KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 81-5

Groundwater Network Design for Groundwater Management District # 4, Northwest Kansas, Using the Theory of Regionalized Variables

by

Marios Sophocleous
James Paschetto
Ricardo Olea

KANSAS GEOLOGICAL SURVEY
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047

KGS
OF
81-5

GROUNDWATER NETWORK DESIGN FOR GROUNDWATER MANAGEMENT DISTRICT #4, NORTHWEST KANSAS, USING THE THEORY OF REGIONALIZED VARIABLES

by

Marios Sophocleous, James Paschetto and Ricardo Olea
Kansas Geological Survey

January 1981

ABSTRACT

The groundwater observation well network in many parts of Kansas has been developed and expanded through the years without any attempt to determine the adequacy of the network for any specified purpose or to assess its cost effectiveness. This study was undertaken to examine the existing groundwater level network in northwest Kansas and to determine the feasibility of bringing the monitoring of groundwater levels in that area to a spatially uniform level of accuracy. In order to achieve this goal, we employed the theory of regionalized variables to estimate the amount of spatial variability of the groundwater surface. The error analysis produced by universal kriging indicates that it is not practical to attempt to reduce the estimation error in the water-table surface uniformly throughout the region, because to do so would increase the cost of monitoring wells drastically. For example, to attempt to reduce the presently existing error by 50 percent throughout the map would require at least 16 times more wells than the currently existing well network in that region. On the other hand, increasing the spacing between wells does not greatly increase the uncertainty already present in the estimation process. Our analysis shows that a water-level well network consisting of one well every four miles yields maps that are, for practical purposes, indistinguishable from those produced using the present network.

INTRODUCTION

The groundwater observation well network in Kansas has been developed and expanded through the years without any attempt to determine the adequacy of the network for any specified purpose or to assess its cost effectiveness.

It is therefore proposed that a systematic redesign of the network be undertaken in order to examine the feasibility of bringing the monitoring of major aquifers within the groundwater management districts to a spatially uniform level of accuracy. This will involve optimizing the information gained from each observation well and modifying (increasing or decreasing) the number of obervation wells in order to upgrade the accuracy of the estimates.

In order to achieve the above goal, it is necessary to estimate the amount of spatial variability of the groundwater surface. This can be done by structural analysis, a statistical procedure that investigates the behavior of a mapped variable with changes in distance (Journel and Huijbregts, 1978; Olea, 1975). The basic tool to be used in assessing the degree of spatial continuity of the water table is the semivariogram, a plot of the semivariance of the water surface versus distance from the observation wells. The semivariance is a statistic characterizing the rate of change of a mapped variable with respect to distance and is based upon the expected value of the squared differences between values of the mapped variable spaced a certain distance apart. The groundwater surface is considered to be a regionalized variable, which is a continuous variable having a variation too complex to be described by a workable mathematical function. Specialized statistical methods, known as "regionalized variable theory" (Matheron, 1963) have been developed to study regionalized variables. Extensive discussions on the theory of regionalized variables are available in the literature (Journel and

Huijbregts, 1978 and references therein). Once the semivariogram(s) of the groundwater surface has been determined, it is possible to estimate the expected error in predictions of the groundwater level at any point, from any specified network of observation wells. KGS-developed computer contouring and Kriging techniques are used to contour the watern surface and to map the likely error at every estimated point in the grid.

This methodology is applied to Groundwater Management District #4 in northwest Kansas in an attempt to show that appreciable improvements in efficiency could be accomplished without impairing the worth of the data gathered from the network. The format of this report follows closely two previous reports on network design of Groundwater Management Districts #1 (Olea and Davis, 1980) and #2 (Olea, 1980).

STRUCTURAL ANALYSIS OF GROUNDWATER MANAGMENT DISTRICT #4

A structural analysis was performed on water level observations made in January 1979 in Groundwater Management District #4, an area of nearly 5,000 square miles in northwest Kansas, including Sherman, Thomas, and Sheridan counties, and parts of Cheyenne, Rawlins, Decatur, Graham, Logan, and Gove counties. The data set consists of 327 measurements (see Appendix A) made in water wells scattered at irregular locations within the District and outside near its boundaries. Average spacing between wells, as defined from the contoured area of Map 4 and the number of wells within that area, is about 3.6 miles. The measurements define a water surface that forms an undulating plane dipping to the east and northeast.

Semivariograms are calculated from measurements made along profiles defined by approximately uniformly spaced observations (Fig. 1). Two profiles are constructed across the District from approximately east to west, one from

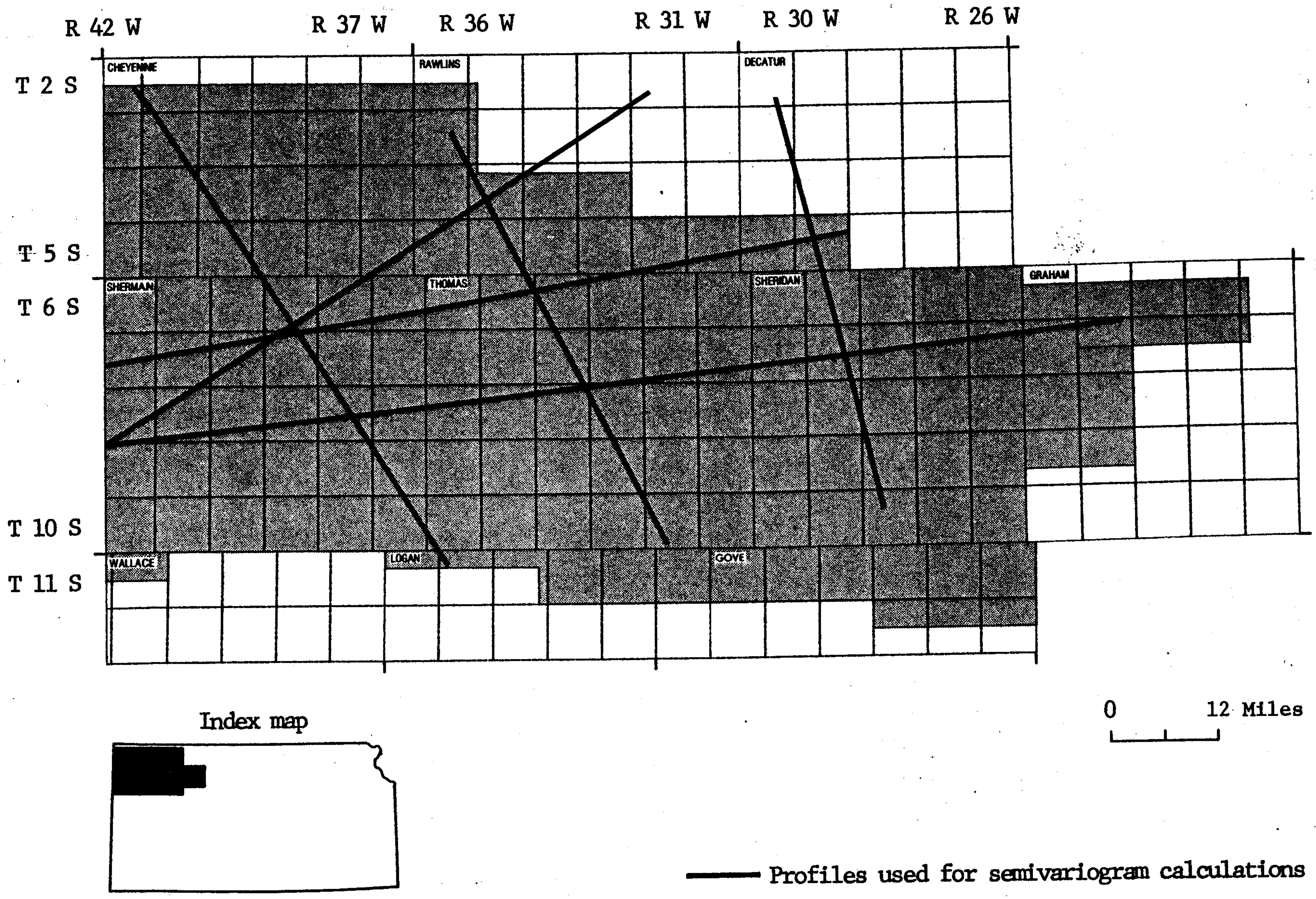

Fig. 1. - Area and location Map

southwest to northeast (all three hereby referred to as E-W profiles), and three from approximately north-northwest to south-southeast (hereby referred to as N-S profiles). The E-W profiles extend through the central part of the District across Sherman, Thomas, Sheridan, Decatur, and Graham counties. One contains 16 wells and is approximately 115 miles long; the second contains 14 wells and is approximately 85 miles long; and the third contains 10 wells and is approximately 70 miles long. The N-S profiles contain 11, 9, and 8 wells, respectively, moving from west to east across the District and are 63, 50, and 45 miles long respectively. The first and longest N-S profile extends from Cheyenne to Sherman County, the second from Rawlins to Thomas County and the third from Decatur to Sheridan County.

SEMIVARIOGRAM ANALYSES

The average semivariogram for the three E-W profiles is shown in Figure 2. Note that the plot of semivariance is concave upwards and tangent to the horizontal axis at the origin. This indicates that the surface is very continuous, with no abrupt discontinuities or changes in slope. Also note that the semivariance continues to rise to the limits of the semivariogram and that the maximum semivariance of $\hat{\gamma} = 453,115$ appreciably exceeds the variance of the observations themselves, which is $\hat{\sigma}^2 = 96,940$. This reflects the pronounced eastward dip of the water-table surface and indicates there is no distinguishable limit to the zone of influence about an observation well within the District. That is, any well within the District can provide some degree of information about any other point.

