Characterization of the Saltwater Interface and Related Parameters

Kansas Geological Survey Open-File Report 94-28b

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A cooperative investigation by

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Big Bend Groundwater Management District No. 5

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 experimental means used to determine salt concentrations and distributions in the groundwater is determination of formation conductivity by logging the network of monitoring wells with a focused electromagnetic (EM) logging tool. The equipment and procedures used have been described in earlier reports (Young et al., 1993).

The data produced by this method consist of a vertical profile 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; and (3) convert the corrected conductivity values into equivalent concentrations of chloride ion in the groundwater. 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 if desired. These correction and conversion techniques have been described in detail by Young et al. (1993) and will not be repeated here.

Also discussed in the earlier report was work in progress on techniques for objectively fitting a physically realistic smooth curve to the sometimes noisy chloride and conductivity profiles. There are three reasons for wishing to do this. First, the low conductivity (upper) end of the profile is sufficiently noisy so that the lowest conductivity depth value that can be reliably read directly from the curve is about 100 mS/m. Although this provides a useful index of the observed transition zone depth, it corresponds to a chloride concentration of about 3300 mg/L, which is too salty for almost all uses. We therefore need a method for estimating the location of some more useful concentration threshold, such as 500 mg/L. Second, a number of our monitoring sites do not penetrate to the bottom of the transition zone, and it is extremely useful (as discussed below) to be able to estimate the characteristics of the portion of the transition zone that cannot be observed. Third, by fitting the data with an equation that is known to represent dispersion or diffusion processes in porous media, the quality of the fit can provide information on the extent to which that particular process is important in controlling the salt distribution at the site in question.

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This report describes the curve-fitting technique employed, and how the fitted curve is used to estimate the elevation of the 500 mg/L chloride concentration. In addition, the integration of the chloride vs. depth profiles is described, as is how these results are used to calculate both total salt load (content) of the aquifer and the average salt concentration in the water column at a given site. The average concentration value is used to calculate a density correction to the observed fluid level. The results of these calculations are tabulated, but their applications are detailed and discussed in subsequent reports (OFR 94-28c-e).

Chloride Profile Curve-fitting and 500 mg/L depth estimation:

The corrected conductivity profiles from different sites are individually reproducible, have a generally similar form, and reflect primarily the salinity of the ground water. However, the natural variability of the geohydrologic environment is reflected in the detailed variations in individual log profile structures—variations which complicate decisions about how to compare profiles in a consistent and generalizable fashion. One approach to developing the needed comparisons is to fit the field data to a mathematical model that is physically reasonable and provides a "cleaned up" version of the natural phenomenon for ease of calculation, manipulation, and comparison.

We have approached the problem of standardized comparisons by adopting a model which is known to accurately represent physical phenomena such as hydrodynamic dispersion or diffusion of a solute within a porous medium (Domenico and Schwartz, 1990) and for which an equation can be fit to the depth profile of corrected conductivity with a good correlation. The model selected is the normal distribution; in effect, we approximate the vertical conductivity profile within the transition zone as the cumulative distribution function of the Gaussian "bell-shaped curve." A normal distribution represents the characteristic probability distribution of a sampled variable (x) that exhibits a symmetric frequency distribution about its mean (M0) and is also a function of its standard deviation (M1):

$$\text{norm}(x, M0, M1) = (M1(2\pi)^{0.5})^{-1}\exp{-[(x-M0)^2/(2-M1^2)]} \qquad (1).$$

The cumulative normal distribution function is the integral curve of the normal distribution function of equation 1 and produces a characteristic S-shaped (sigmoidal) profile that remains a function of the distribution mean and standard deviation. Cumulative normal distributions have been used successfully to characterize the freshwater-saltwater transition zone profile in an unconsolidated coastal aquifer (Schmorak and Mercado, 1969). In this earlier study, significant deviations from the normal distribution profile were found to be directly related to nonsteady-state conditions caused by pumping above the transition zone that resulted in the upward movement of the interface as defined by the 50% concentration level in the transition zone.

Since the equations fitted to the various profiles produce idealized curves of exactly the same form, the fitted profiles can be quantitatively compared. An additional advantage is that the equation provides a consistent picture of that part of the curve that is

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of greatest interest but most subject to uncertainty and distortion—the upper fresh-water limit of the transition zone where deteriorating water quality begins to affect possible uses.

The simplest approach to fitting the corrected EM logs to normal distributions is to convert the corrected conductivities [Cm'; Young et al., (1993)] into chloride concentrations expressed as percentages of the maximum concentration of 42,000 mg/L. The value of 42,000 mg/L was chosen as the maximum end-member concentration based on an approximate average of the higher chloride concentrations observed in wells screened in the Permian (sites 5, 6, and 8) (D. O. Whittemore, pers. comm.). Chloride percentage concentrations (Cl%) were calculated using the equation:

$$Cl\% = MAX[40,(Cm'-18)/0.02388+40]/420 \tag{2.}$$

Equation 2 sets the minimum concentration at 40 mg/L because this value represents the typical minimum level for the upper aquifer determined at site 50 (Whittemore, 1993). The other unit-conversion coefficients used in equation 2 are: 18 mS/m [the baseline aquifer conductance--eqn. 4, Young et al., (1993)]; 0.02388 mS/m per mg/L [the linear regression slope--Fig. 9, Young et al., (1993)]; and 40 mg/L (again the baseline chloride concentration at site 50) is added back to maintain the minimum water concentration. The conductivity log derived concentration value is then divided by 420 to express the value as a percentage of 42,000 mg/L such that a value of 21,000 mg/L becomes 50%.

The transition zone region (D1 to D2; Fig. B1A) used for curve fitting was selected by visual inspection of the chloride concentration profile. D1 locates the depth of the deepest portion of the profile consistently below 500 mg/L. D2 is the depth of either the last point on the profile (for incomplete profiles to bedrock) or the depth of the consistently highest concentration on the profile above bedrock. The transition zone region is then plotted on depth-normal probability axes and fitted with a least-squares line (Fig. B1B). The cumulative distribution function is represented by a straight line on the depth-probability axes. The equation for the fitted line, shown on Fig. B1B, contains the mean (M0) as the offset and standard deviation (M1) as the slope that defines the normal distribution of equation 1, is plotted on Fig. B1C, and the cumulative normal distribution shown in Fig. B1D. Because the concentrations are all expressed as a percentage of 42,000 mg/L, the mean (M0) is the depth of the 21,000 mg/L (50%) concentration of the fitted transition zone and the standard deviation (M1) indicates the thickness of the fitted transition zone (M0 + 2M1 = ~95% of transition zone area). Because the equation of the curve is fixed, the curve-fitting process can also be adapted to the characterization of the complete transition zone by extension of the fitted line for wells having logs that only partially penetrate the transition zone such as the example from site 11 illustrated in Fig B1.

