	9-15-65	23	2.420	20.58	–	–	–	0.21	1.5×10^{5}	7,290	8.25×10^{-3}	–	Good
K56-B	–	9-15-65	23	2.420	20.58	–	65.0	100	3.19	–	–	–	–	–
K57	–	11-6-65	19	1.058	17.94	–	15.9	60	5.85	1.3×10^{4}	724	–	–	Fair
K58	4,214.194	11-10-65	23	6.184	16.82	–	11.4	60	1.62	1.8×10^{4}	1,070	–	–	Fair
K59	–	11-11-65	23	2.530	20.47	–	12.8	60	5.69	2.0×10^{3}	98	–	–	Very poor
K60	–	11-11-65	23	2.335	20.67	–	15.0	60	4.35	5.0×10^{3}	240	–	–	Good
K61	–	11-17-65	23	1.417	21.58	–	14.2	60	3.80	1.0×10^{3}	46	–	–	Fair
K62	–	10-7-65	21	1.799	18.90	–	–	–	0.10	6.0×10^{4}	3,120	7.98×10^{-2}	–	Fair
K62-A	–	10-7-65	21	2.214	18.79	–	23.4	97	1.90	–	–	–	–	–
K63	–	11-22-65	19	3.282	15.72	–	–	–	0.30	8.0×10^{3}	509	1.66×10^{-2}	–	Good
K63-A	–	11-22-65	19	3.254	15.75	–	10.0	180	5.52	–	–	–	–	–
K64	–	11-15-65	19	4.275	14.73	–	22.4	60	1.10	5.1×10^{4}	3,460	–	–	Good
K65	–	8-4-66	19	3.916	15.08	–	4.1	420	3.48	–	–	–	–	–
K65-A	–	8-4-66	19	3.907	15.09	48.3	–	–	0.08	2.08×10^{4}	1,380	2.48×10^{-2}	–	Fair
K65-B	–	8-4-66	10	3.208	6.79	99.9	–	–	–	2.04×10^{4}	3,000	1.88×10^{-2}	–	Good
K66	–	8-9-66	19	1.128	17.87	–	2.9	420	3.50	–	–	–	–	–
K66-A	–	8-9-66	19	1.123	17.88	48.6	–	–	0.97	1.4×10^{3}	78	7.7×10^{-4}	–	Good
K66-B	–	8-9-66	10	0.150	9.85	103.9	–	–	0.57	–	–	–	–	–
K67	–	8-12-66	19	1.693	17.31	–	9.0	421	6.26	–	–	–	–	–
K67-A	–	8-12-66	19	1.663	17.34	48.4	–	–	0.24	2.29×10^{4}	1,360	2.04×10^{-3}	–	Good
K67-B	–	8-12-66	10	1.040	8.96	98.3	–	–	0.14	–	–	–	–	–
K68	–	8-15-66	19	4.154	14.85	–	0.72	360	9.69	–	–	–	–	–
K68-A	–	8-15-66	19	4.335	14.66	51.0	–	–	0.15	1.25×10^{3}	85	5.82×10^{-3}	–	Poor
K68-B	–	8-15-66	10	3.249	6.75	102.6	–	–	0.05	–	–	–	–	–
K69	–	9-12-67	21	7.430	13.50	–	17.8	240	5.97	1.7×10^{3}	126	–	–	Good
K69-A	–	9-12-67	10	10.955	3.35	–	10.7	160	2.04	2.3×10^{3}	687	–	–	Fair
K70	–	9-5-67	21	–	–	–	20.0	420	–	–	–	–	–	–
K70-A	–	9-5-67	21	6.725	14.28	30.0	–	–	0.31	3.7×10^{4}	2,590	2.14×10^{-2}	–	Excellent
7.4[2]	–	9-30-60	11	2.85	8.15	–	–	–	–	7.3×10^{4}	8,970	–	–	Fair
8.4[2]	–	8-10-60	11	3.36	7.64	–	61.2	1,210	–	3.5×10^{4}	4,580	2.0×10^{-3}	100	Very good
9.5[2]	–	9-13-60	11	2.85	8.15	–	–	–	–	2.85×10^{4}	3,500	–	–	Fair
10.0[2]	–	9-15-60	12	4.00	8.00	–	–	–	–	7.8×10^{3}	950	–	–	Fair
10.6[2]	–	9-16-60	12	3.32	8.68	–	–	–	–	1.49×10^{4}	1,620	–	–	Fair
11.4[2]	–	9-29-60	11	2.76	8.24	–	–	–	–	3.23×10^{4}	3,920	–	–	Fair
12.3[2]	–	9-8-60	11	1.01	9.99	–	–	–	–	8.4×10^{3}	842	–	–	Fair
M3.5RI[2]	–	9-28-60	12	0.60	5.56	–	–	–	–	3.1×10^{4}	5,570	–	–	Fair
M4.5RI[2]	–	9-28-60	6	0.64	5.84	–	–	–	–	2.2×10^{4}	3,770	–	–	Fair

[2] Refers to mile post numbers east of Nevada-Utah boundary along U. S. Highway 40. Tests were by Utah State Univ.

coincide with the areas of highest KCl and $MgCl_2$ concentrations as shown in figures 15 and 16.

Storage coefficients range from 0.119 to 0.00005, indicating that aquifer conditions range from unconfined to well confined, mostly unconfined to semiconfined. The variation is not systematic.

Vertical distribution of hydraulic conductivity was estimated by bailer tests during the summer of 1966. Permeable zones up to 2 feet thick were tested at depths of 5 to 18 feet during the sinking of nonperforated casings. Hydraulic conductivity ranged from 52 gpd/ft^2 to 409 gpd/ft^2, with the highest conductivities found in the upper 10 feet of sediments (Davis, 1967). Inasmuch as this gives transmissivity values far lower than those measured in 1965 (figure 13), Davis believes that as much as 70 percent of the transmissivity in areas of thick salt crust may be the result of brine flowing through the highly permeable salt.

Little brine is obtained from depths greater than 10 feet in two pairs of wells tested by the author. Table 10 shows the results of selected aquifer tests. Field data are presented in Appendix C and figures 17 and 18 illustrate the analyses of the data.

Brine Level

Three wells were dug in 1965 and provided with brine level recorders. Figure 19 illustrates the seasonal brine level changes measured from 1965 to 1968 to show the influence of brine production and recharge. Both 1966 and 1967 were relatively wet years.

Shallow Brine Characteristics

Chemical Composition

As shown on figure 20, the dissolved constituents of the brine are mostly sodium and chloride. Table 11 lists analyses of samples from 13 wells. Samples 1 through 8 were collected in 1965 and the other five in 1967. Each well was pumped a minimum of 10 minutes before a sample was taken. Two composite samples of the Bonneville brine analyzed by Polzer and Roberson (1967, p. 116) and by Whitehead and Feth (1961, table 1) are also included in table 11. Additional, less complete analyses of the brine are presented in Appendix D.

General distribution of KCl and $MgCl_2$ in the brine of the playa sediments is shown in figures 15 and 16. Data from the maps were analyses of samples collected from 1965 to 1967 (Appendix D). Only the maximum concentration measured at each point during the period of sampling was used to minimize the number of anomalously low values caused by rainfall dilution.

The isocons are approximately parallel with the original border of the salt crust as measured by Nolan (1927), which suggests that the brine quality was initially influenced by the position of the salt crust. The KCl and the $MgCl_2$ concentrations tend to increase toward the center of the salt crust, except in the area southwest of Salduro where brine has been mined for many years. Davis (1966, p. 18) suggests that the solution of the salt crust has maintained the NaCl content while the underlying KCl-rich brine has

Table 10. Results of selective aquifer tests on the shallow aquifer, 1967 (field data are listed in Appendix C).

Well no.	Date	Depth of well (ft)	Static water depth (ft)	Initial saturated thickness (ft)	Distance to observation well (ft)	Average pumping rate (gpm)	Pumping duration (min)	Transmissivity (gpd/ft)	Storage coefficient
K69-A	9-11-67	10.2	10.95[1]	3.35	measurements in pumped well	10.7	160	2,200	–
K69	9-12-67	21.0	7.43	13.50	measurements in pumped well	17.4	240	1,700	–
K70	9-2-67	10.3	6.20	4.10	–	20.0	210	–	–
K70-A	–	10.3	6.49	3.81	30.0	–	–	40,900	0.018
K70	9-3-67	15.0	6.40	8.60	–	20.0	119	–	–
K70-A	–	15.0	6.59	8.41	30.0	–	–	41,700	0.015
K70	9-5-67	21.0	–	–	–	21.0	420	–	–
K70-A	–	21.0	6.73	14.27	30.0	–	–	37,000	0.022

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[1] Measuring point was 4.1 ft above ground level.

Table 11. Composition of brines in near-surface sediments (reprinted from Turk and others, 1973).

Sample no.[1]	Source	Constituents in milligrams per liter[2]											
		Ca	Mg	Na	Li	K	SO_4	Cl	Br	B	SiO_2	Sr	HCO_3
1	K4	1,200	1,900	81,500	36	5,800	3,900	153,500	40	3	–	–	–
2	K4	1,100	3,600	70,300	15	7,900	5,600	143,200	40	5	–	–	–
3	K24	1,300	1,000	83,900	19	4,300	5,400	155,600	20	3	–	–	–
4	K34	1,300	1,000	82,200	29	4,900	3,500	156,500	40	5	–	–	–
5	K33	1,000	2,300	80,800	41	7,200	4,100	158,800	40	6	–	–	–
6	K52	1,100	700	87,400	17	3,300	3,600	159,500	50	4	–	–	–
7	K58	1,300	1,700	75,000	34	6,000	4,500	149,000	40	4	–	–	–
8	K63-A	1,100	1,100	44,500	25	4,400	4,000	78,600	40	4	–	–	–
9	K29	1,500	3,100	88,300	29	4,200	3,800	156,900	–	–	–	–	–
10[3]	K22	1,200	2,100	81,000	22	3,200	4,000	148,900	–	–	–	–	–
11[3]	K46	1,400	1,900	78,200	24	3,600	4,500	142,400	–	–	–	–	–
12	K48	900	500	45,400	22	2,800	3,200	74,700	–	–	–	–	–
13	K53	1,500	2,200	58,500	29	3,300	6,100	101,900	–	–	–	–	–
14[4]	Surface brine	1,130	1,430	96,800	41	2,660	3,680	159,000	–	–	10	57	42
15[5]	Surface brine	1,770	1,360	96,200	18	2,930	3,770	156,000	35	4.2	7.4	–	40

[1] Sample localities shown on figure 2.

[2] Analyses by Kaiser Chemicals, Division of Kaiser Aluminum and Chemical Corp., San Leandro, California, except nos. 14 and 15.

[3] Insoluble clay in sample bottle.

[4] Composite sample of surface brine; analysis by Polzer and Roberson (1967, p. 116); pH at 25° C = 7.1; density at 20° C = 1.203 gm/cm^3.

[5] Brine beside U. S. Highway 40, collected 4-6-58; analysis reported by Whitehead and Feth (1961, table 1); additional determinations: CO_3 = 0 mg/l; NO_3 = 4.8 mg/l; undetectable amounts of Fe, Mn, As, PO_4; Al = 1.8 mg/l; F = 1.3 mg/l; pH = 7.1; density at 20° C = 1.201 gm/cm^3.

been removed. The highest concentrations of KCl and $MgCl_2$ are in the southeast part of the salt crust where no brine has been produced to deplete the reserves.

The KCl content of the brine varies widely with the season, as shown in figure 21. The three curves represent brine concentrations at three pumping stations along the transfer ditches during the 1967 producing season. The initial low concentration was the result of dilution by heavy spring rainfall.

Temperature

Temperature of shallow brine measured during pumping tests in 1967 ranged from 56° to 77° F; all temperatures are above the mean annual surface temperature of 52° (figure 12). From June to September the temperature of the brine in the wells increased an average of 5° F and was probably the result of solar heating.

Origin

Nolan (1927, p. 40-42) believed that the dissolved constituents in the shallow brine were derived from two sources–those brought in by inward-draining waters and those dissolved from the clay, with those dissolved from clay being the more important source. Jones (1966, p. 198) concluded that high percentages of chloride salts indicate a drainage area of sedimentary rocks of marine origin. Feth (1959) postulated that the bedded evaporites deposited in pre-Lake Bonneville time contributed most of the salt load to the Bonneville Basin.

With the exception of sulfate, ratios of the various constituents are nearly identical in the different brines. The lower ratio of $SO_4^=$ in the shallow brine may be explained by the crystallization of gypsum in the near-surface sediments.

Recharge

Recharge is largely from local rainfall. Winter ponding of surface water and overland flow into the collection ditches may supply significant additional recharge during wet years. Hydrographs of observation wells indicated that rainfall in excess of 0.1 inch in summer and 0.05 inch in winter contributes to recharge in the area of thick salt crust (figure 22; Davis, 1967, p. 12).

SIMULATION OF THE SHALLOW AQUIFER SYSTEM BY DIGITAL COMPUTER

Purpose

Once a potential ore body is delineated and variations in its grade are studied systematically, the problem remains of determining the optimum *rate* at which the ore should be extracted. Inasmuch as the Bonneville brine is replaced in part by fresh water as the brine is harvested, grade of the ore declines with time. A planner needs to know what the approximate chemical concentration of the brine will be 10, 20 or even 50 years hence, if he is to make meaningful projections of the size and type of processing plant that will be required to refine the ore.

Various hydrologic parameters of the shallow aquifer system have been described and evaluated earlier in this paper. Such limiting factors as the *quantity* of brine which can be produced from an area, therefore, may be calculated. A simple mathematical formula to predict accurately the inevitable reduction in brine *quality* is unavailable because the expected decline is not a simple linear relationship with time. Additional complexities are introduced by local inhomogeneities in the hydrologic environment, such as lateral changes in hydraulic conductivity and hydraulic gradient.

A model of the hydrologic system was designed to account for most of these variables to predict the quality of the brine at any future time. This dynamic, multivariate digital model can analyze almost any logical combination of values for the various parameters. The FORTRAN program, KCLCON, is presented in Appendix E. The program may be of use in other studies of shallow brine deposits.

Description and Theory of the Model

Figure 23 is a schematic drawing of the model, which includes an approximation of the true flow system and the artificial two-dimensional model used to simulate the system. No scale is intended and the drawing is highly exaggerated vertically.

Theory of the model is based on a law for the flow of fluid through a porous medium, which was first presented by Darcy (1856). Modern statements of the law are:

$$V = -K\frac{\partial h}{\partial l}, \text{ or } Q = -KA\frac{\partial h}{\partial l}$$

where V = Darcy's "velocity," designated *specific discharge* by Davis and DeWiest (1966, p. 158), in units of length per unit time;

K = coefficient of permeability, designated *hydraulic conductivity* by Davis and DeWiest (1966, p. 162), in units of volume per unit time per unit area;

$\partial h/\partial l$ = hydraulic gradient.

The flow chart shown in figure 24 indicates the sequence of calculations performed by the computer. Important concepts of the model are:

1. The two-dimensional flow model is divided into flow "tubes" as shown in figure 23. Rate of groundwater flow is inversely proportional to the width of the flow tube.

2. A certain concentration of a given compound is assigned to each of the many discrete, hypothetical compartments of the flow system. This concentration is the estimated concentration of that compound (KCl, $MgCl_2$, etc.) in the brine before production begins.

3. After the first year's production, assuming that the amount taken from each flow "tube" is equal, the portion of each tube that is farthest from the ditch is diluted by fresh water. During the second year this slug of diluted brine moves along the tube into the next compartment where it becomes re-enriched by combining with the heretofore undiluted brine of that compartment. Meanwhile, brine left in the first compartment is diluted again, then is enriched as it moves from space to space on its journey to the ditch. The longer flow tubes, therefore, will maintain a high brine concentration at the ditch face longer than the shorter flow tubes.

4. Brine reaching the ditch each year will have a concentration equal to the average concentration of the several flow tubes.

Input and output formats are illustrated in Appendix E.

Hydrologic Parameters

A small unknown amount of water is lost from the aquifer by direct evaporation from the capillary fringe. Most of the discharge, however, is by artificial withdrawal of brine through the ditch system. The quantity of brine removed by this method can be measured to about 10 percent accuracy with weirs placed at strategic points along the ditches. Therefore the discharge (Q) is a known value. The area (A) of the ditch face is easily calculated. The specific discharge (V) is equal to Q/A.

An average value for hydraulic conductivity may be determined by analysis of a pumping test (Appendix C) or a value may be taken from the map of figure 14. The maximum hydraulic gradient ($\partial h/\partial l$) that can be generated over a certain distance is limited by the depth of the ditch. The lateral area effectively drained by a ditch (line-sink) can be estimated using the formula developed by Hooghoudt (1940) for drain spacings, as shown by Luthin (1966, p. 153):

$$X^2 = \frac{4K\,(H^2 - h^2 + 2dH - 2dh)}{w} \qquad (1)$$

in which X = distance between ditches (length)

K = hydraulic conductivity (length/time)

w = rate of recharge (annual recharge rate in this case; length/time)

H, h and d are defined by figure 25, each in dimensions of length.

For practical purposes the drain is considered empty. Hooghoudt's equation then reduces to:

$$X^2 = \frac{4KH}{w}(2d + H) \qquad (2)$$

Davis (1967, p. 14) used equation (2) to develop the graph shown on figure 26.

For the KCLCON program only the specific discharge (V) and the porosity, both total and effective, are needed. The annual discharge, Q_a, must be used to calculate V, which is then introduced to the computer.

Recharge

The program KCLCON assumes that the aquifer is refilled to the ground surface each year. In practice, wide variations in rainfall, and hence, in amount of recharge, mask changes in brine quality within periods of less than 10 years. Therefore, the decline of the brine quality predicted by the model may not correlate well with field data for short periods. Nevertheless, the model should give reasonably close estimates of the brine grade for longer periods of production if values for the hydrologic variables are chosen carefully.

Chemical Factors

Before the computations begin, an initial concentration of a particular compound (KCl, $MgCl_2$, etc.) is assigned to the brine; the initial concentration is assumed to be constant within the boundaries of the model. After simulated production is initiated, dilution of the brine begins. As rainfall continues to replace the volume emptied by brine removal, the fresh water mixes with brine held in the pores by surface tension. For example, it was shown earlier in this paper that a reasonable value for average porosity of the aquifer is 0.45 and a representative value for specific yield is 0.10; thus, the specific retention is 0.35. In this case the amount of brine available for extraction would be 0.10/0.45 or 2/9 of the total volume of aquifer drained each year.

Thus, as rainfall replaces the produced brine, it combines with the remaining interstitial brine, which it dilutes by a factor of 2/9. The following example demonstrates the type of calculations made by the computer program.

Assuming the values 0.45 and 0.10 for porosity and specific yield, respectively, and an initial KCl concentration of 0.02 (2 percent), the KCl concentration in a given compartment after one year would be:

$$(0.35/0.45 \times 0.02\ \text{KCl}) + (0.10/0.45 \times 0.0\ \text{KCl}) = 0.0155\ \text{KCl} \qquad (3)$$

(interstitial brine) + (rainwater) = (diluted brine)

During the subsequent year dilution in the same compartment would produce the following:

$$(0.35/0.45 \times 0.0155\ \text{KCl}) + (0.10/0.45 \times 0.0\ \text{KCl}) = 0.0121\ \text{KCl} \qquad (4)$$

(interstitial brine) + (rainwater) = (diluted brine)

and so on through the years.

However, as brine moves from the diluted compartment near the surface down into the next compartment along the flow tube, enrichment, rather than dilution, occurs. This reversal is shown by:

$$(0.35/0.45 \times 0.02\ \text{KCl}) + (0.10/0.45 \times 0.0155\ \text{KCl}) = 0.0189\ \text{KCl} \qquad (5)$$

(interstitial brine) + (diluted brine) = (enriched brine)

This new concentration is assigned to the retained brine and so on. Thus, the brine will be enriched in successive years until it is finally discharged to the ditch, and hence a slug of brine in the longer flow tubes has time to recover nearly to its original concentration before entering the ditch. The shorter flow tubes are rapidly depleted of KCl, which causes a sharp drop in the average concentration of brine in the ditches during the first few years of production, but the rate of decline decreases with time (figure 27).

Values for total porosity and specific yield used in the example are representative of the Bonneville aquifer, but the factors are programmed as variables so that any combination of the two could be used for analysis of other hydrologic systems.

Assumptions Inherent in the Model

Several basic conditions must be met before the model can be applied. Certain assumptions are necessary for the use of Darcy's law, while others concern variables in the actual flow system at Bonneville. Essentials of the model are listed below with comments on potential errors that may be introduced by the assumption.

1. Brine flows horizontally toward the ditch and upward flow is limited to a small region near the ditch. (Little error is introduced by this assumption because the thickness of the aquifer is small compared to its lateral extent. Large deviation from horizontal flow may occur near the ditch face because of drawdown in

the ditch, but the effect of drawdown decreases rapidly with distance from the ditch; figure 28.)

2. Flow is laminar and Darcy's law applies. (This is valid with the possible exception of a small area near the ditch where steeper gradients may create a flow velocity high enough to cause turbulence, which would invalidate Darcy's law in that area.)

3. The aquifer is homogeneous and isotropic and hence hydraulic conductivity is constant within the boundaries of the model. (The aquifer is not homogeneous, nor is it isotropic; inasmuch as horizontal permeability, however, is much greater than vertical permeability, the anisotropy of the aquifer does not significantly affect the results because of assumption 1 above. Lateral variations in hydraulic conductivity are averaged out by determining the parameter on a large scale with pumping test analysis rather than by laboratory tests on small disturbed samples.)

4. Flow at the ditch face is equal in each tube. (Given a certain specific discharge, which is calculated using the hydraulic conductivity from pumping test evaluation and the hydraulic gradient determined by measurements in observation wells, total discharge at the ditch face is directly proportional to the number of flow tubes. Various discharge rates thus can be introduced into the model by altering the number of flow tubes.)

5. New water from precipitation each year occupies that volume of pore space near the ground surface which is vacated by the brine as it is removed and the brine level recovers to the ground surface each year. (Annual variations in rainfall cause this to be the most seriously limiting factor in the model and prevent its use on a short-term basis. Comparison of real values of concentration from a 5-year period with values predicted by the model likely will reveal large discrepancies. If actual brine qualities are plotted over a longer time span, perhaps greater than 10 years, the theoretical and actual brine qualities will be more nearly the same.)

6. The mixing of brine is complete, that is, pure water added by precipitation enters the sediments and chemically equilibrates with the brine held as specific retention. Therefore, if the total saturated porosity is 0.45 and the specific yield is 0.10, the dilution factor is 0.10/0.45 or 2/9. (This is probably a good assumption because fluid moves through the aquifer slowly and should have time to diffuse and mix with the retained brine.)

7. A certain component of brine flow may be added by artesian and/or osmotic flow from below the shallow aquifer. A fixed number of flow tubes may be added to account for such flow (figure 27), but no dilution of the deeper brine is assumed. (Inasmuch as the vertical permeability is low and vertical hydraulic gradients are small, the amount of brine added by vertical flow is most likely small.)

8. Annual brine production from wells and ditches is constant for the period analyzed. (This factor depends entirely upon management of the brine system.)

Results of the Analysis

Predicted Rates of Decline of Brine Quality

Figures 27, 29 and 30 illustrate the decline of brine quality with time. Additional diagrams are presented in Appendix E.

In each of the cases shown, the specific discharge was held at 700 feet per year, which is somewhat higher than the average velocity estimated by Davis (1967, p. 23). He calculated that velocities north of U. S. Highway 80 averaged 92 feet per year and south of the highway up to 324 feet per year. The higher values were chosen because the brine quality declines more rapidly as the specific discharge increases. Thus the analyses of figures 27, 29 and 30 should be conservative.

In every case brine grade declines sharply, on the order of 0.2 percent, during the first 10 years, followed by a gradual decline throughout the remaining productive life of the deposit.

Predicted Life of the Brine Supply

It is apparent from the diagrams that if the initial concentration of KCl (or $MgCl_2$) was at least 1.0 percent and if average specific discharge is below 700 feet per year, the brine grade will remain above 0.5 percent for at least 40 years. Inasmuch as production of the brine in some areas has been in progress for many years, it is important to know approximately at which year to enter the graphs.

Suggested Method for Extending Life of the Supply

If brine from the deep wells were used to recharge the shallow aquifer instead of rainwater, equation (3) would read:

$$(0.35/0.45 \times 0.02 \text{ KCl}) + (0.10/0.45 \times 0.004 \text{ KCl}) = 0.0173 \text{ KCl} \qquad (6)$$

(interstitial brine) + (deep brine) = (diluted brine) and the actual dilution would be only about 60 percent as great as for fresh rainwater. Moreover, if all the other factors remained the same, the life of the project could be extended some 30 to 40 percent.

Validity of the Analysis

Although the model appears to define the flow system adequately for its expressed purpose, the true test will come as production progresses. An idea of its validity may be gained by a re-examination of figure 15. Notice the area of lowered brine quality which has slightly less than 1.0 percent KCl. If the depleted area once held brine of 2.0 percent KCl, the reasons the grade is lower than the graphs predict after somewhat more than 30 years of erratic production are: (1) the production rate in this area commonly has been higher than the rate assumed in the analysis; (2) ditch spacing is closer than in other areas of the map; and (3) the hydraulic conductivity, and thus the specific discharge, is highest in this area. Also, the average concentration of KCl in the brine may have been somewhat less than 2.0 percent.

In any case it appears relatively certain that current production rates can be maintained for the next 25 to 40 years before the average brine grade declines to 0.5 percent KCl, which is the approximate lower limit at which the brine can be produced economically.

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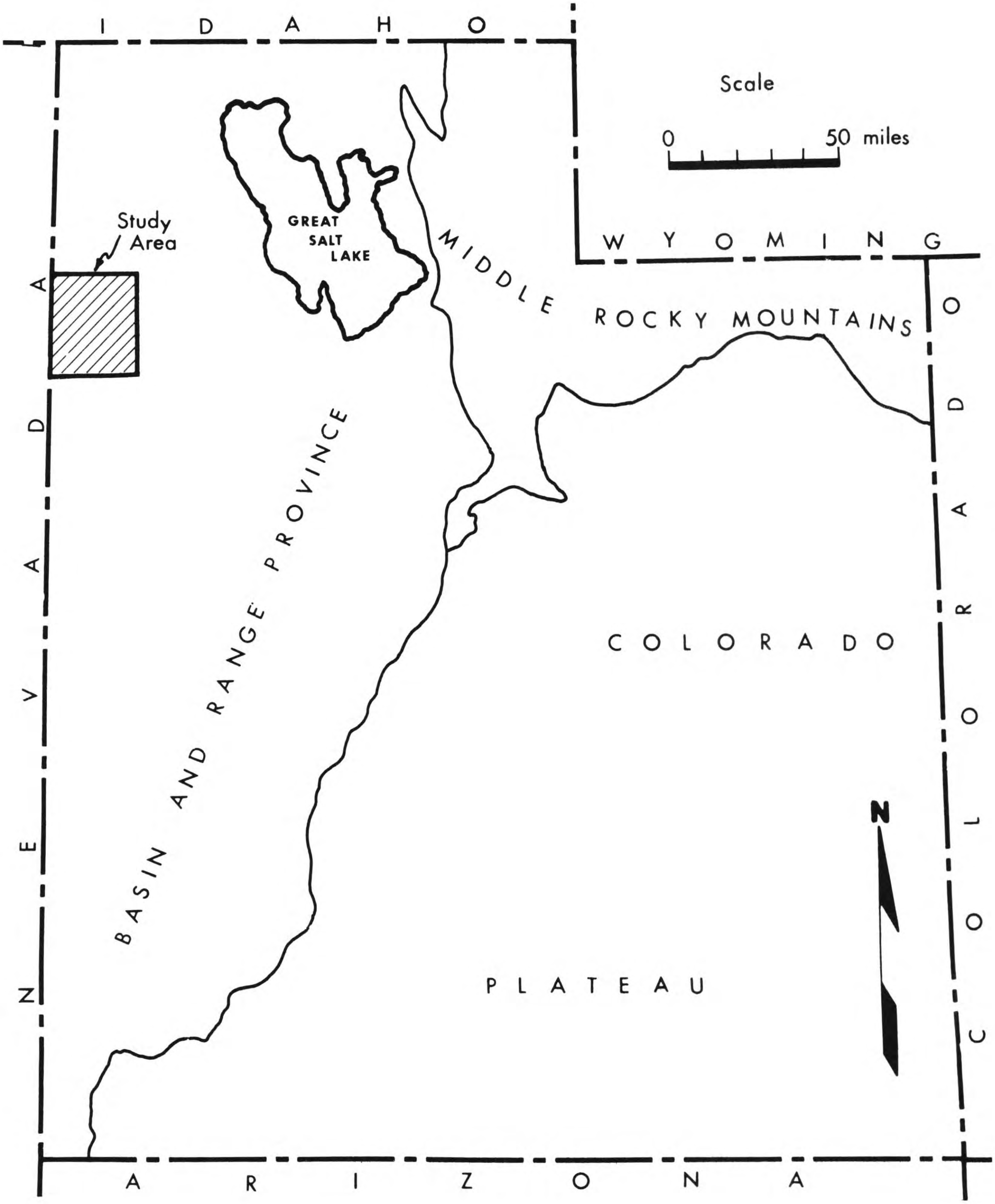


Figure 1. Map of Utah showing physiographic divisions and study area.

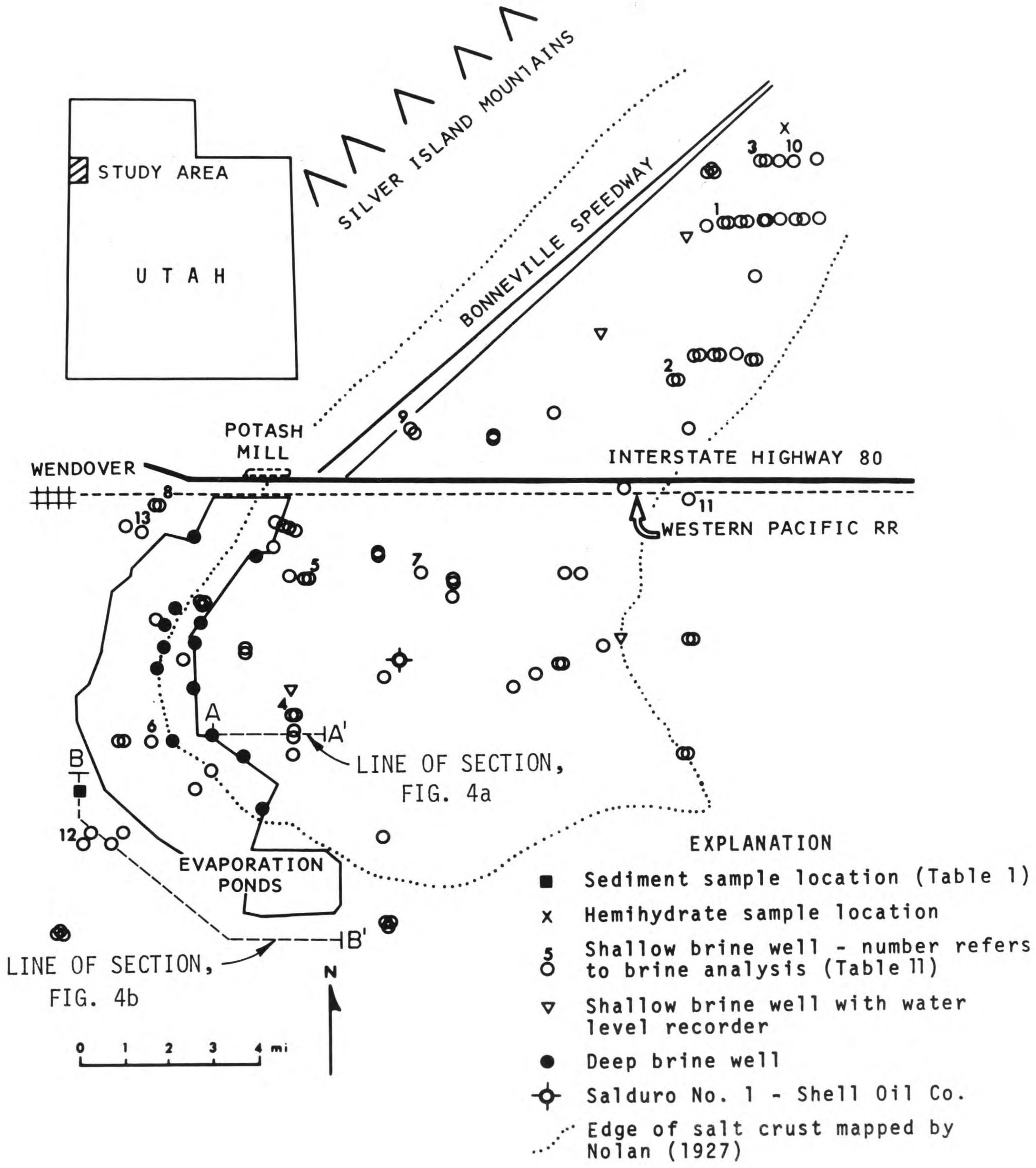


Figure 2. Index map, Bonneville Salt Flats.