A semivariogram for the longest N-S line is shown in Figure 3; this semivariogram also exhibits an increase in semivariance with distance and moderate continuity at the origin. In addition, the semivariogram exhibits an

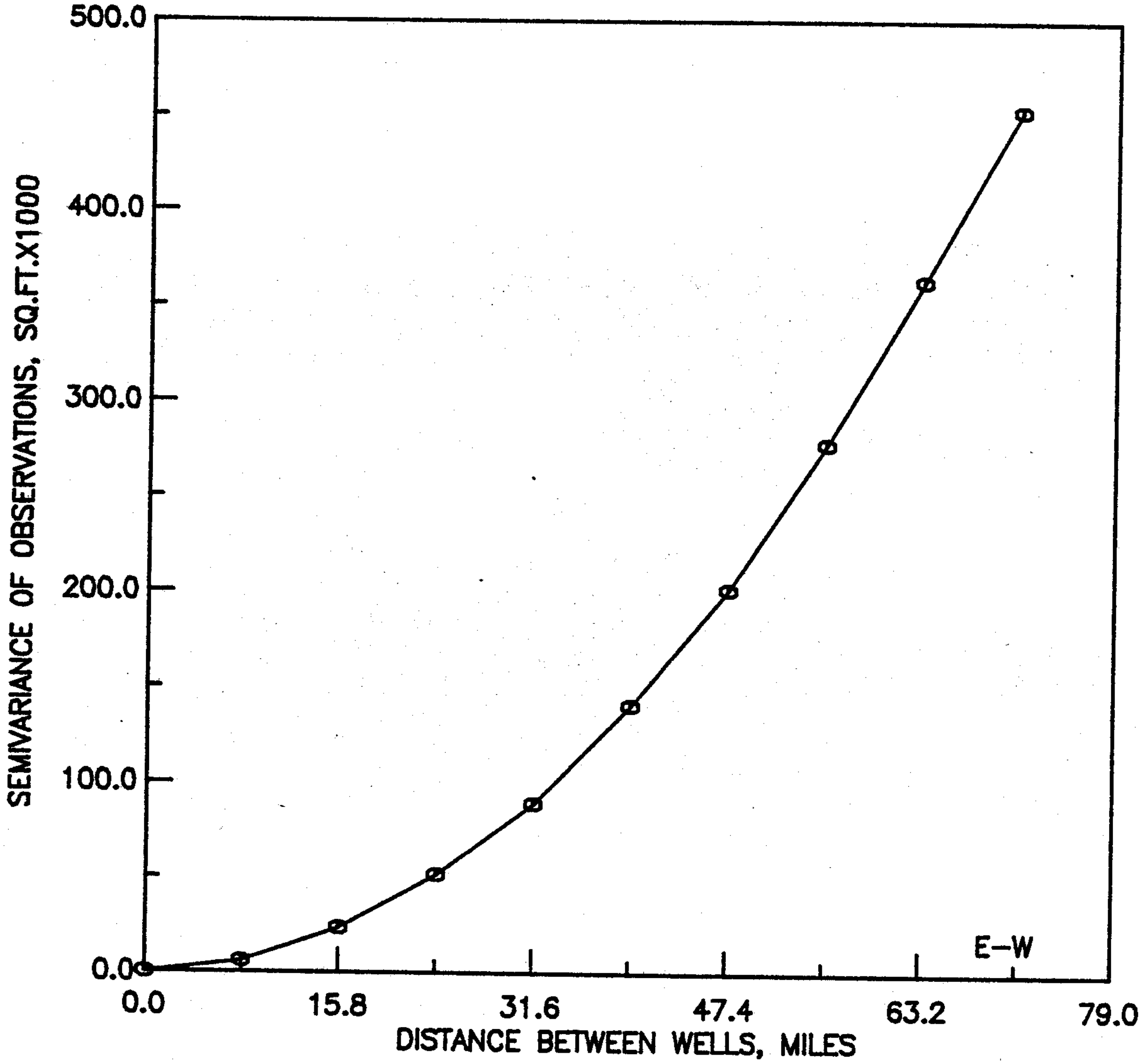

Fig. 2 - Average semivariogram of groundwater observations taken in wells spaced at approximately 7.9-mile intervals along east-west lines through Groundwater Management District #4.

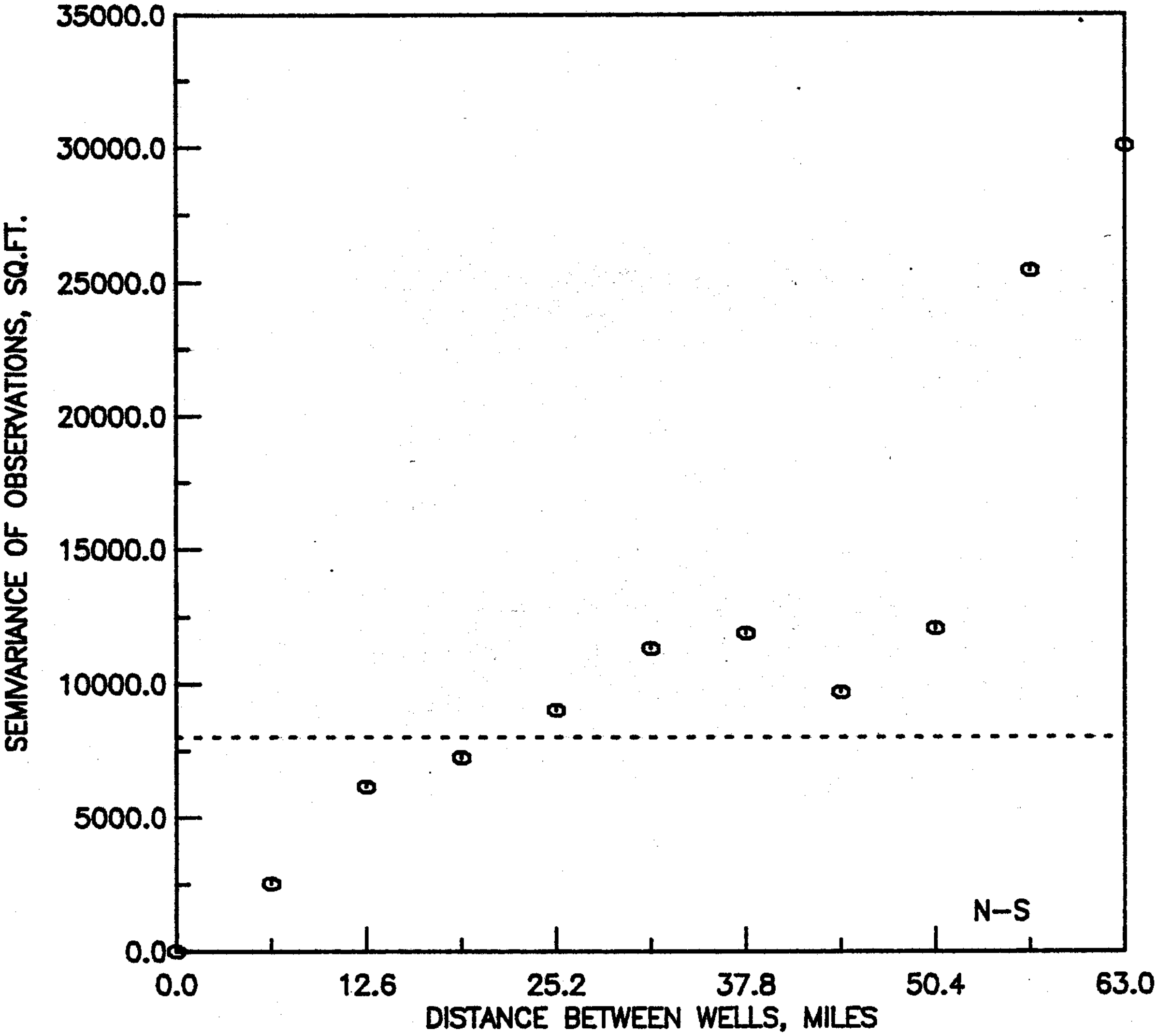

Fig. 3 - Semiovariogram of groundwater observations taken in wells spaced at approximately 6.3-mile intervals along a north-south line through Groundwater Management District #4. The dashed line represents the sill, or variance of water levels, and is equal to 8,024 ft^2. The range is the distance beyond which the difference between the semivariance and sill is considered negligible and is equal to approximately 20 miles.

apparent "semi-sill," or interval of almost constant semivariance. This feature results from small localized differences in water level, which are expressed as relatively minor undulations of the contour lines on maps of the water table (Davis and Olea, 1980). These small-scale differences would appear as closed highs and lows if the regional dip (trend) of the surface were removed from the data. Due to the relatively small number of points in the N-S lines, there is an appreciable amount of fluctuation in the semivariogram.

From the N-S semivariogram a 20-mile neighborhood or range, corresponding to the semi-sill in that semivariogram, was selected. In turn, this neighborhood was employed to determine the degree of the polynomial that best represents the drift. A neighborhood of these dimensions would encompass four data points in any direction. The drift or trend describes the regular manner in which the regionalized variable under study behaves over the neighborhood region. Regionalized variable theory allows for the removal of the local trend and for semivariance calculations for the residuals from this drift. To confirm that most of the characteristics of the E-W and N-S semivariograms result from a pronounced dip of the surface, and that a limited neighborhood is appropriate, semivariograms were computed for all profiles assuming a 20-mile neighborhood and a first-degree polynomial drift. Figures 4 and 5 are semivariograms of the residuals from this drift for the average three E-W and three N-S profiles respectively. Both the experimental semivariogram calculated from the residuals themselves and the expected semivariogram calculated from the assumed first-degree (polynomial) model, are shown. The almost exact correspondence between the two suggests that the selection of neighborhood size and order of drift are appropriate.

