Kansas Geological Survey
Open-file Report 81-6

Final Report

Geochemical Identification of Saltwater Sources in the Smoky Hill River Valley, McPherson, Saline, and Dickinson Counties, Kansas

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Prepared for the U.S. Army Corps of Engineers,
Kansas City District

August, 1981

ABSTRACT

Saltwater contaminates the alluvial aquifer of the Smoky Hill River valley and then discharges into the river to the east of Salina, Kansas. The brine derives primarily from groundwater solution of the Hutchinson Salt Member and associated gypsum and anhydrite of the Permian Wellington Formation. During Federal and State studies to assess reducing mineral intrusion to the river, a question arose as to whether oil-field brine could also be polluting the aquifer. Before substantial control regulations were promulgated, oil-field brines were disposed in surface pits and in disposal wells in evaporite solution cavities of the Wellington Formation, as well as in deeper formations. Some disposal is still allowed in the Wellington Formation.

The sources of salt in the groundwaters were identified by sodium/chloride ratios and curves of bromide/chloride and iodide/chloride versus chloride concentration for mixtures of fresh waters and brines in the area. Magnesium/chloride, lithium/chloride, and boron/chloride ratios helped verify sources. These methods showed no detectable oil-field brine entering the alluvium from shallow aquifers along the valley walls. Either surface disposal pits were little used in the area or any past pollution has not moved appreciably or has been flushed by recharge. However, a few observation wells in the saline Wellington aquifer contained varying mixtures of oil-field and evaporite solution brines. A USGS well pumped to test interception of saltwater in the Wellington Formation produced predominantly halite solution brine.

Over 40 percent of the recharge volume needed to balance the average discharge of saltwater from the Wellington Formation to the Smoky Hill River is presently being injected as oil brine into the Wellington, mainly in south-central Saline County and north-central McPherson County. The total volume injected since 1940 amounts to only about one percent of the total saltwater in the brine aquifer. The disposed oil brine will probably take roughly 100 years before first discharging into the river. Increases in piezometric head from the brine injection have probably already spread to the discharge area. Saltwater disposal into the Wellington Formation should be abandoned as soon as practical to prevent further recharge and increase in piezometric head.

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ACKNOWLEDGEMENTS

The assistance of Phil Worley, Salina office of the Department of Health and Environment, is greatly appreciated for both locating sampling sites and providing data for oil and brine-disposal wells. Special acknowledgement is also made to J.B. Gillespie, U.S. Geological Survey, for providing some samples and helpful information. Lynn Apperson, Kansas Water Resources Board, collected most of the observation well samples. Joan Dietz, Department of Health and Environment in Topeka, and Jo Payne, Kansas Corporation Commission in Wichita supplied selected data concerning oil-brine injection wells.

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INTRODUCTION

Large amounts of brine are derived from the solution of rock salt in the bedrock strata underlying central Saline and McPherson Counties and northeastern Reno County. The brine flows northward, then eastward into the alluvial aquifer of the Smoky Hill River and thence into the river. As a result, the river water and much of the groundwater between Salina and Enterprise are saline. The saline water affects not only residents in Saline and Dickinson Counties, but also downstream users of the Smoky Hill and Kansas Rivers.

Previous studies (Gogel, 1981; Gillespie, 1981) theorize that substantial amounts of fresh water in central Saline County seep through shale layers in the Wellington Formation of Permian age to reach evaporite beds of anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), and halite ($NaCl$). The halite, or rock salt, is termed the Hutchinson Salt Member. As the evaporite beds dissolve, cavernous zones develop containing brine. Past formation of caverns in the evaporites has formed a collapsed zone along the eastern extent of the salt. The cavernous and collapsed zone has been called the Wellington aquifer (Gogel, 1981). The collapse process fractured overlying shale, providing avenues for discharge of the brine into overlying alluvial silt, sand, and gravel. McElwee, et al. (1981) showed that the brine could flow up through the fresh water in the alluvium into the river channel by unstable upconing.

A number of oil fields exist to the east, south, and southwest of Salina. Most of the production is from the Maquoketa Shale and the underlying Viola Limestone. Discovery dates of the first producing oil wells in these fields are generally in the early 1940's. In the past, some oil-field brines have been disposed in pits on the surface which allowed the brine to contaminate shallow groundwater supplies. South of Salina large volumes of oil-field brine have been injected into the Wellington aquifer, hence the evaporite solution zone has also been called the "shallow disposal zone." Much saltwater produced with oil is still disposed in the Wellington. Nearly all of the disposal close to Salina, however, is back into the Maquoketa Shale and Viola Limestone or into permeable strata of the overlying Hunton Group.

The U.S. Army Corps of Engineers (1980) has proposed several measures for managing the mineral intrusion contaminating groundwaters and river waters in central Kansas. A knowledge of all of the sources of mineralized waters could improve the formalization of the management plans. For example, any oil-field brine detected flowing in shallow groundwater into the river valley from past disposal in surface pits could be expected to slowly dissipate. Detection of oil brine formerly injected into the Wellington aquifer could be used to estimate movement of saltwater in the aquifer. Present disposal of brines accompanying oil into the Wellington provides an additional source of water to dissolve salt, because the brines in the oil-fields near Salina are undersaturated with respect to halite. The disposed brine also adds to the piezometric head in the Wellington aquifer, thereby increasing the amount of brine flow to the alluvial aquifer and the river.

In a preliminary study, we analyzed lithium, bromide, and iodide in 74 samples previously collected in 1979 from the network of wells used in the Kansas Water Resources Board, U.S. Geological Survey, and U.S. Army Corps of Engineers investigations of the area. The Kansas Department of

Health and Environment had already determined chloride and sulfate in all samples, and other major dissolved constituents in several samples. In our analyses we applied the method of Whittemore and Pollock (1979) which greatly improves the determination of whether a brine or saline water is derived from halite dissolution or oil-brine disposal. Results showed that a few of the well waters have compositions similar to oil-field brines. The chemistry of most of the samples indicated that they range from fresh waters to various mixtures of primarily fresh water and salt-solution brines to salt-solution brines. However, as the samples obtained had not been preserved after being at the Kansas Department of Health and Environment, we felt that fresh and properly preserved samples would remove the possibility of loss of iodide before analysis. Also, some of the samples collected in 1979 may not have been representative due to insufficient pumping or bailing after freshwater use in many wells for previous head determinations. Thus, a resampling was proposed along with an investigation of the possible presence of oil-field brine leakage from the Salina field into alluvium of the Smoky Hill River.

OBJECTIVES

1. To determine the origin of brines and saline waters in wells in Permian sedimentary rocks and Smoky Hill River alluvium in the vicinity of the proposed saltwater relief and injection wells in Saline County, Kansas. Waters deriving their source of salt from the dissolution of evaporite minerals in the Wellington Formation will be distinguished from those with an oil-field brine source. Amounts of each type of source in a well water will be estimated in case mixtures of the two types of saltwaters are encountered.

2. To delineate the areas where groundwaters have been affected by oil-field brine disposal.

3. To estimate the quantities and probable direction of flow of groundwaters containing oil-field brine relative to the amount and flow direction of brines derived from rock salt solution.

4. To evaluate the need and location of additional observation wells for improving the estimation of the location, amount, and flow of groundwaters affected by oil-field brines.

5. To evaluate the location and operation of the proposed saltwater relief wells relative to the salt solution and oil-field brine sources.

DESCRIPTION OF STUDY AREA

The study location comprised the recharge area of the portion of the Wellington aquifer which discharges into the Smoky Hill River, the discharge area, and oil-fields to the east and south of Salina. Gogel (1981) determined the boundary and potentiometric contours of the Wellington aquifer in Kansas. A map of the general outline of the aquifer which appeared in his report is shown in Figure 1. The recharge area of concern extends from the northeastern corner of Reno County northward through central McPherson and Saline Counties to the Saline River valley several miles northwest of Salina. The area of saltwater discharge from the Wellington to the alluvium and river channel of the Smoky Hill River valley is in the region from New Cambria to Solomon in northeastern Saline County. Saltwater continues to discharge from the alluvium to the Smoky Hill River downstream to south of Sand Springs in west-central Dickinson County (Gillespie and Hargadine, 1981; Hargadine et al., 1979).

The Kansas Water Resources Board collected 63 water samples from observation wells in the Smoky Hill River Valley. Seventeen of the samples were from the Wellington Formation, one from the deeper Cresswell Limestone Member of the Winfield Limestone in the Lower Permian Series, and the rest from alluvium. Four samples from the Wellington aquifer were supplied by the U.S. Geological Survey; two of these were collected during the pump test of a saltwater relief well (Cottonwood Tree well). Locations of the observation and pump test wells are indicated in Figure 2.

Waters were obtained from 18 domestic, stock, and irrigation wells in the vicinity of the south valley wall of the Smoky Hill River from

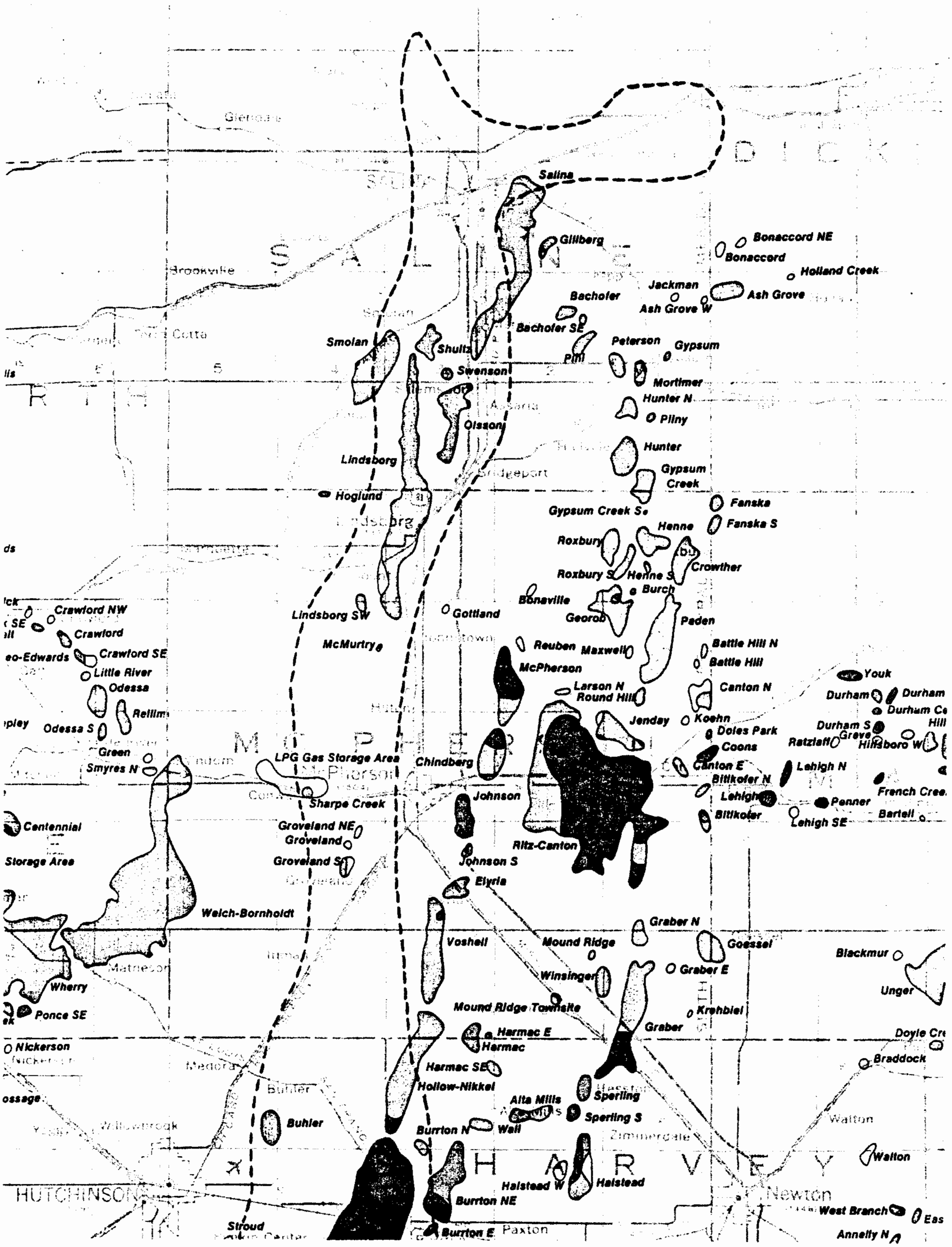


Figure 1. Location of the northern half of the brine aquifer in the Wellington Formation (dashed-line boundary) and oil fields (shaded) in central Kansas.

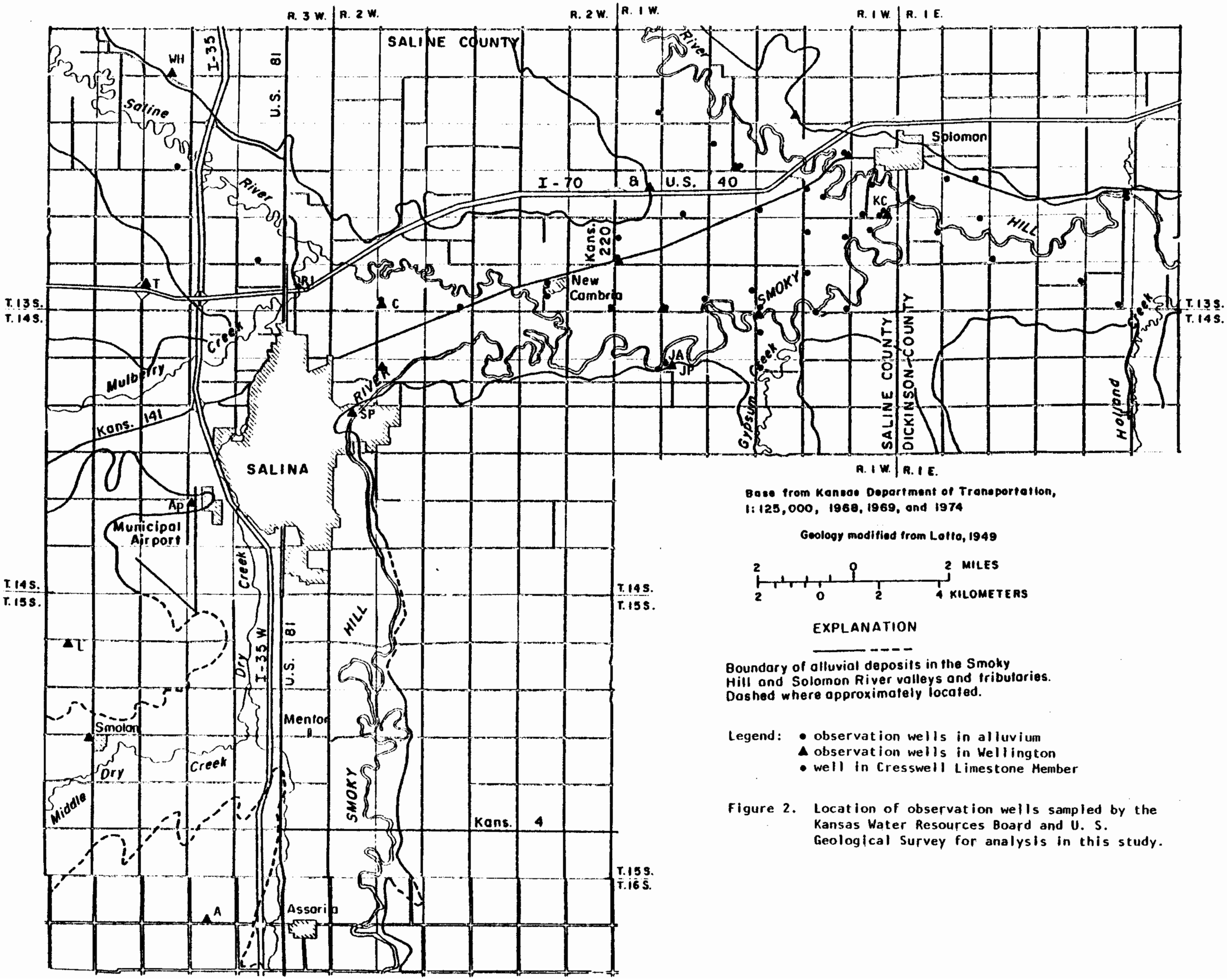
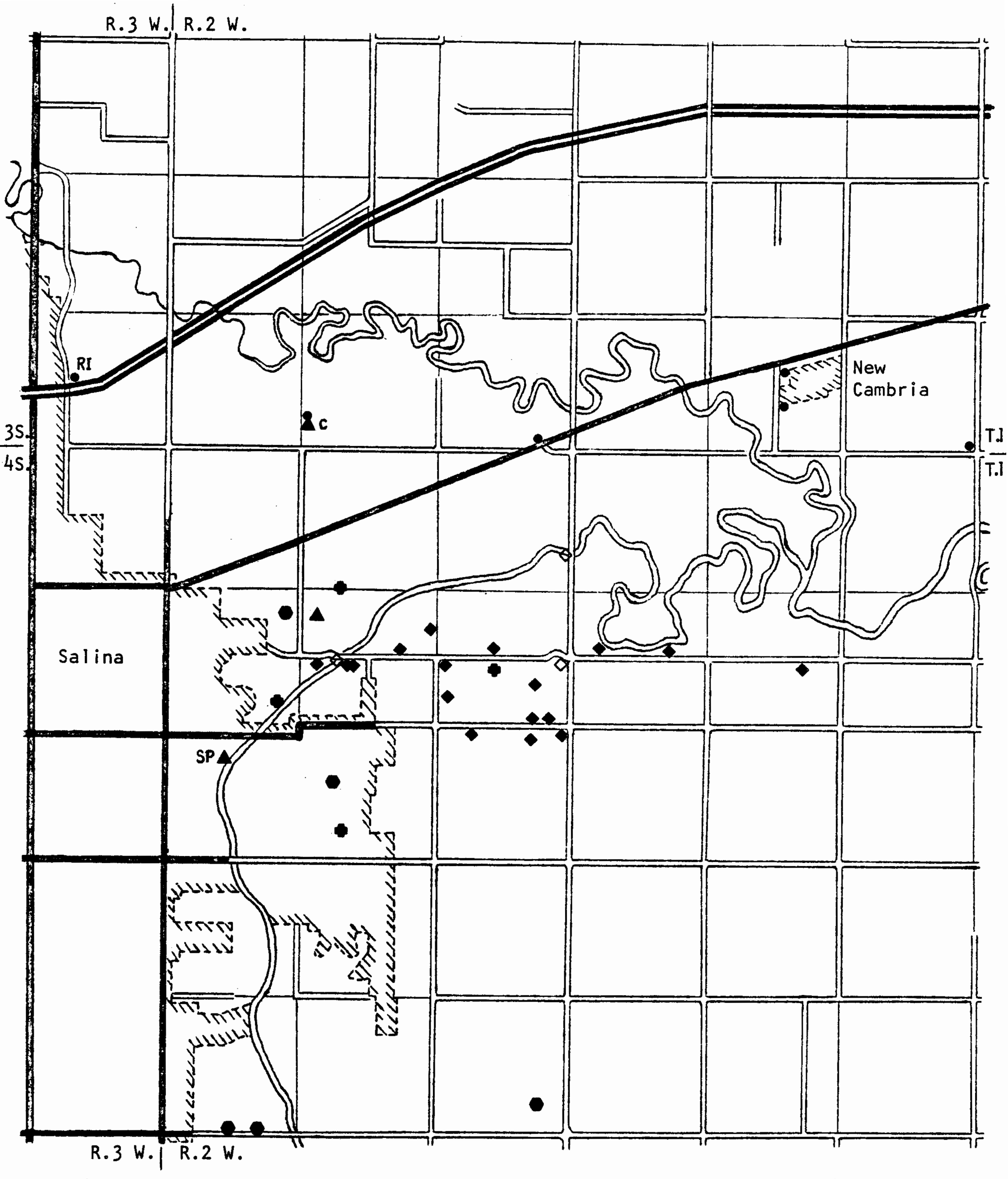


Figure 2. Location of observation wells sampled by the Kansas Water Resources Board and U. S. Geological Survey for analysis in this study.

