

Optimization of the High Plains Aquifer Observation Network, Kansas



Ricardo A. Olea

Groundwater Series 7
1982

Kansas Geological Survey

FOREWORD

If one wishes to know something about a large population of anything, or about the behavior of a large system, especially for predictive purposes, a sampling procedure must be designed. This is true whether the subject of interest is toothpaste preference, voter attitudes, or dwindling reserves of groundwater in the High Plains aquifer in Kansas. Regardless of the size or distribution of a sample, some statistical error will remain; a compromise must be made that balances the smallest acceptable statistical error against the economic cost of obtaining the sample.

The Kansas Geological Survey has been involved for a number of years in research dealing with sampling design for geological problems, part of a larger effort referred to as "spatial analysis." This research experience has been applied by Ricardo A. Olea to a very practical problem, the costly program of monitoring the network of observation wells that measure the water level in the High Plains aquifer (including the Ogallala). This monitoring program has developed over a period of many years without systematic planning and with a considerable investment of State and Federal resources. Because the Kansas Geological Survey contributes funding for this program, the uncontrolled expansion of the sampling network has caused us to address the question of the number and configuration of observation wells required to characterize the water table of the High Plains aquifer with an acceptable error, at an acceptable cost. The U.S. Geological Survey, a cooperator in the groundwater program in Kansas and in other states, has recently defined network analysis as a high-priority concern, again because of uncontrolled costs. This report should provide a model for U.S.G.S. efforts.

The results of our sampling-design study of the High Plains aquifer are clear. A redesigned network will allow a reduction in the number of observation wells that must be monitored without significantly increasing the errors in the estimates of the water table elevation. The monetary savings can provide funds to expand the network into areas that are now inadequately sampled, or a reduced network can be operated at lower cost without significantly degrading the quality of the information. Some local government users of information from the existing network are reluctant to accept the findings of this report. While a sampling network more dense than the one suggested here would not be incompatible with Olea's recommendations, the cost may not be justifiable. Hard decisions must be faced as to who will pay for the additional information.



State Geologist and Director,
Kansas Geological Survey

Martin A. GSWA.

**Optimization of the High Plains Aquifer
Observation Network, Kansas**

by Ricardo A. Olea

**Kansas Geological Survey
Groundwater Series 7
1982**

TABLE OF CONTENTS

	Page
ABSTRACT	1
CHAPTER 1. INTRODUCTION.....	2
CHAPTER 2. OPTIMAL SAMPLING.....	4
2.1 Concepts and assumptions.....	4
2.1.1 Spatial function modeling.....	4
2.1.2 Spatial function estimation.....	5
2.2 Systematic sampling approach.....	8
2.2.1 Measures of sampling performance.....	8
2.2.2 Optimization procedure.....	8
CHAPTER 3. EXISTING SYSTEM.....	11
3.1 Water level.....	11
3.1.1 The High Plains aquifer.....	11
3.1.2 Data collection.....	13
3.2 The present network.....	15
3.2.1 Evaluation of the present network.....	16
3.2.2 Usage.....	17
CHAPTER 4. NETWORK ENHANCEMENT.....	22
4.1 Optimization limited to the existing observation wells.....	22
4.1.1 Specifications for a new network.....	22
4.1.2 An alternative equivalent network.....	23
4.2 Expansion of the network.....	25
4.2.1 Filling in gaps.....	25
4.2.2 Modifying the level of accuracy.....	30
CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS.....	32
5.1 Findings.....	32
5.1.1 The present observation network.....	32
5.1.2 Use of data.....	32
5.1.3 Level of accuracy.....	32

5.2	Suggestions.....	33
5.2.1	Upgrading the network.....	33
5.2.2	Network expansion.....	33
	REFERENCES.....	34
	APPENDICES.....	36
A.	STRUCTURAL ANALYSIS.....	36
A.1	Theory.....	36
A.2	Practice.....	38
B.	STATISTICAL TABLES.....	47
B.1	Selected patterns used in the tables.....	47
B.2	Sampling tables.....	50
C.	SAMPLING DESIGN EXAMPLE.....	59
D.	DISTANCE INDEX.....	61
E.	AVAILABLE OBSERVATION WELLS.....	62
E.1	High Plains aquifer wells.....	62
E.2	Wells in aquifers other than the High Plains aquifer.....	68
E.3	Excess wells per 10-acre tract.....	69
E.4	Wells without land surface elevation.....	70
E.5	Wells without truly static measurements.....	71
F.	WELL LOCATIONS TO BE INCORPORATED INTO THE NETWORK.....	72

ILLUSTRATIONS

	Page
FIGURES	
Figure 2.1	Basic elements in the theory of regionalized variables.....6
Figure 2.2	Graphic representation of the results of universal kriging of a two- dimensional spatial function.....7
Figure 3.1	Areal extension of the High Plains aquifer.....12
Figure 3.2	Well numbering scheme.....14

Figure 3.3	Standard error of water table elevation in present network.....	16
Figure 3.4	Location of 18 clusters of two wells selected for decline curve correlation.....	20
Figure 3.5	Decline curves for four wells in Finney County.....	20
Figure 3.6	Regressions between water table elevations in pairs of wells for four wells in Finney County.....	21
Figure 4.1	Hexagonal stratification used to randomly select observation wells.....	23
Figure 4.2	Standard error of water table elevation in proposed network.....	24
Figure 4.3	Differences between water table elevations estimated using proposed and present networks.....	25
Figure 4.4	Water table elevation and observation well locations in Equus Beds area.....	27
Figure 4.5	Presently unsampled locations where more than 40 feet of saturated thickness is expected.....	29
Figure 4.6	Presently unsampled locations where less than 40 feet of saturated thickness is expected.....	30
Figure 4.7	Network size as a function of level of accuracy.....	31
Figure A.1	Transitive type semivariogram.....	37
Figure A.2	Locations of traverses used in structural analyses.....	39
Figure A.3	Semivariances of water table elevations.....	41
Figure A.4	Semivariances of residuals from a first-degree polynomial drift of water table elevations.....	43
Figure A.5	Average semivariances of residuals from a first-degree polynomial drift for all traverses.....	44
Figure A.6	Semivariances of residuals from a second-degree polynomial drift of water table elevations.....	45
Figure A.7	Average semivariances of residuals from a second-degree polynomial drift for all traverses.....	46
Figure B.1	Sample element patterns investigated in this study.....	48
Figure B.2	Sampling mechanism for stratified patterns.....	49

PLATES [in pocket]

- Plate 1. Water table elevation as perceived using the present network of 1749 wells
- Plate 2. Standard error for the water table elevation as perceived using the present network of 1749 wells
- Plate 3. Water table elevation as perceived using the proposed network of 1135 wells
- Plate 4. Standard error for the water table elevation as perceived using the proposed network of 1135 wells
- Plate 5. Comparison of maps of water table elevation based on current and proposed networks

LIST OF TABLES

	Page
Table 3.1	15
Table 3.2	15
Table 3.3	19
Table 3.4	21
County.....	21
Table 4.1	24
Table 4.2	28
Table A.1	40
Table B.1	50
Table B.2	51
Table B.3	52
Table B.4	53
Table B.5	54
Table B.6	55
Table B.7	56
Table B.8	57
Table B.9	58

OPTIMIZATION OF THE HIGH PLAINS AQUIFER OBSERVATION NETWORK, KANSAS

Ricardo A. Olea

ABSTRACT

The network of observation wells which monitor the water table of the High Plains aquifer in Kansas has developed without systematic planning over a period of many years. The efficiency of this network can be evaluated by sampling design procedures based on universal kriging, an estimation method that is part of the statistical theory of regionalized variables. Information gathered by the High Plains observation well network is used primarily as input to hydrologic models and to assist in decision-making by groundwater managers responsible for controlling the exploitation of the aquifer. It was found that the present observation well network is not optimal because of the haphazard location of observation wells. An alternative network designed in a hexagonal stratified pattern would allow a reduction in the number of observation wells from 1749 to 1135 without significantly changing either the average standard error of the water table elevation [currently at 12 feet (3.7 m)] or the form of the contour map of water table elevations. Monetary savings achieved by reducing the number of wells could be used to operate the network at a lower cost or could provide funds to measure wells in inadequately sampled areas; this would allow reduction of the maximum standard error from its present value of 36.6 feet (11.2 m) to 13.3 feet (4.1 m).

CHAPTER 1

INTRODUCTION

Groundwater is a vital resource in areas with insufficient alternative surface sources of water or with unfavorable annual precipitation. In western Kansas, the High Plains aquifer provides about 95 percent of all the water for irrigation. Prior to 1930, agriculture consisted primarily of dryland farming and cattle grazing. Although groundwater irrigation technology was developing on the Plains, the number of irrigation wells did not increase substantially until after the drought of the 1930's. The agricultural economy of the State developed rapidly because of the availability of low-cost energy and water. However, the situation has reversed in recent years because the cost of pumping is increasing and the water level in the wells is declining. In some areas the economics of the situation have deteriorated to the point where irrigation is no longer profitable and farmers are returning to dryland farming (Gutentag and Weeks, 1980). At the present pumping rate, most of the State will be forced to return to dryland farming by the turn of the century.

Although pumping costs are out of control, groundwater depletion can be avoided with judicious management. If an aquifer is not disturbed by man, it is unexhaustible at the human scale of time because over the long run the recharge equals the discharge. This equilibrium often is disturbed by seasonal and climatic changes. Ideally, a well-managed aquifer can tolerate some artificial upstream pumping provided the material balance is not altered by total natural and artificial withdrawals larger than the recharge. An aquifer, in terms of the use of the resource, can be considered renewable or non-renewable depending on the pumping rate. Under excessive pumping, the aquifer will behave like an oil field which eventually becomes depleted. A properly managed aquifer, on the other hand, is an eternal source of water.

State and federal agencies having regulatory responsibilities over natural resources began monitoring the water level through scattered observation wells which became more numerous as the decline in water level became a real concern. The number and location of observation wells did not follow any rational guidelines; rather, the number of monitored wells increased as if more accurate observation of the effects of depletion would cure its causes. At the present time, the depth to water is measured every winter in more than two thousand observation wells around the State. The budget for measurements in the 1981 season was \$106,000 (United States Geological Survey, 1980). Over the years, the adequacy of the network has been the subject of several conversations and meetings, but with no final resolution. Contradictory opinions have been expressed, as some believe even more observation wells are necessary and others consider that the network is already too expensive to operate and there should be no increase in the number of wells. The lack of a concensus has been partly due to the absence of basic information in network design on which to establish a scientifically sound decision. The existing literature presents a few partial studies of observation networks, primarily in the area of mining. The findings are not conclusive and are difficult to extrapolate to geohydrology.

The Kansas Geological Survey has both an academic and economic interest in the problem. The Geohydrology Section is by far the main research user of observation well data. The operational costs of the network are shared approximately equally between the federal government, represented by the United States Geological Survey, and the State of Kansas, represented by the Division of Water Resources and the Kansas Geological Survey.

The analysis of the Kansas groundwater observation well network is not an isolated problem, but rather an example of the more general problem of data collection for the purpose of characterizing phenomena such as the porosity in a rock formation or the Earth's gravitational field, which are functions of geographical coordinates, or spatial functions. The Kansas Geological Survey decided to sponsor a project to evaluate the Kansas groundwater observation well network and also to investigate the more general problem of the sampling of spatial functions. The project has produced a methodology which requires only the use of a hand calculator and tables (Olea, 1982a, 1982b). Using these simple tools, it requires only a few minutes to design an optimal sampling procedure which will achieve a specified level of accuracy when applied to a spatial function. The methodology is the backbone of this exhaustive study of the High Plains aquifer observation well network in the State of Kansas. The main objectives of the study are:

1. To describe the characteristics of the observation well network as a data gathering system.
2. To determine the main uses of information collected by the observation well network.
3. To determine an appropriate level of accuracy for the observation well network.
4. To present alternative designs to the existing network by applying a systematic sampling procedure designed to optimally sample spatial functions.
5. To clearly state any changes in accuracy and cost that would be obtained by the utilization of modified versions of the present network.

CHAPTER 2

OPTIMAL SAMPLING

This chapter is a brief presentation of the methodology used to design an optimal observation well network for the High Plains aquifer in Kansas. A more complete discussion will be found in Olea (1982a, 1982b).

2.1 CONCEPTS AND ASSUMPTIONS

2.1.1 Spatial function modeling

A water table is a special case of a more general type of n-dimensional surfaces called spatial functions. Mathematically, a spatial function is an association of numbers to a domain of geographical coordinates. Some spatial functions, such as the water table elevation, are time dependent; others, such as the thickness of a geological formation, are invariant at the human scale of time.

Typical spatial functions are continuous and uniquely defined over sizable domains. Some, such as geothermal gradients, are not easily measurable and present an expensive and time-consuming problem in terms of the effort required for their accurate characterization. Commonly, such functions are known only partially through a scattered set of observations. In statistical jargon, the selected observations are called a sample (James and James, 1976, p. 339) and each individual measurement is called a sample element (Williams, 1978, p. 27).

Even if the observations have been carefully taken to avoid measurement error, the spatial function is only known with certainty at the sampled locations. The exact value of the spatial function at unsampled locations is subject to uncertainty, as no method has yet been devised which will yield error-free estimates. Even though there might be only one value of the spatial function at any location in the sampling domain, the unknown estimated value is more thoroughly described by a collection of likely values than by a single number. A tabulation of events and their associated probability of occurrence corresponds to the statistical concept of a probability density function (Hogg and Craig, 1979, Section 1.6). In statistical terms, a quantity which may take any of the values of a certain set with a specified relative frequency is called a random variable or a variate (Kendall and Buckland, 1971, p. 162). There will be as many random variables as locations in the sampling domain. The set of all random variables associated with a given spatial function constitutes what is known as a random function (Matheron, 1971, p. 50).

Listing a random function describing a spatial function is a cumbersome task. It would be desirable to summarize the function in an informative, short description rather than listing all its possible outcomes. For this purpose we may invoke the use of mathematical expectations. The average of all possible outcomes of a variate weighted by their probability of occurrence is the mean and represents a central value of the population. The weighted average of the squares

of the differences between the outcomes and the mean is the variance (Hogg and Craig, 1970, p. 46). The square root of the variance is the standard deviation. As the variance becomes larger when the differences increase, the variance and the standard deviation are a measure of the dispersion of the outcomes relative to the mean value. The standard deviation could also be interpreted as a measure of the uncertainty as to the true value of the spatial function. A small standard deviation indicates the outcomes are clustered tightly around the central value over a relatively narrow range of possibilities. Conversely, a large standard deviation indicates that the actual value could be any of a larger range of possibilities.

