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IDENTIFICATION OF SALTWATER SOURCES AFFECTING GROUNDWATER
IN THE BLOOD ORCHARD AREA, SEDGWICK COUNTY, KANSAS

A Report for the
Kansas Department of Health and Environment

by

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INTRODUCTION

Saltwaters have contaminated groundwaters in portions of the alluvial aquifer located on the south side of Wichita. Well waters used by Gerald Blood to irrigate his commercial peach orchard have become salty as a result of this contamination. Part of the Gladys oil field is located underneath the area of groundwaters that have become saline. Most of the production from this field is now by water flooding under wellhead injection pressures of up to 1,000 psi (Kansas Department of Health and Environment, 1982a). The Division of Environment has discovered improperly plugged boreholes drilled earlier for oil in the area that either were dry or abandoned due to becoming unproductive (Kansas Department of Health and Environment, 1982). At least one of these was found to be bleeding saltwater into the base of the alluvial aquifer.

Mr. Blood is presently suing the oil company operating the water flooding system in the area, because he believes the source of pollution to be oil-field brine under pressure entering the freshwater aquifer through improperly plugged boreholes. Studies of the hydrogeology and water quality are being conducted by consultants for Mr. Blood and the oil company, as well as by the Division of Environment. Certain of these investigations have been designed to determine whether other sources of saltwater could be entering the alluvial aquifer, specifically, from the Wellington Formation which underlies the alluvium.

Mineralized waters present in the Wellington derive from the solution of evaporite beds (anhydrite, gypsum and halite) within the predominant shale of the formation. Where not completely dissolved, the halite is found in the middle of the Wellington and is called the

Hutchinson Salt Member. A map by Gogel (1981) indicates that the Hutchinson Salt is about 100 feet thick in the shale underneath the alluvial aquifer in the Blood orchard area. Gogel's data also shows that the solution zone termed the Wellington aquifer (formed by dissolution of the evaporites) underlies the orchard area.

Samples collected by the Division of Environment and consultants for the oil company and Mr. Blood were made available to the Kansas Geological Survey for the chemical identification of the saltwater source by the procedures of Whittemore et al. (1981). These methods are especially effective for distinguishing oil-field-brine from halite-solution-brine sources contaminating waters. This report gives the results of the chemical identification of the water samples provided. Additional information on the study area can be found in Department of Health and Environment (1982a, 1982b). The general geohydrology of the alluvial aquifer and the Wellington Formation in the region is described in Lane and Miller (1965), and Gogel (1981) respectively.

PROCEDURES

Concentrations of sodium, chloride, and sulfate in the water samples were determined by the Kansas Department of Health and Environment, Wichita Testing Laboratories, or the Kansas Geological Survey as noted in the data tables. Bromide concentrations were measured by an automated phenol red method on a Technicon Autoanalyzer (Basel, et al., 1982). This method gives results which agree excellently with bromide determinations made using x-ray fluorescence spectrophotometry (by Gerald James, Kansas Geological Survey), and ion-chromatography (by Kirk Nordstrom, U.S. Geological Survey, Menlo Park, California). All

samples were filtered through 0.45 μ m membrane filters to remove sediment before analysis at the Survey.

RESULTS AND DISCUSSION

Dissolved constituent concentrations and weight ratios in freshwaters, saline waters, and saltwaters from Blood Orchard and the surrounding area are given in Table 1. Samples provided by the Wichita Testing Laboratories are from observation wells located in T.28S., R.1E., Sec. 28. The series of A through O observation wells are in the adjacent section to the west (T.28S., R.1E., Sec. 29). The designation of the 6 water-supply wells with 3 numbers, for example, 19-250-450, refers to the location of the sample within the section (the first number) of T.28S., R.1E. The following two numbers refer to the distance north and east, respectively, from the southwest corner of the section. All of the above mentioned wells are screened in alluvial sediments except for observation wells A3, B3, C3, and D3 which are screened in shale and interbedded gypsum of the Permian Wellington Formation. The contact between the base of the alluvium and the underlying shale lies at a depth of about 50 ± 3 feet in the area of the observation wells.