Salina to New Cambria. These wells should have intercepted any appreciable oil brine movement in shallow groundwaters if surface disposal in the oil field just east of Salina had ever been prevalent. A small stream draining the oil field and two locations on the Smoky Hill River were also sampled. These well and river sites are shown in Figure 3.

To determine the character of the brine accompanying oil production in the area, a total of 11 waters from separator tanks, disposal tanks, or pumping oil wells were collected; one of these was supplied by the U.S. Geological Survey. Nine of the brines were from the Salina Field, two from the Gillberg Field, and one from the Olsson Field. The general extent of these and other oil fields in or near the recharge and discharge areas of the Wellington aquifer are shown in Figure 1. Locations of 10 of the oil-field brines sampled are plotted in Figure 3; the other brine was taken from a tank about two miles west of Assaria in south-central Saline County.



Legend: ● observation well in alluvium, ▲ observation in Wellington aquifer,
◆ water-supply well, ◇ river or stream, ✚ oil-brine disposal well,
⬣ oil well or tank battery

Figure 3. Location of water sampling sites in the vicinity of northeastern Salina and New Cambria

PROCEDURES

Sample Collection and Preparation

Samples from domestic and stock wells were taken after allowing the water to run for 10-15 minutes. All domestic waters collected did not pass through softeners or other treatment. The irrigation wells at a golf course were pumped from 15 minutes to 1-1/2 hours before sampling. The bulk of the oil accompanying brine obtained from pumping wells was allowed to separate in a polyethylene jar before the brine was drawn from the bottom through a spigot.

Samples were cooled in an ice chest immediately after collection. Soon after reaching the laboratory, the waters were filtered through 0.45 µm membrane filters. Brines collected from pumping oil wells were prefiltered through a coarser filter to remove the bulk of any oil present. An aliquot of 200 ml was acidified with 1 ml of hydrochloric acid to preserve for cation analyses. The remainder of the sample was refrigerated.

Chemical Analyses

Iodide was determined in the waters soon after filtration using a colorimetric method in which iodide catalyzes the reduction of ceric ions by arsenious acid. A modification of the cartridge for food digest analysis produced by Technicon (Method No. 530-77A) was used with a Technicon Auto Analyzer II sampler, pump, and spectrophotometer. Iodide values were corrected for chloride interference using curves which we have generated. Analysis of bromide was by bromination of phenol red and measurement of the absorption at 590 nm in a double beam spectrophotometer (Taras, et al., 1971). As in the case of iodide, a correction was made for chloride interference in the bromide values. An ammonium interference was also discovered which could be removed in some samples by gentle heating at about 45°C for a day. Reports of the magnitude of these interferences have not been published. A chloride interference was also found in the U.S. Geological Survey method for low bromide concentrations in water; it is so severe that bromide in halite-solution brines cannot be very reliably determined by the method. Although some of the interferences in the bromide and iodide methods have been described in Whittemore and Pollock (1979), further studies are being conducted and will be published when completed. It is important to note that certain analyses of iodide and bromide in brines from halite solution published by other workers may contain uncorrected interference errors.

Chloride and sulfate concentrations in all non-oil-field waters were measured using Technicon cartridges and the Auto-Analyzer II system. Argentometric titration was applied to determine chloride and turbidimetry with barium chloride to analyze sulfate in oil-field brines (Taras, et al., 1971). Specific conductance was measured with a Lab-Line Model Mark IV meter which had been calibrated to give correct readings at high conductance.

A Jarrell-Ash inductively-coupled, argon plasma spectrophotometer, Model 975, was used to determine calcium, magnesium, sodium, lithium, and boron. Samples with sodium concentrations greater than 300 mg/L (mg/liter) were diluted to give a sodium of 200-300 mg/L. The 330.2 nm and 589 nm wavelength lines were used for the sodium concentration ranges 100-300 mg/L and 1-100 mg/L respectively. Wavelength for calcium analyses for the same ranges, 100-300 mg/L and 1-100 mg/L were 315.8 nm and 396.8 nm. The spectral wavelength for the other elements were 383.2 nm (magnesium), 670.7 nm (lithium), and 249.7 nm (boron). It was noted that the relative precision and background error were better and lower, respectively, for the lower concentration range (589.0 nm wavelength) of sodium than for the higher range. Thus, for future analyses of samples with high sodium contents it is recommended that the sodium be diluted to within the range 70-100 mg/L; the gain in analytical conditions on the plasma spectrophotometer is greater than the increase in dilution error. The low concentrations of lithium and boron in diluted samples of salt-solution brines were difficult to analyze in the presence of the high sodium concentrations. An attempt was made to improve the detection limit of these elements by diluting the waters less. However, the increase in the sodium concentration (in the range 700-1100 mg/L) increased the background noise more than the increase in the lithium and boron signals. Thus, the dilution of the samples to give a sodium of 200-300 mg/L appeared to be optimum for determination of lithium and boron. Greater dilution would decrease the lithium and boron signals below detection limits.

RESULTS AND DISCUSSION

Chemical Characteristics of Waters

Water sample information, including location, date of collection, well type, and geologic source is given along with chemical analyses of dissolved constituents in Tables 1 and 2. The order of listing within the three groups of samples (observation and water supply wells, river, and stream waters and oil-field brines) is first by range number from east to west, then by increasing township number, and finally by increasing section. Major dissolved cations in these waters are calcium, magnesium and sodium; major anions are chloride, sulfate, and, where combined chloride and sulfate are less than a couple thousand mg/L, bicarbonate. Bicarbonate concentrations were not determined but most probably range between 70 and 300 mg/L based on analyses of similar waters.

Classification of the fresh and saline waters and brines according to predominant cation type is shown on a Piper-Hill diagram (Figure 4). The diagram represents the percentages of each of the major cations, calcium, magnesium, and sodium, of the total of these three. Concentrations are converted to meq/L (milliequivalents/liter) before calculating percentages. Most of the waters are either calcium type or sodium type. Calcium-type waters consist of both those of lower total dissolved solids in which bicarbonate is a major anion, and those of higher dissolved solids in which sulfate is the predominant anion. All of the waters are probably saturated with respect to calcite ($CaCO_3$). Sulfate concentrations increase as greater amounts of gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$)

Table 1. Description and Specific Conductance of Water Samples

Location[a]	Name	Date sampled	Well type[b]	Geol. source[c]	Specific conductance[d]	Name abbrev.[e]
	Observation and water-supply wells					
13-1E-19CAB	Solomon Bridge SE	4-16-81	0	A	97,000	
13-1E-20ACA	Old Solomon City	4-06-81	0	A	840	
13-1E-20BBC	Emig	4-06-81	0	A	2,130	E
13-1E-23DAB	Sand Springs Br.N	4-16-81	0	A	440	
13-1E-23DAB	Sand Springs Br.S	4-16-81	0	A	990	
13-1E-28CCC	Iron Bridge	4-06-81	0	A	7,280	
13-1E-29AAB	Roy Clemence	4-06-81	0	A	818	
13-1E-30ADA	Car Body	4-07-81	0	A	37,300	
13-1E-34ADD2	Concrete	4-07-81	0	A	7,290	RS
13-1E-35DCD2	Red Brick School	4-07-81	0	A	2,370	
13-1W-7DDA	Don Vaupel North	4-08-81	0	A	1,710	
13-1W-10DDB	Riordan House	4-15-81	0	P	1,400	
13-1W-10DCA	Riordan Permian	4-15-81	0	P	2,350	
13-1W-14DAD	RR Triangle East	4-16-81	0	A	45,400	
13-1W-14DAD2	RR Triangle West	4-03-81	0	P	85,500	
13-1W-16BCC	Old Latta	4-07-81	0	A	24,100	
13-1W-16DCC	Swenson North	4-07-81	0	A	4,960	SN
13-1W-16DCC2	Swenson South	4-07-81	0	P	28,200	
13-1W-19ACD	I-70 Borrow Pit	4-08-81	0	P	2,400	
13-1W-20CDD	Ward South	4-09-81	0	A	74,500	
13-1W-22CCB	RR Borrow Pit	4-02-81	0	A	38,800	
13-1W-23BCB2	Railroad	4-08-81	0	A	13,400	
13-1W-23CAA	Shirak No. 2	4-16-81	0	A	53,400	
13-1W-24BDA	Boondocks	4-02-81	0	A	119,000	
13-1W-24CDC	Kelly Road Tee	4-16-81	0	A	28,300	
13-1W-24DDC2	Kelly Alluvial	4-02-81	0	A	165,000	
13-1W-24DDC3	Kelly Permian	4-08-81	0	P	150,000	
13-1W-24DDC4	Kelly Cresswell	4-02-81	0	C	220,000	KC
13-1W-25BDA	Pettijohn East	4-08-81	0	A	151,000	
13-1W-26ADD	Red Barn	4-09-81	0	A	9,880	
13-1W-26BCB	Krebs Pasture	4-09-81	0	A	15,500	

Table 1. (Continued)

Location[a]	Name	Date sampled	Well type[b]	Geol. source[c]	Specific conductance[d]	Name abbrev.[e]
		Observation and water-supply wells				
13-1W-30BCC	USBR Niles Road	4-16-81	0	A	1,460	
13-1W-30CCC	Old 40 Niles Rd.N	4-02-81	0	A	38,700	
13-1W-30CCC2	Old 40 Niles Rd.S	4-01-81	0	P	207,000	
13-1W-32CCC	Telephone	4-02-81	0	A	27,100	
13-1E-32DDA	Dead End Sign	4-02-81	0	A	165,000	
13-1W-33DAA	USBR by Martin	4-16-81	0	A	1,340	
13-1W-34CCC	Albert Martin	4-02-81	0	A	132,000	
13-1W-35BBC2	Kirtland 2" Steel	4-09-81	0	A	7,780	
13-1W-35CDC	Dike	4-09-81	0	A	164,000	
13-1W-35DDD	Welchel	4-09-81	0	A	7,330	W
14-1W-3BCC	Ryan North	4-09-81	0	A	12,800	
14-1W-3BBB	Ryan Permian	4-02-81	0	P	165,000	
14-1W-7AAD	New Cambria Old Gage	4-02-81	0	A	1,040	
14-1W-8BBB	Julia Martin Alluvial	4-16-81	0	A	52,300	JA
14-1W-8BBA	Julia Martin Permian	4-16-81	0	P	30,500	JP
14-1W-10BBC	Ryan South	4-09-81	0	A	1,930	
13-2W-32CCB2	Cottonwood Tree N	4-10-81	0	A	1,140	
13-2W-32CCB3	Cottonwood Tree	9-06-79	0	P	240,000	C
13-2W-32CCB3	Cottonwood Tree	3-12-81	BP	P	244,000	C
13-2W-32CCB3	Cottonwood Tree	4-07-81	BP	P	247,000	C
13-2W-33DDC	Bend in Old 40	4-01-81	0	A	990	
13-2W-35ACC	USBR New Cambria W	4-15-81	0	A	1,130	
13-2W-35DBB	New Cambria	4-01-81	0	A	7,000	NC
13-2W-36DDD	Four Corners	4-02-81	0	A	8,350	FC
14-2W-8ACD	-------	3-06-81	D	A	906	
14-2W-8ADA	Debold	2-16-81	S	A	858	
14-2W-8BBC	Salina Sewer Plant	7-02-80	0	P	202,000	
14-2W-8CAB	Country Club East	3-06-81	I	A	1,460	
14-2W-8CAB2	Country Club Middle	3-06-81	I	A	1,240	
14-2W-8CBB	Country Club West	3-06-81	I	A	1,350	
14-2W-9BDD	Maxey	2-16-81	D	A?	794	

Table 1. (Continued)

Location[a]	Name	Date sampled	Well type[b]	Geol. source[c]	Specific conductance[d]	Name abbrev.[e]
		Observation and water-supply wells				
14-2W-9CBB	Farris	2-16-81	D	A	1,080	
14-2W-9CCB	Morrison	10-07-80	DA	P	4,350	
14-2W-9DBD	Roesner	3-13-81	D,S	A	800	R
14-2W-9DCD	-------	3-06-81	D	A	1,620	
14-2W-9DDC	Magee	3-13-81	D	A	1,730	
14-2W-10ACD	Landes	3-13-81	D,S	A	1,750	
14-2W-10BCD	Simcox	3-13-81	D	A	992	
14-2W-11DBA	Jellison	3-13-81	DN	P	4,600	
14-2W-16AAA	Bell No. 1	3-13-81	D	P	2,750	
14-2W-16AAA2	Bell No. 2	3-13-81	D	P	2,030	
14-2W-16ABA	Sandow	3-06-81	D	A	1,320	
14-2W-16BBA	Eddy	3-13-81	D	A	1,140	
14-2W-18BDA	Salina City Park	4-15-81	0	P	76,000	SP
14-2W-20B	Lagerberg	10-12-79	D	P	------	Lg
13-3W-4DCC	White School House	4-16-81	0	P	200,000	WH
13-3W-16DCD	USBR Tucker	4-15-81	0	A	970	
13-3W-26CDD	Drainage Ditch	4-15-81	0	A	900	
13-3W-33BCC	Trenton Road	4-16-81	0	P	250,000	T
13-3W-36CBA	Ramada Inn	4-03-81	0	A	87,300	RI
14-3W-27BBB	Airport	4-03-81	0	P	208,000	Ap
15-3W-7BAA	Landfill	4-15-81	0	P	240,000	L
15-3W-19AAA	Smolan	4-16-81	0	P	110,000	S
16-3W-3CDC	Assaria	4-15-81	0	P	98,000	A
17-3W-8CCB	Lindsborg	4-15-81	0	P	160,000	Lb
		River and stream waters				
14-2W-9DAA	East Dry Creek	3-13-81	--	-	1,320	
14-2W-8CBA	Smoky Hill River	3-13-81	--	-	1,060	
14-2W-9DBD	Smoky Hill River	3-13-81	--	-	1,110	

Table 1. (Continued)

Location[a]	Name	Date sampled	Well type[b]	Geol. source[c]	Specific conductance[d]	Name abbrev.[e]
		Oil-field brines				
14-2W-5CDC	Winslow 1	2-27-81	Od	V	71,900	
14-2W-7AAD	Haley 1	2-16-81	Ow	V	61,800	
14-2W-7D	Sheldon 4	2-11-81	Os	M	139,000	Sh
14-2W-9CAA	Roesner 1	2-16-81	Od	M	74,000	
14-2W-17BCD	Seitz 1	2-27-81	Ow	V	78,000	
14-2W-17CDB	Prescott 1	2-27-81	Od	M,V	78,300	
14-2W-28ADB	Hagg 2	2-16-81	Os	M	58,000	
14-2W-28DDB	Gillberg 2	2-16-81	Os	M	53,000	
14-2W-30DCD	Sudendorf 2	2-16-81	Os	M	74,700	
14-2W-30CDD	Balaum 2	2-16-81	Ow	M	74,000	
16-3W-10A	Thelander	10-07-80	Od	M	67,000	

[a] Township-range-section, quarter section, quarter-quarter section, quarter-quarter-quarter section.

[b] Type: BP, brine pumping test; DA, domestic abandoned; D, domestic; I, irrigation for golf course; O, observation; Ow, oil brine from oil well; Os, oil brine from separator tank; Od, oil brine from disposal tank; S, stock.

[c] Source: A, alluvium; C, Cresswell Limestone Member; M, Maquoketa Shale; P, Permian Wellington Formation; V, Viola Limestone.

[d] Specific conductance in µS/cm (=µmho/cm) at 25°C.

[e] Abbreviations used on figures.

Table 2. Chemical Analyses of Water Samples. Concentrations are in mg/liter except for iodide which is in µg/liter.

Location[a]	Name	Ca	Mg	Na	Cl	SO_4	Li	B	Br	I
				Observation and water-supply wells						
13-1E-19CAB	Solomon Bridge SE	1130	304	26,400	38,300	3770	0.4	2.3	6.6	94
13-1E-20ACA	Old Solomon City	125	30	20	10	221	0.07	0.060	0.61	10.6
13-1E-20BBC	Emig	530	20	19	14	1230	0.23	0.07	0.19	2.7
13-1E-23DAB	Sand Springs Br.N	55	11	17	25	31	0.021	0.027	0.35	2.5
13-1E-23DAB	Sand Springs Br.S	160	21	23	51	97	0.055	0.067	b	11.6
13-1E-28CCC	Iron Bridge	216	32	1,300	1,900	405	0.15	0.32	0.78	13.8
13-1E-29AAB	Roy Clemence	128	25	26	16	163	0.045	0.052	0.68	6.1
13-1E-30ADA	Car Body	570	111	8,600	13,200	1800	0.6	1.3	2.6	27
13-1E-34ADD2	Concrete	214	36	1,390	1,760	1070	0.13	0.43	1.1	8.7
13-1E-35DCD2	Red Brick School	219	43	283	273	413	0.13	0.42	0.93	6.4
13-1W-7DDA	Don Vaupel North	370	28	58	10	750	0.12	0.20	0.10	7.7
13-1W-10DDB	Riordan House	186	49	77	35	415	0.07	0.14	0.90	3.2
13-1W-10DCA	Riordan Permian	620	99	58	35	1380	0.19	0.50	0.31	6.0
13-1W-14DAD	RR Triangle East	940	121	10,300	16,000	2250	0.5	2.3	3.3	62
13-1W-14DAD2	RR Triangle West	1680	261	21,800	33,700	4590	1.0	2.5	6.1	55
13-1W-16BCC	Old Latta	990	95	5,100	7,450	2720	0.21	1.0	1.2	14.7
13-1W-16DCC	Swenson North	197	24	890	1,240	354	0.07	0.21	0.64	15.6
13-1W-16DCC2	Swenson South	856	102	6,250	9,480	1920	0.23	1.0	1.9	18
13-1W-19ACD	I-70 Borrow Pit	659	80	226	266	1760	0.17	0.56	0.66	6.6
13-1W-20CDD	Ward South	1280	236	18,100	27,900	3740	0.6	2.2	4.6	38
13-1W-22CCB	RR Borrow Pit	750	173	8,800	13,700	1800	0.24	0.83	2.4	22
13-1W-23BCB2	Railroad	306	64	2,720	4,180	600	0.12	0.34	1.3	3.9
13-1W-23CAA	Shirak No. 2	800	153	12,600	19,100	2450	0.6	1.6	5.4	54
13-1W-24BDA	Boondocks	1500	389	31,700	49,400	4170	0.7	2.1	7.6	72
13-1W-24CDC	Kelly Road Tee	420	97	6,300	9,760	1360	0.24	0.85	2.2	32
13-1W-24DDC2	Kelly Alluvial	1810	511	44,600	68,700	6500	1.2	4.1	13	210
13-1W-24DDC3	Kelly Permian	1830	481	44,400	70,400	6300	0.9	4.7	11	160
13-1W-24DDC4	Kelly Cresswell	10900	3980	70,200	138,000	1350	21	25	610	15.6[c]
13-1W-25BDA	Pettijohn East	1810	473	39,800	61,300	5800	0.9	3.8	11	130
13-1W-26ADD	Red Barn	184	31	1,920	2,850	315	0.10	0.37	1.3	11.4
13-1W-26BCB	Krebs Pasture	179	37	3,120	4,660	660	0.13	0.67	1.1	15.0