The means (M0), standard deviations (M1), and correlation coefficients (R, Fig. B1B) generated by the curve-fitting process represent parameters that characterize the transition zone, along with the actual conductivity values at selected points on the curve. Systematic changes in these parameters represent detectable changes in the freshwater-
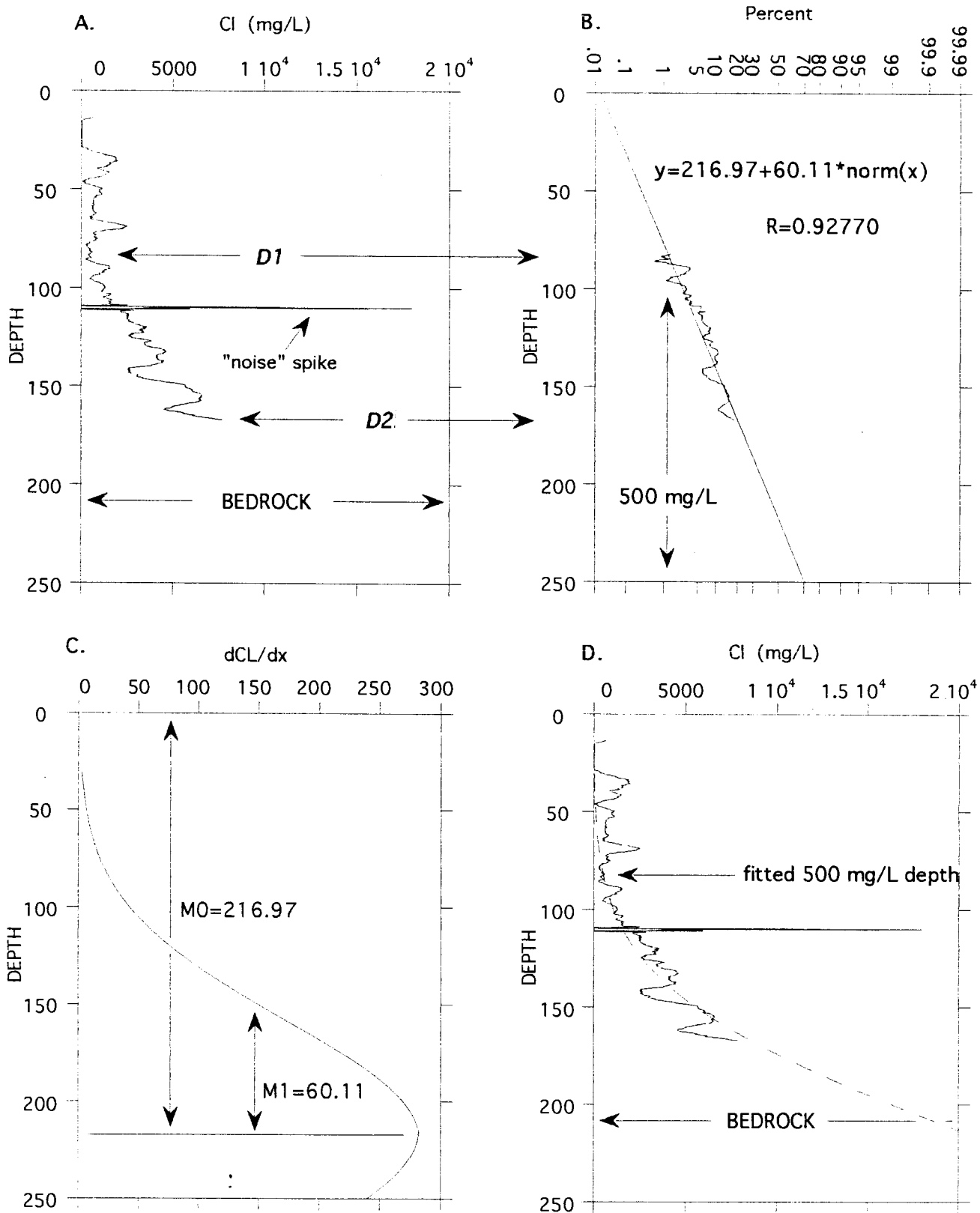
Figure B1. Example (site 11) of cumulative normal distribution fit to transition zone (TZ). A. D1 and D2 indicate range of TZ to be used for fit. TZ is incomplete to bedrock because of well obstruction. B. TZ scaled to percent of 42,000 mg/L and plotted on depth-normal probability axes. Equation of fitted line and correlation coefficient (R) are shown with location of 500 mg/L (1.19%) concentration. C. Normal distribution represented by fitted line in part B: M0=mean; M1=standard deviation. D. Cumulative distribution funtion (dashed line) with chloride concentration profile locates depth of estimated 500 mg/L concentration of TZ and completes TZ profile to bedrock.

saltwater transition zone profile. The correlation coefficient (R) indicates the goodness-of-fit of the cumulative distribution function model to the transition zone at each site. The highest values tend to be at sites that generally have large and distinct transitions from fresh to salt water. Weak transition zones are indistinct, noisier, and thus tend to produce lower correlation coefficients. Changes in the correlation coefficient with time may reflect changes in the freshwater-saltwater distribution at a particular site as the transition zone either shifts towards more (increasing R) or less (decreasing R) ideal behavior.

The curve-fitting process allows the elevation of points near the upper and lower extremes of the transition zone to be estimated. For example, the depth of the 500 mg/L level can be estimated from the normal distribution curve fit with the following formula: $M0+M1*NORM(1.19)$ where $M0$ and $M1$ are the mean and standard deviation (Table B1) and $NORM(1.19)$ is the normal distribution function (equation 1) of 500 mg/L expressed as a percentage of 42,000 mg/L (= 1.19%). The values of $D1$, $D2$, $M0$, $M1$, R, and the depth to the 500 mg/L concentration are tabulated for all sites that have a transition zone in Table B1.

We emphasize that the use of standardized, fitted chloride curves is an empirical approach that supports research purposes and comparisons over time and space. The standardized salinity curves can also be used for salt-budget calculations. However, this approach is not essential to a basic description and understanding of saltwater distribution, and it can not replace interpretation of actual log measurements and chemical analyses in cases of site-specific management and assessment, where the details of the local context will be important.

The basic assumption of the curve fitting process is that the transition zone begins (<500 mg/L) at some point in the aquifer and increases with depth to the bedrock. Therefore, the process can only be successfully applied to logs from sites that have a distinct transition zone (or at least some portion of) that displays this pattern. Sites that are listed as saline transition zone sites in OFR 94-28c that can't be processed by the curve-fitting techniques described above (not included in Table B1) because they lack data from the necessary transition zone depth range are: 15, 40, and 51.

