GEOSTATISTICAL EVALUATION OF A REDUCTION IN NUMBER OF OBSERVATION WELLS IN THE GROUNDWATER LEVEL DATA NETWORK, HIGH PLAINS AQUIFER, KANSAS

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SUMMARY

An observation network of 1368 wells monitors water levels in the High Plains aquifer in Kansas over an area of about 29,000 square miles. In 1994, the United States Geological Survey proposed dropping 29 wells from the system. Based exclusively on the statistical reliability of the network, the elimination of 17 wells does not represent a threat to the ability of the network to detect variations in the water level, because these wells are close to other observation points. Three of the 29 wells (at locations 27S 22W 9DAB, 34S 35W 3DCC, and 31S 38W 17CDA) should remain in the system because they are far from other wells. Elimination of the remaining nine wells would not be as critical, but would have an impact on the reliability of the network. Locations of the 17 wells which may be dropped with slight impact on the effectiveness of the monitoring system are:

35S 34W 3CBC	31S 28W 10BCB	29S 26W 20BDD
29S 25W 3ADA	27S 38W 22CBB	30S 31W 24BBC
4S 41W 25BCB	24S 35W 13CCC	24S 42W 4AAD
24S 39W 35BAC	22S 24W 15BDA	22S 24W 26DDA
22S 24W 24DDD	7S 37W 4BBC	7S 40W 35BBB
9S 39W 2BAB	10S 42W 20ABB	

INTRODUCTION

The Division of Water Resources of the Kansas State Board of Agriculture and the United States Geological Survey, with partial support from the Kansas Geological Survey, measure and archive water levels in a State network comprising about 1400 wells, 1368 of which currently comprise the groundwater level data network of the Kansas portion of the High Plains aquifer.

The United States Geological Survey intends to discontinue measurement in 29 Kansas wells in the High Plains aquifer and has asked the opinion of the Kansas Geological Survey about the reduction in number of wells. This report evaluates the impact that such a reduction will have on the assessment of water levels based on future data gathered by monitoring of the modified network.

METHODOLOGY

Sampling Patterns

When a network of given sampling density is designed to sample an attribute such as groundwater level which is characterized by spatiotemporal variation, pattern of sampling is the parameter that most affects network efficiency (Olea, 1984). Regular sampling patterns are most efficient in the sense that they minimize the mean and the maximum kriging variance related to estimations that can be calculated based on data gathered by the network.

In a regular sampling pattern observation wells are located at the centers of regular polygons that exhaustively partition the plane. In two dimensions these polygons can be triangles, squares, or hexagons (as shown in Fig. 1).

The least efficient pattern of well location is one which contains an agglomeration of wells—that is, clusters of samples. In this instance resources are wasted because redundant information is collected in some areas, while no information is obtained in areas that are devoid of control. All other sampling patterns have properties that affect network efficiency in a manner intermediate to results obtained using a regular pattern or sampling by clusters.

Of special interest are patterns associated with random sampling and stratified sampling. In random sampling, control points are the realization of a Poisson process with a homogeneous average well density, but the points have no systematic arrangement. Stratified sampling is a combination of regular and random sampling. In the stratified sampling approach, the location of each well is randomly situated inside a polygon, destroying the symmetry and uniqueness of the regular sampling pattern, but retaining the same average sampling density. Examples of stratified sampling are shown in Figure 2.

Distance Index

Geographers have been exceptionally active in the testing, modeling, and characterization of sampling patterns. Clark and Evans (1954) introduced distance from sampling site to nearest neighbor as a measure of randomness. Let us considered a sample of size n. Each sampling site will have a nearest neighbor that is some distance r_i away. The average distance to the nearest neighbor, $\bar{r}$, is defined as

$$\bar{r} = \frac{1}{n}\sum_{i=1}^{n} r_i \qquad (1)$$

Clark and Evans (1954) proved that the average distance to the nearest sampling site in a random pattern is

$$\bar{r}_R = \frac{1}{2\sqrt{\rho}} \qquad (2)$$

where ρ is the density of the pattern expressed as the number of sampling sites per unit of area.

The distance index R is the observed average distance to the nearest neighbor divided by the value corresponding to the random pattern

$$R = \frac{\bar{r}}{\bar{r}_E} \qquad (3)$$

For patterns other than regular ones, the distance index is a quick and precise way to determine the pattern of a network. The hexagonal regular network has the highest index with 2.15, closely followed by the square pattern with 2.0. Stratified patterns have indices about 1.3; and random patterns, by definition, have a value of 1.0. Clustered patterns have the lowest indices, with values close to 0.0.