Table 2. (Continued)

Location[a]	Name	Ca	Mg	Na	Cl	SO_4	Li	B	Br	I
				Observation and water-supply wells						
13-1W-30BCC	USBR Niles Road	142	40	108	235	193	0.07	0.11	0.42	11.0
13-1W-30CCC	Old 40 Niles Rd.N	514	122	9,000	13,900	1270	0.1	0.81	2.8	25
13-1W-30CCC2	Old 40 Niles Rd.S	2000	626	72,000	110,000	6000	<1	2.6	18	320
13-1W-32CCC	Telephone	600	130	5,850	9,050	1390	0.15	0.71	1.8	38
13-1E-32DDA	Dead End Sign	1600	512	43,400	66,400	5400	1.0	2.7	12	200
13-1W-33DAA	USBR by Martin	187	26	49	58	97	0.08	0.10	0.72	5.0
13-1W-34CCC	Albert Martin	1640	450	35,200	54,600	5150	0.7	3.0	10	140
13-1W-35BBC2	Kirtland 2" Steel	155	29	1,440	2,140	306	0.09	0.37	1.2	14.3
13-1W-35CDC	Dike	1890	533	48,220	73,200	6400	1.0	4.1	13	160
13-1W-35DDD	Welchel	377	63	1,200	1,600	1290	0.13	0.61	0.99	8.2
14-1W-3BCC	Ryan North	154	35	2,650	3,800	430	0.10	0.62	1.4	16.6
14-1W-3BBB	Ryan Permian	1600	516	46,500	71,900	6200	1.5	4.5	13	180
14-1W-7AAD	New Cambria Old Gage	135	18	115	63	127	0.05	0.16	0.43	9.5
14-1W-8BBB	Julia Martin Alluvial	960	170	12,200	18,800	2370	<0.3	1.0	4.8	94
14-1W-8BBA	Julia Martin Permian	1090	530	5,820	9,820	3330	3.0	11.8	9.0	740
14-1W-10BBC	Ryan South	12	3	427	285	130	0.02	0.36	1.1	14.4
13-2W-32CCB2	Cottonwood Tree N	157	31	56	72	167	0.7	0.10	0.87	19
13-2W-32CCB3	Cottonwood Tree	920	850	99,000	151,000	5100	---	5.3	34	250
13-2W-32CCB3	Cottonwood Tree	1100	900	106,000	162,000	5000	3.0	8.0	33	680
13-2W-32CCB3	Cottonwood Tree	1050	850	103,000	160,000	5100	1.4	6.9	32	580
13-2W-33DDC	Bend in Old 40	138	20	49	79	123	0.05	0.085	0.42	22
13-2W-35ACC	USBR New Cambria W	157	18	113	66	112	0.07	0.17	0.30	10.2
13-2W-35DBB	New Cambria	283	45	1,180	1,800	660	0.09	0.30	0.42	22
13-2W-36DDD	Four Corners	235	51	1,500	2,330	468	0.15	0.35	0.61	23
14-2W-8ACD	------	150	16	22	28	70	0.48	0.054	0.81	5.0
14-2W-8ADA	Debold	118	17	32	22	58	0.043	0.13	b	14
14-2W-8BBC	Salina Sewer Plant	1330	694	66,000	104,000	4150	---	3.2	19	260
14-2W-8CAB	Country Club East	176	51	67	150	250	0.06	0.13	0.63	18
14-2W-8CAB2	Country Club Middle	144	28	69	120	230	0.05	0.10	0.24	20
14-2W-8CBB	Country Club West	167	38	68	140	260	0.06	0.11	0.50	16.3
14-2W-9BDD	Maxey	106	21	34	37	104	0.038	0.046	0.58	3.0

Table 2. (Continued)

Location[a]	Name	Ca	Mg	Na	Cl	SO_4	Li	B	Br	I
				Observation and water-supply wells						
14-2W-9CBB	Farris	155	28	23	31	182	0.05	0.38	b	21
14-2W-9CCB	Morrison	635	214	290	459	2000	0.29	1.8	0.87	16.2
14-2W-9DBD	Roesner	101	32	24	32	145	0.05	0.071	0.56	10.2
14-2W-9DCD	------	250	43	80	110	400	0.07	0.052	1.11	8.6
14-2W-9DDC	Magee	192	40	151	110	275	0.07	0.10	0.94	2.7
14-2W-10ACD	Landes	242	53	44	40	360	0.09	0.15	0.62	10.3
14-2W-10BCD	Simcox	146	26	50	30	152	0.05	0.63	0.92	12.1
14-2W-11DBA	Jellison	590	87	510	656	1500	0.16	0.40	0.78	10.1
14-2W-16AAA	Bell No. 1	610	57	98	134	1280	0.13	0.12	0.88	8.8
14-2W-16AAA2	Bell No. 2	306	60	108	126	630	0.08	0.10	0.85	8.9
14-2W-16ABA	Sandow	186	34	77	64	360	0.06	0.54	0.69	2.6
14-2W-16BBA	Eddy	146	22	69	73	192	0.06	0.62	0.84	4.2
14-2W-18BDA	Salina City Park	1210	894	18,000	27,700	6300	3.8	12	29	1820
14-2W-20B	Lagerberg[d]	520	108	190	1,400	45	---	---	---	---
13-3W-4DCC	White School House	1050	1360	70,000	106,000	11100	7	6	16	200
13-3W-16DCD	USBR Tucker	134	19	59	31	80	0.07	0.13	b	18
13-3W-26CDD	Drainage Ditch	147	18	30	30	74	0.06	0.096	0.48	19
13-3W-33BCC	Trenton Road	1180	530	126,000	193,000	5200	<2	5.0	22	450
13-3W-36CBA	Ramada Inn	3200	680	18,200	34,900	1330	1.0	0.18	b	190
14-3W-27BBB	Airport	970	1030	74,000	112,000	8200	2.0	13	19	330
15-3W-7BAA	Landfill	1240	840	104,000	160,000	7000	3.0	6.0	26	320
15-3W-19AAA	Smolan	900	607	27,500	42,400	4060	<1	6.0	7.8	120
16-3W-3CDC	Assaria	2700	740	23,000	39,800	3070	4.2	11.5	99	2300
17-3W-8CCB	Lindsborg	1280	1040	44,000	68,800	6100	<1	8.2	14	190
				River and stream waters						
14-2W-9DAA	East Dry Creek	200	37	71	22	180	0.05	0.085	b	30
14-2W-8CBA	Smoky Hill River	98	24	95	127	173	0.043	0.11	0.46	20
14-2W-9DBD	Smoky Hill River	100	24	104	143	177	0.05	0.12	0.21	21

Table 2. (Continued)

Location[a]	Name	Ca	Mg	Na	Cl	SO_4	Li	B	Br	I
				Oil-field brines						
14-2W-5CDC	Winslow 1	1960	510	14,900	27,100	1250	4.4	7.0	77	3100
14-2W-7AAD	Haley 1	1440	373	10,700	22,400	740	3.1	4.8	58	2200
14-2W-7D	Sheldon 4	4820	1560	31,600	59,500	1060	5.2	6.1	240	7100
14-2W-9CAA	Roesner 1	1910	591	16,500	28,500	740	4.6	7.2	65	4200
14-2W-17BCD	Seitz 1	2170	600	17,500	30,400	1350	4.8	8.1	93	3800
14-2W-17CDB	Prescott 1	2140	596	17,200	30,500	1340	5.2	7.8	75	3800
14-2W-28ADB	Hagg 2	1560	452	12,800	22,000	840	4.3	7.2	77	2800
14-2W-28DDB	Gillberg 2	1410	389	11,500	19,700	960	3.8	7.2	70	2300
14-2W-30DCD	Sudendorf 2	2040	605	16,700	28,800	830	5.1	8.1	95	3500
14-2W-30CDD	Balaum 2	2040	609	16,700	28,600	810	5.1	8.0	93	3300
16-3W-10A	Thelander	1960	537	14,500	25,800	570	4.1	6.1	79	2800

[a] Township-range-section, quarter section, quarter-quarter section, quarter-quarter-quarter section.

[b] Interference prevented analysis

[c] Concentration in mg/liter

[d] Collected and analyzed by Kansas Department of Health and Environment

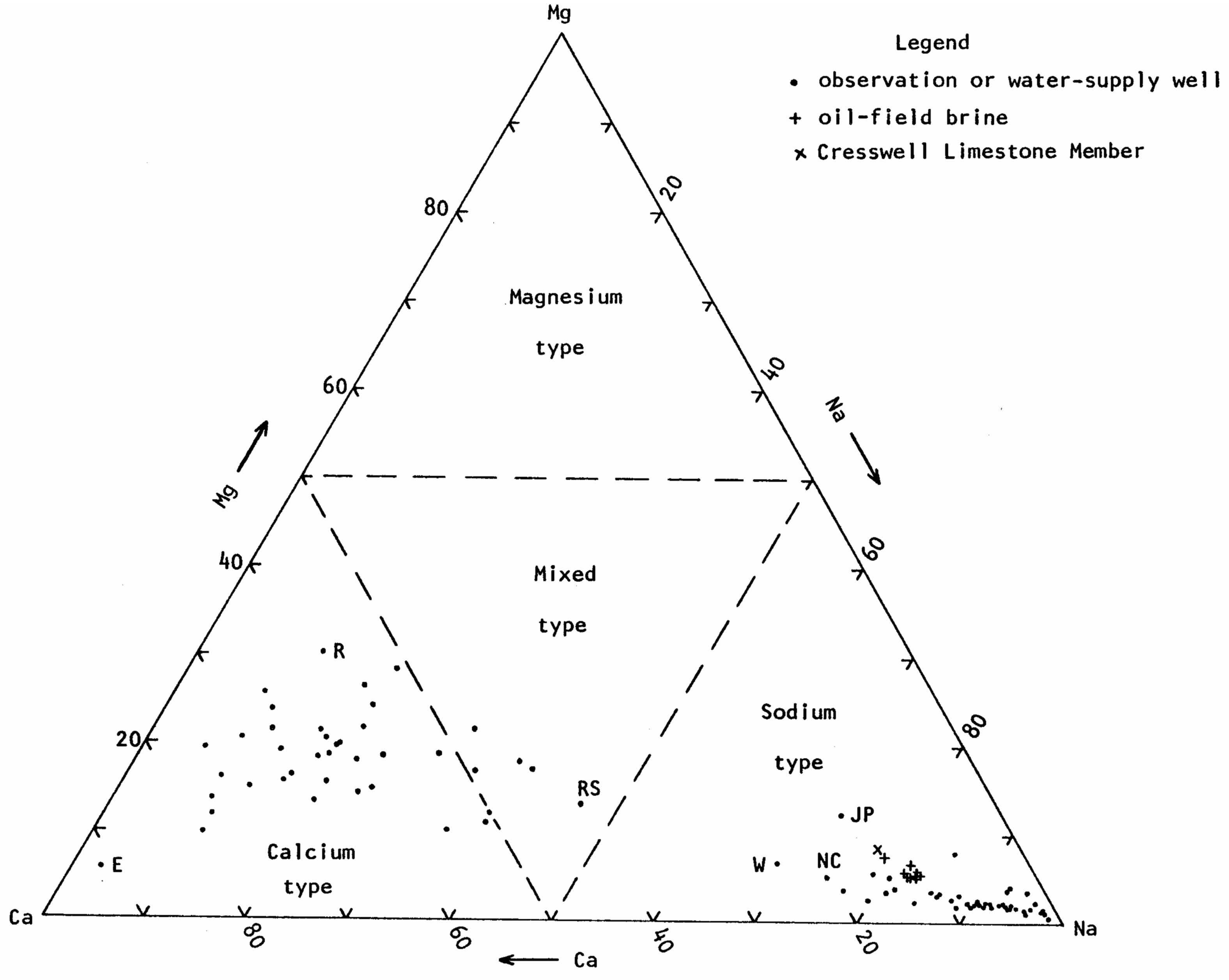


Figure 4. Chemical analyses of waters represented as percentages of total equivalents per liter of major cations. Labeled points refer to water samples with name abbreviations in Table 1.

are dissolved. In the presence of low sodium and chloride concentrations (less than 20 mg/L), only about 600 mg/L calcium and 1500 mg/L sulfate can be dissolved from gypsum. The Emig sample represents a water approaching this condition. The source of magnesium in the waters is predominantly from solution of dolomite [$CaMg(CO_3)_2$].

As the sodium and chloride content of the water becomes greater as a result of mixing with salt-solution brine, the location of a water on Figure 4 moves through the mixed cation type to the sodium type. The rise in dissolved solids increases the ionic strength of the water, decreasing activity coefficients, and allowing more gypsum or anhydrite to dissolve. Sulfate concentrations can then increase to more than several thousand mg/L. Precipitation of calcite, which can cement collapse zone fragments into a rigid, porous framework, keeps the calcium from rising above 2000 mg/L while allowing more gypsum or anhydrite to dissolve to produce the high sulfate values. Calcium concentrations greater than 200 mg/L occur, however, in the oil-field brines or waters polluted by oil brines because the sulfate content is lower than in the evaporite-solution brines.

The triangle representing the sodium type of water in the Piper-Hill diagram of Figure 4 is expanded in Figure 5 to better show the distribution of saline waters and brines. Most of the waters plot in a linear trend (represented by a dashed line) reflecting various mixtures of salt-solution brines and freshwaters. The most concentrated brine occurs at the Trenton Road site (T on Figure 5). The sample from this site contained 193,000 mg/L of dissolved chloride, which is the concentration expected for a solution saturated with respect to halite (NaCl) at 20°C.

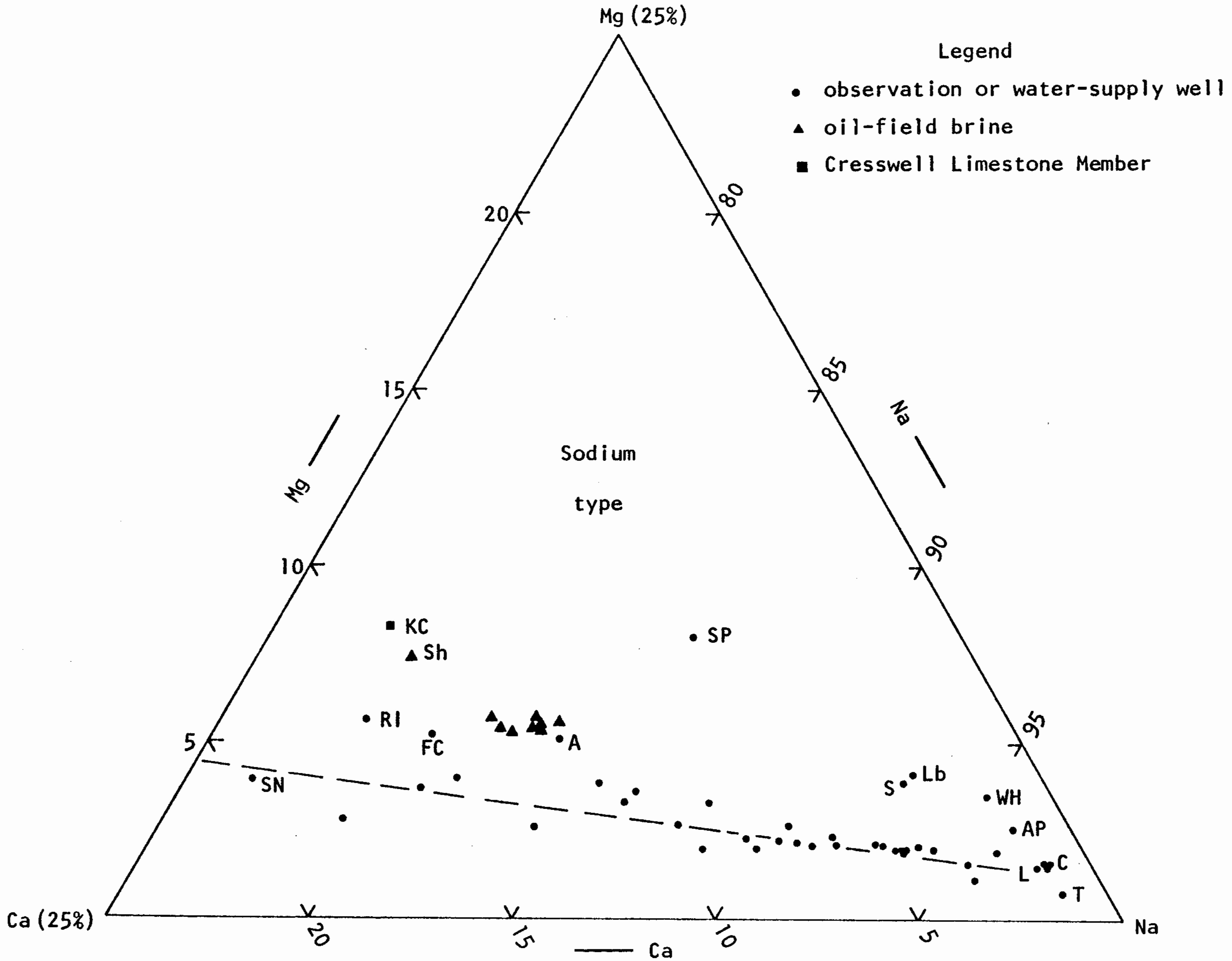


Figure 5. Chemical analyses of waters represented as percentages of total equivalents per liter of major cations: sodium-type waters. The diagram shows only the sodium corner as expanded from Figure 4. Labeled points refer to water samples with name abbreviations in Table 1.

Oil-field brines contain a greater magnesium percentage of the major cations than for most of the saline waters and brines from evaporite solution. The observation well water from the Cresswell Limestone Member below the Wellington Formation plots near to the Sheldon brine, appearing to be quite similar to oil-field chemistry (points labeled KC and Sh on Figure 5). Several other waters plot at higher magnesium percentages than the linear trend of the salt-solution waters. Most of these are from wells in the Wellington aquifer in range 3W, lying to the west of highway I-35W. The source of the magnesium could be small amounts of magnesite ($MgCO_3$) and polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) in addition to dolomite as described later in this report.

