Permian Potentiometric Analysis

J. L. Devary

September 1983

Prepared for
the U.S. Department of Energy
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Pacific Northwest Laboratory
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EXECUTIVE SUMMARY

Pacific Northwest Laboratory (PNL) was requested by the Office of Nuclear Waste Isolation (ONWI) to analyze potentiometric data from the Wolfcamp Formation of the Permian System to evaluate the recommendations by the University of Texas/Bureau of Economic Geology (UT/BEG) that additional geohydrologic boreholes be drilled into the Wolfcamp. The UT/BEG recommended that two stratigraphic and two geohydrologic borings be drilled into the Permian System during FY83 and that several shallow hydrologic tests be made in the Dockum Formation. At PNL, we applied the geostatistical technique known as kriging to objectively evaluate the UT/BEG Wolfcamp geohydrologic borehole recommendations.

The results of our evaluation are:

- The Deaf Smith County location appears to be an excellent choice for a borehole. No high quality potentiometric data are available from Deaf Smith County and a borehole location immediately upgradient from the candidate repository site is needed. Adding this borehole location to the potentiometric data base will significantly reduce field data uncertainty near the location being studied. Also, a simulated head value 300 ft higher than predicted at the borehole location resulted in a 29% increase in hydraulic gradient along the flow path to the Amarillo Uplift. Thus, a potentiometric value at this Deaf Smith County borehole location could significantly affect contaminant travel time predictions to the Amarillo Uplift.
- The Swisher County location does not appear to be the best choice. High quality data values H2206 and H2360 are located immediately upgradient from the proposed repository site. The standard deviation of the estimation error did not decrease significantly by adding this location to the potentiometric data base. Similarly, we observed no significant difference in head value at the location under investigation when the Swisher County borehole value was simulated 300 ft higher than predicted.

- The best placement of additional geohydrological boreholes in the Wolfcamp Formation depends strongly upon the proposed repository location. The variability of the potentiometric data causes estimation errors to rapidly increase away from locations of field measurements. For this reason additional boreholes must be located near the proposed repository location and along the travel paths to the Amarillo Uplift. This conclusion is supported by the recent sensitivity-adjoint work by INTERA (Andrews et al. 1982) involving ground-water modeling of the Palo Duro Basin. Suggested locations for additional boreholes for the Deaf Smith investigations (besides the proposed location) are in northwest Randall or central Potter Counties. Ideal borehole locations for the Swisher County studies appear to be in southeast Randall and Armstrong Counties.

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INTRODUCTION

The University of Texas/Bureau of Economic Geology (UT/BEG) has recommended that two stratigraphic and two geohydrologic borings be placed in the Permian System during FY83 and that several shallow hydrologic tests be made in the Dockum Formation.^(a) Pacific Northwest Laboratory (PNL) was selected by the Office of Nuclear Waste Isolation (ONWI) to analyze potentiometric data from the Wolfcamp formation of the Permian System to evaluate these recommendations. This report satisfies the "Permian potentiometric analysis" milestone of the ONWI Geostatistics Program at PNL.

At PNL, we applied geostatistical data analysis techniques (kriging) to determine whether additional boreholes in Deaf Smith and Swisher Counties will provide a statistically significant amount of additional information. Kriging is a statistical interpolation technique that may be used to estimate a potentiometric surface from irregularly spaced field measurements. The optimal statistical properties of kriging (unbiased, minimum variance) ensures that the maximum amount of information is extracted from the expensive field data. Kriging also allows us to statistically quantify the estimation or interpolation error. This permits us to:

- identify the need for additional field measurements
- select the best borehole locations
- establish data validity
- evaluate measurement error.

We begin this report with an introduction to the Wolfcamp potentiometric data base. This is followed by a discussion of the methods we used in our kriging analysis. Finally, we evaluate the recommended UT/BEG well locations.

(a) This recommendation was made in a letter report, dated October 14, 1982, from E. G. Wermund to Maxwell Blanchard of the Department of Energy, National Waste Terminal Storage (NWTs) Program.