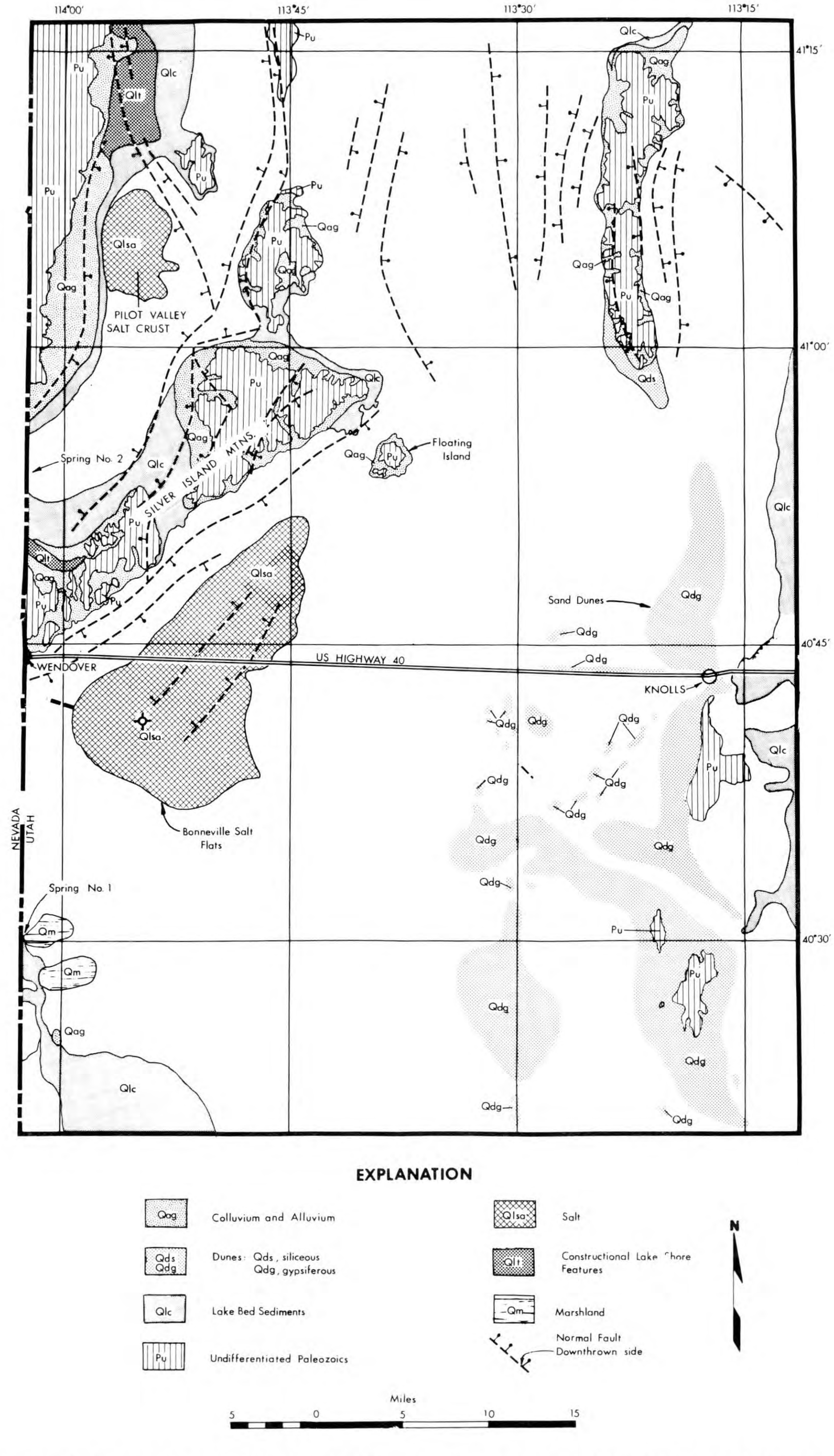


Figure 3. Generalized geologic map of part of the Great Salt Lake Desert (modified from Stokes, 1963, with data from Cook and others, 1964).

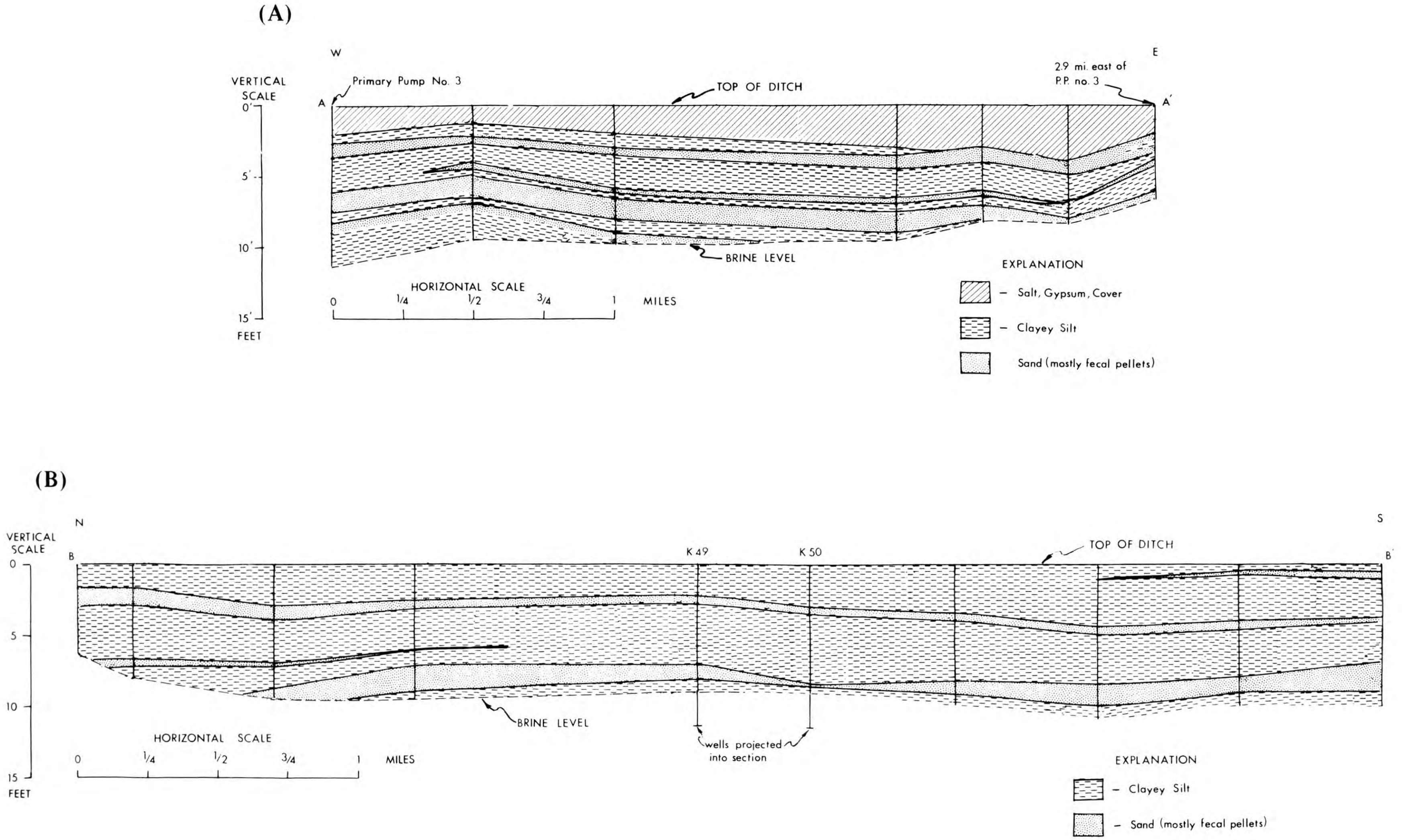


Figure 4. (A) Cross section of shallow sediments exposed in ditch face near Primary Pump No. 3. (B) Cross section of shallow sediments exposed in ditch face near Primary Pump No. 4. (Data collected by C. P. Bingham; see figure 2 for line of section.)

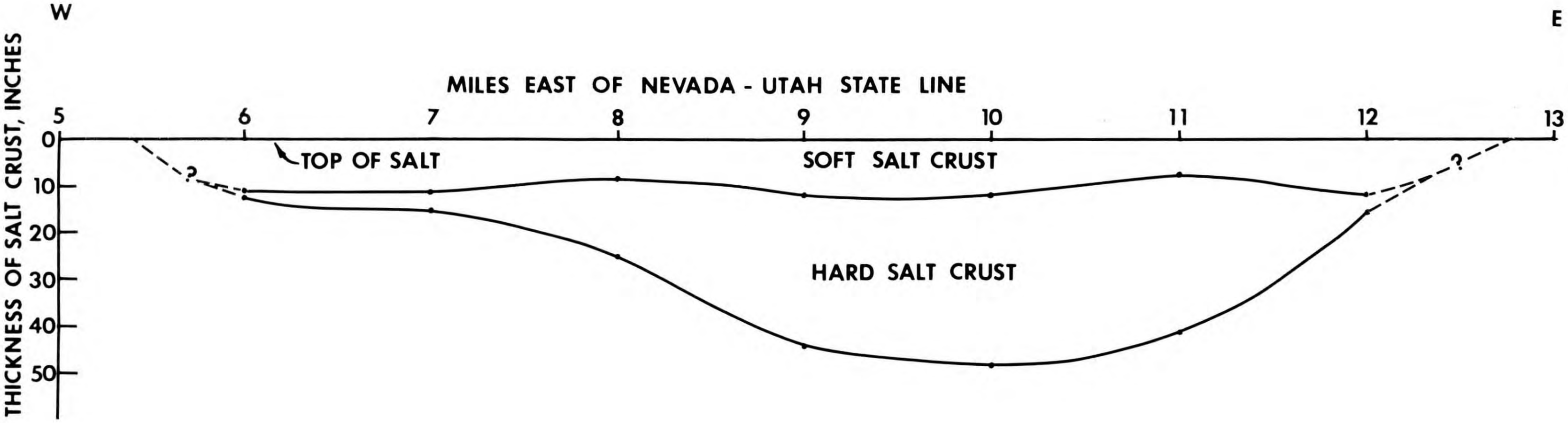


Figure 5. Cross section of the salt crust (data from Christiansen and others, 1962).

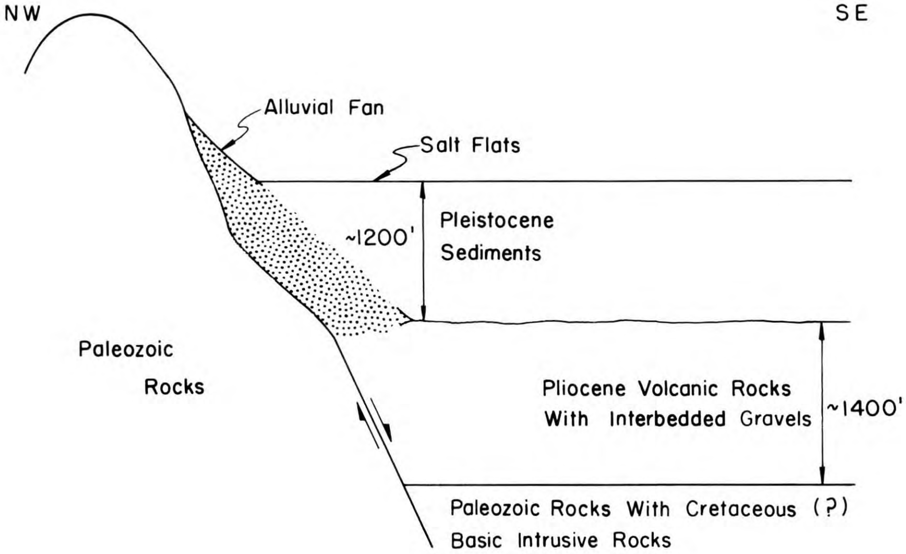


Figure 6. Schematic cross section, west margin of salt flats (no scale intended).

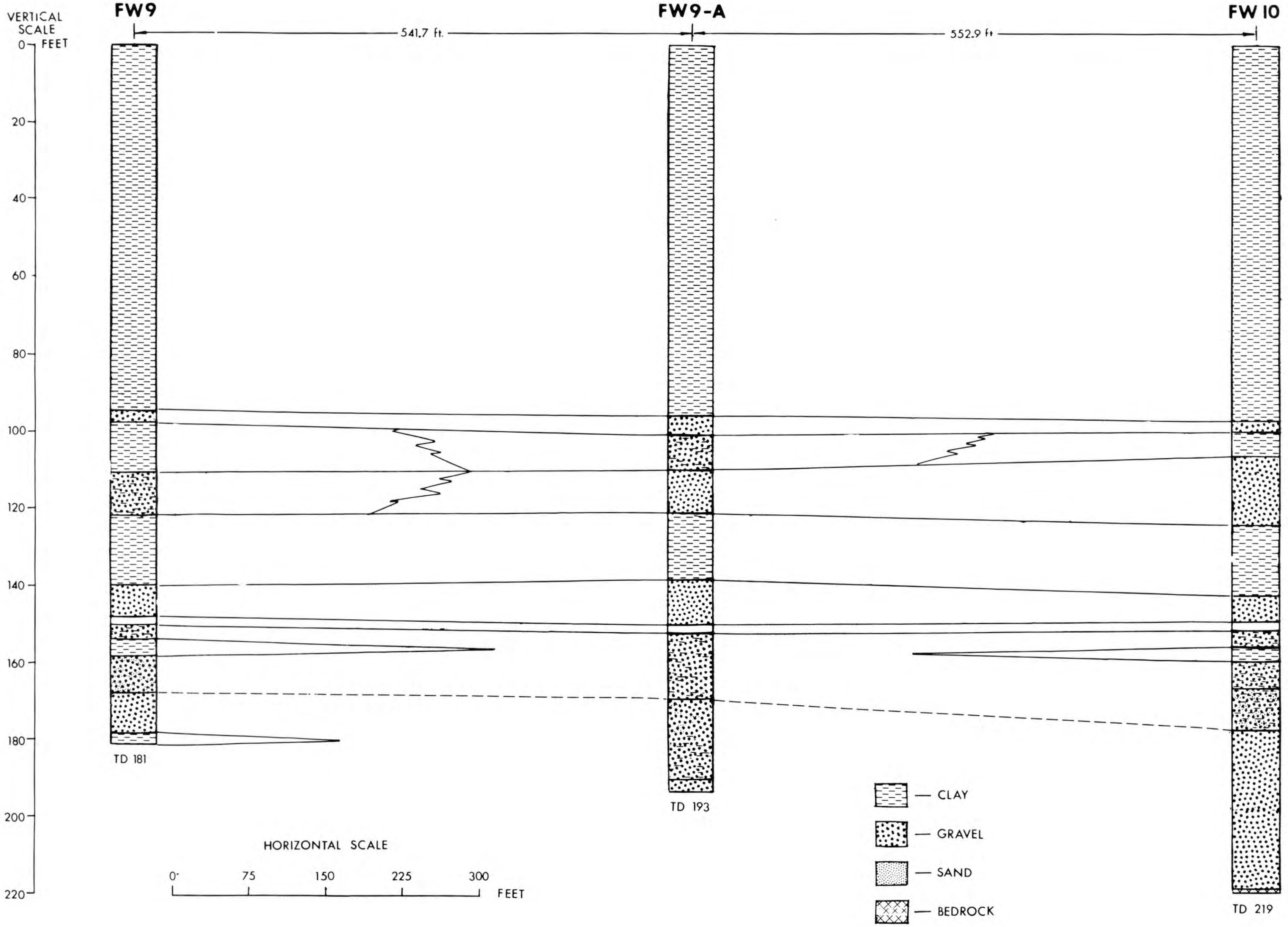


Figure 7. Cross section of alluvial fan aquifer, FW9 to FW10.

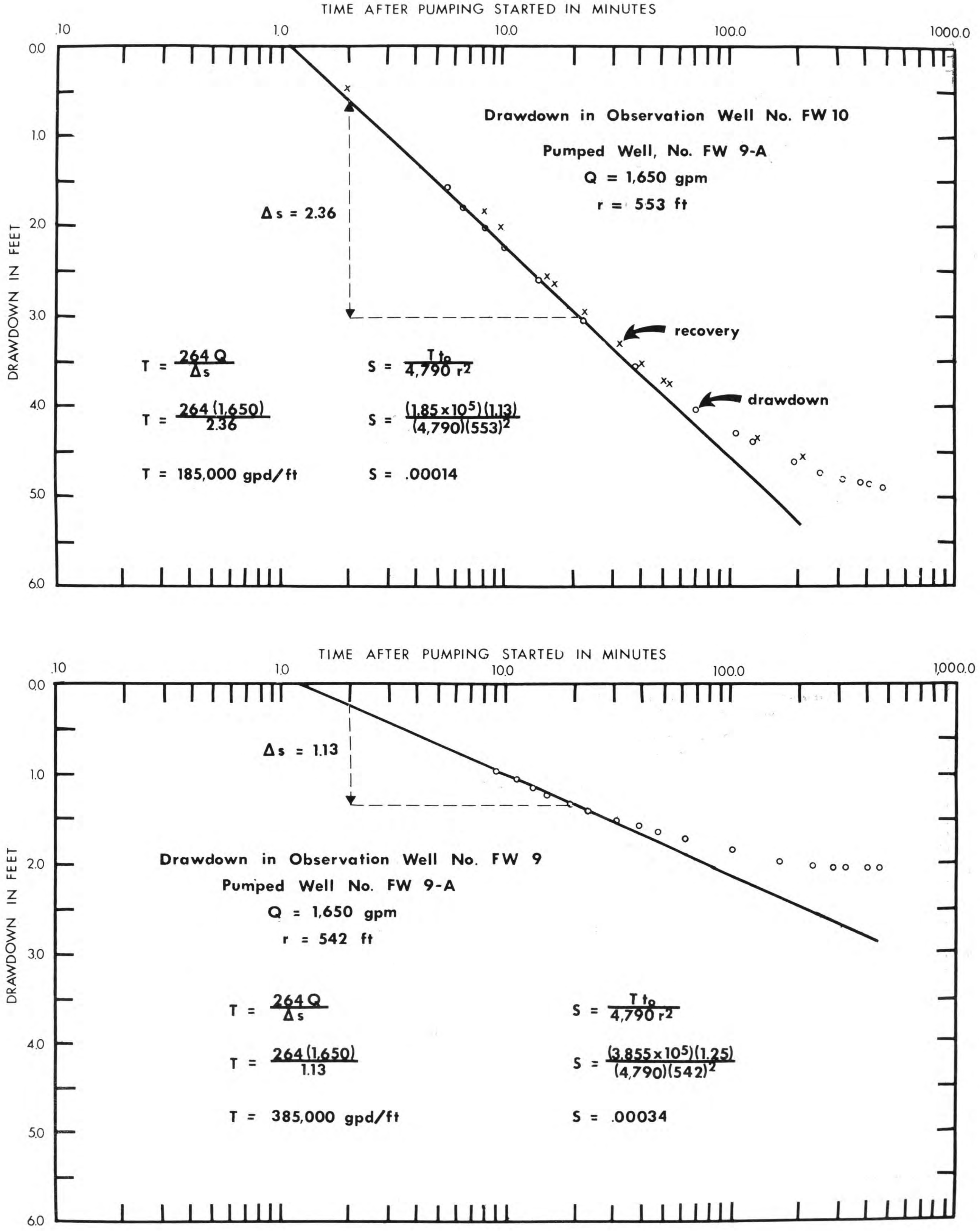


Figure 8. Analysis of pumping test on alluvial fan aquifer, 1966.

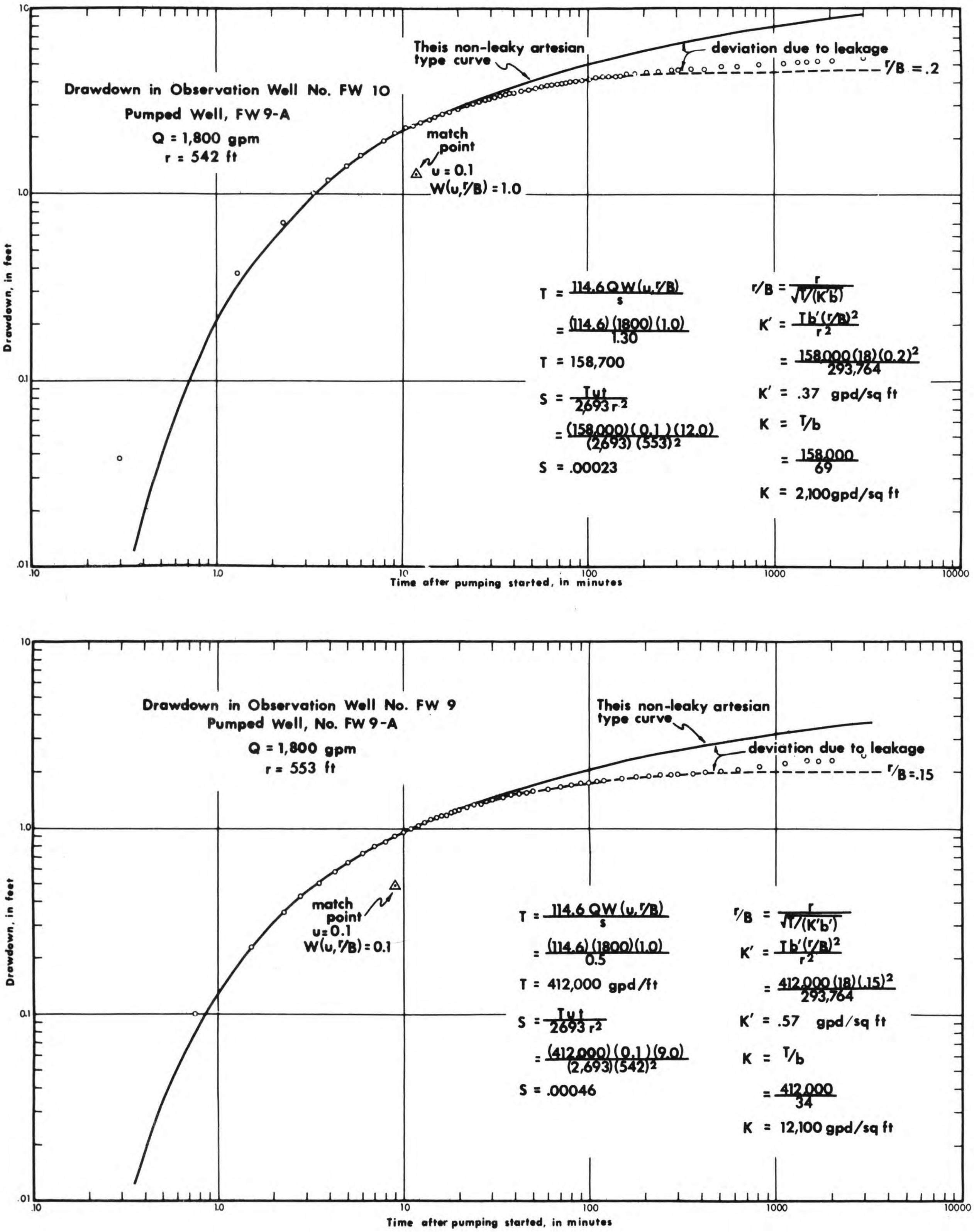


Figure 9. Leaky aquifer analysis of pumping test on alluvial fan aquifer, 1967.

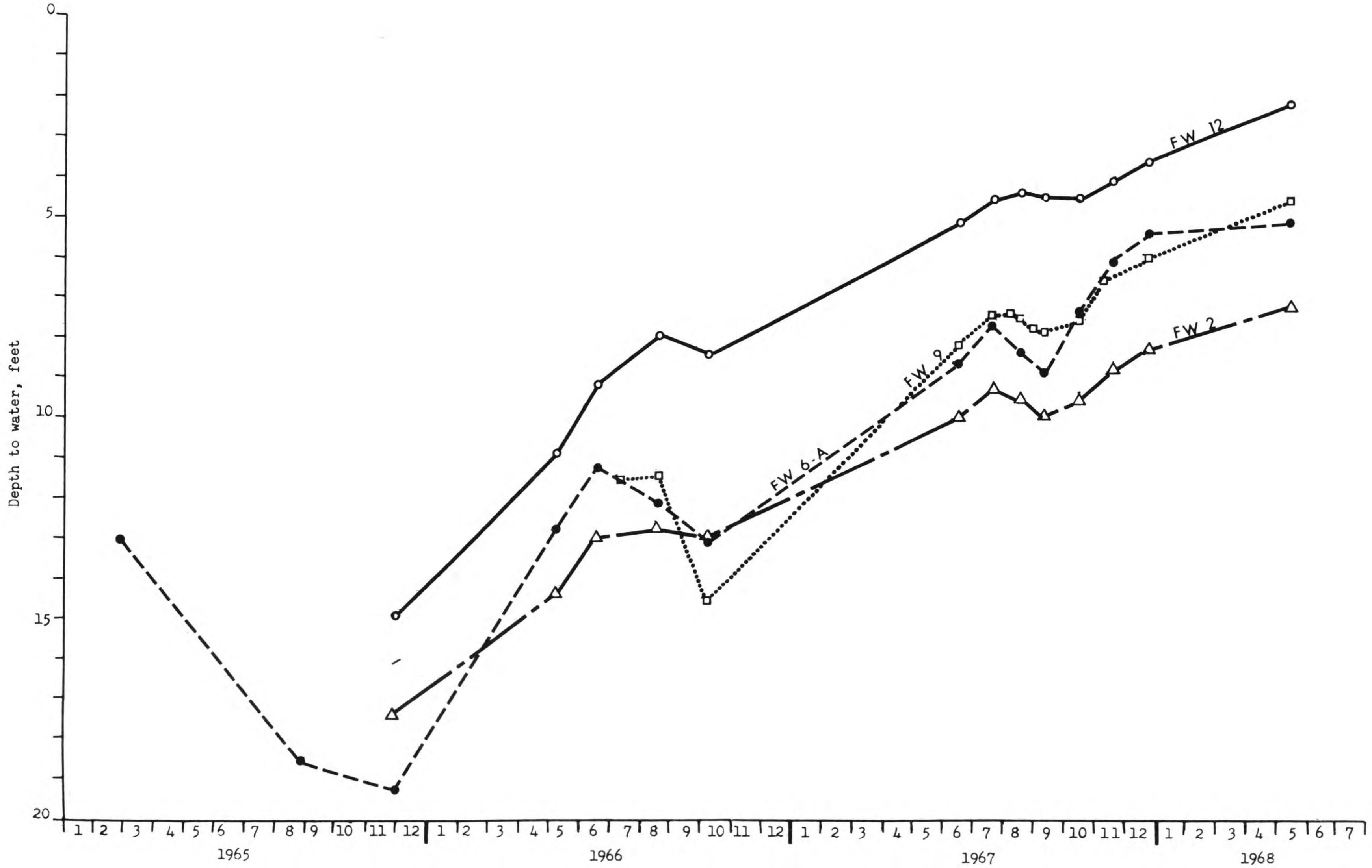


Figure 10. Hydrographs of selected brackish water wells, 1965 to 1968.

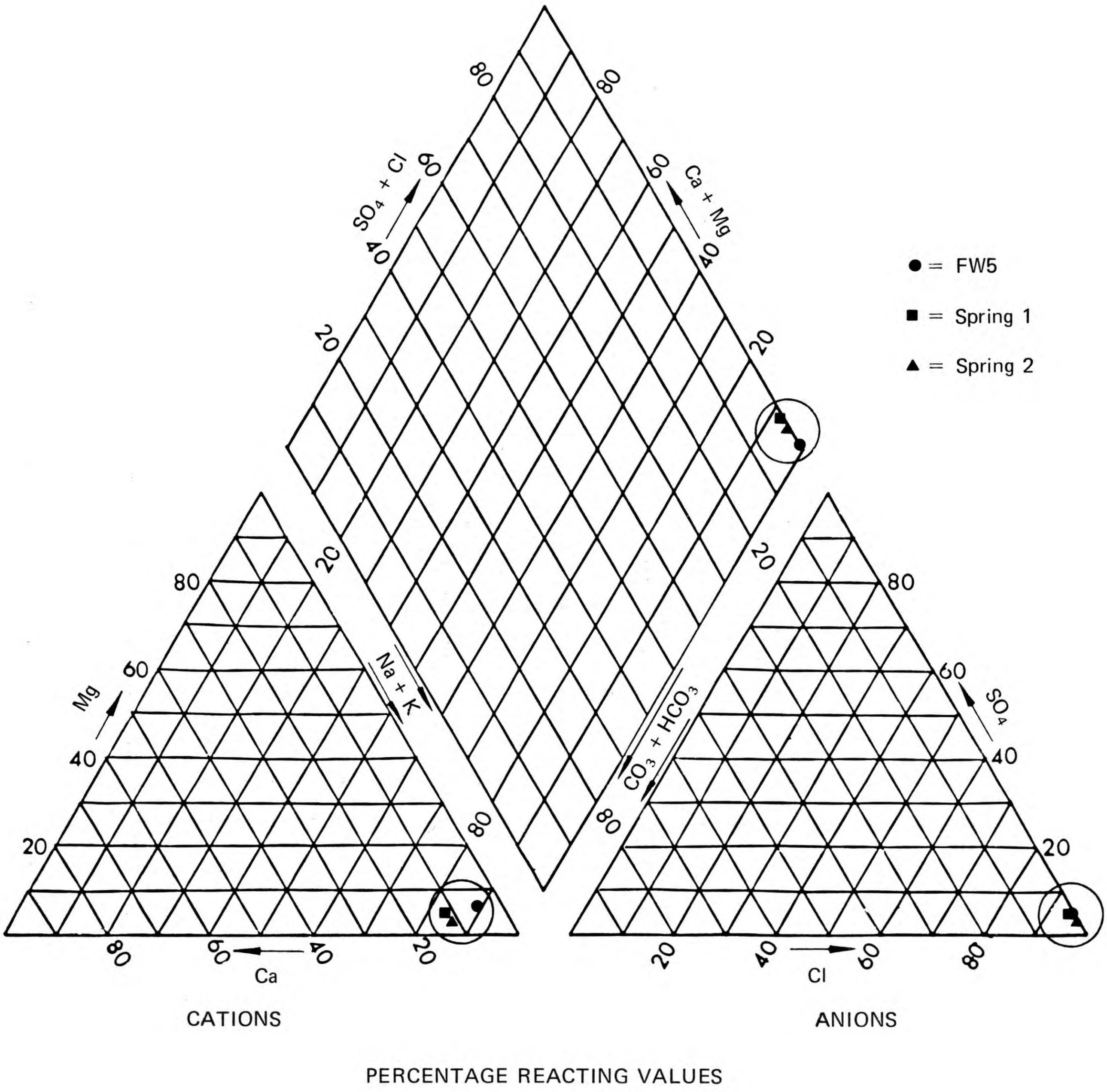


Figure 11. Trilinear diagram showing composition of spring water and brackish water from alluvial fan.