2.1.2 Spatial function estimation

The theory of regionalized variables is a set of statistical principles which describe spatial functions and their sampling without regard to the physical nature of the variable under study. Universal kriging is an estimation method based on regionalized variable theory presenting the unique peculiarity of providing both unbiased estimates of spatial functions and a measure of reliability associated with each of those estimates. For these reasons, universal kriging is particularly suited to estimating the central value and the dispersion of the variates used in spatial function modeling.

Spatial functions which satisfy certain basic assumptions in the theory are called regionalized variables. The term geostatistics has come to mean the specialized body of statistical techniques originally developed in France by Prof. G. Matheron and his associates to treat regionalized variables (Matheron, 1965, 1971). Typical spatial functions amenable to estimation using geostatistics include the ore content in a mineralized body; the porosity of sedimentary rocks; the amount of precipitation per square mile; and the elevation of the tops of subsurface formations. Fluctuations in space- and time-dependent data are erratic and often unpredictable from one location to another, but by and large there is an underlying trend in the fluctuations which precludes regarding the data as the result of a completely random process. Closely spaced samples, for example, typically are statistically autocorrelated. In certain instances sample elements, such as the drill cores used to assay ore grades, have size, shape, and orientation. The spatial characteristics of a sample element constitute what is called the support.

The intrinsic hypothesis is a stationarity constraint used for purposes of statistical inference. Let $Z(\vec{x})$ and $Z(\vec{x}+\vec{h})$ be two of the random variables comprising the regionalized variable. The arrow ($\vec{}$) over the geographical coordinate indicates a vectorial property, implying orientation and magnitude in n-dimensional space. The difference between two random variables [$Z(\vec{x}) - Z(\vec{x}+\vec{h})$] is yet another random variable. A regionalized variable is said to satisfy the intrinsic hypothesis if the difference [$Z(\vec{x}) - Z(\vec{x}+\vec{h})$] is second-order stationary. In other words, a regionalized variable satisfies the intrinsic hypothesis if, for any displacement \vec{h} , the first two moments of the difference [$Z(\vec{x}) - Z(\vec{x}+\vec{h})$] are independent of the location \vec{x} and are a function only of \vec{h} :

$$E [Z(\vec{x}) - Z(\vec{x}+\vec{h})] = M(\vec{h}) \quad (2.1)$$

$$E [\{Z(\vec{x}) - Z(\vec{x}+\vec{h}) - M(\vec{h})\}^2] = 2\gamma(\vec{h}) \quad (2.2)$$

In the specialized language used in geostatistics, $M(\vec{h})$ and $\gamma(\vec{h})$ are referred to as the drift and the semivariance or intrinsic function. The units of $M(\vec{h})$ are the same as the units of $Z(\vec{x})$, and the units of $\gamma(\vec{h})$ are the square of the units of $Z(\vec{x})$. Provided the intrinsic hypothesis is met, both moments can be estimated.

There are a few important circumstances under which geostatistics can be applied even if the intrinsic hypothesis does not hold. Of special interest is the situation when the regionalized variable is not first-order stationary because the drift has a systematic trend, as shown in Figure 2.1. Removing the drift from the regionalized variable results in a difference called the residual. Regionalized variable theory is still applicable if the intrinsic hypothesis holds for the residuals.

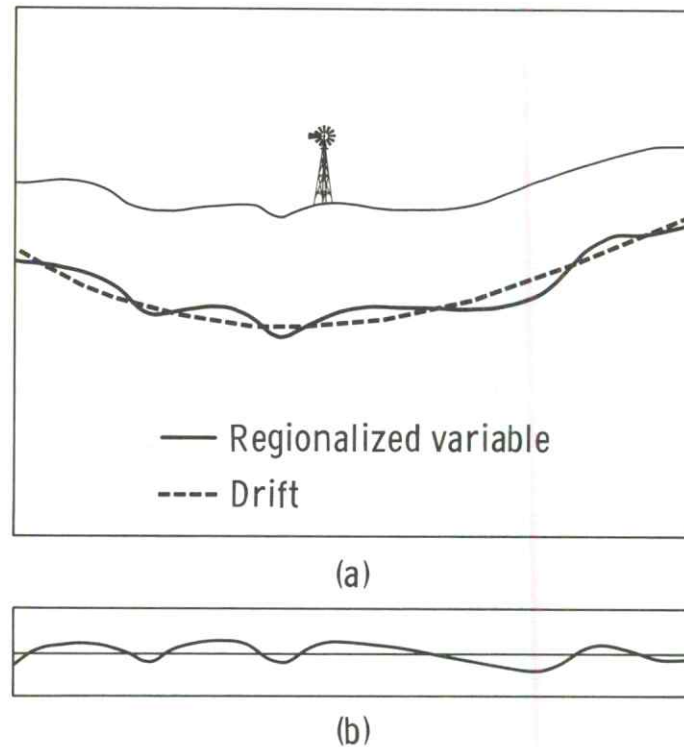


FIGURE 2.1. Basic elements in the theory of regionalized variables. (a) Regionalized variable and drift. (b) Residual after subtraction of the drift from the regionalized variable.

Structural analysis is the term applied to the study of semivariograms for the purpose of extracting information about the nature of fluctuations in a regionalized variable. Appendix A contains a detailed structural analysis of the water table elevation in the High Plains aquifer in Kansas.

Universal kriging is a linear estimator within the regionalized variable theory and has the form:

$$Z^*(\vec{x}_0) = \sum_{j=1}^k \lambda_j Z(\vec{x}_j) \quad (2.3)$$

Finding the set of weights λ_j 's which minimizes the estimation variance under the constraint that the estimator must be unbiased is a linear programming problem. The final product of universal kriging estimation at a given location \vec{x}_0 consists of two numbers: the estimated value of the spatial function and the estimation variance.

The standard deviation of an unbiased estimator is called the standard error (James and James, 1976, p. 139). Since the standard error is given in the same units as the regionalized variable itself, it is more commonly used as a measure of uncertainty in the estimate than is the estimation variance. Universal kriging is the only spatial function estimation method that provides a standard error of the estimate.

If universal kriging is repeatedly performed for discrete locations within the area of interest, the estimates can be passed to a graphical display package to create spatial representations of the regionalized variable. Possible forms of representation include block diagrams, cross-sections, or contour maps of either the variable itself or the standard error of the variable. Figure 2.2a is a graphical solution of the problem of continuously representing a spatial function known only at discrete points and Figure 2.2b shows the corresponding standard error map.

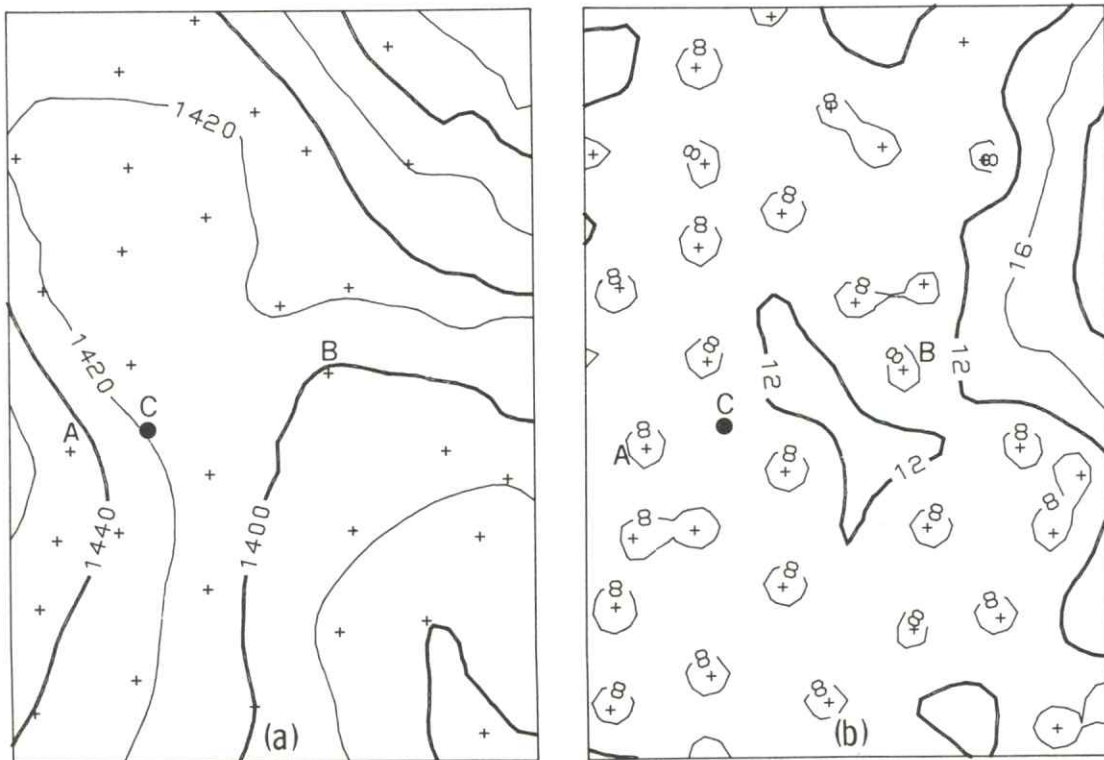


FIGURE 2.2. Graphic representation of the results of universal kriging of a two-dimensional spatial function. Crosses represent locations of sample elements. (a) Most likely representation of the spatial function. (b) Standard error.

2.2 SYSTEMATIC SAMPLING APPROACH

2.2.1 Measures of sampling performance

The global performance of samples over the sampling domain of a spatial function can be judged by two indices, average standard error and the maximum standard error, which in turn depend on:

1. Unmanageable factors
 - a. The semivariance
 - b. The drift
2. Manageable factors
 - a. The size of the sample subset considered by the estimate
 - b. The sample pattern
 - c. The sample density

The factors which influence the sampling efficiency indices are not alike; two have nothing to do with sampling and a third is only partially related to sampling. The semivariance and drift are inherent characteristics of the spatial function. The designer of the sampling program can only select models of these characteristics that provide the best fits to the true semivariance and the drift. Specification of the size of the sample subset to be used in the universal kriging estimation equations is primarily a problem in computational efficiency, with some sampling implications. This leaves sample pattern and sample density as the only two factors which offer wide flexibility in the design of the sampling scheme.

2.2.2 Optimization procedure

The selection of the best sampling efficiency factors is an operations research problem which can be organized as a systematic procedure to yield an optimal solution if the problem is feasible. The procedure is subject to the following constraints: (a) The residuals satisfy the intrinsic hypothesis. (b) The physical size of the support of the sample elements and the estimated value are the same. (c) The sampling space is two dimensional. (d) The semivariogram of the residuals is linear.

All constraints are met by the data on water table elevations in the High Plains aquifer. The constraints are sufficiently weak that the method should be applicable to many other spatial variables as well. The second constraint is the strongest and excludes certain special functions which are of interest in ore reserve estimation. The third constraint is satisfied in all mapping problems. Even in studies of three-dimensional spaces, samples may be collected in a series of two-dimensional planes, which helps to satisfy the second constraint. The semivariance is a monotonically increasing function close to the origin. Because even complex

functions can be approximated by linear piecewise interpolation procedures, the problem of satisfying the fourth constraint becomes one of determining how large a portion of the semivariogram can be approximated by a straight line.

Algorithm 2.1

The following is a procedure for finding the optimal sampling method for a specified sampling efficiency index.

1. Perform a structural analysis.
2. Decide whether the average standard error or the maximum standard error is the index to be minimized.
3. Enter Table B.1 for the specified index and appropriate drift. Choose the pattern with the lowest index in the table. In case of a tie, use the pattern with the minimum alternative index.
4. Specify a value for the sampling efficiency index.
5. Compute the desired density ρ by

$$\rho = \omega^2 \left[\frac{I(1,1)}{I(\omega,\rho)} \right]^4 \quad (2.4)$$

where ω is the slope of the linear semivariogram; $I(1,1)$ is the efficiency index in Table B.1 for the given pattern at a density of one point per square mile (0.39 points/km²) and a semivariogram slope of one; and $I(\omega,\rho)$ is the desired level for the efficiency index of step 2.

6. Calculate the number of sample elements within the neighborhood for which the models in the structural analysis are valid.
7. Compare the number of sample elements inside the neighborhood with the minimum number of points necessary to achieve a solution of the universal kriging system of equations in Table B.3. Should the number of points inside the neighborhood be insufficient, the solution is unfeasible. In case a solution is required, go back to step 1 and redefine parameters. Otherwise, stop. If there are enough sample elements inside the neighborhood, proceed to the next step.
8. Enter Table B.2 and determine the point of no return.
9. Compare the sample elements inside the neighborhood to the point of no return. If the point of no return is smaller than the number of points that can be placed inside the neighborhood, use a number of nearest neighbors equal to the point of no return and stop. Otherwise use a number of nearest neighbors equal to the number of points inside the neighborhood.
10. Find in Appendix B, tables B.4 to B.9, the selected index and appropriate drift. Take the pattern that minimizes the index for the number of nearest neighbors computed in the previous step.

11. Enter the minimum index selected on the preceding step into Equation 2.4 to recompute the optimal density.

Stop.

Appendix C contains an example of the use of the algorithm.

CHAPTER 3

EXISTING SYSTEM

The theoretical review in Chapter 2 is complemented with a description of the High Plains aquifer and the present network used to monitor the groundwater level in the State of Kansas.

3.1 WATER LEVEL

3.1.1 The High Plains aquifer

Groundwater is one of the most precious natural resources in Kansas, and among all aquifers in the State by far the largest and most important is the High Plains aquifer. An aquifer is defined as a water-saturated permeable geologic unit able to transmit significant amounts of fluids under normal pressure gradients (Freeze and Cherry, 1979, p. 47). The High Plains aquifer extends over an area of 177,000 square miles (440,000 km²), 29,000 (75,000 km²) of them in Kansas and the remainder in parts of the states of Wyoming, South Dakota, Nebraska, Colorado, New Mexico, Oklahoma, and Texas, as shown in Figure 3.1. Flat to gently rolling terrain characterizes the High Plains region, which is a remnant of a vast plain which was formed of sediments deposited by streams flowing eastward from the Rocky Mountains. Subsequently, erosion isolated the plains from the mountains. The aquifer consists, as defined by the United States Geological Survey (Gutentag and Weeks, 1980), of one or more hydraulically connected geologic units of late Tertiary or Quaternary age. In ascending order, the late Tertiary rocks consist of the Brule Formation, Arikaree Group, and the Ogallala Formation, the latter being the only one present in Kansas (O'Connor and McClain, 1981, p. 5). The Quaternary deposits consist of alluvial, dune-sand, and valley-fill deposits.

The High Plains aquifer is primarily a closed system, but various vertical and lateral connections with other aquifers preclude regarding it as a perfect hydrologically isolated unit. Thus, the exact boundary of the aquifer is defined differently by various authors. The boundary shown in Figure 3.1 is essentially the eroded edge of the geologic units comprising the aquifer.



FIGURE 3.1. Areal extension of the High Plains aquifer (after Gutentag and Weeks, 1980).