WOLFCAMP POTENTIOMETRIC DATA BASE

The potentiometric data base for the Wolfcamp Formation was received from UT/BEG late in FY82 by the Assessment and Evaluation of Geologic Isolation Systems (AEGIS) Program of PNL. The data base consists of 274 fluid potential measurements derived from two sources:

- analysis of Horner plots generated from transient pressures changes in drill stem tests (DST).
- pressure data from the Texas Petroleum Institute files.

The Horner analysis values are considered to be the most accurate. The pressure data from the Texas Petroleum Institute are sorted into a hierarchy of reliability levels, based on the criteria below:

- Class A head values are derived from drill stem tests where two shut-in periods were recorded for the test and the two final shut-in pressures agreed within 10%.
- Class B head values are derived from drill stem tests where two shut-in periods were recorded for the test and the two final shut-in pressures did not agree within 10%. (In both Class A and Class B the higher pressure was used to calculate heads.)
- Class C head values are derived from drill stem tests where a single shut-in pressure was recorded for the test. As such, we cannot estimate the accuracy of the head value.

Figure 1 contains a plot of the borehole locations for the Wolfcamp potentiometric data base; a complete listing of the data may be found in Appendix A. Figure 2 is a hand-drawn contour plot corresponding to the UT/BEG interpretation of the Wolfcamp potentiometric data.

As discussed in the INTERA draft report Status Report on Regional Groundwater Flow Modeling for the Palo Duro Basin, Texas (Andrews et al. 1982), the travel path for a particle released into the Wolfcamp Formation, whether from a repository in east-central Deaf Smith County or in north-central Swisher County, is toward the Amarillo Uplift; the

FIGURE 1. Borehole Locations for the UT/BEG Wolfcamp Potentiometric Data Base

FIGURE 2. UT/BEG Interpretation of the Wolfcamp Potentiometric Surface

particle presumably continues to the southeast, following the trend of the Amarillo-Arbuckle Uplift.

The travel time for a particle released into the Wolfcamp Formation from a Deaf Smith repository location to the Panhandle gas and oil field is approximately 4.4 million years (see Figure 3). (The head drop is approximately 2000 - 1500 ft = 213.4 m; hydraulic conductivity is approximately 8.0×10^{-4} m/d; effective porosity is approximately 0.05; travel path length is approximately 74 km.) The travel time for a particle released into the Wolfcamp Formation from a Swisher County repository location would be slightly longer. For this reason we used only the 67 potentiometric data values located southwest of the Amarillo Uplift for our kriging analyses (see Figure 4 and Table 1). The notation used in Figure 4 corresponds to data quality (H=Horner values; A=Class A; B=Class B; C=Class C) and to potentiometric value (feet); for example, H3597 is a Horner plot head value of 3597 ft.

FIGURE 3. Approximate Travel Path from Deaf Smith Country Repository to Amarillo Uplift

FIGURE 4. Wolfcamp Potentiometric Data Base
Southwest of the Amarillo Uplift

TABLE 1. Wolfcampian Potentiometric Data Base
Southwest of Amarillo Uplift

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
34.21860	100.45560	1897	H
34.77000	100.68000	1754	H
35.08000	100.81000	1388	H
34.20000	101.16000	3597	H
34.30365	101.31422	2081	H
34.19000	101.91000	2461	H
34.65000	100.86000	1830	H
35.96110	102.42263	3007	H
35.94876	102.19234	1796	H
33.83720	102.31580	2510	H
34.09330	100.99030	1947	H
35.59620	102.65120	1908	H
35.40704	102.34653	1741	H
35.42839	101.62508	1486	H
34.55616	101.90129	2360	H
34.34615	101.33902	2964	H
35.25780	101.24310	1501	H
34.51754	102.32644	2483	H
34.72496	102.48156	2505	H
34.64046	102.02041	2200	H
34.59698	100.09479	1781	H
35.14560	102.31091	739	C
35.16563	102.35189	2746	C
33.84300	102.04130	2730	A
33.91380	101.93360	2998	C
35.28256	102.34347	1267	A
35.35332	102.34273	2133	C
35.24830	102.60463	2382	A
35.27396	102.22845	1452	C
35.27015	102.26120	1630	C
35.51130	102.52788	1900	A
35.51189	102.34523	1455	C
35.33622	102.20307	2131	C
35.40461	102.36758	979	C
35.24871	101.86406	1542	A
35.33357	102.12674	1765	A
35.43167	101.83738	1415	C
35.25933	101.87799	1784	C
35.31056	101.85981	1619	A
35.41645	102.08286	1629	C
35.37728	102.11787	1674	C
34.89558	101.84147	1994	C
34.86696	102.10664	2088	C