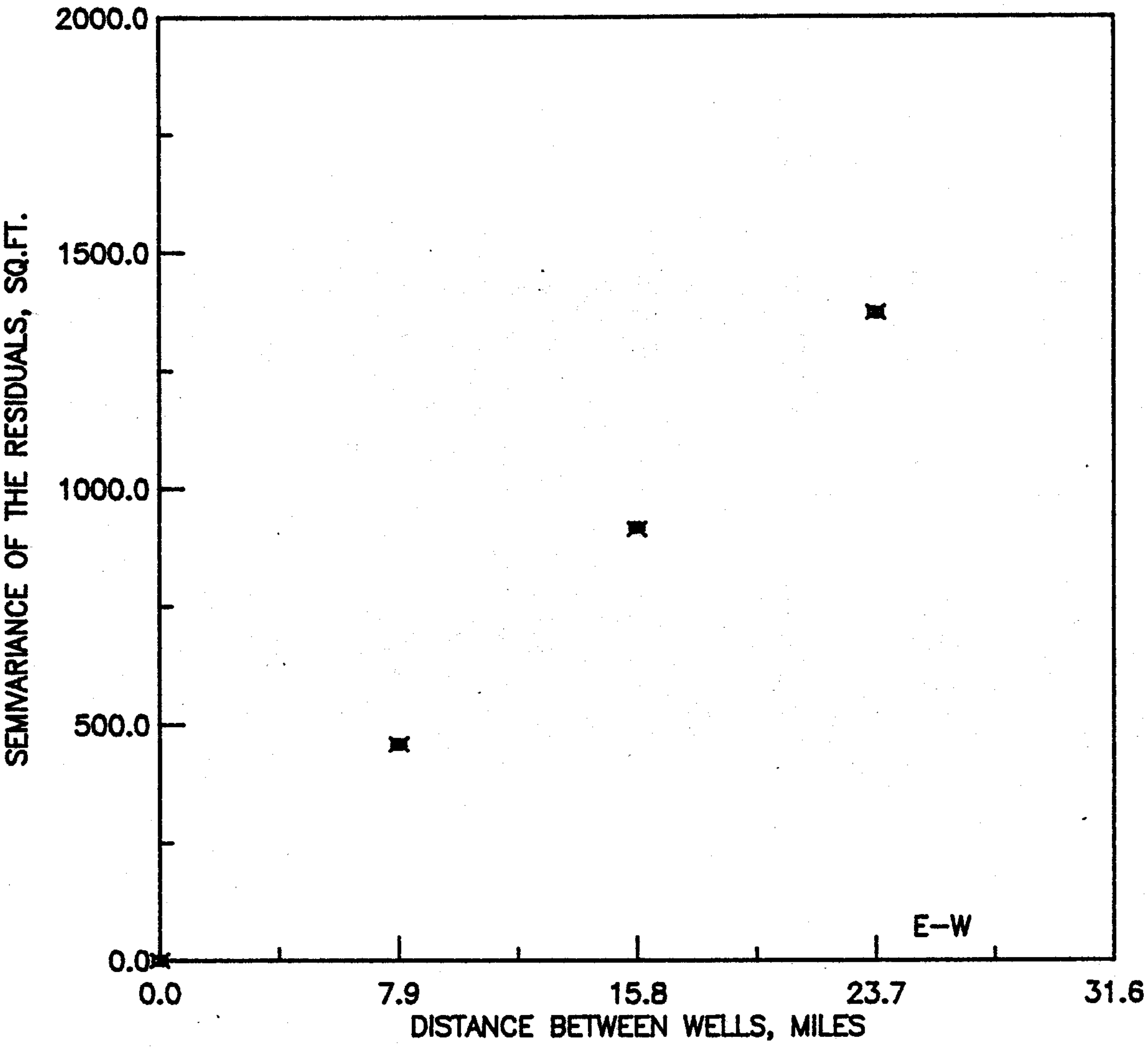

Fig. 4 - Semivariogram for the residuals from a first-degree polynomial drift fitted to the observations of the average east-west semivariogram. The neighborhood (range or zone of influence) is 20 miles and contains four observations. The theoretical semivariogram is shown as x, the experimental semivariogram as o.

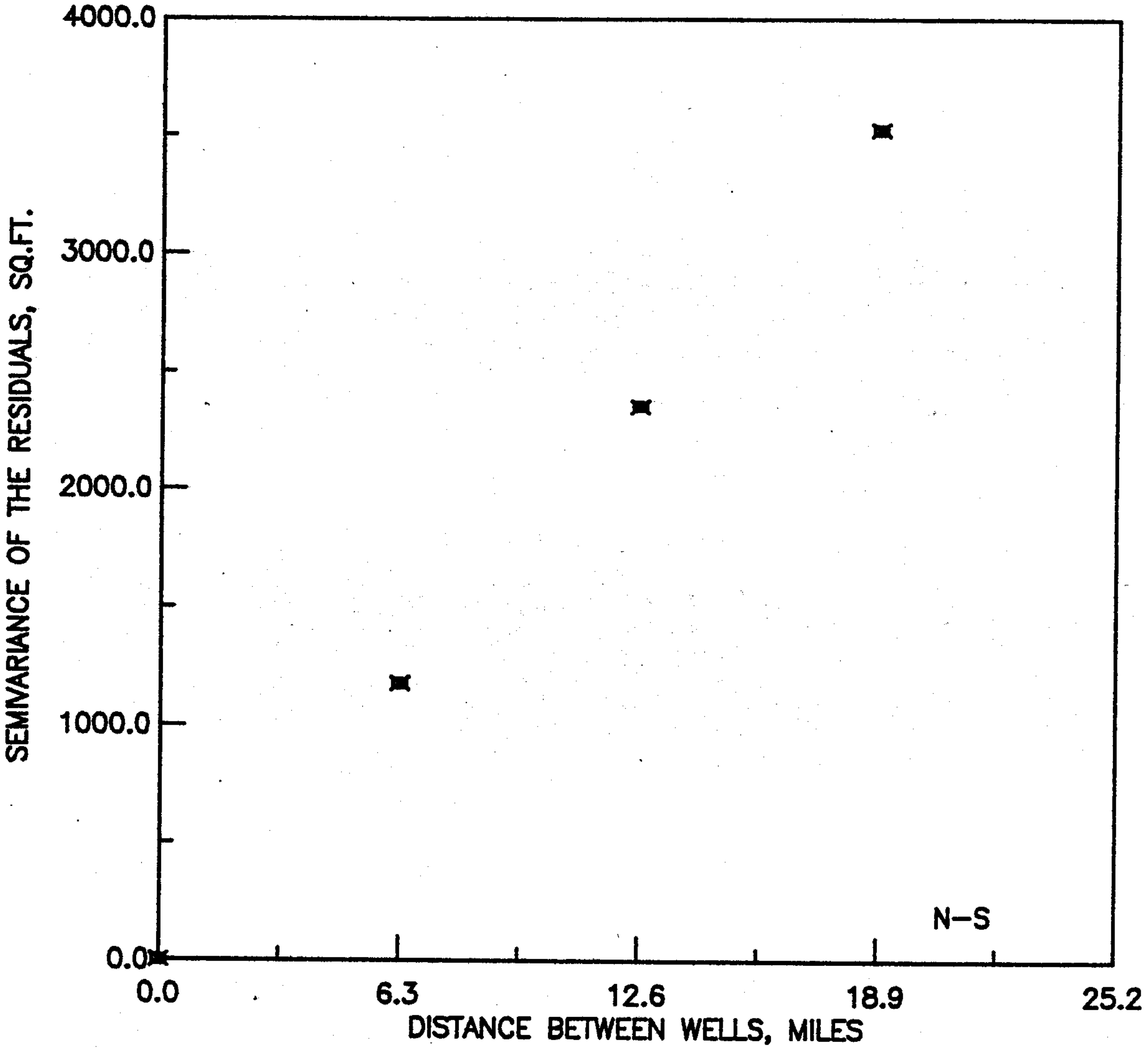

Fig. 5 - Semivariogram for the residuals from a first-degree polynomial drift fitted to the observations of the average north-south semivariogram. The neighborhood is 20 miles and contains four observations. The theoretical semivariogram is shown as x, the experimental semivariogram as o.

DESIGN OF A NETWORK FOR GROUNDWATER MANAGEMENT DISTRICT #4

The water-level surface is regarded as isotropic with a circular zone of influence having a radius of 20 miles extending around each observation well. Since the surface is presumed isotropic, the most efficient space-covering pattern that can be devised is, for practical reasons, a regular square grid of observation wells which is very easy to fit into the township and range system. Only a portion of the District, corresponding to a block whose dimensions are equal to the neighborhood size, need be considered. The entire map may be envisioned as a series of such blocks adjacent to one another.