The weight ratio of sodium/chloride (Na/Cl) ranged from 0.413 to 0.576 for all water samples from observation wells in the alluvium and for well C3 and the first sample from well B3. Sodium/chloride ratios of less than 0.6 for saline waters in Kansas usually indicates that the source of the dissolved salt is from oil-field brine; ratios close to 0.65 in saltwaters generally signifies that the source of the salt is solution of halite (NaCl), (Whittemore and Pollock, 1978; Whittemore

TABLE 1. Dissolved Constituent Concentrations and Weight Ratios in Water Samples from the Blood Orchard and Surrounding Area. Determinations of the Na, Cl, SO₄ values by Wichita Testing Laboratories or Kansas Department of Health and Environment except for the last 9 samples in the table or as noted. Concentrations of Br in all samples and Cl in the last 9 samples determined by the Kansas Geological Survey.

Well	Screened Interval, Feet	Date Collected ^a	Na mg/L	Cl mg/L	SO ₄ mg/L	Br mg/L	Na/Cl	Br/Cl x10 ⁴	SO ₄ /Cl
Samples from Wichita Testing Laboratories									
1-1	36-40	3-1-82	680	1,275	101	4.61	0.533	36.0	0.079
1-2	43-47	"	3,830	7,380	168	28.9	0.519	39.1	0.023
2-1	35-39	"	470	838	95	3.08	0.561	36.7	0.113
2-2	41-45	"	2,060	3,850	132	15.3	0.535	39.9	0.034
2-3	46-50	"	5,600	10,780	196	42.3	0.520	39.2	0.018
3-1	34-38	"	820	1,550	98	5.67	0.529	36.6	0.063
3-2	42-46	"	3,000	5,500	132	b	0.545	--	0.024
3-3	46-50	"	3,990	7,400	164	28.2	0.539	38.0	0.022
Samples from Kansas Department of Health and Environment									
A1	49-52.5	5-26-82	4,540	9,500	310	36.8	0.478	38.7	0.033
A1	"	7-16-82	4,540	9,680	340	38.3	0.469	39.6	0.035
A1	"	8-09-82	4,840	10,100	254	37.7	0.479	37.3	0.025
A2	35-38	5-26-82	389	720	129	2.54	0.540	35.3	0.179
A2	"	7-16-82	400	780	149	2.43	0.513	31.2	0.191
A2	"	8-09-82	395	711	153	2.18	0.556	30.7	0.215
A3	60-100	7-??-82 ^c	616	824	2,820	3.00	0.748	36.4	3.42
A3	"	7-16-82	616	820	2,650 ^d	3.17	0.751	38.7	3.23

Well	Screened Interval, Feet	Date Collected ^a	Na mg/L	Cl mg/L	SO ₄ mg/L	Br mg/L	Na/Cl	Br/Cl x10 ⁴	SO ₄ /Cl
Samples from Kansas Department of Health and Environment (Cont.)									
A3	60-100	8-09-82	567	540	3,550	0.63	1.050	11.6	6.57
B1	50-53	5-26-82	4,710	10,000	275	39.4	0.471	39.4	0.028
B1	"	7-16-82	4,540	10,200	340	40.6	0.455	39.8	0.033
B1	"	8-09-82	4,910	10,600	241	e	0.463	--	0.023
B2	35-38	5-26-82	546	1,040	140	4.02	0.525	38.7	0.135
B2	"	7-16-82	455	920	147	3.27	0.495	35.6	0.160
B2	"	8-09-82	482	915	129	e	0.527	--	0.141
B3	70-80	7-16-82	680	1,290	1,970	5.14	0.527	39.8	1.53
B3	"	8-09-82	494	673	2,850	1.50	0.734	22.2	4.23
C1	48-51	5-26-82	3,650	7,400	240	28.4	0.493	38.4	0.032
C1	"	7-16-82	3,660	7,370	385	30.2	0.497	40.9	0.052
C1	"	8-09-82	4,070	8,070	195	29.6	0.504	36.7	0.024
C2	34.5-37.5	5-26-82	392	700	148	2.49	0.560	35.6	0.211
C2	"	7-16-82	329	645	139	1.75	0.510	27.1	0.216
C2	"	8-09-82	359	623	113	e	0.576	--	0.181
C3	60-70	7-??-82 ^c	2,370	5,700	1,580	22.8	0.416	40.1	0.277
C3	"	7-16-82	2,230	5,400	1,700	21.7	0.413	40.2	0.315
C3	"	8-09-82	3,910	8,530	1,170	30.4	0.458	35.7	0.137
D1	50-53	5-26-82	3,420	7,500	255	27.6	0.456	36.7	0.034