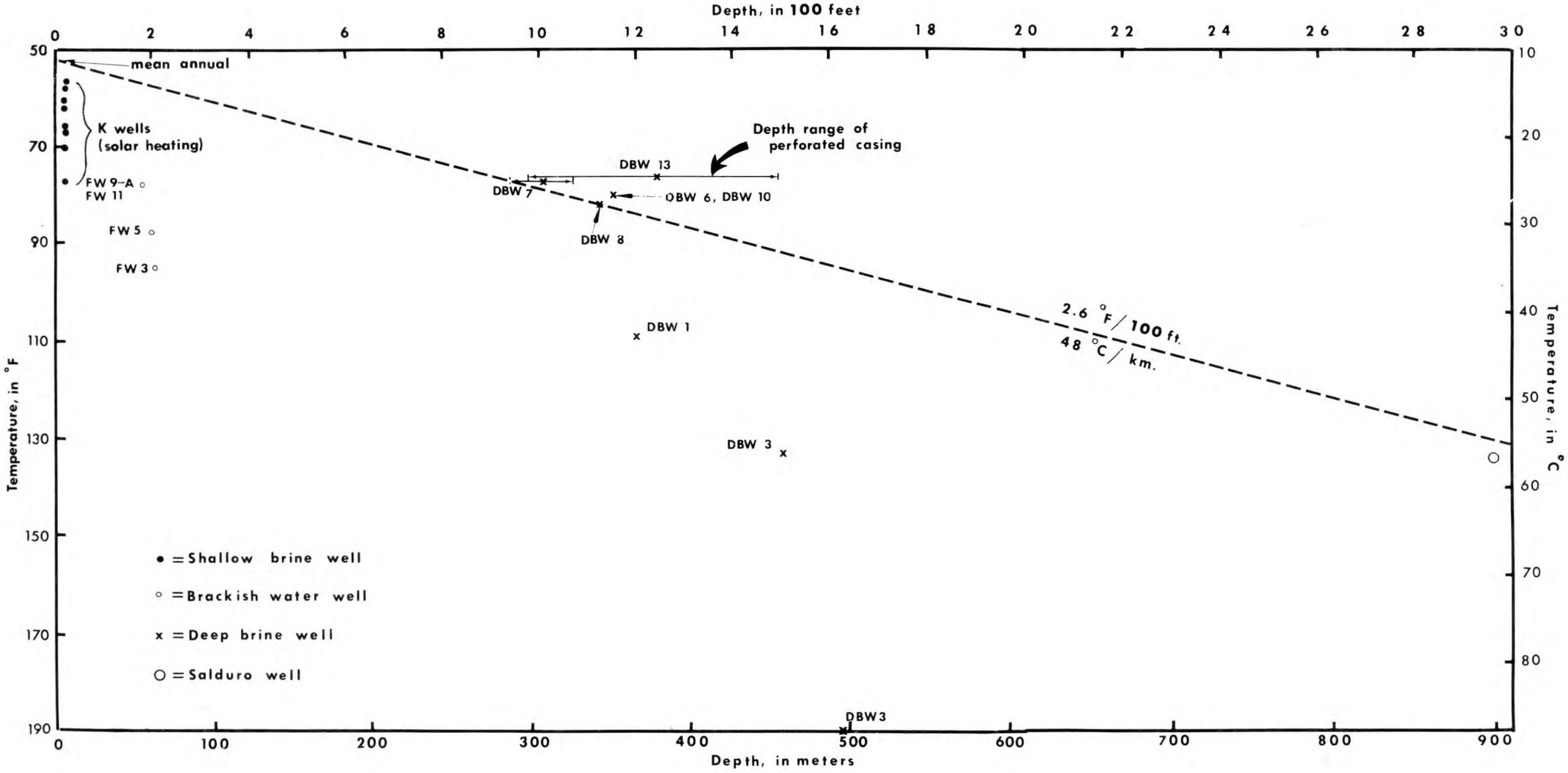


Figure 12. Depth-temperature profile, Bonneville Salt Flats.

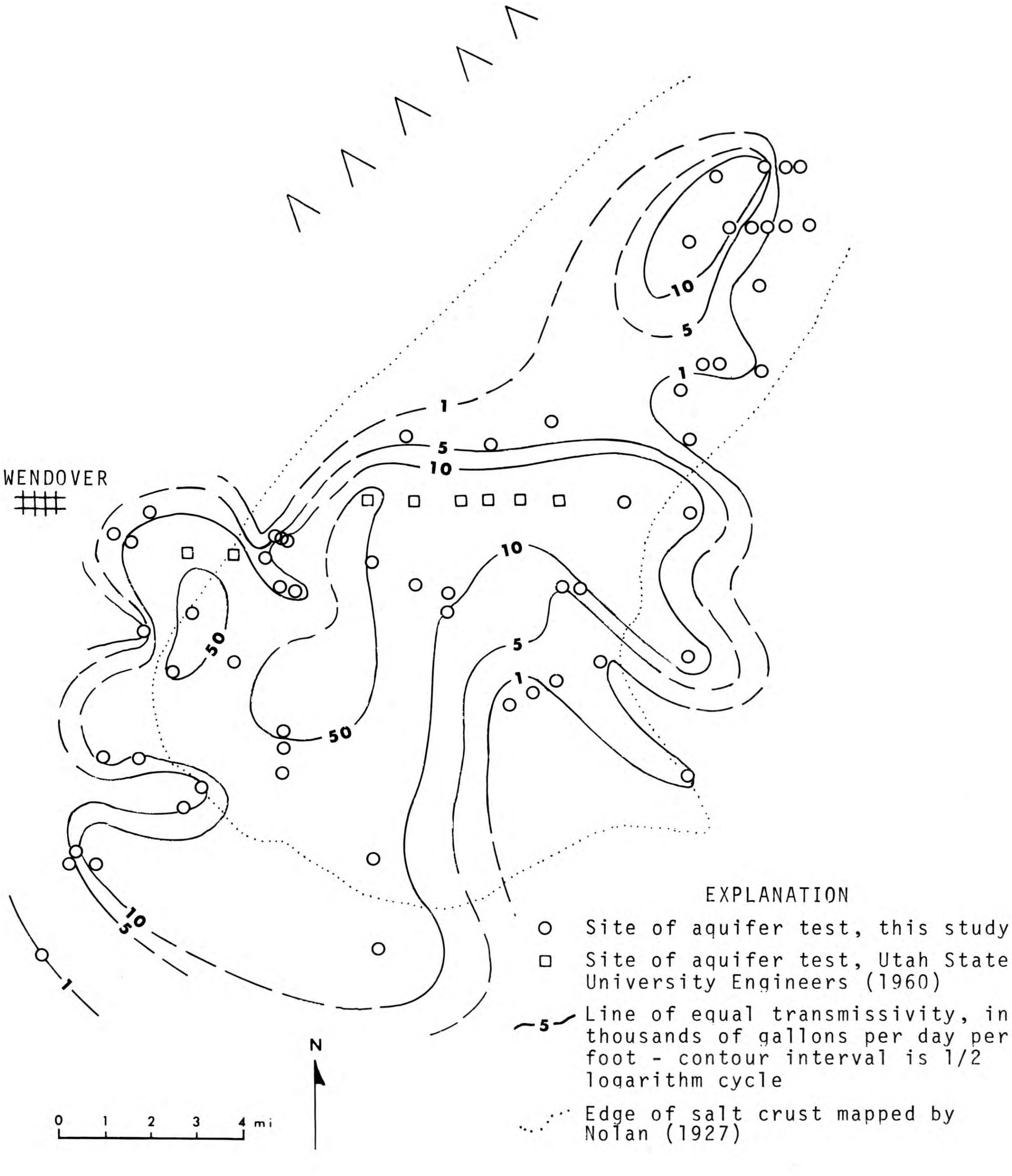


Figure 13. Transmissivity map, Bonneville Salt Flats (reprinted from Turk and others, 1973).

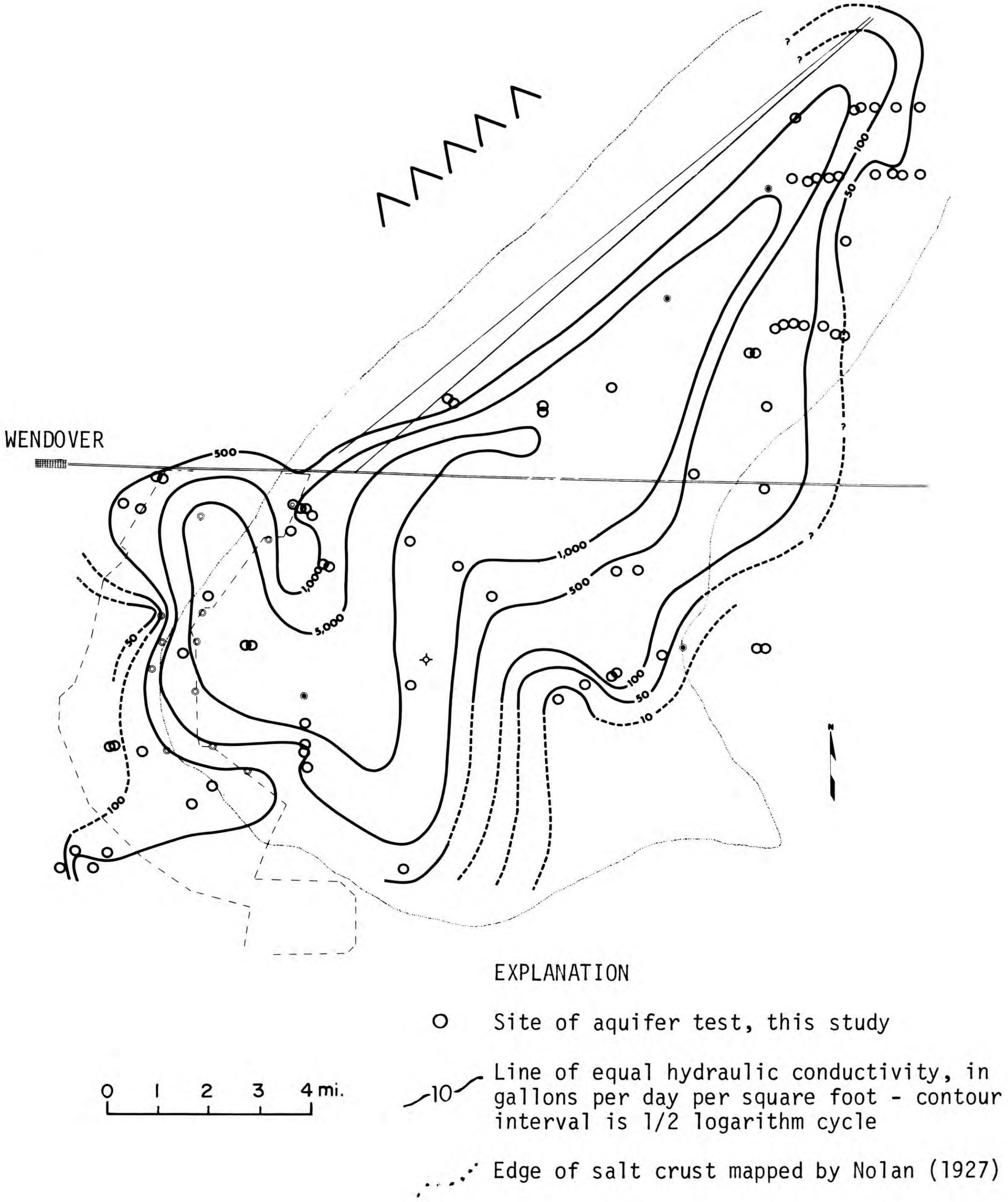


Figure 14. Hydraulic conductivity map, Bonneville Salt Flats.

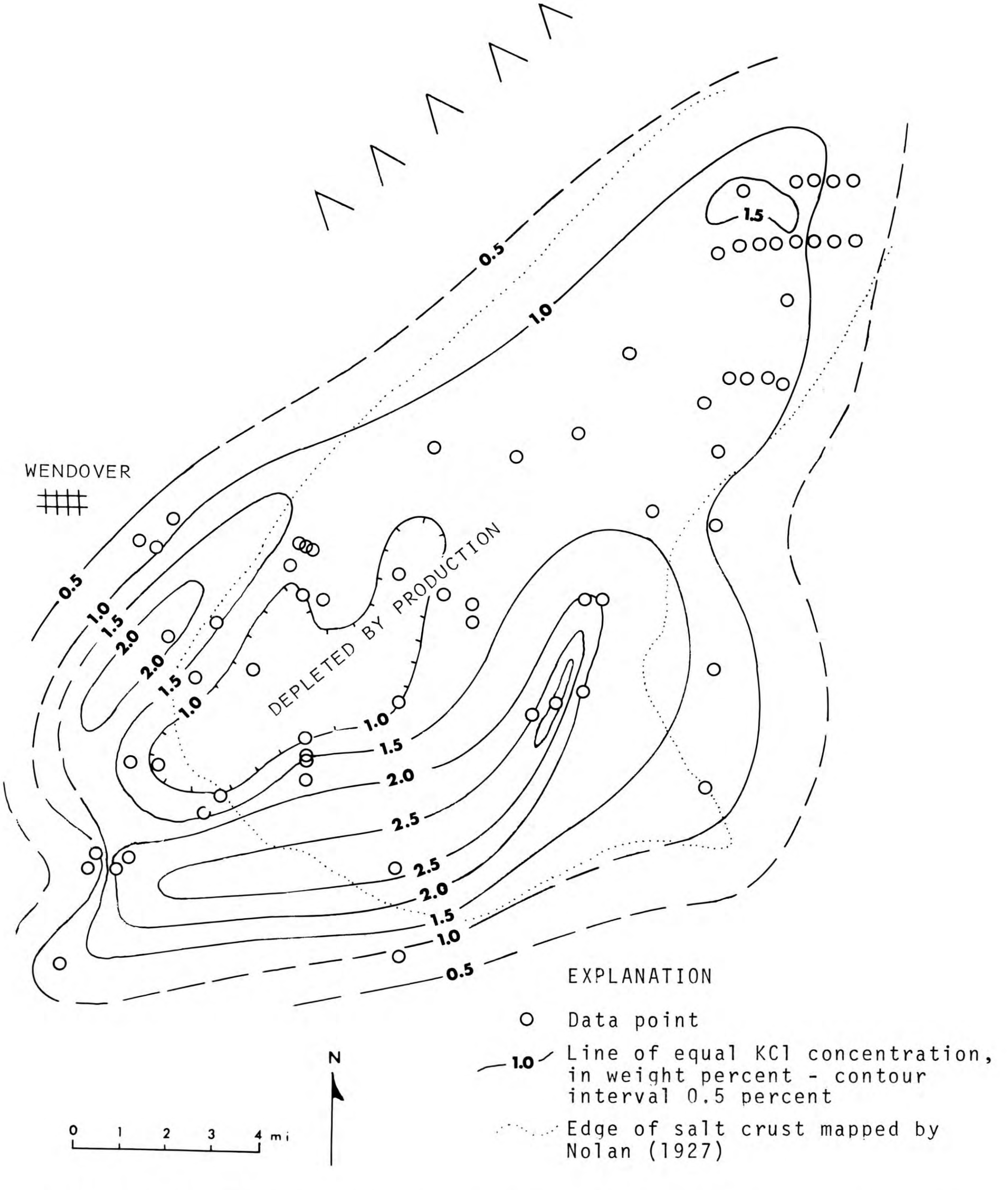


Figure 15. Maximum KCl concentration during 1965 to 1967, Bonneville Salt Flats (reprinted from Turk and others, 1973).

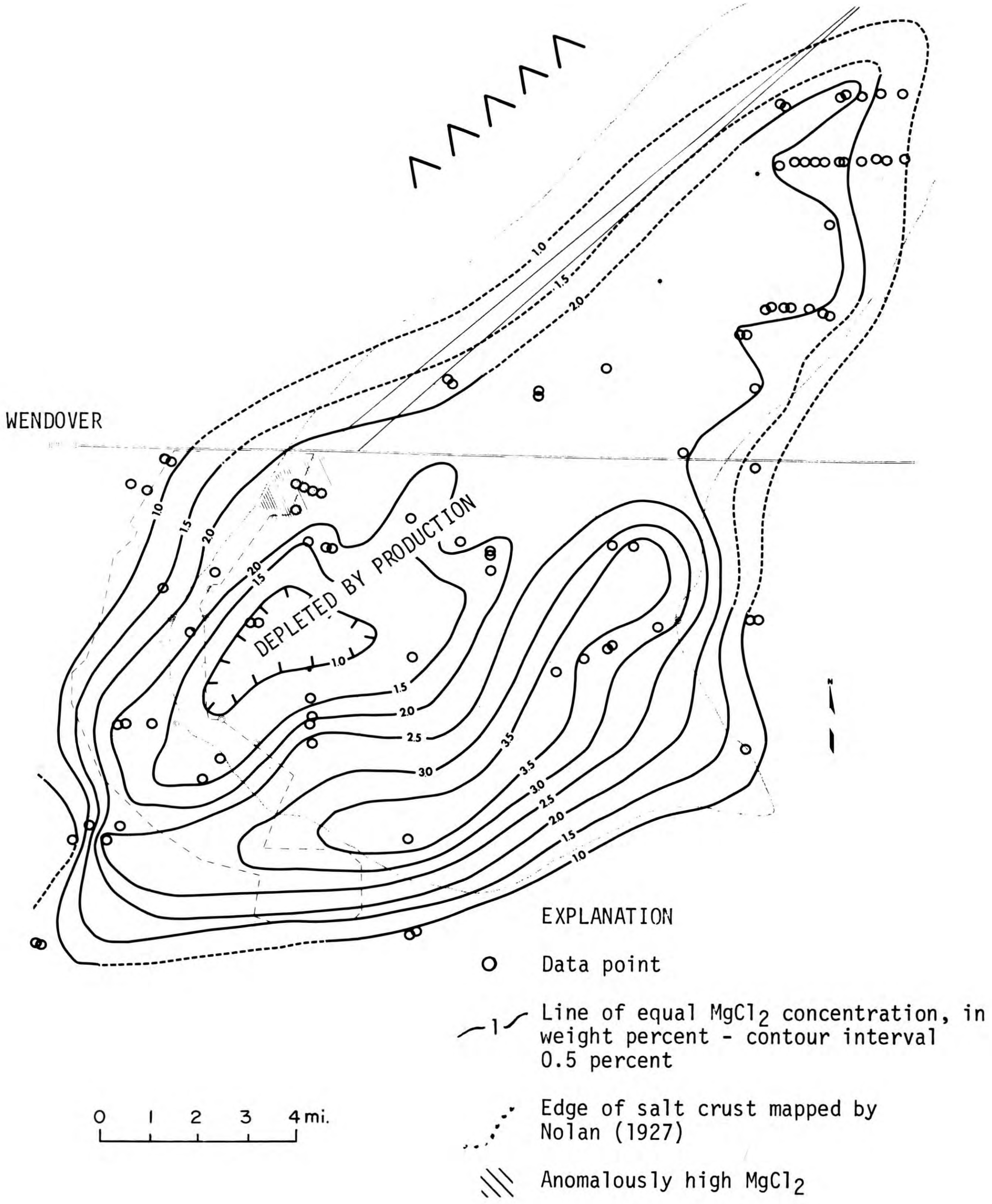
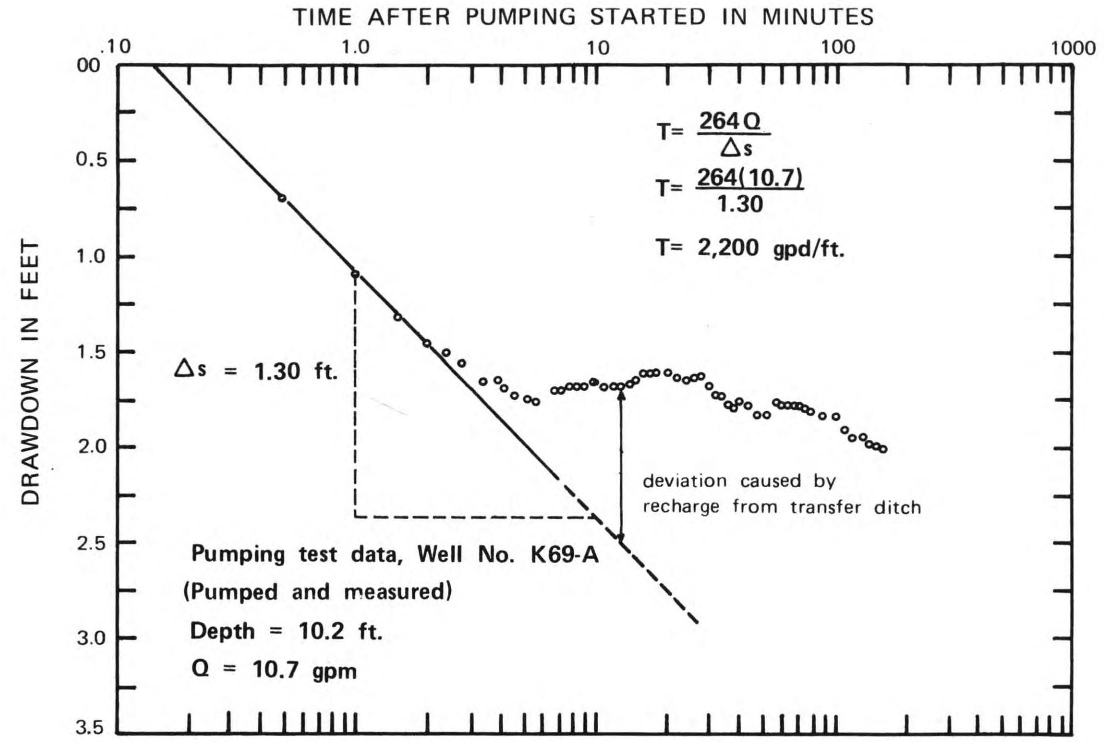


Figure 16. Maximum $MgCl_2$ concentration during 1965 to 1967, Bonneville Salt Flats.



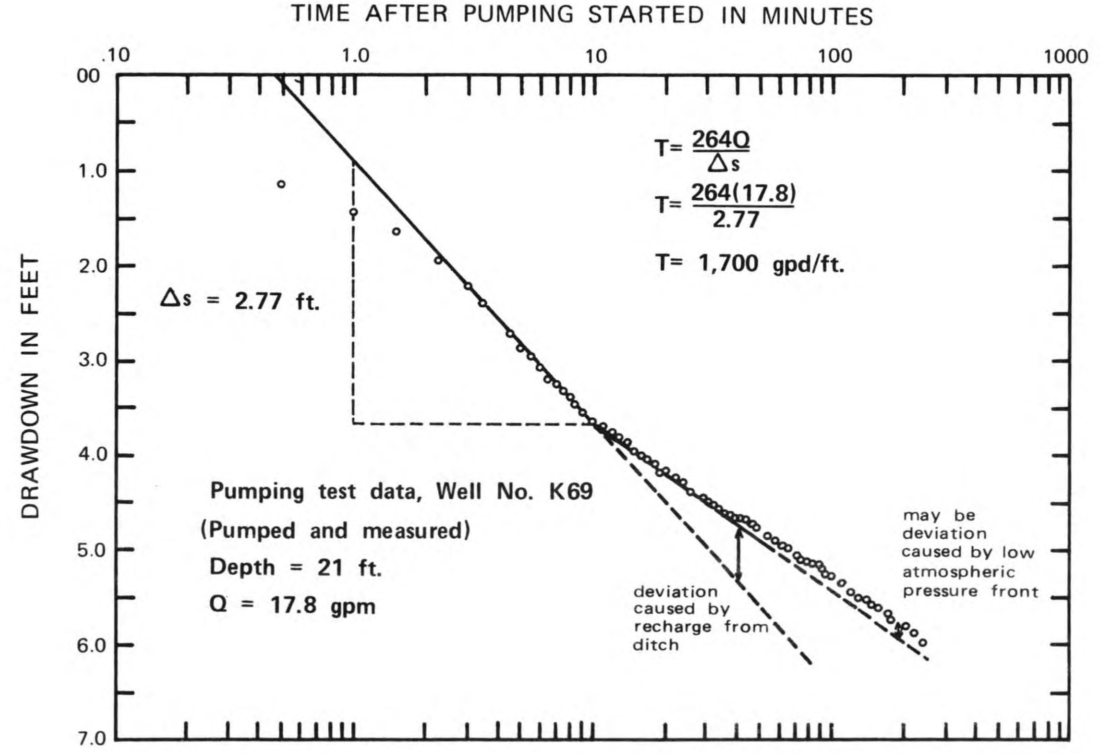


Figure 17. Analysis of selective aquifer tests: K69 and K69-A.

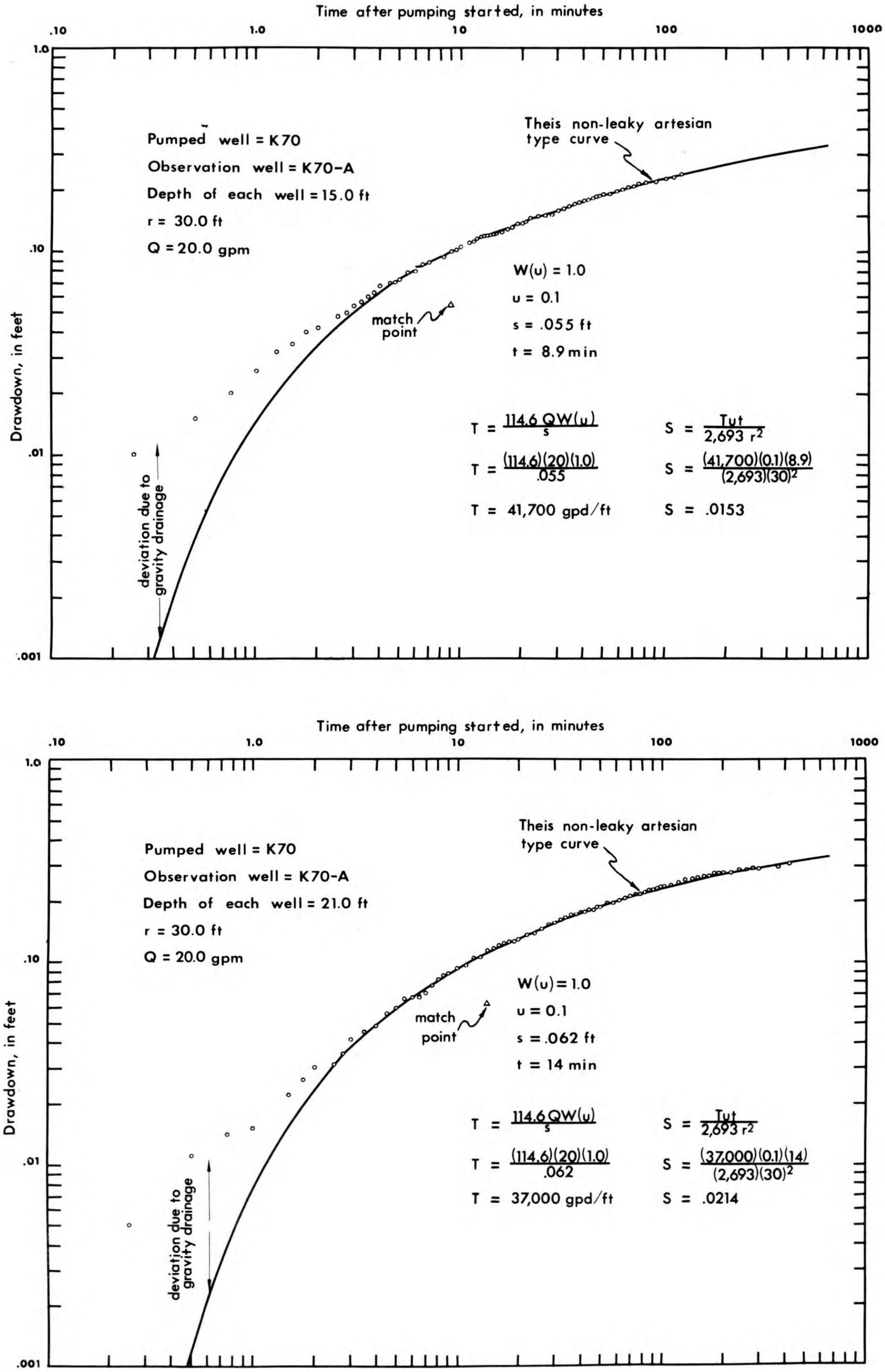


Figure 18. Analysis of selective aquifer tests: K70 and K70-A.