THE PRESENT NETWORK

The existing groundwater level data network measures water levels in several aquifers across the State. More than 99% of the wells, however, are monitoring the High Plains aquifer. Because all of the wells proposed for elimination in Kansas are monitoring this aquifer, the present analysis is restricted to that portion of the network in the High Plains aquifer. Figure 3 is a posting of the 1368 wells comprising that portion of the State network that monitors the High Plains aquifer.

Figure 4 shows the distribution of distances to the nearest observation point for the High Plains portion of the network. Ninety-eight percent of the wells are closer than 6 mi to the nearest well in the network, but some of the wells in the remaining fraction are as far as 15 mi from the closest well. The distance, on average, to the nearest well is 2.8 mi.

Considering the areal extension of the aquifer to be approximately 29,000 sq mi, the well density in the network is 0.047 wells per square mile, or one well every 21.2 sq mi. According to equation (3), the distance index for the network is 1.22, which falls in the range of a stratified sampling.

REDUCTION IN NUMBER OF OBSERVATION WELLS

A positive change in an observation network would be a new configuration more closely approximating a regular sampling scheme. In an existing network, such an alternative is hardly feasible. For a system such as the High Plains aquifer network that has been in operation for decades (Olea, 1982), it is more realistic to limit expectations to development of an efficient stratified network.

The present system approximates a stratified network, with some areas of low sampling density and some clustering. If expansion of well coverage were under consideration, the goal should be to remedy lack of observation wells in areas of poor control. Reduction in number of wells calls for the elimination of clusters.

Table 1 records distance to nearest sampling site (observation well) and ranks the 29 wells proposed for elimination, providing the following information:

(1) There are 17 wells with a distance to nearest sampling site that is less than half the average distance. These wells fall in the lowest 11% of the cumulative distribution given in Figure 4.

(2) A second group of nine wells ranks between 510 and 923, fluctuating close to the average distance of 2.8 mi.

(3) Finally, there are three wells with distances greater than 3.3 mi.

Figure 5 summarizes the impact of the elimination of each one of the 29 wells. The proximity of wells in the first class means that they are all in clusters and can be eliminated safely from the data network. In fact, most of the other wells in the lower decile could also be eliminated without deterioration of network reliability. There are several pairs of wells so close to each other that they are in the same 10-acre tract, thus having the same well number; they do not, however, appear on the list of wells being considered for deletion. At least one well in every such pair is redundant.

Table 1. Distance and rank of wells in the proposed reduction.

	County	Location	Distance to nearest neighbor, mi	Rank
1	SEWARD	32S 33W 4BAA	2.648	621
2	SEWARD	35S 31W 18BBA	3.005	843
3	SEWARD	35S 34W 3CBC	0.372	14
4	MEADE	31S 28W 10BCB	1.056	73
5	MEADE	32S 29W 5CC	2.813	715
6	FORD	29S 26W 20BDD	0.638	33
7	FORD	29S 25W 3ADA	1.148	88
8	FORD	27S 22W 9DAB	3.611	1124
9	FORD	28S 26W 10BBA	2.491	524
10	FINNEY	21S 32W 8ABD	2.536	552
11	GRANT	28S 36W 21CDD	2.554	557
12	GRANT	27S 38W 22CBB	0.994	65
13	GRAY	25S 29W 27CCB	3.050	868
14	GRAY	28S 28W 7CDD	3.132	923
15	HASKELL	30S 31W 24BBC	0.998	68
16	STEVENS	31S 36W 24BCB	2.460	510
17	STEVENS	31S 38W 17CDA	3.342	1025
18	STEVENS	34S 35W 3DCC	3.401	1057
19	CHEYENNE	4S 41W 25BCB	1.245	107
20	KEARNY	24S 35W 13CCC	0.376	17
21	HAMILTON	24S 42W 4AAD	0.634	31
22	HAMILTON	24S 39W 35BAC	0.394	18
23	HODGEMAN	22S 24W 15BDA	0.628	28
24	HODGEMAN	22S 24W 26DDA	0.879	52
25	HODGEMAN	22S 24W 24DDD	1.006	71
26	SHERMAN	7S 37W 4BBC	1.187	94
27	SHERMAN	7S 40W 35BBB	1.244	104
28	SHERMAN	9S 39W 2BAB	1.450	148
29	SHERMAN	10S 42W 20ABB	0.500	20