The procedure to obtain both the errors of estimation (as measured by the standard deviation of estimation) and the most likely value of the water table elevation is called <u>universal kriging</u>. In order to make estimations using universal kriging, there must be enough measurements located inside the neighborhood or zone of influence. A convenient number is 10 to 12. No significant improvements are obtained by adding more wells inside the neighborhood, if they are farther away from the closest 16 wells (Olea, 1980). Any radius of search smaller than the radius of the zone of influence is theoretically acceptable as the maximum distance between sample points, but it is obvious that the maximum areal coverage of the wells occurs when the radius of search is equal to the radius of the zone of influence. Since the objective is to utilize the minimum number of wells, a radius of search equal to 20 miles is considered, which corresponds to the range shown in the semivariogram in Figure 3 for the water-table elevation. In view of the east-west semivariograms in which there is no discernible limit to the zone of influence, this range selection is considered conservative. The maximum number of wells inside the zone of influence is set to 16 to allow for the possibility of missing observations and to still be able to make an estimation. Although 16 wells must be found inside a circle, around the point being estimated, it is easier to think in terms of an equivalent square pattern. A square pattern of 4 by 4 wells yields 16 wells inside the zone of influence if the diagonal of the square pattern is equal to the range. The spacing between wells in such a pattern is 4.7 miles. If the spacing is conservatively reduced to 4 miles between wells, the pattern contains 9 wells per 4 townships or 2.25 wells per township. This represents the minimum acceptable density of wells, as determined by the structural analysis.

Because, as we have seen, the water-table surface shows a pronounced eastward dip (trend) and the selected semivariogram (Fig. 3) shows a moderate continuity, we must postulate a drift and use the semivariogram of the residuals rather than the semivariogram for the regionalized variable itself. Drifts of zero (no trend), one (first-order trend), and 2 (second-order trend) are usually considered. From the structural analysis, a first-degree drift is most suitable, yielding a linear semivariance for the first order residuals for Groundwater Management District #4 of

$$\gamma(h) = 115\ h \qquad (\mathrm{ft}^2/\mathrm{mi}) \qquad ,\mathrm{for}\ h \leq 20\ \mathrm{miles} \tag{1}$$

The average slope of all semivariograms at their origin is approximately 115 ft^2/mile. Changes of the semivariance with respect to distance, h, provide information about the spatial variation of the regionalized variable, in this case the water level measurements. The relatively steep slope near the origin indicates a distribution that changes relatively rapidly with respect to distance.

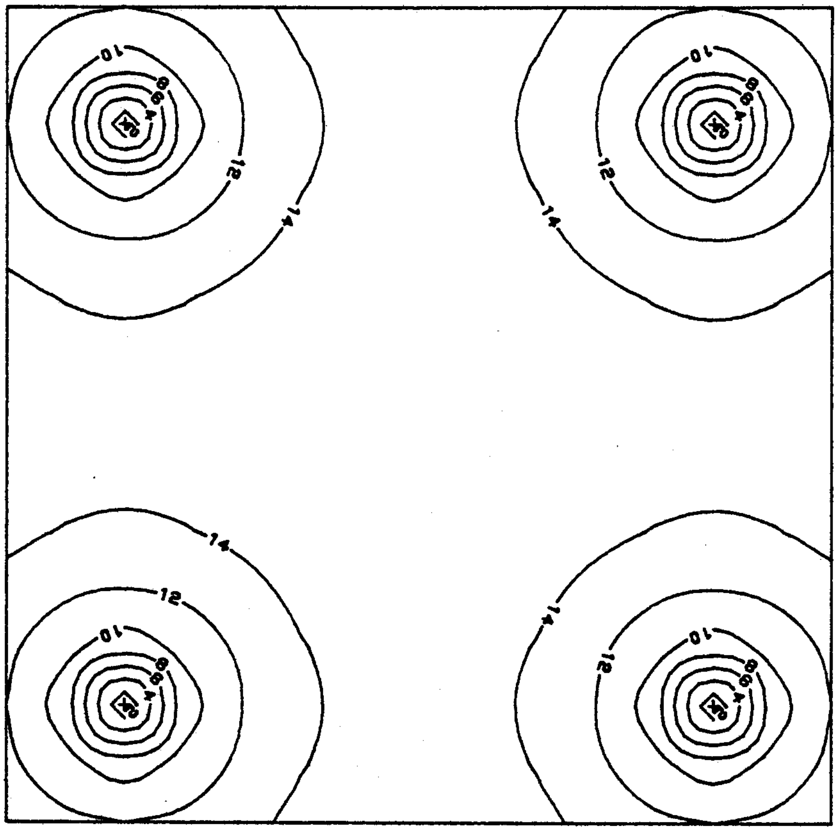

Fig. 6 - Estimation standard deviation contours for Groundwater Management District #4 for observation wells spaced 4 miles apart in a square pattern.

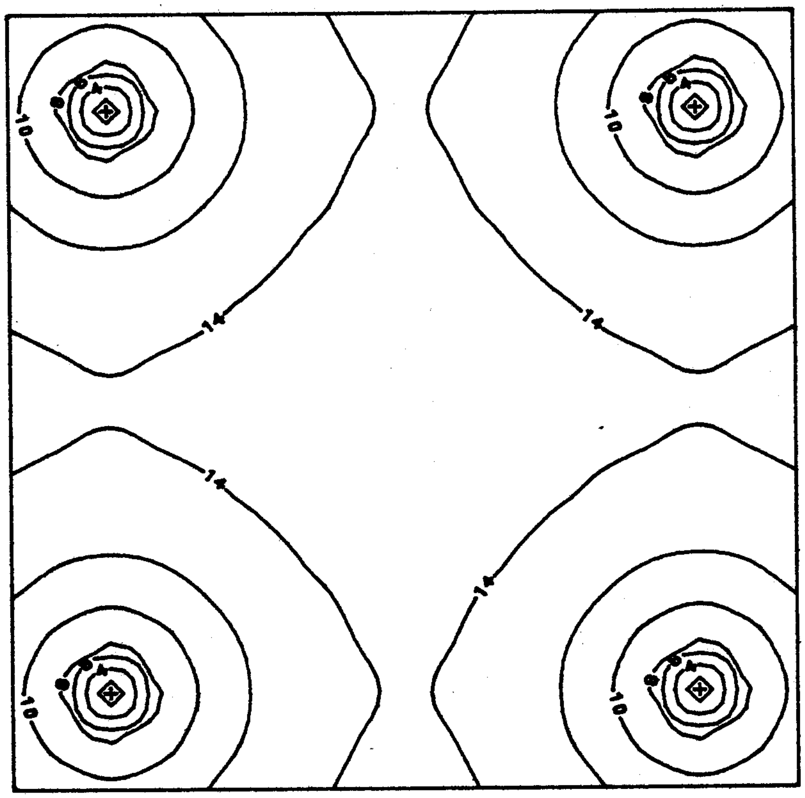

Fig. 7 - Estimation standard deviation contours for Groundwater Management District #4 for observation wells spaced 3.6 miles apart in a square pattern.

ESTIMATION OF ERRORS IN AN "OPTIMAL" NETWORK

Since the calculated errors depend only upon the characteristics of the semivariogram and/or the geographic locations of the observation wells, they do not change with differences in the actual values of the surface. If we ignore border effects, the standard deviation of estimation, which is a measure of the calculated error, will repeat indefinitely as a pattern inside the squares defined by sets of four wells. The boundary effect is only present within 10 miles of the actual map borders. Figure 6 is a contoured map of the standard deviation of estimation for Groundwater Management District #4, within an area defined by four wells of the observation network where wells are spaced four miles apart. The standard deviation rises sharply away from the wells, reaching a maximum of almost 16-foot in the center of the square pattern, because the center locations are the most distant from the control points. Throughout the map, no more than 5% of the estimated values will deviate by more than 32 feet (twice the 16 feet standard error) from the value of the water table at the center of the regular pattern (a square pattern of 4 wells separated by a spacing of 4 miles), which is the location where the water table will be estimated with the least reliability. This value also represents the <u>minimum</u> accuracy that will be obtained if Groundwater Management District #4 is sampled on a 4-mile grid.

A theoretical network of observation wells may be constructed that corresponds to the present well density in Groundwater Management District #4, but the wells are shifted to a square grid pattern. A complete 20- by 20-mile block will contain about 30 wells located on approximately 3.6-mile centers. Figure 7 is a contoured map similar to Figure 6, but with the existing average spacing of 3.6 miles. The maximum standard deviation of 15 feet is not very different from the 16 feet calculated from the four-mile spaced network.

A sensitivity analysis can be conducted to test other alternative networks. The problem is already bounded as a 4-mile spacing represents a minimum in terms of network density, yielding a map with a minimum level of confidence. The theory of regionalized variables predicts that in a contoured map generated by universal kriging, the estimation variance is a linear function of the distance between wells if the semivariance is linear (viz eqn 1). A standard deviaton of 16 feet is the equivalent of a variance of 256 feet. In order to reduce the estimation variance by a factor of 4, the distance between wells must be reduced by a factor of 4 as well, that is, from 4 miles to 1 mile. Such a network will produce a map whose maximum estimation variance at the center of any square pattern of wells, spaced 1 mile apart, will be 64 feet, or a standard deviation of the estimate of 8 feet. Figure 8 is a contour map of the standard deviation of estimation for an infinite network having wells spaced every 1 mile. Figures 6 and 8 illustrate that by using 16 times as many wells, the standard deviation of estimation can be reduced by one-half at every location in the map. This implies that the minimum network is almost optimal when compared to any practically achievable sampling density. No significant change in the map confidence will be observed with major increases in the number of wells. For example, doubling the number of wells in a regular network will only reduce the standard deviation of estimation by a factor of 1.2. It can be inferred from the above that significant reductions in standard errors of the estimated water table can be achieved only at great expense.