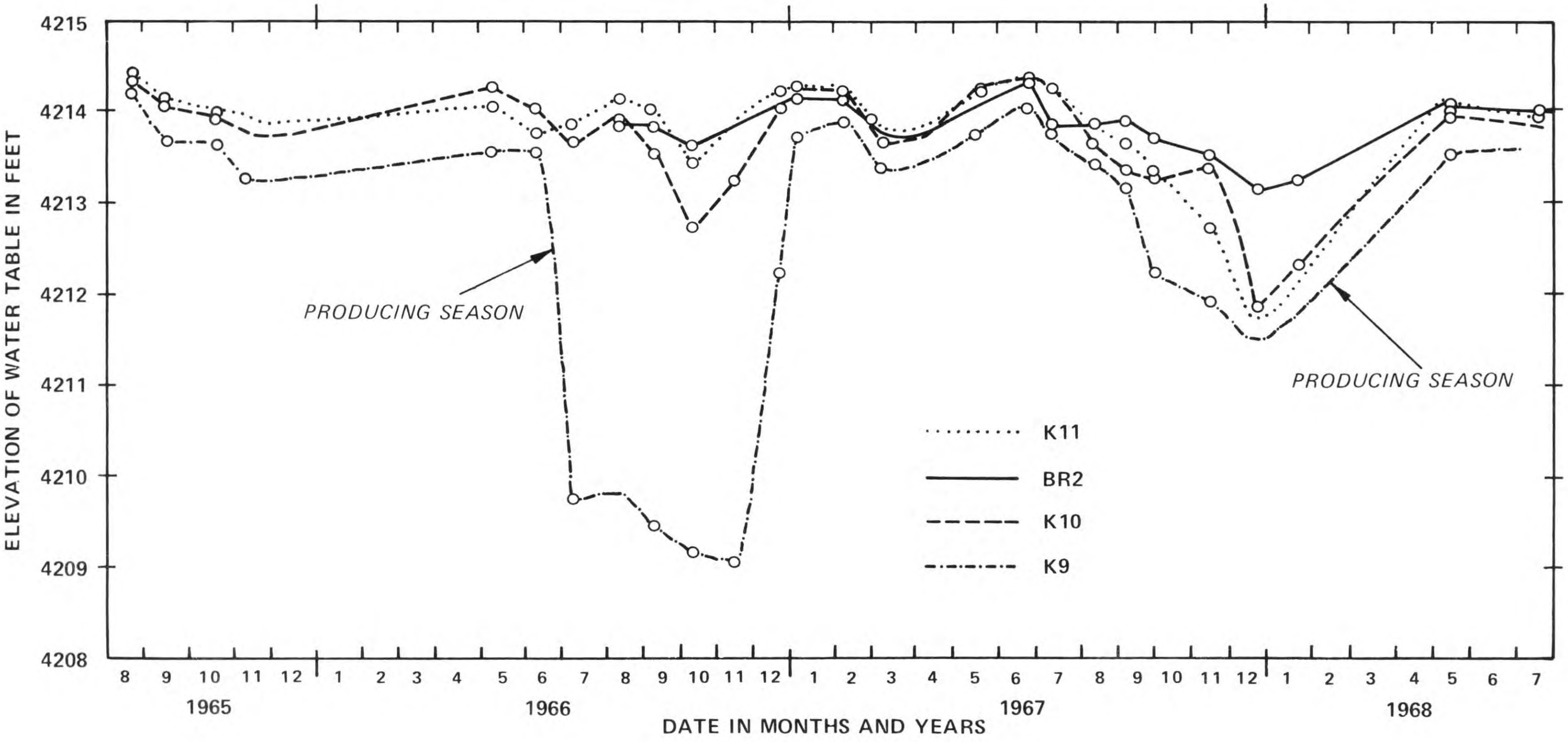


Figure 19. Hydrographs of K11, BR2, K10 and K9 showing seasonal variations in brine levels, 1965 to 1968.

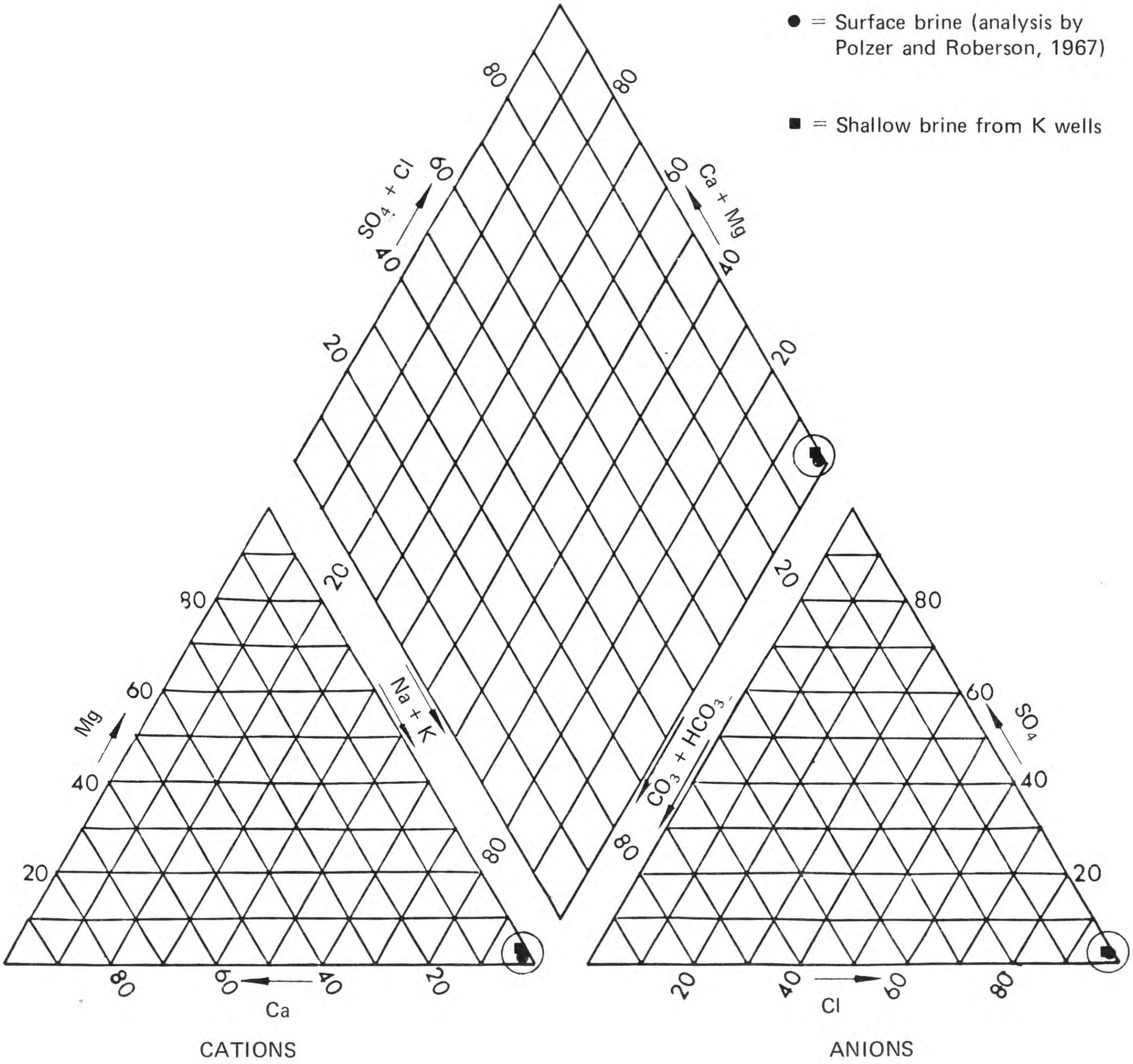


Figure 20. Trilinear diagram showing composition of shallow brine.

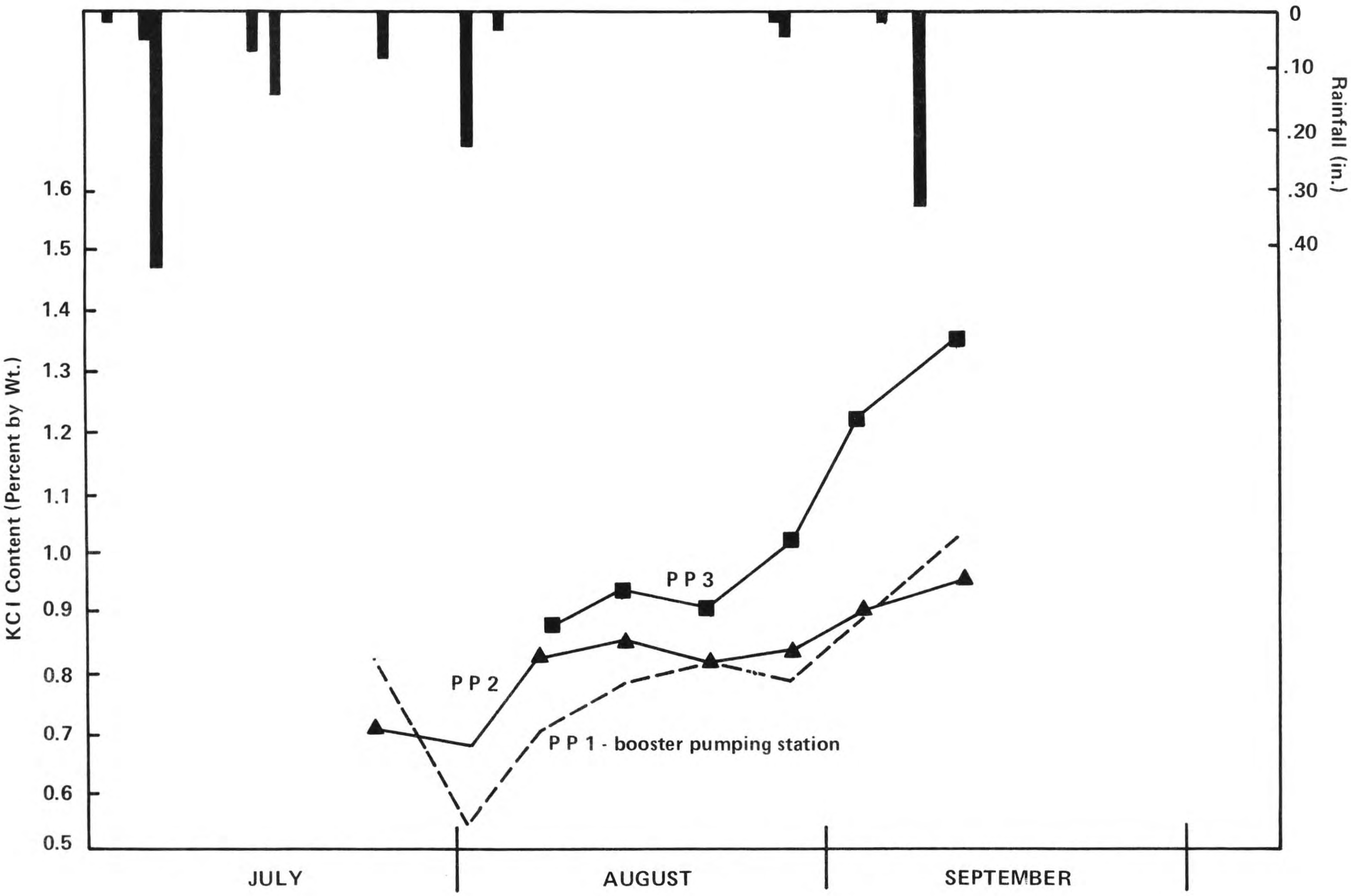


Figure 21. Seasonal changes in brine quality, 1967.

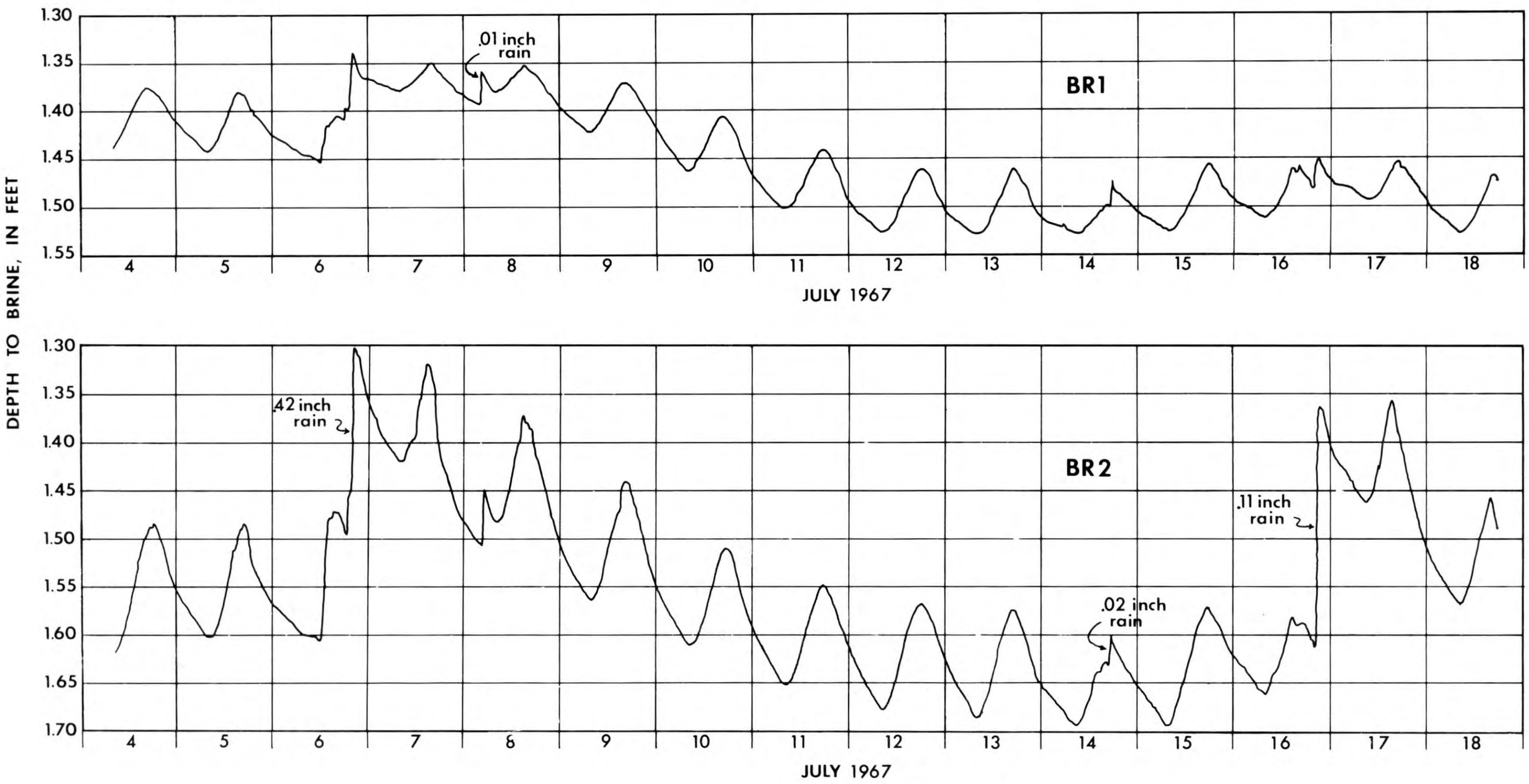


Figure 22. Hydrographs of BR1 and BR2. 4 July-18 July 1967.

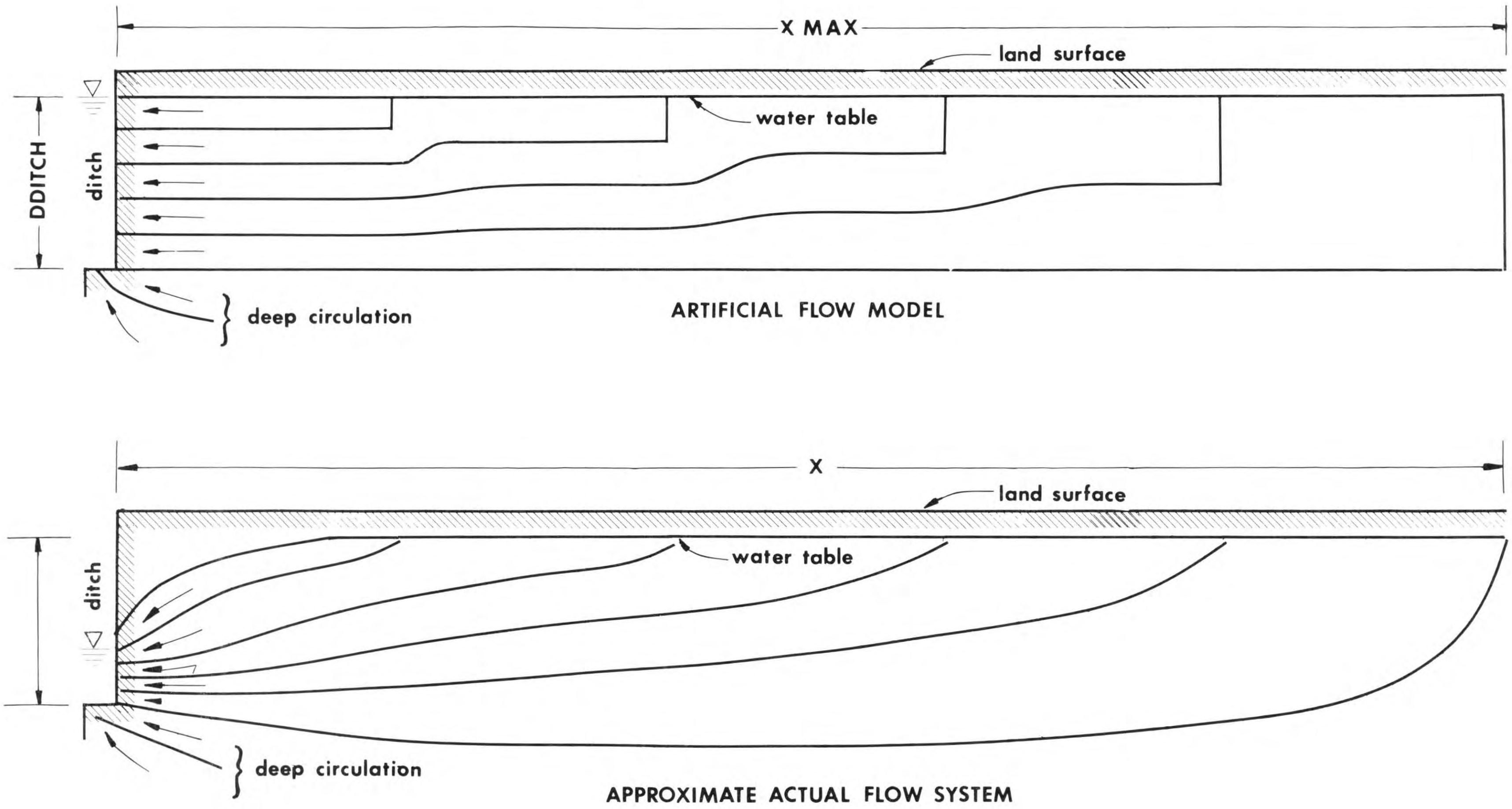


Figure 23. Conceptual model of the shallow flow system (no scale intended).

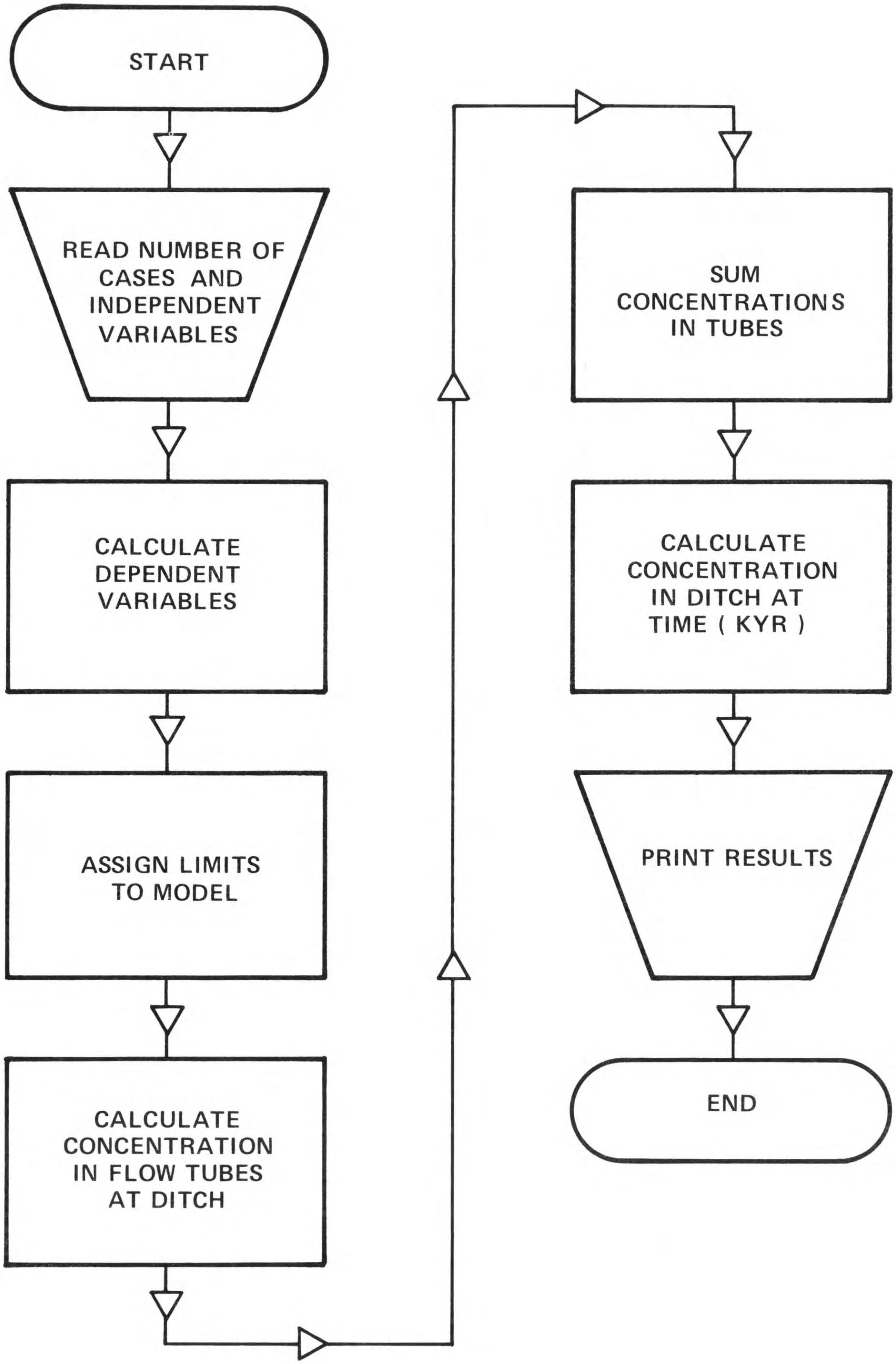


Figure 24. Flow chart of computer program KCLCON.

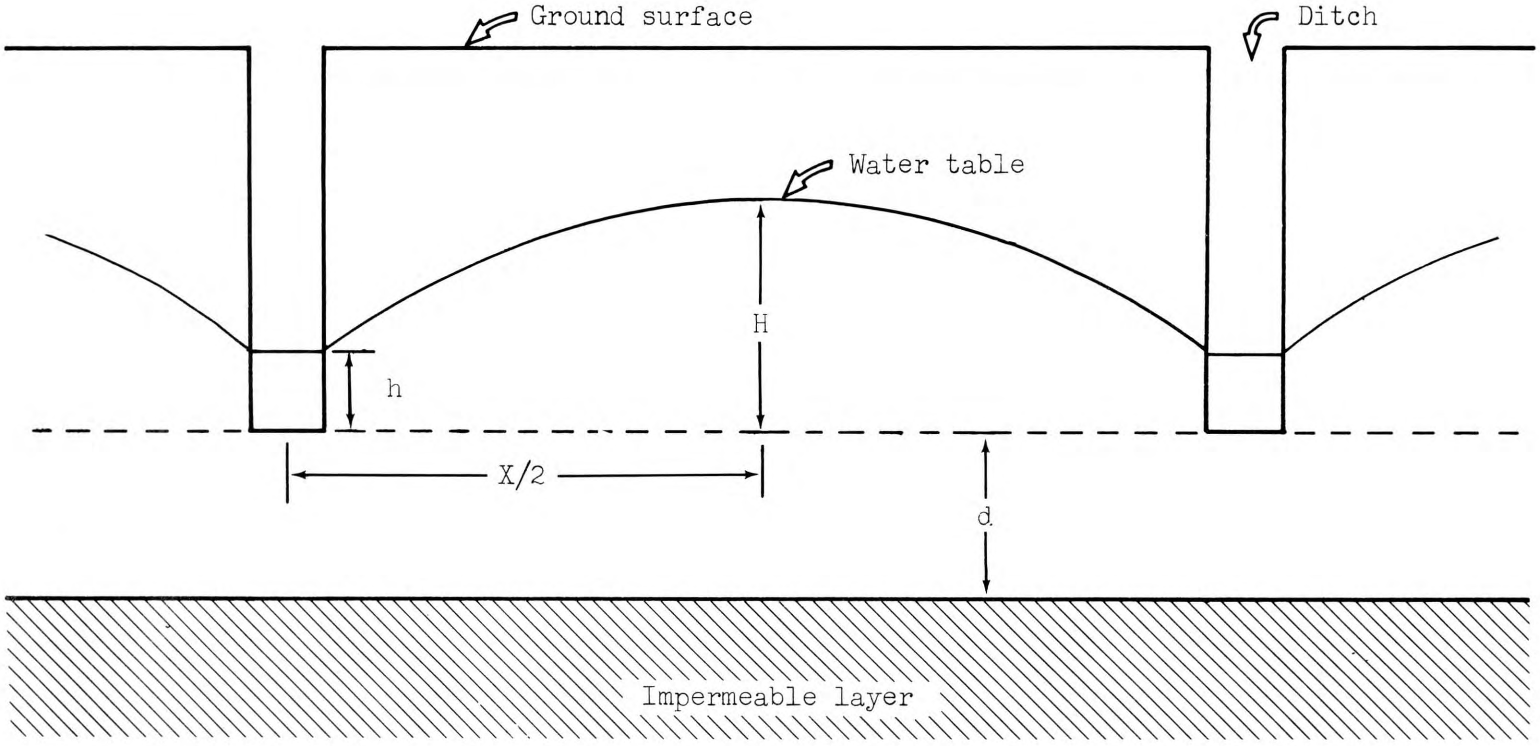


Figure 25. Variables in Hooghoudt's drain spacing equation.

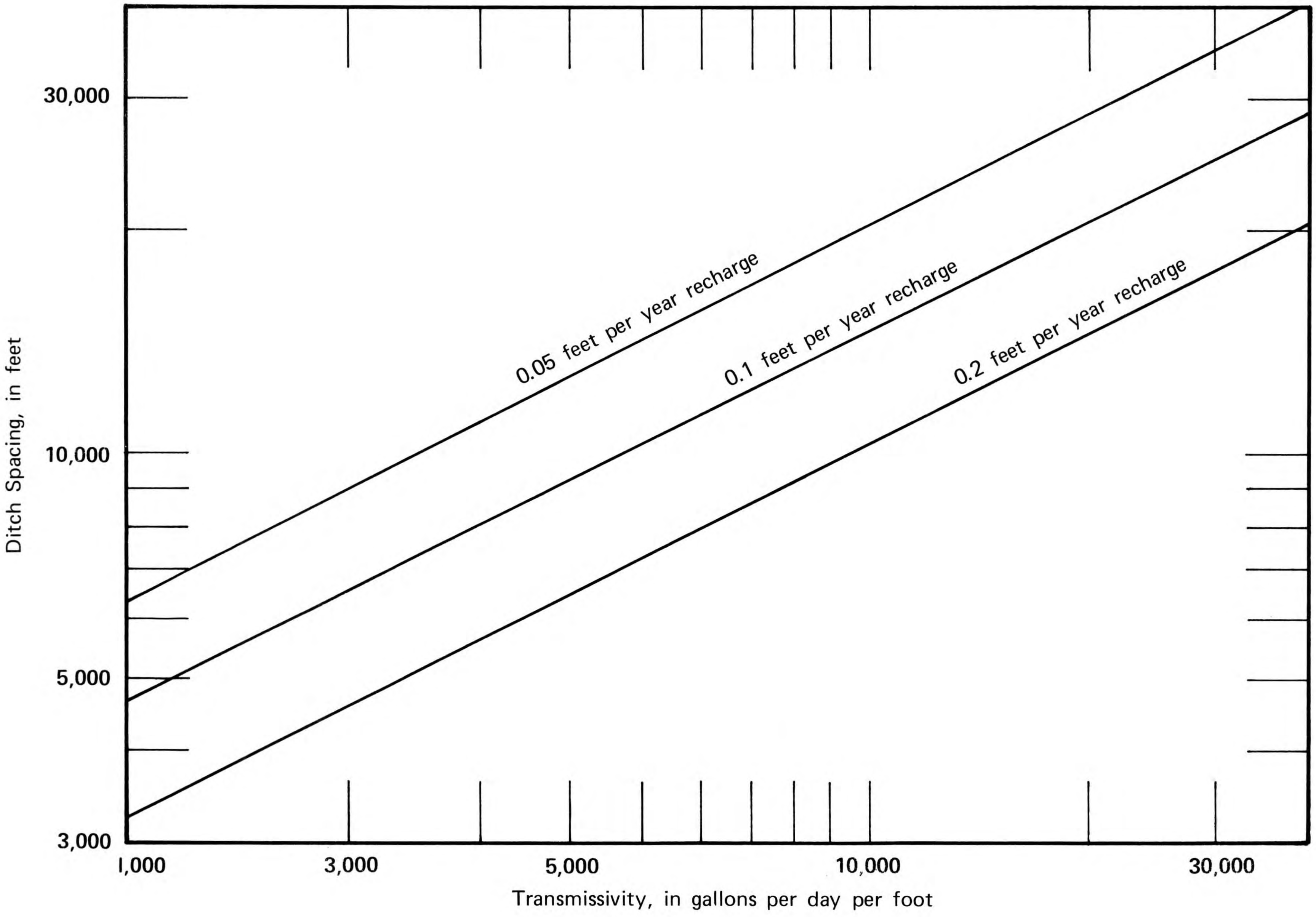


Figure 26. Ditch spacing based on Hooghoudt's drain-spacing formula (from Davis, 1966).

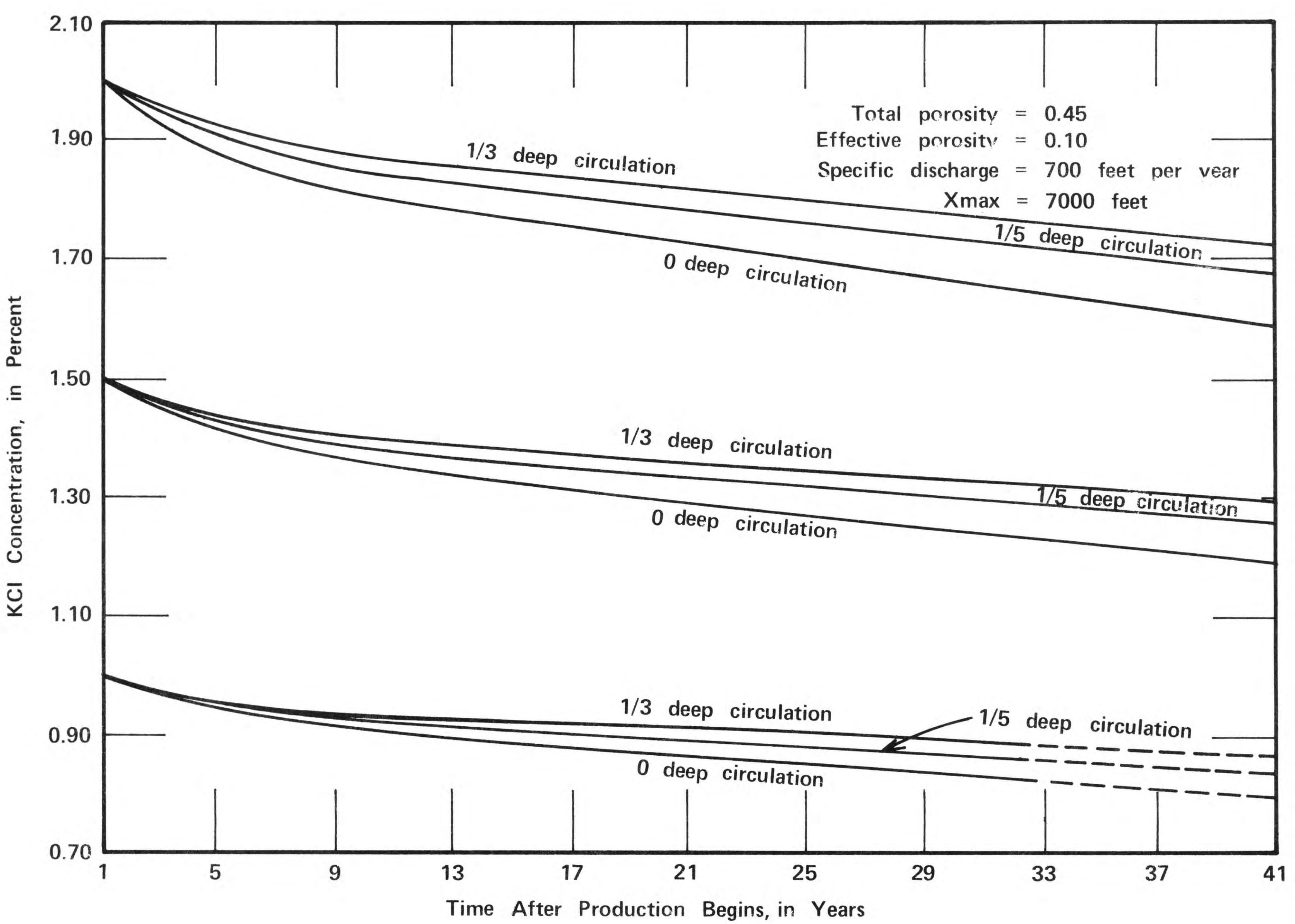


Figure 27. Projected declines of brine grade.

