Kansas Geological Survey

The Mineral Intrusion Project:

Investigation of Salt Contamination of Ground Water in the Eastern Great Bend Prairie Aquifer

Progress and Activites during Fiscal Year 1995

Kansas Geological Survey Open-File Report 95-45
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GEOHYDROLOGY

The University of Kansas, Lawrence, KS 66047 Tel. (913) 864-3965

THE MINERAL INTRUSION PROJECT: INVESTIGATION OF SALT CONTAMINATION OF GROUND WATER IN THE EASTERN GREAT BEND PRAIRIE AQUIFER—PROGRESS AND ACTIVITIES DURING FISCAL YEAR 1995

FY95 REPORT

Kansas Geological Survey Open-File Report 95-45, which consists of the following component reports:

OFR 95-45a: Freshwater-Saltwater Interface and Related Transition Zone Parameter Characterization in the Mineral Intrusion Area of South-Central Kansas
G. W. Garneau, D. P. Young, and R. W. Buddemeier

OFR 95-45b: Variability of Freshwater-Saltwater Transition Zone Characteristics and Related Parameters in the Great Bend Prairie Aquifer, South-Central Kansas
D. P. Young, G. W. Garneau, R. W. Buddemeier, D. Zehr, and J. Lanterman

OFR 95-45c: Effects of Groundwater Pumpage on Freshwater-Saltwater Transition Zone Characteristics, Water Quality and Water Levels at the Siefkes Intensive Study Site, Stafford County, Kansas
D. P. Young

OFR 95-45d: Initial Monitoring Results and Installation Details from the Witt Intensive Study Site on Rattlesnake Creek, Stafford County, Kansas
D. P. Young, J. M. Healey, and D. O. Whittemore

A cooperative project between the Kansas Geological Survey and Big Bend Groundwater Management District No. 5

KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 95-45a

FRESHWATER-SALTWATER INTERFACE AND RELATED TRANSITION ZONE PARAMETER CHARACTERIZATIONIN THE MINERAL INTRUSION AREA OF SOUTH-CENTRAL KANSAS

by

G.W. Garneau
D.P. Young
R.W. Buddemeier

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Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

Freshwater-Saltwater Interface and Related Transition Zone Parameter Characterization in the Mineral Intrusion Area of South-Central Kansas

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Introduction

The Mineral Intrusion project has as one of its primary objectives the determination of the amount, distribution, and movement of naturally occurring saltwater in the Great Bend Prairie aquifer. Background information on the objectives, setting, and methods of the project may be found in Buddemeier et al. (1992) and the references contained therein.

The primary observational means used to determine salt concentrations and distributions in the groundwater is measurement of aquifer conductivity by logging a network of monitoring wells (Figure 1) with a focused electromagnetic (EM) logging tool. The equipment and procedures used have been described in an earlier report (Young et al., 1993).

The data produced by this method consists of vertical profiles of conductivity values. These are determined primarily by the salinity (salt content) of the groundwater, but the absolute values are also affected to some extent by formation porosity, by the lithologic contributions to the total conductivity signal, and by instrument calibration.

In order to provide the best possible information on the groundwater characteristics, techniques have been developed to: (1) standardize instrument readings and correct for drift; (2) statistically remove a significant fraction of the overall lithologic contribution to the signal; (3) convert the corrected conductivity values into equivalent concentrations of chloride ion in the groundwater; and (4) reduce the processed logs to a set of objective, quantitative parameters that characterize the freshwater-saltwater transition zone. Because the ratio of chloride ion to salinity or total dissolved solids is nearly constant for salt derived from the Permian formation brines (Whittemore, 1993), the chloride values can be used to calculate total salt concentration and vice versa. These correction and conversion techniques have been described in detail by Garneau (1995) and will not be repeated here.

This report updates descriptions of methods for well logging and log data processing developed since the previous status report (Garneau et al., 1994). During this interval, the EM logging probe (Century Geophysics model no. 9510) was modified with the installation of new circuitry. As a consequence of this modification, the instrument calibration of the updated probe (now model no. 9511) was different from that of the earlier probe (model 9510). As mentioned above, the absolute value of the aquifer conductivity is