Weight ratios of chemical constituents in the water samples are listed in Table 3. The sodium/chloride ratio expected for simple solution of halite is 0.649, while the ratios for oil-field brines in Kansas are usually 0.5 ± 0.1. Observation well waters at saturation (Trenton Road) or close to saturation (Cottonwood Tree and Landfill) all had sodium/chloride values of 0.65. The ratios for oil-field brines in this study were within the range 0.53 ± 0.5, and averaged 0.56. For the sodium/chloride ratio to be applied to possible differentiation of waters affected predominantly by salt-solution brines from those polluted by oil brine, the chloride concentration should generally be above 500 mg/L. Sodium concentrations in fresher waters in sedimentary rocks are largely governed by ion exchange reactions with clays. Most shales have been deposited in marine environments and thus the adsorbed cation in greatest concentration on clay surfaces is usually sodium. Interaction of freshwaters of calcium, magnesium-bicarbonate type in limestones and

Table 3. Weight Ratios of Chemical Constituents in Water Samples

Location[a]	Name	Na/Cl	Ca/SO$_4$	Mg/Cl	Li/Cl x 10^5	B/Cl x 10^5	Br/Cl x 10^4	I/Cl x 10^6
	Observation and water-supply wells							
13-1E-19CAB	Solomon Bridge SE	0.68	0.30	0.0079	1.1	6.0	1.7	2.4
13-1E-20ACA	Old Solomon City	1.96	0.57	3.0	700	600	610	1060
13-1E-20BBC	Emig	1.36	0.43	1.4	1600	500	140	190
13-1E-23DAB	Sand Springs Br. N	0.68	1.77	0.39	80	108	140	100
13-1E-23DAB	Sand Springs Br. S	0.45	1.65	0.41	107	131	-	230
13-1E-28CCC	Iron Bridge	0.68	0.53	0.167	8	17	4.1	7.3
13-1E-29AAB	Roy Clemence	1.62	0.79	1.5	280	320	420	380
13-1E-30ADA	Car Body	0.65	0.32	0.0084	4.8	9.6	2.0	2.0
13-1E-34ADD2	Concrete	0.79	0.200	0.0205	7	24	6.1	4.9
13-1E-35DCD2	Red Brick School	1.04	0.53	0.158	46	155	34	23
13-1W-7DDA	Don Vaupel North	5.9	0.49	2.8	1200	2000	100	790
13-1W-10DDB	Riordan House	2.2	0.45	1.40	210	390	260	91
13-1W-10DCA	Riordan Permian	1.66	0.45	2.83	550	1430	89	170
13-1W-14DAD	RR Triangle East	0.64	0.42	0.0076	3.3	14	2.1	3.8
13-1W-14DAD2	RR Triangle West	0.65	0.37	0.0077	3.0	7.4	1.8	1.6
13-1W-16BCC	Old Latta	0.68	0.36	0.0128	2.8	14	1.6	2.0
13-1W-16DCC	Swenson North	0.72	0.56	0.0192	6	17	5.2	12.6
13-1W-16DCC2	Swenson South	0.66	0.45	0.0108	2.5	11	2.0	1.8
13-1W-19ACD	I-70 Borrow Pit	0.85	0.37	0.301	60	210	25	25
13-1W-20CDD	Ward South	0.65	0.34	0.0085	2.1	7.9	1.6	1.4
13-1W-22CCB	RR Borrow Pit	0.65	0.42	0.0126	1.8	6.1	1.7	1.6
13-1W-23BCB2	Railroad	0.65	0.51	0.0153	2.9	8.2	3.1	0.9
13-1W-23CAA	Shirak No. 2	0.66	0.33	0.0080	3.2	8.2	2.8	2.8
13-1W-24BDA	Boondocks	0.64	0.36	0.0079	1.4	4.3	1.5	1.5
13-1W-24CDC	Kelly Road Tee	0.65	0.31	0.0099	2.5	8.7	2.2	3.3
13-1W-24DDC2	Kelly Alluvial	0.65	0.277	0.0074	1.8	6.0	1.9	3.1
13-1W-24DDC3	Kelly Permian	0.63	0.291	0.0068	1.3	6.6	1.6	2.3
13-1W-24DDC4	Kelly Cresswell	0.51	8.1	0.0289	15	18	44	113
13-1W-25BDA	Pettijohn East	0.65	0.31	0.0077	2.3	6.1	1.8	2.1
13-1W-26ADD	Red Barn	0.67	0.58	0.0109	3.7	13	4.4	4.0
13-1W-26BCB	Krebs Pasture	0.67	0.272	0.0079	2.8	14	2.4	3.2

Table 3. (Continued)

Location[a]	Name	Na/Cl	Ca/SO$_4$	Mg/Cl	Li/Cl x 10^5	B/Cl x 10^5	Br/Cl x 10^4	I/Cl x 10^6
	Observation and water-supply wells							
13-1W-30BCC	USBR Niles Road	0.46	0.74	0.170	29	45	18	47
13-1W-30CCC	Old 40 Niles Road N.	0.65	0.40	0.0088	0.9	5.8	2.0	1.8
13-1W-30CCC2	Old 40 Niles Road S	0.66	0.33	0.0057	<1	2.4	1.6	2.9
13-1W-32CCC	Telephone	0.65	0.43	0.0144	1.7	7.9	2.0	4.2
13-1W-32DDA	Dead End Sign	0.65	0.297	0.0077	1.5	4.1	1.8	3.0
13-1W-33DAA	USBR by Martin	0.84	1.93	0.45	140	170	120	86
13-1W-34CCC	Albert Martin	0.64	0.32	0.0082	1.3	5.5	1.9	2.6
13-1W-35BBC2	Kirtland 2" Steel	0.67	0.51	0.0136	4.2	17	5.6	6.7
13-1W-35CDC	Dike	0.66	0.296	0.0073	1.4	5.6	1.8	2.2
13-1W-35DDD	Welchel	0.75	0.292	0.0394	8	38	6.2	5.1
14-1W-3BCC	Ryan North	0.70	0.36	0.0092	2.6	16	3.6	4.4
14-1W-3BBB	Ryan Permian	0.65	0.257	0.0072	1.8	6.3	1.8	2.5
14-1W-7AAD	New Cambria Old Gage	1.83	1.06	0.283	90	250	68	150
14-1W-8BBB	Julia Martin Alluvial	0.65	0.41	0.0090	<1.5	5.5	2.6	5.0
14-1W-8BBA	Julia Martin Permian	0.59	0.33	0.054	30	120	9.2	76
14-1W-10BBC	Ryan South	1.50	0.092	0.0095	7	130	39	51
13-2W-32CCB2	Cottonwood Tree North	0.78	0.94	0.43	100	150	120	260
13-2W-32CCB3	Cottonwood Tree	0.65	0.180	0.0056	-	3.5	2.3	1.7
13-2W-32CCB3	Cottonwood Tree	0.65	0.220	0.0056	1.9	4.9	2.0	4.2
13-2W-32CCB3	Cottonwood Tree	0.65	0.204	0.0053	0.9	4.3	2.0	3.6
13-2W-33DDC	Bend in Old 40	0.62	1.12	0.256	70	110	53	280
13-2W-35ACC	USBR New Cambria W	1.71	1.40	0.268	100	260	46	150
13-2W-35DBB	New Cambria	0.66	0.43	0.0250	4.9	17	2.3	11.9
13-2W-36DDD	Four Corners	0.64	0.50	0.0219	6	15	2.6	9.7
14-2W-8ACD	———	0.79	2.14	0.58	170	190	290	180
14-2W-8ADA	Debold	1.46	2.05	0.78	200	580	-	630
14-2W-8BBC	Salina Sewer Plant	0.63	0.320	0.0067	-	3.1	1.8	2.5
14-2W-8CAB	Country Club East	0.45	0.70	0.340	41	87	42	121
14-2W-8CAB2	Country Club Middle	0.58	0.63	0.233	43	87	20	170
14-2W-8CBB	Country Club West	0.49	0.64	0.271	40	78	36	116
14-2W-9BDD	Maxey	0.92	1.02	0.58	100	120	160	81

Table 3. (Continued)

Location[a]	Name	Na/Cl	Ca/SO_4	Mg/Cl	Li/Cl x 10^5	B/Cl x 10^5	Br/Cl x 10^4	I/Cl x 10^6
	Observation and water-supply wells							
14-2W-9CBB	Farris	0.75	0.85	0.89	160	1220	-	670
14-2W-9CCB	Morrison	0.63	0.318	0.46	60	380	19	36
14-2W-9DBD	Roesner	0.76	0.70	1.00	150	220	180	320
14-2W-9DCD	———	0.73	0.62	0.39	5	47	100	78
14-2W-9DDC	Magee	1.37	0.70	0.36	70	94	86	25
14-2W-10ACD	Landes	1.10	0.67	1.32	220	380	160	260
14-2W-10BCD	Simcox	1.67	0.96	0.87	170	210	300	400
14-2W-11DBA	Jellison	0.78	0.393	0.133	24	61	12	15
14-2W-16AAA	Bell No. 1	0.73	0.48	0.43	100	87	66	66
14-2W-16AAA2	Bell No. 2	0.86	0.49	0.48	60	81	68	71
14-2W-16ABA	Sandow	1.20	0.52	0.53	90	84	110	41
14-2W-16BBA	Eddy	0.95	0.76	0.30	80	85	120	58
14-2W-18BDA	Salina City Park	0.65	0.193	0.0323	14	44	10.4	66
14-2W-20B	Lagerberg[b]	0.14	11.6	0.077	-	-	-	-
13-3W-4DCC	White School House	0.66	0.095	0.0128	7	5.4	1.6	1.8
13-3W-16DCD	USBR Tucker	1.90	1.68	0.61	230	430	-	590
13-3W-26CDD	Drainage Ditch	1.00	1.99	0.61	220	320	160	650
13-3W-33BCC	Trenton Road	0.65	0.228	0.0028	<1	2.6	1.2	2.3
13-3W-36CBA	Ramada Inn	0.52	2.41	0.0195	2.9	0.5	-	5.3
14-3W-27BBB	Airport	0.66	0.118	0.0092	1.8	12	1.7	2.9
15-3W-7BAA	Landfill	0.65	0.178	0.0052	1.9	3.7	1.6	2.0
15-3W-19AAA	Smolan	0.65	0.222	0.0143	<2	14	1.8	2.8
16-3W-3CDC	Assaria	0.58	0.88	0.0186	11	29	25	59
17-3W-8CCB	Lindsborg	0.64	0.211	0.0151	<1.5	12	2.1	2.8
	River and stream waters							
14-2W-9DAA	East Dry Creek	3.2	1.11	1.68	220	390	-	1350
14-2W-8CBA	Smoky Hill River	0.75	0.57	0.189	34	84	36	156
14-2W-9DBD	Smoky Hill River	0.73	0.56	0.168	36	83	15	146

Table 3. (Continued)

Location[a]	Name	Na/Cl	Ca/SO_4	Mg/Cl	Li/Cl $\times 10^5$	B/Cl $\times 10^5$	Br/Cl $\times 10^4$	I/Cl $\times 10^6$
			Oil - field brines					
14-2W-5CDC	Winslow 1	0.55	1.57	0.0188	16	26	28	115
14-2W-7AAD	Haley 1	0.48	1.94	0.0167	14	21	26	98
14-2W-7D	Sheldon 4	0.53	4.55	0.0262	8.7	10.3	40	119
14-2W-9CAA	Roesner 1	0.58	2.57	0.0207	16	25	23	146
14-2W-17BCD	Seitz 1	0.58	1.61	0.0197	16	27	31	125
14-2W-17CDB	Prescott 1	0.56	1.60	0.0195	17	26	25	126
14-2W-28ADB	Hagg 2	0.58	1.86	0.0205	20	33	35	127
14-2W-28DDB	Gillberg 2	0.58	1.47	0.0197	19	37	36	115
14-2W-30DCD	Sudendorf 2	0.58	2.46	0.0210	18	28	33	122
14-2W-30CDD	Balaum 2	0.58	2.51	0.0213	18	28	33	116
16-3W-10A	Thelander	0.56	3.44	0.0208	16	24	31	107

[a] Township-range-section, quarter section, quarter-quarter section, quarter-quarter-quarter section

[b] Collected and analyzed by Kansas Department of Health and Environment

dolomites with clays in weathering shales generally results in the exchange of some calcium and magnesium for sodium. Thus, sodium/chloride values in the freshwaters are usually greater than 0.7.

As noted above, the calcium concentrations in oil-field brines are high and the sulfate contents low relative to salt-solution brines, especially when compared on the basis of similar chloride concentrations. A plot of calcium/sulfate versus chloride concentration for the samples in this study illustrates the chemical separation of the two sources of saltwater (Figure 6). The calcium/sulfate ratio generally increases with increasing chloride values for the oil-field and Cresswell Limestone Member brines, while decreasing with increasing chloride content for mixtures of freshwater and salt-solution brines.

The ratio magnesium/chloride can also be used to differentiate some waters affected by oil-field brines from those containing mainly salt-solution brines. Waters derived from burial of seawater (magnesium/chloride = 0.067) could be expected to have higher magnesium/chloride ratios than for brines derived from solution of halite and calcium sulfate minerals, even if the magnesium in the seawater were decreased by dolomitization. However, an investigation by Jones (1965) showed magnesite and polyhalite in addition to dolomite in the Hutchinson Salt near Hutchinson. The presence of magnesite and polyhalite in the salt being dissolved in the western part of the Wellington aquifer could be major sources of magnesium above that derived from dolomite, which is the major carbonate rock interbedded with shale and anhydrite below and above the Hutchinson Salt. As the brine moves away from areas in which magnesite and polyhalite are dissolved, dolomite might slowly precipitate, lowering

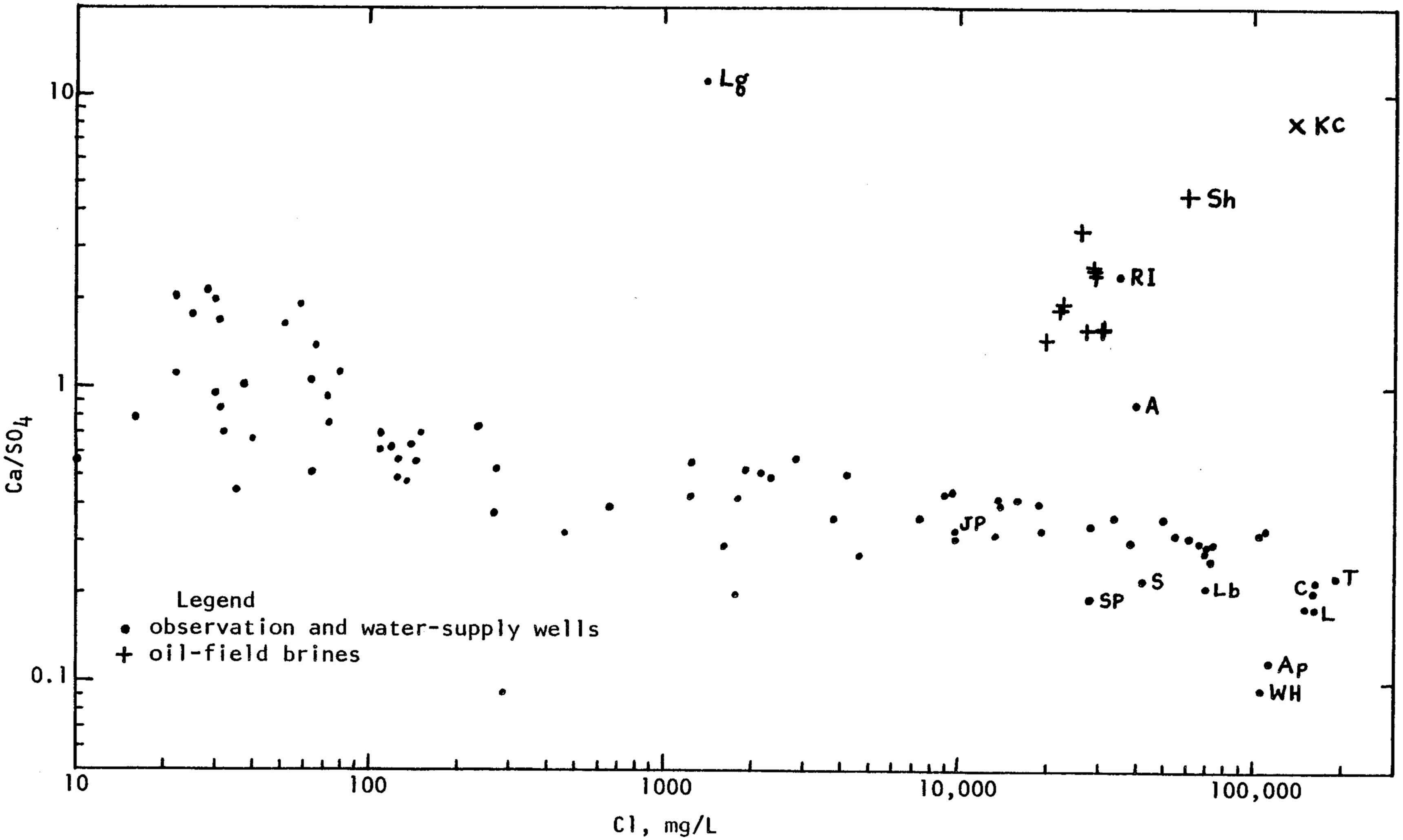


Figure 6. Variation in the weight ratio calcium/sulfate with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1.

the magnesium/chloride ratio. Figure 7 shows the variation of magnesium/chloride versus chloride concentration. Magnesium/chloride ratios generally decrease with increasing chloride for most waters, although they increase for the oil-field and Cresswell formation brines. Many saline waters and brines from observation wells have higher magnesium/chloride values at a given chloride concentration than for the trend of most of the salt-solution mixtures. These same samples plotted above the linear trend on the Piper-Hill diagram of Figure 5.

Lithium/chloride ratios decrease with increasing chloride concentrations in a zone of mixing of freshwaters with salt-solution brines such as at the Landfill and Cottonwood Tree wells (Figure 8). The boundary lines for this zone, as well as that for the mixing of freshwaters and oil brines, are theoretical curves for the mixing of varying amounts of the freshwater and brine endpoints. Reliable values were not obtained for the Trenton Road, Smolan, and Lindsborg well samples due to the difficulty of analyzing low concentrations of lithium in the presence of high sodium; the lithium/chloride x 10^5 values would be less than 2, which would place these waters in the salt-solution mixing zone. Lithium/chloride ratios also form a decreasing trend, but at higher values, with increasing chloride from the Wellington Formation sample at the Julia Martin site, through the oil-field brines, Saline City Park and Assaria well waters, to the brine at the White School House site. The ratio for the Cresswell formation brine is even further separated from that of the salt-solution waters.

Changes in boron/chloride with chloride concentration (Figure 9) show somewhat similar trends as those for lithium/chloride versus chloride.

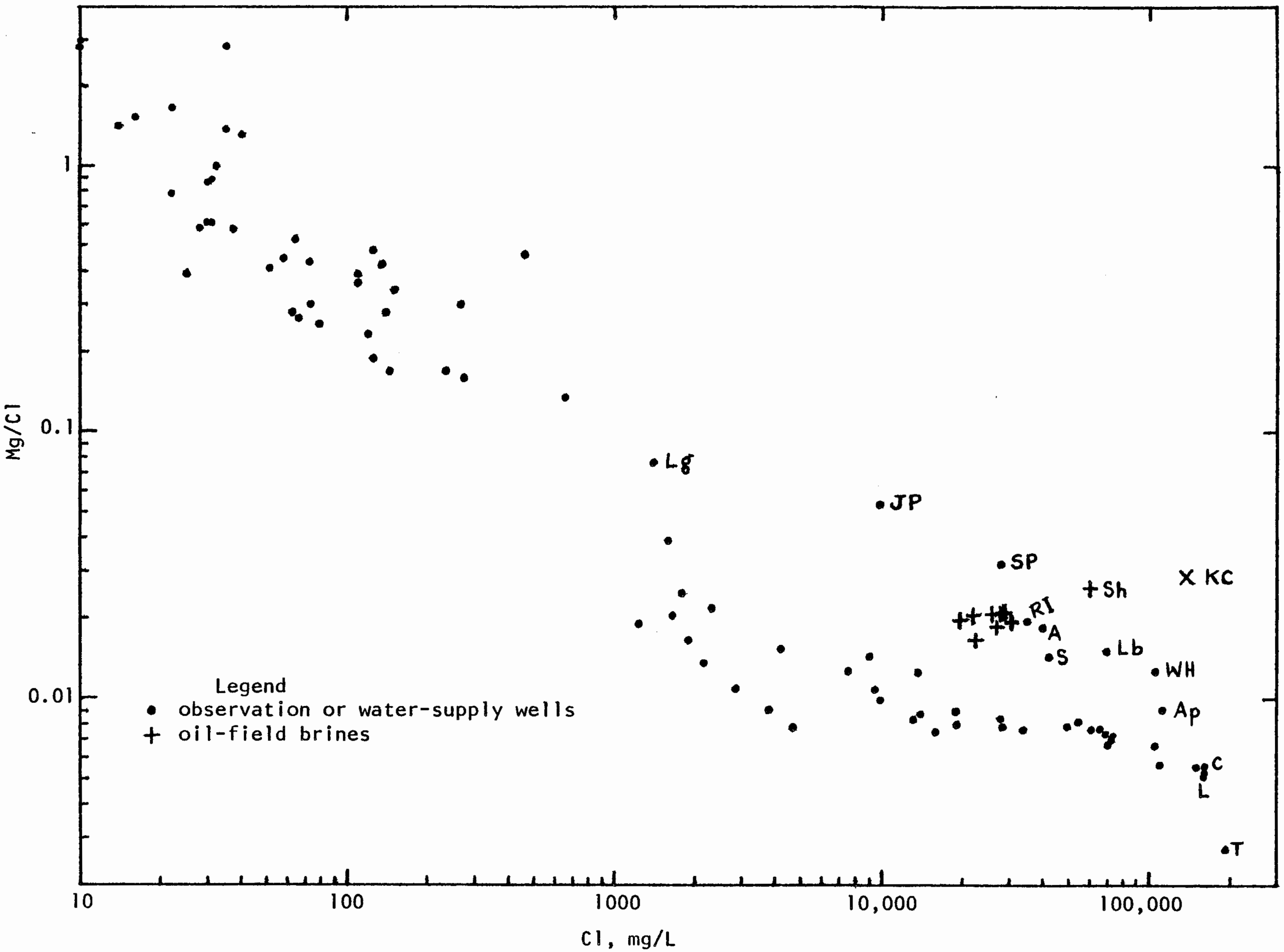


Figure 7. Variation in the weight ratio magnesium/chloride with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1.