Well	Screened Interval, Feet	Date Collected ^a	Na mg/L	Cl mg/L	SO ₄ mg/L	Br mg/L	Na/Cl	Br/Cl x10 ⁴	SO ₄ /Cl
Samples from Kansas Department of Health and Environment (Cont.)									
D1	50-53	7-16-82	3,110	6,600	295	26.5	0.471	40.2	0.045
D1	"	8-09-82	3,430	7,230	233	25.8	0.474	35.7	0.032
D2	35.5-38.5	5-26-82	513	940	129	3.38	0.546	36.0	0.137
D2	"	7-16-82	540	1,070	136	3.67	0.505	34.3	0.127
D2	"	8-09-82	606	1,140	137	e	0.532	--	0.120
D3	58-145	7-??-82 ^c	1,440	2,200	2,800	3.62	0.655	16.4	1.27
D3	"	7-16-82	2,530	3,500	4,200 ^d	4.15	0.723	11.9	1.20
D3	"	8-09-82	3,260	3,880	8,250	4.95	0.840	12.8	2.13
I1A	Alluvium	5-26-82	526	1,000	127	3.76	0.526	37.6	0.127
I1B	Alluvium	5-26-82	631	1,220	130	4.33	0.517	35.5	0.107
I2	46-52	7-16-82	2,000	4,310	212	16.2	0.464	37.6	0.049
I2	"	8-09-82	2,100	4,140	197	e	0.507	--	0.048
O1	49.5-52.5	7-16-82	4,380	9,290	370	36.9	0.471	39.7	0.040
O1	"	8-09-82	4,630	9,630	242	36.5	0.481	37.9	0.025
O2	48.5-51.5	7-16-82	6,490	14,400	410	56.6	0.451	39.3	0.028
O2	"	8-09-82	6,660	14,200	296	e	0.469	--	0.021
O3	48-51	7-??-82 ^c	3,620	7,660 ^f	295	29.9	0.473	39.0	0.039
O3	"	7-16-82	3,660	7,630 ^f	310	30.6	0.480	40.2	0.041
O3	"	8-09-82	3,830	7,720	214	e	0.496	--	0.028
O4	50-53	7-16-82	2,950	6,900	325	26.2	0.428	38.0	0.047
O4	"	8-09-82	3,230	7,270	237	e	0.444	--	0.033

Well	Screened Interval, Feet	Date Collected ^a	Na mg/L	Cl mg/L	SO ₄ mg/L	Br mg/L	Na/Cl	Br/Cl x10 ⁴	SO ₄ /Cl
Samples from Kansas Department of Health and Environment (Cont.)									
11-1 min.	Alluvium	8-10-82	564	1,070	121	e	0.527	--	0.133
11-3 min.	"	"	564	1,080	122	e	0.522	--	0.113
11-5 min.	"	"	573	1,080	122	e	0.531	--	0.113
11-7 min.	"	"	581	1,110	122	e	0.523	--	0.110
11-10 min.	"	"	583	1,100	120	3.90	0.530	35.5	0.109
11-15 min.	"	"	590	1,130	123	e	0.522	--	0.109
11-20 min.	"	"	592	1,140	121	e	0.519	--	0.106
11-30 min.	"	"	608	1,170	121	e	0.520	--	0.103
11-40 min.	"	"	612	1,190	123	e	0.514	--	0.103
11-50 min.	"	"	622	1,210	123	e	0.514	--	0.102
11-60 min.	"	"	635	1,230	125	4.32	0.516	35.1	0.102
11-24 hr.	"	8-11-82	934	1,930	138	6.92	0.484	35.9	0.072
11-48 hr.	"	8-12-82	1,022	2,150	137	7.86	0.475	36.6	0.064
19-250-450	Alluvium	8-24-82	e	117	e	0.09	--	7.5	--
20-280-050	"	8-24-82	e	102	e	0.14	--	13.8	--
21-285-017	"	8-25-82	e	214	e	0.33	--	15.4	--
27-260-130	"	8-26-82	e	103	e	0.23	--	22.4	--
28-500-460	"	8-25-82	e	262	e	0.34	--	13.0	--
33-010-430	"	8-25-82	e	61	e	0.10	--	16.8	--