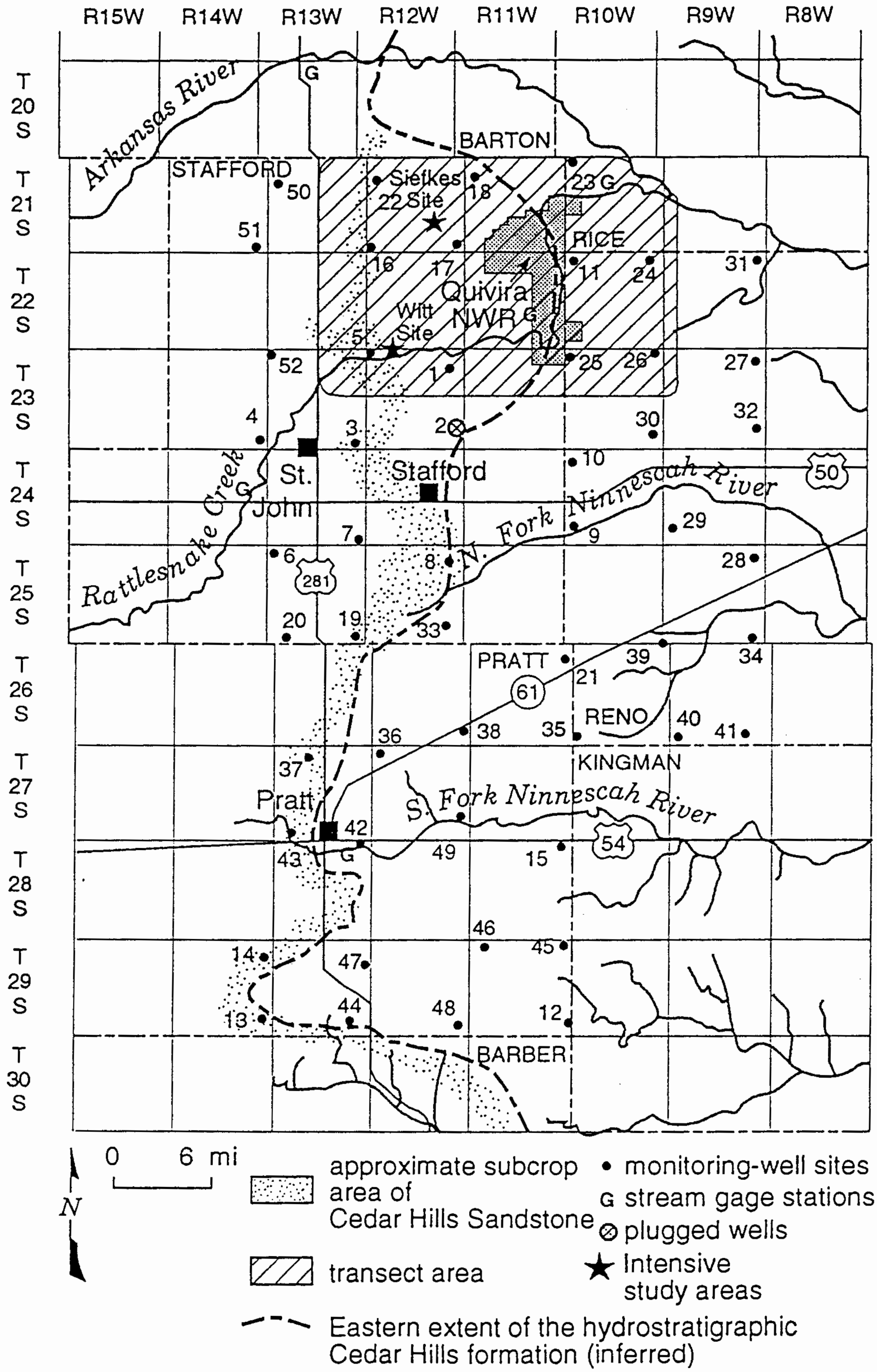


Figure 1. Observation wells and other physical features in the area of the KGS/GMD5 monitoring-well network.

affected by the instrument calibration. Conversion of the new 9511 units into the old 9510 units is therefore necessary for direct comparisons between old and new (all 1995) processed logs.

This report also compares logs recorded with the 9511 probe of the Kansas Geological Survey (KGS) with logs of the 9511 probe of the Groundwater Management District No. 5 (GMD5). The absolute values of the raw logs were again different. However, by conversion of the GMD5 9511 units into 9510 units, comparisons can be made between logs recorded with the different probes. The methods to make the various unit conversions, and discussion of examples of the log processing and analysis techniques developed for this project, are presented below.

Examples of borehole fluid conductivity logs collected with the Century Geophysics model 9042 logging probe are also presented. These logs show water quality variations with depth inside the well casing. These variations may have implications for methods used to correct for density effects on hydraulic heads in the Great Bend Prairie aquifer and the underlying Permian bedrock.

Calibration and Conversion of EM Log Data

Figure 2 is a comparison of EM logs from the 9510 probe (March, 1993) and the 9511 probe (April, 1995) at site 50 of the monitoring well network (Figure 1). The 9511 log values (S. I. conductivity units of millisiemens per meter; abbreviated as mS/m) have essentially the same baseline value of approximately 18 mS/m as the 9510 log. The baseline value at site 50 represents the 'clean-sand' (or 'clay-free') conductivity of the aquifer fully saturated with ground water having a chloride concentration of approximately 40 mg/L (Whittemore, 1993).

The conductivity variations on the logs of Figure 2 -- higher for the 9511 log -- are caused by shaly-sand effects in the aquifer (Garneau, 1995). The shaly-sand effects are caused by the presence of clay minerals which contribute additional conductance to the total or bulk conductivity baseline of the ideal clay-free aquifer material. The methods to reduce the shaly-sand effects and thus produce vertical profiles of changes of aquifer conductivity directly related to changes of groundwater salinity were developed for the Mineral Intrusion project by Garneau (1995). Logs from site 50 were used to develop the methods to correct for the shaly-sand effects and to make corrections for apparent 9510 instrument drift during 1993 and 1994. The recent circuitry modifications to the KGS logging probe were intended to eliminate the necessity of a drift correction. However, logs recorded in June 1995 required a drift correction of approximately 3.5 mS/m in order to maintain the 18 mS/m baseline at site 50 when compared to April 1995 logs. The use of a stable freshwater site to determine the precise baseline response of the logging probe is probably still the most reliable and effective means of high-precision instrument calibration.

Figure 3A compares the new 9511 conductivity units with the earlier 9510 units at monitoring site 16 (Figure 1). The higher absolute values of the 9511 data, which also can be seen in Figure 2, are apparent in Figure 3A. A least-squares line was fit to these data (see inset: Figure 3A) to allow conversion of the raw 9511 log into comparable 9510 units. The data conversion is necessary because the shaly-sand correction methods and chloride concentration conversion are based originally on the 9510 log-data statistics. The log data from site 16 -- between the depth range of 50 to 217 ft -- is used for the unit conversion because these values span the dynamic range of saturated-zone bulk conductivity values logged in the Great Bend Prairie aquifer. Additionally, there have been no significant changes apparent on the log profiles collected at site 16, allowing long-time inter-comparisons between logs.