Deviations from the archetypal transition zone assumption may exist because of incomplete removal of background lithologic contributions to the conductivity signal; "perched" transition zones; or the presence of relatively saltier water in the upper aquifer compared with the lower aquifer possibly from evaporative enrichment, agricultural chemicals, or oil brine contamination. The actual first occurrence of water with a concentration of 500 mg/L may therefore be at a lesser depth than indicated from the curve fitting process because of the ambiguous situations mentioned above. The selection of the depth range to be used for curve fitting (D1 to D2) is an attempt to include as much of the profile extending to the bedrock as possible, exclude possible ambiguities, and to maximize (high R value) the fit to a cumulative distribution function. The relative success of the curve fitting process can be assessed by the R value: most sites consistently exceed 0.85; sites where R is less than 0.85 have less distinct and broad

Table B1.								
Curve-fitting statistics from logs with a transition zone.								
				MO	M1	R	DEPTH TO	DEPTH
SITE	Date	D1	D2	(MEAN)	(STD DEV)	(CORR)	500 mg/L	CHANGE
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	-0.5
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	1.7
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	-0.017
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	-0.836
5	4/19/94	66	106	97.269	12.539	0.9754	68.912	1.46
6	4/19/93	bad log data						
6	4/13/94	78	97	156.2	31.731	0.88445	84.445	
8	4/21/93	500 mg/L set at bedrock depth					117	
8	4/7/94	500 mg/L set at bedrock depth					117	0
9	4/25/93	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	0.583
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	1.76
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	-4.779
11	7/9/93	82	167.1	220.58	63.57	0.9286	76.819	0.56
11	7/30/93	82	167.1	220.22	63.285	0.9279	77.103	0.284
11	9/22/93	82	167.1	221.78	65.076	0.9276	74.611	-2.492
11	10/13/93	82	167.1	221.69	65.06	0.9291	74.56	-0.051
11	4/8/94	82	167.1	226.16	66.184	0.912	76.429	1.869
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	0.59
16	7/8/93	122	187	177.19	21.757	0.9686	127.99	-0.68
16	7/31/93	122	187	176.88	22.301	0.9734	126.44	-1.55
16	9/8/93	122	187	176.03	19.329	0.9773	132.31	5.87
16	10/21/93	122	187	176.88	22.319	0.9704	126.41	-5.9
16	3/31/94	122	187	176.63	21.89	0.974	127.13	0.71999
17	3/25/93	61	100	111.1	20.366	0.9412	65.046	
17	5/19/93	61	100	112.15	21.578	0.9446	63.348	-1.698
17	7/8/93	61	100	112.49	21.759	0.9447	63.281	-0.067
17	7/28/93	61	100	112.95	22.45	0.9455	62.178	-1.103
17	9/8/93	61	100	111.01	20.179	0.9384	65.372	3.194
17	10/21/93	61	100	111.08	20.447	0.9409	64.843	-0.529
17	4/1/94	61	100	111.02	20.488	0.9395	64.681	-0.162
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	-1.68
18	7/9/93	107	172	183.09	32.716	0.85	109.1	0.33
18	7/29/93	107	172	183	32.624	0.844	109.22	0.12
18	10/14/93	107	172	182.55	32.282	0.8482	109.55	0.33

SITE	Date	D1	D2	M0 (MEAN)	M1 (STD DEV)	R (CORR)	DEPTH TO 500 mg/L	DEPTH CHANGE
18	4/8/94	107	172	181.63	31.233	0.8407	110.99	1.44
19	4/19/93	142	163	237.37	41.181	0.78367	144.23	
19	4/7/94	142	163	237.49	41.545	0.78048	143.54	-0.69
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	3.453
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	1.38
22	7/9/93	133	204	197.91	24.926	0.9262	141.53	0
22	7/30/93	133	204	197.93	25.114	0.9271	141.14	-0.39
22	10/14/93	133	204	197.08	24.427	0.938	141.84	0.7
22	3/31/94	133	204	197.82	24.549	0.9523	142.3	0.46001
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	-8.318
24	4/20/93	88	112	146.88	24.408	0.86403	91.68	
24	4/19/94	88	112	148.55	25.444	0.8805	91.008	-0.672
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	-0.774
25	9/14/93	8	38	34.9	11.64	0.8947	8.577	-0.476
25	10/22/93	8	38	34.91	11.568	0.8944	8.748	0.171
25	4/4/94	8	38	35.56	11.099	0.9477	10.46	1.712
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	-6.37
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	-2.266
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	2.49
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	1.81
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	1.337
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	1.629
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	3.97
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	-0.96001
36	4/21/93	121	188	202.18	31.618	0.9544	130.67	
36	9/16/93	121	188	199.77	28.096	0.9635	136.23	5.56
36	4/14/94	121	188	203.65	32.828	0.9462	129.41	-6.82
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	0.38
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	0.2
39	10/22/93	500 mg/L set at bedrock depth					55	
39	4/20/94	500 mg/L set at bedrock depth					55	0
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	0.82999

SITE	Date	D1	D2	M0 (MEAN)	M1 (STD DEV)	R (CORR)	DEPTH TO 500 mg/L	DEPTH CHANGE
43	4/22/93	40	55	61.092	7.1996	0.9387	44.81	
43	4/19/94	40	55	60.55	6.8257	0.938	45.113	0.303
49	6/22/94	40	70	87.13	17.6	0.9264	102.7	
SP	4/17/93	123	180	167.27	16.4	0.9766	130.18	
SP	5/20/93	123	180	166.63	16.224	0.9743	129.94	-0.23999
SP	7/8/93	123	180	166.17	15.487	0.969	131.14	1.2
SP	7/27/93	123	180	166.04	14.993	0.968	132.13	0.99001
SP	7/29/93	123	180	166.09	15.343	0.9704	131.39	-0.74001
SP	9/18/93	123	180	166.63	17.193	0.9702	127.75	-3.64
SP	10/21/93	123	180	166.46	17.707	0.9655	126.41	-1.34
SP	3/24/94	123	180	166.07	16.676	0.9744	128.35	1.94
SP	3/31/94	123	180	166.08	16.473	0.9753	128.82	0.47
SP	4/13/94	123	180	166.01	16.166	0.97535	129.45	0.62999
SP	4/21/94	123	180	166.12	16.32	0.9752	129.21	-0.23999
SP	5/19/94	123	180	166.25	17.325	0.9762	127.07	-2.14
SD	4/17/93	123	158.3	165.45	15.87	0.8824	129.56	
SD	5/20/93	123	158.3	164.17	15.372	0.8888	129.41	-0.14999
SD	7/8/93	123	158.3	163.97	15.389	0.8918	129.17	-0.24001
SD	7/27/93	123	158.3	163.66	14.788	0.8795	130.22	1.05
SD	7/29/93	123	158.3	163.85	15.154	0.8863	129.58	-0.64
SD	9/18/93	123	158.3	163.92	15.128	0.9001	129.71	0.13
SD	10/21/93	123	158.3	164.18	15.327	0.8992	129.52	-0.19
SD	3/31/94	123	158.3	164.31	15.503	0.8608	129.25	-0.27
SD	4/13/94	123	158.3	164.06	15.311	0.87022	129.44	0.19
SD	4/21/94	123	158.3	164.27	15.574	0.8621	129.05	-0.39
SD	5/19/94	123	158.3	164.4	15.624	0.8656	129.06	0.009995

(M1 > 40 ft) transition zones that are most subject to distortions due to the presence of ambiguities.

Concentration levels calculated from the fitted profiles, such as the 500 mg/L depth, are intended to represent estimates of idealized, vertically controlled transition zone values as a product of possible hydrodynamic dispersion or diffusion processes starting with an original source brine with a concentration of 42,000 mg/L.
The use of 42,000 mg/L chloride as an assumed bedrock limit of the upper end of the transition zone is an estimate based on the limiting concentration. We are aware that in some locations the transition zone extends into the bedrock, and that the actual maximum bedrock concentration may be less than 42,000 mg/L. As part of future work we will explore the effects of this assumption and the utility of alternative approaches. It is presented here as an illustration of the utility of a standardized comparison technique, and an initial estimate of some key parameters. Biases introduced by this assumption should have little effect on the use of the parameters to evaluate changes at a single site. Where the assumption is inaccurate, it will tend to skew the results toward higher salt inventories and sharper transition zones than may actually be the case.