Figure 9 represents a nomogram for calculating the spacing and relative well density that would be required to reduce the estimation standard deviation of water-table elevation, shown in Figure 6, for a 4-mile well spacing to any desired value. For example, to reduce the maximum standard

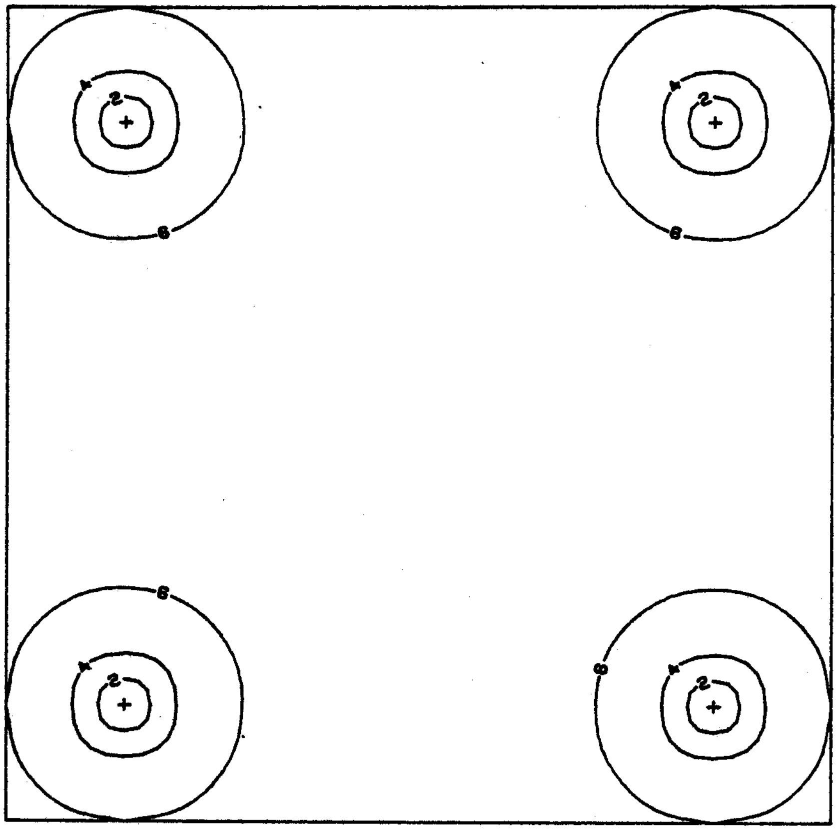

Fig. 8 - Estimation standard deviation contours for Groundwater Management District #4 for observation wells spaced 1 mile apart in a square pattern.

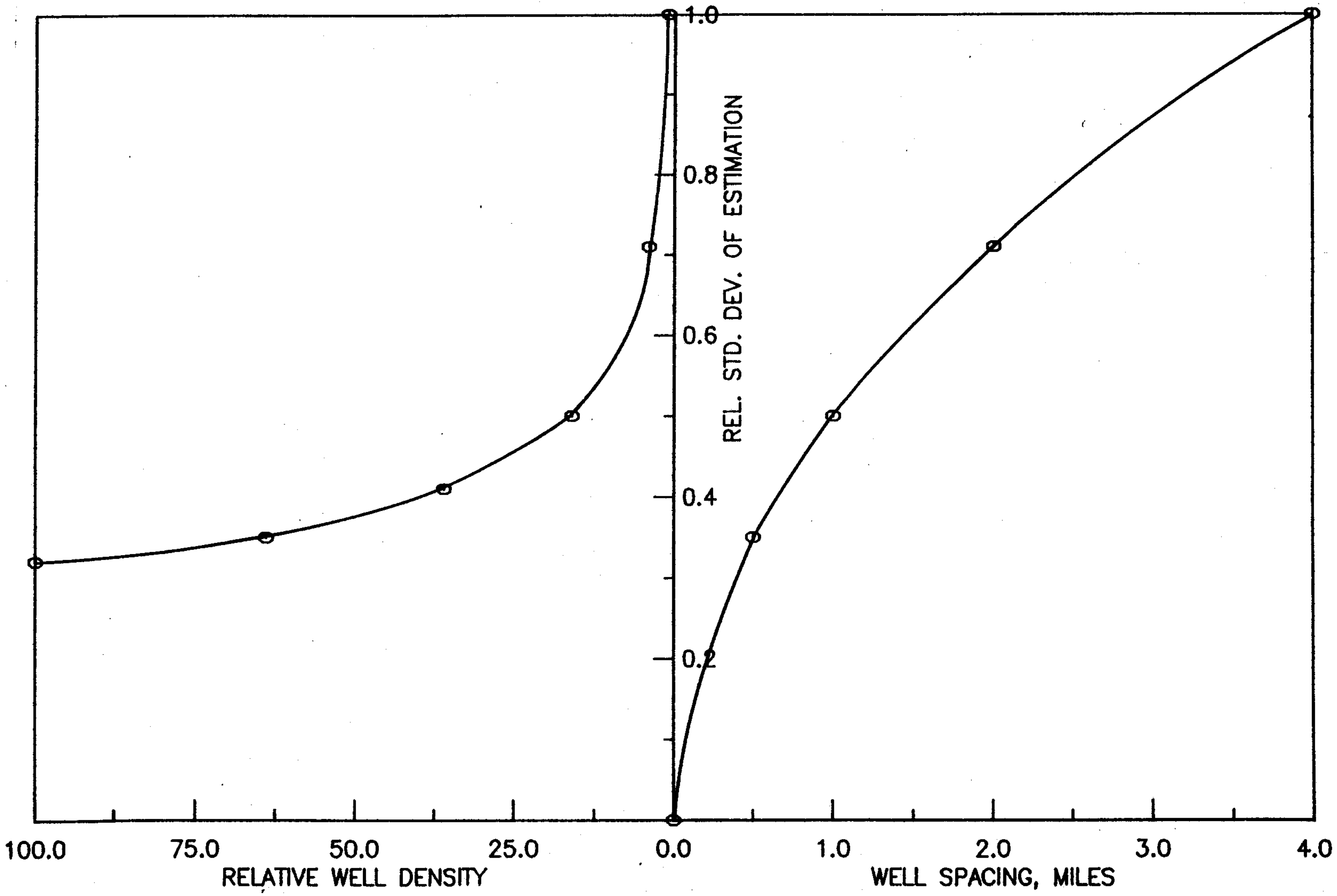

Fig. 9. - Nomogram for calculating the spacing and relative well density that would be required to reduce the estimation standard deviation of water-table elevation for a 4-mile well spacing, shown in Fig. 6, to any desired value.

deviation of 16 feet in a regular grid with a 4-mile well spacing by 50 percent, one enters the relative standard deviation ordinate at 0.50 and moves horizontally in both directions until the curves are intersected; then, one moves downwards toward the absissas to read the well spacing value (1 mile in this case) and the relative well density (in this case, 16 times more wells relative to the 4-mile square grid).

MAPPING RESULTS

Map 3 shows the 327 water wells used in this study, representing the present network. Map 4 shows the resulting contour map, produced by universal kriging, of the water-table elevation using the KGS graphics system SURFACE II (Sampson, 1978). This map represents the closest possible approximation to reality, as it uses all information available. Map 5 is a contour map of the estimation error, given as the square root of the estimation variance (i.e., the standard deviation of estimation for this pattern of 327 wells). In fact, this map shows the uncertainty already present in the water-level estimation process using the existing well network. Let us suppose that at some location on the map the water level is estimated to be at 3,050 feet and 10 feet is recorded on the error map. If the error is assumed to be distributed normally, the probability is 95 percent that the difference between the estimated water-table elevation and the true one is less than 20 feet (twice the 10-foot standard error).

Map 6 shows the location of wells selected as being closest to those in a regular network, which has wells every four miles. The selection procedure retains 9 wells per 4 townships. The final pattern contains 241 wells, a net reduction of 26 percent or 86 wells. Map 7 is the contour map produced using only measurements from the reduced network of 241 wells. Map 8 is a contour map of the standard deviation of estimation for the reduced network of wells. Comparison of the two standard deviation Maps 5 and 8 indicates that the estimation errors for both maps are very similar, despite their 26 percent difference in the number of wells. It should also be noticed that in both maps the calculated maximum standard deviation is greater than the estimated maximum standard deviation for the ideal network (Figs. 7 and 6) due to non-regular spacing, boundary effects, and missing data for a number of blocks in the maps. Map 9c is the difference in water-table elevations shown in Maps 4 and 7. The maximum discrepancy is consistent with the standard deviation maps.

In order to evaluate the significance of the standard deviation Map 5, a saturated thickness map was derived (Map 10). The relative error Map 11 shows the ratio of the standard deviation of estimation to the saturated thickness map. Thus, critical areas are defined where a certain error of estimation will have significant impact on the groundwater reserve estimations.

CONCLUSIONS

The error analysis produced by universal kriging indicates that most of the increase in estimation error in the water-table surface occurs within a short distance of the observation wells. It is not practical to attempt to reduce this error uniformly throughout the region, because to do so would increase the cost of monitoring the water wells by at least an order of magnitude. For example, to attempt to reduce the presently existing error (Map 3) by 50 percent throughout the map would require at least 16 times more wells than the currently existing well network of Groundwater Management

District #4 (Fig. 9). On the other hand, increasing the spacing between wells does not greatly increase the uncertainty already present in the estimation process.

A water-level well network consisting of one well every four miles yields maps that are for practical purposes indistinguishable from those produced using the present network. Assuming the present network is satisfactory for the purposes of predicting changes in the water-table elevation related to various pumping or recharge mechanisms, the reduced network should be equally satisfactory.

The error map is a very powerful tool that can be used to evaluate the reliability of features on a map produced by universal kriging (Olea and Davis, 1977). Certain probable and fictitious structures can be differentiated in an objective manner. The error map and the semivariogram can also be used to determine where more information is necessary to refine the map and to estimate the number of additional measurements that will be needed. In this way, regionalized variable theory provides criteria by which future measurements can be planned in order to achieve specified levels of reliability. The estimation error can be reduced to a prescribed limit by taking more measurements in these critical areas. Therefore, the best return in terms of improvement in confidence per new well added, can be obtained by locating the new well where the estimation standard deviation is a maximum. As kriging is a statistically optimal method of estimation, no other technique will provide better estimates in areas of poor control.