3.1.2 Data collection

In the High Plains aquifer today, an estimated 168,000 irrigation wells are producing 30 million acre-feet ($3.7 \times 10^9 \text{ m}^3$) of water each year which is used to irrigate about 16 million acres ($64.7 \times 10^6 \text{ km}^2$) (Gutentag and Weeks, 1980). To judge the impact on the aquifer of pumping by more than 25,000 wells in Kansas, periodic measurements of the water table depth are made. A water table is defined as the static locus of those locations where the fluid pressure confined in a porous aquifer is equal to the atmospheric pressure (Freeze and Cherry, 1979, p. 39). The water table at a particular location is revealed by the level to which water stands in the borehole of a well deep enough to penetrate into the aquifer. For most wells, measurement of depth to water is made directly with a metallic tape lowered through a hole in the surface flange. The measurement represents depth to water in the annular space between the protective casing and the production pipe. Provided that the beginning of the scale in the tape is always at the bottom of the well, the depth to water is computed directly as the difference between the reading on the surface minus the length of the wet portion of the tape. The trickiest part of the measuring consists in guaranteeing that the tape stays straight inside the annular space.

A small fraction of the observation wells are only used to measure depth to water, but most of the wells used in the survey are producing wells. To avoid drawdown cone effects due to recent pumping in the well itself or in the surrounding wells, the measurements are taken during the wintertime when irrigation stops for several months.

The United States Geological Survey, Division of Water Resources, and the Kansas Geological Survey support a program to measure, file, and report the depth to water in more than 2,000 wells throughout the State. The reported values are location, depth to water, and land surface elevation. The difference of the last two provides the altitude of the water table, called water table elevation. Location is reported in the Bureau of Land Management's system of land subdivision. In that system, the first set of digits of a well number indicates the township; the second set, the range east or west of the Sixth Principal Meridian; and the third, the section in which the well is located. The first letter denotes the 160-acre tract; the second, the 40-acre tract; and the third, the 10-acre tract. The example in Figure 3.2 shows that the well number 26 2W 22ABA means the well is in the NE 10-acre tract of the NW 40-acre tract of the NE 160-acre tract in section 22, township 26 south, range 2 west (Broeker et al., 1977, p. 2). The well number system, although very practical in the field, has two major analytical drawbacks. The location of a well is not referred to orthogonal axes, which necessitates intermediate conversions and map projection in order to convert the locations to a form suitable for standard mapping packages. Secondly, wells in the same 10-acre tract have the same well number. The problem has been partially solved for inventory purposes by adding a sequential number. For instance, the well number 26 8W 26CAB 2 means that the well is the second in the 10-acre tract 26S 8W 26CAB. The sequential number tells nothing about the location of the well within the 10-acre tract. Because of the lack of information, existing computer programs to convert well numbers to orthogonal coordinates assign the same abscissa and ordinate to all wells within the same 10-acre tract (Morgan and McNellis, 1969; Ross, 1981).

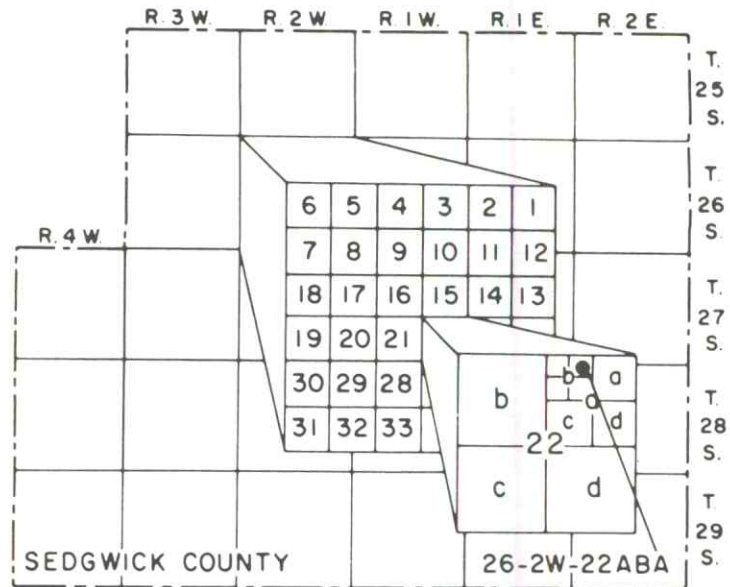


FIGURE 3.2. Well numbering scheme, based on the Bureau of Land Management system of land subdivision. Illustration shows location of a well whose number is 26S 2W 22ABA (after Broeker, et al., 1977, p. 5).

The United States Geological Survey archives the information and releases an annual report containing depth to water for most of the observation wells in western Kansas, in forms such as Open-File Report 81-1001 (Pabst, 1981). Other measurements are available on request to the USGS computer files at the national headquarters in Reston, Virginia. Presently, data collection is a joint effort of the United States Geological Survey, the Division of Water Resources of the Kansas State Board of Agriculture, and the city of Wichita, Kansas.

Data used in the study were the latest available at the outset of the study and consist of measurements made from December 1980 to March 1981. These observations are called the "January 1981 data" because, except in special circumstances, annual measurements are scheduled to be taken during the first month of every year. The High Plains aquifer is thoroughly covered by the observation wells monitored by the United States Geological Survey except for the extreme northeast area around McPherson County. A few additional wells were obtained from the local Groundwater Management District No. 2 (T. C. Bell, 1981, personal letter). Table 3.1 lists the wells by file source.

Not all observation wells measured throughout the State are of interest for this study. Only 1749 of the original 2091 observation wells were included; these are listed in Appendix E.1. A total of 189 observation wells was deleted because they were in aquifers other than the High Plains aquifer (see Appendix E.2). Wells having the same coordinates cause duplicate equations in universal kriging, which results in singular matrices. Therefore, all wells except one were discarded from 10-acre tracts which contain more than one well. These wells with duplicate coordinates are listed in Appendix E.3. Wells which have no reported land surface elevation cannot be used to calculate the water table elevation. Appendix E.4 lists 40 wells

TABLE 3.1

DEPTHS TO WATER TABLE IN JANUARY 1981 OBSERVATION WELLS
LISTED BY ORIGIN OF DATA

Source	No. of Wells
United States Geological Survey	1988
Groundwater Management District No. 2	<u>103</u>
Total	2091

that were deleted because they did not have this basic information. Finally, Appendix E.5 contains 20 wells whose depths to water were considered not to represent the true static depth, as determined by both the history of the well and the surrounding records (Pabst, 1981; M. E. Pabst, 1982, personal communication). Table 3.2 lists the number of wells in each category.

TABLE 3.2

OBSERVATIONS THAT WERE DISCARDED FROM THE SET OF JANUARY 1981
OBSERVATION WELL DEPTHS TO WATER,
WITH REASON FOR DISCARDING

Category	High Plains	Other Aquifers
Same 10-acre tract	93	---
No land surface elevation	24	16
Not truly static	20	---
Net measurements	<u>1749</u>	<u>189</u>
Total	1886	205

3.2 THE PRESENT NETWORK

The present observation network for the Kansas High Plains aquifer consists primarily of the 1749 wells measured during January 1981. The exact count of wells varies from year to year as a few additional observation wells are incorporated into the system, others are dropped, and a small percent are not measured because of access problems resulting from severe weather.

3.2.1 Evaluation of the present network

The water table elevation was first analyzed to define its spatial characteristics. From the structural analysis in Appendix A, it can be seen that:

- a. The water table is not first-order stationary. There is an east dipping trend which can be modeled by a first-degree polynomial.
- b. Within a neighborhood of 28 miles (45 km) in diameter, the semivariance of the residuals is well described by a linear model with a slope of 60 feet²/mile (3.5 m²/km).

The results of the structural analysis and the 1749 water table elevations were entered into the graphics package SURFACE II (Sampson, 1978) to produce a contoured map of the surface of the water table (Plate 1) and its associated standard error (Plate 2). The aquifer boundary shown in the Plates is slightly different from the general boundary in Figure 3.1, as the Plates incorporate corrections by McClain and O'Connor (1981) and the results of detailed work done on the lithological description of the observation wells. Some of the "windows" or areas where the aquifer is missing represent local outcropping bedrock or thin, impervious parts of the aquifer which are not hydraulically connected to the main aquifer and which are not of economic interest. Crosses indicate locations of the 1749 observation wells. Figure 3.3 is a relative frequency graph based on the 5820 values in the regular grid computed by SURFACE II as an intermediate step in the preparation of the contour map. The mean of the standard errors is 12 feet (3.7 m), the standard deviation of the standard error is 4.1 feet (1.25 m), and the maximum standard error is 36.6 feet (11.2 m).

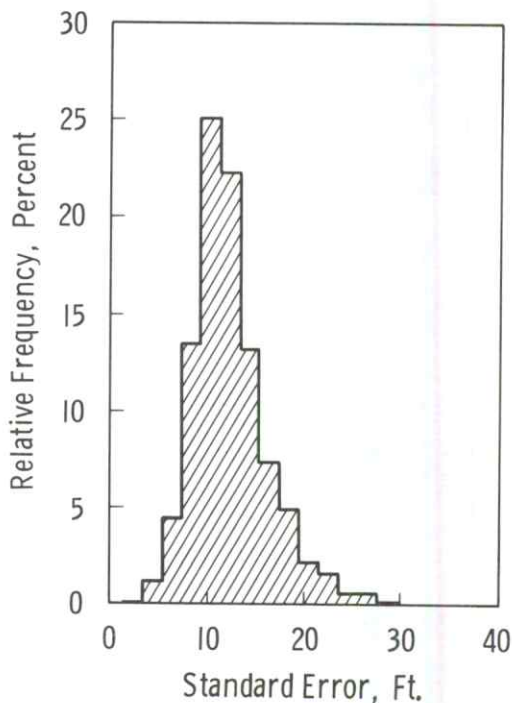


FIGURE 3.3. Relative frequency of the standard error of the water table elevation in the High Plains aquifer in Kansas as perceived by the present network of 1749 wells. The mean is 12 feet and the standard deviation is 4.1 feet.

A computer program to estimate the average distance to the nearest neighbor for observations wells in the network (Olea, 1982a, Appendix B) produced a value of 2.16 miles (3.5 km). The areal extent of the aquifer is 29,000 square miles (44,000 km²), so the distance index (Appendix D) for the present network is 1.06, which is very close to the index of a random pattern. In some localities such as Harvey and Ford counties, clusters of observation wells can be clearly observed, whereas other areas are devoid of observation wells. The present network contains unsampled areas and clusters of observations, although most of the pattern is random. These patterns are not particularly efficient, as shown in Table B.1. Almost any other arrangement of observation wells would be more efficient than the pattern of the present observation network.

3.2.2 Usage

The present observation network in the High Plains aquifer in Kansas is justified by the need for information in order to manage exploitation of the aquifer. The network is used for both research and regulatory purposes.

The aquifer yield can be defined as the maximum rate of withdrawal that can be sustained without disturbing the system (Freeze and Cherry, 1979, p. 306). The yield of the High Plains aquifer is of intense interest, because the record obtained over more than two decades of observations in the Kansas network indicates there is a regional decline in the water table resulting from withdrawals larger than the aquifer yield.

Prediction of aquifer performance is normally done by complex numerical simulations on digital computers, in an attempt to answer questions about the effects of the number, location, and pumping rate of wells in the aquifer. Simulation programs have been improved to the stage where the accuracy of the results is limited by the amount and quality of the data supplied to the models (Foley and Dove, 1982). Water table elevation is only one of several spatial properties of an aquifer which are required as input to the models. Others include the water density, viscosity, surface tension, and compressibility; the formation porosity, permeability, and compressibility; the bedrock elevation; the aquifer boundary; and the percolation rate. Some variables such as water density are easy to measure and have a narrow range of variation. Others, such as permeability, are difficult to determine and vary suddenly over several orders of magnitude in a short distance (Delhomme, 1979). Considering the imperfect state of knowledge about these other variables, an average standard error of 12 feet (3.7 m) in the water table elevation contour maps is not a critical source of uncertainty in simulation.

A rational approach to the overall accuracy of the simulation model should involve sensitivity analysis to assess the impact of changes in the variables on the results. The number of observation wells in the network should not be increased unless it can be shown that the resulting higher precision in estimates of the water table elevation will improve the performance of hydrologic models, resulting in forecasts of increased accuracy.

Local agencies use historic records of water depth for short-range planning, such as deciding to accept or reject a request to drill a new well, a matter involving legal as well as real estate implications. The decision is influenced greatly by the water table elevation decline rate as well as by the saturated thickness in the area. The saturated thickness is the interval of permeable, porous material between the water table and the bedrock. The decline rate is the ratio of the difference in water table elevation to the duration of time over which the change occurred. Both the saturation thickness and the decline rate can be analyzed on an individual, well-by-well basis, or regionally by using contour maps.

The relevance of the estimation error of the water table elevation is increasingly critical as the saturated thickness becomes smaller and smaller. A discrepancy of 20 feet (6.1 m) does not have the same relevance where the saturated thickness is 120 feet (36.6 m) as it does where the estimated saturated thickness is only 30 feet (9.1 m). If the margins of the aquifer are of economic interest, the effectiveness of the sample design is even more important than in areas with large saturated thickness. As the present network has poor or no sampling toward the boundaries of the aquifer, a reduction of the high standard errors in these areas is a worthy goal.

Table 3.3 and Figure 3.4 show the location of 36 wells used to analyze changes in the water table decline in wells close to each other. The wells were selected in such a way that they form 18 clusters of two wells each. Throughout the aquifer, by and large, changes in water table elevation in one well in a pair have been consistently followed by a variation equal in sign and magnitude by the other well over the last 20 years. Figure 3.5 shows four typical decline curves for the wells in Finney County.

Figure 3.6 shows regressions of the elevation in well A on elevations in well B, a regression of elevations in C on elevations in D, and a regression of elevations in B on elevations in C. The results, summarized in Table 3.4, were obtained using four computer routines (Davis, 1973, programs 4-1, 4-2, 4-9, and 5-3). The almost perfect 45-degree slopes and correlations for the pairs A and B as well as C and D are clear evidence of statistical dependence between observations. Information on elevation in well B is completely redundant relative to the information gathered in well A, 4 miles (6.4 km) away. The same can be said of well D relative to C, which are as far apart as 8.6 miles (13.8 km) from each other. Other well pairs such as B and C, which are 20.8 miles (33.5 km) apart, although correlated, are sufficiently separated so as to have different rates of decline. These results suggest that, for use in the study of decline rates, the present network which has an average distance between nearest pairs of wells of only 2.16 miles (3.5 km) is unnecessarily dense.

In summary, except near the boundaries of the aquifer where too few observation wells are located, the average standard error in the network is more than adequate for the purposes of modeling and generation of decline curves.