Well	Screened Interval, Feet	Date Collected ^a	Na mg/L	Cl mg/L	SO ₄ mg/L	Br mg/L	Na/Cl	Br/Cl x10 ⁴	SO ₄ /Cl
Samples from Kansas Department of Health and Environment (Cont.)									
Arkansas River ^g		8-10-82	302	451	e	0.22	0.669	4.8	--
Samples from W. Hendrix									
Magnolia	?	10-??-82	480	862	e	3.26	0.556	37.9	--
BP Well 1	?	10-??-82	118,000	184,000	e	38.2	0.643	2.08	--

^aMonth - day - year

^bNo sample provided

^cBefore July 12

^dEstimated from charge-balance equation for major dissolved constituents

^eConstituent not determined in sample

^fAverage of KDHE and KGS analyses

^gCollected from the Broadway Bridge, Highway 81, south Wichita

et al., 1981). Ratios of sodium/chloride were greater than 0.65 for samples from observation wells B3 (second sample), A3, and D3 in the Permian shale.

Dissolved sulfate (SO_4) contents were highest in waters from wells C3, B3, A3, and D3, with concentrations increasing in the order given which reflects screened intervals of increasing depths in the Permian shale. Sulfate/chloride ratios were above 0.27 for well C3 waters, and higher than 1.1 for all B3, A3, and D3 samples. These concentrations and ratios reflect the solution of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) intercepted in the shale during the drilling of the wells. Waters from observation wells in the alluvium had low sulfate/chloride ratios (less than 0.22) which generally decreased with increasing chloride content. This latter trend also occurred during the two day pumping of well 11.

Sulfate concentrations and sulfate/chloride and sodium/chloride ratios increased with time in waters from wells B3, A3, and D3. This could be explained by incongruent dissolution of gypsum providing more dissolved calcium and sulfate relative to sodium and chloride. The higher calcium concentrations could not remain in solution, however, because they would cause the solution to be supersaturated with respect to calcite (CaCO_3) and calcite would precipitate. Also, the high calcium/sodium ratio initially formed during gypsum dissolution would not be in equilibrium with the exchangeable cations on the clays of the shale, and sodium would be released to the solution as calcium was adsorbed for it on clay surfaces.

Chloride and bromide concentrations and weight ratios of bromide/chloride (Br/Cl) are listed for freshwaters and saltwaters in Table 1 and for oil-field waters in Table 2. Bromide/chloride ratios are

TABLE 2. Dissolved Constituent Concentrations and Weight Ratios in Oil-Field Brines near the Blood Orchard Area. The first sample was supplied by the Kansas Department of Health and Environment, the last 7 by W. Hendrix. Determinations of all constituent concentrations were made at the Kansas Geological Survey.

Sample Name	Date Collected ^a	Na	Cl	SO ₄	Br	Na/Cl	Br/Cl
		mg/L	mg/L	mg/L	mg/L	x 10 ⁴	SO ₄ /Cl
Stelbar, T28S-RIE-21B	8-10-82	48,300	95,500	528	387	0.506	40.5 0.0055
Gladys Unit #38-2	10-15-82	11,700	21,800	503	91.6	0.536	42.0 0.0231
Gladys Unit #38-4	10-15-82	11,000	20,600	438	83.6	0.532	40.6 0.0213
E.G.U. Tucker #2	10-15-82	17,700	34,900	620	138	0.508	39.6 0.0178
E.G.U. Tucker #1	10-15-82	12,300	24,400	236	93.2	0.503	38.3 0.0097
E.G.U. Parton #4	10-15-82	20,600	40,800	227	156	0.506	38.4 0.0056
E.G.U. Parton #5	10-15-82	6,660	12,700	106	44.4	0.524	35.0 0.0083
E.G.U. Parton #6	10-15-82	7,500	14,200	144	49.9	0.528	35.1 0.0101

^aMonth - day - year

plotted versus chloride concentration in Figures 1 and 2. Bromide/chloride values are usually greater than 0.003 (30×10^{-4} as plotted in the figures) for oil-field brines in Kansas, and within 0.0001 to 0.0003 (1×10^{-4} to 3×10^{-4} in the figures) for halite-solution brines.