REFERENCES

Davis, J.C., and Olea, R.A., 1980. Optimal design of a network of groundwater observation wells in Kansas: Kansas Geological Survey unpublished report.

Journel, A.G., and Huijbregts, C.J., 1978, Mining Geostatistics: Academic Press, London, 600 p.

Matheron, G., 1963, Principles of geostatistics: Economic Geology, 58:1246-1266.

Olea, R.A., 1975, Optimum mapping techniques using regionalized variable theory: Kansas Geological Survey, Spatial Analysis Series No. 2, 137 p.

Olea, R.A., and Davis, J.C., 1977. Regionalized variables for evaluation of petroleum accumulation in Magellan Basin, South America: American Association of Petroleum Geology Bulletin, 61(4):558-572.

Olea, R.A., 1980. Design of an observation well network, with an application to Kansas Groundwater Management District #2: Kansas Geological Survey unpublished report.

Sampson, R.J., 1978. SURFACE II Graphics System: Kansas Geological Survey Spatial Analysis Series no. 1, 240 p.

APPENDIX A

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
1	1 38W 2 CDC	-101.555	39.989	56.293	102.471	3008.
2	1 38W 8 DCC	-101.607	39.975	53.538	101.460	3041.
3	1 38W 30 BDC	-101.630	39.939	52.285	98.958	3080.
4	1 39W 25 CBC	-101.654	39.935	51.041	98.703	3092.
5	2 39W 27 BBB	-101.692	39.857	49.054	93.321	3216.
6	2 40W 28 DBA	-101.811	39.850	42.687	92.801	3339.
7	2 41W 33 DBC	-101.926	39.834	36.598	91.677	3412.
8	2 42W 14 DDD	-101.993	39.874	33.009	94.444	3461.
9	3 37W 19 BBC	-101.523	39.783	58.048	88.239	3239.
10	3 37W 21 DDD	-101.469	39.772	60.909	87.506	3196.
11	3 37W 36 ADB	-101.416	39.752	63.775	86.151	3175.
12	3 39W 20 DAC	-101.715	39.776	47.808	87.691	3306.
13	3 39W 24 DDD	-101.638	39.772	51.920	87.461	3285.
14	3 39W 32 BDB	-101.725	39.752	47.308	86.064	3333.
15	3 40W 9 BAA	-101.816	39.814	42.435	90.299	3338.
16	3 40W 22 BCA	-101.802	39.781	43.182	88.049	3270.
17	3 40W 28 CBB	-101.824	39.763	42.054	86.794	3295.
18	3 40W 35 AAC	-101.772	39.754	44.808	86.178	3344.
19	3 41W 16 AAC	-101.921	39.798	36.840	89.172	3434.
20	3 41W 31 ADB	-101.959	39.752	34.854	86.049	3435.
21	3 42W 4 AAA	-102.031	39.829	31.006	91.329	3496.
22	4 37W 14 BAB	-101.444	39.712	62.286	83.394	3205.
23	4 38W 4 BAC	-101.594	39.740	54.296	85.223	3295.
24	4 38W 11 CCC	-101.561	39.714	56.046	83.482	3292.
25	4 38W 20 CCC	-101.618	39.685	53.048	81.469	3330.
26	4 38W 21 ADC	-101.585	39.693	54.799	81.978	3308.
27	4 39W 2 DBC	-101.664	39.732	50.550	84.705	3317.
28	4 39W 15 CCA	-101.690	39.701	49.176	82.573	3350.
29	4 39W 18 CAB	-101.744	39.705	46.310	82.809	3372.
30	4 39W 27 CCA	-101.690	39.673	49.178	80.574	3367.
31	4 40W 22 BCB	-101.805	39.694	43.050	82.044	3395.
32	4 41W 16 DAA	-101.920	39.705	36.951	82.789	3387.
33	4 41W 25 BCB	-101.880	39.680	39.054	81.031	3429.
34	4 41W 31 ACA	-101.962	39.665	34.717	80.042	3454.
35	5 37W 15 DBB	-101.459	39.618	61.546	76.892	3244.
36	5 38W 13 BAD	-101.536	39.624	57.421	77.245	3312.
37	5 38W 22 ACB	-101.571	39.607	55.550	76.110	3339.
38	5 38W 26 CCA	-101.560	39.586	56.173	74.614	3341.
39	5 39W 8 CCC	-101.730	39.627	47.054	77.438	3411.
40	5 39W 11 CBC	-101.674	39.631	50.052	77.704	3380.
41	5 39W 18 CCC	-101.749	39.613	46.051	76.432	3412.
42	5 39W 25 CDA	-101.649	39.586	51.428	74.588	3403.
43	5 40W 4 CBD	-101.822	39.645	42.171	78.662	3444.
44	5 40W 14 BCD	-101.784	39.620	44.172	76.921	3429.
45	5 40W 15 ACB	-101.796	39.622	43.548	77.042	3433.
46	5 40W 27 BBA	-101.803	39.596	43.171	75.290	3454.
47	5 41W 12 ADC	-101.866	39.634	39.791	77.901	3469.
48	5 41W 20 DAA	-101.939	39.604	35.946	75.784	3517.
49	5 42W 4 AAB	-102.034	39.655	30.848	79.305	3496.
50	5 42W 14 CBC	-102.011	39.616	32.093	76.671	3531.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
51	5 42W 36 CCB	-101.992	39.571	33.084	73.539	3589.
52	1 26W 18 DDB	-100.276	39.962	124.168	101.463	2391.
53	1 29W 3 DDB	-100.557	39.991	109.223	103.196	2508.
54	1 29W 19 BDD	-100.620	39.953	105.948	100.519	2549.
55	1 30W 34 DDD	-100.667	39.917	103.497	97.986	2575.
56	2 26W 11 BBA	-100.213	39.900	127.589	97.241	2423.
57	2 28W 13 ABA	-100.409	39.886	117.193	96.074	2456.
58	2 29W 24 BCC	-100.534	39.866	110.584	94.592	2587.
59	2 30W 26 DCC	-100.655	39.845	104.179	92.990	2683.
60	3 26W 30 CBB	-100.291	39.763	123.656	87.688	2484.
61	3 27W 32 ABA	-100.373	39.756	119.316	87.106	2563.
62	3 28W 6 DCB	-100.506	39.818	112.127	91.243	2528.
63	3 28W 32 BCA	-100.495	39.752	112.824	86.753	2616.
64	3 29W 12 BBA	-100.532	39.814	110.762	90.969	2525.
65	3 29W 17 DCB	-100.600	39.788	107.200	89.158	2562.
66	3 29W 31 DCC	-100.618	39.743	106.250	86.015	2608.
67	3 30W 26 BBB	-100.665	39.770	103.744	87.852	2617.
68	4 26W 8 DDD	-100.256	39.714	125.571	84.328	2426.
69	4 26W 19 DCA	-100.280	39.687	124.365	82.438	2445.
70	4 27W 17 DAC	-100.371	39.703	119.495	83.482	2543.
71	4 27W 33 BBB	-100.366	39.669	119.781	81.110	2509.
72	4 28W 15 AAA	-100.443	39.712	115.617	84.043	2607.
73	4 28W 30 DDD	-100.500	39.671	112.662	81.126	2635.
74	4 30W 7 BBB	-100.740	39.727	99.803	84.788	2683.
75	5 26W 5 ADD	-100.257	39.648	125.646	79.824	2479.
76	5 26W 26 DDA	-100.201	39.584	128.689	75.480	2414.
77	5 26W 33 DCC	-100.245	39.569	126.357	74.325	2457.
78	5 28W 7 BBC	-100.516	39.638	111.824	78.864	2625.
79	5 28W 14 ADD	-100.425	39.620	116.714	77.683	2589.
80	5 28W 17 DAC	-100.483	39.616	113.596	77.388	2633.
81	5 29W 11 BAA	-100.546	39.640	110.201	78.959	2657.
82	5 29W 22 CBB	-100.572	39.604	108.864	76.433	2673.
83	5 30W 35 BCB	-100.666	39.578	103.900	74.590	2769.
84	11 26W 4 CDC	-100.216	39.118	128.528	43.274	2517.
85	11 27W 16 AAA	-100.315	39.102	123.232	42.080	2608.
86	11 29W 4 DAD	-100.535	39.123	111.403	43.298	2732.
87	11 30W 27 ABB	-100.636	39.075	106.050	39.878	2793.
88	6 24W 35 DDD	-99.958	39.481	141.826	68.627	2357.
89	6 25W 28 CBC	-100.124	39.499	132.909	69.671	2432.
90	8 23W 24 BBD	-99.842	39.347	148.265	59.491	2124.
91	11 32W 4 ACD	-100.873	39.127	93.255	43.314	2953.
92	11 32W 19 AAB	-100.908	39.089	91.401	40.684	2970.
93	11 34W 16 CDB	-101.103	39.093	80.923	40.817	3099.
94	11 36W 6 ADD	-101.350	39.128	67.601	43.081	3219.
95	11 36W 6 DBB	-101.357	39.126	67.224	42.956	3216.
96	13 35W 23 BCC	-101.184	38.910	76.699	28.163	2912.
97	13 36W 20 CCB	-101.351	38.905	67.696	27.734	3011.
98	1 33W 29 CCC	-101.055	39.931	82.871	98.695	2878.
99	2 31W 3 CAD	-100.788	39.906	97.058	97.151	2646.
100	2 32W 14 DCA	-100.876	39.876	92.395	94.953	2700.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
101	2 32W 20 DCD	-100.932	39.859	89.461	93.784	2721.
102	2 33W 26 DCC	-100.990	39.845	86.384	92.743	2772.
103	2 35W 13 ABB	-101.195	39.886	75.425	95.505	3009.
104	2 36W 13 DDD	-101.301	39.874	69.827	94.598	3096.
105	2 36W 15 CDD	-101.347	39.874	67.347	94.566	3131.
106	2 36W 36 BAA	-101.310	39.843	69.342	92.466	3086.
107	3 31W 7 CBD	-100.849	39.805	93.924	90.095	2814.
108	3 31W 23 BBB	-100.777	39.785	97.776	88.769	2776.
109	3 33W 3 DCC	-101.009	39.816	85.408	90.730	2795.
110	3 33W 8 CDC	-101.051	39.801	83.178	89.701	2830.
111	3 34W 3 ABB	-101.121	39.828	79.437	91.537	2866.
112	3 34W 26 BAC	-101.107	39.768	80.207	87.419	2886.
113	3 34W 33 BCC	-101.149	39.750	77.976	86.149	2926.
114	3 35W 24 CBB	-101.205	39.778	74.976	88.000	2973.
115	3 36W 14 CBB	-101.336	39.792	67.993	88.950	3128.
116	3 36W 17 CCC	-101.392	39.787	65.012	88.538	3161.
117	4 31W 16 ABD	-100.802	39.710	96.474	83.619	2748.
118	4 31W 25 DDD	-100.742	39.670	99.723	80.902	2737.
119	4 33W 18 DDA	-101.058	39.701	82.847	82.824	2981.
120	4 33W 28 DCA	-101.026	39.673	84.608	80.849	2972.
121	4 34W 33 CBC	-101.150	39.660	78.016	79.897	3039.
122	4 35W 6 DCD	-101.287	39.729	70.630	84.600	3092.
123	4 35W 13 DAD	-101.189	39.703	75.883	82.878	2986.
124	4 35W 29 DDD	-101.264	39.671	71.899	80.606	3068.
125	4 36W 6 BBB	-101.411	39.741	64.025	85.403	3176.
126	4 36W 9 CDD	-101.367	39.714	66.397	83.555	3172.
127	5 31W 10 DDA	-100.779	39.629	97.780	78.000	2774.
128	5 31W 20 CCA	-100.831	39.600	95.079	75.969	2830.
129	5 31W 23 DDD	-100.761	39.598	98.793	75.881	2829.
130	5 32W 14 CDD	-100.882	39.613	92.346	76.817	2889.
131	5 33W 29 BDA	-101.050	39.593	83.396	75.334	3023.
132	5 34W 1 BBB	-101.094	39.654	81.001	79.553	3021.
133	5 34W 28 ADC	-101.136	39.591	78.793	75.154	3072.
134	5 35W 10 CDD	-101.236	39.627	73.418	77.613	3099.
135	5 36W 21 BCD	-101.372	39.606	66.177	76.055	3200.
136	6 27W 3 DCD	-100.317	39.554	122.569	73.275	2526.
137	6 27W 8 DCA	-100.354	39.542	120.593	72.364	2568.
138	6 27W 27 BCC	-100.328	39.503	122.000	69.754	2557.
139	6 28W 28 ADD	-100.443	39.504	115.903	69.662	2636.
140	6 29W 10 DBC	-100.542	39.544	110.531	72.333	2693.
141	6 29W 24 ABB	-100.505	39.524	112.525	70.993	2680.
142	6 29W 33 CDA	-100.563	39.484	109.482	68.181	2726.