TABLE 3.3

LOCATION INFORMATION FOR WELLS USED IN DECLINE CURVE CORRELATION

County	Well Number	Surface Elevation
CHEYENNE	5S 41W 12ADC 1	3679.0
CHEYENNE	5S 41W 20DAA 1	3742.0
DECATUR	1S 29W 19BDD 1	2572.0
DECATUR	1S 30W 34DDD 1	2610.0
EDWARDS	25S 17W 13BCD 1	2107.0
EDWARDS	25S 17W 17AAC 1	2129.0
FINNEY	22S 34W 26ADD 1	2928.0
FINNEY	22S 34W 32BCB 1	2983.0
FINNEY	26S 32W 35CDA 1	2864.0
FINNEY	26S 33W 3DBB 1	2886.0
HARVEY	24S 2W 8BAA 3	1420.8
HARVEY	24S 2W 16CBB 1	1413.1
MEADE	30S 29W 28BBB 1	2758.0
MEADE	30S 29W 32BBB 1	2756.0
PRATT	26S 13W 16DAA 1	1929.0
PRATT	26S 13W 19BBD 1	1953.0
SCOTT	16S 34W 22BDC 1	3128.0
SCOTT	16S 34W 29CBB 1	3160.0
SEDGWICK	25S 2W 22AAA 1	1386.0
SEDGWICK	25S 2W 24DDD 3	1372.8
SHERIDAN	7S 29W 21ABB 1	2860.0
SHERIDAN	7S 29W 30ABA 1	2886.6
SHERMAN	9S 40W 13CDC 1	3722.0
SHERMAN	9S 40W 29BBB 1	3782.0
STAFFORD	22S 14W 29BBA 1	1953.0
STAFFORD	22S 14W 35DDB 1	1930.0
STANTON	30S 39W 32DA 1	3226.0
STANTON	30S 39W 36BDD 1	3181.0
STEVENS	31S 37W 9BCC 1	3103.0
STEVENS	31S 37W 22BCC 1	3096.0
THOMAS	9S 33W 30CAA 1	3216.0
THOMAS	9S 33W 35AAD 1	3145.0
WALLACE	15S 40W 3BAB 1	3636.0
WALLACE	15S 40W 7BBB 1	3706.0
WICHITA	16S 38W 5BBB 1	3497.0
WICHITA	16S 38W 16ACC 1	3452.0

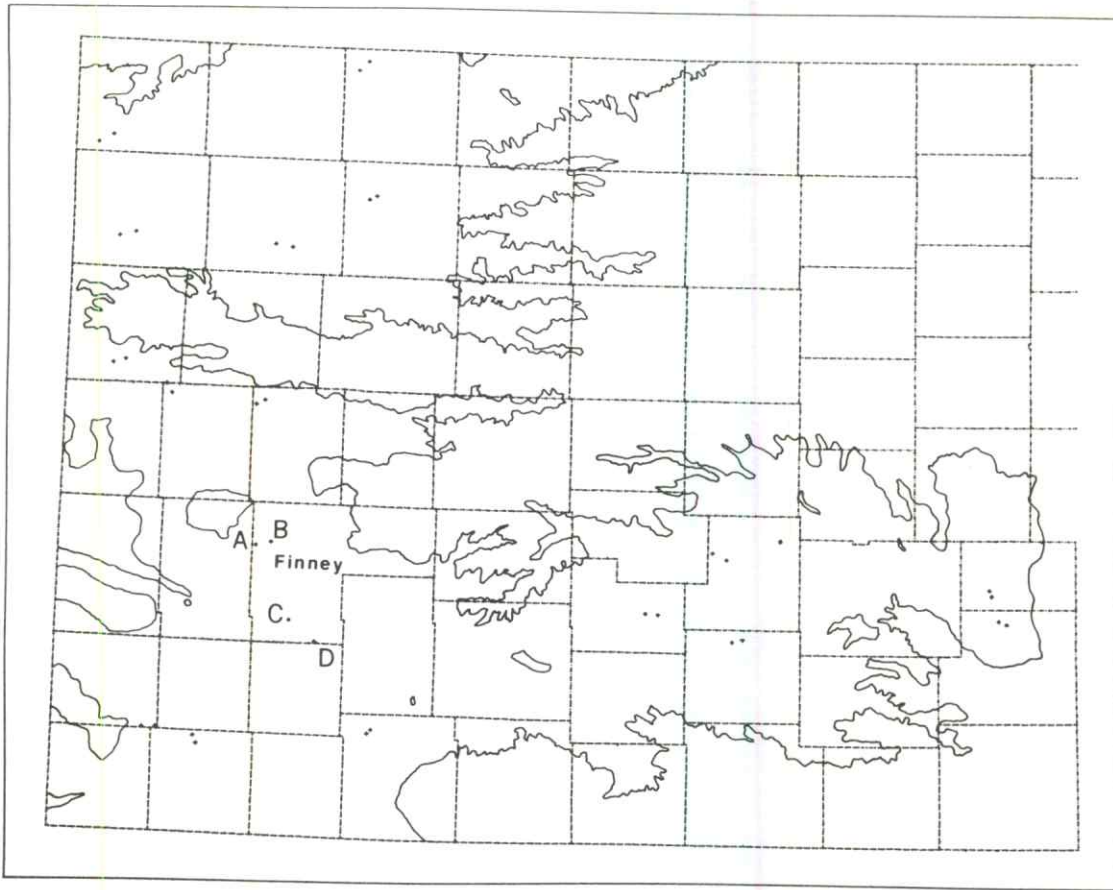


FIGURE 3.4. Location of 18 clusters of two wells selected for decline curve correlation. Details are presented for wells A, B, C, and D.

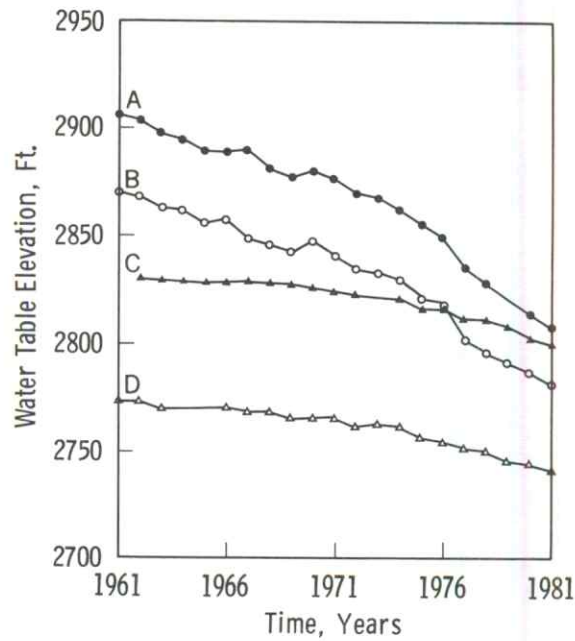


FIGURE 3.5. Decline curves for four wells in Finney County. Solid dots represent well A; open dots, well B; solid triangles, well C; and open triangles, well D.

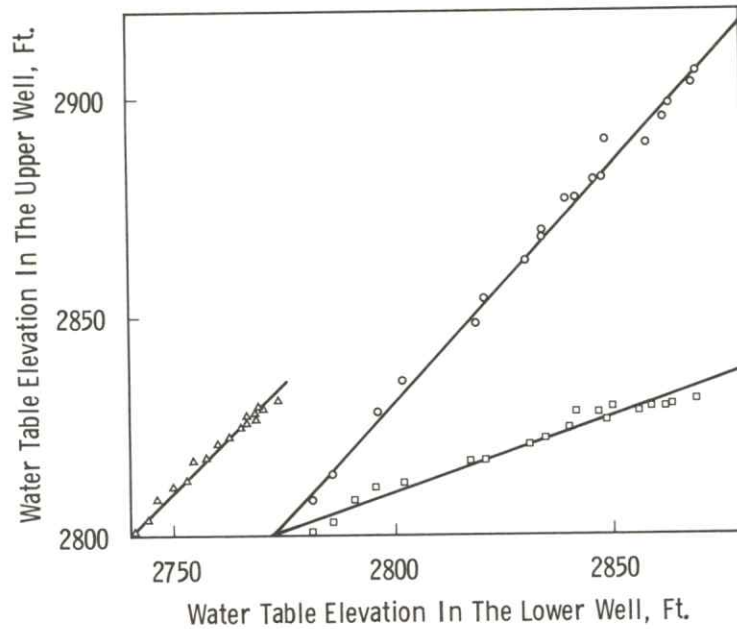


FIGURE 3.6. Regressions between water table elevations in pairs of wells, for four wells in Finney County. Circles are a cross-plot of elevations in wells A and B; triangles are a cross-plot of elevations in wells C and D; and squares are a cross-plot of elevations in wells B and C. Solid lines are linear regressions.

TABLE 3.4
REGRESSION ON THE WATER TABLE ELEVATIONS
OF FOUR WELLS IN FINNEY COUNTY

Wells	Distance Miles	Regression Line Slope	Correlation Coefficient
A and B	4.0	0.95	99.2%
C and D	8.6	1.07	99.7%
B and C	20.8	0.34	98.0%

CHAPTER 4

NETWORK ENHANCEMENT

The systematic approach for optimally sampling spatial functions introduced in Chapter 2 is applied to improve the performance of the present groundwater network in the monitoring of water table elevation in the High Plains aquifer in Kansas presented in Chapter 3.

4.1 OPTIMIZATION LIMITED TO THE EXISTING OBSERVATION WELLS

4.1.1 Specifications for a new network

From the analysis in the previous chapter, it is apparent that the present network should be upgraded by optimizing the locations of observation wells. Any reallocation should be done with minimal disruption to the network. From Table B.1, the most efficient way to sample a spatial function is with a hexagonal pattern of sampling locations. Had this study been done 40 years ago, this would have been the ideal pattern of wells to use. Today, implementing a hexagonal pattern would mean retaining no more than 100 of the existing observation wells. The remainder would have to be new wells, so historical records for almost all the observation wells would be discontinued. In addition, there would have to be a significant effort in the surveying and drilling of these new wells. The potential benefit of such a severe remodeling of the network might not be justifiable. The next three patterns in Table B.1 are also regular and would have the same practical drawbacks as a hexagonal pattern. The next most effective arrangement is a stratified pattern, which is irregular and so allows the flexibility required to maximize the use of existing wells. The rearrangement which has minimum disruption of the present network is thus a stratified hexagonal pattern using existing wells.

From the discussion in the previous section, the present average standard error represents an arbitrary but convenient level of accuracy. The redesign will be done without altering the average standard error. The following constraints define what may be considered an unchanged level of the standard error throughout the aquifer.

- a. The average standard error for the new network should not differ by more than 5 percent from the average standard error of the present network.
- b. The area over which estimations can be made in the new network should not be less than 1 percent smaller than the area over which estimations can be made using the present network.
- c. Water table elevations predicted by the new network should be within 5 feet (1.5 m) of the estimates provided by the present network at 95 percent or more of the estimated nodes in the contouring grid. Under no circumstances should the new estimates deviate from the old by more than 20 feet (6.1 m).

4.1.2 An alternative equivalent network

A new network will be designed to more efficiently measure the High Plains aquifer, subject to the constraints established in part 4.1.1. As no new observation wells are included in the alternative network, it will cover only those parts of the aquifer already sampled by the present network and will not resolve the problem of unsampled areas. Thus, at this stage our attention will be concentrated on upgrading the pattern. The average standard error for the present network is 12 feet (3.7 m); 5 percent of this value is 0.6 foot (0.18 m). Over most of the contoured area shown in Plate 2, the sampling density is relatively high and the standard error is closer to 10 feet (3 m) rather than 12 feet (3.7 m). Along the margins of the aquifer, the standard error is closer to 20 feet (6.1 m), but the area is significantly smaller. The alternative network should be designed to have an average standard error somewhat lower than 12 feet (3.7 m) in most areas to compensate for higher than average standard errors in areas not sampled. Appendix C contains details for a sample design with a 10-percent penalty on the 12-foot (3.7 m) standard error which requires a density of 0.06 point/square mile (0.023 point/km²). This value can be approximately achieved by stratification in a pattern of hexagons which are 16 square miles (41.4 km²) in area. A pattern such as the one shown in Figure 4.1 was prepared which contained appropriate-sized hexagons at the one-to-one-million scale of Plate 1.

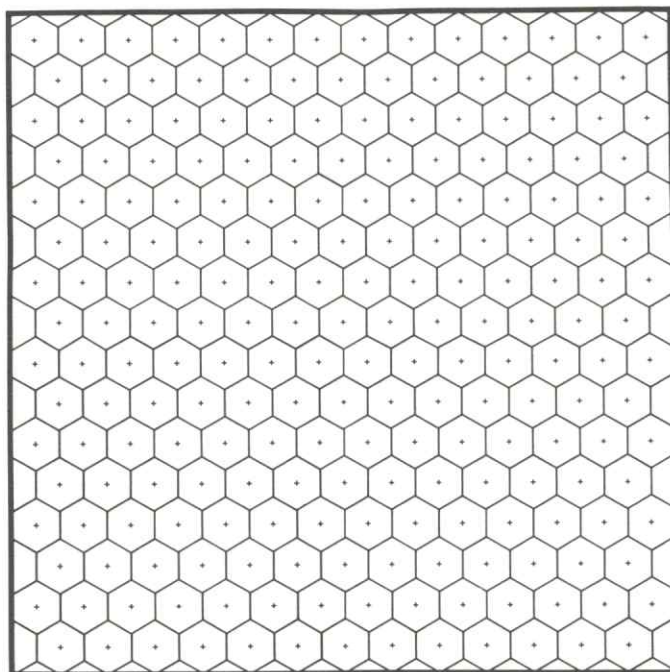


FIGURE 4.1. Hexagonal stratification used to randomly select one observation well inside each polygon.

Plate 3 shows the resulting map of water table elevation using a stratified hexagonal pattern of observation wells spaced at a density of 1/16 point/square mile (0.024 point/km²). Plate 4 is the corresponding standard error map; a relative frequency graph of the standard errors appears in Figure 4.2. The alternative stratified hexagonal network retains 1135 of the 1749 observation wells shown in Plates 1 and 2. Table 4.1 compares the two networks and shows

that all critical parameters are within specifications. The wells discarded from the present network are marked by an asterisk in the listing in Appendix E.1.