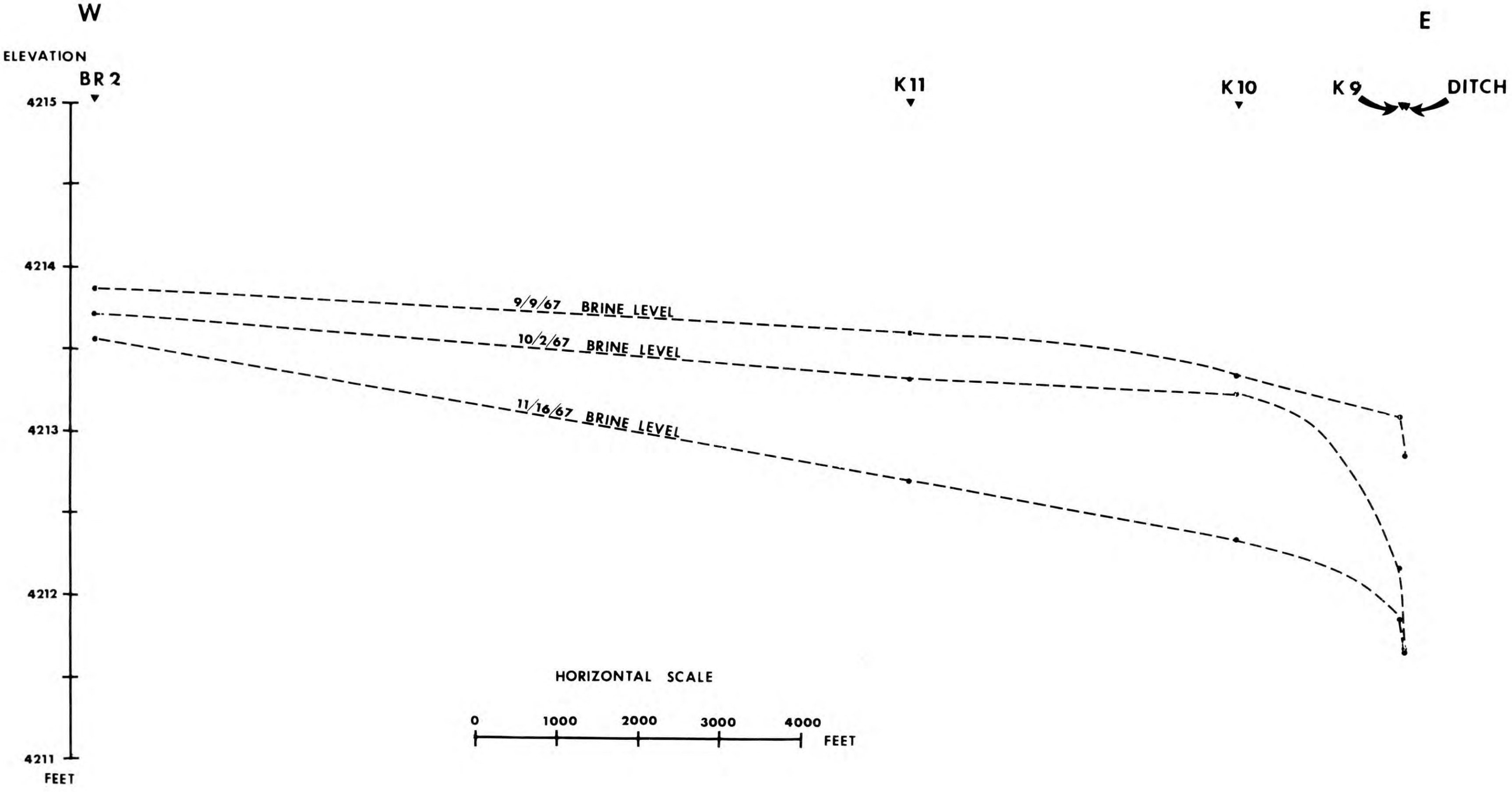


Figure 28. Brine-level profiles from BR2 to transfer ditch.

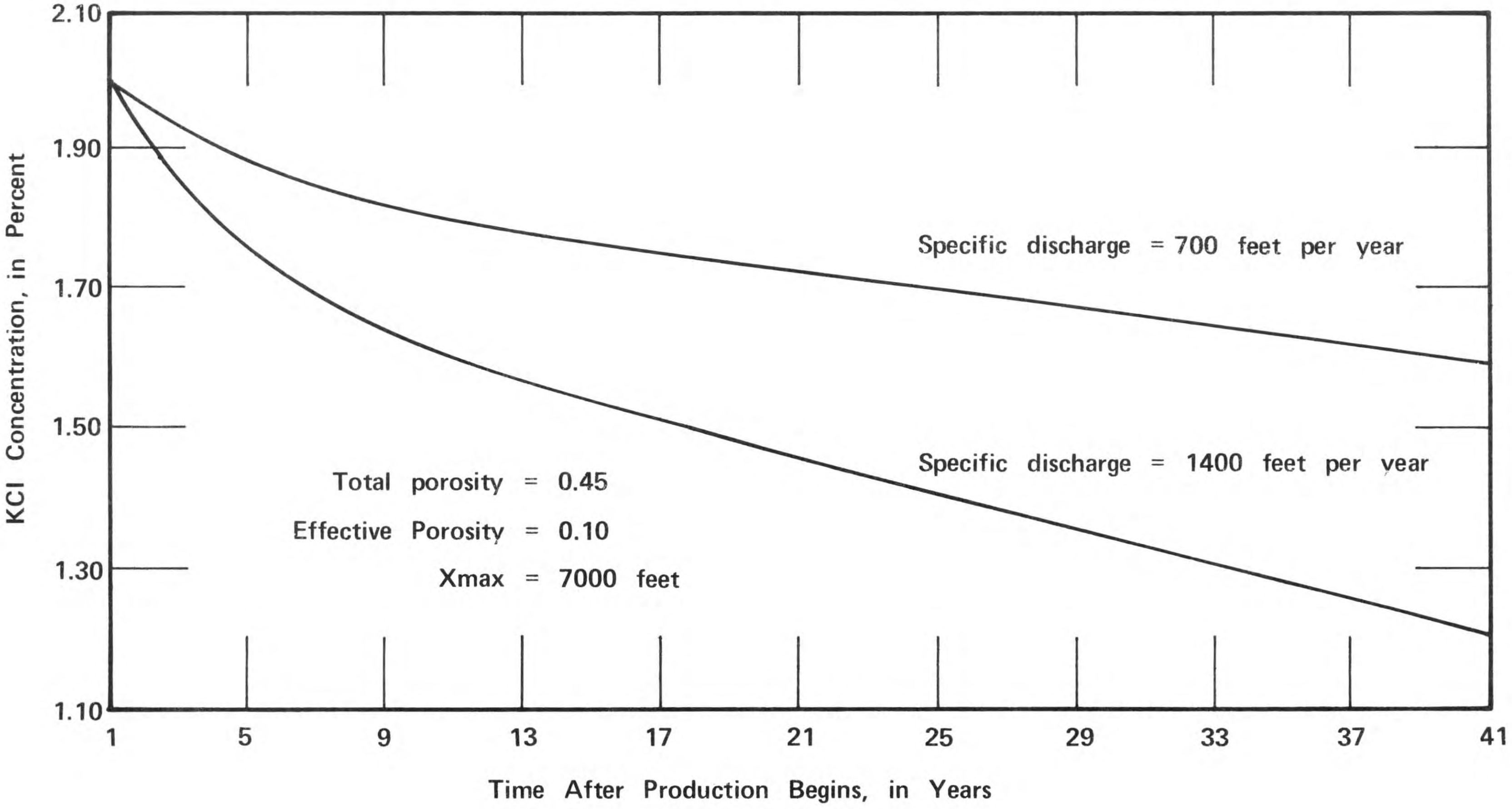


Figure 29. Effect of ground water velocity on decline of brine grade.

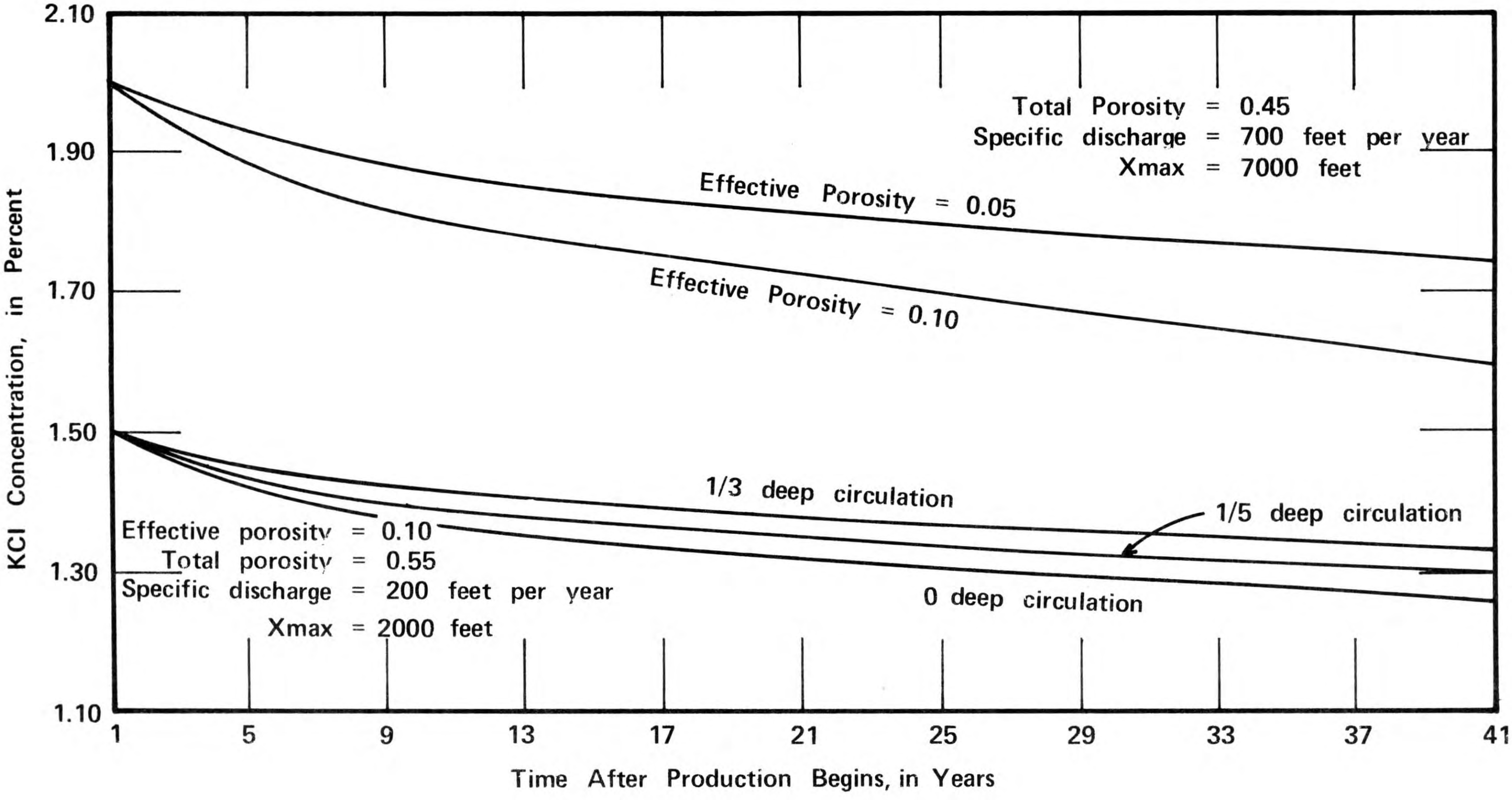


Figure 30. Effect of porosity on decline of brine grade.

APPENDIX A

LOCATIONS OF WELLS

Well no.	Elevation (ft)	¼ Section	Section	Township	Range
BR1	–	NE	22	1N	17W
BR2	–	SE	32	1N	17W
BR3	–	SW	6	2S	19W
BR4	–	NW	5	2S	17W
K1	4,214.15	SE	24	1S	19W
K2	4,214.29	NE	24	1S	19W
K3	4,215.24	NE	23	1N	17W
K4	4,214.94	NW	23	1N	17W
K5	4,215.25	NW	23	1N	17W
K6	4,215.14	NE	23	1N	17W
K7	4,215.13	NW	24	1N	17W
K7-A	4,215.15	NW	24	1N	17W
K8-B	4,215.50	NW	14	1N	17W
K8-C	4,215.46	NW	14	1N	17W
K9	4,215.28	SW	35	1N	17W
K10	4,215.34	SE	34	1N	17W
K10-A	4,215.29	SE	34	1N	17W
K11	4,215.25	NE	4	1S	17W
K11-A	4,215.30	NE	4	1S	17W
K12	4,215.14	SW	35	1N	17W
K13	–	SE	35	1N	17W
K14	–	NW	2	1S	17W
K14-A	4,215.15	NW	2	1S	17W
K15	–	NW	25	1N	17W
K16	4,215.29	SE	9	1S	17W
K17	4,215.03	SW	17	1S	17W
K18	4,215.27	NE	24	1N	17W
K19	4,215.47	NE	24	1N	17W
K20	4,215.08	NW	19	1N	16W
K21	–	NW	19	1N	16W
K22	4,215.04	SE	12	1N	17W
K23	4,215.97	SE	12	1N	17W
K24	4,215.19	SW	12	1N	17W
K24-A	4,215.92	SW	12	1N	17W
K25	4,215.04	SW	7	1N	16W
K26	–	NE	12	1S	18W
K27	–	SE	11	1S	18W
K27-A	–	SE	11	1S	18W
K28	–	NE	9	1S	18W
K29	–	NE	9	1S	18W
K30	4,214.22	NW	19	1S	18W
K31	4,215.28	NE	24	1S	18W
K32	4,214.39	NW	30	1S	18W
K33	4,214.34	SW	30	1S	18W
K33-A	4,214.35	SW	30	1S	18W
K34	4,214.25	NW	7	2S	18W
K34-A	4,214.48	NW	7	2S	18W
K35	4,214.20	SW	7	2S	18W
K36	4,214.49	SW	7	2S	18W
K37	4,214.45	NW	18	2S	18W
K38	–	SW	4	2S	18W
K39	4,214.54	SE	27	1S	18W
K39-A	4,214.30	SE	27	1S	18W
K40	4,214.23	NE	34	1S	18W
K41	4,214.71	SE	2	2S	18W
K42	4,214.63	SW	1	2S	18W
K43	4,214.58	SE	1	2S	18W
K43-A	4,214.52	SE	1	2S	18W
K44	4,214.43	SE	25	1S	18W
K45	4,214.43	SW	30	1S	17W
K46	–	NE	21	1S	17W
K47	–	NE	6	2S	17W
K48	–	NE	29	2S	19W
K49	–	SE	20	2S	19W
K50	–	NW	28	2S	19W
K51	–	SW	21	2S	19W
K52	–	SW	21	2S	19W
K53	–	NE	21	1S	19W
K54	–	NE	21	1S	19W
K55	4,214.00	SW	19	1S	18W
K56	–	NW	35	1S	19W
K56-A	–	NW	35	1S	19W
K56-B	–	NW	35	1S	19W
K57	–	NE	29	2S	18W
K58	4,214.19	NE	28	1S	18W
K59	–	SW	14	2S	19W
K60	–	NE	22	2S	19W
K61	–	NW	34	1S	19W
K62	–	SW	9	2S	19W
K63	–	SW	15	1S	19W
K63-A	–	SW	15	1S	19W
K64	–	NE	3	1S	19W
K65	–	NE	4	2S	17W
K65-A	–	NE	4	2S	17W
K66	–	SW	16	2S	17W
K66-A	–	SW	16	2S	17W
K67	–	NE	5	3S	18W
K67-A	–	SE	32	2S	18W
K67-B	–	SE	32	2S	18W
K68	–	NE	6	2S	19W
K68-A	–	NE	6	2S	18W
K68-B	–	NE	6	2S	19W
K69	–	NW	1	1S	19W
K69-A	–	NE	2	1S	19W
K70	–	NW	28	1S	18W
K70-A	–	SW	21	1S	18W
DBW1	–	NE	14	2S	19W
DBW2	–	SW	35	1S	19W
DBW3 (abandoned)	–	SW	24	2S	19W
DBW4	–	SW	24	1S	19W
DBW5	–	SW	11	2S	19W
DBW6	–	SW	34	1S	19W
DBW7	–	NW	34	1S	19W
DBW8	–	NW	3	2S	19W
DBW9	–	NW	35	1S	19W
DBW10	–	NE	34	1S	19W
DBW11	–	SW	10	2S	19W
DBW12	–	SE	3	2S	19W
DBW13	–	SW	23	1S	19W
FW2	–	NE	9	1S	19W
FW3	–	NW	10	1S	19W
FW4	–	NW	10	1S	19W
FW5	–	NW	10	1S	19W
FW6	–	NE	10	1S	19W
FW6-A	–	SE	3	1S	19W
FW7	–	SE	3	1S	19W
FW7-A	–	SE	3	1S	19W
FW8	–	SE	3	1S	19W
FW8-A	–	SW	2	1S	19W
FW9	–	SW	2	1S	19W
FW9-A	–	SW	2	1S	19W
FW10	–	SW	2	1S	19W
FW11	–	SW	2	1S	19W

Appendix A (continued)

Well no.	Elevation (ft)	¼ Section	Section	Township	Range
FW12	–	NE	2	1S	19W
FW13	–	NE	2	1S	19W
FW14	–	NE	2	1S	19W
FW15	–	NW	1	1S	19W
FW16	–	NW	1	1S	19W
FW17	–	SW	31	1N	18W
FW18	–	SW	31	1N	18W
FW19	–	SE	31	1N	18W
FW20	–	SE	31	1N	18W
FW21	–	NE	31	1N	18W
FW22	–	NE	31	1N	18W
FW23	–	NE	31	1N	18W
FW24	–	SW	29	1N	18W

APPENDIX B

DRILLERS' LOGS
(From files of Bonneville, Ltd.)

WELL NO. FW9

Location: 225.5 ft E. and 1,348.8 ft N. from SW cor. sec. 2, T. 1 S., R. 19 W. (541.7 ft SW of FW9-A)
Year drilled: 1947
Total depth: 181 ft

Depth (ft)	Description	Remarks
0-95	Blue clay	
95-98	Gravel	Flowing 40 gpm
98-111	Blue clay	
111-122	Gravel and little clay	Flowing 150 gpm
122-140	Blue clay	
140-148	Gravel	Flowing 150 gpm
148-150	Hard pan	
150-154	Gravel and clay	
154-158	Clay	
158-168	Gravel and sand	Flowing 325 gpm
168-178	Gravel	Flowing free
178-181	Clay	
181		Flowing 2,500 gpm

WELL NO. FW9-A

Location: 713.4 ft E. and 1,555.9 ft N. from SW cor. sec. 2, T. 1 S., R. 19 W. (541.7 ft NE of FW9)
Year drilled: 1947
Total depth: 193 ft

Depth (ft)	Description	Remarks
0-96	Clay	
96-101	Gravel	
101-110	Gravel and clay	
110-121	Gravel	
121-139	Clay	
139-150	Gravel	
150-152	Hard pan	
152-169	Gravel and clay	
169-190	Gravel and conglomerate	
190-193	Loose gravel	

WELL NO. FW10

Location: 1,176.5 ft E. and 1,915.7 ft N. from SW cor. sec. 2, T. 1 S., R. 19 W. (552.9 ft NE of FW9-A)
Year drilled: 1947
Total depth: 219 ft

Depth (ft)	Description	Remarks
0-97	Blue clay	
97-100	Gravel	Flowing 50 gpm
100-112	Blue clay	
112-124	Gravel	Flowing 150 gpm
124-141	Blue clay	
141-149	Gravel	Flowing 200 gpm
149-151	Hard pan	
151-155	Gravel and clay	
155-159	Clay	
159-166	Clay and gravel	
166-177	Clay, sand and gravel	
177-219	Gravel	
219	Bed rock	Flowing 500 gpm (approximately)

WELL NO. DBW1

Location: SE¼NE¼ sec. 14 (on east section line), T. 2 S., R. 19 W.
Year drilled: Started 1939, completed 1943
Total depth: 1,200 ft
Casing: 1,175 ft, 8-inch

Depth (ft)	Description	Remarks
0-5	Salt, white, hard	Water in hole
5-50	Clay, light gray, soft	Water in hole to 40 ft; dry hole at 45 ft
50-80	Clay, dark gray, soft	Little water from 55 ft to 70 ft
80-100	Clay, light gray, soft	Dry hole
100-120	Clay, dark gray, soft	Little water 85 ft to 105 ft
120-180	Clay, light gray, soft	Dry hole except little water at 140 ft
180-205	Clay, dark gray, soft	
205-270	Clay, light gray, soft	
270-340	Gypsum and little clay, medium hard	Lots of water at 290 ft; water level 100 ft
340-345	Gypsum and light gray, hard	
345-395	Gypsum and little clay, medium hard	
395-410	Straight gypsum, medium hard	Lots of water at 405 ft
410-415	Clay and showing of gypsum	Water level 30 ft after standing 15 hrs
415-460	Gypsum and some clay, medium hard	
460-525	Gypsum and some clay, medium hard	Water level 268 ft after standing 12 hrs
525-585	Gypsum and little clay, medium hard	Hole caving at 565
585-595	Gypsum and clay, medium hard	
595-620	Straight gypsum, medium hard	
620-660	Gypsum and clay, medium hard	
660-676	Blue clay	
676-677	Hard pan	

Appendix B–WELL NO. DBW1 (continued)

Depth (ft)	Description	Remarks
677-690	Blue clay	
690-695	Salt and sand	More water; water level 76 ft after 12 hrs
695-705	Blue clay	
705-710	Blue clay and gypsum	
710-760	Blue clay	
760-765	Blue clay and gypsum	
765-791	Blue clay	Trace sand at 780 ft
791-792	Blue clay and gypsum	Drills harder than clay
792-844	Blue clay	
844-852	Blue clay and gypsum	Hole began filling with water at 844 ft, apparently from gypsum
852-866	Blue clay	
866-867	Gypsum	
867-870	Blue clay	
870-875	Blue clay and gypsum	
875-885	Blue clay	
885-898	Blue clay and gypsum	
898-918	Blue clay	
918-920	Fine sand	Water
920-923	Blue clay	
923-930	Fine sand and clay	Water
930-940	Blue clay	
940-950	Fine sand with streaks of clay	
950-955	Blue clay	Water level 420 ft
955-975	White clay	
975-1,000	White clay	
1,000-1,015	White clay	
1,015-1,025	Blue clay	Water broke in
1,025-1,027	Sand, hard	Water level 215 ft
1,027-1,030	White clay	After standing three days the water level is 125 ft
1,030-1,040	Blue clay	Water level 85 ft
1,040-1,058	Blue clay	Water level 90 ft
1,058-1,062	Blue clay	Water level 105 ft
1,062-1,071	Blue clay	
1,071-1,074	Blue clay	
1,074-1,092	White clay	Water level 85 ft
1,092-1,104	White clay and gypsum	
1,104-1,106	Blue clay	
1,106-1,107	Blue clay	
1,107-1,109	Sand	
1,109-1,113	Blue clay	Water level 150 ft
1,113-1,115	Blue clay	
1,115-1,118	Sand	Water level 105 ft
1,118-1,135	White clay, sandy	Water level 85 ft
1,135-1,139	Sandy blue clay	Water level 65 ft
1,139-1,142	Hard sand, gypsum and clay	
1,142-1,145	Blue clay	
1,145-1,151	Blue clay	
1,151-1,152	Yellow clay	
1,152-1,157	Dark blue clay	Water level 80 ft
1,157-1,163	Blue sticky clay	
1,163-1,166	Hard sand	
1,166-1,168	Hard sand	
1,168-1,171	Rock	
1,171-1,177	Rock	
1,177-1,180	Rock (black sand running in from above)	
1,180-1,185	Black volcanic rock	

WELL NO. DBW1 (continued)

Depth (ft)	Description	Remarks
1,185-1,196	Black volcanic rock	
1,196-1,198	Black volcanic rock	
1,198-1,200	Black volcanic rock	Water level 25 ft (water cannot be bailed below 25 ft)

WELL NO. DBW2

Location: SW¼SW¼ sec. 35, T. 1 S., R. 19 W.
Year drilled: 1948-1949
Total depth: 1,540 ft
Casing: No record

Depth (ft)	Description	Remarks
0-194	Blue clay	
194-196	Hard pan	
196-255	Clay	
255-269	Tough sticky clay	
269-273	Hard pan with much gypsum	
273-300	Clay	
300-315	Sticky clay	
315-328	Hard clay and gypsum	
328-350	Soft clay	
350-353	Hard pan	
353-363	Clay	
363-365	Hard clay with much gypsum	
365-387	Clay	
387-415	Soft clay and gypsum	
415-441	Clay	
441-467	Sticky green clay	
467-471	Dark gray clay	
471-478	Sticky green clay	
478-500	Gray sticky clay, some gypsum	
500-515	Hard gray clay	
515-526	Light green clay, some gypsum	
526-530	Hard green clay	
530-550	Light gray clay, sticky	
550-567	Light green clay with much gypsum	
567-574	Green clay, sticky	
574-580	Hard sandy clay, some gypsum	
580-592	Green sticky clay	
592-598	Green sticky clay	
598-602	Hard sandy clay and gypsum	
602-618	Green clay, very sticky	
618-622	Hard clay, much gypsum	
622-630	Green clay, sticky	Hot sample
630-634	Hard clay, much gypsum	
634-652	Sandy clay, some gypsum	
652-656	Hard clay, much gypsum	
656-660	Dark blue clay	Hot sample

Appendix B–WELL NO. DBW2 (continued)

Depth (ft)	Description	Remarks
660-692	Sticky gray clay, some gypsum	
692-694	Gypsum seam	
694-708	Sticky gray clay	Hot sample
708-720	Dark sticky clay, some gypsum	
720-740	Very sticky gray clay, some gypsum	
740-752	Light gray, some gypsum	
752-803	Light gray, much gypsum	
803-807	Almost straight gypsum	
807-823	Blue clay	Hot sample
823-832	Light blue clay, some gypsum	
832-842	Blue clay, some gypsum	
842-851	Blue clay	
851-856	Much gypsum	
856-859	Hard	Warm sample
859-883	Gray clay	
883-886	Hard	
886-938	Light gray clay	
938-945	Hard gray sandy clay	
945-950	Hard gray clay	
950-963	Hard pan	
963-980	Dark blue clay	
980-985	Very hard clay	
985-989	Blue sticky clay	
989-990	Sandy clay	
990-997	Yellow clay, soft	
997-1,012	Hard blue clay	
1,012-1,014	Yellow clay, soft	
1,014-1,540	Conglomerate	Ran test pump at 250 gpm; water all seemed to come from surface
	Conglomerate	From 1,014 to 1,540 ground was solid conglomerate of gravel and sand cemented with lime At about 1,300 formation started turning brown but when sample was washed the rocks were the same as above When finished, the well delivered 1,500 gpm on a pump test

WELL NO. DBW3

Location: NE¼SW¼ sec. 24, T. 2 S., R. 19 W.
Year drilled: 1949 (?)
Total depth: 2,068 ft
Casing: 36 ft, 20-inch; 418 ft, 16-inch

Note: This well was abandoned and later covered by a pond; no trace of the well at the surface.