SITE 50 EM LOGS

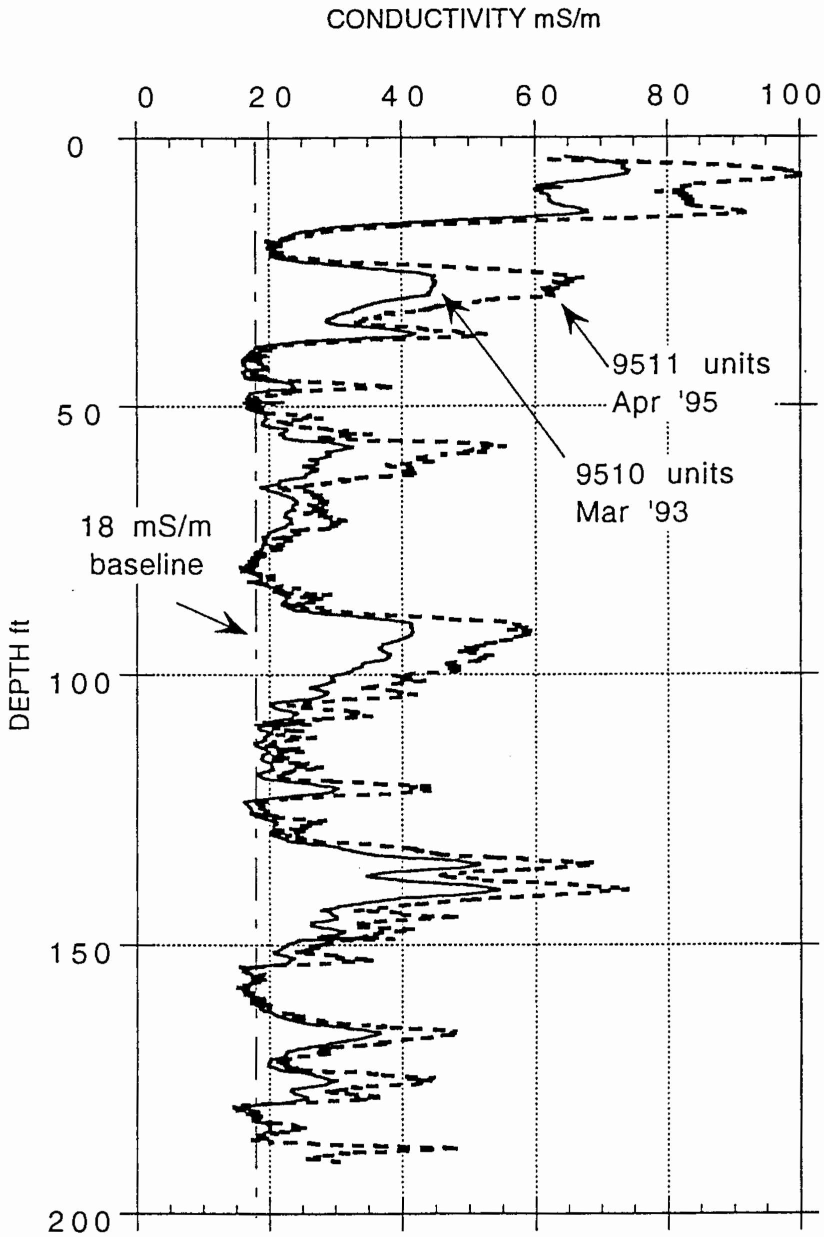
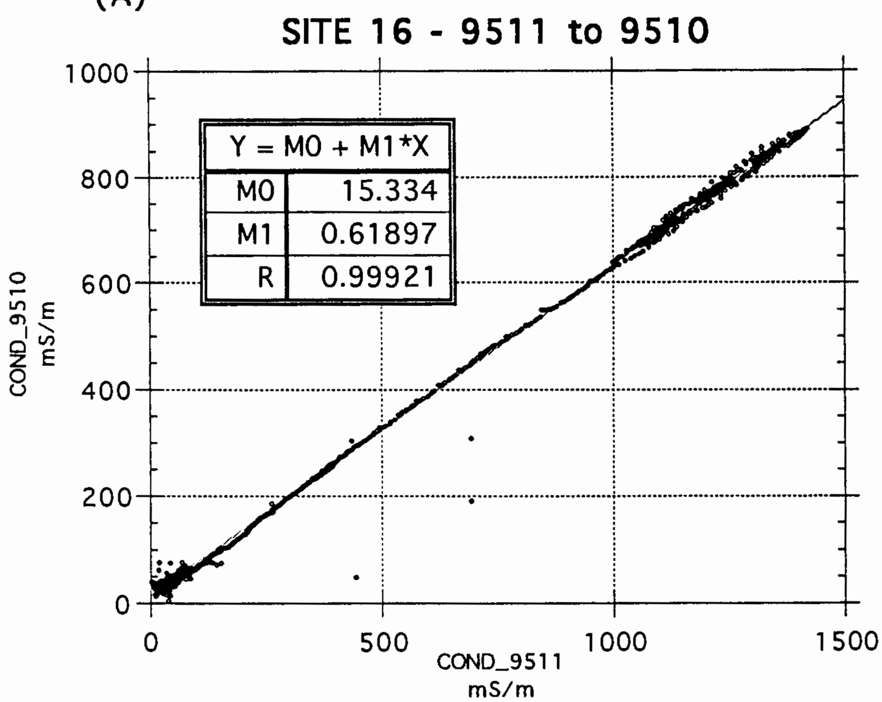


Figure 2. Comparison between EM log 9510 and 9511 conductivity units at freshwater site 50.

(A)



(B)

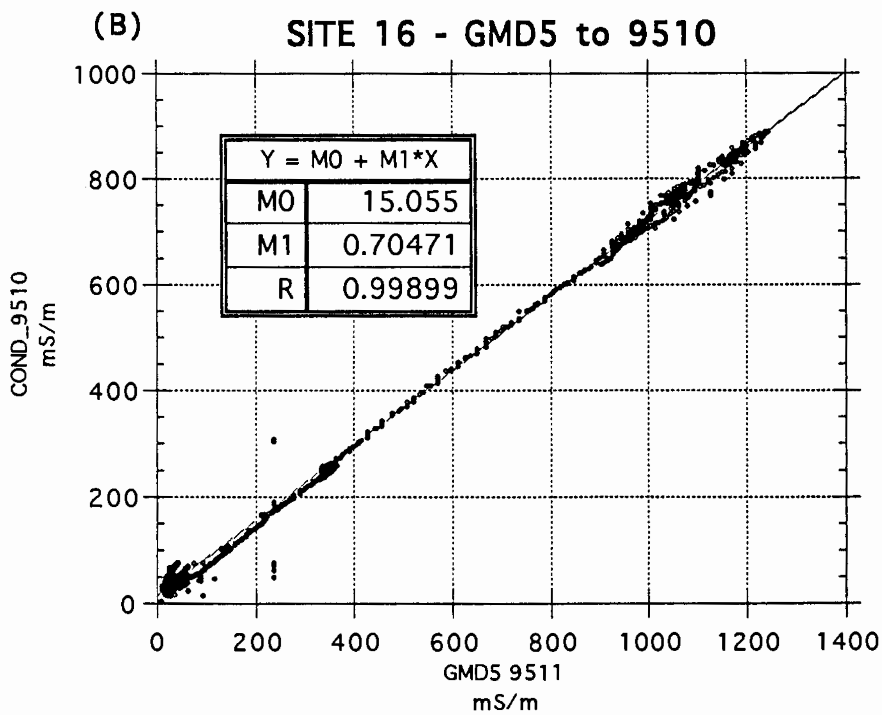


Figure 3. Conversions of (A) KGS 9511 and (B) GMD5 9511 raw conductivity units into 9510 units. Comparisons made at site 16 over the depth interval of 50 to 217 ft.