TABLE 1. Continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
34.98288	101.63751	1252	C
35.05146	101.88579	2048	C
34.97224	102.14690	2004	A
35.03562	101.14980	1186	C
35.13255	101.35767	1387	B
35.12109	101.41995	1647	B
35.21572	101.42065	1866	C
35.20928	101.51457	1294	C
35.40112	101.61410	1615	B
35.24985	101.41474	1451	B
34.63043	102.15479	1511	C
35.90354	102.58322	1572	A
35.97172	102.18989	1395	A
35.97407	102.22813	1559	B
35.98628	102.22638	1616	A
36.01475	102.76378	3378	A
35.90699	102.40475	3353	C
35.73935	102.68905	1500	C
35.65638	102.68798	1351	C
33.96830	100.43250	1811	A
34.21551	100.29468	1472	A
34.78633	100.74778	1651	A
33.91190	100.78890	1871	A
33.93250	100.55040	1733	A

KRIGING ANALYSIS-BEST FIT POTENTIOMETRIC SURFACE

As mentioned before, kriging is a statistically based interpolator of irregularly spaced data. To krig an estimate of potentiometric head at a particular location where no field measurement is available, the following steps are required:

1. Select the nearest boreholes (with data) for the location to be estimated; typically, between eight and sixteen neighboring boreholes are used in the interpolation procedure.
2. Determine the weights (i.e., the kriging weights) to be used for the averaging process; the kriging weights depend on the drift (overall trend) of the data and the covariance (variogram or generalized covariance) that corresponds to data fluctuations superimposed on the drift.
3. Derive the estimate of potentiometric head by calculating a weighted average of the nearest neighbor values using the kriging weights; the variance and standard deviation corresponding to the estimation error are calculated by using the kriging weights and covariance.

For potentiometric data without evidence of large sources or sinks, the drift is generally constant or is a linear function of the spatial coordinates. The generalized covariance is generally a linear function with a 'nugget' effect, that is,

$$C_1 \delta(h) + C_2 |h| \quad (1)$$

where h is the distance between two boreholes, $\delta(h)$ is the 'Dirac-delta' function [$\delta(h) = 0$ if $h \neq 0$, $\delta(0) = 1$], and C_1, C_2 are non-negative values. The Dirac-delta or 'nugget' component stems from a measurement error that may be caused by instrument problems or incorrectly surveyed data locations. A full discussion of kriging theory, including drift and generalized covariance estimation may be found in Chiles 1977; Delfiner -- 1975; Delfiner and Chiles 1978; Delhomme 1976; Gambolati and Volpi 1979; Gelb 1974; Matheron 1965, 1967, 1969, 1973; Mejia 1974; Olea 1975; Volpi and Gambolatti 1978; and Devary and Doctor 1982.

We screened the 67 potentiometric values (listed in Table 1) for data validity by calculating a kriging estimate of potentiometric head for each observed data value. The eight nearest neighbors (excluding the observed data value itself) with no drift and a linear generalized covariance (Equation 1 without 'nugget') were used. The true potentiometric head surface is continuous by definition and, therefore, a discontinuous nugget term is not physically realistic. In this way the observed potentiometric value could be compared to the predicted potentiometric value to reveal inconsistencies in the data base. The following potentiometric data values were deleted from the 67-element data base. The H and A data were not scrutinized as closely as the less accurate B and C data; for this reason a significant number of C-values were deleted.