The nine wells at the following locations fall into the second class:

32S 33W 4BAA	28S 26W 10BBA	25S 29W 27CCB
35S 31W 18BBA	21S 32W 8ABD	28S 28W 7CDD
32S 29W 5CC	28S 36W 21CDD	31S 36W 24BCB

It would be desirable to keep all nine wells in the second class in the network. They have a distance close to the average distance, and the elimination of any one of them will produce a moderate local deterioration in the reliability of estimates derived for the modified network.

The three wells in the last class, located at 27S 22W 9DAB, 34S 35W 3DCC, and 31S 38W 17CDA, must stay in the network. These wells provide important information about groundwater levels in areas away from any other observation well. Discarding these wells will produce a significant local increase in the uncertainty about water levels. If the wells have mechanical problems that preclude their continued use as observation wells, they should be replaced by other wells situated within 1 mi of their location.

CONCLUSIONS AND RECOMMENDATIONS

Ignoring logistic considerations or mechanical problems with the wells proposed for deletion, sound practice in the sampling of spatial attributes would dictate:

(1) *Eliminating 17 of the 29 wells* in the proposal at the following locations:

35S 34W 3CBC	31S 28W 10BCB	29S 26W 20BDD
29S 25W 3ADA	27S 38W 22CBB	30S 31W 24BBC
4S 41W 25BCB	24S 35W 13CCC	24S 42W 4AAD
24S 39W 35BAC	22S 24W 15BDA	22S 24W 26DDA
22S 24W 24DDD	7S 37W 4BBC	7S 40W 35BBB
9S 39W 2BAB	10S 42W 20ABB	

These are the only wells than can be discarded without having an impact on the reliability of the network.

(2) *Retaining three wells* located at 27S 22W 9DAB, 34S 35W 3DCC, and 31S 38W 17CDA which are far away for other observation wells. Either these wells or replacement wells situated within a short distance of these

locations should remain in the system to avoid a negative impact on network performance.

(3) *Retaining the other nine wells,* which should stay in the system if a moderate deterioration in the capability of the network to detect water lever fluctuations is to be avoided.

References

CLARK, P.J., and EVANS, R.C., 1954, Distance to nearest neighbors as a measure of spatial relationships in populations: *Ecology,* v. 35, no. 4, p. 445–453.

OLEA, R.A., 1982, Optimization of the High Plains aquifer observation network, Kansas: *Groundwater Series 7,* Kansas Geol. Survey, Lawrence, KS, 73 pp., 5 plates.

OLEA, R.A., 1984, Systematic Sampling of Spatial Functions: *Series on Spatial Analysis 7,* Kansas Geol. Survey, Lawrence, KS, 57 pp.