Figure 3B compares the GMD5 9511 conductivity units (logged on 04/13/95) with the KGS 9510 units over the same depth interval at site 16. The GMD5 raw log must also be converted into equivalent 9510 units for processing and analysis. Additionally, the GMD5 log required an adjustment of 0.7 ft (upwards) to bring it into depth registration with the KGS log using EM signal noise spikes caused by metallic fittings on the well casing. These noise spikes (for example see Figure 10 in part b of this Open-File Report) corrupt the EM log yet also provide convenient depth markers that were used to register the two logs. This example shows that meticulous care must be used to precisely position the logging probe (accuracy to within 0.1 ft) to a consistent local well datum for each log. All further references to this GMD5 log include the depth adjustment.

Figure 3B shows that the GMD5 9511 units are also generally greater than the 9510 units. A significant linear-regression relationship (see inset: Figure 3B), indicates that the GMD5 data (based on the instrument calibration as of the log date) can also be converted into comparable 9510 units for log processing and analysis. Conversions of both the KGS and GMD5 9511 raw conductivity units (C_{9511}) into 9510 units (C_{9510}) were made with the equation

$$C_{9510} = C_{18} + M1(C_{9511}) \qquad (1)$$

where M1 is the regression-line slope value for each probe (from insets of Figures 3A and 3B) and C_{18} is an offset that maintains the 18 mS/m baseline level. This offset was calculated for each probe as

$$C_{18} = 18 - C_b(M1) \qquad (2)$$

where C_b is the clean-sand aquifer baseline value (C_b = 18 mS/m for the KGS 9511 and C_b = 14 mS/m for the GMD5 9511 as of 04/13/95) so that: C_{18} = 6.8585 mS/m for the KGS 9511 and C_{18} = 8.1341 mS/m for the GMD5 9511 probe (for the GMD5 logs recorded on 04/13/95). The above conversion of the GMD5 9511 logs into equivalent 9510 units should only be considered valid for the date of these logs because the GMD5 probe is also likely subject to drift and to changes of calibration settings by the probe operator.

Figure 4 shows comparisons made between KGS 9511 and GMD5 9511 logs recorded on the same date at three other monitoring well sites (19, 20, and 33; Figure 1). The KGS data have been converted into 9510 units using equation (1); the GMD5 units are raw and thus Figure 4 is comparable to the unit comparison used in Figure 3B. These three examples cover only a fraction of the dynamic range of bulk aquifer conductivity as compared to site 16 and have somewhat variable linear-regression slopes (see insets on Figure 4). Any spatially-correlated difference between the two probes is probably caused by slight differences in the depth registration between logs or in the focused electromagnetic field created by the four induction coils in each of the probes. Whatever the cause of these differences, the variation of the linear-regression slopes indicates that the relationship between raw conductivity units for different probes is probably non-linear -- particularly for low values.

The effectiveness of the above described unit conversions can be assessed by comparison of processed log characteristics. At site 16 the difference between the 500 mg/L interface depth determined by curve-fit analysis (Garneau, 1995) from the last 9510 log (10/06/94) and the KGS 9511 log (04/13/95) is only 0.02 ft (from Table 1 which is described in the next section). The difference between the interface from the KGS 9511

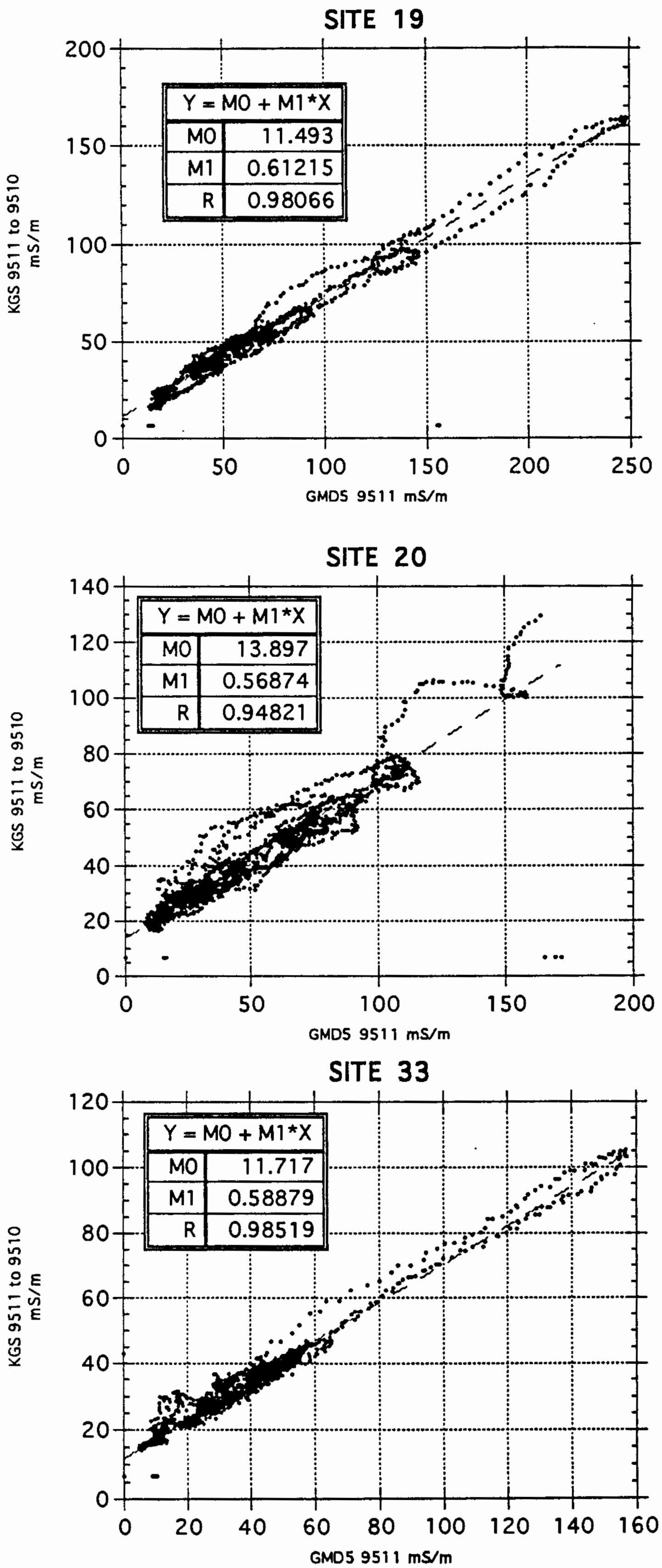


Figure 4. Comparisons between GMD5 9511 log data and KGS 9511 data converted into 9510 units at sites 19, 20, and 33.