Depth (ft)	Description	Remarks
0-249	Blue clay	
249-251	Gypsum	

WELL NO. DBW3 (continued)

Depth (ft)	Description	Remarks
251-280	Blue clay	
280-282	Gypsum	
282-293	Blue clay	
293-296	Gypsum	
296-400	Clay and gypsum	
400-420	Gypsum (trace gravel)	
420-450	Clay	
450-555	Clay, gypsum, gravel (hard)	
555-575	Gypsum, clay	
575-620	Clay, sticky	
620-630	Gypsum (trace gravel)	
630-646	Clay	
646-652	Gypsum	
652-675	Clay	
675-687	Blue clay	
687-690	Gypsum, clay, gravel	
690-697	Clay, sticky	
697-700	Gypsum (hard)	
700-705	Gray sandy clay	
705-719	Conglomerate	
719-785	Clay, sticky, gray	
785-788	Gypsum (hard)	
788-820	Clay, sticky, gray	
820-822	Conglomerate, hard	
822-835	Clay, gray	
835-836	Gypsum, hard	
836-879	Clay, blue and gray	
879-881	Gypsum	
881-920	Clay, dark, sticky	
920-922	Gypsum	
922-1,017	Clay, gray, sticky to hard	
1,017-1,018	Gypsum	
1,018-1,061	Clay, sticky to hard	
1,061-1,070	Conglomerate, hard	
1,070-1,075	Clay, sticky	
1,075-1,079	Sand and gypsum	
1,079-1,147	Clay, sticky	
1,147-1,148	Conglomerate, hard	
1,148-1,166	Clay, sticky, sandy	
1,166-1,170	Clay, sticky, and gravel (first iron)	
1,170-1,193	Clay, sticky to sandy	
1,193-1,195	Gravel	
1,195-1,210	Conglomerate	
1,210-1,214	Conglomerate, hard	
1,214-1,215	Clay, sticky	
1,215-1,218	Gravel, tight	
1,218-1,220	Clay and gravel	
1,220-1,277	Conglomerate	
1,277-1,281	No log	
1,281-1,289	Conglomerate	
1,289-1,291	Clay, sticky, and gravel	
1,291-1,386	Conglomerate	
1,386-1,420	Gravel and sand	
1,420-1,423	Conglomerate	
1,423-1,427	No log	
1,427-1,429	Sand and gravel	
1,429-1,432	Sand and clay, very sticky	
1,432-1,435	Conglomerate, sticky	
1,435-1,449	Conglomerate, hard	
1,449-1,452	No log	
1,452-1,479	Conglomerate, sticky	

Appendix B–WELL NO. DBW3 (continued)

Depth (ft)	Description	Remarks
1,479-1,514	Sand and gravel, hard; some blue clay (132.8° F at 1,502 ft)	
1,514-1,557	Conglomerate, hard	
1,557-1,558	Clay, sticky	
1,558-1,712	Hard (190.4° F at 1,634 ft)	
1,712-1,768	Conglomerate and gravel	
1,768-1,788	Conglomerate, sticky	
1,788-1,834	Conglomerate	
1,834-1,858	Conglomerate, sticky	
1,858-1,890	Conglomerate and gravel	
1,890-1,907	Conglomerate, sticky	
1,907-1,914	Conglomerate, hard	
1,914-1,965	Conglomerate, light brown	
1,965-2,006	Conglomerate, gray, sticky	
2,006-2,012	Core (no description)	
2,012-2,042	Conglomerate, gray, sticky	
2,042-2,068	Hard	

WELL NO. DBW4

Location: NE¼NW¼ sec. 25, T. 1 S., R. 19 W.
Year drilled: No record
Total depth: 1,644 ft
Casing: No record

Depth (ft)	Description	Remarks
0-150	Clay	
150-209	Blue clay	
209-216	Hard white clay	
216-280	Clay and gypsum	
280-293	Clay	
293-296	Solid gypsum	
296-310	Hard blue clay	
310-311	Solid gypsum	
311-315	Hard blue clay	
315-401	Clay	
401-405	Hard gray clay, caving	
405-414	Soft green clay, sticky	
414-491	Blue clay, sticky, caving	
491-493	Gypsum	
493-528	Blue clay	
528-535	Blue clay with a lot of gypsum	
535-539	Solid gypsum	
539-540	Blue clay	
540-545	Gypsum	
545-555	Blue clay	
555-557	Gypsum	
557-644	Blue clay	
644-645	Gypsum	
645-667	Blue clay	
667-682	Gypsum	
682-695	Clay	
695-696	Gypsum	
696-745	Clay	
745-756	No log	
756-758	Gypsum	
758-848	Clay	
848-850	Gypsum	
850-885	Clay	
885-895	Gypsum	
895-897	Clay	
897-901	Gypsum	
901-914	Clay, a little sticky	
914-932	Gypsum	
932-940	Clay, sticky	
940-941	Gypsum	
941-987	Clay	
987-989	Gypsum	
989-1,013	Clay	
1,013-1,028	Gypsum	
1,028-1,058	Clay	
1,058-1,070	Gypsum	
1,070-1,100	Clay	
1,100-1,102	Gypsum	
1,102-1,109	Yellow clay	
1,109-1,117	Hard clay	
1,117-1,154	Sticky clay	
1,154-1,184	Sandy clay, hard	
1,184-1,185	Sticky clay	
1,185-1,187	Hard clay	
1,187-1,191	Sticky clay	
1,191-1,192	Hard clay	
1,192-1,195	Gypsum sand, hard	
1,195-1,202	Sticky clay	
1,202-1,205	Gypsum sand	
1,205-1,221	Sticky clay	
1,221-1,228	Hard clay	
1,228-1,230	Hard clay and gypsum	
1,230-1,234	Gravel	
1,234-1,373	Conglomerate	
1,373-1,376	Clay, very sticky	
1,376-1,423	Conglomerate	
1,423-1,433	Brown mud and gravel	
1,433-1,446	Brown mud, sticky	
1,446-1,451	Green conglomerate	
1,451-1,455	Brown sticky mud	
1,455-1,458	Hard green conglomerate	
1,458-1,480	Conglomerate	
1,480-1,486	Clay and gravel, sticky	
1,486-1,487	Sticky conglomerate	
1,487-1,503	Hard conglomerate	
1,503-1,510	Black hard conglomerate	
1,510-1,515	Dark sticky conglomerate	
1,515-1,522	Hard conglomerate	
1,522-1,528	Sticky dark conglomerate	
1,528-1,535	Hard conglomerate	
1,535-1,537	Clay or soft conglomerate	
1,537-1,596	Conglomerate	
1,596-1,599	Sticky conglomerate	
1,599-1,644	Hard conglomerate	

WELL NO. DBW5

Location: SE¼SW¼ sec. 11, T. 2 S., R. 19 W.
Year drilled: No record
Total depth: 1,540 ft
Casing: 1,118 ft, 16-inch

Appendix B–WELL NO. DBW5 (continued)

Depth (ft)	Description	Remarks
0-174	Clay	
174-205	Blue clay	
205-282	Clay	
282-285	Gypsum	
285-289	Clay	
289-294	Gypsum	
294-323	Hard clay	
323-372	Clay	
372-396	Dark gray clay	
396-405	Clay	
405-410	Gypsum	
410-420	Clay	
420-421	Gypsum	
421-425	Clay, sticky	
425-469	Green clay with a large amount of gypsum showing	
469-521	Clay	
521-525	Gypsum	
525-530	Hard clay	
530-545	Gypsum	
545-548	Gray clay, sticky	
548-561	Gypsum	
561-603	Blue clay	
603-611	Gypsum	
611-684	Clay with gypsum showing	
684-692	Gypsum	
692-827	Clay	
827-841	Clay with gypsum showing	
841-842	Gypsum	
842-919	Clay	
919-935	Gypsum	
935-995	Clay	
995-1,004	Gypsum	
1,004-1,022	Sticky clay	
1,022-1,024	Gypsum	
1,024-1,029	Sticky clay	
1,029-1,040	Hard clay	
1,040-1,116	Sticky clay	
1,116-1,124	Gravel, sticky	
1,124-1,132	Hard conglomerate	
1,132-1,136	Sticky clay	
1,136-1,138	Hard conglomerate	
1,138-1,141	Sticky clay	
1,141-1,154	Hard conglomerate	
1,154-1,155	Sticky clay	
1,155-1,173	Hard conglomerate	
1,173-1,174	Sticky conglomerate	
1,174-1,212	Hard conglomerate	
1,212-1,213	Sticky conglomerate	
1,213-1,425	Hard conglomerate	
1,425-1,434	Conglomerate, lighter in color	
1,434-1,488	Hard conglomerate	
1,488-1,497	Black conglomerate	
1,497-1,540	Conglomerate	

WELL NO. DBW6

Location: SE¼SW¼ sec. 34, T. 1 S., R. 19 W.
Year drilled: No record
Total depth: 1,153 ft
Casing: No record

WELL NO. DBW6 (continued)

Depth (ft)	Description	Remarks
0-265	Clay	
265-268	Gypsum	
268-315	Clay	
315-318	Gypsum	
318-455	Clay	
455-459	Gypsum	
459-487	Clay	
487-489	Gypsum	
489-492	Clay	
492-500	Gypsum	
500-634	Clay with gypsum showing	
634-645	Gypsum	
645-714	Clay	
714-716	Gypsum	
716-835	Clay	
835-875	Hard clay	
875-885	Hard clay with a small amount of gypsum and gravel showing	
885-902	Sticky clay	
902-918	Hard clay	
918-932	Sand, gravel and clay	
932-944	Hard clay	
944-1,153	Conglomerate	

WELL NO. DBW8

Location: SE¼NW¼ sec. 34, T. 1 S., R. 19 W.
Year drilled: 1950
Total depth: 1,126 ft
Casing: No record

Depth (ft)	Description	Remarks
0-268	Clay	
268-272	Gypsum	
272-320	Clay	
320-323	Gypsum	
323-380	Clay	
380-381	Gypsum	
381-390	Clay	
390-391	Gypsum	
391-400	Clay	
400-416	Clay and gypsum	
416-460	Clay	
460-463	Gypsum	
463-475	Sticky clay	
475-485	Clay	
485-487	Gypsum	
487-496	Sticky clay	
496-507	Gypsum	Caving, hole filled up 11 ft
507-513	Clay	
513-515	Gypsum	
515-565	Clay	
565-571	Gypsum	
571-608	Clay	
608-610	Gypsum	
610-628	Clay	
628-634	Hard gypsum	
634-638	Clay	
638-645	Gypsum	

Appendix B—WELL NO. DBW8 (continued)

Depth (ft)	Description	Remarks
645-700	Clay	
700-704	Gypsum	
704-745	No log	
745-754	Clay	
754-757	Gypsum	
757-872	Clay	
872-894	Gypsum	
894-918	Clay	
918-930	Clay, gravel showing in sample	
930-944	Gravel	
944-1,039	Conglomerate	
1,039-1,046	Gravel	
1,046-1,060	Hard conglomerate, brown in color	
1,060-1,126	Conglomerate	
		Pumping test: 1,300 gpm produced at 1,800 rpm. Hole filled up to 1,045 ft Pumping test: 1,270 gpm with 85 ft drawdown 1,000 gpm with 70 ft drawdown (T≈25,000 gpd/ft)

WELL NO. DBW10

Location: NW¼NE¼ sec. 34, T. 1 S., R. 19 W.
Year drilled: 1951 (?)
Total depth: 1,152 ft (?)
Casing: No record

Depth (ft)	Description	Remarks
0-60	No log	
60-190	Clay	
190-192	Gypsum	
192-262	Clay	
262-265	Gypsum	
265-268	Clay	
268-272	Gypsum	
272-278	Clay	
278-285	Gypsum	
285-321	Clay	
321-323	Gypsum	
323-350	Clay	
350-352	Gypsum	
352-370	Clay	
370-381	Gypsum	
381-498	Clay	
498-505	Gypsum	
505-518	Clay	
518-521	Gypsum	
521-531	Sticky clay	
531-533	Hard	
533-600	Sticky clay	
600-605	Gypsum	
605-632	Sticky clay	
632-643	Gypsum	
643-677	Clay	

WELL NO. DBW10 (continued)

Depth (ft)	Description	Remarks
677-687	Sticky clay	
687-692	Gypsum	
692-831	Sticky clay	
831-836	Hard	
836-840	Sticky clay	
840-853	No log	
853-860	Hard	
860-862	Gypsum	
862-866	No log	
866-867	Hard	
867-880	Clay	
880-882	Hard	
882-904	Clay	
904-914	Sticky clay	
914-926	Hard	
926-933	Clay	
933-965	Sticky clay	
965-1,016	Hard	
1,016-1,018	Conglomerate	
1,018-1,115	Hard	
1,115-1,121	No log	
1,121-1,129	Hard	
1,129-1,130	Sticky clay	
1,130-1,131	Hard	
1,131-1,137	Conglomerate	
1,137-1,152	Hard	

WELL NO. DBW7

Location: SW¼NW¼ sec. 3, T. 2 S., R. 19 W.
Year drilled: 1950
Total depth: 1,070 ft
Casing: 138 ft perforated casing on bottom

WELL NO. DBW9

Location: SW¼NW¼ sec. 35, T. 1 S., R. 19 W.
Year drilled: 1950
Total depth: 1,424 ft
Casing: 120 ft of 12-inch perforated casing on bottom

WELL NO. DBW11

Location: SE¼SW¼ sec. 10, T. 2 S., R. 19 W.
Year drilled: 1951
Total depth: 1,370 ft
Casing: 372 ft of 12-inch perforated casing on bottom

WELL NO. DBW12

Location: SW¼SW¼ sec. 2, T. 2 S., R. 19 W.
Year drilled: 1951
Total depth: 1,508 ft
Casing: No record

WELL NO. DBW13

Location: NW¼SW¼ sec. 23, T. 1 S., R. 19 W.
Year drilled: 1951
Total depth: 1,496 ft
Casing: 511.5 ft of 10-inch perforated casing on bottom

APPENDIX C

PUMPING TEST DATA

PUMPING TEST ON ALLUVIAL FAN AQUIFER

Pumped well: FW9-A
Started pump: 9:00 am Aug. 28, 1967
Stopped pump: 11:23 am Aug. 30, 1967
Remarks: Discharge measured with calibrated orifice

Time after pumping started (min)	Discharge (gpm)	Drawdown in observation wells (ft)		
		FW10 (r=544 ft)	FW9 (r=554 ft)	FW8-A (r=1,048 ft)
0.0	0	–	–	–
0.3		0.038	0.0	–
0.75		–	0.100	–
1.00	1,885	–	–	–
1.30		0.380	–	–
1.50		–	0.231	–
2.00	1,865	–	–	–
2.25		–	0.353	–
2.30		0.703	–	–
2.75		–	0.432	–
3.00	1,850	–	–	–
3.30		1.003	–	–
3.50		–	0.504	–
4.00	1,850	1.189	–	–
4.25		–	0.580	–
5.00	1,845	1.402	0.656	–
6.00	1,840	1.603	0.732	–
7.00	1,840	–	0.795	–
8.00	1,835	1.927	0.853	–
9.00	1,830	–	0.904	–
9.20		2.116	–	–
10.00	1,830	–	0.957	–
10.50		2.293	–	–
11.00		–	0.998	–
11.50		2.304	–	–
12.00	1,825	–	1.042	–
12.50		2.417	–	–
13.00		–	1.074	–
14.00	1,825	2.530	1.114	–
15.00		2.593	1.153	–
16.00	1,825	–	1.170	–
16.50		2.699	–	–
17.00		–	1.194	–
18.00	1,825	2.779	1.220	–
19.00		–	1.241	–
20.00	1,825	2.889	1.263	–
22		2.986	1.303	–
24		3.063	1.339	–
26	1,820	3.153	1.368	–
28		3.208	1.397	–
30	1,820	3.264	1.422	–
32		3.323	–	–
34		3.380	1.467	–
36	1,820	3.434	–	–
38		3.478	1.508	–
40	1,815	3.522	–	–
42		3.562	1.537	–
44		3.599	–	–
46		3.635	1.568	–
48		3.663	–	–
50	1,810	3.693	1.593	–
52		3.723	–	–

Appendix C–FW9-A (continued)

Time after pumping started (min)	Discharge (gpm)	Drawdown in observation wells (ft)		
		FW10 (r=544 ft)	FW9 (r=554 ft)	FW8-A (r=1,048 ft)
54		3.743	–	–
56		3.783	–	1.087
58		3.807	–	–
60	1,810	3.832	1.643	–
64		3.896	–	–
68		3.922	–	–
70		–	1.685	–
72		3.961	–	–
76	1,810	3.992	–	–
80		4.033	1.722	–
84		4.072	–	1.205
88		4.090	–	–
90	1,810	–	1.750	–
92		4.119	–	–
100		4.163	1.771	–
110	1,805	4.223	1.799	–
115		–	–	1.274
120	1,805	4.272	1.815	–
130		4.314	–	–
140		4.363	–	–
150	1,805	4.383	1.866	–
160		4.422	–	–
175		–	–	1.352
180	1,805	4.473	1.895	–
210	1,805	4.593	1.920	–
240		4.603	1.939	–
245		–	–	1.398
276		–	1.953	–
277		4.674	–	–
300	1,805	–	1.968	–
306		–	–	1.429
360		4.733	1.985	–
420	1,800	4.772	2.011	–
500		–	–	1.487
510		–	2.026	–
515		4.822	–	–
632		–	2.071	–
635	1,800	4.887	–	–
645		–	–	1.531
825		4.987	–	–
833	1,795	–	2.143	–
837		–	–	1.598
1,123	1,795	5.092	–	–
1,130		–	2.233	–
1,135		–	–	1.678
1,354		5.166	–	–
1,360	1,795	–	2.305	–
1,362		–	–	1.731
1,495		5.196	–	–
1,500	1,795	–	2.333	–
1,505		–	–	1.758
1,687		5.204	–	–
1,695	1,795	–	2.320	–
1,701		–	–	1.747
2,015		5.216	–	–
2,021	1,795	–	2.305	–
2,027		–	–	1.730
2,990		5.399	–	–
3,000	1,795	–	2.491	–
3,004		–	–	1.894
3,010		5.397	–	–
3,016	1,795	–	2.485	–
3,020		–	–	1.891

Appendix C (continued)

PUMPING TESTS ON SHALLOW BRINE AQUIFER

Pumped well: K33
Observation well: K33-A, 49.7 ft from pumped well
Date: Sept. 10, 1967
Started pump: 12:00 noon
Stopped pump: 4:00 pm

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-6.00	6.219	–	Static level
-1.00	6.219	–	Static level
0.0	–	–	Start pump
0.25	6.230	0.011	
0.50	6.235	0.016	
0.75	6.236	0.017	
1.00	6.235	0.016	
1.50	6.239	0.020	
2.00	6.241	0.022	
2.50	6.241	0.022	
3.00	6.242	0.023	
5.00	6.250	0.031	
6.00	6.255	0.036	
6.50	6.258	0.039	
7.00	6.259	0.040	
8.00	6.260	0.041	
9.00	6.267	0.048	
10.00	6.269	0.050	
11	6.267	0.048	
13	6.272	0.053	
15	6.278	0.059	
16	6.280	0.061	
18	6.282	0.063	
20	6.290	0.071	
22	6.292	0.073	
24	6.296	0.077	
26	6.299	0.080	
28	6.300	0.081	
30	6.301	0.082	
34	6.309	0.090	
37	6.311	0.092	
40	6.311	0.092	
45	6.314	0.095	Q=17.9 gpm
50	6.320	0.101	
60	6.318	0.099	
70	6.321	0.102	
80	6.321	0.102	
90	6.324	0.105	
100	6.323	0.104	
120	6.328	0.109	Q=17.9 gpm
140	6.330	0.111	Temp.=64° F
160	6.335	0.116	
180	6.339	0.120	
210	6.340	0.121	
240	6.341	0.122	Stop pump

Pumped well: K69
Depth of well: 21 ft
Observation well: Measurements in pumped well
Date: Sept. 12, 1967
Started pump: 3:15 pm
Stopped pump: 7:15 pm
Remarks: Transfer ditch 130 ft north of K69 is a recharge boundary

K69 (continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-15.00	7.430	–	Scattered clouds, cool, windy
-13.00	7.430	–	
-11.00	7.430	–	
- 3.00	7.420	–	
- 2.00	7.430	–	
- 1.00	7.425	–	
0.00	–	–	Start pump
0.10	7.775	0.345	
0.50	8.558	1.128	
1.00	8.862	1.432	
1.50	9.069	1.639	
2.25	9.365	1.935	
3.00	9.635	2.205	
3.50	9.832	2.402	
4.50	10.150	2.720	
5.00	10.280	2.850	
5.50	10.398	2.968	
6.00	10.490	3.060	
6.50	10.610	3.180	
7.00	10.677	3.247	
7.50	10.750	3.320	
8.00	10.823	3.393	
8.50	10.890	3.460	
9.25	10.967	3.537	
10.00	11.040	3.610	
11.25	11.105	3.675	
12	11.178	3.748	
13	11.220	3.790	
14	11.280	3.850	
15	11.359	3.929	
16	11.420	3.990	
17	11.466	4.036	
18	11.509	4.079	
19	11.535	4.105	
20	11.577	4.147	
22	11.645	4.215	
24	11.700	4.270	
26	11.775	4.345	Q=17.8 gpm
29	11.865	4.435	Windy
30	11.888	4.458	
32	11.938	4.508	
34	11.989	4.559	
36	12.021	4.591	
38	12.039	4.609	
40	12.064	4.634	
42	12.076	4.646	
44	12.092	4.662	
46	12.123	4.693	
48	12.150	4.720	
50	12.179	4.749	
54	12.244	4.814	
58	12.309	4.879	
62	12.352	4.922	
66	12.407	4.977	
71	12.452	5.022	Q=17.2 gpm
74	12.502	5.072	Temp.=63° F
78	12.534	5.104	
82	12.559	5.129	
87	12.570	5.140	
90	12.610	5.180	
94	12.641	5.211	
100	12.700	5.270	
110	12.754	5.324	

Appendix C–K69 (continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
120	12.836	5.406	
130	12.902	5.472	Windy
140	12.929	5.499	Q=17.2 gpm
150	12.980	5.550	
160	13.020	5.590	Very windy
170	13.080	5.650	
180	13.140	5.710	
200	13.210	5.780	
220	13.289	5.859	
240	13.400	5.970	Stop pump

Pumped well: K69-A
Depth of well: 10.2 ft
Observation well: Measurements in pumped well, inside 2-inch perforated pipe; measuring point 4.1 ft above ground level
Date: Sept. 13, 1967
Started pump: 1:20 pm
Stopped pump: 4:00 pm
Remarks: Transfer ditch 130 ft north of K69-A is a recharge boundary

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-10.00	10.995	–	
- 7.00	10.969	–	
- 5.00	10.958	–	
- 3.00	10.954	–	
- 2.00	10.951	–	
0.00	–	–	Start pump
0.10	11.394	0.439	
0.50	11.658	0.703	
1.00	12.054	1.099	
1.50	12.280	1.325	
2.00	12.410	1.455	
2.40	12.460	1.505	
2.80	12.521	1.566	
3.40	12.608	1.653	
3.90	12.610	1.655	
4.20	12.650	1.695	
4.65	12.687	1.732	
5.25	12.695	1.740	
5.70	12.713	1.758	
6.75	12.660	1.705	
7.00	12.656	1.701	
7.65	12.640	1.685	
8.50	12.632	1.677	
9.00	12.630	1.675	
10.00	12.619	1.664	
11	12.638	1.683	
12	12.630	1.675	
13	12.640	1.685	
14	12.618	1.663	
15	12.600	1.645	
16	12.570	1.615	
17	12.569	1.614	
18	12.560	1.605	

K69-A (continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
20	12.566	1.611	
22	12.587	1.632	
24	12.600	1.645	Q=10.7 gpm
26	12.590	1.635	
28	12.581	1.626	
30	12.629	1.674	
32	12.678	1.723	
34	12.678	1.723	
36	12.730	1.775	
38	12.740	1.785	
40	12.708	1.753	
44	12.730	1.775	
48	12.780	1.825	
52	12.783	1.828	Q=10.7 gpm
56	12.720	1.765	Temp.=64° F
60	12.705	1.750	
64	12.722	1.767	
68	12.729	1.744	
72	12.743	1.788	Q=10.7 gpm Temp.=64°F
76	12.751	1.796	
80	12.770	1.815	
90	12.791	1.836	
100	12.801	1.846	
110	12.874	1.919	Q=10.7 gpm
120	12.900	1.945	Temp.=64° F
130	12.900	1.945	
140	12.932	1.977	
150	12.942	1.987	
155	12.971	2.016	
160	12.991	2.036	Stop pump

Pumped well: K70 (Test no. 1)
Depth of well: 10.3 ft
Observation well: K70-A, 30 ft from pumped well
Date: Sept. 2, 1967
Started pump: 7:50 am
Stopped pump: 11:20 am
Remarks: Both wells were open-hole; each was 10.3 ft deep

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
0.00	6.488	–	Static water level
0.25	6.500	0.012	
0.50	6.506	0.018	
0.75	6.516	0.028	
1.00	6.522	0.034	
1.25	6.527	0.039	
1.50	6.533	0.045	
2.00	6.541	0.053	
2.50	6.547	0.059	
3.00	6.550	0.062	
3.25	6.551	0.063	
3.75	6.556	0.068	
4.25	6.559	0.071	

Appendix C–K70 (test no. 1–continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
4.50	6.562	0.074	
5.00	6.568	0.080	
5.50	6.574	0.086	
6.00	6.573	0.085	
6.50	6.573	0.085	
7.00	6.577	0.089	
7.50	6.580	0.092	
8.00	6.587	0.099	
8.50	6.588	0.100	
9.00	6.589	0.101	
10.00	6.590	0.102	
11	6.593	0.105	Q=20.0 gpm
12	6.600	0.112	
13	6.608	0.120	
14	6.608	0.120	
15	6.609	0.121	
16	6.610	0.122	
17	6.610	0.122	
18	6.609	0.121	
19	6.615	0.127	
20	6.620	0.132	
21	6.620	0.132	
22	6.619	0.131	
23	6.625	0.137	
24	6.636	0.148	
25	6.636	0.148	
26	6.637	0.149	
27	6.638	0.150	
28	6.638	0.150	
29	6.641	0.153	
30	6.644	0.156	
32	6.644	0.156	
34	6.648	0.160	
36	6.650	0.162	
40	6.659	0.171	
44	6.666	0.178	
48	6.669	0.181	
52	6.675	0.187	
56	6.679	0.191	
60	6.686	0.198	
64	6.684	0.196	
68	6.690	0.202	
74	6.691	0.203	
78	6.700	0.212	
82	6.700	0.212	
86	6.700	0.212	
90	6.705	0.217	
94	6.709	0.221	
98	6.711	0.223	
100	6.711	0.223	Q=20.0 gpm
110	6.713	0.225	Temp.=62° F
120	6.720	0.232	
130	6.726	0.238	
140	6.727	0.239	
150	6.733	0.245	
160	6.736	0.250	
170	6.738	0.251	
180	6.739	0.253	
190	6.741	0.260	
200	6.748	0.267	
210	6.755	0.267	Stop pump

RECOVERY DATA

Time after pumping started (min)	Time after pumping stopped (min)	Depth to water (ft)	Residual drawdown (ft)
210.00	0.00	6.755	0.267
210.15	0.15	6.750	0.262
210.65	0.65	6.746	0.258
210.90	0.90	6.740	0.252
211.10	1.10	6.739	0.251
211.35	1.35	6.733	0.245
211.60	1.60	6.728	0.240
211.90	1.90	6.722	0.234
212.15	2.15	6.720	0.232
212.40	2.40	6.717	0.229
212.70	2.70	6.710	0.222
213.15	3.15	6.703	0.215
213.40	3.40	6.699	0.211
213.65	3.65	6.697	0.209
214.00	4.00	6.696	0.208
214.75	4.75	6.692	0.204
215.25	5.25	6.676	0.188
215.75	5.75	6.671	0.183
216.25	6.25	6.668	0.180
216.75	6.75	6.660	0.172
217.25	7.25	6.662	0.174
218.75	8.75	6.650	0.162
219.25	9.25	6.650	0.162
222.75	12.75	6.630	0.142
225.50	15.50	6.621	0.133
226.50	16.50	6.619	0.131
228.50	18.50	6.613	0.125
230.50	20.50	6.610	0.122
234	24	6.601	0.113
236	26	6.601	0.113
238	28	6.600	0.112
240	30	6.595	0.107
242	32	6.589	0.101
244	34	6.590	0.102
246	36	6.590	0.102
248	38	6.588	0.100
250	40	6.583	0.095
252	42	6.581	0.093
254	44	6.586	0.098
256	46	6.584	0.096
258	48	6.578	0.090
260	50	6.578	0.090
264	54	6.575	0.087
268	58	6.574	0.086
273	63	6.570	0.082

Pumped well: K70 (Test no. 2)
Depth of well: 15 ft
Observation well: K70-A, 30 ft from pumped well
Date: Sept. 3, 1967
Started pump: 8:00 am
Stopped pump: 10:00 am
Remarks: Both wells were open-hole; each was 15 feet deep

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-12.00	6.595	–	
- 8.00	6.591	–	

Appendix C–K70 (test no. 2–continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-7.00	6.590	–	
-2.00	6.591	–	
0.00	–	–	Start pump
0.25	6.600	0.010	
0.50	6.605	0.015	
0.75	6.610	0.020	
1.00	6.616	0.026	
1.25	6.622	0.032	
1.50	6.625	0.035	
1.75	6.630	0.040	
2.00	6.632	0.042	
2.50	6.638	0.048	
2.75	6.640	0.050	
3.00	6.644	0.054	
3.25	6.647	0.057	
3.50	6.650	0.060	
3.75	6.653	0.063	
4.00	6.658	0.068	
4.50	6.660	0.070	
4.75	6.661	0.071	
5.00	6.663	0.073	
5.50	6.669	0.079	
6.00	6.670	0.080	
6.50	6.676	0.086	
7.00	6.678	0.088	
8.25	6.684	0.094	
9.00	6.690	0.100	
9.50	6.691	0.101	
10.00	6.695	0.105	Q=20.0 gpm
11.00	6.700	0.110	
11.50	6.701	0.111	
12.00	6.706	0.116	
12.50	6.708	0.118	
13.00	6.709	0.119	
13.50	6.710	0.120	
14.00	6.710	0.120	
14.50	6.711	0.121	
15.00	6.712	0.122	
16.00	6.715	0.125	
17.00	6.719	0.129	
18.00	6.721	0.131	
19.00	6.727	0.137	
20.00	6.728	0.138	
21.00	6.730	0.140	
22.00	6.736	0.146	
24.00	6.739	0.149	
26.00	6.740	0.150	
28.00	6.741	0.151	
30	6.749	0.159	
32	6.751	0.161	
34	6.757	0.167	
36	6.760	0.170	
38	6.764	0.174	
40	6.768	0.178	
42	6.769	0.179	
44	6.771	0.181	
46	6.774	0.184	
48	6.777	0.187	
50	6.780	0.190	
54	6.780	0.190	
58	6.787	0.197	
62	6.790	0.200	
66	6.797	0.207	

K70 (test no. 2–continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
70	6.799	0.209	
74	6.805	0.215	Q=20.0 gpm
80	6.805	0.215	Temp.=62° F
90	6.810	0.220	
100	6.817	0.227	
110	6.820	0.230	
119	6.830	0.240	
120	–	–	Stop pump

RECOVERY DATA
(Measured in K70)

Time after pumping started (min)	Time after pumping stopped (min)	Depth to water (ft)	Residual drawdown (ft)
120.00	0.00	7.530	1.133
121.00	1.00	6.710	0.313
121.50	1.50	6.674	0.277
122.00	2.00	6.652	0.255
122.50	2.50	6.630	0.233
123.00	3.00	6.617	0.220
123.50	3.50	6.606	0.209
124.00	4.00	6.600	0.203
124.50	4.50	6.590	0.193
125.00	5.00	6.580	0.183
125.50	5.50	6.578	0.181
126.00	6.00	6.570	0.173
126.50	6.50	6.562	0.165
127.00	7.00	6.558	0.161
127.50	7.50	6.554	0.157
128.00	8.00	6.556	0.159
128.50	8.50	6.550	0.153
129.00	9.00	6.545	0.148
129.50	9.50	6.540	0.143
130.00	10.00	6.540	0.143
131	11	6.536	0.139
132	12	6.520	0.123
133	13	6.520	0.123
134	14	6.518	0.121
135	15	6.517	0.120
136	16	6.511	0.114
137	17	6.507	0.110
138	18	6.505	0.108
139	19	6.503	0.106
140	20	6.495	0.098
142	22	6.490	0.093
144	24	6.492	0.095
146	26	6.486	0.089
148	28	6.488	0.091
150	30	6.483	0.086
152	32	6.480	0.083
154	34	6.480	0.083
156	36	6.470	0.073
158	38	6.471	0.074
160	40	6.465	0.068
162	42	6.469	0.072
164	44	6.467	0.070
166	46	6.462	0.065
168	48	6.467	0.070
170	50	6.463	0.066

Appendix C–K70 (continued)

Time after pumping started (min)	Time after pumping stopped (min)	Depth to water (ft)	Residual drawdown (ft)
172	52	6.463	0.066
176	56	6.456	0.059
180	60	6.454	0.057
184	64	6.452	0.055
188	68	6.450	0.053
192	72	6.450	0.053
196	76	6.444	0.047
200	80	6.442	0.045
204	84	6.441	0.044
208	88	6.440	0.043
212	92	6.444	0.047
220	100	6.432	0.035
230	110	6.435	0.038
240	120	6.432	0.035
250	130	6.435	0.038

Pumped well: K70 (Test no. 3)
Depth of well: 21 ft
Observation well: K70-A, 30 ft from pumped well
Date: Sept. 5, 1967
Started pump: 9:00 am
Stopped pump: 4:00 pm
Remarks: Both wells were open-hole; each was 21 ft deep