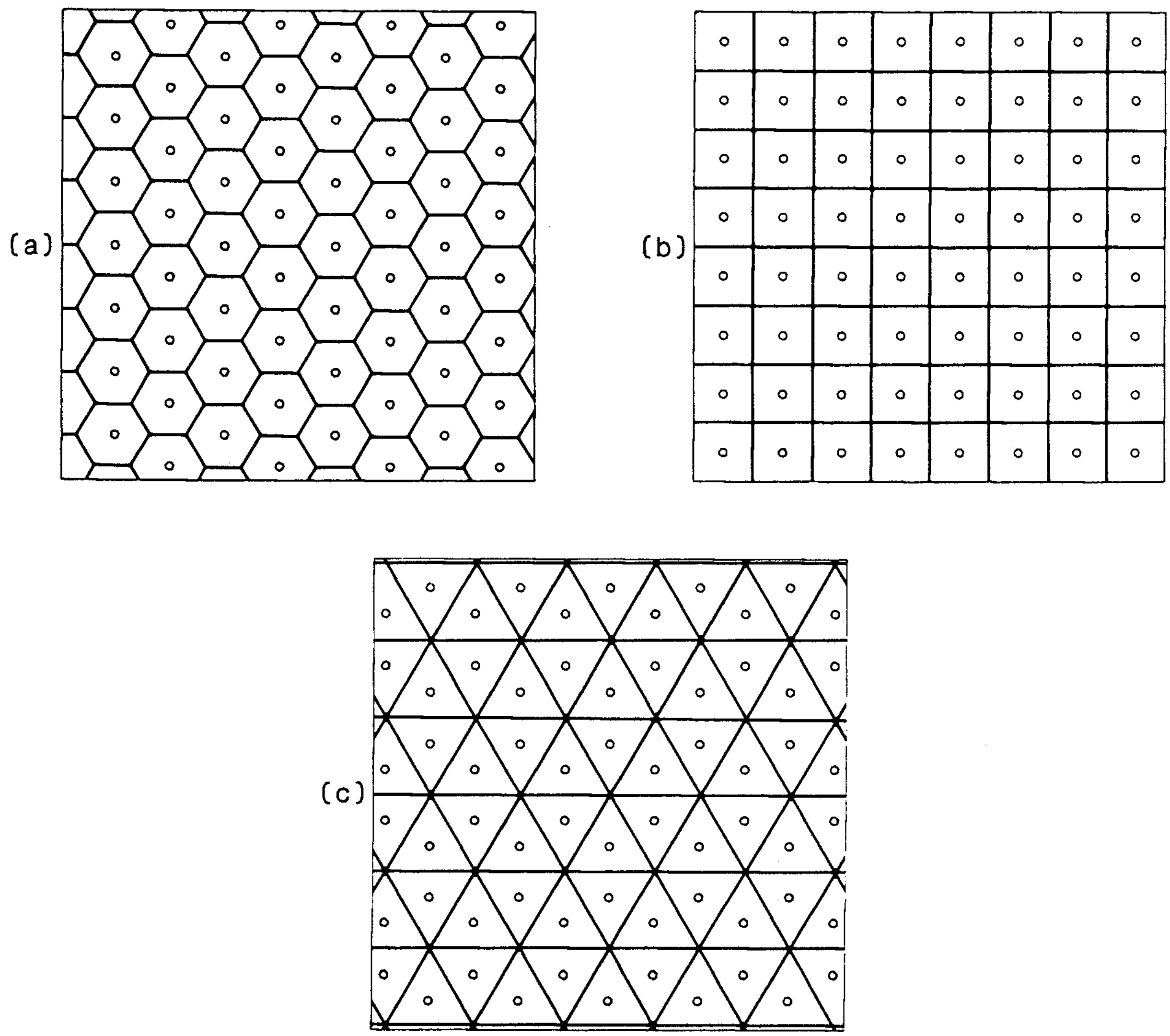

Figure 1. Regular sampling patterns: (a) Hexagonal, (b) Square, (c) Triangular.

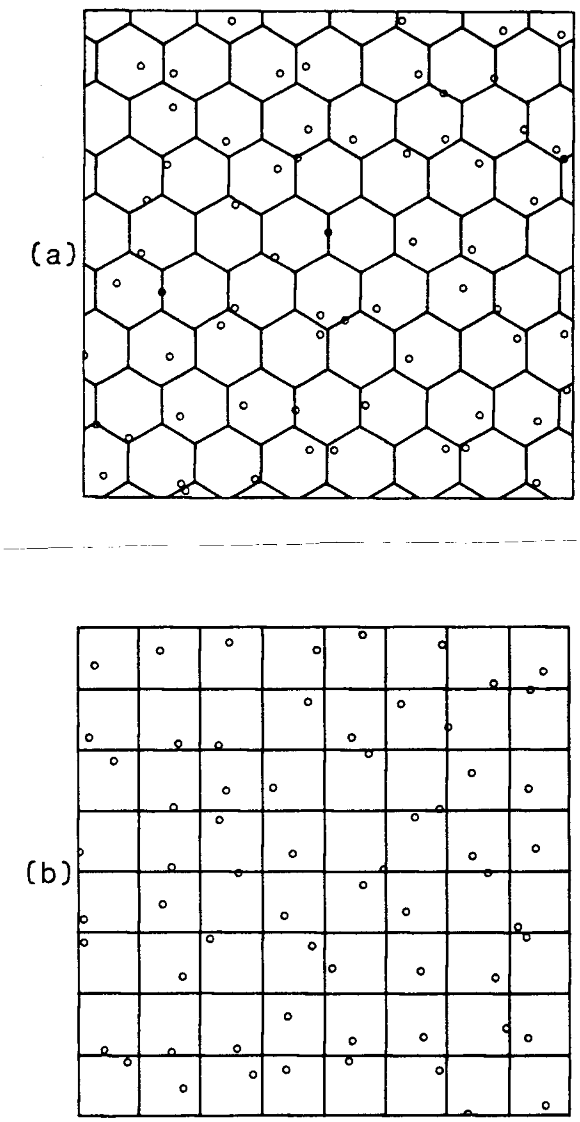

Figure 2. Stratified sampling patterns: (a) Hexagonal, (b) Square.