and the GMD5 9511 logs (both converted into 9510 units) at site 16 is about 3 ft (also given in Table 1). This difference -- about the same as the overall observed variability of the interface at site 16 -- is probably caused by the differences of the focused primary fields of the logging probes. These differences can cause the non-linear responses in the low range of conductivity values (noted above) which will slightly skew the curve fitted to the processed log. However, the depth to the 100 mS/m level (or the approximately 3400 mg/L chloride interface) -- which can be read directly from the processed logs -- is exactly the same (146.4 ft) on both the KGS and GMD5 9511 processed logs. Further comparisons of the KGS and GMD5 9511 probes will be conducted for inter-calibration of the instruments.

Summary of Transition Zone (TZ) Characteristics

Table 1 contains the TZ characteristics determined from the processed EM logs collected at sites that have a distinct transition from fresh to saline water above 500 mg/L chloride. The values D1 and D2 locate the shallow and deep portions of the processed log used for curve fitting, respectively. The 21,000 mg/L depth (21k) is the fitted-curve midpoint of the idealized TZ or inflection point of the normal cumulative distribution function (CDF) assuming a source brine concentration of 42,000 mg/L chloride (Garneau, 1995). Because the fitted TZ curve is a CDF, the value sigma (σ) or standard deviation provides a standardized measure of the vertical thickness of the TZ. The value R (unitless correlation coefficient) is a measure of the goodness-of-fit of the log data to a CDF over the region D1 to D2. The depth to the 500 mg/L interface can be calculated from the 21k depth and σ by the equation

$$TZ_{500} = 21k + \sigma N(1.19) \qquad (3)$$

where N(1.19) is the normal probability of 500 mg/L expressed as a percent of 42,000 mg/L (1.19%) and is equal to approximately -2.26.

Table 1 includes the TZ data. The data clearly demonstrate the elegant simplicity by which the EM log processing and analysis technique captures the essence of variability of the freshwater-saltwater distribution in the Great Bend Prairie aquifer. Some examples, with data from Table 1, are presented in part b of this Open-File Report.

Further analysis of the TZ characteristics summarized in Table 1 will be made to discern any trends in the overall freshwater-saltwater distribution of the Great Bend Prairie aquifer. The reduction of the processed logs into such a set of objective, quantitative parameters allows a basic site classification scheme to be developed. Variations of the parameters with time can be classified as: monotonic (increasing or decreasing); cyclical (seasonal or non-seasonal); or stable (within a certain range). The temporal behavior of the parameters with respect to each other can also be incorporated into a classification scheme. Some sites may exhibit synchronous changes of the TZ parameters related to systematic changes of the freshwater-saltwater distribution. Possible interrelationships between changes of the TZ characteristics and changes of hydraulic heads in the aquifers will also be an important element for further analysis.

Borehole Fluid Conductivity and Hydraulic Head Corrections

Figure 5 shows two borehole fluid conductivity logs collected at sites SP and 16 (Permian bedrock wells) using the Century Geophysics model 9042 logging probe in August, 1994. These two log profiles show a non-uniform distribution of specific conductance -- and therefore water quality -- in the well casings at these sites. Both

Table 1. Transition zone characteristics (see text for definition of parameters).

SITE	DATE	D1 ft	D2 ft	21k ft	sigma ft	R	500 mg/L ft
1	3/26/93	90	127.7	133.18	17.07	0.9909	94.6
1	4/15/94	90	127.7	134.54	17.894	0.9892	94.1
1	4/25/95	90	127.7	135.04	17.476	0.98619	95.519
3	5/19/93	94	119	197.41	43.008	0.8229	100.15
3	4/13/94	94	119	192.14	39.927	0.8102	101.85
3	4/26/95	94	119	175.17	31.153	0.79875	104.72
4	4/22/93	80	100	177.57	49.714	0.764	65.144
4	4/13/94	80	100	165.23	44.262	0.8814	65.127
4	5/4/95	80	100	167.48	44.599	0.81951	66.619
5	9/17/93	66	106	98.876	12.641	0.972	68.288
5	10/16/93	66	106	96.891	13.018	0.9755	67.452
5	4/19/94	66	106	97.269	12.539	0.9754	68.912
5	7/6/94	66	106	97.057	11.724	0.97142	70.542
5	8/10/94	66	106	97.396	11.963	0.97299	70.341
5	10/6/94	66	106	97.18	11.867	0.97203	70.344
5	4/25/95	66	106	97.811	12.011	0.97382	70.648
6 bad data	4/19/93						
6	4/13/94	78	97	156.2	31.731	0.88445	84.445
6	5/4/95	78	97	137.14	22.445	0.78373	86.381
8	4/18/93						118
8	4/7/94						118
8	4/25/95						118
9	4/18/93	40	79.5	90.065	17.336	0.5944	50.859
9	4/14/94	40	79.5	88.037	16.182	0.5655	51.442
9	5/4/95	40	79.5	84.717	14.147	0.53264	52.724
10	4/18/93	111	126	164.71	24.533	0.81843	109.23
10	4/7/94	111	126	160.34	21.824	0.82634	110.99
10	5/2/95	111	126	161.34	21.943	0.84105	111.72
11	3/27/93	82	167.1	216.97	60.108	0.9277	81.038
11	5/20/93	82	167.1	221.95	64.422	0.9289	76.259
11	7/9/93	82	167.1	220.58	63.57	0.9286	76.819
11	7/30/93	82	167.1	220.22	63.285	0.9279	77.103
11	9/22/93	82	167.1	221.78	65.076	0.9276	74.611
11	10/13/93	82	167.1	221.69	65.06	0.9291	74.56
11	4/8/94	82	167.1	226.16	66.184	0.912	76.429
11	5/26/94	82	167.1	222.89	64.193	0.91631	77.715
11	7/6/94	82	167.1	220.27	61.708	0.91444	80.713
11	7/19/94	82	167.1	223.05	63.782	0.91581	78.807
11	8/12/94	82	167.1	223.38	64.246	0.91709	78.092
11	10/6/94	82	167.1	218.48	60.946	0.91707	80.65
11	4/25/95	82	167.1	223.89	63.498	0.92236	80.286
16	3/25/93	122	187	176.97	21.62	0.9691	128.08
16	5/19/93	122	187	177.19	21.454	0.9695	128.67
16	7/8/93	122	187	177.19	21.757	0.9686	127.99
16	7/31/93	122	187	176.88	22.301	0.9734	126.44