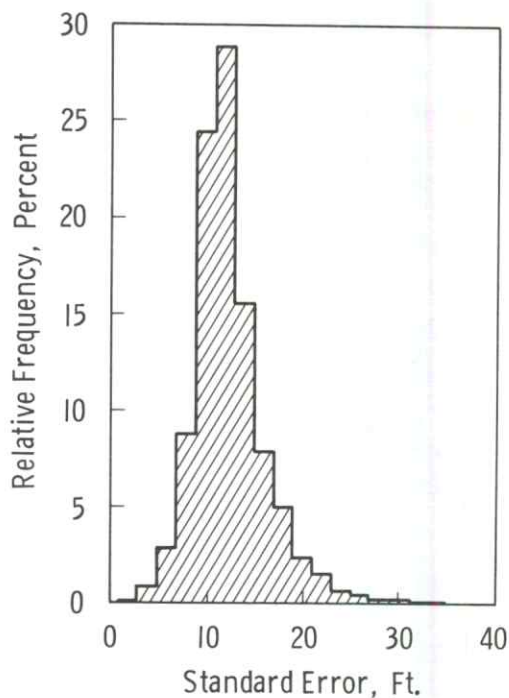


FIGURE 4.2. Relative frequency of the standard error of the water table elevation in the High Plains aquifer in Kansas as perceived by a proposed hexagonal stratified network of 1135 wells. The mean is 12.45 feet and the standard deviation is 3.75 feet.

TABLE 4.1
COMPARISON BETWEEN THE PRESENT AND ALTERNATIVE NETWORKS

	Present	Alternative	Change
Pattern	Random	Hex. Strat.	
Number of wells	1749	1135	-35.1%
Average standard error, feet	12.02	12.45	3.6%
Nodes estimated	5820	5802	-0.3%

Plate 5 is an overlay of the isolines of Plates 1 and 3 and shows the difference in the perception of the water table elevation which results from modifying the network as well as the location of the discarded wells. The differences are expressed as a relative frequency graph in Figure 4.3. The maximum difference is 18.8 feet (5.7 m); 97.4 percent of estimated nodes in the alternative network are within ± 5 feet (1.5 m) of the corresponding node calculated from the present network.

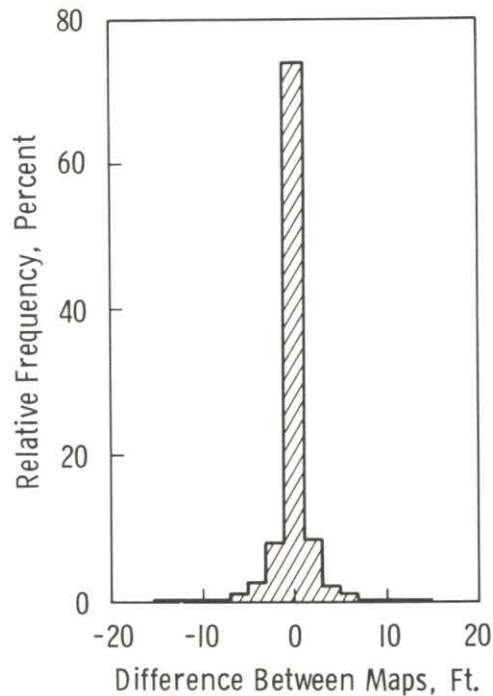


FIGURE 4.3. Differences between water table elevations estimated using the proposed network of 1135 wells and elevations estimated by present network of 1749 wells. The mean is zero and the standard deviation is 2 feet.

As all the critical parameters are within bounds, the network of 1135 wells may be an acceptable solution under the constraints in part 4.1.1. The alternative network produces an equivalent estimate of the water table elevation but uses 614 fewer observation wells than the present network. If the 137 wells in Table 3.2 that were previously discarded for reasons other than the sampling efficiency are added to these, it can be seen that the number of observation wells surveyed during January 1981 could have been reduced by almost 40 percent without impairing the worth of the network for estimating the water table.

4.2 EXPANSION OF THE NETWORK

4.2.1 Filling in gaps

Using a network of 1135 wells could reduce the costs of annual measurement, or the savings could be used to finance improvements in the network.

The alternative network, by using only existing wells, has the same unsampled areas as the present network. However, it would be desirable to expand the observation network so it would have a uniform density throughout the entire aquifer.

Currently, it is not possible to estimate the water table elevation for the High Plains aquifer in some areas, while in other areas the estimates are unreliable and could lead to the

making of erroneous decisions. The easternmost area of the aquifer was selected to perform an experiment which shows the dangers of allowing gaps to remain in the sampling pattern.

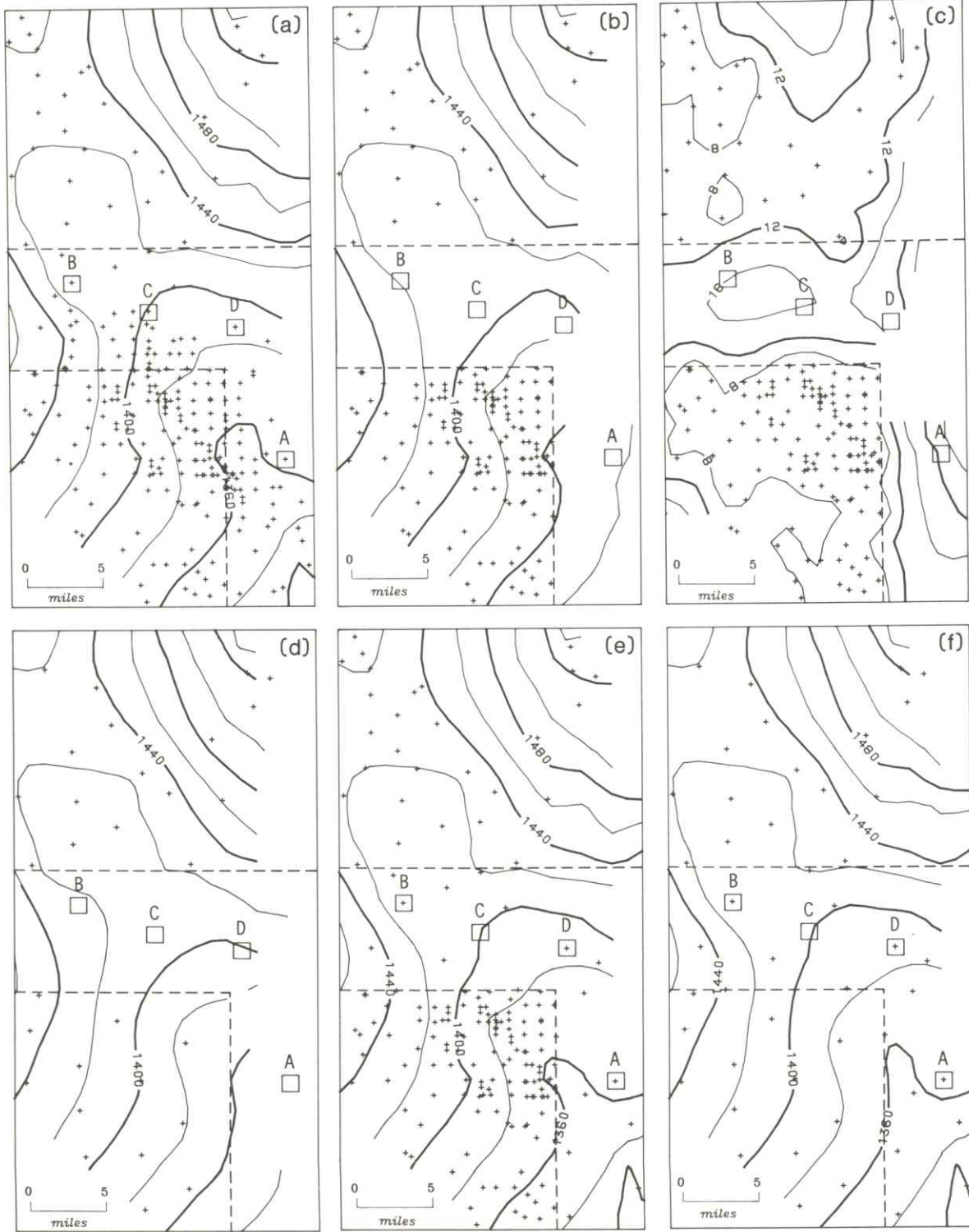
As shown in Plate 1, the area east of range 4W has the highest density of observation wells of any area in the aquifer. This area is known as the Equus Beds. Within this region, the hexagonal stratified pattern of observation wells covers a continuous area without gaps (Plate 3). This makes the Equus Beds particularly suitable as an area in which to perform an experiment to illustrate what may happen in other places where sampling is incomplete.

Figure 4.4a shows the water table elevation, the location of observation wells, and the zone within which observation wells will be deleted to artificially create a gap in the sampling pattern. The deleted wells can be compared against the estimates generated using only the incomplete network. The differences should be equivalent to those seen in a presently unsampled area if additional observation wells were drilled. Figure 4.4b shows the water table elevation estimated using only wells outside the artificially created gap. The corresponding standard error is shown in Figure 4.4c. Four locations were selected for comparison; results are presented in Table 4.2.

The largest errors are to the southeast. The estimated values are the result of extrapolation as all observations lie to one side of the area. The depression in the water table shown on the original map has been distorted to a southeast dipping plane. Points around location A were estimated with more than 30 feet (9.1 m) of error. Locations B and C are in the horizontal part of the strip, which is surrounded by control points in at least two directions. Because of the better control, that part of the map made with the censored data set has almost the same character as the equivalent area in the map made using the full observation well network. Only errors of detail, such as those around locations B and C, are evident. The random nature of the error is demonstrated at location D. Despite the fact that location D is no better sampled than locations B and C, the estimated value for the water table elevation does not suffer from the elimination of wells. Even though the exact amount of an error is unpredictable, the errors can at least be confined within probabilistic bounds. All errors in Table 4.2 are, for instance, within 1.5 times the standard error. The example demonstrates the advantages of analyzing the map of a spatial function with the help of a standard error map. In this way it is possible to pinpoint areas of likely significant error as well as to identify the dangerous effect of gaps in the sampling pattern.

Figure 4.4d represents the situation existing in the alternative network of 1135 observation wells after the elimination of the excess wells. The map in Figure 4.4d is essentially identical to that in Figure 4.4b. The further reduction in the number of wells outside the L-shaped strip neither worsens nor improves the uncertainties created by the sampling gap as demonstrated in Figure 4.4b.

FIGURE 4.4. Water table elevation and observation well locations in Equus Beds area. A, B, C, and D are four locations selected for comparison. Within L-shaped area indicated by dashed lines, wells are deliberately omitted from calculations. (a) Contour map based on present observation well network. (b) Contour map with wells omitted from L-shaped area. (c) Standard error of water table elevation map b. (d) Contour map based on hexagonal stratified sample of observation wells outside L-shaped area. (e) Contour map made using all available wells outside L-shaped area and a hexagonal stratified pattern of wells inside area. (f) Contour map based on a hexagonal stratified pattern having a density of one well in 16 square miles.



Figures 4.4e and 4.4f illustrate the benefits of adding observations in a hexagonal stratified pattern at a density of 1/16 well per square mile (0.024 wells/km²) inside the L-shaped gap. The inserted wells restore the details evident in the original Figure 4.4a. Note that the careful placement of a few added wells in the gap can be as effective as the unplanned generous insertion of many wells, as this will result in reversion to the original situation. Figure 4.4f is the most efficient sampling pattern, a hexagonal stratified sample with no gaps at a density of 1/16 well per square mile (0.024 well/km²). Figure 4.4f represents the same solution as in Plate 3 for the Equus Beds. This experiment illustrates the benefits and advantages of extending the hexagonal stratified network to presently undersampled areas elsewhere in the aquifer.

TABLE 4.2
EVALUATION OF THE EFFECT OF GAPS IN
SAMPLING PATTERN

Location	Actual Elevation ft.	Estimated Elevation ft.	Difference ft.	Standard Error ft.
A	1374	1445	29	20
B	1402	1420	18	15
C	1397	1405	8	16
D	1390	1390	--	17

The total number of observation wells required to cover the entire aquifer with a hexagonal stratified network is 1795; that is, 660 observation wells should be measured in addition to the 1135 selected in part 4.1.2. Because there is limited interest in improving sampling in areas of marginal economics, the additional 660 wells are grouped into two categories based on the estimated saturated thickness (Bayne and Ward, 1967; O'Connor and McClain, 1981, Plates 5A and 5B). Remember that a hexagonal stratification implies the random selection of one well inside each hexagon on a regular network (Fig. B.2a). Figure 4.5 shows the location of the centers of those hexagons where additional wells are required to complete the network in areas expected to have more than 40 feet (12.2 m) of saturated thickness. There are 324 such locations. Figure 4.6 shows the centers of 336 additional hexagons in areas where the expected saturated thickness is less than 40 feet (12.2 m). Appendix F lists the locations of these 660 centers of hexagons.

Should the entire High Plains aquifer in Kansas be sampled following these recommendations, the average standard error would be equal to the 10.8 feet (3.3 m) value obtained in Appendix C. The most dramatic changes would occur in the maximum standard error which would be reduced to 13.3 feet (4.1 m), only 36.3 percent of the present maximum standard error. Also note that

the new network would contain 91 fewer observation wells than the present network as measured during January 1981.

In summary, the savings generated by cutting the present network to 1135 wells could be used to finance a more exhaustive sampling of the aquifer in areas which are now insufficiently surveyed. The modified network could yield a more complete and accurate picture of the water table than does the present network.

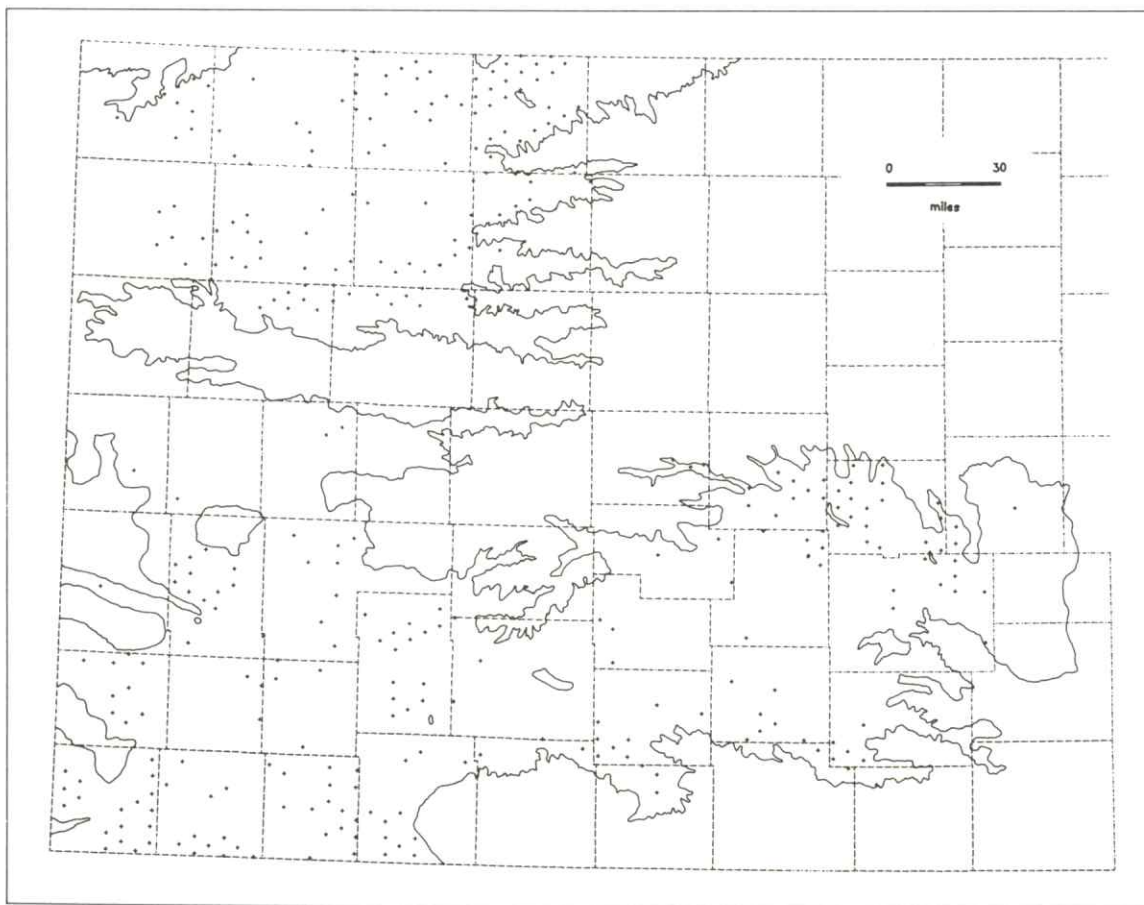


FIGURE 4.5. Locations of the centers of 324 regular hexagons 16 square miles in size in areas where more than 40 feet of saturated thickness is expected. An observation well should be located within each hexagon.