- H3597 -- the only H-value deleted; predicted minus observed equals -1587 ft
- B1267 -- predicted minus observed equals 834 ft
- C739 -- predicted minus observed equals 1762 ft
- C2998 -- predicted minus observed equals -303 ft;
H2510, H2730, H2461 are reliable neighbor values
- C2133 -- predicted minus observed equals -708 ft
- C1452, C1630, C1455 -- predicted minus observed equals 218, -181, 225 ft; H1741, A1542, B1765, and B1619 are more reliable neighbor values
- C2131 -- predicted minus observed equals -708 ft
- C979 -- predicted minus observed equals 790 ft
- C1252 -- predicted minus observed equals 731 ft
- C1866 -- predicted minus observed equals -424 ft
- C1294 -- predicted minus observed equals 425 ft
- C1511 -- predicted minus observed equals 807 ft
- C3353 -- predicted minus observed equals -914 ft

- C1351 -- predicted minus observed equals 384 ft
- C1186 - predicted minus observed equals 271 ft;
H1500, H1388, A1651 are reliable neighbor values.

The resulting data base of 50 values (Figure 5) was used to generate a first kriged potentiometric surface (Figure 6). The kriged estimates were generated by using a linear generalized covariance (Equation 1 without 'nugget'), no drift, and eight neighboring values. Notice that the potentiometric contours have a ragged, rough character corresponding to the presence of significant measurement error in the Wolfcamp data. A generalized covariance analysis on the 50-element data base of Figure 5 found the following best-fit generalized covariance:

$$8130 \delta(h) - 1789|h| \quad (2)$$

where the distance between boreholes (h) is measured in miles. Equation (2) corresponds to a measurement error of ± 90 ft, entirely within the error-band of the Permian drill-stem testing program.

To remove this significant measurement error we used a geostatistical technique known as 'block-average' kriging. Block-average kriging involves estimating the average value of potentiometric head over a square block (e.g., 1 mile by 1 mile block) rather than of just a point value. Block-average kriging requires the drift, generalized covariance, and the neighboring values to calculate a weighted average estimate; the only difference between block-average and point kriging is that an integrated covariance is used in the load vector of the kriging equations to determine the block-average kriging weights.

A sequence of block-average head values were kriged (5-10 mi block widths) to select the block width that removed the ± 90 ft measurement error, yet did not overly smooth the data. Kriging 5 mile by 5 mile square blocks centered at each observed data value produced a more regular data base resulting in a physically realistic potentiometric surface without evidence of measurement error. A generalized covariance analysis

FIGURE 5. The Final Wolfcamp Potentiometric Data Base Used in the Kriging Analysis

FIGURE 6. First Kriged Potentiometric Surface with Evidence of Significant Measurement Error

using the 5 mile by 5 mile block-average data of Table 2 revealed a best-fit generalized covariance:

$$- 1766|h| \quad (3)$$

Notice that the lack of measurement error 'nugget' and the coefficient on the linear term is not too different from that of Equation (2) -- (-1766 vs. -1789). This established that the 5 mile by 5 mile block-average effectively removed the ± 90 -ft measurement error without oversmoothing the original data. The generalized covariance analysis also revealed that H2081, H3007, H2964, A1572, and A3378, all of which are data values near the Matador Arch or the Oldham Nose, were statistically significant outliers (i.e., the predicted minus observed potentiometric values were over 2.5 X sigma larger than expected). Future analyses involving the Wolfcamp data will have to resolve this unacceptable data variability near these two regions.

TABLE 2. Original and Block-Averaged Wolfcamp Potentiometric Values

Original Potentiometric Value (ft)	5 mi x 5 mi Block Average Potentiometric Value (ft)	Difference (ft)	Comments
1897	1858	39	
1754	1730	24	
1388	1402	-14	
2081	2283	-202	- - - located near Matador Arch
2461	2468	-7	
1830	1838	-8	
3007	2793	214	- - - located near Oldham Nose
1796	1660	136	- - - located near Oldham Nose
2510	2524	-14	
1947	1946	1	
1908	1883	25	
1741	1778	-37	
1486	1516	-30	
2360	2345	15	
2964	2730	234	- - - located near Matador Arch
1501	1484	17	
2483	2480	3	
2505	2495	10	
2206	2221	-15	
2730	2705	25	
1572	1768	-196	- - - located near Oldham Nose
1395	1581	-186	- - - located near Oldham Nose
1616	1676	-60	
3378	3255	123	- - - located near Oldham Nose
2382	2384	-2	
1900	1894	6	
1542	1646	-104	- - - located in Potter County
2004	2043	-39	
1559	1694	-135	- - - located near Oldham Nose
1765	1779	-14	
1619	1623	-4	
1387	1450	-63	- - - located in Armstrong County
1647	1598	49	
1615	1561	54	- - - located in Carson County
1451	1470	-19	
1811	1791	20	
1472	1516	-44	
1651	1670	-19	
1871	1866	5	
1733	1753	-20	
2746	2657	89	- - - located in Deaf Smith County
1500	1579	-79	- - - located near Oldham Nose
1415	1443	-28	
1784	1688	96	- - - located in Potter County
1629	1633	-4	
1674	1687	-13	
1994	2008	-14	
2088	2085	3	
2048	2014	34	