SITE	DATE	D1 ft	D2 ft	21k ft	sigma ft	R	500 mg/L ft
16	9/8/93	122	187	176.03	19.329	0.9773	132.31
16	10/21/93	122	187	176.88	22.319	0.9704	126.41
16	3/31/94	122	187	176.63	21.89	0.974	127.13
16	5/26/94	122	187	176.87	22.098	0.97604	126.9
16	6/23/94	122	187	176.81	22.09	0.97455	126.86
16	7/20/94	122	187	177.63	21.387	0.97324	129.26
16	8/11/94	122	187	176.7	21.115	0.97523	128.95
16	10/6/94	122	187	177.2	21.174	0.97164	129.32
16	4/13/95	122	187	177.94	21.508	0.9694	129.3
16 (GMD5 t	4/13/95	122	187	179.21	22.754	0.97271	127.76
17	3/24/93	61	100	111.1	20.366	0.9412	65.046
17	5/19/93	61	100	112.15	21.578	0.9446	63.348
17	7/8/93	61	100	112.49	21.759	0.9447	63.281
17	7/28/93	61	100	112.95	22.45	0.9455	62.178
17	9/8/93	61	100	111.01	20.179	0.9384	65.372
17	10/21/93	61	100	111.08	20.447	0.9409	64.843
17	4/1/94	61	100	111.02	20.488	0.9395	64.681
17	5/26/94	61	100	110.87	20.314	0.93957	64.929
17	7/6/94	61	100	110.9	20.346	0.93851	64.892
17	7/19/94	61	100	111.55	21.037	0.94186	63.978
17	8/11/94	61	100	111.73	21.303	0.94094	63.554
17	10/26/94	61	100	111.48	21.034	0.94098	63.907
17	4/24/95	61	100	113.03	21.883	0.94487	63.537
18	3/25/93	107	172	182.26	31.753	0.8504	110.45
18	5/21/93	107	172	183.84	33.194	0.8618	108.77
18	7/9/93	107	172	183.09	32.716	0.85	109.1
18	7/29/93	107	172	183	32.624	0.844	109.22
18	10/14/93	107	172	182.55	32.282	0.8482	109.55
18	4/8/94	107	172	181.63	31.233	0.8407	110.99
18	5/26/94	107	172	181.28	30.684	0.84729	111.89
18	7/6/94	107	172	177.75	27.738	0.83438	115.07
18	7/20/94	107	172	179.06	28.73	0.83941	114.08
18	8/10/94	107	172	179.64	29.102	0.83505	113.82
18	10/7/94	107	172	178.39	28.301	0.84471	114.38
18	4/25/95	107	172	183.08	31.362	0.84795	112.15
19	4/19/93	142	174	237.37	41.181	0.78367	144.23
19	4/7/94	142	174	237.49	41.545	0.78048	143.54
19	5/4/95	142	174	251.03	47.336	0.83768	143.98
21	5/20/93	80	136.1	161.27	34.198	0.9653	83.934
21	4/7/94	80	136.1	160.13	32.164	0.9642	87.387
21	4/27/95	80	136.1	162.38	33.02	0.96396	87.708
22	3/25/93	133	204	198.15	25.648	0.9338	140.15
22	5/21/93	133	204	197.44	24.721	0.944	141.53
22	7/9/93	133	204	197.91	24.926	0.9262	141.53
22	7/30/93	133	204	197.93	25.114	0.9271	141.14
22	10/14/93	133	204	197.08	24.427	0.938	141.84
22	3/31/94	133	204	197.82	24.549	0.9523	142.3
22	5/26/94	133	204	197.17	25.474	0.93199	139.56

SITE	DATE	D1 ft	D2 ft	21k ft	sigma ft	R	500 mg/L ft
22	6/23/94	133	204	197.13	25.637	0.92303	139.16
22	7/20/94	133	204	197.7	24.173	0.94928	143.03
22	8/4/94	133	204	198.52	24.341	0.9374	143.47
22	10/7/94	133	204	197.12	25.045	0.93326	140.48
22	4/24/95	133	204	198.45	25.362	0.93596	141.1
23	4/20/93	52.5	82	123.87	21.585	0.5614	75.05
23	4/19/94	52.5	82	158.41	40.539	0.6778	66.732
23	5/3/95	52.5	82	143.25	33.27	0.63166	68.008
24	10/23/93	88	112	146.88	24.408	0.86403	91.68
24	4/19/94	88	112	148.55	25.444	0.8805	91.008
24	5/3/95	88	112	148.27	24.515	0.89022	92.829
25	3/28/93	8	38	35.675	11.43	0.9346	9.827
25	7/31/93	8	38	34.896	11.427	0.901	9.053
25	9/14/93	8	38	34.9	11.64	0.8947	8.577
25	10/22/93	8	38	34.91	11.568	0.8944	8.748
25	4/1/94	8	38	35.56	11.099	0.9477	10.46
25	8/18/94	8	38	35.814	11.5	0.95474	9.8067
25	4/25/95	8	38	35.326	10.357	0.96946	11.903
26	4/20/93	64	102	102.11	12.625	0.9278	73.56
26	4/15/94	64	102	106.61	17.432	0.9788	67.19
26	7/7/94	64	102	108.2	19.586	0.98397	63.903
26	5/5/95	64	102	108.93	19.155	0.98166	65.614
27	4/20/93	53	66	78.229	7.5943	0.9907	61.054
27	4/15/94	53	66	84.086	11.187	0.9905	58.788
27	5/3/95	53	66	85.361	11.66	0.98732	58.991
29	4/25/93	94	150	254.31	67.954	0.634	100.64
29	4/7/94	94	150	248.73	64.379	0.6457	103.13
29	5/4/95	94	150	248.33	64.735	0.58363	101.93
30	4/25/93	85	132	216.98	48.91	0.5368	106.36
30	4/14/94	85	132	204.65	42.662	0.4906	108.17
30	5/4/95	85	132	198.67	39.274	0.48003	109.85
31	4/20/93	73	90	196.27	52.737	0.8467	77.008
31	4/15/94	73	90	192	50.257	0.8138	78.345
32	4/24/93	75	135	158.26	31.292	0.6085	87.497
32	4/19/94	75	135	151.87	27.745	0.551	89.126
32	4/27/95	75	135	147.06	23.608	0.53067	93.67
33	5/20/93	120	139	191.41	26.976	0.794	130.41
33	4/7/94	120	139	176.71	18.718	0.8117	134.38
33	5/4/95	120	139	179.48	20.322	0.75274	133.53
35	4/21/93	115	142	186.37	27.447	0.8686	124.3
35	4/20/94	115	142	188.79	28.937	0.8685	123.34
35	4/27/95	115	142	196.5	32.407	0.86728	123.22
36	4/21/93	121	188	202.18	31.618	0.9544	130.67
36	9/17/93	121	188	199.77	28.096	0.9635	136.23
36	4/14/94	121	188	203.65	32.828	0.9462	129.41
36	4/27/95	121	188	204.73	32.218	0.95512	131.87
37	4/21/93	212	233	260.55	17.497	0.902	220.98
37	4/13/94	212	233	259.04	16.663	0.9271	221.36