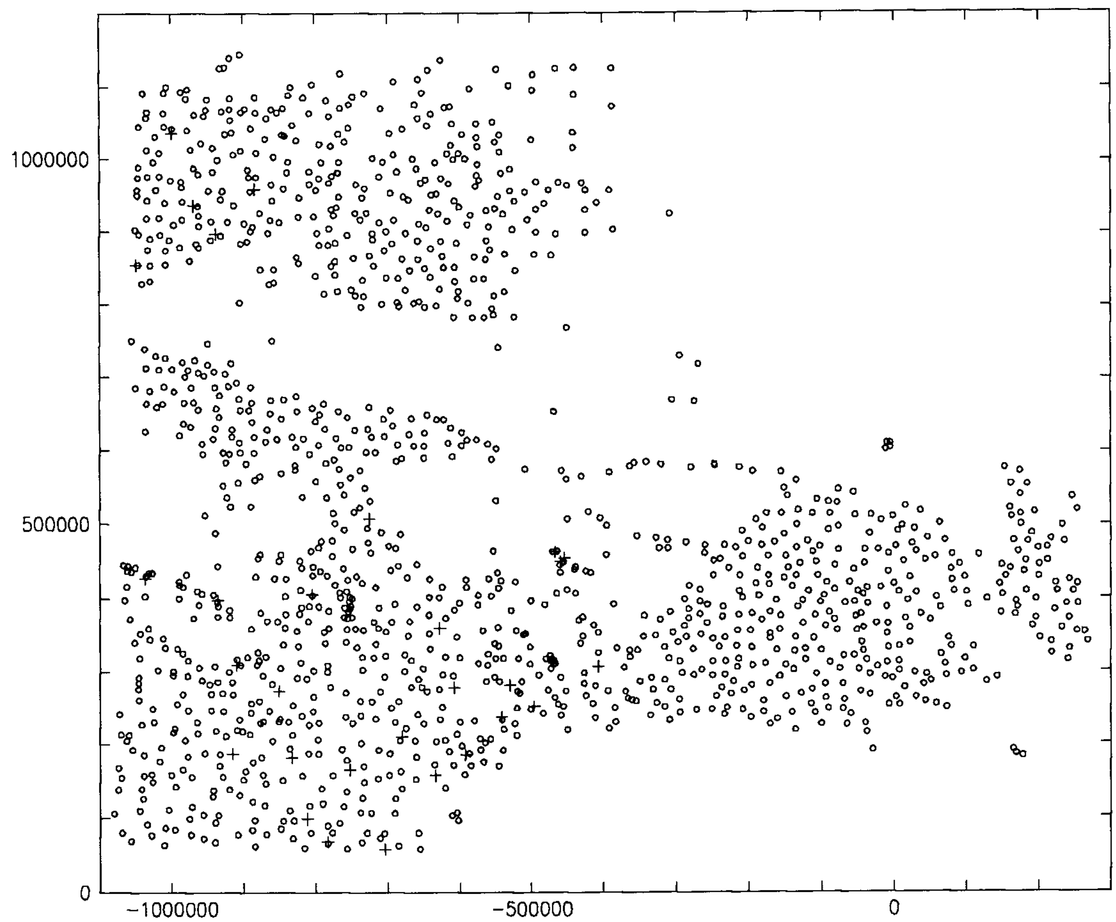

Figure 3. Groundwater level data network for the High Plains aquifer of Kansas. Crosses denote candidates for deletion; open circles indicate remaining wells.