Table 2 contains a list of the original potentiometric values, the block-averaged potentiometric values, and the difference between the two quantities. Notice that the largest differences (greater than 50 ft) between the original and block-average values occur in regions near the Matador Arch and the Oldham Nose. These regions contain potentiometric data with high variability (e.g., H2964 and H2081 near the Matador Arch, and H3007 and A1572 near the Oldham Nose).

Figure 7 contains a plot of the kriged potentiometric surface using the 5 mile by 5 mile block-average data, no drift, a linear generalized covariance (Equation 1 without 'nugget'), and eight neighboring points. Notice that this potentiometric surface is quite smooth and regular and is generally similar to the UT/BEG surface (Figure 2). The major differences between this kriged surface and the UT/BEG surface are:

FIGURE 7. Kriged Potentiometric Surface Using 5 mi x 5 mi Block-Average Data

- Our inclusion of C2746 in Deaf Smith County causes a high gradient in NE Deaf Smith County; UT/BEG does not include C2746 in their interpretation of the potentiometric surface.
- UT/BEG includes C1252 to produce an 1800-ft contour through central Randall County; we have deleted C1252 as being erroneous.
- The extreme variability of the potentiometric data near Matador Arch and Oldham Nose precludes kriging the symmetric contours as seen on the UT/BEG surface; this variability does not appear to adversely affect the kriged potentiometric contours in the vicinity of the flow paths from east-central Deaf Smith or north-central Swisher Counties to the Amarillo Uplift.

EVALUATION OF THE UT/BEG WELL LOCATIONS

The 5 mile by 5 mile block-average interpretation of the potentiometric data will serve as the basis for our evaluation of UT/BEG's borehole recommendations. The borehole locations that UT/BEG have recommended to NWTS are indicated in Figure 8.

Figure 9 contains a plot of the best-fit kriged potentiometric surface without C2746, using the 5 mile by 5 mile block-average data, no drift, and generalized covariance, given by

$$-1766|h| \quad (3)$$

and eight neighboring points. Approximate travel paths from Deaf Smith and Swisher County repository locations are also indicated on Figure 9. The C2746 data value was not used in the borehole evaluation because it was judged to be unreliable and not used in the UT/BEG interpretation of the potentiometric surface (Figure 2) and was also found to be a statistical outlier at the 1.46 x sigma level of significance in the generalized covariance analysis.

Figure 10 contains a contour plot of the standard deviation surface for the kriging error, using the 5 mile by 5 mile block-average data without the two additional UT/BEG boreholes. Notice that the standard deviation is approximately 140 ft at the Deaf Smith County repository location and approximately 120 ft at the Swisher County location.

Figure 11 contains a contour plot of the kriging error standard deviation using the 5 mile by 5 mile block-average data including the two additional UT/BEG boreholes. As expected, the standard deviations decrease substantially at the proposed borehole locations. The standard deviation at the Deaf Smith repository location has dropped to 120 ft, whereas the standard deviation at the Swisher location has remained unchanged at approximately 120 ft. This shows that the Swisher County borehole location, as recommended by UT/BEG, has not significantly reduced the field data uncertainty near the Swisher County repository

FIGURE 8. UT/BEG Wolfcamp Geohydrologic Borehole Location Recommendations

FIGURE 9. Best-Fit Potentiometric Surface Using 5 mi x 5 mi Block-Average Data Without C2746

R - APPROXIMATE REPOSITORY LOCATION

FIGURE 10. Kriging Error Standard Deviation Plot Without Two UT/BEG Boreholes

B - BOREHOLE LOCATION
R - APPROXIMATE REPOSITORY LOCATION

FIGURE 11. Kriging Error Standard Deviation Plot With Two UT/BEG Boreholes

location. The Deaf Smith County borehole location appears to be an excellent choice because the kriging error standard deviation is reduced approximately 20 ft at the repository site.