SITE	DATE	D1 ft	D2 ft	21k ft	sigma ft	R	500 mg/L ft
37	4/27/95	212	233	263.92	19.108	0.90916	220.71
38	4/21/93	150	177	198.04	19.209	0.8461	154.6
38	4/14/94	150	177	197.33	18.805	0.8577	154.8
38	4/27/95	150	177	204.38	22.721	0.85736	152.99
39	10/22/93						55
39	4/20/94						55
42	4/22/93	74	149	187.52	37.412	0.93	102.91
42	4/14/94	74	149	188.01	37.263	0.9392	103.74
42	4/27/95	74	149	193.14	40.154	0.93284	102.33
43	4/22/93	40	55	61.092	7.1996	0.9387	44.81
43	4/14/94	40	55	60.55	6.8257	0.938	45.113
43	4/27/95	40	55	62.361	8.1126	0.9252	44.014
49	6/22/94	40	70	87.128	17.603	0.9264	47.139
SP	4/17/93	123	180	167.41	16.836	0.97614	129.34
SP	5/20/93	123	180	166.76	16.647	0.97414	129.12
SP	7/8/93	123	180	166.35	16.02	0.97034	130.12
SP	7/27/93	123	180	166.32	15.718	0.97175	130.77
SP	7/29/93	123	180	166.35	16.034	0.97393	130.09
SP	9/18/93	123	180	166.68	17.462	0.96892	127.19
SP	10/21/93	123	180	166.53	17.995	0.9648	125.83
SP	3/24/94	123	180	166.18	17.069	0.97529	127.57
SP	3/31/94	123	180	166.21	16.911	0.97632	127.97
SP	4/13/94	123	180	166.6	16.988	0.97741	128.18
SP	4/21/94	123	180	166.28	16.807	0.977	128.27
SP	5/19/94	123	180	166.33	17.633	0.97606	126.45
SP	6/21/94	123	180	166.41	17.503	0.97491	126.82
SP	7/5/94	123	180	166.47	17.314	0.97185	127.32
SP	7/8/94	123	180	166.47	17.971	0.97307	125.83
SP	8/9/94	123	180	166.42	18.031	0.96552	125.64
SP	8/17/94	123	180	166.65	18.539	0.96358	124.73
SP	9/16/94	123	180	166.3	18.178	0.96089	125.19
SP	10/26/94	123	180	166.26	18.434	0.96091	124.57
SP	11/16/94	123	180	166.25	18.431	0.95999	124.56
SP	4/12/95	123	180	166.97	17.067	0.97678	128.38
SP	5/15/95	123	180	166.84	16.852	0.97816	128.73
SP	6/20/95	123	180	166.57	16.748	0.97525	128.69
SD	4/17/93	123	155.8	165.63	15.956	0.83722	129.54
SD	5/20/93	123	155.8	164.05	15.296	0.84618	129.46
SD	7/8/93	123	155.8	163.87	15.334	0.85122	129.19
SD	7/27/93	123	155.8	163.33	14.602	0.83302	130.31
SD	7/29/93	123	155.8	163.63	15.026	0.84281	129.65
SD	9/18/93	123	155.8	163.79	15.061	0.86172	129.73
SD	10/21/93	123	155.8	164.27	15.379	0.8613	129.49
SD	3/31/94	123	155.8	164.27	15.454	0.80825	129.32
SD	4/13/94	123	155.8	163.98	15.241	0.82066	129.51
SD	4/21/94	123	155.8	164.18	15.492	0.8096	129.15
SD	5/19/94	123	155.8	164.31	15.265	0.81592	129.78
SD	6/21/94	123	155.8	163.81	14.744	0.8291	130.46

SITE	DATE	D1 ft	D2 ft	21k ft	sigma ft	R	500 mg/L ft
SD	7/5/94	123	155.8	163.45	14.028	0.84395	131.73
SD	7/8/94	123	155.8	163.81	14.806	0.83947	130.33
SD	8/17/94	123	155.8	163.78	14.708	0.86707	130.51
SD	9/16/94	123	155.8	163.86	14.744	0.86097	130.51
SD	4/12/95	123	155.8	163.15	14.02	0.83917	131.44
SD	5/15/95	123	155.8	163.83	14.547	0.80844	130.93
SD	6/19/95	123	155.8	162.55	13.595	0.83305	131.8
WP	9/15/94	12	140	93.891	31.993	0.98326	21.652
WP	10/7/94	12	140	93.055	30.507	0.9818	24.063
WP	10/12/94	12	140	93.091	29.896	0.98129	25.482
WP	10/27/94	12	140	92.91	28.571	0.97957	28.296
WP	4/12/95	12	140	94.702	27.012	0.98033	33.613
WP	5/2/95	12	140	94.255	27.703	0.9808	31.605
WP	5/19/95	12	140	94.112	27.626	0.98031	31.636
WP	6/20/95	12	140	94.233	27.139	0.98119	32.857