WORK IN PROGRESS

The following sections represent work in progress because the analysis so far has concentrated on sites in the northern Mineral Intrusion study area.

Salt inventory:

The integrated salt load within the aquifer at each site is determined by calculating the area underneath the chloride concentration profile derived from the corrected conductivity log between the water table (wt) and the bedrock (br). For sites lacking a complete profile to bedrock, the cumulative distribution function fitted to the transition zone (described above) is used to estimate the missing section of the chloride concentration profile. Sites requiring extrapolation of the chloride profile were: 1, 5, 11, and 21. The area (A) was calculated by using the curve integration function in KaleidaGraph™ software running on a Macintosh Quadra. The integrated area (A) under the curve is based on the Riemann sum:

$$A = \sum_{wt}^{br} Cl(x)\,\Delta x \tag{3}$$

where: Cl(x) is the concentration (mg/L) at depth x, $\Delta x = 0.1$ ft, and from the fundamental theorem of calculus:

$$A = \lim_{\Delta x \to 0} \sum_{a}^{b} f(x)\,\Delta x = \int_{a}^{b} f(x)\,dx \tag{4}$$

provided that f(x) is continuous and its derivative exists between a and b. The total mass of chloride per unit aquifer surface area is:

$$Cl(mg/ft^2) = 28.32An \qquad (5)$$

where A is the area under the depth profile of chloride concentration (mg-ft/L); 28.32 is a volumetric conversion factor (L/ft^3); and n is effective aquifer porosity (unitless; assumed to be 0.16). The total chloride mass is a measure of the salt load for that portion of the aquifer. Table B2 includes the area (A), the chloride mass, and the equivalent saturated thickness at 42,000 mg/L required to equal the mass at sites in the northern part of the study area. Further discussion of these results and their implications will be found in OFR 94-28c and e.

Variable density head correction:

The applications of complete chloride concentration profiles for sites in the Great Bend Prairie aquifer include corrections for density effects on hydraulic head measurements and the determination of total salt mass for a particular site. Density-corrected head measurements will allow the development of an accurate horizontal and vertical component flow field within the aquifer. Together, the flow field and salt inventory will be used to determine the aquifer salt budget for the Mineral Intrusion study area.

Flow-field calculations involving water of high total dissolved solids (TDS) or higher or lower than normal temperatures requires that the effects of density be included in the formulations. For example, a salt water with a TDS of approximately 35,000 mg/L will have a density of 1.025 gm/cm^3 as compared to pure water with a density of 0.999973 gm/cm^3 at 4 deg C; pure water at 50 deg C has a density of 0.988047 gm/cm^3 (Anderson and Woessner, 1992). These seemingly small changes in density can have a significant influence on the flow-field calculations, especially when potentiometric gradients are commensurately small to begin with. However, since the total thickness of the Great Bend Prairie aquifer is relatively small with small changes in temperature, only density variations due to changes in chloride concentration and not temperature need to be considered.

Figure B2 demonstrates the relationship between chloride concentration and density of seawater at 15 deg. C (Williams, 1962), the typical temperature (in situ) of ground water in the Great Bend Prairie aquifer. The linear relationship must be extrapolated to concentrations of 42,000 mg/L (the maximum groundwater concentration) because the relationship was developed for seawater with typical chloride concentrations of less than 25,000 mg/L. Although there are slight differences between the ionic ratios of seawater and of Permian formation brine, they are similar enough to justify the use of this relationship.

Figure B3 illustrates the concepts of hydraulic heads in variable density situations as described by Lusczynski (1961). The point-water head (Fig. B3A) is the field-

SITE.well no.	DEPTH TO BEDROCK	DEPTH TO WATER TABLE	AREA UNDER CHLORIDE PROFILE	CHLORIDE MASS PER UNIT AREA	EQUIVALENT 42k CONCEN. SAT. THICK
Table B2 part 1.					
Salt inventory at some monitoring well sites in the Mineral Intrusion study area (1993).					
1.1	146	5.3	6.43E+05	2.91E+06	15.308
SP	186	10.8	7.96E+05	3.60E+06	18.94
3.1	130	25.73	33561	1.52E+05	0.79907
4.1	129	8.7	1.91E+05	8.66E+05	4.5492
5.1	181	1.77	3.06E+06	1.39E+07	72.775
8.1	118.3(1)	8.8	68715	3.11E+05	1.6361
9.1	87	9	1.96E+05	8.89E+05	4.6693
10.1	156	18.3	84985	3.85E+05	2.0234
11.1	208	13.5	8.65E+05	3.92E+06	20.592
16.1	220	11.98	1.68E+06	7.60E+06	39.915
17.1	114	11.6	2.49E+05	1.13E+06	5.9393
18.1	214	19.25	8.52E+05	3.86E+06	20.295
21.1	137	21.6	2.67E+05	1.21E+06	6.3524
22.1	215	16.1	8.07E+05	3.66E+06	19.208
23.1	94	21.42	41453	1.88E+05	0.98698
24.1	123	21	3.65E+05	1.66E+06	8.6993
25.1	98	6.3	1.31E+06	5.95E+06	31.241
26.1	177	6.8	9.52E+05	4.31E+06	22.661
27.1	104	10.12	82905	3.76E+05	1.9739
30.1	138	14.54	56876	2.58E+05	1.3542
31.1	93	13.65	37273	1.69E+05	0.88746
32.1	172	2.6	2.48E+05	1.12E+06	5.9067
36.1	195	28	4.26E+05	1.93E+06	10.15
37.1	240	58.63	95705	4.34E+05	2.2787
42.1	160	13.03	1.53E+05	6.91E+05	3.6311
43.1	65	4.87	71699	3.25E+05	1.7071
50.1	223	26.15	13657	61885	0.32518
51.1	200	17.3	23314	1.06E+05	0.5551
52.1	221	30.79	15816	71667	0.37658
NOTES:					
(1) Depth to bedrock changed from 117 ft based on inspection of conductivity log.					
Depths and thicknesses in feet; Area - (mg-ft)/L; mass (mg/sq. ft).					