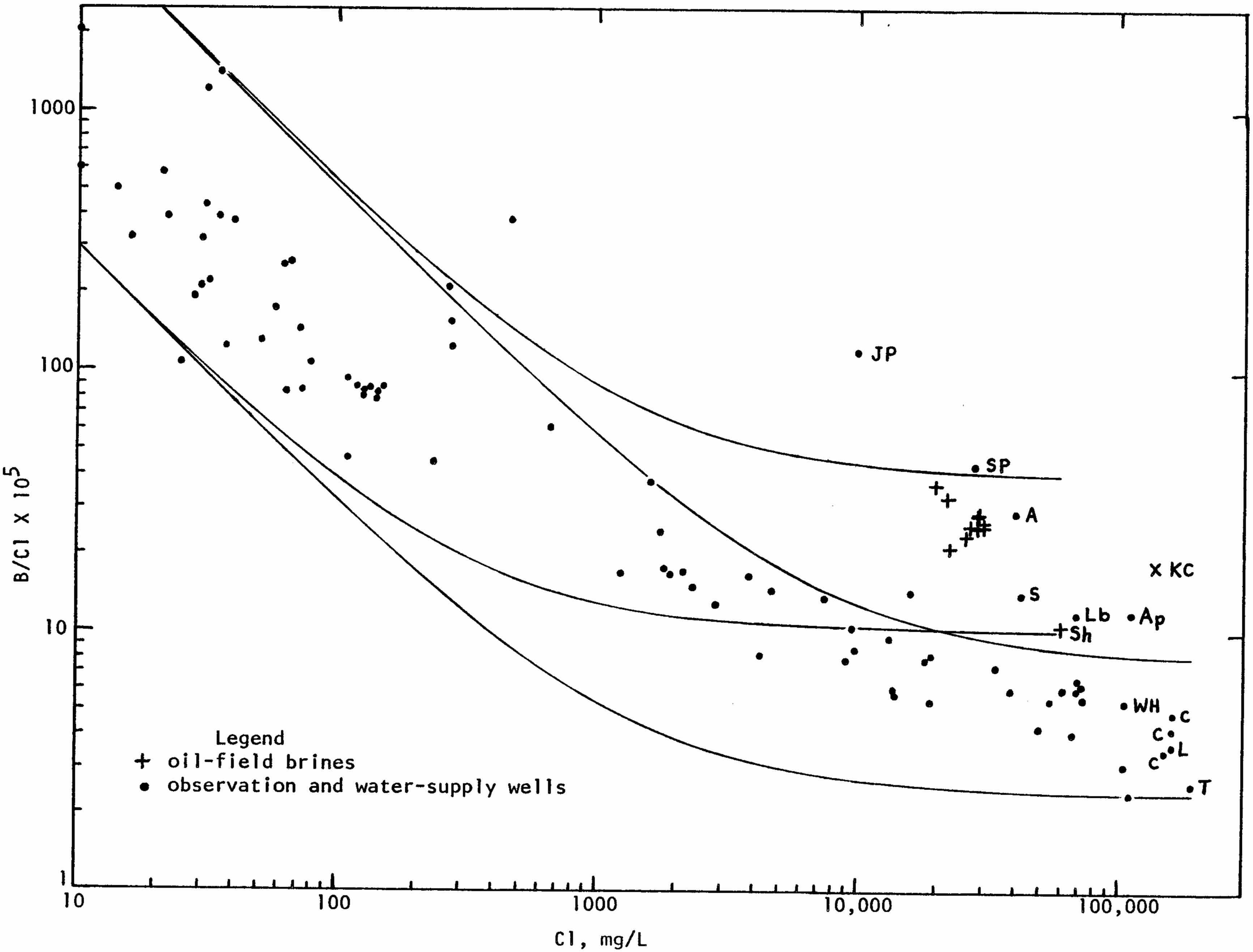


Figure 9. Variation in the weight ratio boron/chloride with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1. Curves are the boundaries of mixing zones of freshwaters with oil-field brines and salt-solution brines.

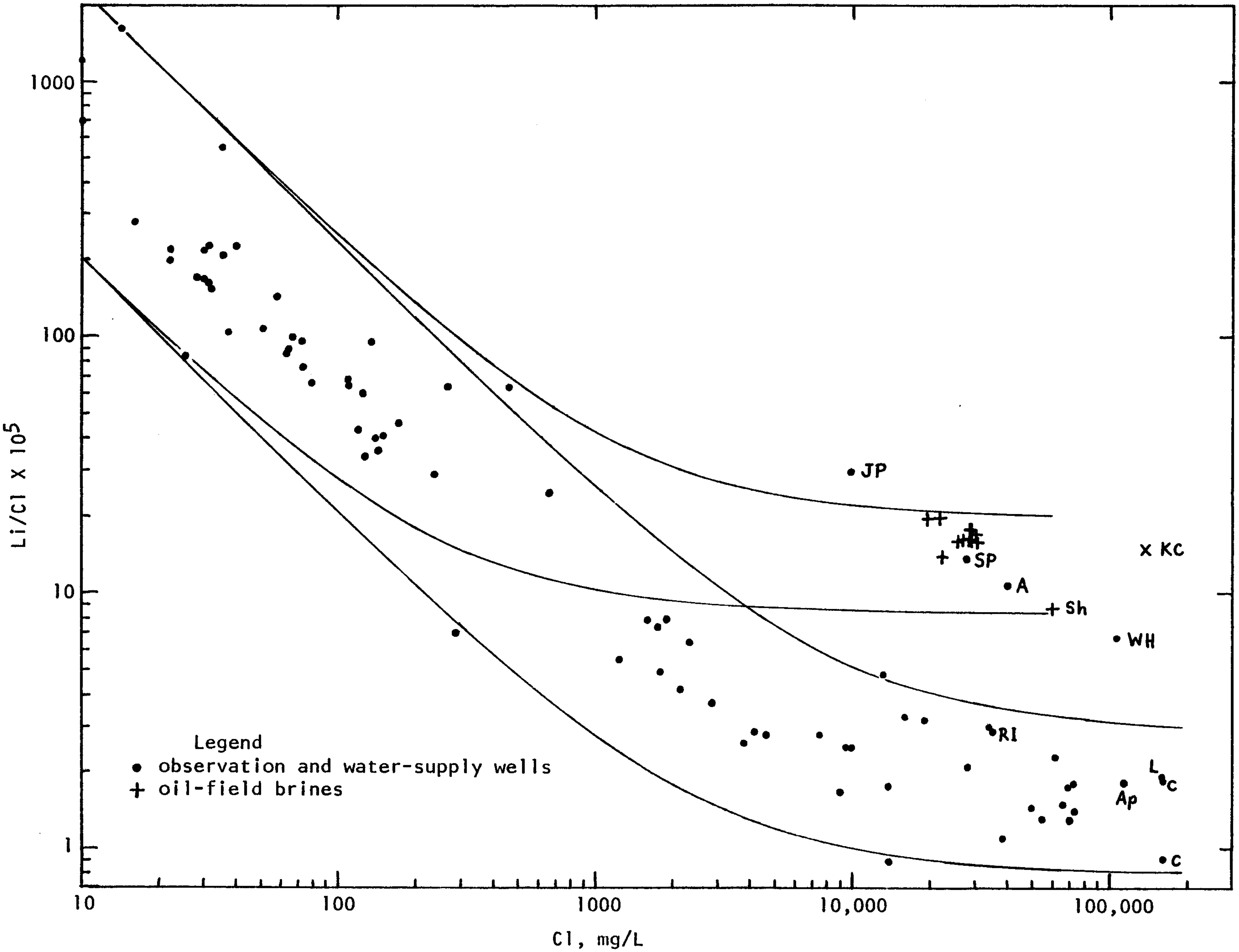


Figure 8. Variation in the weight ratio lithium/chloride with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1. Curves are the boundaries of mixing zones of freshwaters with oil-field brines and salt-solution brines.

Analytical error is less than that for lithium.

Experience in studying other areas indicates that bromide and iodide are generally the best trace constituents for distinguishing waters affected by salt solution from those contaminated by oil-field brine. In Figures 10 and 11 the ratios bromide/chloride and iodide/chloride, respectively, have been plotted versus chloride concentration for the water samples. The separation in the ratios of oil-field from salt-solution brines is greater at a given chloride content than for lithium/chloride and boron/chloride. Again, zones of mixing of freshwaters with salt-solution and oil brines are delineated. Based on Figures 10 and 11, the Cresswell formation water is chemically similar to the oil-field brines, as also shown by the lithium and boron results.

No single ratio can be relied on heavily by itself to identify the source of salt in a water. Rather, a combination of chemical evidence should be used to evaluate the salt origin. On this basis, the water from the observation well in the Wellington aquifer at the Assaria site closely matches the chemistry of oil-field brine in the area, having similar sodium/chloride, magnesium/chloride, lithium/chloride, boron/chloride, and iodide/chloride values. The only ratio which did not plot within those of the oil brines was calcium/sulfate. This is not unexpected in that mixing of oil-field brine with salt solutions could produce undersaturation of the solution with respect to gypsum or anhydrite. Calcium sulfate minerals would be dissolved incongruently with concurrent precipitation of calcite maintaining the calcium concentration, while the sulfate concentration increased, thus decreasing calcium/sulfate. Oxidation of hydrogen sulfide in the oil brine would also have increased

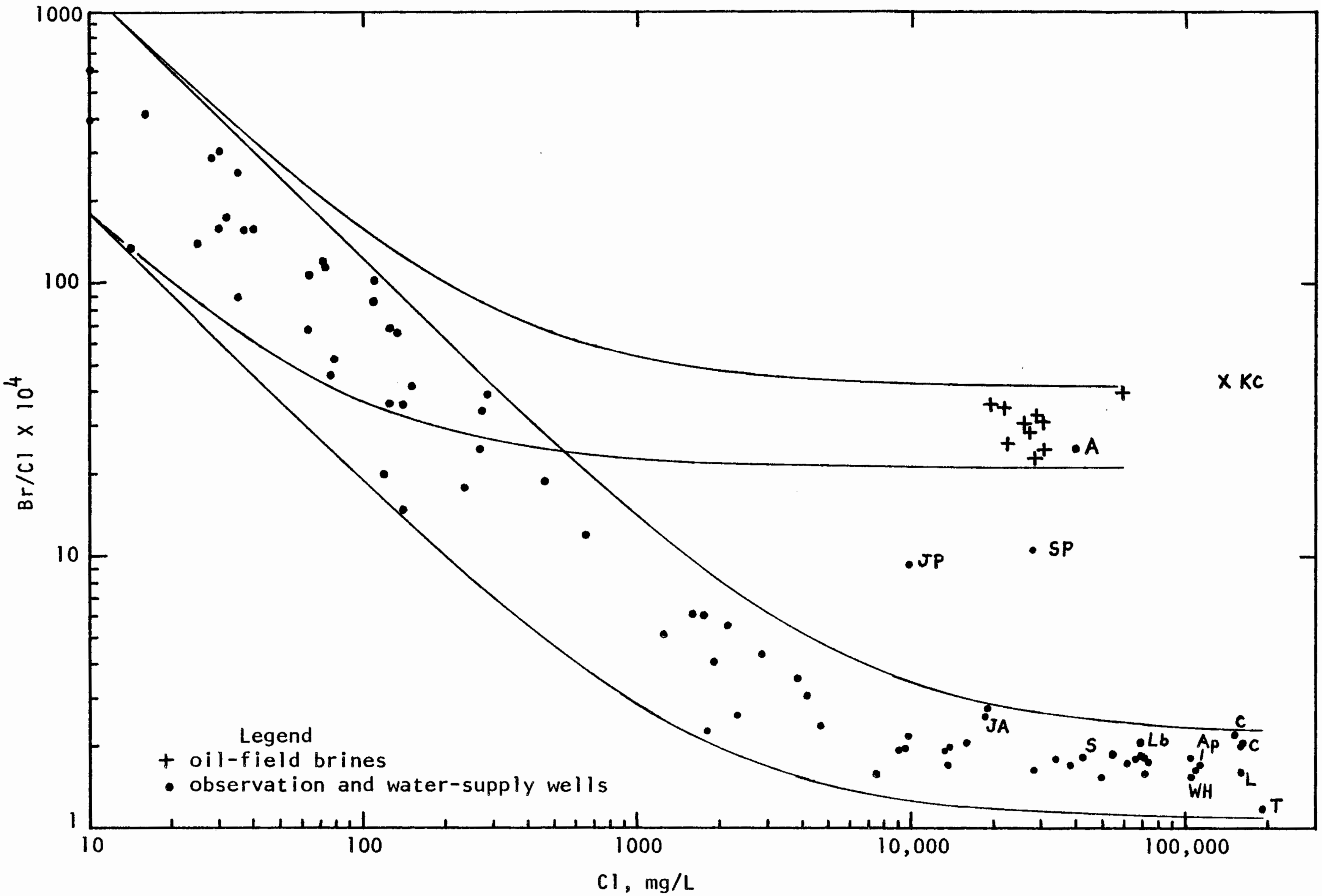


Figure 10. Variation in the weight ratio bromide/chloride with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1. Curves are the boundaries of mixing zones of freshwaters with oil-field brines and salt-solution brines.

the sulfate concentration by a small amount. Apparently, oil-field brine injected into a well in the Wellington aquifer less than 1/4 mile distant from the Assaria observation well, has mixed with a small amount of salt-solution brine and migrated to the Assaria site. During its movement mineral-water interactions have slightly altered its calcium/sulfate ratio. Assuming the water from this observation well is a mixture of the oil-field brine from the Thelander location and a salt solution with a chloride content of 160,000 mg/L, there would be about 90% oil brine and 10% salt brine.

The water from the Salina City Park well in the Wellington aquifer is mainly oil-field brine mixed with some evaporite-solution brine with a similar chloride content. Magnesium/chloride, lithium/chloride, boron/chloride, bromide/chloride, and iodide/chloride ratios all plot close to those of the brines accompanying oil produced in the area. The mixture from the observation well has apparently had more time than at the Assaria site to chemically interact with the rock in the Wellington aquifer, and thus alter sodium/chloride and calcium/sulfate ratios to within the salt solution mixing zones.

The sample obtained from the observation well in Permian strata at the Julia Martin site appears to be a mixture of freshwater and oil-field brine as indicated by its sodium/chloride value and five out of the six ratios for which mixing curves were plotted. As in the case of the Salina City Park sample, the calcium/sulfate ratio has been altered from that of oil brine to within the evaporite solution range. This indicates that the brine has traveled through enough of the Wellington Formation to equilibrate calcium and sulfate concentrations with the minerals present. The well in

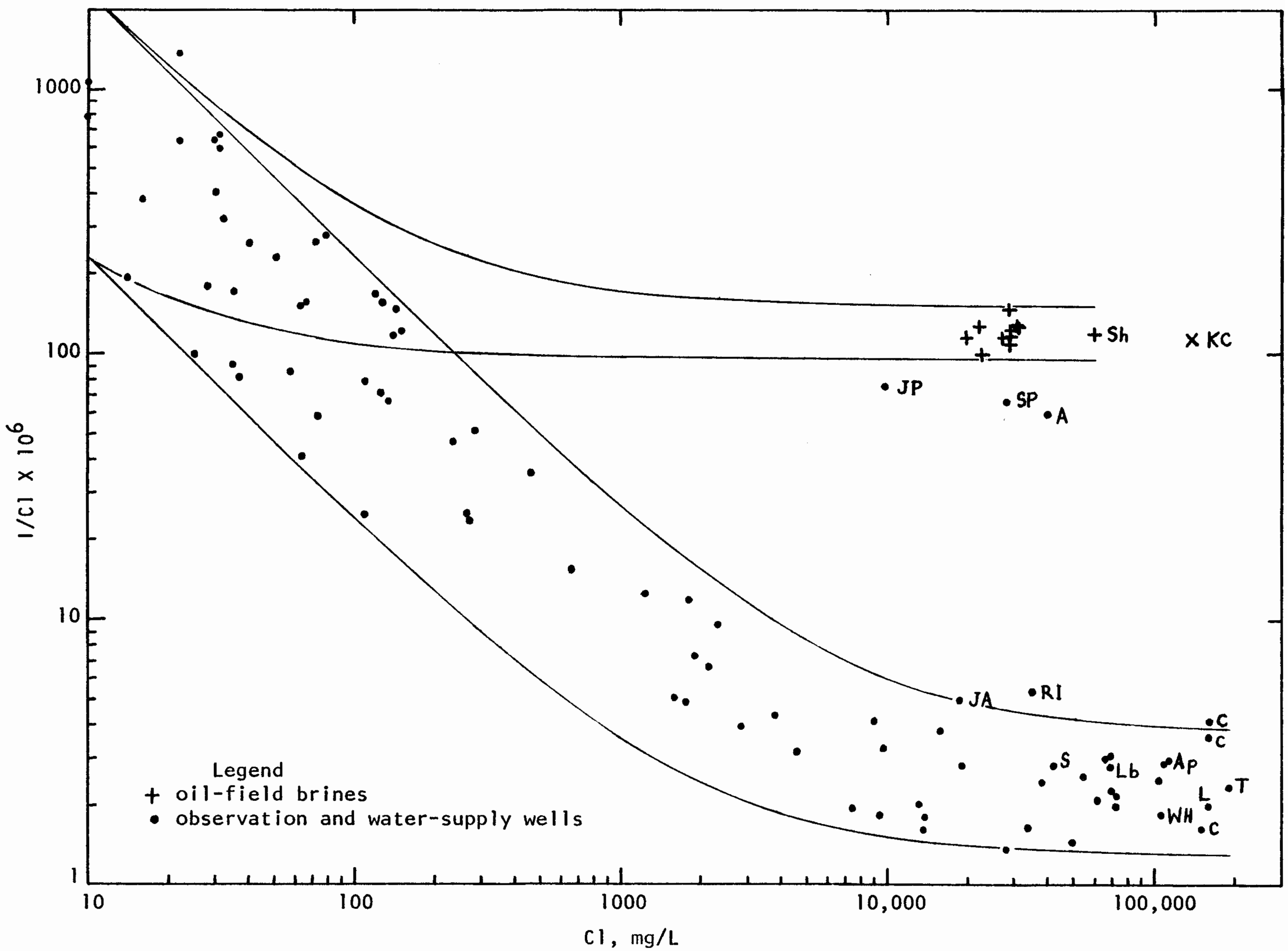


Figure 11. Variation in the weight ratio iodide/chloride with chloride concentration. Labeled points refer to water samples with name abbreviations in Table 1. Curves are the boundaries of mixing zones of freshwaters with oil-field brines and salt-solution brines.

the alluvium at the Julia Martin location yielded water which had a chloride content approximately twice that of the sample from the Permian well. The chemistry of the water in the alluvium generally plotted within the freshwater and salt-solution mixing zones for all ratios, although the bromide/chloride and iodide/chloride ratios were at or near the upper boundary of the zones. A small amount of the water from the Wellington Formation may thus be seeping from the valley wall, where the Permian well is located, into the alluvium. Probably most of the saline water at the alluvial well is derived from salt-solution brine moving from the Wellington underneath the well location or into the alluvium further to the west and north and flowing thence to the well site.