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
-11.00	6.726	–	
- 5.00	6.726	–	
- 3.00	6.725	–	Static level
0.00	–	–	Start pump
0.25	6.730	0.005	
0.50	6.736	0.011	
0.75	6.739	0.014	
1.00	6.740	0.015	
1.50	6.747	0.022	
1.75	6.751	0.026	
2.00	6.755	0.030	
2.50	6.756	0.031	
2.75	6.760	0.035	
3.00	6.766	0.041	
3.50	6.770	0.045	
4.00	6.773	0.048	
4.50	6.780	0.055	
5.00	6.784	0.059	
5.50	6.790	0.065	
6.00	6.791	0.066	
6.50	6.791	0.066	
7.00	6.795	0.070	
7.50	6.801	0.076	
8.00	6.806	0.081	
8.50	6.810	0.085	
9.00	6.812	0.087	
10.00	6.817	0.092	
11	6.820	0.095	

K70 (test no. 3–continued)

Time after pumping started (min)	Depth to water (ft)	Drawdown (ft)	Remarks
12	6.829	0.104	
13	6.830	0.105	
14	6.838	0.113	
15	6.841	0.116	
16	6.845	0.120	
17	6.847	0.122	
18	6.850	0.125	
19	6.850	0.125	
20	6.853	0.128	
22	6.860	0.135	
24	6.863	0.138	
26	6.871	0.146	Q=21.4 gpm
28	6.877	0.152	
30	6.881	0.156	
32	6.885	0.160	
34	6.890	0.165	
36	6.895	0.170	
38	6.896	0.171	
40	6.900	0.175	
42	6.901	0.176	
44	6.905	0.180	
46	6.905	0.180	
48	6.910	0.185	
50	6.911	0.186	
54	6.920	0.195	
58	6.920	0.195	
62	6.925	0.200	
66	6.930	0.205	
70	6.935	0.210	
74	6.939	0.214	Q=20.0 gpm
78	6.940	0.215	Temp.=62° F
82	6.945	0.220	
86	6.950	0.225	
90	6.951	0.226	
94	6.955	0.230	
98	6.957	0.232	
102	6.961	0.236	
110	6.964	0.239	
120	6.970	0.245	
130	6.977	0.252	
140	6.980	0.255	
150	6.985	0.260	Q=20.0 gpm
160	6.988	0.263	Temp.=62° F
170	6.989	0.264	
180	6.997	0.272	
190	6.998	0.273	
200	6.997	0.272	
220	7.001	0.276	Q=20.0 gpm
240	7.010	0.285	Temp.=62° F
260	7.011	0.286	
280	7.015	0.290	
300	7.014	0.289	
370	7.021	0.296	
420	7.030	0.305	Severe rainstorm began; stopped pump. No recovery measurements

APPENDIX D

CHEMICAL ANALYSES OF SHALLOW BRINE

COMPOSITION OF BRINE FROM SHALLOW WELLS

(Analyses by Bonneville, Ltd.)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
K1	7-13-65	0-15.75	B	1.2145	1.39	7.00	17.65		
	7-30-65	0-15.75	P	1.2140	1.41	6.86	17.20		
	11-19-65	0-15.75	PT-60	1.2140	1.38	6.94	17.43		
K2	6-26-65	0-17.0	BP	1.2150	1.32	7.64	16.53		
	6-30-65	0-20.0	BP	1.2120	1.33	7.47	16.53		
	7-30-65	0-20.0	BP	1.2135	1.34	8.01	15.91		
K3	7-31-65	0-24.4	BP	1.2050	1.11	1.63	22.61		
	10-4-65	0-24.4	PT	1.2015	1.15	1.70	22.11		
K4	9-28-65	0-30.0	PT	1.2020	1.06	1.65	22.43		
K4-A	11-9-65	0-23.0	BP	1.1950	1.07	1.75	21.69		
K5	7-31-65	0-25.0	BP	1.2105	1.19	1.85	23.18		
	10-4-65	0-25.0	PT	1.2020	1.23	1.80	21.81		
	7-18-66	0-25.0	P-10	1.2010	1.10	1.83	–		
	8-23-66	0-25.0	P-10	1.2000	1.23	1.90	–		
	10-10-66	0-25.0	PT-10	1.2000	1.27	1.90	–		
	7-1-67	0-25.0	P-10	1.2005	1.06	1.35	22.34		57
	9-9-67	0-25.0	P-10	1.1990	1.14	1.50	22.24	0.50	
K6	7-27-65	0-23.0	BP	1.2040	1.04	1.60	23.04		
	10-3-65	0-23.0	PT	1.2020	0.99	1.51	22.59		
K7	6-18-65	0-25.0	PT	1.2035	1.48	1.49	22.26		
	7-18-66	0-25.0	P-10	1.1990	1.04	1.55	–		
K7-A	9-2-65	0-25.0	BP	–	1.03	1.51	23.03		
K8-B	10-19-65	0-1.0	B	1.2100	1.14	1.46	23.51		
	11-7-65	0-23.0	PT-120	1.2035	1.18	1.79	22.83		
K8-C	10-4-65	0-23.0	PT	1.2040	1.18	1.64	22.57		
	5-23-66	0-23.0	BP	1.2040	1.03	1.49	–		
	6-15-66	0-23.0	BP	1.2045	1.03	1.58	–		
	7-31-66	0-23.0	PT	1.2050	1.12	1.61	–		
	8-23-66	0-23.0	P-10	1.2065	1.15	1.66	–		
	10-10-66	0-23.0	P-10	1.2085	1.16	1.67	–		
	7-1-67	0-23.0	P-10	1.2005	1.06	1.35	22.34		58
	9-9-67	0-23.0	P-10	1.2085	1.14	1.30	23.48	0.44	67
K9	7-30-65	0-25.0	BP	1.1945	1.17	2.19	21.04		
	9-30-65	0-25.0	PT	1.1955	1.20	2.02	20.94		
	7-18-66	0-25.0	P-10	1.1900	1.13	1.98	–		
	8-23-66	0-25.0	P-10	1.2000	1.26	1.97	–		
	10-10-66	0-25.0	P-10	1.1990	1.24	1.96	–		
K10	7-30-65	0-25.0	BP	1.1950	1.23	2.19	21.05		
	9-29-65	0-25.0	PT	1.1960	1.26	2.12	20.71		
	7-1-67	0-25.0	P-10	1.1995	1.29	1.93	21.46		59
	9-9-67	0-25.0	P-10	1.1975	1.32	1.88	21.26	0.61	64
K10-A	11-9-65	0-23.0	B	1.1990	1.03	1.84	22.10		
K11	7-30-65	0-25.0	BP	1.1940	1.18	1.88	21.13		
	9-28-65	0-25.0	PT	1.1925	1.19	0.97	20.61		

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
	10-19-65	0-0.7	BP	1.2080	0.87	1.35	23.87		
	10-19-65	0-4.3	BP	1.2005	1.30	1.96	21.87		
	7-18-66	0-25.0	P-10	1.1930	1.21	1.91	–		
	8-19-66	0-25.0	PT-450	1.1930	1.22	1.95	–		
	8-23-66	0-25.0	P-10	1.1925	1.22	1.98	–		
	10-10-66	0-25.0	P-10	1.1890	1.18	1.89	–		
K11-A	7-30-65	0-25.0	BP	1.1990	1.17	1.95	21.90		
K12	11-15-65	0-25.0	PT	–	1.10	1.84	20.95		
	6-9-66	0-25.0	BP	1.1915	1.10	1.89	–		
K13	6-9-66			1.1920	1.18	2.14	–		
K14	6-9-66		BP	1.1935	1.03	1.65	–		
K14-A	11-9-65	0-23.0	B	1.1740	0.63	1.13	20.18		
	8-15-66	0-23.0	PT-120	1.1960	1.12	1.81	–		
K15	7-30-65	0-25.0	BP	1.2055	1.10	2.10	22.31		
	10-2-65	0-25.0	PT	1.1965	1.08	1.88	21.77		
K16	9-30-65	0-25.0	PT	1.2020	1.24	2.06	21.45		
K17	8-13-65	0-22.0	BP	1.2045	1.31	2.06	22.31		
	10-5-65	0-22.0	PT-50	1.1990	1.37	2.03	21.89		
	7-18-66	0-22.0	BP	1.2035	1.33	1.99	–		
K18	11-9-65	0-23.0	B	1.1905	0.65	1.21	22.11		
	11-16-65	0-23.0	PT	–	0.71	1.16	22.39		
K19	11-9-65	0-23.0	B	1.1900	0.59	1.08	22.30		
	11-16-65	0-23.0	PT-60	–	0.64	1.04	22.41		
K20	11-9-65	0-23.0	B	1.1850	0.65	1.20	21.40		
	11-16-65	0-23.0	PT	–	0.69	1.14	21.72		
K21	9-2-65	0-23.0	B	–	0.67	1.07	24.43		
K22	9-2-65	0-25.0	BP	–	0.59	1.02	23.96		
	10-3-65	0-25.0	PT	1.2010	0.71	1.13	23.22		
	9-15-67	0-25.0	B	1.1970	0.72	0.78	23.12	0.38	
K23	10-19-65	0-3.6	BP	1.2020	1.21	2.00	22.13		
	10-19-65	0-25.0	BP	1.1990	1.11	1.77	22.04		
	11-16-65	0-25.0	PT	–	1.13	1.90	21.23		
K24	7-26-65	0-23.0	BP	1.1995	1.25	2.03	21.94		
	10-4-65	0-23.0	PT-50	1.1945	1.23	1.99	20.95		
	7-18-66	0-23.0	P-10	1.1990	1.07	1.77	–		
	8-23-66	0-23.0	P-10	1.1995	1.01	1.74	–		
	10-10-66	0-23.0	P-10	1.1945	1.09	1.78	–		
K24-A	10-22-65	0-4.8	BP	1.1970	1.26	2.03	21.45		
	10-22-65	5.5-10.5	BP	1.1980	1.21	1.98	21.12		
	10-22-65	10.5-15.0	BP	1.1905	1.14	1.93	20.67		
	11-1-65	15.5-19.0	BP	1.1875	1.10	1.87	20.68		
	11-7-65	0-19.0	PT-64	1.1945	1.23	2.00	21.34		
K25	11-9-65	0-23.0	B	1.1945	0.70	1.14	22.56		
	8-14-66	0-23.0	PT-90	1.1940	0.74	1.16	–		
K26	7-26-65	0-23.0	BP	1.2075	0.98	1.46	23.65		
	9-30-65	0-23.0	PT-50	1.2055	1.18	1.75	22.57		

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[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
	8-6-67	0-23.0	P-10	1.2035	1.36	2.02	22.49	0.50	63
	9-9-67	0-23.0	P-10	1.2045	1.26	1.65	22.59	0.49	65
K27	10-19-65	0-0.7	B	1.2095	0.92	1.41	23.97		
	11-8-65	0-23.0	B	1.2100	1.04	1.63	23.57		
K27-A	10-26-65	0-1.0	BP	1.2085	0.85	1.12	24.12		
	10-26-65	0-5.5	BP	1.2095	0.86	1.15	23.99		
	10-28-65	5.5-9.7	BP	1.2005	1.43	2.23	21.05		
	10-28-65	0-10.5	BP	1.2085	0.94	1.31	23.77		
	10-28-65	10.5-15.5	BP	1.1980	1.41	2.19	21.03		
	10-28-65	15.5-20.4	BP	1.1975	1.17	1.77	21.81		
	11-8-65	0-20.4	PT-120	1.1995	1.34	2.09	21.10		
	5-23-66	0-20.4	BP	1.2090	1.23	2.02	–		
	6-15-66	0-20.4	BP	1.2095	1.30	2.05	–		
	7-31-66	0-20.4	PT	1.2045	1.37	2.16	–		
	8-17-66	0-20.4	PT-450	1.2015	1.33	2.06	–		
	10-10-66	0-20.4	P-10	1.2060	1.32	2.02	–		
	7-1-67	0-20.4	P-10	1.2060	1.20	1.62	22.97		67
	9-9-67	0-20.4	P-10	1.2105	1.35	1.86	22.90	0.51	67
K28	7-27-65	0-23.0	BP	1.2075	1.02	1.50	23.62		
	9-30-65	0-23.0	PT-50	1.2055	1.07	1.55	22.93		
K29	7-26-65	0-23.0	BP	1.2095	1.26	1.70	23.28		
	10-1-65	0-23.0	PT-50	1.2075	1.08	1.49	23.41		
	8-6-67	0-23.0	P-10	1.2070	0.94	1.32	24.00	0.38	68
	9-9-67	0-23.0	P-10	1.2080	0.87	0.96	24.13	0.37	70
K30	6-28-65	0-6.0	BP	1.2075	1.31	3.35	20.85		
	6-28-65	0-12.0	BP	1.2075	1.32	3.32	20.80		
	6-30-65	0-22.0	BP	1.2080	1.32	3.55	20.95		
	9-10-65	0-22.0	PT	1.2080	1.34	3.26	20.91		
	10-20-65	0-3.9	BP	1.2075	1.18	2.60	21.97		
	5-23-66	0-22.0	BP	1.2060	1.32	3.13	–		
	7-15-66	0-22.0	P-10	1.2060	1.34	3.30	–		
	8-23-66	0-22.0	P-10	1.2065	1.34	3.23	–		
	10-7-66	0-22.0	P-10	1.2060	1.36	3.31	–		
	7-3-67	0-22.0	P-10	1.2080	1.31	3.14	21.13		56
	9-9-67	0-22.0	P-10	1.2080	1.34	3.17	21.08	0.49	64
K31	6-30-65	0-9.5	BP	1.2230	3.28	7.02	16.80		
	7-13-65	0-20.0	BP	1.2181	1.27	12.11	12.24		
	10-20-65	0-0.6	BP	1.2195	2.18	1.85	15.06		
	11-20-65	0-20.0	PT-50	1.2195	1.89	10.36	13.70		
K32	8-10-65	0-23.0	BP	1.1855	0.95	1.50	21.08		
	9-10-67	0-23.0	P-10	1.1905	0.83	0.98	21.69	0.43	66
K33	8-13-65	0-23.0	BP	1.1835	0.88	1.22	21.17		
	11-17-65	0-23.0	PT	–	1.04	1.43	22.32		
	6-15-66	0-23.0	BP	1.2060	1.40	1.36	–		
	6-24-66	0-23.0	BP	1.2020	0.97	1.31	–		
	7-15-66	0-23.0	P-10	1.2060	0.96	1.34	–		
	8-4-66	0-23.0	PT	1.2050	1.09	1.29	–		
	8-24-66	0-23.0	PT	1.2055	1.15	1.88	–		
	10-7-66	0-23.0	P-10	1.2040	1.17	1.74	–		
	9-10-67	0-23.0	PT-240	1.2085	0.99	1.03	24.02	0.41	66
K33-A	10-8-65	2.3-5.0	BP	1.2030	0.95	1.32	23.61		
	10-8-65	5.0-10.0	BP	1.2075	0.98	1.41	23.73		
	10-8-65	10.0-14.0	BP	1.2075	1.01	1.36	23.54		
	10-9-65	15.0-19.4	BP	1.2045	1.23	1.78	22.38		
	10-9-65	0-19.4	BP	1.2075	0.97	1.32	23.66		

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
K34	8-23-65	0-23.0	BP	1.2090	0.66	1.16	24.34		
	9-11-65	0-23.0	PT-60	1.1990	0.93	1.26	23.56		
K34-A	7-27-65	0-23.0	BP	1.2090	0.65	1.06	24.66		
	10-19-65	0-1.5	BP	1.2095	0.87	1.26	24.21		
	5-10-66	0-23.0	B	1.2065	0.57	0.95	24.73		
	6-10-66	0-23.0	BP	1.2065	0.58	0.98	–		
	7-15-66	0-23.0	P-10	1.2085	0.59	1.02	–		
	8-23-66	0-23.0	P-10	1.2085	0.58	1.01	–		
	10-7-66	0-23.0	P-10	1.2065	0.58	0.98	–		
K35	7-27-65	0-23.0	BP	1.2060	1.28	1.66	22.79		
	10-1-65	0-23.0	PT	1.1975	1.18	1.53	22.17		
K36	8-9-65	0-23.0	BP	1.2085	0.80	1.24	24.48		
	11-6-65	0-23.0	PT-60	1.2080	1.81	2.46	21.73		
K37	8-9-65	0-23.0	BP	1.2105	1.49	2.05	22.88		
	10-21-65	0-1.7	BP	1.2100	0.70	1.09	24.14		
	11-4-65	0-23.0	PT	1.2090	1.78	2.39	21.85		
	5-10-66	0-23.0	B	1.2080	0.81	1.26	24.28		
	6-10-66	0-23.0	BP	1.2085	0.83	1.29	–		
	7-15-66	0-23.0	P-10	1.2095	1.80	2.33	–		
	8-23-66	0-23.0	P-10	1.2100	1.66	2.24	–		
	10-11-66	0-23.0	P-10	1.2095	1.90	2.55	–		
K38	8-10-65	0-23.0	BP	1.2085	0.93	1.31	24.31		
	5-10-66	0-23.0	B	1.2075	0.66	0.99	24.54		
	6-15-66	0-23.0	BP	1.2075	0.67	1.04	–		
	7-31-66	0-23.0	PT	1.2070	0.91	1.28	–		
	8-23-66	0-23.0	P-10	1.2065	0.94	1.34	–		
	10-11-66	0-23.0	P-10	1.2060	0.99	1.32	–		
K39	10-29-65	0-23.0	B	1.2080	0.65	0.98	24.31		
	11-10-65	0-23.0	PT-120	1.2055	1.35	1.89	22.56		
	6-9-66	0-23.0	BP	1.2075	0.53	0.92	–		
K39-A	10-29-65	0-23.0	B	1.2070	0.78	1.17	24.00		
K40	10-29-65	0-23.0	B	1.2085	0.88	1.20	23.75		
	11-10-65	0-23.0	PT-60	1.2070	1.26	1.76	22.95		
K41	9-3-65	0-23.0	BP	1.2005	1.99	2.95	19.93		
	9-21-65	0-23.0	PT	1.1907	1.86	2.68	19.98		
	6-1-66	0-23.0	BP	1.1885	1.74	2.73	–		
	6-24-66	0-23.0	BP	1.1895	1.76	2.69	–		
	8-24-66	0-23.0	PT	1.1995	2.11	3.86	–		
	10-11-66	0-23.0	P-10	1.1980	2.14	3.08	–		
K42	9-3-65	0-23.0	BP	1.2065	2.22	3.34	19.78		
	11-5-65	0-23.0	PT-50	1.2050	1.76	2.80	21.30		
K43	9-3-65	0-23.0	BP	1.2055	2.02	3.10	20.05		
	9-21-65	0-23.0	PT-100	1.1937	2.01	3.16	19.54		
	6-1-66	0-23.0	BP	1.2020	1.58	2.73	–		
	6-15-66	0-23.0	BP	1.2025	1.47	2.38	–		
	7-15-66	0-23.0	BP	1.2020	1.64	2.60	–		
	8-12-66	0-23.0	PT-420	1.2005	1.91	2.98	–		
	10-11-66	0-23.0	P-10	1.2030	1.85	2.91	–		
K43-A	9-3-65	0-23.0	BP	1.2050	1.85	2.77	20.46		
K44	9-3-65	0-23.0	BP	1.2060	2.02	3.16	19.87		

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
	9-21-65	0-23.0	BP	1.1957	1.53	2.28	21.23		
	6-1-66	0-23.0	BP	1.2025	1.44	2.35	–		
K45	11-4-65	0-23.0	BP	1.1990	1.63	2.52	20.68		
	11-5-65	0-23.0	PT-60	1.1995	1.90	3.05	19.74		
	6-1-66	0-23.0	BP	1.2025	1.89	2.89	–		
	7-15-66	0-23.0	P-10	1.2000	1.92	3.06	–		
	8-24-66	0-23.0	PT	1.1990	1.45	3.78	–		
	10-11-66	0-23.0	P-10	1.2020	1.93	3.07	–		
K46	11-5-65	0-23.0	PT	1.1845	0.77	1.08	22.12		
	11-20-65	0-2.5	BP	1.1905	0.74	1.16	22.20		
	7-8-66	0-23.0	P-10	1.1885	0.72	0.77	22.03		68
	9-15-67	0-23.0	B	1.1905	0.74	0.78	22.01	0.41	71
K47	11-2-65	0-5.5	BP	1.2050	1.96	3.12	20.55		
	11-2-65	3.0-4.0	BP	1.2070	1.94	3.19	20.48		
	11-2-65	5.5-10.5	BP	1.2070	1.97	3.19	20.55		
	11-2-65	10.5-15.5	BP	1.2020	1.86	3.11	20.24		
	11-5-65	0-19.0	PT-60	1.2035	1.95	3.15	20.19		
	6-1-66	0-19.0	BP	1.2055	1.51	2.31	–		
K48	8-3-65	0-23.0	BP	–	0.61	0.47	11.90		
	9-27-65	0-23.0	PT	1.0990	0.62	0.46	11.93		
	6-1-66	0-23.0	BP	1.0980	0.59	0.45	–		
	6-15-66	0-23.0	BP	1.0985	0.60	0.45	–		
	8-6-67	0-23.0	P-10	1.0990	0.67	0.41	11.87	0.29	66
	9-15-67	0-23.0	P-10	1.0990	0.60	0.27	11.66	0.29	66
K49	8-11-65	0-23.0	BP	1.0880	0.56	0.57	10.44		
	9-27-65	0-23.0	PT	1.0850	0.55	0.62	9.96		
	6-1-66	0-23.0	BP	1.1140	0.69	0.80	–		
K49-A	6-9-66	6.0-7.0	BP	1.1355	0.85	1.07	–		
K50	8-11-65	0-23.0	BP	1.1425	0.87	0.98	16.55		
	9-27-65	0-23.0	PT	1.1440	0.94	1.04	16.74		
	10-20-65	0-1.7	BP	1.1445	0.89	0.97	16.66		
	6-1-66	0-23.0	BP	1.1470	0.91	1.10	–		
	6-24-66	0-23.0	BP	1.1475	0.91	1.06	–		
	8-24-66	0-23.0	PT	1.2045	1.64	2.46	–		
	10-8-66	0-23.0	P-10	1.1540	0.94	1.18	–		
K51	8-30-65	0-23.0	BP	–	1.37	1.77	19.09		
	6-1-66	0-23.0	BP	1.1710	1.57	1.99	–		
	6-15-66	0-23.0	BP	1.1715	1.60	2.05	–		
K52	8-12-65	0-23.0	BP	1.2050	0.70	1.64	24.65		
	10-21-65	0-0.7	BP	1.2085	0.46	0.86	24.45		
	11-8-65	0-23.0	PT-60	1.2030	0.85	1.32	23.09		
	5-10-66	0-23.0	B	1.2065	0.45	0.90	24.74		
	7-31-66	0-23.0	PT	1.2085	0.56	0.92	–		
	8-24-66	0-23.0	PT	1.2085	0.52	1.06	–		
	10-12-66	0-23.0	P-10	1.2065	0.44	0.75	–		
	7-3-67	0-23.0	P-10	1.2070	0.15	0.15	25.42		74
	9-9-67	0-23.0	P-10	1.2060	0.30	0.34	25.09	0.35	77
K53	8-10-65	0-23.0	BP	1.1055	0.64	0.87	12.61		
	9-23-65	0-23.0	PT	1.1005	0.64	0.81	11.59		
	10-21-65	0-2.4	BP	1.0935	0.55	0.81	10.34		
	7-3-67	0-23.0	P-10	1.1355	0.70	0.84	15.16		67
	9-15-67	0-23.0	P-10	1.1360	0.73	0.89	15.49	0.55	70
K54	11-6-65	0-23.0	PT-60	1.0785	0.64	0.87	9.00		

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
K55	7-13-65	0-18.0	BP	1.2080	1.25	2.98	21.66		
	7-28-65	0-18.0	BP	1.2085	1.26	2.91	21.56		
	11-11-65	0-18.0	PT-60	1.2080	1.25	2.82	21.94		
K56	8-12-65	0-23.0	BP	1.2095	2.66	2.02	21.54		
	8-20-65	0-23.0	BP	1.1925	2.25	1.79	19.65		
	5-10-66	0-23.0	B	1.2230	3.52	1.59	22.80		
	6-10-66	0-23.0	BP	1.2225	3.14	1.40	–		
	7-31-66	0-23.0	PT	1.1965	2.88	1.88	–		
	8-24-66	0-23.0	PT	1.1985	2.99	2.30	–		
	10-12-66	0-23.0	P-10	1.2075	3.35	1.82	–		
K56-B	9-15-65	0-23.0	PT	1.1935	1.76	2.38	19.91		
K57	10-23-65	0-4.0	BP	1.2095	2.65	3.74	19.20		
	10-23-65	0-6.0	BP	1.2050	2.42	3.34	19.21		
	10-23-65	0-10.0	BP	1.2045	2.40	3.28	19.40		
	10-23-65	0-15.0	BP	1.2055	2.40	3.31	19.64		
	10-23-65	0-19.0	BP	1.2070	2.41	3.33	19.74		
	11-6-65	0-19.0	PT-60	1.2020	2.35	3.33	20.15		
	6-1-66	0-19.0	BP	1.2030	2.07	2.89	–		
	6-24-66	0-19.0	BP	1.2025	2.07	2.88	–		
	7-31-66	0-19.0	PT	1.2025	2.02	2.76	–		
	8-24-66	0-19.0	PT	1.2015	1.91	3.27	–		
	10-12-66	0-19.0	P-10	1.2025	1.78	2.44	–		
K58	8-10-65	0-23.0	BP	1.1985	0.96	1.44	22.93		
	10-20-65	0-1.6	BP	1.2075	0.64	0.93	24.54		
	11-10-65	0-23.0	PT-60	1.1975	0.86	1.25	22.46		
	6-9-66	0-23.0	BP	1.1975	0.77	1.15	–		
	7-15-66	0-23.0	P-10	1.1985	1.09	1.48	–		
	8-24-66	0-23.0	PT	1.2010	1.46	2.85	–		
	10-7-66	0-23.0	P-10	1.2005	1.38	1.87	–		
K59	8-16-65	0-23.0	BP	1.2115	1.00	1.01	24.66		
	11-11-65	0-23.0	PT-60	1.2010	0.89	1.12	23.72		
K60	8-16-65	0-23.0	BP	1.2095	0.71	1.24	24.26		
	11-11-65	0-23.0	PT-60	1.2070	0.61	1.08	24.57		
	5-10-66	0-23.0	B	1.2070	0.53	0.96	–		
	7-31-66	0-23.0	PT	1.2085	0.60	1.18	–		
	8-24-66	0-23.0	PT	1.2080	0.52	1.23	–		
	10-12-66	0-23.0	P-10	1.2070	0.50	0.88	–		
K61	9-29-65	0-23.0	BP	1.2080	0.68	1.05	24.64		
	10-19-65	0-1.5	BP	1.2135	1.49	1.20	23.82		
	11-17-65	0-23.0	PT-60	–	2.08	1.34	22.65		
	5-10-66	0-23.0	B	1.2095	0.89	0.85	24.77		
	7-31-66	0-23.0	PT	1.2140	1.40	1.01	–		
	8-24-66	0-23.0	PT	1.2235	2.92	1.49	–		
	10-12-66	0-23.0	P-10	1.2150	1.75	1.06	–		
K62	10-?-65	0-4.0	BP	1.2100	0.69	1.15	24.33		
	10-?-65	5.0-10.0	BP	1.2085	1.17	1.65	23.18		
	10-?-65	10.0-15.0	BP	1.2060	1.17	1.64	22.79		
	10-?-65	15.0-20.0	BP	1.1930	1.04	1.55	21.20		
K62-A	10-7-65	0-23.0	PT	1.2105	1.02	1.54	23.47		
K63	10-25-65	0-4.2	BP	1.0855	0.52	0.72	9.78		
	10-27-65	5.5-10.5	BP	1.1105	0.69	0.88	12.69		
	10-27-65	0-19.0	BP	1.0910	0.56	0.77	10.35		

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

Well no.	Date	Depth interval (ft)	Sampling method[1]	Specific gravity	Percent				Temperature (° F)
					KCl	$MgCl_2$	NaCl	SO_4	
K63-A	10-25-65	0-3.5	BP	1.0705	0.44	0.68	7.94		
	10-25-65	0-7.0	BP	1.0800	0.46	0.68	9.16		
	10-25-65	0-12.0	BP	1.0685	0.51	0.76	10.00		
	10-25-65	0-19.0	BP	1.0900	0.53	0.74	10.24		
	11-22-65	0-19.0	PT	1.1010	0.61	0.90	11.60		
K64	10-30-65	0-1.8	BP	1.2065	0.09	0.40	25.25		
	10-30-65	0-5.0	BP	1.2055	0.11	0.38	25.30		
	10-30-65	0-10.0	BP	1.2055	0.10	0.36	25.29		
	10-30-65	0-15.0	BP	1.2000	0.84	1.34	22.99		
	10-30-65	0-19.0	BP	1.2005	0.80	1.27	23.02		
	11-15-65	0-19.0	PT-60	–	1.43	2.04	20.74		
	5-10-66	0-19.0	BP	1.2045	0.10	0.33	25.48		
	6-10-66	0-19.0	BP	1.2055	0.19	0.54	–		
	7-31-66	0-19.0	PT	1.2040	0.63	1.08	–		
	8-24-66	0-19.0	PT	1.2050	0.64	1.30	–		
	10-12-66	0-19.0	P-10	1.2000	0.95	1.42	–		
K65	6-24-66	0-19.0	B	1.1340	0.29	0.65	–		
	8-8-66	0-19.0	PT-420	1.1355	0.31	0.64	–		
K65-A	6-24-66	0-19.0	B	1.1350	0.30	0.64	–		
K66	8-10-66	0-19.0	PT-420	1.1870	0.75	1.23	–		
K66-A	6-28-66	0-19.0	BP	1.1915	0.78	1.23	–		
K66-B	6-28-66	0-10.0	BP	1.1930	0.76	1.23	–		
K67	7-3-66	0-19.0	B	1.1685	0.70	0.97	–		
	8-14-66	0-19.0	PT-420	1.1670	0.69	0.93	–		
K67-A	7-3-66	0-19.0	B	1.1710	0.70	0.94	–		
K68	8-16-66	0-19.0	PT-360	1.1255	1.23	0.84	–		
K69	9-11-67	0-10.0	PT-120	1.1885	0.72	0.82	21.92	0.40	
	9-12-67	0-21.0	PT-240	1.1875	0.73	0.79	21.70	0.40	63
K69-A	9-13-67	0-10.2	PT-80	1.1885	0.76	0.85	21.93	0.41	
K70	9-2-67	0-10.3	PT-210	1.1995	0.80	1.66	23.24	0.40	63
	9-3-67	0-15.0	PT-120	1.2000	0.82	0.86	23.10	0.40	62
	9-5-67	0-21.0	PT-420	1.1995	0.86	0.88	23.29	0.41	
BR1	7-21-65	0-5.5	P	1.2035	1.42	2.29	21.68		
BR2	7-21-65	0-5.5	P	1.2115	1.23	1.62	23.65		
BR3	7-22-65	0-3.0	BP	1.2100	0.59	0.98	25.26		
	7-23-65	0-5.5	BP	1.2095	0.60	0.99	24.68		

---

[1] B = Bailed. BP = Bailed or pumped. P = Pumped. PT = Pumping test. P-10 = Pumped 10 minutes.

Appendix D (continued)

COMPOSITION OF BRINE FROM DITCHES
(Analyses by Bonneville, Ltd.)