The curves in Figures 1 are the boundary lines for the zone of mixing of freshwaters with halite-solution brines from the Wellington Formation. The location of the zone in the figure is based on analytical data for a large number of fresh to saline groundwaters and subsurface brines, as well as samples prepared by dissolving different sections of cores of the Hutchinson Salt Member of the Wellington Formation (Whittemore and Pollock, 1978; Whittemore et al., 1981; Whittemore, unpublished data). The boundary curves for the zone are theoretical lines for the mixing of various amounts of the freshwater (low chloride) and brine (high chloride) endpoints. Points for the samples from the water-supply wells (chloride concentrations of 61 to 262 mg/L) and for the Arkansas River sample all fall within the freshwater and halite-solution-brine mixing zone. This would be expected because the natural source of most chloride in the river and low levels of chloride in the alluvium is probably the Wellington Formation to the west. The BP Well #1 water is a halite-solution brine (184,000 mg/L chloride) as indicated by its low bromide/chloride ratio.

Figure 2 is an enlarged section of Figure 1 from 100 to 100,000 mg/L chloride concentrations. The mixing zone for freshwaters in the alluvium and oil-field brines from the Blood Orchard area is plotted in addition to the freshwater and halite-solution-brine mixing zone. The average chloride concentration for fresh groundwaters from the Blood Orchard area is about 150 mg/L based on the water-supply wells sampled in 1982