The water near the bottom of the alluvium at the Ramada Inn observation well north of Salina also has chemical aspects of oil-brine pollution. Both the sodium/chloride and magnesium/chloride ratios are what are expected for oil-field brines in the area. The iodide/chloride ratio definitely lies above the salt-solution mixing zone, but not as close to the oil-brine mixing zone as the sodium/chloride and magnesium/chloride ratios would suggest. Unfortunately, a chemical interference in the sample (believed to be ammonium ion which is present in some oil-field brines) could not be removed sufficiently to determine a reliable value for the bromide concentration. Research is currently underway to try to improve the removal of this interference. The Ramada Inn sample is being kept in order that a reliable bromide value may be eventually obtained. The boron/chloride ratio was by far the lowest found for any of the waters, while the lithium/chloride was near the upper boundary of the salt-solution mixing zone. The fact that the water at this site is in the alluvium indicates that oil brine had to seep up through shale layers in the underlying Wellington or had to travel from a more distant source through the alluvium. In either case, mineral-water interactions, especially with clays, could have altered the chemistry of oil brine, possibly adsorbing some of the lithium, boron, and iodide. Bromide is adsorbed much less than these trace constituents and will be valuable in verifying the amount of oil-field versus salt-solution brine at this site, providing a good analysis can be made.

A well (Lagerberg) in the upland area east of Salina and in the oil field appears to have been polluted by oil-field brine. The sample, analyzed by the Kansas Department of Health and Environment, contained a much higher chloride concentration than for shallow aquifers in that area. The very low sodium/chloride and high calcium/sulfate ratios can best be explained by the presence of oil brine.

The two samples taken during the pump test of the Cottonwood Tree well had bromide/chloride ratios near the upper boundary and iodide/chloride ratios at or slightly above the upper boundary of the salt-solution mixing zones. Based on this evidence, no more than a couple percent of, if any, oil-field brine could be affecting this site. The other ratios were all in the middle of the range expected for salt solution at the chloride concentration present.

The higher magnesium/chloride ratios for samples from the White School House, Airport, Smolan, and Lindsborg observation wells than for the salt-solution mixing zone, accompanied by greater lithium/chloride or boron/chloride are not believed to be caused by oil-field brine pollution. The sodium/chloride values of 0.65 ± 0.01 and low bromide/chloride and iodide/chloride ratios all strongly point to essentially only evaporite solution for these waters. The greater magnesium/chloride may be derived from solution of magnesite and polyhalite in the western part of the Wellington aquifer. The larger boron/chloride values of the Airport, Smolan, and Lindsborg brines probably result from a combined contribution of higher boron in anhydrite, polyhalite, and dolomite. Permian anhydrite in Oklahoma has been found to have a higher boron content than gypsum (Ham, et al., 1961). Much of the boron from the hydration of anhydrite to gypsum formed exsolution nodules. Hydration of anhydrite is probably occurring in the western part of the Wellington aquifer where the mineral is presently being exposed to water. Solution of the boron rich nodules may be a major source of the greater boron concentrations in the brine. Dolomite generally contains boron in amounts a few times greater than in limestones. Potassium and magnesium salts such as polyhalite in evaporites are often relatively high in boron (Harder, 1974). However, the polyhalite also contains greater concentrations of bromide than in halite, and would be associated with some halite with more bromide than most of the Hutchinson Salt. Thus, polyhalite is probably not the major contributor to the bulk of the greater boron concentrations in the waters. Little is known about the chemistry of lithium in evaporites, perhaps due to the difficulty of analysis in the presence of large sodium and calcium concentrations. The greater lithium/chloride ratio in the sample from the White School House well than in other salt-solution brines may be related in some way to the very high sulfate concentration present at this site, that is, the lithium might have been concentrated in certain sulfate minerals in the evaporite sequence.

All of the other saline waters and brines not specifically discussed have chemical characteristics indicating that the source of mineralization is evaporite solution.

Oil Wells and Oil-Field Brine Disposal

Discharge Area of the Wellington Aquifer

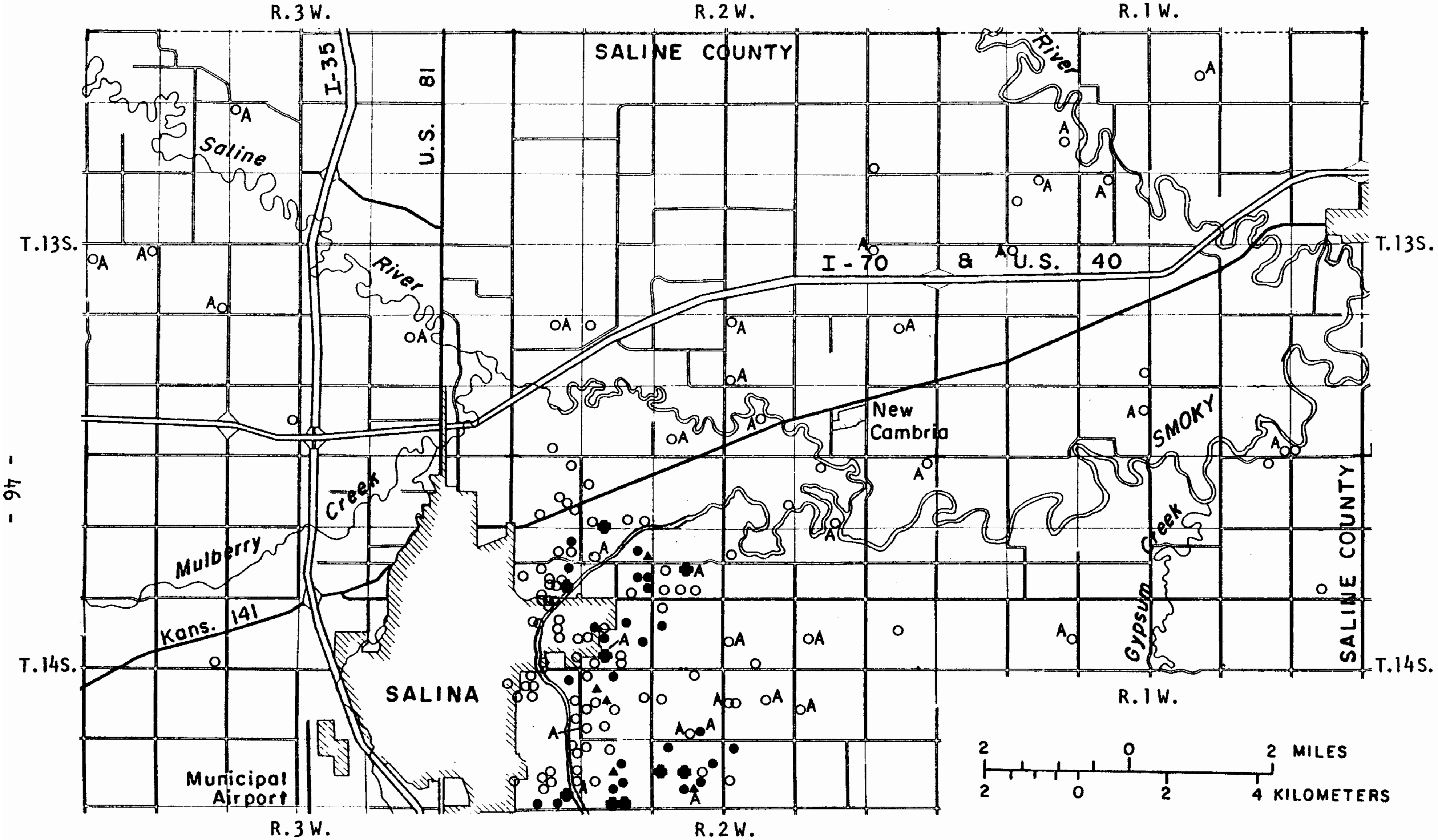
Production of oil from formations underlying the northern region of the Wellington brine aquifer first began in 1938 from the Lindsborg field (See Figure 1). For this study, most of the early investigation of the oil-fields near Salina was focused on the area comprised by township 13S and 14S, ranges 1W through 3W. This included the salt-water discharge area to the Smoky Hill River and the northernmost recharge area of the Wellington aquifer. The closest oil field to the discharge zone of the Wellington aquifer is the Salina field. The northern half of this field began pumping oil from the Maquoketa Shale in 1943 at Sudendorf well number 1, 14S-2W-30DBB. Several wells are known to have been drilled in and surrounding Salina from 1927 to 1943 through the Maquoketa Shale to the Simpson and Arbuckle Groups, but were reported as dry and abandoned. If any oil had been noticed before 1954 at the levels of the presently producing strata, the amounts were apparently not sufficient by the standards of those days to warrant completion and pumping of the well.

Most of the initial production in the northern portion of the Salina field began in the period 1945-1947. Additional pumping wells were steadily added through about 1966, including several in the adjacent Gillberg field. Fewer than 10 more wells were drilled in the 1970's, and of these only a few have produced oil. Most of the oil is obtained from the dolomite in the Maquoketa Shale of the Upper Ordovician Series, with some oil coming from the underlying Viola Limestone of the Middle Ordovician Series.

Probably over 90% of the fluid currently drawn from the field is brine ranging from about 20,000-60,000 mg/L chloride (Table 2).

Over 180 holes were drilled for oil exploration in the northeastern part of Saline County comprised of townships 13S and 14S and ranges 1W-3W: recorded boreholes were all dry and totaled 10, 10, 6, 8, and 2 for townships 13S-1W, 13S-2W, 13S-3W, 14S-1W, and 14S-3W, respectively. The sum of dry and producing oil wells in township 14S-2W is 146. The locations of these boreholes along with their present status are shown in Figure 12. The Petroleum Information Corporation biannually publishes a list of operable oil wells with production information in the Kansas Crude Petroleum Report. Table 4 gives the wells in northeastern Saline County which were included in the latest Report. However, during field investigation and brine sampling of selected wells in township 14S-2W, many of the data given by the Report were found to be out of date. Subsequent research, with assistance from R. Worley, Kansas Department of Health and Environment, revealed that several of the wells had been converted to saltwater disposal or repressuring use, and some had been plugged. Changes uncovered during study of well status in sections 1-30, township 14S-2W, are noted along with identification of wells for which present operation is unknown and was not checked.

The information in Figure 12 and Table 4 is useful to this study in two respects. First of all it provides the locations of boreholes through the Wellington aquifer. Boreholes which were not plugged, were poorly plugged, or have deteriorated plugs, missing or corroded casing, or open sections or breaks in casing could provide avenues for the flow in various directions of salt-solution brine from the Wellington aquifer, freshwater



Legend: ○ abandoned borehole or oil well, ● oil well operating in 1981, ▲ oil well listed as operable 1980, ⬣ saltwater injection well, A borehole extends to the Arbuckle Group

Figure 12. Location of boreholes drilled for oil in northeastern Saline County and present status.

Table 4. Oil Wells Listed in the *Kansas Crude Production Report* for Northeastern Saline County. The report was published by the Petroleum Information Corporation for production through December, 1980.

Location[a]	Number of wells	Lease name and well	Discovery date	Date of last withdrawal	Producing unit[b]	Notes[c]
13-1W	None					
13-2W	None					
13-3W	None					
14-1W	None					
14-2W-5CDC	1	Winslow 1	1966	1971	Mq	Now a disposal well
14-2W-7AAS/2	1	Haley 1	1951	1980	Vi	
14-2W-7CDD	1	Jarvis 1	1962	1973	Mq	Changed to disposal, then abandoned
14-2W-7DAB	3	Sheldon 4	1962	1980	Mq	
14-2W-7DDB		Fee 2	1961	?	Vi	Now a repressuring well
14-2W-7DBC		Fee-Sheldon 2	1947	?		Plugged
14-2W-8ADB	1	Cusick 1	1962	1980	Mq	
14-2W-8DDA	1	Dieter 1	1964	1980	Mq	
14-2W-8ACC	1	Haley	1979	1980	Mq?	
14-2W-8DAD	2	Johnson 1	1964	1980	Mq	
14-2W-8DAB		Johnson 2	1964	1980	Mq	
14-2W-9CC	1	Anderson 1	1964	1971	Mq	Plugged?

Table 4. (Continued)

Location^a	Number of wells	Lease name and well	Discovery date	Date of last withdrawal	Producing unit^b	Notes^c
14-2W-9CB	2	Graham 1	1964	1974	Vi	Changed to repressuring, then plugged
14-2W-8ADD		Graham 2	1965		Mq	Changed to repressuring, then plugged
14-2W-16BC	2	Gilmore 1	1963	1980	Mq	
14-2W-17DD		Gilmore 2	1964	?	Mq	Plugged?
14-2W-17CDB	3	Prescott 1	1945	?	Mq-Vi	Changed to disposal well
14-2W-17CAB		Prescott 2	1945	1980	Mq-Vi?	May be plugged soon
14-2W-17CCD		Prescott 4	1952	?	Mq-Vi?	Changed to disposal, then plugged
14-2W-17BCD	2	Seitz 1	1945	1980	Vi?	Plugged?
14-2W-17BDC		Seitz 2	1946	?	Vi	
14-2W-17DA	1	Vanier 1	1965	1980	Mq	
14-2W-18ACD	1	Crawford 1	1946	1970	Mq?	Probably plugged
14-2W-19AAC	1	Union Cemetaries	1964	1980	Mq	
14-2W-20BCA	1	Burkholder 1	1963	1974	Mq	Plugged?
14-2W-20CDB	1	Craven 1	1960	1964	Mq	Changed to disposal, then plugged
14-2W-20BAA	2	Airport 1	1963	1980	Mq	
14-2W-20BDC		Airport 2	1963	?	Mq	
14-2W-21DCD	1	Weiss 3	1978	1980	Mq?	
14-2W-27BB	1	Dillard 1	1963	1978	Mq	

Table 4. (Continued)

Location[a]	Number of wells	Lease name and well	Discovery date	Date of last withdrawal	Producing unit[b]	Notes[c]
14-2W-28DBC	2	Gillberg 1	1959	1980	Mq	
14-2W-28DBA		Gillberg 2	1959		Mq	
14-2W-28ACD	2	Hagg 1	1960	?	Mq	Changed to repressuring well?
14-2W-28ADB		Hagg 2	1974	1980	Mq	
14-2W-28CAD	1	Sheldon 1	1959	1980	Mq	
14-2W-28BBA	1	Wuerth 3	1962	1980	Mq	Wuerth 1, 2 now disposal wells
14-2W-29BDD	1	Becker Unit 1	1963	1977	Mq	
14-2W-29CDD	2	Cline 1	1958	?	Mq	Changed to repressuring well
14-2W-29CAD		Cline 2	1959	1980	Mq	
14-2W-29DCC	2	Gurley 1	1959	?	Mq	Changed to disposal well
14-2W-29DBB		Gurley 2	1962	1980	Mq	
14-2W-29ACB	1	Oliver 1	1962	1977	Mq	
14-2W-30CDD	1	Balaum 2	1963	1980	Mq	
14-2W-30DBB	3	Sudendorf 1	1943	?	Mq	Abandoned
14-2W-30DCS/2		Sudendorf 2	1962	1980	Mq	
14-2W-30D		Sudendorf 3	1963	?	Mq	Changed to disposal well
14-2W-31BDD	1	Miller (B)	1980	1980		
14-2W-32	5	Haag	1946	1980		

Table 4. (Continued)

Location[a]	Number of wells	Lease name and well	Discovery date	Date of last withdrawal	Producing unit[b]	Notes[c]
14-2W-32	3	Norton	1947	1980		
14-2W-32CDD	1	Norton (A)	1947	?		
14-2W-32CD	1	O'Connor	1958	1980		
14-3W	None					

[a] Township-range-section-quarter section, quarter-quarter section, quarter-quarter-quarter section

[b] Units: Mq, dolomite in Maquoketa Shale; Vi, Viola Limestone

[c] Multi-well locations and present status of some wells are not listed in the Report, but were obtained from Kansas Geological Survey and Kansas Department of Health and Environment records.

from overlying alluvium, and oil-field type brine from underlying sedimentary strata.

In the upland regions of the Salina oil field, the part of the Wellington Formation overlying the zone where the Hutchinson Salt would appear if present, contains several gypsum beds which have been dissolved providing aquifers for domestic and stock wells (Dunlap, 1975). Injection wells with corroded casing through this zone could provide passageways for oil brine to migrate if nearby repressuring or disposal operations supplied enough pressure to force the brine into these aquifers. All repressuring and disposal wells which were recorded (starting in the 1950's) or are in operation in sections 1-30, township 14S-2W, are listed in Table 5. Those in which the brine was injected under gravity feed would probably be less of a potential problem than those with pressure injection. Most of the injected brine would only be maintaining pressure in the Maquoketa Shale and Viola Limestone because no extra water for secondary recovery operations is known to be introduced. Local pressures could possibly build up, however, in the vicinity of an injection well. However, none of the domestic, stock, or irrigation wells in the upper Wellington gypsum cavities or in alluvium in contact with these cavities, and located near the southern valley wall of the Smoky Hill River just east of Salina, gave indication of oil-field brine pollution. This evidence suggests that there is no detectable problem of oil brine flow from shallow aquifers into the alluvium just south of the proposed saltwater relief wells. The probable contamination at the Lagerberg well at 14-2W-20B suggests a local problem from oil-brine pollution, perhaps from a broken or corroded pipe running saltwater from the tank battery to the disposal well.

Table 5. Oil-Brine Disposal and Repressuring Wells in Township 14S, Range 2W, Sections 1-30.