To further investigate the UT/BEG recommendations, we purposely simulated high potentiometric values for the two proposed borehole locations and added these to the Wolfcamp data base. Figure 12 contains a plot of the kriged surface using the 5 mile by 5 mile block-average data, plus a 2750-ft simulated head value at the Deaf Smith borehole location. (2750 ft is 300 ft (approximately $3 \times \sigma$) higher than predicted.) The Deaf Smith County repository potentiometric value increased 200 ft (compare to Figure 9), resulting in approximately a 29% increase in hydraulic gradient from Deaf Smith County to the southwestern border of the Amarillo Uplift. This corresponds to a 22% reduction in travel time.

Figure 13 contains a plot of the kriged surface using the 5 mile by 5 mile block-average data, plus a 2725-ft simulated head value at the Swisher County borehole (approximately 300 ft higher than expected). The Swisher County repository location potentiometric value does not change appreciably and does not cause any significant change in the flow path or travel time. Thus, the Swisher County borehole location does not appear to be able to add a significant amount of information to the Wolfcamp data base.

B - BOREHOLE LOCATION
R - APPROXIMATE REPOSITORY LOCATION

FIGURE 12. Kriged Potentiometric Surface with 2750 ft Head Value at Deaf Smith Borehole

B - BOREHOLE LOCATION
R - APPROXIMATE REPOSITORY LOCATION

FIGURE 13. Kriged Potentiometric Surface with 2725 ft Head Value at Swisher County Borehole

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APPENDIX A

WOLFCAMPIAN POTENTIOMETRIC DATA BASE

APPENDIX A

Wolfcampian Potentiometric Data Base

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
34.21860	100.45560	1897	H
33.96830	100.43250	1811	A
34.21551	100.29468	1472	A
36.20173	102.37371	1571	C
36.30941	102.72216	2528	C
36.40867	102.30734	2282	C
36.45301	102.26688	2686	C
36.41433	102.18723	1443	C
36.40859	102.30755	2282	C
35.14560	102.31091	759	C
35.16563	102.35189	2746	C
34.78633	100.74778	1651	A
34.77000	100.68000	1754	H
35.08000	100.81000	1388	H
34.20000	101.16000	3597	H
34.30365	101.31422	2081	H
35.50600	100.62403	1140	A
35.59541	100.54465	1123	A
35.57972	100.67169	1220	C
35.59560	100.61391	1130	C
35.49065	100.69738	1695	C
33.84300	102.04130	2730	A
34.19000	101.91000	2461	H
33.91380	101.93360	2998	C
34.65000	100.66000	1850	H
34.49970	100.66636	1762	C
36.13098	101.43086	1306	C
36.36296	101.54537	1675	C
36.21361	101.51638	1813	A
36.30430	101.31719	1091	C
36.35241	101.19113	1380	C
36.12373	101.52121	1055	C
36.49331	101.42595	1419	C
36.44683	101.28144	1139	C
36.23206	101.08919	1196	C
36.42341	101.11976	1185	C
36.47434	101.15192	1072	C
36.12380	101.54384	1179	A
36.30458	101.21312	1319	C
36.07010	101.42019	1734	C
36.10403	101.31078	1199	A
36.11195	101.47715	1301	C