Figure 1. Zone of Mixing of Freshwaters with Halite-Solution Brines

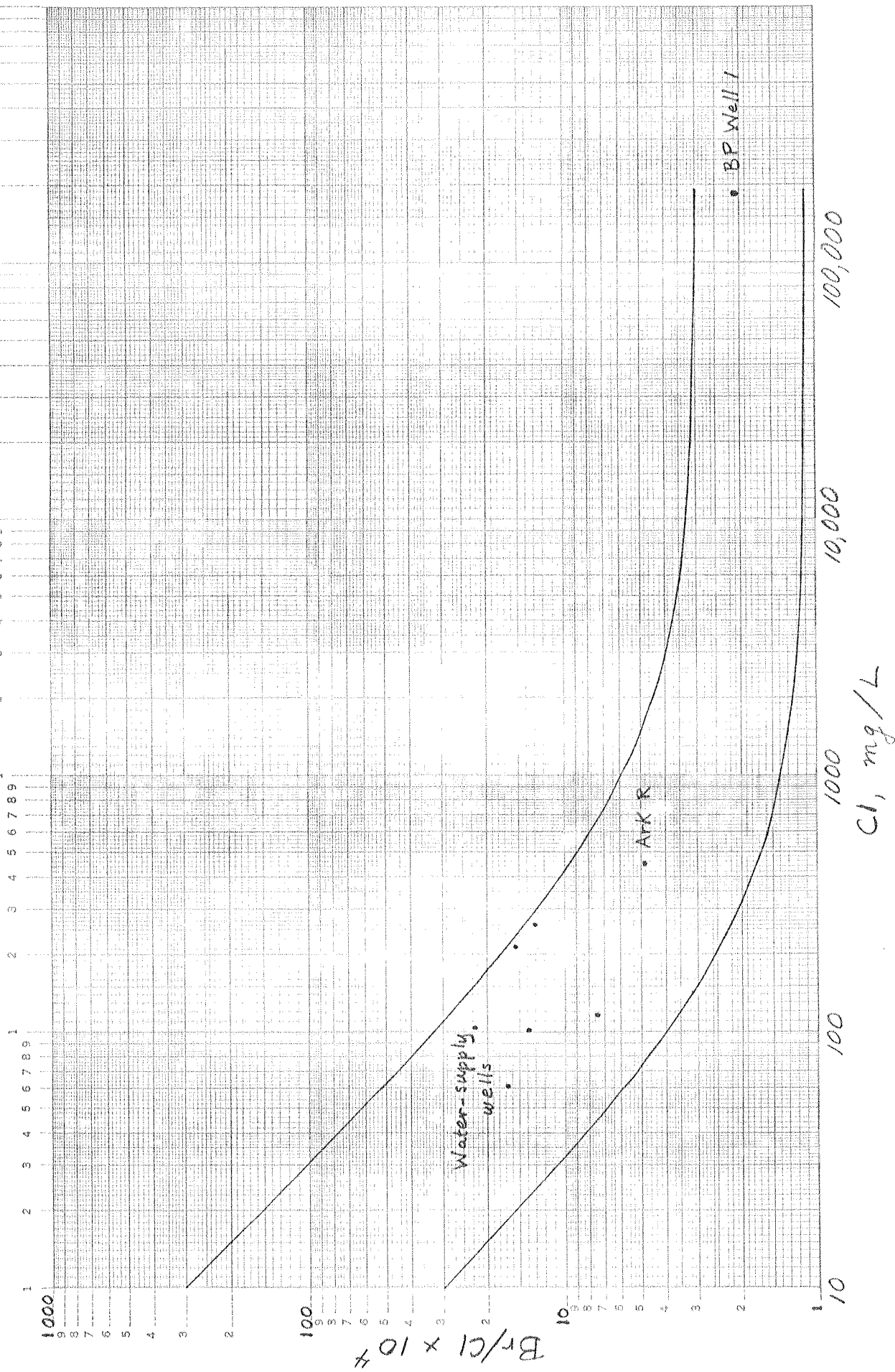
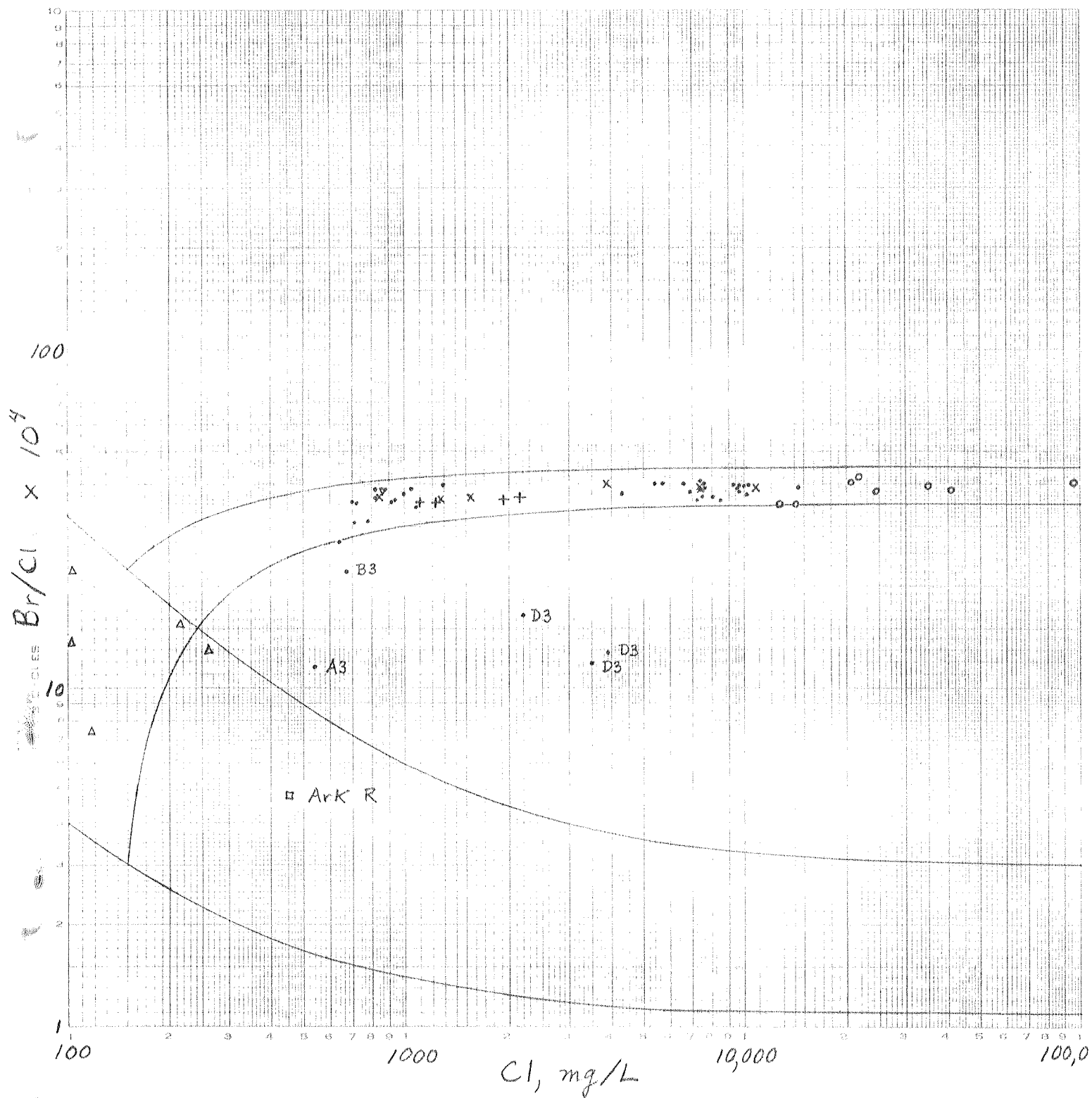