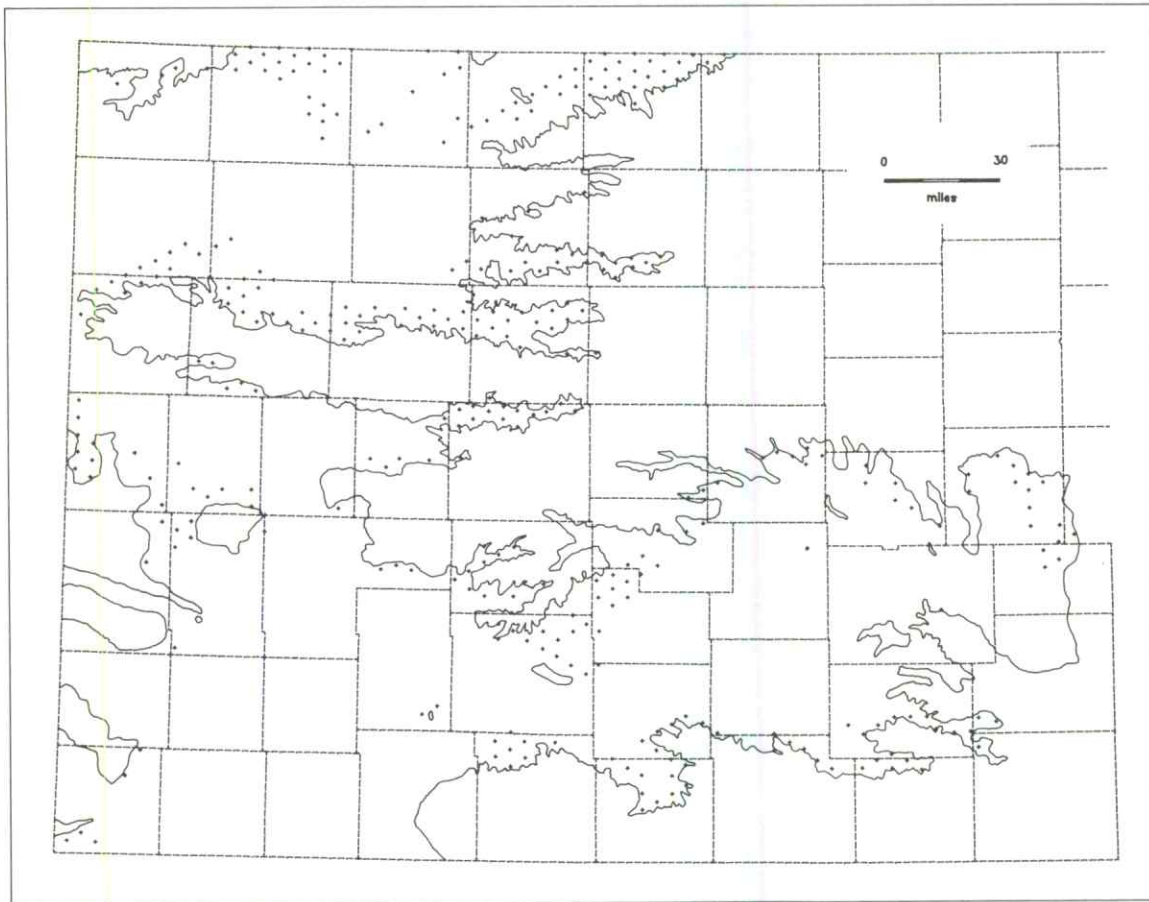


FIGURE 4.6. Locations of the centers of 336 regular hexagons 16 square miles in size in areas where less than 40 feet of saturated thickness is expected. An observation well should be located within each hexagon.

4.2.2 Modifying the level of accuracy

The analysis in parts of 4.1.2 and 4.2.1 is conditional on maintaining a level of accuracy similar to the present level. The advantages of changing to a hexagonal stratified pattern and expanding the network are not tied to the level of accuracy selected for the network. Other accuracy levels are certainly possible, but, as predicted by Equation 2.4, producing a radical change in the standard error throughout the aquifer will require a substantial change in the number of observation wells.

Figure 4.7 shows the changes in total number of wells required to uniformly vary the accuracy throughout the aquifer if a hexagonal stratified pattern is used. From part 4.2.1, 1795 observation wells would be required to produce an average standard error of 10.8 feet (3.3 m) for the water table elevation of the High Plains aquifer in Kansas. Due to the parabolic nature of the relationship between standard error and density, the marginal return on changes in either direction is not favorable. As the curve flattens to the right, reducing the number of wells will cause significant increases in the standard error. The converse is true if the

number of wells is increased. The curve rises sharply to the left and the addition of significant numbers of wells will cause only minor reductions in the standard error. For example, keeping the density uniform, a reduction of 1000 wells from the network would increase the standard error by 22.5 percent, but increasing the density by adding 1000 more wells would only reduce the standard error by 10.5 percent.

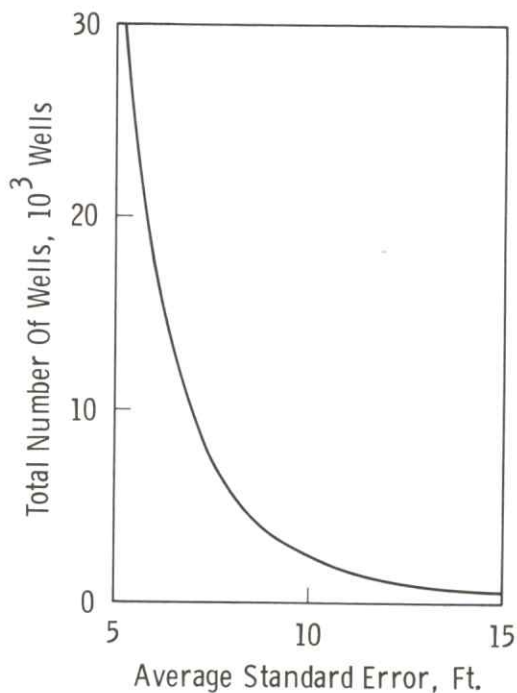


FIGURE 4.7. Network size as a function of level of accuracy in the estimation of water table elevations in the High Plains aquifer in Kansas. Sampling is assumed to follow a hexagonal stratification.

In summary, if the sampling pattern is kept constant, the sampling efficiency indices can be modified by changing the density of observations. The rate of deterioration caused by reducing the sample size is higher than the rate of improvement produced by increasing the sample size by the same amount.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study has been to analyze the sampling efficiency of the observation well network used to monitor water table elevations in the High Plains aquifer in Kansas and to propose modifications that will enhance the network. The conclusions and recommendations of this investigation are best expressed through consideration of each of the specific objectives of the study.

5.1 FINDINGS

5.1.1 The present observation network

This study of the Kansas High Plains aquifer network is based on information gathered during the period December 1980 to March 1981, consisting of measurements of depth to the water table in 1886 observation wells. The water table elevations contain a spatial drift which can be modeled by a first-degree polynomial of the geographic coordinates. The semivariance of the residuals can be represented by a linear semivariogram having a slope of 60 feet² per mile (3.5 m²/km) within a neighborhood which is 28 miles (45 km) in diameter.

The observation wells are concentrated in areas which include about three-fourths of the aquifer in Kansas. Undersampled areas occur mostly near the aquifer's boundaries. There are some local clusters of wells. Overall, the network has a distance index of 1.06, indicating that the observation wells are distributed essentially at random. The water table elevation can be estimated with an average standard error of 12 feet (3.7 m) and a maximum standard error of 36.6 feet (11.2 m) using the 1749 wells which have acceptable measurements.

5.1.2 Use of data

Information gathered by the network is used primarily as input to hydrologic models and to assist groundwater managers in planning the exploitation of the aquifer. Prediction of aquifer performance is normally done by complex numerical simulations on digital computers in an attempt to answer questions about the effects of the number, location, and pumping rate of wells. The process is complemented by information on water saturation and decline rate prepared from the same basic data.

5.1.3 Level of accuracy

The observation wells are spaced sufficiently close and the average standard error of the water table elevation associated with the present observation network is sufficiently low to satisfactorily fulfill all the requirements placed on data gathered by the network. The network is adequate for determining the location of new irrigation wells and the error of estimation is

much smaller than the relative average standard error of other variables used in hydrologic modeling. If a decision is made to invest more money in surveys of the High Plains aquifer in Kansas, these additional funds should be directed to improving the accuracy of other variables required for hydrologic modeling, rather than attempting to reduce the average standard error of the water table elevation. A substantial reduction in average standard error cannot be easily achieved. Because of the parabolic nature of the change in standard error with well density, 16 times as many wells would be required to reduce the present average standard error by one-half. However, areas of low sampling, particularly near the edges of the aquifer, result in a maximum standard error which could be substantially reduced by reallocating wells from areas that presently are oversampled.

5.2 SUGGESTIONS

5.2.1 Upgrading the network

The present observation well network should be modified to be more efficient. That part of the aquifer already covered by the network should be redesigned, maintaining the same level of average error as the present network. A stratified pattern of observation wells is recommended because this will allow enhancement of the network utilizing existing observation wells, thus minimizing disruption in the historical records and requiring no additional surveying or drilling. Application of the systematic sampling procedure contained in Algorithm 2.1 to the High Plains aquifer produces a stratified pattern of wells spaced within hexagonal areas containing 16 square miles (41.4 km^2). Contour maps of the water table elevation can then be produced with no deterioration in the quality of the estimates using only eight nearest neighbors. If the present network is modified following these recommendations, the new network would contain only 1135 observation wells, a reduction of 39.8 percent in the number of wells which must be measured each year. This reduction in network size would produce only a 3.6 percent increase in the average standard error. The difference between water table elevation contour maps produced by the present and the proposed networks is less than 5 feet (1.5 m) at 97.4 percent of the grid nodes and in no case is greater than 18.8 feet (5.7 m). This difference is less than a single contour interval on maps typically used to show the water table elevation in the High Plains aquifer.

5.2.2 Network expansion

The savings generated by reducing the size of the network could be used to operate the network at a lower cost or to expand the sampled region, providing measurements in areas where presently there are no observation wells. A total of 324 observation wells should be added to the 1135 wells in the alternative observation network, to assure complete coverage of all areas of the aquifer expected to have 40 feet (12.2 m) or more of saturated thickness. An additional 336 wells would be required to completely cover the High Plains aquifer everywhere in the State of Kansas at a uniform density of one well in every 16-square-mile (41.4 km^2) regular hexagon.

Elimination of unsampled areas would reduce the maximum standard error to 13.3 feet (4.1 m), significantly below the 36.6 feet (11.2 m) value for the current network. The 1795 wells required for the expanded network still would be 91 wells fewer than the number of observation wells actually measured in January 1981.

REFERENCES

- Armstrong, M., and R. Jabin, 1981, Variogram models must be positive-definite: *Journal of the International Association for Mathematical Geology*, vol. 13, no. 5, p. 455-459.
- Bayne, C. K., and J. R. Ward, 1967, Saturated thickness and specific yield of Cenozoic deposits in Kansas: *Kansas Geological Survey Map Series, Map M5*, University of Kansas, Lawrence, Kansas.
- Broeker, M. E., H. J. McIntyre, Jr., and J. M. McNellis, 1977, Ground-water levels in observation wells in Kansas, 1971-1975: *Kansas Geological Survey Basic Data Series, Ground-water Release 6*, University of Kansas, Lawrence, Kansas, 526 p.
- Clark, I., 1979, *Practical Geostatistics*: Applied Science Publishers Ltd., London, England, 129 p.
- Clark, P. J., and R. C. Evans, 1954, Distance to nearest neighbors as a measure of spatial relationships in populations: *Ecology*, vol. 35, no. 4, p. 445-453.
- David, M., 1977, *Geostatistical Ore Reserve Estimation*: Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, 364 p.
- Davis, J. C., 1973, *Statistics and Data Analysis in Geology*: John Wiley & Sons, Inc., New York, N.Y., 550 p.
- Delhomme, J. P., 1979, Spatial variability and uncertainty in groundwater flow parameters: A geostatistical approach: *Water Resources Research*, vol. 15, no. 2, p. 269-280.
- Foley, M. G., and F. H. Dove, 1982, Hydrology: *Geotimes*, vol. 27, no. 2, p. 40-41.
- Freeze, R. A., and J. A. Cherry, 1979, *Groundwater*: Prentice-Hall, Inc., Englewood Cliffs, N.J., 604 p.
- Gutentag, E. D., and J. B. Weeks, 1980, Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming: *United States Geological Survey Open-File Report 80-50*, Lakewood, Colorado, 1 Plate.
- Hogg, R. V., and Craig, A. T., 1970, *Introduction to Mathematical Statistics*: The Macmillan Company, New York, N.Y., 415 p.
- James, G., and R. C. James, 1976, *Mathematics Dictionary*: Van Nostrand Reinhold Company, New York, N.Y., 509 p.
- Journel, A. G., and C. J. Huijbregts, 1978, *Mining Geostatistics*: Academic Press, London, England, 600 p.
- Kendall, M. G., and W. R. Buckland, 1971, *A Dictionary of Statistical Terms*: Oliver & Boyd, Edinburgh, Scotland, 166 p.