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
36.14223	101.53634	1092	A
36.47095	101.50908	1312	A
36.42593	101.23300	1228	C
36.23599	101.58020	1183	A
36.36712	101.19170	1410	C
36.29638	101.42740	1017	C
36.23584	101.58023	1183	A
36.44209	101.56237	1617	A
36.31615	101.12617	1152	C
36.33019	101.13055	1198	C
36.35497	101.14577	478	C
36.37937	101.12147	1503	C
36.36627	101.17430	805	C
36.31993	101.10810	952	C
35.96110	102.42263	3007	H
35.90354	102.58322	1572	A
35.97172	102.18989	1395	A
35.97407	102.22813	1559	B
35.98828	102.22638	1616	A
35.94876	102.19234	1796	H
36.01475	102.76378	3378	A
35.90699	102.40475	3353	C
35.73935	102.68903	1500	C
35.65638	102.68798	1351	C
35.70782	100.52085	1447	A
35.94101	100.18481	1620	A
35.68630	100.53277	1873	B
35.81056	100.46089	1591	B
35.72306	100.50789	1104	C
35.91894	100.09302	620	C
35.72980	100.44110	1335	A
35.82124	100.52258	1066	C
35.76875	100.46840	1109	C
35.84302	100.20508	950	C
35.90938	100.40805	1627	B
35.68703	101.18255	602	H
35.93967	101.43995	926	A
36.03431	101.30324	1316	C
35.66456	101.46030	986	C
36.03924	101.28730	1334	C
36.02981	101.28515	1345	C
35.99869	101.25892	1010	A
35.89259	101.22464	1350	C
35.70788	101.20885	803	C
33.83720	102.31580	2510	H

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
36.23574	100.53683	1404	A
36.12479	100.33630	1443	A
36.35863	100.09761	1155	C
36.41643	100.09268	1236	C
36.43108	100.07940	1402	C
36.29325	100.21100	1349	C
36.46316	100.29490	1145	C
36.42428	100.53675	1288	B
36.27798	100.12632	2432	C
36.28644	100.51442	1028	C
36.13590	100.30514	1613	C
36.19241	100.51854	1629	C
35.94563	102.07782	1585	C
36.00387	102.07686	1407	C
36.00389	102.07670	1408	C
34.09330	100.99030	1947	H
33.91190	100.78890	1871	A
33.93250	100.55040	1733	A
36.29173	100.66968	1466	A
36.44604	100.72896	1281	A
36.06897	100.92565	1105	C
36.37326	100.94089	1329	C
36.10752	100.66398	1422	C
36.49225	100.84834	1026	C
36.43481	101.05909	1579	A
36.14056	100.94366	918	C
36.10207	100.64020	1219	C
36.13383	100.77241	1081	C
36.32857	100.97869	1286	C
36.06856	100.92570	1105	C
35.59620	102.65120	1908	H
35.28256	102.34347	1267	B
35.40704	102.34653	1741	H
35.35332	102.34273	2133	C
35.24830	102.60463	2382	A
35.27396	102.22845	1452	C
35.27015	102.26120	1630	C
35.51130	102.52784	1900	A
35.51189	102.34523	1455	C
35.33622	102.20307	2131	C
35.40461	102.36758	979	C
35.24671	101.86406	1542	A
35.42839	101.62503	1486	H
35.33357	102.12674	1765	B
35.43167	101.83738	1415	C

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
35.25933	101.87799	1784	C
35.31056	101.85981	1619	C
35.41645	102.08286	1629	C
35.37728	102.11787	1674	C
34.89558	101.84147	1994	C
34.86696	102.10564	2088	C
34.98288	101.83751	1252	C
35.05146	101.88579	2048	C
34.97224	102.14690	2004	A
35.84572	100.78090	1279	C
35.90490	100.78810	1052	C
35.85372	100.60314	1123	A
35.77228	100.59352	1334	C
35.63888	101.02202	1322	A
35.76906	100.75344	1422	A
36.05313	100.95012	1292	A
35.88884	100.98886	1431	A
35.91126	100.76565	1388	A
35.64800	100.59454	1207	A
35.79111	100.94927	1103	A
35.89489	100.69373	1408	A
35.99244	100.77795	1377	A
35.74036	100.56653	1153	A
35.74315	100.73807	1057	A
35.76507	100.70031	1107	A
36.02738	100.92320	1305	A
36.05457	100.93844	1570	A
36.03046	100.62776	1427	A
35.84637	100.58092	1365	A
35.68570	100.75593	1230	C
35.68204	100.75585	1263	C
35.70779	100.80292	1035	C
35.69108	100.72300	1315	C
36.00489	101.05182	1144	C
36.01953	101.05148	954	C
35.77899	100.71185	1237	A
35.83950	100.54430	977	C
35.81252	100.84708	1024	C
36.05245	100.85357	1090	A
35.80955	100.65651	1223	A
35.94050	100.74283	1532	A
36.05167	100.76126	1440	A
35.68397	100.71322	849	C
35.70648	100.73961	1127	C
35.92192	100.85609	1174	C