Figure 2. Zones of Mixing of Freshwaters with Halite-Solution Brines and Oil-Field Brines



- x Wichita Testing Lab samples
- + Pump test samples
- KDHE samples - Obs. wells
- o Oil-field samples
- Δ KDHE samples - Water-supply wells
- ∇ Magnolia well
- Arkansas River

and well waters analyzed previous to 1965 (Lane and Miller, 1965). The freshwater endpoints for the mixing zone with oil-field brines derive from the intersection of 150 mg/L chloride with the boundaries of the halite-solution-brine mixing zone, while the oil-field-brine endpoints were chosen based on the range in the bromide/chloride values for the oil-field samples. Oil-production in the area is from Mississippian strata and thus, the oil-field waters are brines from this horizon or mixtures of the brines with other waters injected during water flooding.

All of the observation well samples from the alluvium fall in the mixing zone of freshwaters with oil-field brines. The samples from the shallowest well screened in the Wellington shale (C3) and the first and first two samples from two observation wells screened at greater depths in the Wellington (B3 and A3, respectively) also plot in the oil-field-brine mixing zone. The water sample designated Magnolia falls within the same zone.

The last samples collected from observation wells B3 and A3 and all samples from well D3 (the deepest well screened in the Wellington shale) plotted between the oil-field-brine and halite-solution-brine mixing zones. These samples represent mixtures of freshwaters with both oil-field brines and saltwater solutions in the Wellington.

The results observed for the samples from the two-day pumping test of well I1 all fall within the zone of mixing with oil-field brine. The bromide/chloride ratios increased slightly with increases in the chloride concentration during pumping as would be expected for waters having greater proportions of oil-field brine. Sodium/chloride and sulfate/chloride ratios decreased during the pumping, also indicating waters with larger amounts of oil brine relative to freshwaters.

CONCLUSIONS

The source of saltwater contaminating all of the saline waters in the alluvium of the Blood Orchard area is oil-field brine similar to that from Mississippian strata in the area. Saline groundwaters with appreciable amounts of dissolved evaporites (halite and gypsum) underlying the Blood Orchards are only found in the observation wells screened within the Wellington Formation. The Wellington well samples also derived a substantial portion of their dissolved solids from oil-field brine. In general, the deeper the screened intervals in the Wellington shale and the later the sample date, the smaller the contribution to the salinity by oil-field brine. A pumping test of saline groundwaters in the alluvium indicated increasing proportions of oil-field brine were being drawn to the well.

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