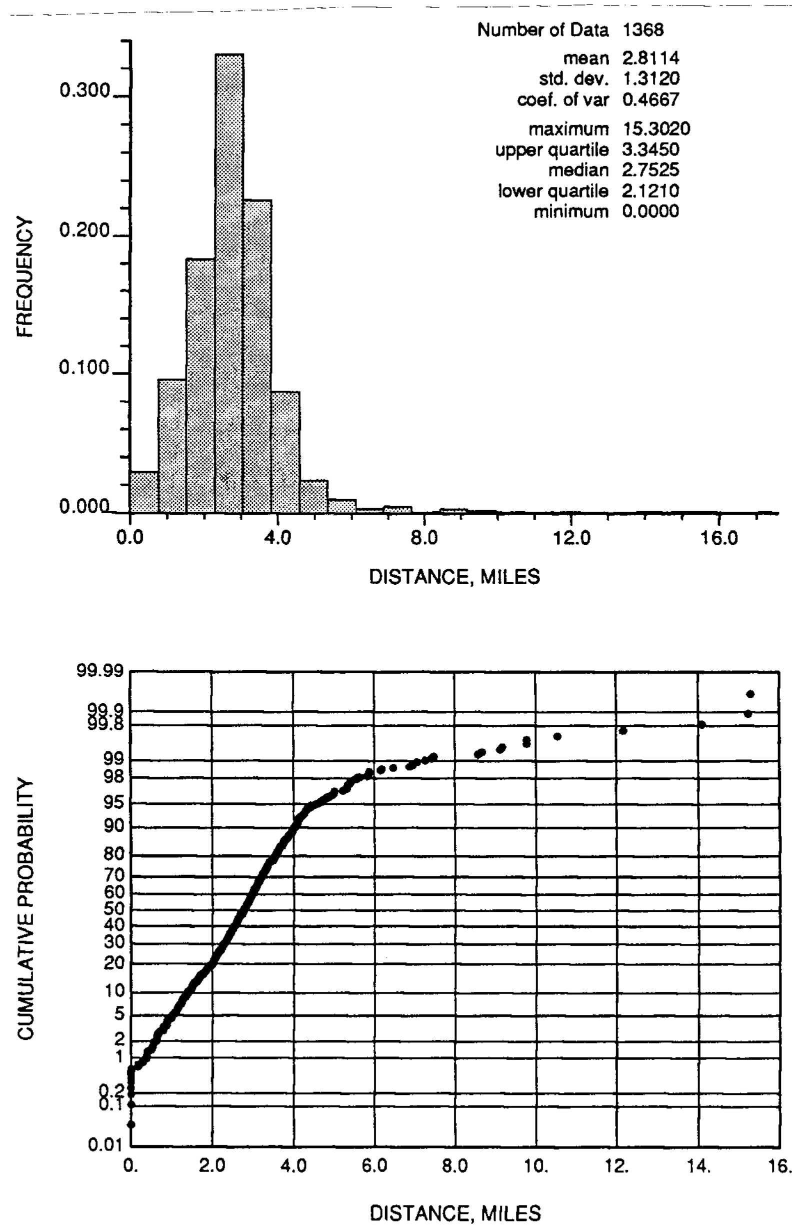

Figure 4. Distance to nearest sampling site: (a) Histogram, (b) Cumulative frequency.