Table B2 part 2.					
Salt inventory at some monitoring well sites in the Mineral Intrusion study area (1994).					
			AREA UNDER	CHLORIDE	EQUIVALENT
	DEPTH TO	DEPTH TO	CHLORIDE	MASS PER	42k CONCEN.
SITE.well no.	BEDROCK	WATER TABLE	PROFILE	UNIT AREA	SAT. THICK
1.1	146	6.35	6.10E+05	2.76E+06	14.517
SP	186	11.3	8.05E+05	3.65E+06	19.172
3.1	130	20.54	32818	1.49E+05	0.78138
4.1	129	7.87	2.17E+05	9.82E+05	5.1603
5.1	181	2.08	3.05E+06	1.38E+07	72.522
8.1	118.3(1)	11.1	75413	3.42E+05	1.7955
9.1	87	9.36	2.07E+05	9.39E+05	4.9332
10.1	156	13.75	79998	3.62E+05	1.9047
11.1	208	11.39	8.04E+05	3.64E+06	19.135
16.1	220	7.64	1.66E+06	7.50E+06	39.412
17.1	114	10.54	2.57E+05	1.16E+06	6.1104
18.1	214	11.02	8.59E+05	3.89E+06	20.454
21.1	137	23.07	2.16E+05	9.80E+05	5.1505
22.1	215	12.71	8.09E+05	3.67E+06	19.267
23.1	94	22.4	40763	1.85E+05	0.97055
24.1	123	23.9	2.57E+05	1.16E+06	6.1079
25.1	98	6.02	1.32E+06	6.00E+06	31.535
26.1	177	8.76	1.03E+06	4.66E+06	24.47
27.1	104	11.22	1.09E+05	4.92E+05	2.5833
30.1	138	17.19	47496	2.15E+05	1.1308
31.1	93	15.06	35320	1.60E+05	0.84096
32.1	172	9.1	2.60E+05	1.18E+06	6.1963
36.1	195	27.84	4.30E+05	1.95E+06	10.249
37.1	240	57.1	92821	4.21E+05	2.21
42.1	160	13.01	1.50E+05	6.79E+05	3.5671
43.1	65	5.14	81034	3.67E+05	1.9294
49.1	106	1	196670	8.91E+05	4.6826
50.1	223	22.34	14846	67271	0.35348
51.1	200	13.68	24149	1.09E+05	0.57498
52.1	221	23.67	16859	76390	0.40139
NOTES:					
(1) Depth to bedrock changed from 117 ft based on inspection of conductivity log.					
Depths and thicknesses in feet; Area - (mg-ft)/L; mass (mg/sq. ft).					

S	ρ (gm/cm^3)	Cl (mg/L *1000)
0	0.9991	-0.0166
5	1.0030	2.7618
10	1.0068	5.5613
15	1.0107	8.3821
20	1.0145	11.224
25	1.0183	14.087
30	1.0222	16.972
35	1.0260	19.878
40	1.0299	22.805

where: S = salinity (parts per thousand); ρ = density of seawater at 15 deg. C; and Cl = [(S-0.03)/1.805]ρ. Source: Table 111-1 and eqn. 3.1 (Williams, 1962)
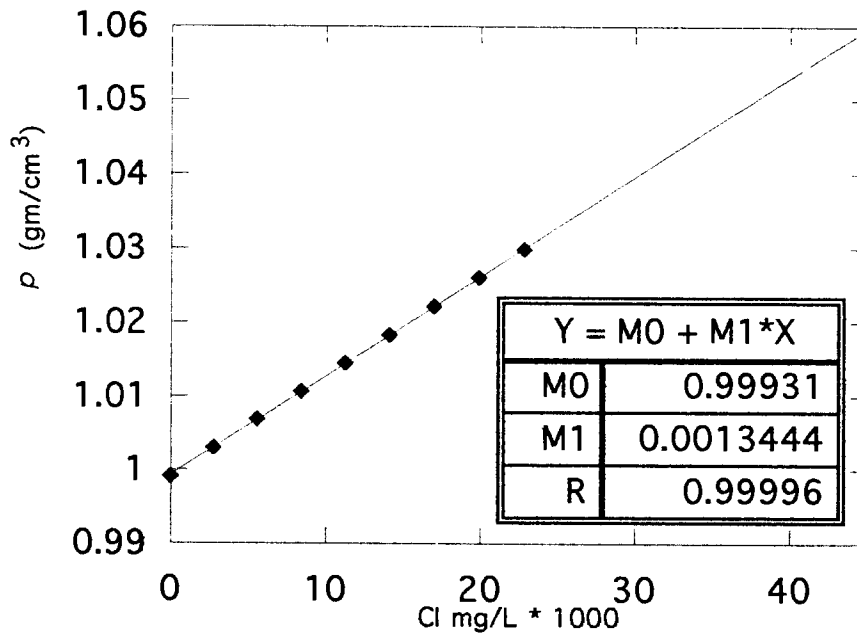

Figure B2. Conversion of chloride concentration to density.

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A. Point-water head.   B. Fresh-water head.   C. Environmental-water head.

Fresh
water

$P/\rho_i g$

Z_r

Salt
water

i

Z

datum

$H_{ip} = z + P/\rho_i g$ $H_{if} = H_{ip}(\rho_i/\rho_f) - z(\rho_i - \rho_f)/\rho_f$ $H_{in} = H_{if} - (z - z_r)(\rho_f - \rho_a)/\rho_f$
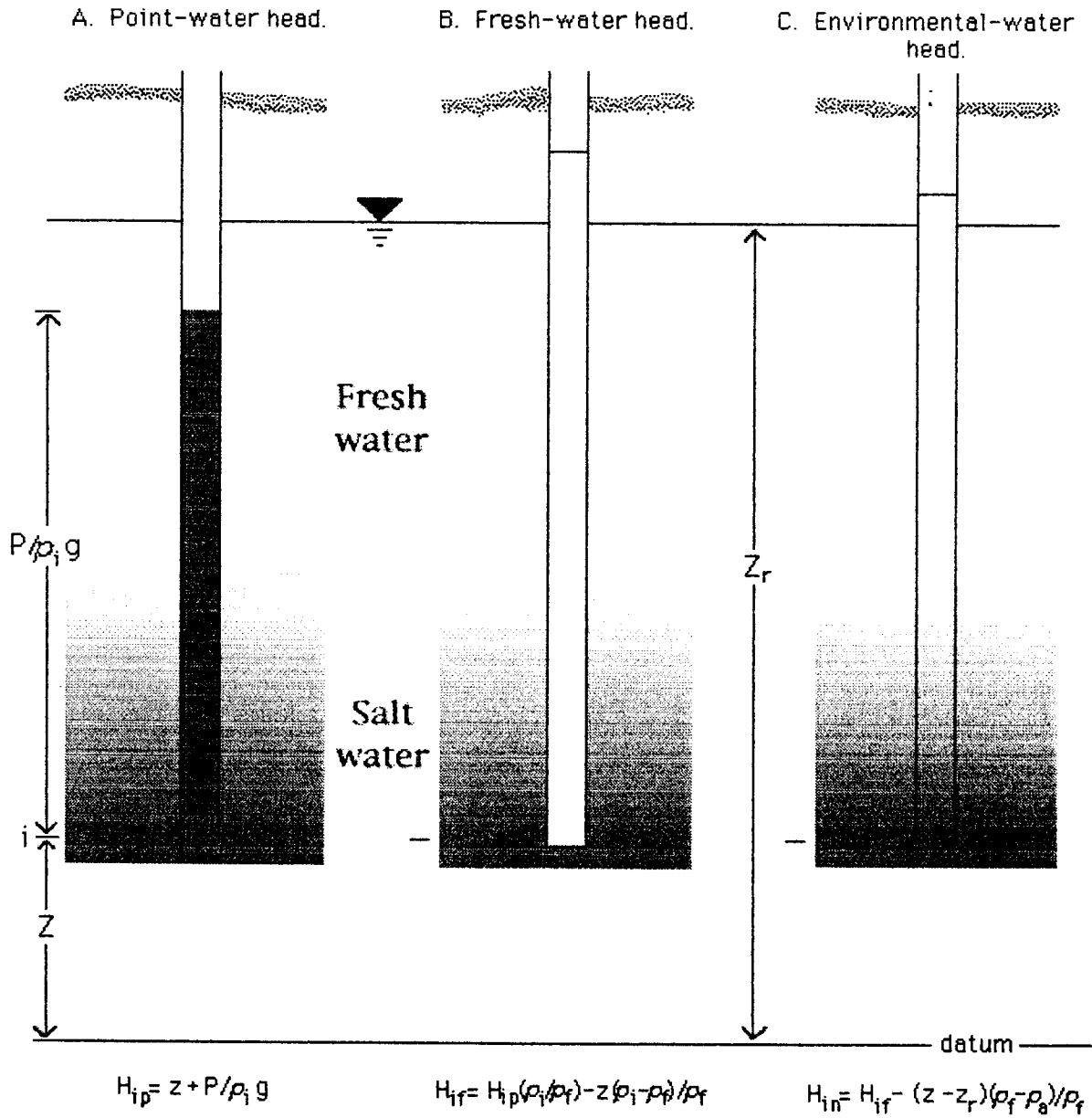
where: ρ_i = density at depth i ; ρ_f = fresh water density; ρ_a = average density.