SITES SP & 16 - PERMIAN BOREHOLE FLUID

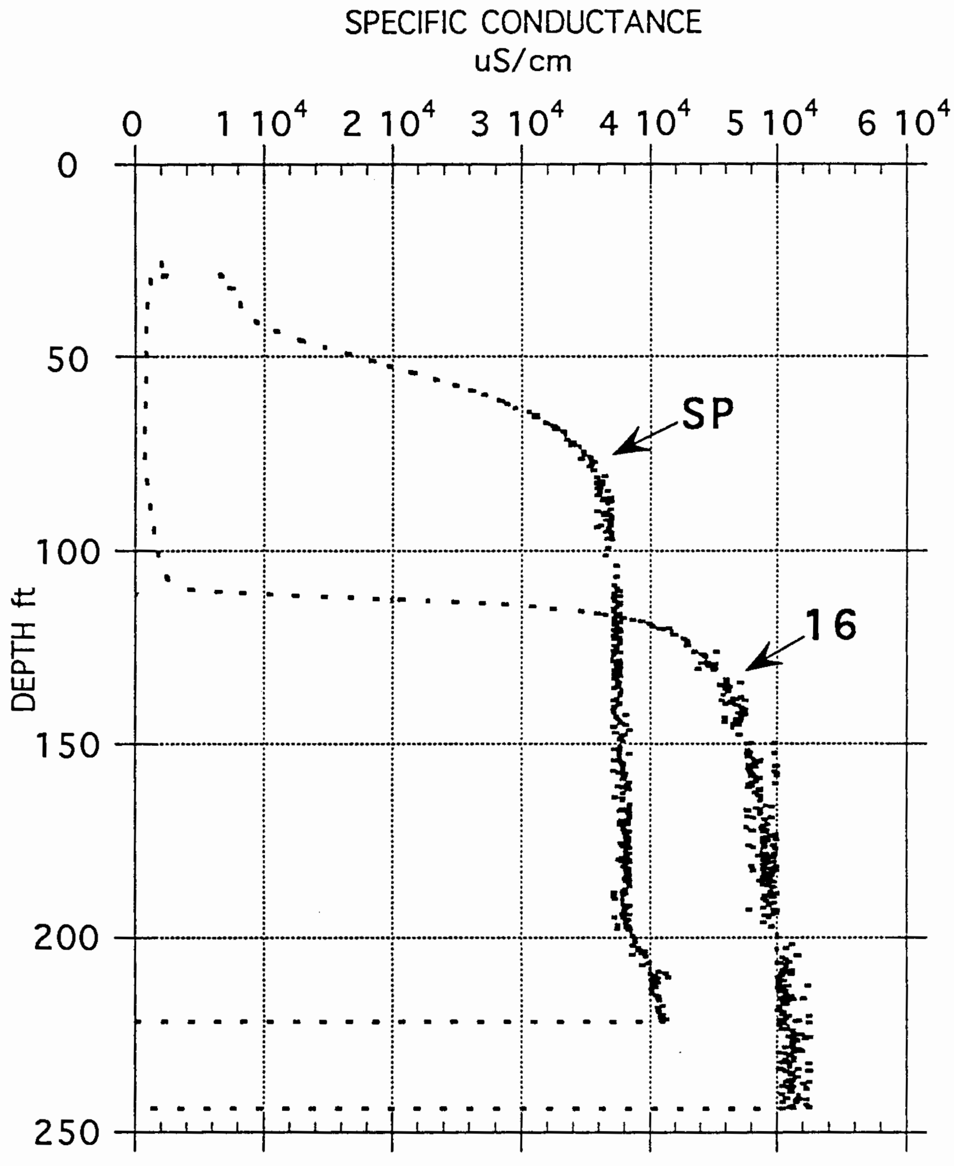


Figure 5. Borehole fluid conductivity profiles in the Permian monitoring wells at sites SP and 16 from Aug., 1994. Data from the Century Geophysics model 9042 probe.

profiles indicate fresh (low conductance) water above salty (high conductance) water, especially at site 16. The large amount of fresh water at site 16 may be left over from well development. The fact that these wells (and others) contain water of a non-uniform density affects to some extent the fluid levels and thus the measurement and intepretation of hydraulic heads at these sites.

At present the 9042 fluid conductivity profiles provide only a semiquantitative measure of the amount of borehole fluid variation. The highest specific conductivity readings -- adjacent to the screen at the bottom of the well -- are significantly less than the specific conductivity determined from lab analysis of water samples obtained from the Permian wells at sites SP and 16: about 40,000 (probe) vs 60,000 (lab) uS/cm at site SP, and 50,000 vs 90,000 uS/cm at site 16 (Whittemore, 1993). Calibration and conversion of the 9042 probe fluid conductivity log data into a useful measure of water quality such as density requires empirical adjustment of the fluid conductivity to correspond to chemical and/or formation measurements. More accurate logs of the borehole fluid density would allow adjustments to be made to measured fluid levels to correct for variable density effects on the hydraulic heads in the Great Bend Prairie aquifer and the underlying Permian bedrock.

The current methods in use to make such head adjustments assume that the borehole fluid density is the same as that of the ground water occurring at the well screen (Garneau, 1995). Calculations for both the freshwater-equivalent adjustment (used for horizontal head comparisons) and the environmental-water adjustment (used for vertical head comparisons) use borehole fluid density converted from chloride concentration of water samples from the bedrock wells. Head adjustments for wells screened in the aquifer are based on borehole fluid density estimates from bedrock-well EM log-derived chloride concentration profiles (median value from the screened interval). If the borehole fluid composition in the screened interval corresponds to the values determined by EM and chemical measurement, then simple adjustment of the borehole fluid conductivity logs to make them coincident with the EM profile at the screen midpoint will provide a first-order calibration. When this is done and the curves in Fig. 5 are partitioned between fresh water and Permian brine (locally measured concentrations), the first-order correction can be estimated. This approach suggests that the SP well contains about 90% brine and 10% fresh water, while the site 16 well has a 65%-35% ratio. This means that the density corrections, and density-derived head corrections, to these wells should be reduced by an appropriate percentage from the value calculated for pure brine.

It must also be noted that the Permian well borehole fluid density profiles may differ from profiles that have developed in the deep aquifer well casings. A program of Permian and deep aquifer well head measurement, logging and instrument calibration should be undertaken to resolve the effects of borehole fluid density variations on hydraulic heads in both the Great Bend Prairie aquifer and the bedrock.

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