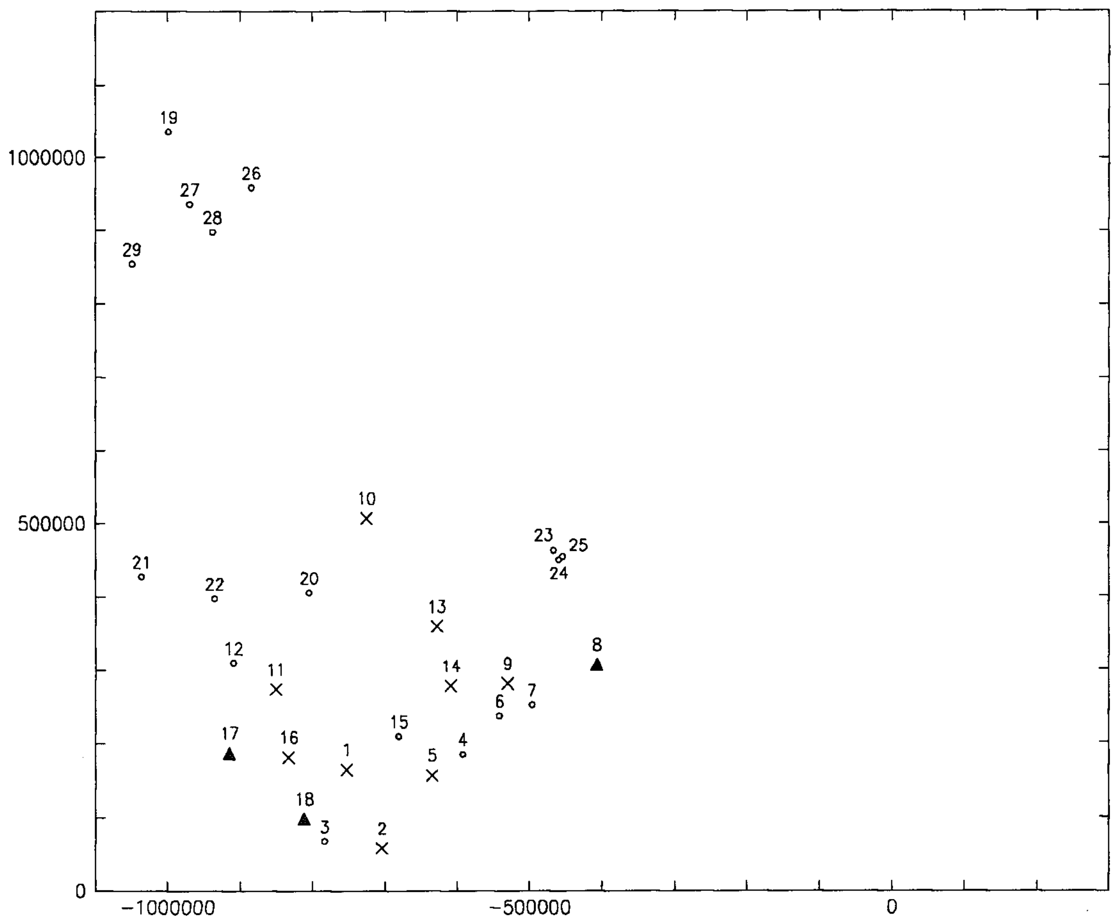

Figure 5. Wells considered for deletion. Labels are the sequential numbers in Plate 1. Open circles show locations of wells that need not remain in network; crosses denote wells that should be retained; solid triangles indicate wells that must remain in the network to avoid compromising network performance.

APPENDIX

Letter Requesting Evaluation of Proposed Well Deletions
List of Wells Accompanying Letter of Request

United States Department of the Interior

U.S. GEOLOGICAL SURVEY

Water Resources Division
4821 Quail Crest Place
Lawrence, Kansas 66049-3839

November 28, 1994

Dr. Lee Gerhard
Kansas Geological Survey
1930 Constant Avenue
Lawrence, Kansas 66045

Dear Lee:

Reference my letter to you dated October 25, 1994, concerning a reduction in scope for the Ground-Water Level Data Network. Since the USGS normally measures water levels in approximately 640 wells during the annual mass measurement of water levels, it was determined that we would reduce this number by 20 wells, or approximately three percent.

We have prepared a list of 30 wells from which to consider for deletion. Many of these wells have problems that would warrant their deletion irrespective of this funding situation. We feel that a reduction of 20 of these wells will not severely impact the network. Please let us know by December 16, 1994, which of these wells should be included on the final deletion list so we can make plans for this year's mass water level measurement beginning in January 1995.

Thank you for your continued cooperation in this important water level program. Should you have any questions, please contact me at 832-3505.

Sincerely,

Walter R. Aucott
District Chief

Enclosure

Copy to: David Pope, Division of Water Resources, Topeka, KS
Claude Geiger, Lawrence, KS
Barb Dague, Garden City, KS

LIST OF WELLS

Meade County

32S-33W-04BAA
35S-31W-18BBA
35S-34W-03CBC
31S-28W-10BCB
32S-29W-05CC

Ford County

29S-26W-20BDD
29S-25W-03ADA
27S-22W-09DAB
28S-26W-10BAA

Finney County

21S-32W-08ABD

Grant County

28S-36W-21CDD
27S-38W-22CBB

Gray County

25S-29W-27CCB
28S-28W-07CDD

Haskell County

30S-31W-24BBC

Stevens County

31S-36W-24BCB
31S-38W-17CDA
34S-35W-03DCC

Cheyenne County

04S-41W-25BCB

Kearny County

24S-35W-13CCC

Hamilton County

24S-42W-04AAD
24S-39W-35BAC

Hodgeman County

22S-24W-15BDA
22S-24W-26DDA
22S-24W-24DDD

Sherman County

07S-37W-04BBC
07S-40W-35BBB
09S-39W-02BAB
10S-42W-20ABB