KCC permit number	Well location[a]	Well use[b]	Date permit approved	Formation receiving injection[c]	Injection rate (barrels/day)	Injection pressure (pounds)	Lease name and well[d]	Notes
C-11469	5CDC	Dis	11-19-64	Maquoketa	50-2000	50-1000	Winslow 1	Operating
C-9749	7CDS/2	Dis	10-08-62	Maquo. dol.	6-25	Gravity	Jarvis 1	Abandoned
C-10643	7DC	Dis	10-25-63	Maquo. dol.	5-20	Gravity	Jarvis 2	Plugged
C-14045	7CAD	Rep	01-22-68	Maquoketa	125 max.	Gravity	Jarvis (Twin) 2	Plugged
C-17237	7DD	Rep	12-20-73	Maquoketa	240-260	Gravity	Fee 2	Operating
C-16311	8ADE/2 8AAD 9CB	Rep	10-14-71	Maquo. dol.	100-500	0-300	Graham 2 ? Graham 1	Cancellation 06-30-77 (Plugged)
C-11162	9CAA	Dis	07-01-64	Hunton Gr	160-510	Gravity	Roesner 1	Operating[e]
C-10772	17CDB	Dis	01-21-64	Hunton Gr	100-1000	50-500	Prescott 1	Operating
C-6176	17CCD	Rep	02-04-58	Viola Ls	50-350	50-250	Prescott 4	Plugged
C-3759	18ABA	Rep	10-07-53	Viola Ls	150-400	Gravity	Marymount 1?	Plugged
C-13808	17DCC 20B	Rep	09-05-67	Maquoketa	120-190	Gravity	Foran 1 ?	Plugged
C-7147	19BBD	Dis	04-27-59	Maquo. dol.	20-40	Gravity	Faith 1	Plugged
C-11110	20CDB	Dis	06-04-64	Maquo. dol.	20-300	0-300	Craven 1	Plugged
C-9878	28BCC	Dis	12-06-62	Maquo. dol.	300-600	115-500	Wuerth 2	Abandoned

Table 5. (Continued)

KCC permit number	Well location[a]	Well use[b]	Date permit approved	Formation receiving injection[c]	Injection rate (barrels/day)	Injection pressure (pounds)	Lease name[d] and well	Notes
C-11429	28BDD	Dis	11-02-64	Maquoketa	30-400	0-300	Wuerth 1	Operating
C-18025	28A 29CDD	Rep	09-26-75	Maquoketa	40-300	0-300	Hagg 1? Cline 1	? Operating
C-17495	29DCC	Dis	07-23-74	Hunton Gr	50-300	0-300	Gurley 1	Operating
C-7019	30D	Dis	05-14-59	Wellington	25-50	Gravity	Sudendorf 3	Operating

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[a] Section, quarter section, quarter-quarter section, quarter-quarter-quarter section; S/2 = south half, etc.

[b] Use: Dis, disposal; Rep, repressuring

[c] Formation: Maquo. dol., dolomite in Maquoketa Shale; Gr, Group; Ls, Limestone

[d] Lease name from scout cards on file in Kansas Geological Survey

[e] Disposal for 9 producing wells; has been down for repairs since early 1981

The presence of oil-field brine in the water from the observation wells at the Salina City Park, Ramada Inn, and Julia Martin sites indicates that there are avenues for oil brine migration to the Wellington aquifer and deep alluvium in the Salina area. Drill-stem test data from the Arbuckle Group well of the U.S. Geological Survey near the Cottonwood Tree wells showed that the static levels of formation water in the strata of the Missisippian System, the Hunton Group, and the Viola Limestone would lie below the static levels of the Wellington aquifer in that area (J. Gillespie, personal communication). The level in the Arbuckle Group is within the Wellington zone, but the formation water has a low salinity and thus is not as dense as the Wellington brine. The static level of brine in the Lansing, Kansas City Groups is probably between the top and bottom of the alluvium. Brine in these strata in the nearest counties for which analyses are available generally contains 100,000-130,000 mg/L chloride, thus approaching the density of Wellington aquifer brine. A well drilled in 1901 near Abilene, 1260 feet in depth, encountered brine which flowed over the top of a pipe extended 20 feet above the ground surface (Bailey, 1902). The water contained 110,000 mg/L chloride and was probably in the Shawnee or Douglas Groups overlying the Lansing and Kansas City Groups. If an old uncased, unplugged, or deteriorated borehole was open to all strata from the Wellington aquifer to the Arbuckle Group, but had intact casing through the alluvium to the top of the Wellington bedrock surface, brine flow would probably be from the Wellington Formation, Shawnee, Douglas, Lansing, and Kansas City Groups, and any other formations containing dense brine at higher heads into the units with lower static levels depending on their relative permeabilities. Holes open to the alluvium could possibly allow fresher waters to flow into deeper horizons. The possibility of formation brines with chemistry similar to oil-field brine moving into the Wellington aquifer or alluvium would depend on a particular set of conditions in a borehole, such as less permeable strata unable to accept formation waters of higher pressures fast enough or boreholes containing deteriorated casing and plugging with openings connecting only those units of greater static levels with the near surface.

Another mechanism by which oil-brines might enter the Wellington aquifer or alluvium involves injection wells for disposal or repressuring. Although one well in the central part of the Salina oil field is disposing oil brine directly into the Wellington aquifer (Table 5), others may have also disposed into this zone before recording of injection wells began in Kansas. As noted before, wells injecting brine into lower formations could have deteriorated through corrosion, providing openings for oil brine to enter the Wellington Formation or alluvium during active disposal or repressuring.

Within a 2000 foot radius of the observation well in the Wellington aquifer at the Salina City Park site, there are 10 wells which had been drilled for oil, 9 of which may have at one time been producers. Eight of these 9 were bored in the period 1945 to 1948. The earliest record of an injection well in the area is 10-07-53, with a location in "part of lot 1 and 4, lot 2 being part of the NE/4 of section 18 and SE/2 of section 7, 14S-2W" (C-3759 in Table 5). This is probably the old Marymount College well number 1, 14-2W-18ABA shown on the 1955 topographic map of the Salina quadrangle. The well is about 2000 feet to the northeast of the Salina City Park well. The location and method of oil brine disposal in this area before the permit date of this well are unknown. Within a mile radius of the observation well there is record of seven other disposal or repressuring wells, two of which are presently operating. The probability that oil brine pollution may have migrated from the Sudendorf disposal well in the Wellington aquifer about 2-1/2 miles to the south is small given the amount being injected and the expected flow rate in the Wellington.

The Ramada Inn observation well, which yielded water appearing to contain oil-field brine, is located about 3 miles to the northwest of the Salina City Park well. The closest oil exploration boreholes are about 1-1/2 miles to the northwest and southwest and both were dry and abandoned. The closest well which may have at one time produced oil and thus may have had nearby disposal is 2 miles to the southeast. The most active oil brine disposal has been in sections 7 and 18 of 14S-2W about three miles to the southeast. The bedrock surface map of Gillespie and Hargadine (1981) shows the bottom of the alluvium in the Smoky Hill River valley near Salina to be deepest in the vicinity of the Ramada Inn well. Thus, dense brine entering the alluvium could possibly flow down along the bedrock surface towards the Ramada Inn site. Test holes indicate that the sediments in the bottom of the alluvium are generally the most permeable and are composed of sand and gravel (Latta, 1947). This would facilitate the movement of a saltwater plume to the deeper portions of the alluvial valley. The possibility of the flow of oil-field brine from farther to the south where much disposal has been directly into the Wellington aquifer is remote, as suggested by flow rates calculated in the next section. A well in the

Wellington aquifer at the Ramada Inn location would be very useful for answering questions concerning the origin of the apparent oil-field brine in the alluvium.

The source of the water with the chemical characteristics of oil-field brine at the Julia Martin Permian well is difficult to explain. The closest oil exploration borehole is 1-1/2 miles to the southeast and was dry and abandoned when drilled in 1944. Two other dry wells were bored in 1947 and 1966 about two miles to the northwest and southwest, respectively. The closest oil and brine disposal wells that are or have previously been in operation, are in section 9, 14S-2W, approximately 5 miles to the west. As described before in the chemistry section, the source of the saline water in the Wellington Formation at this site probably is from under the valley wall, because water in the Wellington aquifer underlying the alluvium should have a much higher chloride concentration and characteristics mainly of salt-solution brine. Thus oil-field brine probably followed conduits in gypsum solution cavities in the upper Wellington Formation to reach this site.

One of the alternatives for disposal of saltwater removed from the Wellington aquifer to decrease the salt discharge to the Smoky Hill River is injection into deep formations. Among the units favorable for the disposal are the Hunton Group, limestones and dolomites of Silurian and Devonian ages, and the Arbuckle Group, dolomites of Cambrian and Lower Ordovician ages. Both units have permeabilities high enough to accept disposal brine. The Hunton Group directly overlies the oil bearing Maquoketa Shale, whereas the Arbuckle strata is much deeper and underlies the Simpson Group. Some of the brine disposal wells in the northern part of the Salina oil field inject into the Hunton Group. The test relief well of the U.S. Geological Survey (Cottonwood Tree well) has pumped brine from the Wellington aquifer into the nearby U.S.G.S. Arbuckle well. The Arbuckle Group water at this site contained only 3500 mg/L chloride ion. The denser, salt-solution brine decreased the static water level in the Arbuckle well, originally 140 feet below the surface, by several hundred feet after disposal (J. Gillespie, personal communication).

One concern in the injection of large volumes of additional water in a single well or many wells in a small area is that the local increases in pressure in the formation could in time force water up into nearby boreholes without casing or plugging or with deteriorated casing and plugs. This has caused some pollution of groundwater in areas of secondary recovery operations for oil in Kansas. Although the saltwater from the proposed relief wells in the Wellington aquifer would probably be disposed by gravity, the dense brine might, over a long time, displace enough formation water and increase the pressure sufficiently to force the lighter saline water up any open, abandoned boreholes in the Arbuckle Group. All the wells drilled for oil which either penetrated or reached the top of the Arbuckle Group in northeastern Saline County are given in Table 6. The list could also be useful for locating a well which could possibly be reentered and fitted for disposal use into the Arbuckle. Figure 12 shows that three of the abandoned Arbuckle wells are within a mile of the Cottonwood Tree wells. According to J. Gillespie, another exploration well was drilled nearby at 14S-2W-33C about 1979.

Table 6. Wells Drilled for Oil Which Penetrated the Simpson and Arbuckle Groups Underlying Northeast Saline County

Location[a]	Well name and number	Date drilled	Total depth	Depth to top of formation				Present Use[c]
				Maquoketa (Maq. dol.)[b]	Viola Limestone	Simpson Group	Arbuckle Group	
13-1W-3DBA	Herrington 1	1935	3360				e	
13-1W-8DAB	Mynatt 1	1959	3245	2946	3044	3152	3232	
13-1W-16BAA	Markley 1	1952	3335		3089	3219	3285	
13-1W-17BAA	Tobin 1	1949	3225		3003	3108	3193	
13-1W-20BBB	Rockhold 1	1943	3267		3055	3171	3242	
13-1W-33ADA	Cusick	1944	3400	3082	3180	3296	3370	
13-1W-35DDD	Duncan 1	1944	3307	2990	3090	3200	3275	
13-2W-12CCC	Maneval 1	1947	3359	- - - - - - - - ends in Simpson - - - - - - -				
13-2W-24BBB	Royal 1	1959	3460		3263	3410	3444	
13-2W-25BAD	Ruch 1	1942	3320	3026	3125	3249	3308	
13-2W-27BBB	Geis 1	1955	3365	3076	3185	3284	3358	
13-2W-27CCC	Walden 1	1945	3355	3063	3162	3258	3344	
13-2W-30AB	Shippel "A" 1	1959	3440				3420	
13-2W-33C	Geis 1	1964	3440	3073	3169	3292	3366	
13-2W-34ACC	Cambria 1	1960	3600	3064	3160	3280	3347	
13-3W-9BBB	Link 1	1952	3674	3422	3529	3634		
13-3W-19BBC	Baird 1	1946	3886		3680	3788	3870	
13-3W-19AAA	Shank 1	1945	3819		3545	3655	3747	
13-3W-20DDD	Craig 1	1956	3769	3430	3526	3636	3732	
13-3W-26ACB	Crawford 1	1939	3632	3312	3389	3570	3615	
14-1W-17DAA	Ryan 1	1944	3568	3134	3228	3331	3412	
14-2W-1AAN/2	Stauffer 1	1947	3406					
14-2W-2DCC	Hoeffner 1	1952	3387	(3139)	3163	3239	3330	
14-2W-8BCD	Vanier 1	1947	3402	(3184)	3319	3392		
14-2W-9CAA	Roesner 1	1951	3373	(3165)	3191	3286	3365	Disposal

Table 6. (Continued)

Location[a]	Well name and number	Date drilled	Total depth	Depth to top of formation: Maquoketa (Maq. dol.)[b]	Depth to top of formation: Viola Limestone	Depth to top of formation: Simpson Group	Depth to top of formation: Arbuckle Group	Present Use[c]
14-2W-14CBA	Sailors 1	1954	3400	3104	3211	3316	3380	
14-2W-15CBB	Burrell 1	1933	3407			3380		
14-2W-17CDB	Prescott 1	1945	3484		3238	3366	3443	Disposal
14-2W-20CDB	Craven 1	1947	3452		3276	3395		Disposal
14-2W-20CCB	Van Ness 1	1945	3505		3243	3373	3452	Plugged
14-2W-21CDC	Weiss 3	1978	3450	(3267[d])	3366[d]	3373[d]	3450	Producing
14-2W-21DCC	Weiss 2	1951	3428	(3224)	3290	3355	3417	
14-2W-22BCS/2	Thelander "A" 1	1975	3400	3224	3256	3356		
14-2W-22ACW/2	Thelander 1	1945	3500	3239	3259	3363	3422	
14-2W-22BCC	Thelander 1	1956	3399		3180	3320	3378	
14-2W-23CBB	Hoeffner 1	1952	3526	(3326)	3334	3438	3509	
14-2W-27CBB	Robertson 1	1929	3587	3215	3295	3420	e	
14-2W-28DBC	Gillberg 1	1959	3446	(3224)		3370	3425	Producing
14-2W-29CBA	Davis 1	1927	3453	3190	3268	3452		
14-2W-30CBB	Rinhardt	1943	3415		3217	3375		
14-2W-30DAA	Sudendorf 1	1931	3512	3200	3265	3396	e	Plugged
14-3W-17DDB	Beil 1	1946	3765		3560	3663	3749	

a Township-range-section, quarter-section, quarter-quarter section, quarter-quarter-quarter section

b Maq. dol.: dolomite in Maquoketa Shale

c Use: a blank space means dry and abandoned; Plugged, may have pumped oil but is now plugged

d Bottom of formation

e Entered Arbuckle Group

Recharge Area of the Wellington Aquifer

Many shallow wells in the Wellington Formation have been used to dispose oil-field brine. Over 90 percent of these are located in the recharge area of the northern half of the Wellington aquifer. Most of the wells are in the Lindsborg, Smolan, and Olsson oil fields of Saline and McPherson Counties; one is in the Salina field and two are in the Buhler field of Reno County (Figure 1 and Table 7). The list of disposal wells in Table 7 was originally obtained by T. Gogel in 1975 from the Kansas Department of Health and Environment. The data was subsequently updated to July, 1981 for this report through information from the Department of Health and Environment and the Kansas Corporation Commission. Six wells in the list have been plugged, reducing the average volume of brine disposal in Saline County from 3679 to 3039 bbl/day (barrels/day), in McPherson County from 2407 to 2362 bbl/day, and in Reno County from 1710 bbl/day to none. The well in the Salina field was not in Gogel's list. Although the relative amount of disposal into this well is small, it is the closest well to the discharge area.

In addition to the oil-brine disposal, Gogel (1981) reported a net average of 460 bbl/day of salt-solution brine removed from liquid petroleum gas cavities was injected into the Wellington aquifer during 1974-1975 by the Home Petroleum Company at Conway, McPherson County. He also noted that about 1000 bbl/day of saltwater were withdrawn from the Wellington Formation and used for secondary recovery operations in an oil field in southern Saline County. The saltwater withdrawal is still continuing as part of a waterflood operation in the Smolan field.

Table 7. Oil-Field Brine Disposal in the Northern Half of the Wellington Brine Aquifer

KCC permit number	Location[a]	Lease name	Application date	Disposal depth (feet)	Average disposal rate (barrels/day)	Notes
			Saline County			
C-7019	14-2W-30D	Sudendorf 3	05-14-59	225 - 486	37	
C-7052	15-3W-19C	Richter	03 — 59	236 - 265	50	
C-15553	15-3W-30C	Ostenberg	04 — 70	237 - 260	475	
C-7868	15-4W-36DW/2	Bengtson	05 — 60	245 - 299	325	
C-9907	16-3W-2BE/2	Fox	12 — 62	328 - 332	62	
C-9941	16-3W-3CN/2	Anderson	01 — 63	235 - 280	175	Plugged 08-01-69
C-9906	16-3W-3A	Burmerster	12 — 62	235 - 280	175	
C-9919	16-3W-3B	Bengston	12 — 62	250 - 280	400	Plugged 01-12-81
C-15627	16-3W-5DC	Applequist	05 — 70	231 - 256	475	
C-15628	16-3W-5DN/2	Leander	05 — 70	231 - 260	475	
C-4607 [b]	16-3W-8BE/2	Lindholm	08 — 55	300 - 320	150	
C-8200	16-3W-10A	Olsson	10 — 60	225 - 280	40	
C-9046	16-3W-29CE/2	Lindshield	11 — 61	271 - 275	65	Plugged 01-16-69
C-5814	16-3W-31A	Holmquist	10 — 57	300 - 330	300	
C-10122	16-3W-32CS/2	Nelson	03 — 63	235 - 273	100	
C-11918	16-4W-1B	Ryding	06 — 65	270 - 280	125	
C-4284	16-4W-11BN/2	Lagestrom	12 — 54	270 - 300	250	
			McPherson County			
C-6532	17-3W-5CS/2	Runbeck 3 SWD	06-20-58	250 - 320	250	
C-8281	17-3W-5A	Sands 1	11-21-60	250 - 265	45	Plugged 09-28-79
C-15899	17-3W-5B	Hven-Ferm 1	11-24-70	225 - 235	700	
C-8627	17-3W-8CB	P. Sundquist 1	04-21-61	230 - 245	55	
C-3513	17-3W-18AN/2	Helberg A-1-W	09-29-53	315 - 460	375	
C-9422	17-3W-18BS/2	Hoglund 3	05-18-62	220 - 230	275	
C-9936	17-3W-19CN/2	Johnson A-1	01-08-63	285 - 295	145	
C-5562	17-3W-30CN/2	Lillian 2	04-22-57	250 - 275	162	
C-8210	17-3W-31C	Stark 3	10-28-60	300 - 350	100	
C-4424	18-3W-6B	Landgren 1	03-25-55	290 - 330	300	

Table 7. (Continued)

KCC permit number	Location[a]	Lease name	Application date	Disposal depth (feet)	Average disposal rate (barrels/day)	Notes
			Reno County			
C-3215	22-5W-24D	Robinson	08-20-52	500 - 685	460	Plugged 01-08-62
C-3141	22-5W-25D	Johns 2	05-27-52	468 - 650	1250	Plugged 07-10-74

a Township-range-section, quarter section, quarter-quarter section or half of quarter section

b Oil production abandoned; only saltwater disposal on lease

Gogel determined from a digital model that the average discharge from the Wellington aquifer to the Smoky Hill and Arkansas Rivers is 1.46 ft^3/sec of saltwater with a chloride concentration of 180,000 mg/L, and the freshwater recharge via areal leakage through the confining bed is 0.6 ft^3/sec. This leaves 0.86 ft^3/sec in a hydrologic budget as recharge from other sources. The model included recharge by disposal wells totaling 0.64 ft^3/sec. Observed discharge from the Wellington was estimated to average 1.36 ft^3/sec, which with the injection recharge of 0.64^3ft /sec, leaves 0.72 ft^3/sec as recharge from areal leakage. However, Gogel did not subtract from the total disposal volume the amount of brine which he stated was being removed for secondary recovery operations. Also, three of the disposal wells which he included as operating in the northern half of the Wellington aquifer had been plugged before 1970. If the actual net injection during 1975, 8100 bbl/day or 0.53 ft^3/sec, is subtracted from the observed discharge, an areal leakage recharge of 0.93 ft^3/sec is obtained for the whole aquifer.

Gogel also estimated the average discharge of Wellington brine to the Smoky Hill River to be 0.76 ft^3/sec (based on observations of Gillespie and Hargadine, 1981). The net recharge to the northern half of the Wellington aquifer via operating disposal wells is presently 0.32 ft^3/sec. This leaves 0.44 ft^3/sec as recharge from freshwater areal leakage through the confining strata, assuming the hydrologic balance calculation is valid. The brine disposal now amounts to over 40 percent of the total recharge, and earlier would have been over 60 percent of the total. The injected brine can dissolve more salt and also increases the piezometric head in the Wellington Formation. However, the total volume of brine disposed into the Wellington amounts to only about one percent of the total saltwater in the northern part of the aquifer. Nevertheless, this method of disposal should be abandoned as soon as practical to prevent further additions to the system.