- Matérn, B., 1960, Spatial variation: Meddelanden från Statens Skogsforskningsinstitut, Stockholm, vol. 49, no. 5, p. 1-144.
- Matheron, G., 1965, Les variables régionalisées et leur estimation: Masson et Cie, Editeurs, Paris, France, 305 p.
- Matheron, G., 1971, The theory of regionalized variables and its applications: Les Cahiers du Centre de Morphologie Mathématique, Ecole Nationale Supérieure des Mines, Paris, France, 211 p.
- Morgan, C. O., and J. M. McNellis, 1969, FORTRAN IV program, KANS, for conversion of General Land Office locations to latitude and longitude coordinates: Kansas Geological Survey Special Distribution Publication 42, University of Kansas, Lawrence, Kansas, 24 p.
- O'Connor, H. G., and T. J. McClain, 1981, Geologic and hydrologic characteristics of the Ogallala and peripheral aquifers in western Kansas: Kansas Geological Survey, Internal Distribution Publication, University of Kansas, Lawrence, Kansas, 103 p.
- Olea, R. A., 1975, Optimum mapping techniques using regionalized variable theory: Kansas Geological Survey Series on Spatial Analysis No. 2, University of Kansas, Lawrence, Kansas, 137 p.
- Olea, R. A., 1977, Measuring spatial dependence with semivariograms: Kansas Geological Survey Series on Spatial Analysis No. 3, University of Kansas, Lawrence, Kansas 29 p.
- Olea, R. A., 1982a, Systematic approach to sampling of spatial functions: D.E. dissertation, Chemical and Petroleum Engineering Department, University of Kansas, Lawrence, Kansas, 277 p.
- Olea, R. A., 1982b, Systematic sampling of spatial functions: Kansas Geological Survey Series on Spatial Analysis No. 8, University of Kansas, Lawrence, Kansas, in preparation.
- Pabst, M. E., 1981, January 1981 water levels, and data related to the water level changes, western and south-central Kansas: U. S. Geological Survey Open-File Report 81-1001, Lawrence, Kansas, 168 p.
- Ripley, B. D., 1981, Spatial Analysis: John Wiley & Sons, New York, N.Y., 252 p.
- Ross, C. G., 1981, GIMMAP: Geodata Interactive Management Map Analysis and Production: M.S. thesis, Computer Science Department, University of Kansas, Lawrence, Kansas, 231 p.
- Sampson, R. J., 1978, SURFACE II graphics system: Kansas Geological Survey Series on Spatial Analysis No. 1, University of Kansas, Lawrence, Kansas, 240 p.
- United States Geological Survey, 1980, Project document for Kansas Geological Survey, Ground-water level data: U. S. Geological Survey Report KS00-002, Lawrence, Kansas, 12 p.
- Williams, W. H., 1978, A Sampler on Sampling: John Wiley & Sons, New York, N.Y., 254 p.

APPENDIX A

STRUCTURAL ANALYSIS

A.1 Theory

The semivariance $\gamma(\vec{h})$ can be plotted against values of the lag \vec{h} to yield the semivariogram, a graph analogous to the correlogram used in time series analysis. Structural analysis is the term applied to the study of semivariograms for the purpose of extracting information about the nature of fluctuation in a regionalized variable. The objectives of structural analysis are two-fold; to make genetic interpretations about the regionalized variable, and to provide parameters which are required in its estimation.

To obtain a semivariogram, it is necessary to sample the regionalized variable at regular intervals. Let

$$z(\vec{x}_1), z(\vec{x}_2), \dots, z(\vec{x}_i), \dots, z(\vec{x}_n)$$

be n values of either residuals or outcomes of the regionalized variable. Provided that the regionalized variable is first-order stationary and the intrinsic hypothesis holds, the following is an unbiased estimator of the semivariance (Olea, 1977, p. 20):

$$\gamma^*(h) = \frac{1}{2(k-p)} \sum_{j=k'}^{k'+k-p-1} [z(\vec{x}_j + \vec{h}) - z(\vec{x}_j)]^2 \quad (\text{A.1})$$

Here, \vec{h} is p times the sampling interval \vec{a} ; $k + k' \leq n$; and $p = 0, 1, 2, \dots, k-1$. The study may be done along one traverse or, more desirably, along a series of traverses. The estimation of a semivariogram for observations of a regionalized variable is fairly straightforward, but this is not true for the semivariogram of the residuals. Before the residuals can be obtained, it is necessary to know the semivariogram. The problem is solved recursively by assuming a semivariogram, computing the drift and residuals, and comparing the resulting semivariogram to that assumed (Olea, 1975, p. 90-93; David, 1977, p. 272-274).

Satisfactory results for moderately tractable regionalized variables can be obtained by assuming drifts of the type

$$M^*(\vec{x}) = \sum_{i=0}^n a_i f^i(\vec{x}) \quad (\text{A.2})$$

where the a_i are n unknown coefficients to be determined and the $f^i(\vec{x})$ are functions of \vec{x} , typically monomials of the spatial coordinates up to degree 2. The smooth and slowly varying

surfaces represented by $M^*(\vec{x})$ accord with the mathematical notion of the drift being a highly continuous function incorporating only the low frequency component of the regionalized variable without the local fluctuations. The terms local and regional are relative and depend upon the scale of the regionalized variable. A feature that at the scale of a county could be a dominant element in the drift could be an anomaly when considering an entire state, and could be completely negligible at a continental scale. Therefore, there is no single, unique drift for a given regionalized variable; as in curve fitting, the user must decide what should be fitted and what should be regarded as anomalous.

Certain major characteristics of the regionalized variable of interest in this study can be deduced from the semivariogram. These include:

1. Continuity. The shape of the semivariogram, and in particular its slope near the origin, is related to the regularity and smoothness of the regionalized variable. A parabolic semivariogram which is tangent to the x-axis at the origin means the variable is extraordinarily regular relative to the sampling interval. In contrast, highly erratic sequences will produce a semivariogram which is almost vertical at the origin.

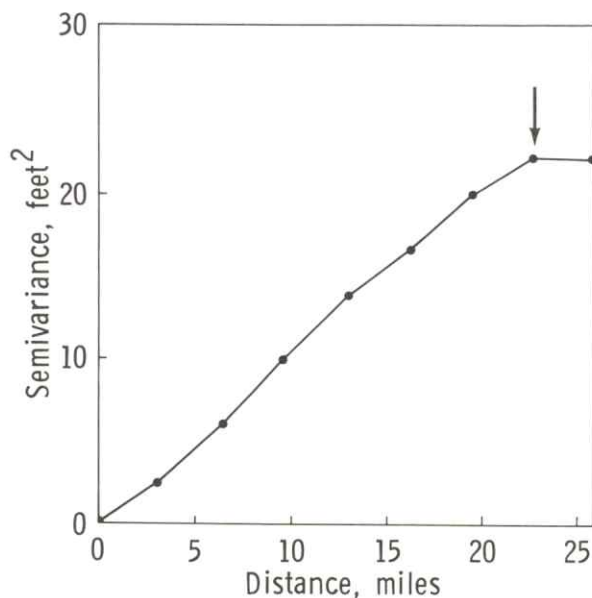


FIGURE A.1. Transitive type semivariogram with a range of 22.5 miles.

2. Zone of influence. Figure A.1 is a transitive type of semivariogram, expressing moderate continuity of the regionalized variable within a local neighborhood, and random behavior over larger distances. The semivariance steadily increases to a maximum value and then remains constant at a value called the sill. In instances where the regionalized variable is second-order stationary, the asymptote is equal to the sample variance (Olea, 1982a, p. 15). The arrow at the slope break indicates the range, a distance which divides elements in a sample into two categories. Samples taken at distances which are smaller than the range are autocorrelated and

are ideally suited to be used in common for estimation purposes. Samples spaced further apart than the range are statistically independent and behave as independent random variables.

3. Anisotropy. Anisotropy is revealed by different behavior of the semivariograms computed along lines having different orientations. The differences in the semivariogram appear mainly in the slope at the origin, in the range, and in the sill, if any. The semivariance of a regionalized variable could be anisotropic and at the same time the semivariance of the residuals could be isotropic, if the cause of the anisotropy is an underlying drift. This situation can be diagnosed if along the dip the semivariogram is highly regular with no sill and along the strike the semivariogram is transitive in form. If the regionalized variable is isotropic, the semivariance depends only on the magnitude h of the vector \vec{h} and not on the direction \hat{h} .

Although any function that fits the observed semivariance could be used as a model, sound geostatistical practice recommends the use of only those functions which are positive-definite (Journel and Huijbregts, 1978, p. 161-168; Armstrong and Jabin, 1981). Among the positive-definite models, the simplest one is linear:

$$\gamma(\vec{h}) = \omega \vec{h} \quad (\text{A.3})$$

The linear model is a convenient choice to represent a transitive semivariogram provided the argument \vec{h} never becomes larger than the range. That is, the estimators are restricted to sample subsets inside the zone of influence.

When the model must incorporate the presence of a sill, the most commonly used function is the spherical model

$$\gamma(h) = \begin{cases} c \left[\frac{3}{a} \frac{h}{L} - \frac{1}{2} \left(\frac{h}{L} \right)^3 \right], & h \leq L \\ c & , h > L \end{cases} \quad (\text{A.4})$$

A.2 Practice

Ideally, the semivariogram should be estimated along regularly sampled traverses of the regionalized variable. These traverses should run in at least three different orientations and should contain a minimum of about 30 sample elements (Journel and Huijbregts, 1978, p. 194). In circumstances such as the measurement of water table elevation in the High Plains aquifer of Kansas, these ideal conditions cannot be met because the samples have already been taken at irregularly spaced locations. Some sampling approximations are allowable, however, such as

minor changes in orientation along the traverses, interpolation of a few missing points, and small variations in the spacing (Clark, 1979, p. 118-119). Figure A.2 shows the traverses selected through the well locations given in Appendix E.1 which best fulfill the ideal requirements. These six traverses run in four different orientations approximately 45 degrees apart.

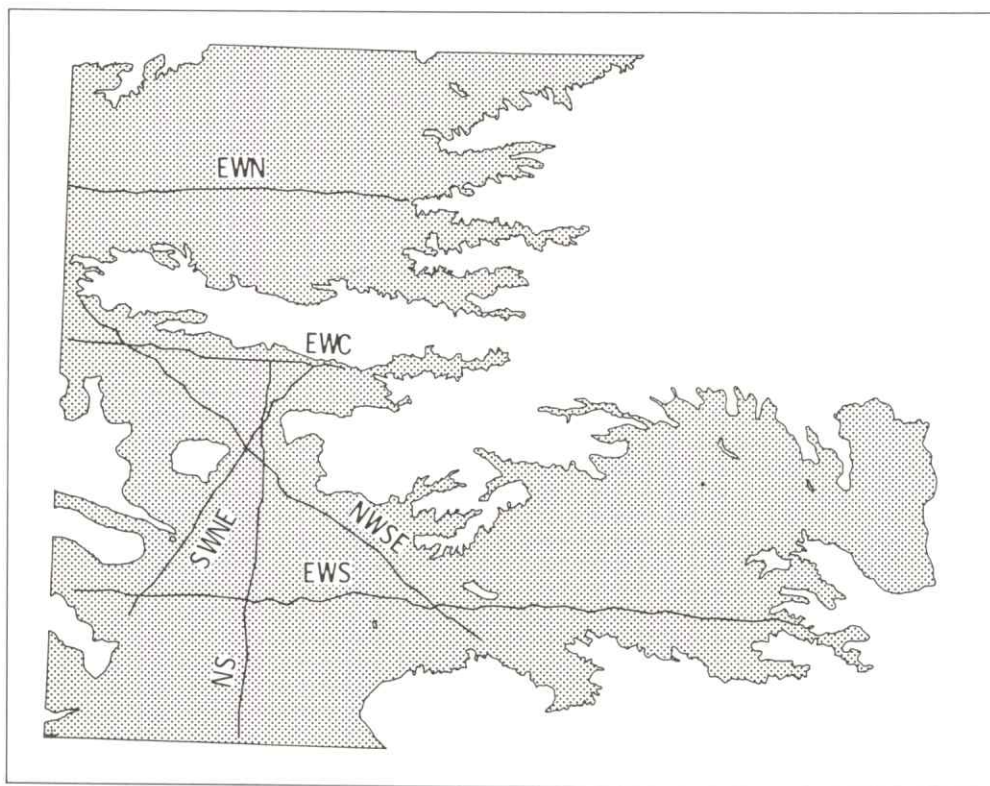


FIGURE A.2. Locations of traverses used in structural analyses.

Structural analysis was performed using the program SEMIVAR (Olea, 1977). In general the water table elevation dips east with a slope of 8 feet per mile (3.9 m/km), meaning that, except along the north-south strike, the assumption of stationarity required by the semivariance estimator in Equation A.1 is not met. This is revealed by the anisotropy shown in the semivariograms of Figure A.3. The semivariogram for traverse NS in Figure A.3a is transitive. From the discussion in the previous part A.1, its range is approximately 28 miles (45 km). On the other hand, traverse NWSE (Fig. A.3c) does not possess a sill but rather is a monotonically increasing semivariogram tangent to the x-axis at the origin. Because of the lack of stationarity in the drift, we must seek the semivariance of the residuals.

Estimation of the semivariance of the residuals is an undetermined problem, because the calculation of residuals requires computation of the drift, and estimation of the drift presumes knowledge of the semivariance. The problem is solved recursively by assuming a semivariogram, computing the drift, estimating the residuals, and comparing the semivariogram for these residuals with the initially assumed semivariance.