143	6 30W 2 BCA	-100.642	39.564	105.184	73.609	2759.
144	6 30W 13 BAA	-100.619	39.538	106.460	71.882	2745.
145	6 30W 14 CCD	-100.642	39.525	105.222	70.982	2776.
146	6 30W 24 DDC	-100.612	39.511	106.861	70.013	2760.
147	7 26W 12 BAC	-100.176	39.463	130.205	67.108	2462.
148	7 26W 28 CAB	-100.232	39.414	127.302	63.687	2481.
149	7 28W 8 BDC	-100.473	39.460	114.332	66.633	2652.
150	7 28W 19 BBA	-100.494	39.437	113.236	64.989	2662.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
151	7 28W 21 ABB	-100.450	39.437	115.600	65.021	2623.
152	7 28W 36 ABA	-100.392	39.407	118.741	63.061	2587.
153	7 29W 2 DBD	-100.522	39.471	111.716	67.344	2690.
154	7 29W 21 ABB	-100.561	39.437	109.652	64.929	2712.
155	7 29W 30 ABA	-100.596	39.422	107.815	63.898	2738.
156	8 26W 14 DAA	-100.183	39.356	129.961	59.707	2380.
157	8 26W 16 CDD	-100.230	39.351	127.498	59.300	2411.
158	8 27W 11 DCD	-100.299	39.365	123.765	60.254	2494.
159	8 27W 33 BBD	-100.346	39.318	121.322	56.958	2535.
160	8 28W 9 ABC	-100.450	39.377	115.665	60.886	2631.
161	8 29W 1 DCB	-100.506	39.382	112.674	61.221	2681.
162	8 29W 29 BAA	-100.582	39.335	108.644	57.903	2748.
163	8 30W 11 CBC	-100.645	39.370	105.250	60.224	2768.
164	8 30W 13 DAA	-100.610	39.357	107.136	59.382	2756.
165	8 30W 30 ABC	-100.710	39.333	101.782	57.666	2840.
166	9 27W 12 CCC	-100.292	39.278	124.233	54.242	2569.
167	9 27W 19 DDD	-100.369	39.249	120.149	52.177	2622.
168	9 28W 4 BCC	-100.460	39.300	115.245	55.617	2650.
169	9 28W 6 CCB	-100.497	39.295	113.263	55.216	2686.
170	9 28W 31 AAC	-100.483	39.232	114.077	50.841	2686.
171	9 29W 17 BAB	-100.584	39.277	108.577	53.896	2755.
172	9 30W 3 AAB	-100.649	39.306	105.060	55.844	2796.
173	9 30W 16 CDA	-100.675	39.266	103.723	53.071	2822.
174	9 30W 35 BBB	-100.645	39.234	105.381	50.845	2799.
175	10 27W 20 CBC	-100.367	39.166	120.358	46.415	2585.
176	10 28W 5 DDB	-100.464	39.208	115.094	49.225	2684.
177	10 28W 29 DAA	-100.462	39.153	115.274	45.468	2664.
178	10 29W 20 CCC	-100.589	39.163	108.440	46.010	2762.
179	10 30W 8 DDD	-100.685	39.192	103.296	47.937	2830.
180	10 30W 12 ADA	-100.610	39.201	107.287	48.623	2774.
181	10 30W 17 DAD	-100.685	39.181	103.304	47.187	2829.
182	6 37W 3 BCC	-101.445	39.562	62.327	73.025	3261.
183	6 37W 7 BBA	-101.498	39.553	59.498	72.384	3294.
184	6 37W 16 CDD	-101.456	39.526	61.719	70.521	3288.
185	6 38W 9 ABD	-101.563	39.551	56.035	72.237	3354.
186	6 38W 20 ACC	-101.584	39.519	54.926	69.977	3391.
187	6 39W 9 DDD	-101.670	39.540	50.315	71.450	3439.
188	6 40W 10 AAC	-101.765	39.551	45.240	72.169	3481.
189	6 40W 30 DCC	-101.825	39.496	42.042	68.397	3555.
190	6 40W 35 BCC	-101.761	39.489	45.475	67.916	3510.
191	6 41W 1 ABB	-101.843	39.567	41.076	73.273	3518.
192	6 41W 9 BCB	-101.908	39.549	37.562	72.030	3572.
193	6 41W 19 DBD	-101.934	39.515	36.176	69.655	3606.
194	6 41W 27 DBD	-101.878	39.500	39.176	68.647	3580.
195	6 42W 2 AAA	-101.967	39.568	34.426	73.289	3583.
196	6 42W 8 CBB	-102.040	39.546	30.511	71.793	3631.
197	6 42W 22 DCC	-101.993	39.511	33.028	69.409	3645.
198	6 42W 30 ADA	-102.043	39.506	30.377	69.037	3671.
199	7 37W 4 BBC	-101.463	39.479	61.358	67.267	3318.
200	7 37W 5 CCB	-101.482	39.470	60.369	66.635	3336.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
201	7 37W 11 ACB	-101.417	39.463	63.834	66.162	3290.
202	7 37W 17 BDA	-101.475	39.448	60.744	65.136	3337.
203	7 39W 9 BBB	-101.686	39.466	49.440	66.312	3477.
204	7 39W 24 BAA	-101.623	39.437	52.827	64.330	3440.
205	7 39W 30 CCB	-101.724	39.411	47.434	62.546	3502.
206	7 40W 6 ADB	-101.820	39.476	42.279	67.021	3559.
207	7 40W 29 BBA	-101.814	39.422	42.634	63.270	3571.
208	7 40W 35 BBB	-101.761	39.408	45.461	62.285	3524.
209	7 40W 36 BAB	-101.738	39.408	46.692	62.292	3509.
210	7 41W 7 BCB	-101.946	39.462	35.540	66.026	3646.
211	7 41W 10 BBA	-101.888	39.466	38.666	66.270	3611.
212	7 41W 16 ADC	-101.895	39.446	38.286	64.895	3624.
213	7 41W 28 DBB	-101.900	39.415	38.029	62.767	3648.
214	7 42W 7 DAA	-102.043	39.459	30.365	65.781	3706.
215	7 42W 17 CCC	-102.041	39.439	30.488	64.403	3729.
216	7 42W 27 AAB	-101.989	39.422	33.263	63.273	3700.
217	8 37W 21 CCC	-101.464	39.337	61.380	57.513	3356.
218	8 37W 28 ABC	-101.455	39.334	61.880	57.268	3349.
219	8 37W 32 ABB	-101.474	39.321	60.884	56.381	3372.
220	8 38W 17 CDD	-101.587	39.352	54.818	58.458	3445.
221	8 38W 24 AAB	-101.506	39.350	59.142	58.366	3391.
222	8 38W 28 ACC	-101.566	39.330	55.933	56.964	3443.
223	8 39W 2 BAA	-101.642	39.393	51.826	61.319	3452.
224	8 39W 15 CCC	-101.668	39.352	50.446	58.432	3476.
225	8 39W 17 DCD	-101.694	39.352	49.065	58.424	3491.
226	8 39W 27 AAB	-101.654	39.335	51.203	57.309	3468.
227	8 39W 28 CAB	-101.682	39.328	49.692	56.800	3495.
228	8 40W 12 DBA	-101.731	39.371	47.061	59.791	3504.
229	8 40W 17 CDB	-101.812	39.353	42.737	58.518	3596.
230	8 40W 20 CBC	-101.817	39.340	42.484	57.641	3600.
231	8 40W 20 CCC	-101.817	39.337	42.485	57.391	3602.
232	8 40W 20 DAA	-101.801	39.342	43.350	57.770	3596.
233	8 40W 24 AAA	-101.727	39.350	47.306	58.290	3508.
234	8 40W 25 AAC	-101.729	39.333	47.181	57.163	3517.
235	8 40W 35 CCB	-101.762	39.310	45.448	55.528	3571.
236	8 41W 17 CBA	-101.926	39.357	36.643	58.763	3702.
237	8 41W 25 BBC	-101.854	39.333	40.498	57.137	3641.
238	8 42W 15 DDB	-101.989	39.353	33.249	58.515	3736.
239	8 42W 19 ABB	-102.051	39.350	29.968	58.268	3761.
240	8 42W 29 ACB	-102.032	39.332	30.972	57.015	3782.
241	8 42W 31 DCD	-102.048	39.308	30.085	55.387	3797.
242	8 42W 34 DCB	-101.994	39.310	32.990	55.509	3766.
243	9 38W 13 BCC	-101.520	39.272	58.406	52.978	3433.
244	9 39W 2 BAB	-101.645	39.306	51.707	55.309	3480.
245	9 39W 17 BBA	-101.704	39.277	48.560	53.289	3544.
246	9 39W 19 CCC	-101.725	39.250	47.427	51.407	3558.
247	9 40W 8 CCB	-101.817	39.281	42.466	53.514	3623.
248	9 40W 8 CDB	-101.813	39.281	42.715	53.514	3612.
249	9 40W 13 CDC	-101.739	39.264	46.682	52.404	3563.
250	9 40W 27 CDC	-101.776	39.235	44.690	50.394	3597.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
251	9 40W 29 BBB	-101.818	39.248	42.457	51.262	3625.
252	9 41W 5 DCC	-101.919	39.293	37.004	54.382	3693.
253	9 41W 14 BBC	-101.873	39.275	39.484	53.132	3664.
254	9 41W 28 AAA	-101.894	39.248	38.359	51.253	3680.
255	9 41W 34 BAB	-101.887	39.234	38.727	50.253	3693.
256	9 42W 8 AAA	-102.025	39.292	31.344	54.259	3788.
257	9 42W 11 CCC	-101.985	39.279	33.489	53.381	3757.
258	9 42W 14 AAA	-101.968	39.277	34.371	53.254	3733.
259	9 42W 16 CDD	-102.016	39.264	31.843	52.380	3801.
260	9 42W 35 ABB	-101.976	39.234	33.984	50.250	3776.
261	10 37W 23 ABB	-101.418	39.176	63.917	46.422	3228.
262	10 40W 10 ADC	-101.767	39.199	45.182	47.893	3606.
263	10 41W 15 CAD	-101.885	39.181	38.837	46.624	3742.
264	10 42W 21 BBB	-102.023	39.175	31.446	46.244	3859.
265	10 42W 24 BBA	-101.964	39.175	34.606	46.243	3807.
266	6 31W 3 ADB	-100.761	39.563	98.838	73.507	2838.
267	6 31W 33 CCD	-100.791	39.482	97.304	67.866	2887.
268	6 32W 12 CBC	-100.849	39.544	94.165	72.087	2903.
269	6 32W 29 CDC	-100.918	39.497	90.491	68.797	2952.
270	6 33W 7 BBB	-101.054	39.553	83.205	72.579	3039.
271	6 33W 23 DDD	-100.962	39.511	88.119	69.771	2983.
272	6 33W 31 CAB	-101.049	39.488	83.494	68.087	3050.
273	6 34W 10 DDA	-101.093	39.542	81.112	71.805	3060.
274	6 34W 11 CDD	-101.084	39.540	81.607	71.686	3054.
275	6 34W 17 CBC	-101.146	39.529	78.275	70.898	3101.
276	6 35W 2 CDD	-101.195	39.555	75.658	72.627	3112.
277	6 35W 26 ACB	-101.193	39.506	75.804	69.251	3146.
278	6 36W 6 BCD	-101.387	39.562	65.411	73.045	3219.
279	6 36W 11 ACC	-101.305	39.548	69.799	72.090	3189.
280	6 36W 30 DCB	-101.380	39.499	65.809	68.678	3263.
281	6 36W 34 DDB	-101.319	39.484	69.070	67.704	3229.
282	7 31W 1 DCA	-100.726	39.469	100.778	67.026	2842.
283	7 31W 26 CCC	-100.756	39.410	99.224	62.886	2870.
284	7 32W 7 ACA	-100.930	39.463	89.889	66.415	2979.
285	7 32W 13 AAA	-100.833	39.451	95.101	65.720	2920.
286	7 33W 7 BDA	-101.047	39.462	83.637	66.339	3041.
287	7 33W 21 DBC	-101.007	39.428	85.782	63.990	3026.
288	7 33W 35 ADD	-100.963	39.403	88.168	62.266	2992.
289	7 34W 8 BBB	-101.147	39.466	78.308	66.522	3124.
290	7 34W 25 AAA	-101.056	39.423	83.161	63.585	3055.
291	7 34W 26 DBD	-101.080	39.413	81.926	62.945	3065.
292	7 35W 10 CCC	-101.221	39.453	74.327	65.613	3169.
293	7 36W 17 CCC	-101.371	39.439	66.330	64.558	3273.
294	7 36W 35 CBB	-101.315	39.401	69.348	61.952	3252.
295	8 31W 20 CDD	-100.805	39.337	96.682	57.858	2916.
296	8 32W 7 BAA	-100.935	39.379	89.677	60.656	2985.
297	8 32W 12 DBC	-100.840	39.370	94.790	60.089	2947.
298	8 33W 2 CDD	-100.973	39.381	87.678	60.760	2999.
299	8 33W 7 AAB	-101.040	39.379	84.060	60.598	3041.
300	8 33W 34 BBC	-100.999	39.319	86.337	56.495	3018.