Note: if well is screened in fresh water— $H_{ip} = H_{if} = H_{in}$

Figure B3. Heads in ground water of variable density (after Lusczynski, 1961).

measured fluid level, which is assumed to reflect the head of the well filled with water of uniform density equal to that occurring at the depth of the well screen. The fresh-water head (Fig. B3B) is the hypothetical head of the same well filled with uniformly fresh water. The environmental-water head (Fig. B3C) is the hypothetical head of the same well filled with the variable density water reflecting the actual vertical density gradient in the aquifer. The environmental-water correction can also be thought of as the fresh-water correction reduced by an amount corresponding to the difference between the salt mass in fresh water and that in the actual (environmental) water in the interval from the top of the zone of saturation to the well screen (Lusczynski, 1961). Because the environmental-water head correction reflects the actual vertical mass distribution in the aquifer and thus an approximation of the density-related, gravity-driven component of flow, this correction is used to calculate vertical gradients within the aquifer.

For assessing the probable rate of inflow of saltwater from the Permian to the Great Bend Prairie aquifer formations, the critical head gradient is across the bedrock interface. In order to estimate that value on the basis of normalized densities, we use the difference between the calculated freshwater head of the Permian well (H_{if}, assumed to represent the density-corrected driving force for upward flow) and the environmental head at the bedrock datum (H_{in}, assumed to represent the density-corrected confining pressure of the overlying water column). These gradients are presented and discussed in reports OFR 94-28d and e.

The environmental head, based on the average density, is calculated quite simply from the integrated chloride profile area A (from eqn 4 above) by dividing the value of A (mg-ft/L) by the saturated thickness of the aquifer. This provides the average chloride concentration over the depth in question; that value can be transformed into average density using the expression presented in Figure B2.

The results of head corrections for several sites, with measurements from 1993 and 1994, are contained in Table B3 parts 1 and 2. Two examples from Table B3 illustrate the necessity and precision of the head corrections. For site 5, the point-water heads indicate a recharge (downward) potential between the upper (number 3 well) and the lower (number 2 well) aquifer whereas the environmental-water corrected heads indicate a discharge (upward) potential. Because site 5 is located close to the gaining (discharge) Rattlesnake Creek and has an unusually thick and massive salt-water profile (Table B2), a discharge gradient appears to reflect the actual fluid potential within the aquifer. For site 8, the number 2 and 3 wells are both screened in the lower aquifer with approximately 30 ft of depth separation. The point-water heads for these two wells are approximately 0.3 ft different for both 1993 and 1994 measurements whereas the density-corrected heads are brought into coincidence to within 0.06 ft for 1993 and to within 0.01 ft for 1994 -- the much smaller gradients, at site 8, again reflecting congruity of fluid potentials. This high level of precision in matching the corrected heads indicates that very accurate potential flow field calculations, especially critical in the vertical direction within the Mineral Intrusion study area, can be calculated for the Great Bend Prairie aquifer if adequate elevation data are available.

Table B3 part 1.

Variable-density head corrections for monitoring well sites in the northern and selected sites in the southern Mineral Intrusion study area (1993).

SITE.well no.	DEPTH TO BEDROCK	DEPTH TO SCREEN	DEPTH TO WATER TABLE	DEPTH TO WATER	DENSITY AT SCREEN (1)	AVERAGE DENSITY (2)	POINT-WATER HEAD (3)	FRESH-WATER HEAD	ENVIRONMENTAL-WATER HEAD
1.1	146	146	5.3	6.8	1.0171	1.0055	139.2	141.67	140.74
1.2	146	106	5.3	5.7	1.0036	0.99973	140.3	140.73	140.68
1.3	146	36	5.3	5.3	0.99936	0.9995	140.7	140.7	140.69
	186	197	10.8	20.9	1.0352	1.0054	175.2	181.88	180.75
3.1	130	120	25.73	28.31	1.0135	0.99974	101.69	102.99	102.93
3.2	130	65	25.73	25.73	0.9994	0.99941	104.27	104.27	104.26
4.1	129	217	8.7	5.8	1.041	1.0015	123.2	132.01	131.51
4.2	129	106	8.7	5.8	1.0004	1.0013	123.2	123.31	123.08
4.3	129	53	8.7	8.7	1.0009	1.001	120.3	120.37	120.27
5.1	181	193	1.77	1	1.0547	1.0222	180	190.64	186.17
5.2	181	92	1.77	3.26	1.0282	1.0019	177.74	180.31	180.06
5.3	181	40	1.77	1.77	0.99936	0.99973	179.23	179.23	179.21
8.1	118.3 (4)	237	8.8	25.1	1.0582	1.0002	93.2	105.69	105.48
8.2	118.3 (4)	116	8.8	15.8	1.0024	1.0001	102.5	102.81	102.71
8.3	118.3 (4)	87	8.8	15.5	1.0001	1.0002	102.8	102.86	102.77
8.4	118.3 (4)	46	8.8	8.8	0.99998	0.99955	109.5	109.52	109.51
9.1	87	86	9	9	1.0037	1.0027	78	78.34	78.018
9.2	87	62	9	8.8	1.0012	1.0004	78.2	78.301	78.223
9.3	87	38	9	9	0.99936	0.99955	78	78.001	77.99
10.1	156	160	18.3	22.9	1.0016	1.0001	133.1	133.42	133.27
10.2	156	143	18.3	22.7	1.0013	1	133.3	133.54	133.43
10.3	156	100	18.3	20.8	1.0004	0.99961	135.2	135.29	135.25
10.4	156	74	18.3	18.3	0.99961	0.99942	137.7	137.72	137.71
11.1	208	237	13.5	31.89	1.0329	1.0053	176.11	183.01	181.51
11.2	208	61	13.5	13.5	1.0002	1.0002	194.5	194.54	194.48
16.1	220	243	11.98	29.2	1.0461	1.0101	190.8	200.81	198.05
16.2	220	198	11.98	19.25	1.0452	1.0065	200.75	208.96	207.45
16.3	220	80	11.98	11.98	0.99948	1.0003	208.02	208.03	207.94
17.1	114	129	11.6	45.7	1.0126	1.0026	68.3	69.407	68.946
17.2	114	102	11.6	10.8	1.0105	1.002	103.2	104.22	103.92
17.3	114	41	11.6	11.6	0.99936	0.99952	102.4	102.4	102.39
18.1	214	231	19.25	34.32	1.0157	1.0052	179.68	182.91	181.43
18.2	214	197	19.25	32.76	1.0189	1.004	181.24	184.46	183.44
18.3	214	45	19.25	19.25	0.99961	0.99961	194.75	194.76	194.74