The question arises as to how fast the brine injection can affect the discharge of saltwater from the Wellington aquifer. Has the increased volume and piezometric head yet caused increased discharge, or will increased discharge occur in the near or long-term future? To determine the possible velocity of flow of oil-field brine in the Wellington, two sets of calculations were made.

The first computation was based on the observed discharge from the Wellington of 0.76 ft^3/sec of brine having a chloride concentration of 180,000 mg/L. The average valley width of the discharge area as used by McElwee et al. (1981) was 18,500 feet. This is also the approximate width of the discharge area of the Wellington aquifer as mapped by Gogel (1981). The average thickness of the brine aquifer is about 30 feet (from the disposal well data in Table 7). This gives a cross section of 5.5×10^5 ft^2. Assuming an average porosity for the aquifer of 20 percent, the brine cross section is $1.1 \times 10^5 ft^2$. Dividing this figure into the discharge results in an average saltwater velocity of 220 ft/year.

The second calculation was suggested by C. McElwee. Water velocity can be computed from Darcy's law

$$V = -\frac{K}{n}\frac{\Delta h}{\Delta l}$$

where K is the hydraulic conductivity, n is the porosity, and $\Delta h/\Delta l$ is the hydraulic gradient. Using piezometric surface maps, McElwee estimated the hydraulic gradient to average 0.0008. The hydraulic conductivity can be determined from the transmissivity divided by the saturated thickness. Values of transmissivity for the Wellington aquifer are 0.03 ft^3/sec (Gogel, 1981) and 0.03-0.07 ft^3/sec (McElwee et al., 1981) giving a hydraulic conductivity of 86-200 ft/day if a saturated thickness of 30 feet is assumed. Using a porosity of 20 percent results in a brine velocity of 0.35-0.81 ft/day or 130-290 ft/year. These values bracket the velocity of 220 ft/year obtained by the first method.

This velocity indicates that it would take about 20 years for oil-field brine to move only one mile through the Wellington aquifer. However, the aquifer is a solution and collapse zone with great variations in permeability. Larger solution cavities could possibly provide conduits for flow rates an order of magnitude greater than estimated above. Even at this velocity, oil brine would only flow about a mile every two years. Thus, the bulk of the oil-field brine disposed in the Wellington (from the Smolan, Lindsborg, and Olsson fields) would take at least about 40 years, and probably 100 years or more before discharging into the Smoky Hill River between New Cambria and Solomon.

Increases in piezometric head caused by the oil-field brine injection in the Wellington Formation have probably already spread to the area of the saltwater discharge into the alluvium and the river. McElwee and Butt (1981) have calculated that the head redistribution caused by a system of saltwater relief wells in the Wellington aquifer would take 0.5-5 years to travel 8 miles. Even at the slowest redistribution rate, the head effects from early oil-field brine disposal in southern Saline and northern McPherson Counties would have reached the discharge area. The effect of the maximum disposal rates during the 1950's and 1960's may not have reached the discharge area if the redistribution rate is slow. Thus, saltwater discharge volumes might even increase somewhat for the next several years or more. As the brine injection wells are plugged and abandoned, a small decrease in the saltwater discharge volume may then eventually occur. Increases in the saltwater discharge to the Smoky Hill River caused by oil-field brine injection are probably less than the amount of brine disposed, however, because the head increases from brine injection may decrease the rate of freshwater recharge into the Wellington aquifer.

Chemical Variations in Observation Well Waters

A summary of the chloride and sulfate concentrations determined for waters from the observation wells sampled by the Kansas Water Resources Board and U.S. Geological Survey for this and earlier studies is given in Table 8. Many of the variations may be due to samples not being representative of the actual water in the screened interval of the aquifer. This could be caused partly by insufficient pumping or bailing of the well, especially after use of freshwater for head measurements and in wells in material of low permeability. In general, samples from 1976 and 1981 are probably more representative. Examples of this are the high chloride concentrations for 1976 and 1981, and low chloride for 1979 in samples from the RR Triangle East, Kelly Cresswell, White School House, and Ramada Inn wells.

Where chloride and sulfate contents generally increase, such as in the Solomon Bridge SE, Old Latta, RR Borrow Pit, Railroad, Boondocks, Kelly Permian, Dike, Welchel, Ryan Permian, and Landfill wells, part of the increase could be due to a more representative sample after each repeated pumping or bailing. Relatively constant concentrations obtained for three samples should be very representative of the water from the screened interval (Car Body, RR Triangle West, Swenson North, Ward South, Kelly Alluvial, Telephone, Albert Martin, Kirtland 2" Steel, New Cambria, Four Corners, and Assaria wells). Concentrations approximately the same for two samples and higher than a third sample, or without a third value, are probably relatively representative (Dickinson Co., Turn, Ward, Pettijohn East, Dead End Sign, Pioneer Seed Sign, Cottonwood Tree, White School House, Trenton Road, and Smolan wells, for example). Some of the well

Table 8. Chloride and Sulfate Concentrations of Observation Well Waters from 1976 to 1981. Concentrations are in mg/l.

GS[a]	Location[b]	Name	Cl 1976	Cl 1979	Cl 1981	SO_4 1976	SO_4 1979	SO_4 1981
	13-1E-14BDB	Greyhound Ranch	200	-	-	70	-	-
	13-1E-17AAA	I-70 Dead End	110	-	-	310	-	-
	13-1E-17BBB	Harvey Woods I-70	140	-	-	300	-	-
	13-1E-17CDA	Harvey Woods Tree	180	-	-	41	-	-
	13-1E-19CAB	Solomon Bridge SE	9,800	22,000	38,300	1,100	1,880	3,770
	13-1E-2DACA	Old Solomon City	810	14	10	230	125	221
	13-1E-20BBC	Emig	490	54	14	1,300	1,430	1,230
	13-1E-22CAC	Watermelon Stand	14	-	-	21	-	-
	13-1E-23CBC	Sand Springs West	590	-	-	21	-	-
	13-1E-23DAB	Sand Springs Br. N	-	29	25	-	34	31
	13-1E-23DAB	Sand Springs Br. S	120	42	51	35	84	97
	13-1E-26DDC	Palmer	5,400	4,950	-	1,000	1,000	-
	13-1E-27BAC	Lawrence Clemence	160	15	-	160	54	-
	13-1E-28CCC	Iron Bridge	2,700	2,070	1,900	560	448	405
	13-1E-28DDD	90° Bend	1,500	1,180	-	410	338	-
	13-1E-29AAB	Ray Clemence	91	-	16	160	-	163
	13-1E-30ADA	Car Body	13,000	13,000	13,200	3,400	1,720	1,800
	13-1E-30BCC	USBR Cowlot	-	121	-	-	53	-
	13-1E-30BDC	County Road East	27,000	-	-	3,700	-	-
P	13-1E-30BDC2	County Road	58,000	-	-	5,700	-	-
	13-1E-30DAA	USBR Green House	-	19	-	-	20	-
	13-1E-31BBB	Dickinson Co. Turn	21,000	21,900	-	3,200	3,380	-
	13-1E-32CCC	Ditch	8,300	-	-	2,100	-	-
	13-1E-33DDD	USBR South 90° Bend	-	40	-	-	697	-
	13-1E-34ADD2	Concrete	3,400	2,360	1,760	1,000	1,060	1,070
	13-1E-35DCD2	Red Brick School	560	326	273	750	660	413
	13-1E-35DDB	USBR Palmer	-	1,320	-	-	286	-
	13-1W-4DCC	Road Tree	44	45	-	760	990	-
	13-1W-7BCC	Tri-Rivers Coon	190	23	-	990	1,020	-
	13-1W-7DDA	Don Vaupel North	27	33	10	680	669	750
	13-1W-9DBC	Hound Dog	5,400	3,200	-	2,100	1,360	-

Table 8. (cont.)

GS[a]	Location[b]	Name	Cl 1976	Cl 1979	Cl 1981	SO_4 1976	SO_4 1979	SO_4 1981
P	13-1W-10DCA	Riordan Permian	-	-	35	-	-	1,380
	13-1W-14DAD	RR Triangle East	20,000	6,200	16,000	3,100	890	2,250
P	13-1W-14DAD2	RR Triangle West	33,000	32,500	33,700	4,300	4,490	4,590
	13-1W-16BCC	Old Latta	5,700	7,150	7,450	2,200	2,860	2,720
	13-1W-16DCC	Swenson North	1,400	1,140	1,240	-	385	354
P	13-1W-16DCC2	Swenson South	11,000	10,300	9,480	2,200	2,210	1,920
	13-1W-17CBB	Calabresi	350	45	-	1,100	1,300	-
	13-1W-17DCC	McCall	3,500	2,200	-	2,200	2,160	-
	13-1W-19ACD	I-70 Borrow Pit	310	300	266	1,700	1,790	1,760
P	13-1W-19BCD	I-70 Borrow Pit	20,000	-	-	2,200	-	-
	13-1W-20CBB	Ward	20,000	22,700	-	4,000	4,310	-
	13-1W-20CDD	Ward South	25,000	26,300	27,900	3,700	3,940	3,740
	13-1W-22CCB	RR Borrow Pit	10,000	12,700	13,700	1,300	1,730	1,800
	13-1W-23BCB2	RR Well	1,800	3,320	4,180	360	486	600
	13-1W-23CAA	Shirak No. 2	10,000	-	19,100	2,700	-	2,450
	13-1W-24BDA	Boondocks	13,000	44,000	49,400	1,200	4,550	4,170
	13-1W-24CDC	Kelly Road Tee	8,400	-	9,760	1,000	-	1,360
	13-1W-24DDC2	Kelly Alluvial	67,000	66,200	68,700	6,000	5,850	6,500
P	13-1W-24DDC3	Kelly Permian	59,000	66,000	70,400	5,500	5,800	6,300
C	13-1W-24DDC4	Kelly Cresswell	107,500	18,000	138,000	2,700	1,640	1,350
	13-1W-25BDA	Pettijohn East	49,000	64,000	61,300	5,400	5,800	5,800
	13-1W-26ADD	Red Barn	5,900	3,200	2,850	660	400	315
	13-1W-26BCB	Krebs Pasture	8,000	5,850	4,660	1,100	810	660
	13-1W-26DDD	Pettijohn South	31,000	20,800	-	3,100	2,150	-
	13-1W-30BCC	USBR on Niles Road	-	181	235	-	230	193
	13-1W-30CCC	Old 40 Niles Road N	21,000	22,000	13,900	1,800	2,020	1,270
P	13-1W-30CCC2	Old 40 Niles Road S	89,000	106,000	110,000	5,500	5,370	6,000
	13-1W-32CCC	Telephone	8,600	9,150	9,050	1,200	1,480	1,390
	13-1W-32DDA	Dead End Sign	68,000	55,000	66,400	5,500	5,080	5,400
	13-1W-33DAA	USBR by Martin N	-	60	58	-	100	97
	13-1W-34CCC	Albert Martin	50,000	53,200	54,600	5,000	5,400	5,150
	13-1W-28BBC	Pioneer Seed Sign	2,100	2,540	-	320	410	-

Table 8. (cont.)

GS[a]	Location[b]	Name	Cl			SO_4		
			1976	1979	1981	1976	1979	1981
	13-1W-35BBC2	Kirtland 2" Steel	2,700	2,040	2,140	300	311	306
	13-1W-35CDC	Dike	63,000	65,000	73,200	6,300	5,970	6,400
	13-1W-35DDD	USBR by Welchel	-	290	-	-	80	-
	13-1W-35DDD2	Welchel	1,000	1,280	1,600	1,200	1,110	1,290
	14-1W-3BCC	Ryan North	4,900	11,900	3,800	540	1,190	430
P	14-1W-3BBB	Ryan Permian	65,000	68,500	71,900	-	6,140	6,200
	14-1W-7AAD	New Cambria Old Gage	-	560	63	-	144	127
	14-1W-8BBB	Julia Martin Alluvial	5,400	-	18,800	1,300	-	2,370
P	14-1W-8BBA	Julia Martin Permian	24,000	12,900	9,820	3,900	2,420	3,330
	14-1W-10BBC	Ryan South	220	271	285	220	124	130
	13-2W-28DDD	USBR Burial Ground Road	-	224	-	-	103	-
P	13-2W-32CCB	Cottonwood Tree 2"	180,000	136,000	-	6,100	4,730	-
	13-2W-32CCB2	Cottonwood Tree North	210	81	72	190	176	167
P	13-2W-32CCB3	Cottonwood Tree	-	151,000	161,000	-	5,100	5,100
	13-2W-33DDC	Bend in Old 40	295	81	79	120	102	123
	13-2W-35ACC	USBR New Cambria W	-	70	66	-	110	112
	13-2W-35DBB	New Cambria	1,940	1,980	1,800	540	635	660
	13-2W-36DDD	Four Corners	2,660	2,180	2,330	400	104	468
	14-2W-8BBC	Salina Sewer Plant	-	-	104,000[c]	-	-	4,150[c]
P	14-2W-18BDA	Salina City Park	22,000	38,600	27,700	4,200	6,990	6,300
P	13-3W-4DCC	White School House	110,000	500	106,000	6,500	215	11,100
	13-3W-16DCD	USBR Tucker	-	55	31	-	92	80
	13-3W-26CDD	USBR Drainage Ditch	-	32	30	-	75	74
P	13-3W-33BCC	Trenton Road	190,000	-	193,000	4,900	-	5,200
	13-3W-36CBA	Ramada Inn	48,000	2,920	34,900	2,100	240	1,330
P	14-3W-27BBB	Salina Airport	120,000	131,000	112,000	7,100	8,120	8,200

Table 8. (cont.)

GS[a]	Location[b]	Name	Cl			SO_4		
			1976	1979	1981	1976	1979	1981
P	15-3W-7BAA	Landfill	70,000	130,500	160,000	3,300	6,270	7,000
P	15-3W-19AAA	Smolan	170,000	178,000	42,400	5,700	5,700	4,060
P	16-3W-3CDC	Assaria	41,000	40,800	39,800	3,100	3,090	3,070
P	17-3W-8CCB	Lindsborg	-	440	68,800	-	234	6,100

a Geologic Source: No letter, alluvium; C, Cresswell Limestone Member; P, Permian Wellington Formation

b Township-range-section, quarter section, quarter-quarter section, quarter-quarter-quarter section

c Collected in July, 1980

waters (Iron Bridge, Red Brick School, Swenson South, Red Barn, and Krebs Pasture wells) show steady declines in both chloride and sulfate content from 1976-1981. Other wells have steadily decreasing chloride, but fluctuating or approximately constant sulfate concentrations (Old Solomon City, Emig, Concrete, and Julia Martin Permian wells). These decreases may reflect actual dilution of water within the aquifer with time. Some of the increases in chloride and sulfate noted above may also indicate true changes in aquifer water quality.

The chloride and sulfate variations were examined by locations for any general trends such as areas of increases or decreases both across and along the Smoky Hill River valley, and for alluvial versus Permian wells. Chloride concentrations decreased in alluvial well waters in the valley east of Solomon from 1976 to 1981. This may reflect a decrease in the great flux of saltwater pushed from the Wellington Formation after the heavy rains and high river stages of 1974. No clear pattern emerged, however, in other areas probably because changes caused by non-representative samples obscurred real variations in the system. This points out the importance of pumping or bailing observation wells sufficiently during any future sampling programs.

CONCLUSIONS

1. Sodium/chloride, bromide/chloride, and iodide/chloride ratios were generally the most diagnostic for distinguishing waters with oil-field brine pollution from those containing mainly salt solutions. Magnesium/chloride, lithium/chloride, and boron/chloride ratios were useful for further verifying the identification of salt sources after the above three ratios had been examined. Calcium/sulfate values, although much different for oil-field brines and salt-solution brines, tended to alter in mixture of these two towards the ratios found in waters in the Wellington aquifer.

2. No detectable oil-field brine pollution was found to flow in shallow aquifers from the northern part of the Salina oil field into the alluvium along the southern part of the Smoky Hill River. However, oil-brine pollution was found in the Wellington aquifer at the observation well in the Salina City Park (14-2W-18BDA), the northwestern edge of the Salina Field. Also, oil brine is being disposed into the Wellington aquifer about 2-1/2 miles to the south of this site (14-2W-30D). Five miles to the east of the northeastern part of the Salina field, saline water with oil-brine characteristics was found in the Wellington Formation at the Julia Martin observation well (14-1W-8BBA). No appreciable amount of oil-field brine could be flowing in the Wellington aquifer directly from the northern edge of the Salina field to the pump test wells at the Cottonwood Tree site (13-2W-32CCB), because all chemical ratios indicated only salt-solution brine at the Salina Sewer Plant site (14-2W-8BBC). Oil-field brine mixed with about 10 percent salt-solution brine occurs in the Wellington at the Assaria observation well (16-3W-3CDC) several

miles south of Salina, reflecting nearby disposal of oil-brine. Evidence for oil-brine was also found in the deep alluvium of the Smoky Hill River valley at the Ramada Inn site (13-3W-36CBA).

3. Over 40 percent of the recharge volume needed to balance the average discharge of saltwater from the Wellington aquifer to the Smoky Hill River is presently being injected as oil brine into the Wellington. Most of this disposal occurs in south-central Saline County and north-central McPherson County. The total volume of brine injected into the Wellington since 1940 amounts to only about one percent of the total saltwater in the northern half of the brine aquifer. The average flow velocity of saltwater in the Wellington is estimated to be 220 ft/year in the discharge area. However, local flow through conduits of larger solution cavities could be as much as an order of magnitude greater. The first portion of the bulk of the oil-field brine disposed in the Wellington aquifer will probably take at least about 40 years, and probably 100 years or more before discharging into the Smoky Hill River. Increases in piezometric head from the brine injection have probably already spread to the saltwater discharge area, and may cause small future increases in the discharge rate as the effects of the maximum disposal rates are felt. Saltwater disposal into the Wellington should be abandoned as soon as practical to prevent further recharge and increase in piezometric head. Small decreases in saltwater discharge may eventually occur several years after most of the disposal wells are plugged.

4. An observation well should be drilled into the Wellington aquifer at the Ramada Inn site (13-3W-36CBA). Analysis of samples from this location would help determine the source of apparent oil-brine pollution in the

deep alluvium. A pair of observation wells, one screened in the base of the alluvium and one in the Wellington brine aquifer, is recommended for the deepest part of the bedrock surface in the Smoky Hill River valley between Salina and Mentor. These two wells could be used to determine whether disposed brine had migrated north in the Wellington or as a dense plume in the bedrock channel of the alluvium. All of the above wells should be constructed to facilitate yearly monitoring for many years.

5. The chemistry of waters from the Cottonwood Tree well (13-2W-33CCB3), which is being used for a saltwater relief test indicated that essentially only concentrated salt-solution brines are present in the Wellington aquifer at this location. Thus, the selection of this area for additional wells for the proposed saltwater relief appears to be suitable.

6. Chloride concentrations decreased in observation well waters in the alluvium of the Smoky Hill River valley east of Solomon from 1976 to 1981. Variations in chloride and sulfate concentrations in samples taken from other areas during this period did not show any definite patterns along or across the Smoky Hill River valley, or for alluvial versus Permian wells. Any real trends present in the system were obscurred by non-representative samples from some of the wells, especially in 1979. Future collection with sufficient pumping or bailing to produce representative samples may be valuable for determining the effects of saltwater relief wells.

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