Source	Date	Specific gravity	Percent		
			KCl	$MgCl_2$	NaCl
PP1	7-24-67	1.1960	0.83	–	–
	8-1-67	1.1360	0.545	0.605	–
	8-7-67	1.1700	0.694	0.744	–
	8-14-67	1.1905	0.779	0.808	–
	8-21-67	1.1985	0.818	0.841	–
	8-28-67	1.1880	0.780	0.848	–
	9-3-67	1.1925	0.881	0.960	–
	9-11-67	1.1935	1.023	1.111	–
PP2	7-24-67	1.1630	0.70	–	–
	8-1-67	1.1570	0.668	0.831	–
	8-7-67	1.1830	0.814	0.968	–
	8-14-67	1.1915	0.846	0.961	–
	8-21-67	1.1915	0.816	0.884	–
	8-28-67	1.1910	0.832	0.923	–
	9-3-67	1.1890	0.894	0.962	–
	9-11-67	1.1920	0.943	1.037	–
PP3	8-8-67	1.1990	0.869	0.840	–
	8-14-67	1.2090	0.93	1.06	–
	8-21-67	1.2040	0.90	1.03	–
	8-28-67	1.1990	1.02	1.11	–
	9-3-67	1.2020	1.22	1.37	–
	9-11-67	1.2040	1.35	1.47	–
PP4	8-2-67	1.1570	1.09	1.15	–
Booster 1-NLA	9-15-67	1.2095	0.68	0.79	–
Booster-Encl. Area	8-30-67	1.1950	0.45	0.92	–
	9-15-67	1.2010	1.01	1.15	–

APPENDIX E

COMPUTER PROGRAM: KCLCON

```
C******************************        PROGRAM KCLCON        *************************
C***********************************************************************************************
C
C
C                 CALCULATES KCL CONCENTRATION IN BRINE AFTER KYRS OF PRODUCTION
C                                             PROGRAMMED BY  L.J. TURK
C
C
C..........DEFINE VARIABLES.........
C
C          NUMBER = NUMBER OF CASES
C          XMAX = DISTANCE IN FEET FROM DITCH TO LIMIT OF FLOW SYSTEM
C          THICK = AQUIFER THICKNESS (FEET)
C          DDITCH = DEPTH OF DITCH (FEET)
C          DBRINE = DEPTH TO BRINE IN DITCH (FEET)
C          POR = TOTAL POROSITY OF AQUIFER
C          EPOR = EFFECTIVE POROSITY (SPECIFIC YIELD) OF AQUIFER
C          XPOR = TOTAL POROSITY - EFFECTIVE POROSITY
C          RCONC = KCL CONCENTRATION OF RAIN
C          CONC1 = INITIAL KCL CONCENTRATION OF AQUIFER
C          VEL1 = AVERAGE FLOW VELOCITY AT DITCH FACE (FEET/YEAR)
C          NTUBE = TOTAL NUMBER OF FLOW TUBES
C          NTUBE2 = NUMBER OF FLOW TUBES CONTRIBUTING DEEPLY CIRCULATED BRINE
C          N = NUMBER OF FLOW TUBES SUBJECT TO BRINE DILUTION
C          KYR = NUMBER OF YEARS OF BRINE PRODUCTION
C          ACONC(KYR) = AVERAGE KCL CONCENTRATION OF BRINE IN ANY YEAR
C
C
C..........DIMENSION ARRAYS.........
      DIMENSION CONC(60), FCONC(100, 60), ACONC(60), CONTUB(61)
C
      NUFF = 0
C
C
C..........READ IN NUMBER OF CASES TO BE CALCULATED.........
      READ (5,51)  NUMBER
   51 FORMAT (I5)
C
C..........READ INDEPENDENT VARIABLES.........
 1000 READ (5, 50)  XMAX, THICK, DDITCH, DBRINE, POR, EPOR, RCONC, CONC1
     .      , VEL1, NTUBE, NTUBE2, KYR
   50 FORMAT (9F7.0, 3I4)
C
      NUFF = NUFF + 1
C
C..........CALCULATE DEPENDENT VARIABLES.........
           XPOR = POR - EPOR
           DIL = EPOR / POR
           RATIO = XPOR / POR
           N = NTUBE - NTUBE2
           RNTUBE = FLOAT(NTUBE)
           RNTUB2 = FLOAT(NTUBE2)
```

Appendix E–Program KCLCON (continued)

```
C
C.........CALCULATE MAXIMUM DILUTION AFTER KYRS.........
          CONC(1) = CONC1
          RAIN = RCONC * DIL
      DO 222  J = 2, KYR
         CONC(J) = CONC(J-1) * RATIO  +  RAIN
  222 CONTINUE
C
C.........INITIALIZE CONCENTRATION IN ALL FLOW TUBES.........
      DO 333  I = 1, N
         DO 333  J = 1, KYR
            FCONC(I,J) = CONC1
  333 CONTINUE
C
C.........ITERATE CONCENTRATIONS TO FIND MAXIMUM DILUTION IN ANY FLOW TUBE......
            II = 1
      DO 444  I = 2, N
            II = II + I
            KK = II + 1
            KOUNT = 0
            JJ = 2
         DO 444  J = KK, KYR
              KOUNT = KOUNT + 1
  445         IF (KOUNT .GT. I)  GO TO 100
                 FCONC(I, J) = CONC(JJ)
                 GO TO 444
  100         JJ = JJ + 1
              KOUNT = 1
              GO TO 445
  444 CONTINUE
C
C.........FIX CONCENTRATION IN FIRST FLOW TUBE.........
      DO 12  J = 1, KYR
   12    FCONC(1, J) = CONC(J)
C
C
C.........CALCULATE CONCENTRATION AT FACE OF DITCH IN EACH FLOW TUBE
C                         AS A FUNCTION OF TIME.........
         II = 1
      DO 1003  I = 2, N
         II = II + I
         KK = II + 1
         DO 999  J = 1, KYR
  999    CONTUB(J) = FCONC(I,J)
            LL = II - 1
            DO 1002  J = KK, KYR
               JY =  J + 1
               LL = LL + 1
               DO 1001  MM = 1, LL
                 JY = JY - 1
                 JYL = JY - 1
                 IF (JYL .EQ. 0)  JYL = 1
                 DUMMY = CONTUB(JY) * DIL  +  CONTUB(JYL) * RATIO
                 CONTUB(JYL) = DUMMY
 1001          CONTINUE
 1002       FCONC(I,J) = DUMMY
 1003 CONTINUE
C
```

Appendix E–Program KCLCON (continued)

```
C
C.........CALCULATE AVERAGE KCL CONCENTRATION OF BRINE IN DITCH AT
C                               ANY TIME.........
      DO 667  J = 1, KYR
             TCONC = 0.0
         DO 666  I = 1, N
              TCONC = TCONC + FCONC(I,J)
  666    CONTINUE
              ACONC(J) = (TCONC + CONC1 * RNTUB2) / RNTUBE
  667 CONTINUE
C
C
C.........COMPUTATIONS COMPLETE, WRITE RESULTS.........
      WRITE (6, 60)
   60 FORMAT (1H1)
      NAMELIST/NAM/ XMAX, THICK, DDITCH, DBRINE, POR, EPOR, XPOR, RCONC,
     .              CONC1, VEL1, NTUBE, NTUBE2, KYR
      WRITE (6, NAM)
      WRITE (6, 60)
      WRITE (6, 61)
   61 FORMAT (1H0, 10X, 6H  YEAR, 10X, 19H  KCL CONCENTRATION/, 27X,
     .       20H IN DITCH (PER CENT))
C
C
          DO 777  J = 1, KYR
            JJ = J
            BCONC = ACONC(J) * 100.0
            WRITE (6, 62)  JJ, BCONC
   62       FORMAT (1HT, 12X, I3, 16X, F8.4)
  777     CONTINUE
C
      IF (NUFF .LT. NUMBER)  GO TO 1000
C
      RETURN
      END
C
C
C**********************************************************************************
```

Appendix E (continued)

SAMPLE OUTPUT OF KCLCON

Case 1.

```
$NAM

XMAX    =    0.70000000E 04,        YEAR        KCL CONCENTRATION
                                                IN DITCH (PER CENT)
THICK   =    0.15000000E 02,          1              1.0000
                                      2              0.9778
DDITCH  =    0.15000000E 02,          3              0.9605
                                      4              0.9468
DBRINE  =    0.             ,         5              0.9358
                                      6              0.9268
POR     =    0.45000000E 00,          7              0.9192
                                      8              0.9129
EPOR    =    0.09999999E 00,          9              0.9074
                                     10              0.9026
XPOR    =    0.34999999E 00,         11              0.8983
                                     12              0.8944
RCONC   =    0.             ,        13              0.8907
                                     14              0.8873
CONC1   =    0.10000000E-01,         15              0.8839
                                     16              0.8807
VEL1    =    0.70000000E 03,         17              0.8775
                                     18              0.8744
NTUBE   =             10,            19              0.8712
                                     20              0.8681
NTUBE2  =              0,            21              0.8650
                                     22              0.8618
KYR     =             30,            23              0.8587
                                     24              0.8555
$ END                                25              0.8523
                                     26              0.8492
                                     27              0.8459
                                     28              0.8427
                                     29              0.8395
                                     30              0.8362
```

Case 2.

```
$NAM

XMAX    =    0.70000000E 04,        YEAR        KCL CONCENTRATION
                                                IN DITCH (PER CENT)
THICK   =    0.15000000E 02,          1              2.0000
                                      2              1.9111
DDITCH  =    0.15000000E 02,          3              1.8420
                                      4              1.7872
DBRINE  =    0.             ,         5              1.7431
                                      6              1.7070
POR     =    0.45000000E 00,          7              1.6770
                                      8              1.6516
EPOR    =    0.09999999E 00,          9              1.6297
                                     10              1.6104
XPOR    =    0.34999999E 00,         11              1.5932
                                     12              1.5775
RCONC   =    0.             ,        13              1.5629
                                     14              1.5491
CONC1   =    0.20000000E-01,         15              1.5358
                                     16              1.5228
VEL1    =    0.14000000E 04,         17              1.5101
                                     18              1.4975
NTUBE   =              5,            19              1.4850
                                     20              1.4725
NTUBE2  =              0,            21              1.4599
                                     22              1.4474
KYR     =             50,            23              1.4348
                                     24              1.4221
$ END                                25              1.4094
                                     26              1.3966
                                     27              1.3838
                                     28              1.3709
                                     29              1.3579
                                     30              1.3449
                                     31              1.3318
                                     32              1.3187
                                     33              1.3055
                                     34              1.2923
                                     35              1.2790
                                     36              1.2658
                                     37              1.2525
                                     38              1.2392
                                     39              1.2258
                                     40              1.2125
                                     41              1.1992
                                     42              1.1859
                                     43              1.1726
                                     44              1.1593
                                     45              1.1460
                                     46              1.1327
                                     47              1.1195
                                     48              1.1063
                                     49              1.0931
                                     50              1.0799
```

NUMBER
2

CARD NO. 1: SETS COUNTER FOR NUMBER OF TIMES PROGRAM IS TO BE REPEATED, i.e., NUMBER OF DATA CARDS.

CARD NO. 2: INPUT DATA, ONE CARD FOR EACH CASE.

	XMAX	THICK	DDITCH	DBRINE	POR	EPOR	RCONC	CONC1	VEL1	NTUBE	NTUBE2	KYR
Case 1.	7000.	15.	15.	0.	.45	.10	0.	.010	700.	10	0	30
Case 2.	7000.	15.	15.	0.	.45	.10	0.	.020	1400.	5	0	50

Figure A1. Input format for KCLCON.

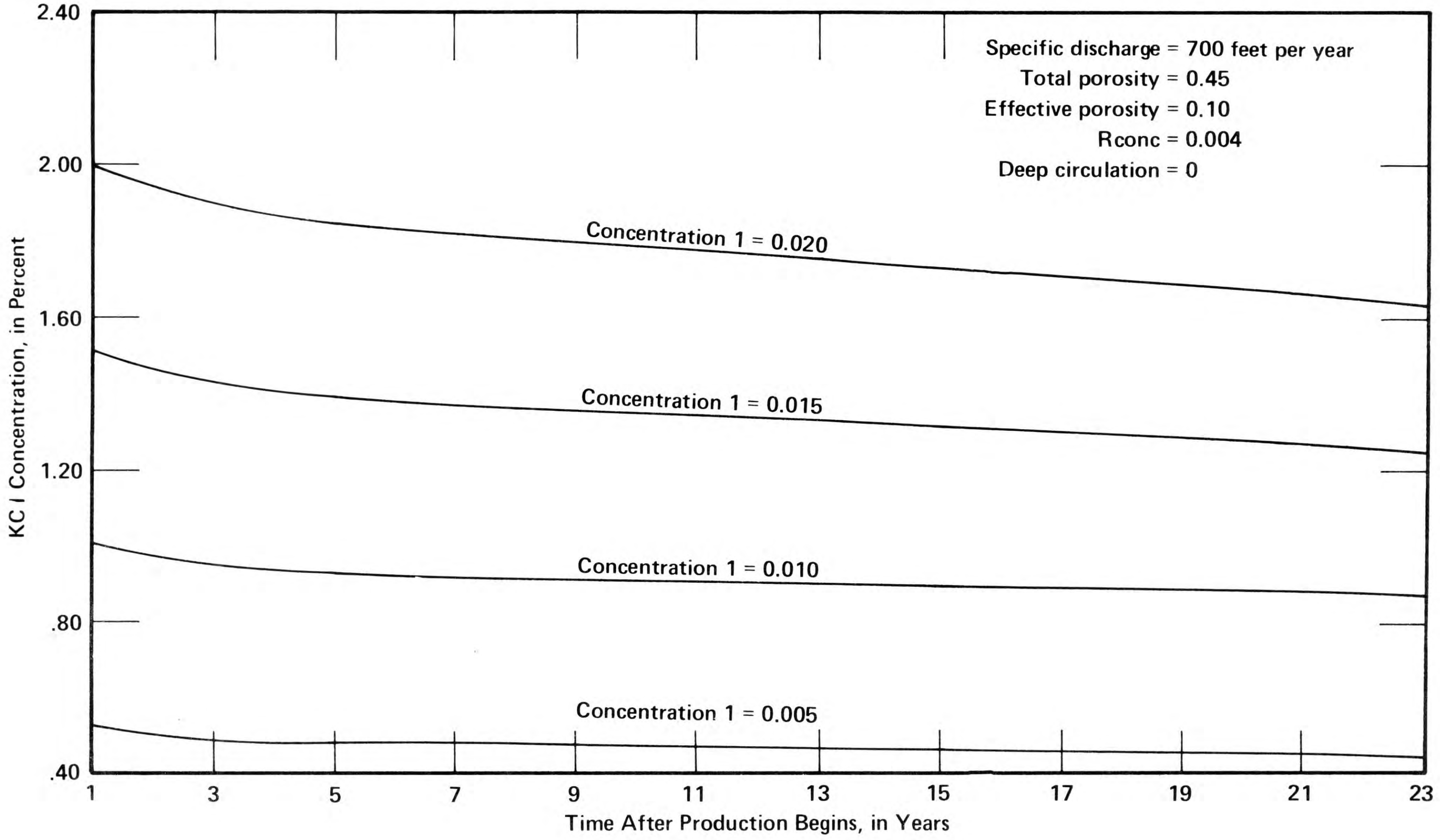

Figure A2. Effect of beginning concentration on decline of brine grade with artificial recharge from deep brine.

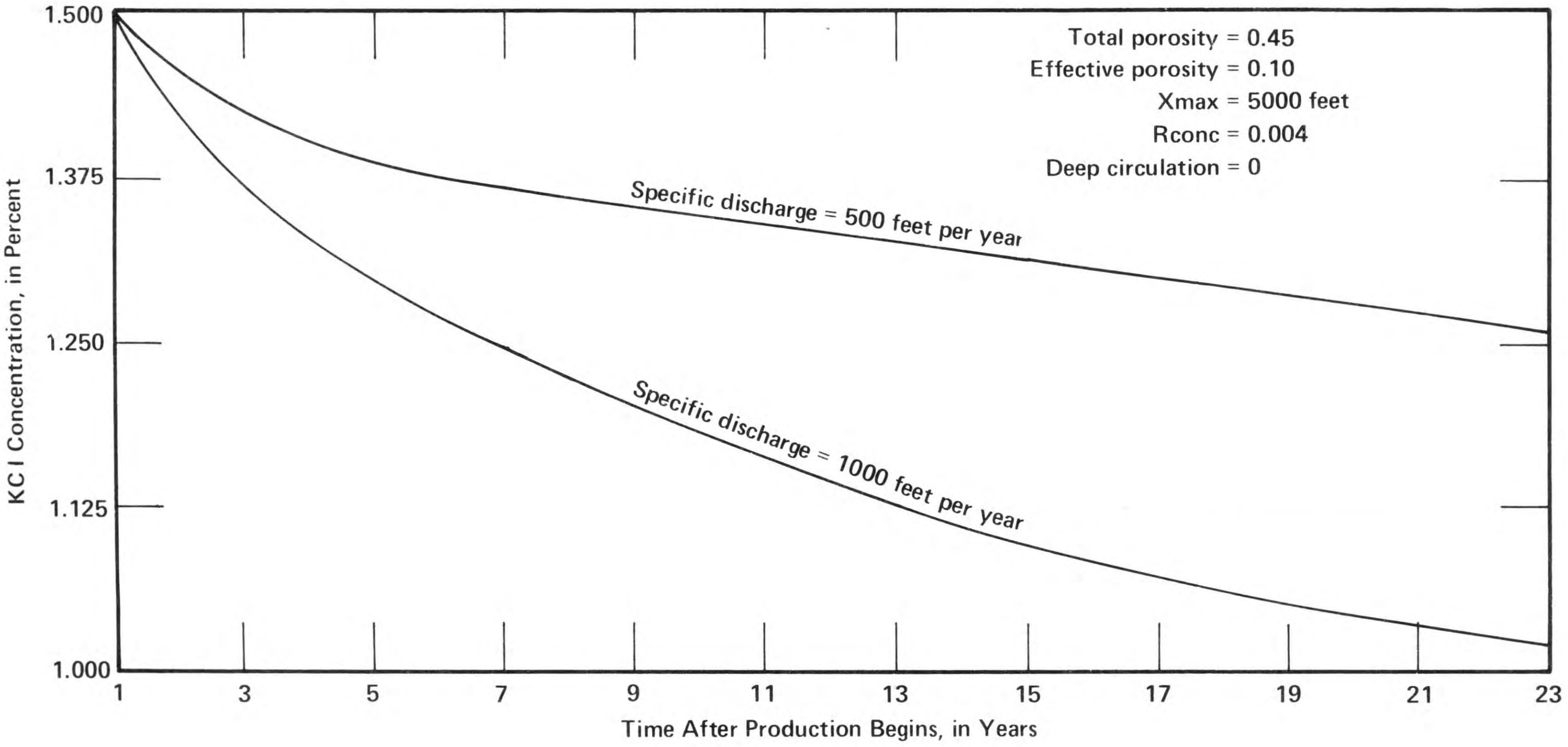

Figure A3. Effect of specific discharge on decline of brine grade with artificial recharge from deep brine.

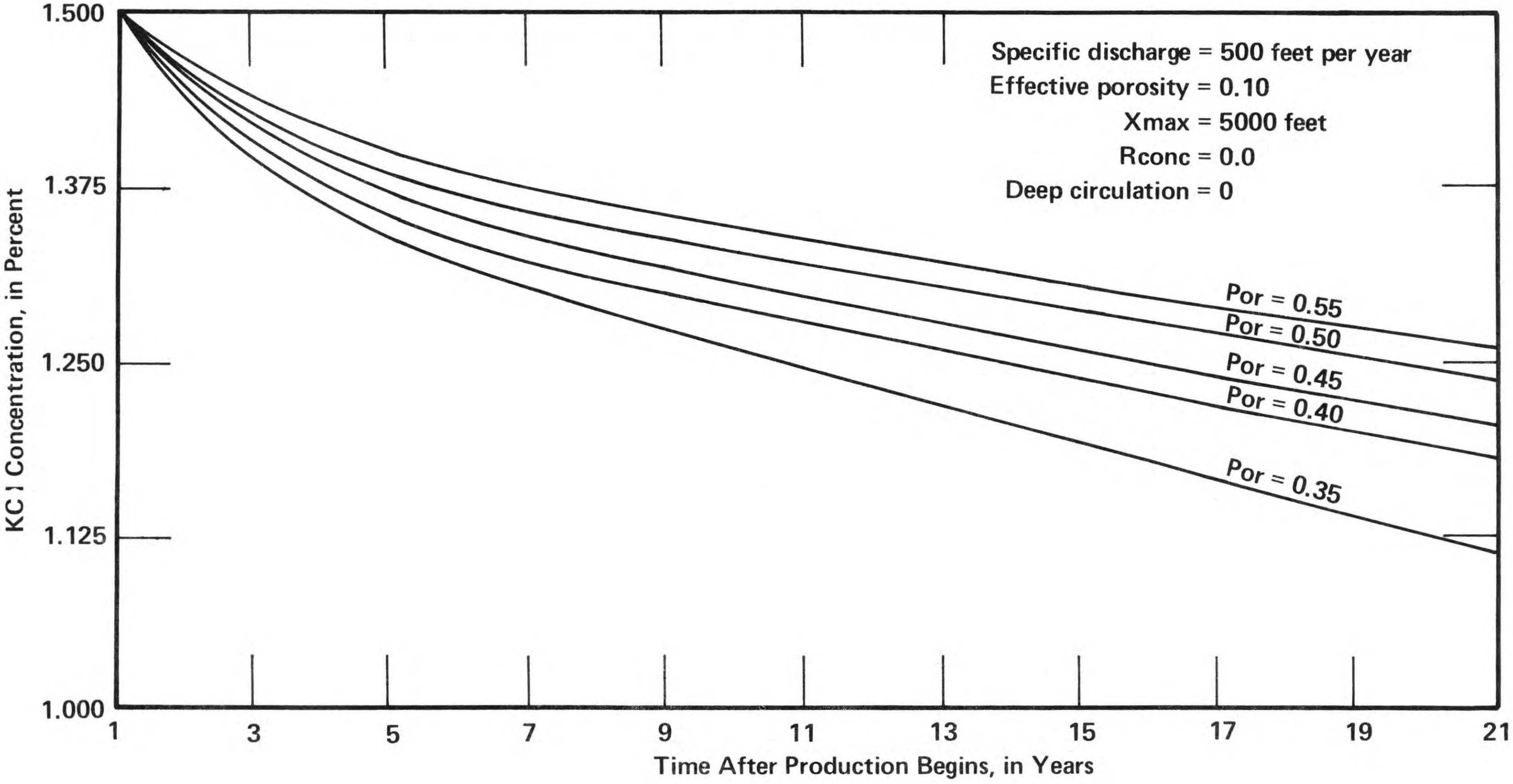

Figure A4. Effect of total porosity on decline of brine grade.

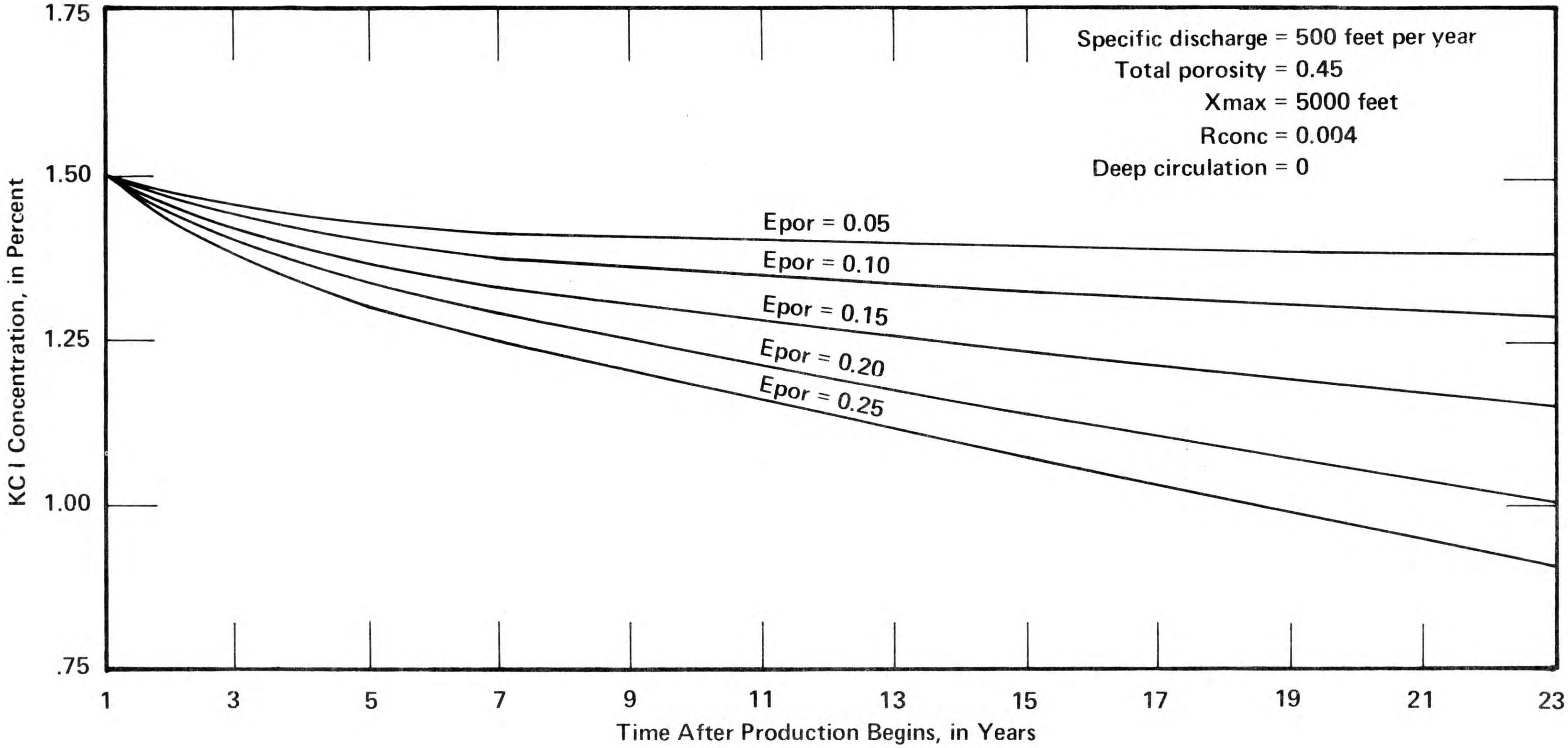

Figure A5. Effect of effective porosity on decline of brine grade with artificial recharge from deep brine.

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W.P. HEWITT; DIRECTOR
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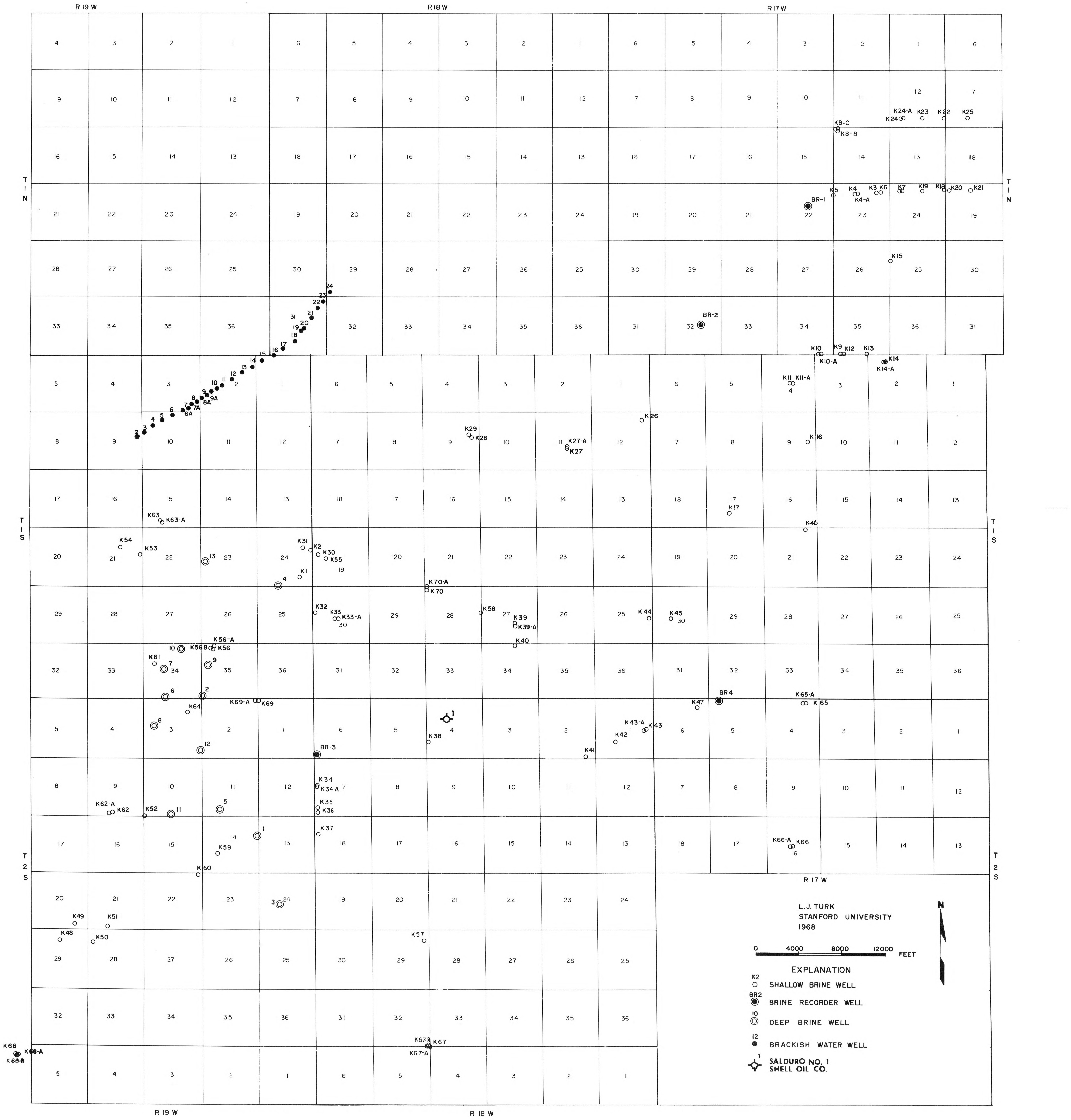
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH 84112



UTAH GEOLOGICAL AND MINERAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERAL SURVEY, a Division of the Utah Department of Natural Resources, operates with a professional staff under the guidance of a policy-making Board appointed by the Governor of Utah from various representatives of industry and the public as specified by law.

The Survey is instructed to investigate areas of geologic and topographic hazards, to survey the geology and mineral occurrences, and to collect and distribute reliable information concerning the mineral industry and mineral resources, topography and geology of the state so as to contribute to the effective and beneficial development of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-1 through 12,* describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineral Survey for the latest list of available publications.)

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH is a library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance. Initiated by the Utah Geological and Mineral Survey in cooperation with the departments of geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists, the library was made possible in 1951 by a grant from the University of Utah Research Fund and is maintained by donations of collections from mineral resource companies operating in Utah. It collects, catalogs, and systematically files geologically significant specimens for library reference, comparison, and research, particularly cuttings from important wells and exploratory holes drilled in Utah, and from strategic wells in adjacent states. For catalogs, facilities, hours and service fees, contact the Utah Geological and Mineral Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i. e., our employees shall have no interest in lands within Utah where there is a conflict of interest deleterious to the goals and objectives of the Survey; nor shall they obtain financial gain by reason of information obtained through their work as an employee of the Survey. For permanent employees this restriction is lifted after a two-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

Directors:
William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961