21.1	137	145	21.6	25.2	1.015	1.0024	111.8	113.69	113.17
21.2	137	113	21.6	22.9	1.0047	1.0007	114.1	114.59	114.4
21.3	137	43	21.6	21.6	1.0003	1.0013	115.4	115.42	115.29
22.1	215	231	16.1	29.3	1.043	1.0048	185.7	194.52	193.17
22.2	215	206	16.1	24.7	1.0313	1.0036	190.3	196.1	195.15
22.3	215	35	16.1	16.1	0.99936	0.99936	198.9	198.9	198.9
23.1	94	122	21.42	24.22	1.008	1.0001	69.78	70.632	70.522
23.2	94	79	21.42	22.99	0.99995	1	71.01	71.046	70.977
23.3	94	44	21.42	21.42	0.99936	1.0008	72.58	72.581	72.484
24.1	123	131	21	23.8	1.0018	1.0041	99.2	99.462	98.73
24.2	123	86	21	21.2	0.99997	1.0056	101.8	101.84	101.17
25.1	98	120	6.3	11.4	1.0227	1.0185	86.6	89.142	86.711
25.2	98	95	6.3	12	1.0343	1.0181	86	88.906	87.001
25.3	98	44	6.3	6.3	1.0266	1.0123	91.7	92.73	92.076
26.1	177	190	6.8	16.2	1.0174	1.0068	160.8	163.95	162.47
26.2	177	118	6.8	11.1	1.0154	1.0038	165.9	167.62	167.06
26.3	177	60	6.8	6.8	0.99961	0.99963	170.2	170.22	170.19
27.1	104	115	10.12	10.75	1.0018	1.0005	93.25	93.508	93.36
27.2	104	60	10.12	10.1	1.0005	1.0001	93.9	93.959	93.904
27.3	104	30	10.12	10.12	0.99994	1.0008	93.88	93.893	93.833
30.1	138	155	14.54	17.3	1.0026	0.99993	120.7	121.15	121.04
30.2	138	123	14.54	14.57	1.0003	0.99986	123.43	123.54	123.46
30.3	138	60	14.54	14.54	0.99936	0.99993	123.46	123.46	123.42
31.1	93	108	13.65	13.43	1.0017	0.99994	79.57	79.795	79.718
31.2	93	85	13.65	13.78	1.0004	0.9999	79.22	79.298	79.239
31.3	93	55	13.65	13.65	1.0002	0.99941	79.35	79.387	79.38
32.1	172	189	2.6	45.83	1.0018	1.0013	126.17	126.53	126.15
32.2	172	161	2.6	45.88	1.0022	1.0012	126.12	126.45	126.14
32.3	172	113	2.6	1.48	1.0025	1.0004	170.52	170.88	170.75
32.4	172	78	2.6	2.6	1.0002	0.99968	169.4	169.47	169.44
36.1	195	210	28	29.9	1.0286	1.0027	165.1	170.38	169.56
36.2	195	191	28	27.8	1.022	1.0023	167.2	170.91	170.25
36.3	195	146	28	26	1.0026	1	169	169.4	169.27
36.4	195	85	28	28	1.0004	0.99969	167	167.06	167.02
37.1	240	255	58.63	60.84	1.0024	1	179.16	179.76	179.54
37.2	240	235	58.63	58.63	1.0023	0.99996			
37.3	240	151	58.63	59.06	0.99947	0.99972	180.94	180.95	180.87
37.4	240	82	58.63	58.63	0.99951	0.99983	181.37	181.37	181.3
42.1	160	178	13.03	21.28	1.0059	1.0007	138.72	139.75	139.49
42.2	160	157	13.03	20.36	1.0042	1.0006	139.64	140.31	140.09
42.3	160	103	13.03	13.03	1.0007	0.99948	146.97	147.1	147.08

43.1	65	88	4.87	5.4	1.0023	1.0009	59.6	59.844	59.695
43.2	65	40	4.87	4.87	0.9996	0.99946	60.13	60.14	60.133
50.1	223	190	26.15	25.94	0.99952	0.9994	197.06	197.09	197.07
50.2	223	120	26.15	26.09	0.99936	0.99943	196.91	196.91	196.9
50.3	223	45	26.15	26.15	0.99936	0.99956	196.85	196.85	196.83
51.1	200	170	17.3	17.83	1.0011	0.99948	182.17	182.45	182.41
51.2	200	95	17.3	17.3	0.99941	0.99954	182.7	182.71	182.68
52.1	221	195	30.79	30.4	0.99952	0.99942	190.6	190.63	190.61
52.2	221	97	30.79	30.79	0.99954	0.99943	190.21	190.23	190.21

NOTES:

(1) Median density across screened interval from processed log profiles except for wells screened in bedrock (DEPTH TO SCREEN > DEPTH TO BR) where density is calculated from chloride concentration reported by Whittemore (1993).

(2) Average density calculated between water table and smaller of screen and bedrock depths.

(3) Bedrock depth used for datum at each site.

(4) Depth to bedrock changed from 117 ft based on inspection of conductivity log.

Table B3 part 2.
Variable-density head corrections for monitoring well sites in the northern and selected sites in the southern Mineral Intrusion study area (1994).