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
35.64673	100.70708	1067	C
35.63706	100.68896	1042	C
35.67855	100.73981	1008	C
36.00867	100.80482	1454	C
35.70869	100.77161	1314	C
35.90159	100.70100	922	C
35.72922	100.81122	1328	C
35.72562	100.81120	1289	C
35.68739	100.72274	1322	C
35.68794	100.71351	708	C
35.68572	100.74023	1301	C
35.68030	100.73130	1065	C
35.69104	100.73568	998	C
35.69100	100.73140	1318	C
35.68822	100.78384	1499	C
35.69478	100.73152	1280	C
35.68337	100.73998	1309	C
35.68920	100.75585	1516	C
35.69268	100.75160	1419	C
35.84919	100.77291	1285	C
35.93629	100.85652	1693	C
35.70575	100.74485	1340	C
35.68062	100.74273	1540	C
35.87394	100.80325	542	C
35.67860	100.71366	999	C
35.78465	101.04260	1090	C
35.68278	100.56618	800	C
35.64495	100.72252	601	C
35.70752	100.76026	960	C
35.69471	100.76017	1241	C
35.71137	100.82478	1511	C
35.71716	100.78842	1349	C
35.73652	100.61587	1698	C
35.71123	100.80341	1846	C
35.93207	100.89613	1429	A
35.88194	100.84698	1263	A
35.64867	100.84398	983	A
35.85723	100.60190	1278	A
35.73658	100.81594	1418	C
35.83584	100.80053	1100	C
35.88614	100.80667	985	C
35.69628	100.68595	731	C
35.68264	100.70459	1044	C
35.83892	100.65179	1350	C
35.79524	100.75852	1361	C

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
36.01340	100.57660	1166	C
36.05162	100.76115	1440	A
35.82817	100.69157	1043	C
35.93912	100.74206	1537	H
35.84629	100.58060	1365	A
35.90140	100.69575	922	C
35.63711	100.68900	1042	C
35.90981	100.80926	476	C
35.72169	100.85160	1992	C
35.78471	101.04117	1066	A
36.02039	100.91537	1373	C
35.68216	100.84653	1097	C
35.67807	100.69051	1320	C
35.92213	100.85567	1174	C
35.64707	100.70691	1067	C
36.05285	100.85371	1090	C
35.87104	100.62852	1317	A
35.73903	100.76603	913	C
36.15744	101.65656	1246	A
36.22072	101.70281	1157	A
36.47234	101.80982	1402	A
36.47211	101.71707	1024	C
36.33493	101.98220	1815	C
36.41353	102.06908	2337	C
36.17755	101.78107	1194	A
36.45269	102.07627	1649	C
36.49384	102.05790	2047	C
36.36872	102.03119	1294	C
36.49697	102.03624	2520	C
34.55616	101.90129	2360	H
35.42748	100.48090	1038	A
35.30982	100.13993	1332	A
35.53531	100.50892	1240	C
35.56538	100.37280	1328	A
35.58620	100.38383	1609	B
35.59536	100.39045	1338	A
35.30116	100.07344	1106	C
35.47302	100.43166	990	C
35.03562	101.14980	1186	C
35.13255	101.35767	1387	H
35.12109	101.41995	1647	C
34.34615	101.33902	2964	H
35.25780	101.24310	1501	H
35.21572	101.42065	1866	C

APPENDIX A - continued

<u>Latitude</u>	<u>Longitude</u>	<u>Potentiometric Head (ft)</u>	<u>Type</u>
35.20928	101.51457	1294	C
35.40112	101.61410	1515	B
35.24985	101.41474	1451	B
34.51754	102.32644	2483	H
34.72496	102.48156	2505	H
34.63043	102.15479	1511	C
34.64046	102.02041	2206	H
34.59698	100.09479	1781	H

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