I.D.	LOCATION	LAT.	LONG.	X-COORD (MI)	Y-COORD (MI)	WATER LEVEL
301	8 34W 1 BAC	-101.068	39.392	82.559	61.454	3056.
302	8 34W 6 CBC	-101.165	39.384	77.355	60.885	3124.
303	8 34W 23 CBD	-101.089	39.341	81.470	57.941	3062.
304	8 36W 18 ABA	-101.378	39.365	65.983	59.435	3302.
305	9 31W 10 BBB	-100.775	39.292	98.336	54.750	2912.
306	9 31W 22 ABD	-100.764	39.261	98.984	52.632	2910.
307	9 31W 36 AAB	-100.724	39.234	101.130	50.781	2870.
308	9 32W 9 BDA	-100.899	39.288	91.720	54.424	2972.
309	9 32W 27 BCD	-100.885	39.243	92.498	51.306	2952.
310	9 33W 15 ACC	-100.990	39.272	86.859	53.249	3014.
311	9 33W 30 CAA	-101.048	39.242	83.765	51.101	3017.
312	9 33W 35 AAD	-100.964	39.232	88.245	50.508	2990.
313	9 34W 12 ADA	-101.057	39.289	83.240	54.345	3043.
314	9 35W 32 DAA	-101.243	39.227	73.286	49.965	3173.
315	10 31W 26 AAA	-100.741	39.161	100.323	45.772	2881.
316	10 31W 29 AAB	-100.799	39.161	97.198	45.737	2908.
317	10 32W 4 CAB	-100.901	39.212	91.637	49.168	2972.
318	10 32W 11 BAA	-100.862	39.205	93.781	48.697	2959.
319	10 32W 29 DCB	-100.916	39.151	90.913	44.905	2971.
320	10 33W 3 DBC	-100.990	39.211	86.888	48.998	2999.
321	10 33W 19 CBD	-101.053	39.167	83.560	45.979	3057.
322	10 34W 1 ABA	-101.062	39.220	83.031	49.595	3015.
323	10 34W 12 BCD	-101.071	39.200	82.544	48.213	3038.
324	10 34W 14 BCC	-101.092	39.185	81.432	47.195	3076.
325	10 36W 36 ACC	-101.288	39.141	70.932	44.064	3189.
326	11 38W 35 CCC	-101.515	39.047	58.794	37.484	3229.
327	11 42W 8 DDC	-102.000	39.105	32.661	41.354	3844.