SITE.well no.	DEPTH TO BEDROCK	DEPTH TO SCREEN	DEPTH TO WATER TABLE	DEPTH TO WATER	DENSITY AT SCREEN (1)	AVERAGE DENSITY (2)	POINT-WATER HEAD (3)	FRESH-WATER HEAD	ENVIRONMENTAL-WATER HEAD
1.1	146	146	6.35	6	1.0171	1.0052	140	142.49	141.59
1.2	146	106	6.35	6.51	1.0036	0.99973	139.49	139.92	139.87
1.3	146	36	6.35	6.35	0.99936	0.99945	139.65	139.65	139.65
	186	197	11.3	18.4	1.0352	1.0055	174.7	181.36	180.22
3.1	130	120	20.54	23.31	1.0117	0.99971	106.69	107.89	107.83
3.2	130	65	20.54	20.54	0.99939	0.99941	109.46	109.46	109.46
4.1	129	217	7.87	5.54	1.041	1.0017	123.46	132.28	131.74
4.2	129	106	7.87	3.16	1.0012	1.0015	125.84	126.03	125.78
4.3	129	53	7.87	7.87	1.001	1.0011	121.13	121.21	121.1
5.1	181	193	2.08	1.53	1.0547	1.0222	179.47	190.08	185.62
5.2	181	92	2.08	3.6	1.028	1.0017	177.4	179.94	179.71
5.3	181	40	2.08	2.08	0.99936	0.99955	178.92	178.92	178.91
8.1	118.3 (4)	237	11.1	23.52	1.0582	1.0003	94.78	107.36	107.12
8.2	118.3 (4)	116	11.1	17.19	1.0032	1.0002	101.11	101.49	101.38
8.3	118.3 (4)	87	11.1	16.86	0.99999	1.0003	101.44	101.49	101.39
8.4	118.3 (4)	46	11.1	11.1	0.99998	0.99955	107.2	107.22	107.21
9.1	87	86	9.36	9.34	1.0037	1.0029	77.66	77.998	77.656
9.2	87	62	9.36	9.2	1.0013	1.0003	77.8	77.905	77.834
9.3	87	38	9.36	9.36	0.99936	0.99944	77.64	77.641	77.635
10.1	156	160	13.75	20.4	1.0016	1.0001	135.6	135.92	135.79
10.2	156	143	13.75	20.16	1.0012	0.99995	135.84	136.07	135.97
10.3	156	100	13.75	18.12	1.0003	0.99959	137.88	137.96	137.93
10.4	156	74	13.75	13.75	0.99956	0.99942	142.25	142.27	142.26
11.1	208	237	11.39	29.37	1.0329	1.0048	178.63	185.61	184.25
11.2	208	61	11.39	11.39	1.0003	1.0003	196.61	196.66	196.59
16.1	220	243	7.64	20.85	1.0461	1.0098	199.15	209.55	206.92
16.2	220	198	7.64	14.93	1.0445	1.0063	205.07	213.35	211.91
16.3	220	80	7.64	7.64	0.99936	0.99982	212.36	212.36	212.32
17.1	114	129	10.54	44.06	1.0126	1.0026	69.94	71.069	70.603
17.2	114	102	10.54	9.91	1.0106	1.002	104.09	105.13	104.83
17.3	114	41	10.54	10.54	0.99936	0.99954	103.46	103.46	103.45
18.1	214	231	11.02	26.44	1.0157	1.005	187.56	190.92	189.54
18.2	214	197	11.02	26.97	1.0192	1.0038	187.03	190.41	189.48
18.3	214	45	11.02	11.02	0.99957	0.99954	202.98	202.99	202.98

21.1	137	145	23.07	26.04	1.015	1.0019	110.96	112.83	112.4
21.2	137	113	23.07	23.93	1.0042	1.0004	113.07	113.51	113.36
21.3	137	43	23.07	23.07	0.99999	1.0008	113.93	113.94	113.85
22.1	215	231	12.71	24.57	1.043	1.0047	190.43	199.46	198.14
22.2	215	206	12.71	20.11	1.0305	1.0035	194.89	200.69	199.77
22.3	215	35	12.71	12.71	0.99936	0.99936	202.29	202.29	202.29
23.1	94	122	22.4	23.93	1.008	1.0001	70.07	70.925	70.814
23.2	94	79	22.4	21.95	1.0006	0.99969	72.05	72.124	72.085
23.3	94	44	22.4	22.4	0.99939	0.99942	71.6	71.602	71.594
24.1	123	131	23.9	25.94	1.0018	1.0028	97.06	97.317	96.778
24.2	123	86	23.9	24.15	0.99991	1.0036	98.85	98.887	98.415
25.1	98	120	6.02	11.8	1.0227	1.0187	86.2	88.733	86.292
25.2	98	95	6.02	12.64	1.0318	1.0182	85.36	88.038	86.128
25.3	98	44	6.02	6.02	1.0267	1.0121	91.98	93.021	92.381
26.1	177	190	8.76	16.72	1.0174	1.0075	160.28	163.42	161.79
26.2	177	118	8.76	12.61	1.0166	1.0042	164.39	166.21	165.59
26.3	177	60	8.76	8.76	0.99994	0.99983	168.24	168.27	168.24
27.1	104	115	11.22	11.52	1.0018	1.0009	92.48	92.736	92.538
27.2	104	60	11.22	11.05	1.0008	1.0004	92.95	93.023	92.945
27.3	104	30	11.22	11.22	1.0002	1.0013	92.78	92.797	92.715
30.1	138	155	17.19	18.59	1.0026	0.99984	119.41	119.85	119.76
30.2	138	123	17.19	17.15	1.0002	0.99976	120.85	120.94	120.88
30.3	138	60	17.19	17.19	0.99937	0.99974	120.81	120.81	120.78
31.1	93	108	15.06	14.3	1.0017	0.99992	78.7	78.923	78.848
31.2	93	85	15.06	14.6	1.0004	0.99988	78.4	78.477	78.42
31.3	93	55	15.06	15.06	0.99998	0.9994	77.94	77.967	77.96
32.1	172	189	9.1	48.64	1.0018	1.0015	123.36	123.71	123.29
32.2	172	161	9.1	47.87	1.0023	1.0014	124.13	124.47	124.11
32.3	172	113	9.1	4.95	1.0026	1.0006	167.05	167.41	167.25
32.4	172	78	9.1	9.1	1.0003	0.99981	162.9	162.97	162.92
36.1	195	210	27.84	28.43	1.0286	1.0028	166.57	171.9	171.07
36.2	195	191	27.84	27.65	1.0193	1.0024	167.35	170.62	169.94
36.3	195	146	27.84	24.83	1.0026	1.0001	170.17	170.57	170.43
36.4	195	85	27.84	27.84	1.0001	0.99971	167.16	167.21	167.16
37.1	240	255	57.1	59.09	1.0024	0.99999	180.91	181.52	181.31
37.2	240	235	57.1		1.0022	0.99993			
37.3	240	151	57.1	57.53	0.99944	0.99971	182.47	182.48	182.4
37.4	240	82	57.1	57.1	0.99944	0.99984	182.9	182.9	182.83
42.1	160	178	13.01	18.48	1.0059	1.0007	141.52	142.57	142.31
42.2	160	157	13.01	17.61	1.0039	1.0006	142.39	143.03	142.81
42.3	160	103	13.01	13.01	1.0006	0.99947	146.99	147.11	147.09

43.1	65	88	5.14	5.19	1.0023	1.0011	59.81	60.055	59.885
43.2	65	40	5.14	5.14	0.99955	0.99979	59.86	59.868	59.847
50.1	223	190	22.34	22.2	0.99952	0.99943	200.8	200.84	
50.2	223	120	22.34	22.29	0.99936	0.99946	200.71	200.71	200.69
50.3	223	45	22.34	22.34	0.99936	0.99956	200.66	200.66	200.64
51.1	200	170	13.68	14.17	1.0011	0.99948	185.83	186.11	186.08
51.2	200	95	13.68	13.68	0.99941	0.99954	186.32	186.33	186.3
52.1	221	195	23.67	28.83	0.99952	0.99942	192.17	192.2	192.18
52.2	221	97	23.67	23.67	0.9995	0.99945	197.33	197.34	197.33

NOTES:

(1) Median density across screened interval from processed log profiles except for wells screened in bedrock (DEPTH TO SCREEN > DEPTH TO BR) where density is calculated from chloride concentration reported by Whittemore (1993).

(2) Average density calculated between water table and smaller of screen and bedrock depths.

(3) Bedrock depth used for datum at each site.

(4) Depth to bedrock changed from 117 ft based on inspection of conductivity log.

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