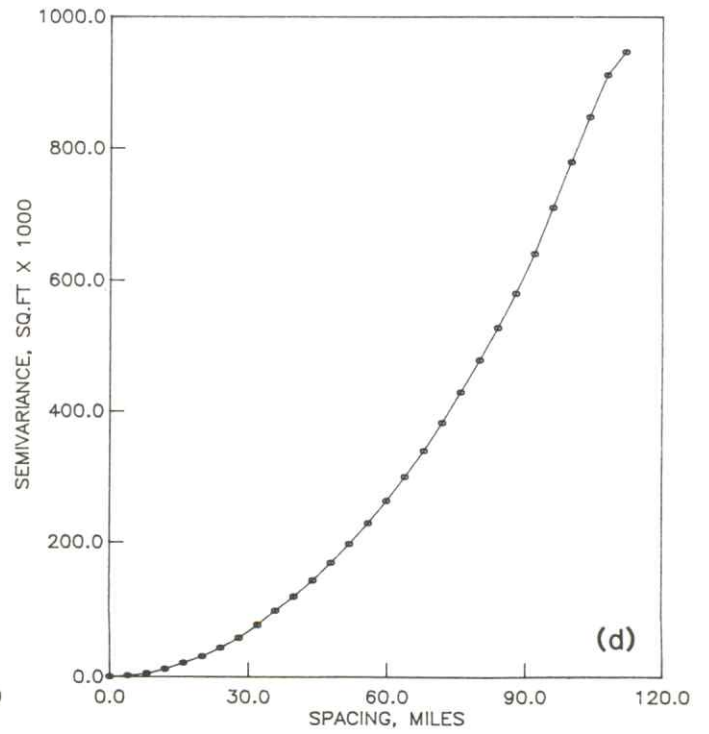
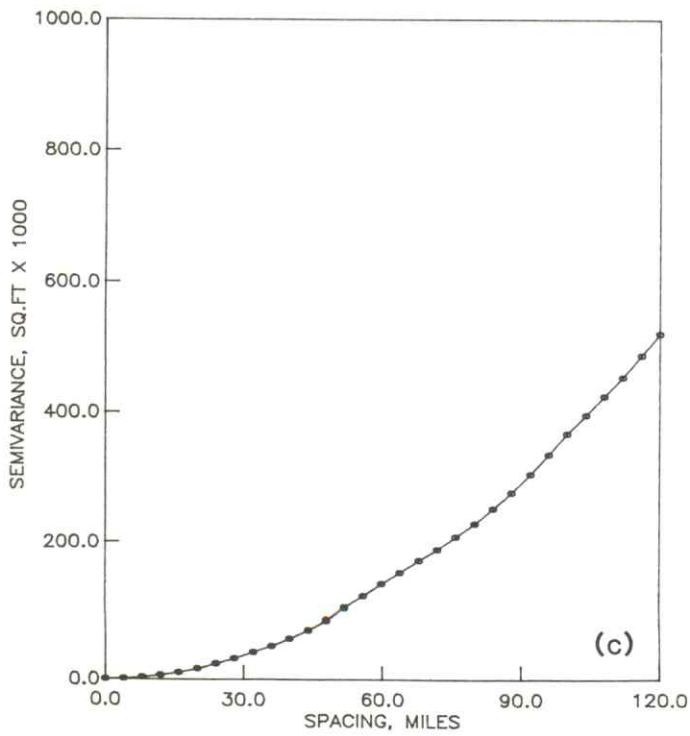
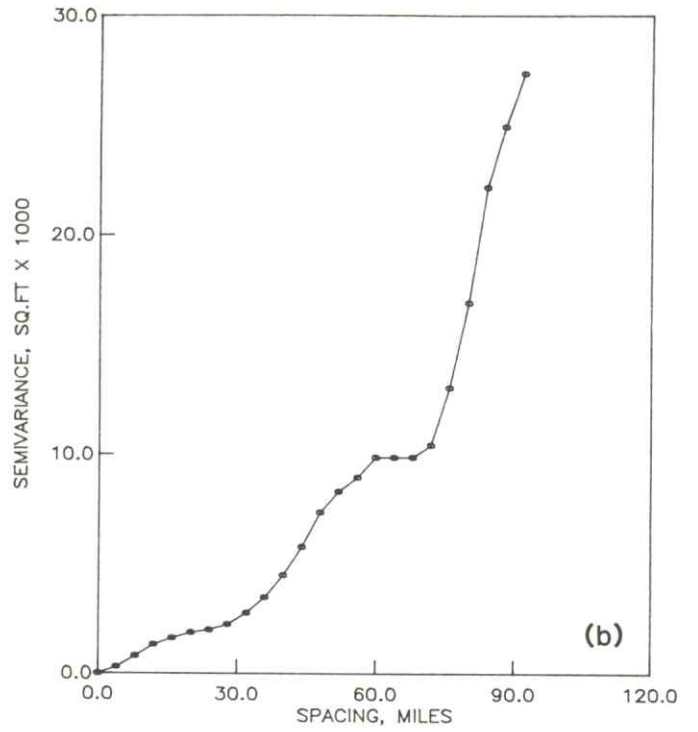
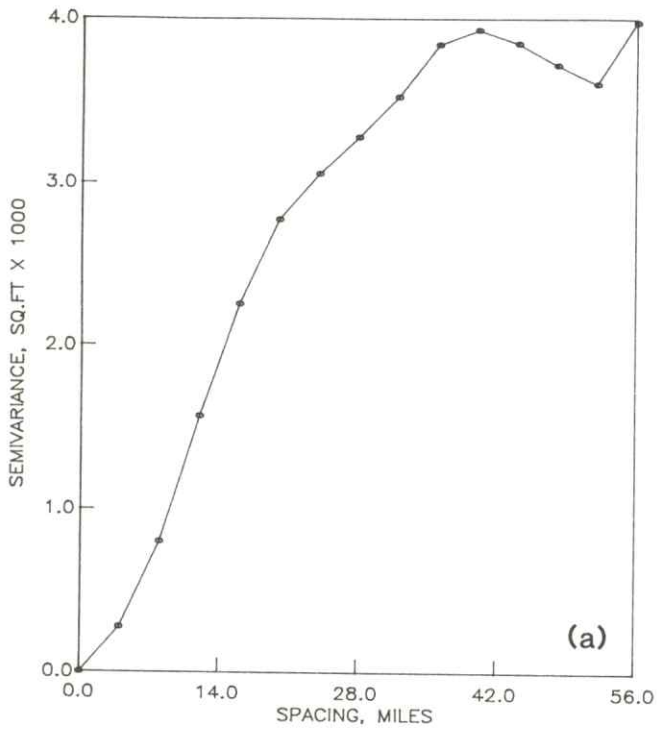
The simplest starting model is a linear semivariogram, whose drift is not a function of the slope ω (Olea, 1975, p. 54). Therefore, the estimated semivariogram is invariant under a change of assumed slope. Rather than estimating the assumed slope by a regression line through the estimated semivariogram, the practice is to make that slope equal to the slope at the origin in the estimated semivariogram. The justification for this practice is the fact that the reliability of the estimated semivariance decreases as the argument increases, primarily because of the decreasing number of pairs in Equation A.1 as the distance between sample elements increases (Clark, 1979, p. 18; Journel and Huijbregts, 1978, p. 193). However, the analysis will depend on what portion of the semivariance is modeled. A linear model will perform well only for arguments no larger than the range. From Figure A.3, analysis should be confined to arguments no larger than 28 miles (45 km). Polynomials of degree one and two were selected as drifts. Figures A.4 to A.7 show the results of the structural analysis which are also expressed in condensed form in Table A.1.

TABLE A.1
SEMIVARIOGRAM SLOPES FOR LINEAR MODELS

Traverse	Length mi.	Degree of Drift Polynomial		
		0	1	2
NS	121	71	65	46
SWNE	92	76	70	63
NWSE	156	217	70	58
EWN	112	343	38	39
EWC	94	233	36	38
EWS	224	193	64	65
	Average	177	59	54

The discrepancy among the traverses is substantially reduced by subtracting the drift, but regardless of the type of drift, the assumed and experimental semivariograms are different. Based on the results for the east-west traverses, the remaining discrepancy is considered to be within the statistical variation of the estimates and should be cancelled out by averaging all traverses. For some traverses, a second-degree polynomial drift model provides slightly better results in terms of removing the anisotropy and fitting the estimated semivariogram to the assumed semivariogram. However, the improvement is not that dramatic so as to change the geological notion that the drift of the water elevation is a plane.

FIGURE A.3. Semivariances of water table elevations along traverses across the High Plains aquifer. (a) Semivariance along traverse NS. (b) Semivariance along traverse SWNE. (c) Semivariance along traverse NWSE. (d) Average semivariance for east-west traverses.

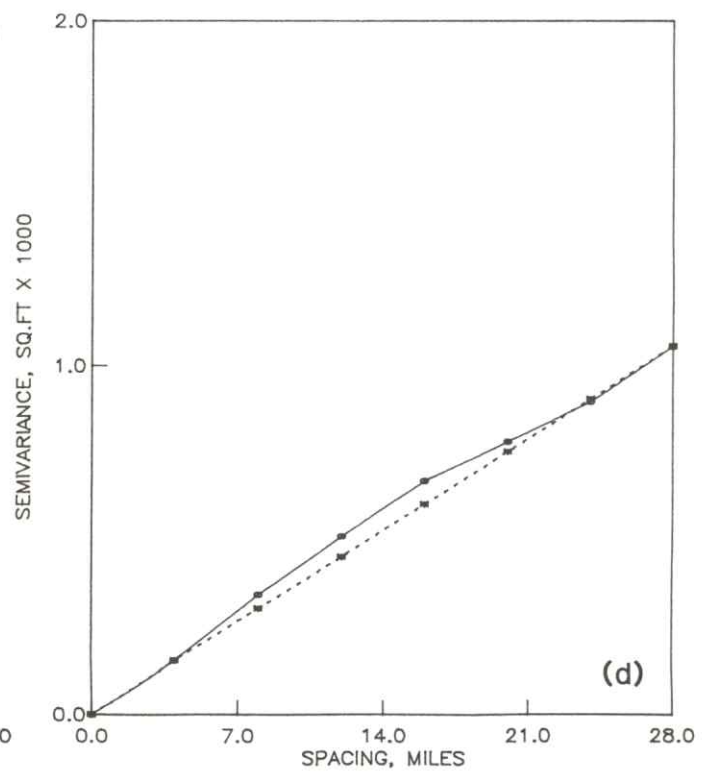
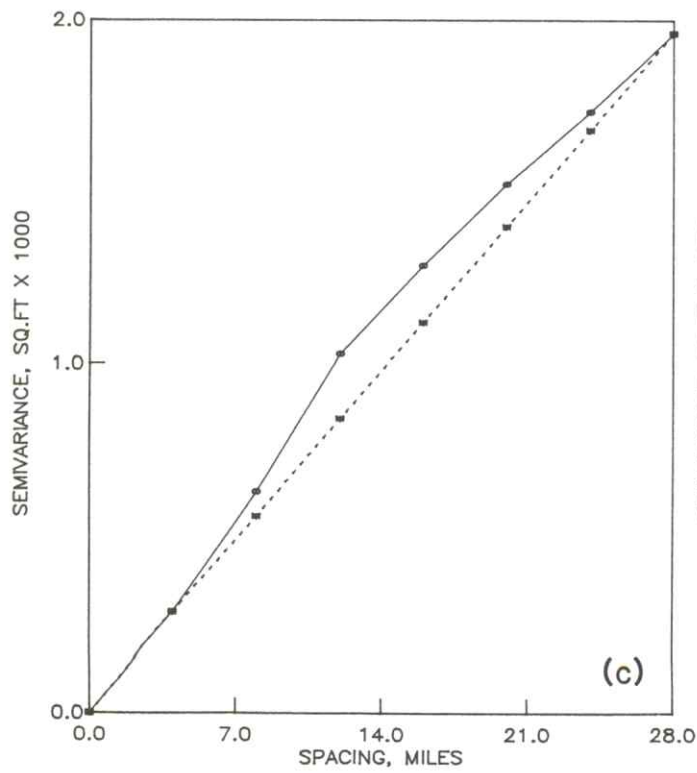
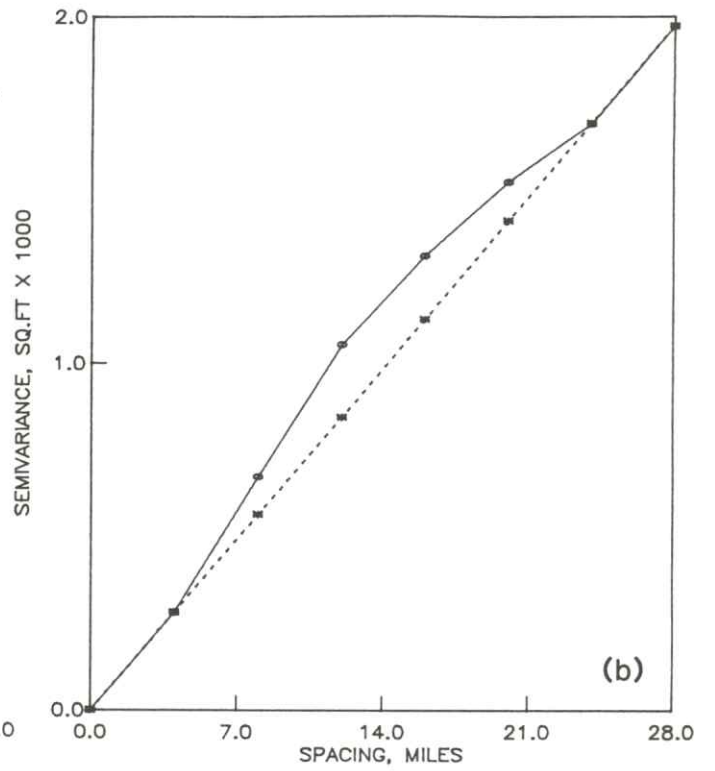
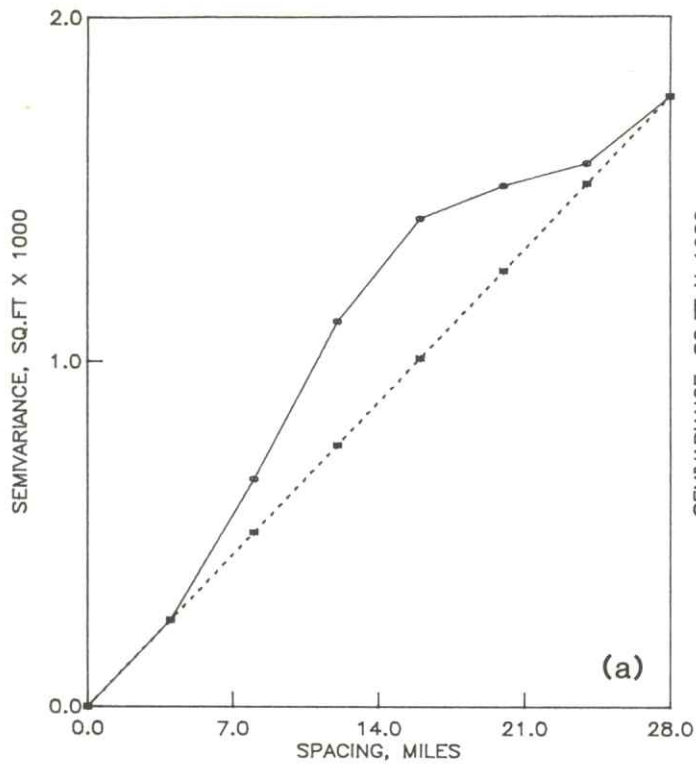


For the purpose of this study, the following is considered a satisfactory model for the semivariance of the residuals

$$\gamma(h) = 60 h \quad (A.5)$$

for arguments no larger than 28 miles (45 km). This value is sufficiently large that it is not necessary to extend the analysis to models valid for larger arguments which include the presence of a sill.

FIGURE A.4. Semivariances of residuals from a first-degree polynomial drift of water table elevations in the High Plains aquifer. (a) Semivariance of residuals along traverse NS. (b) Semivariance of residuals along traverse SWNE. (c) Semivariance of residuals along traverse NWSE. (d) Average semivariance of residuals along east-west traverses.



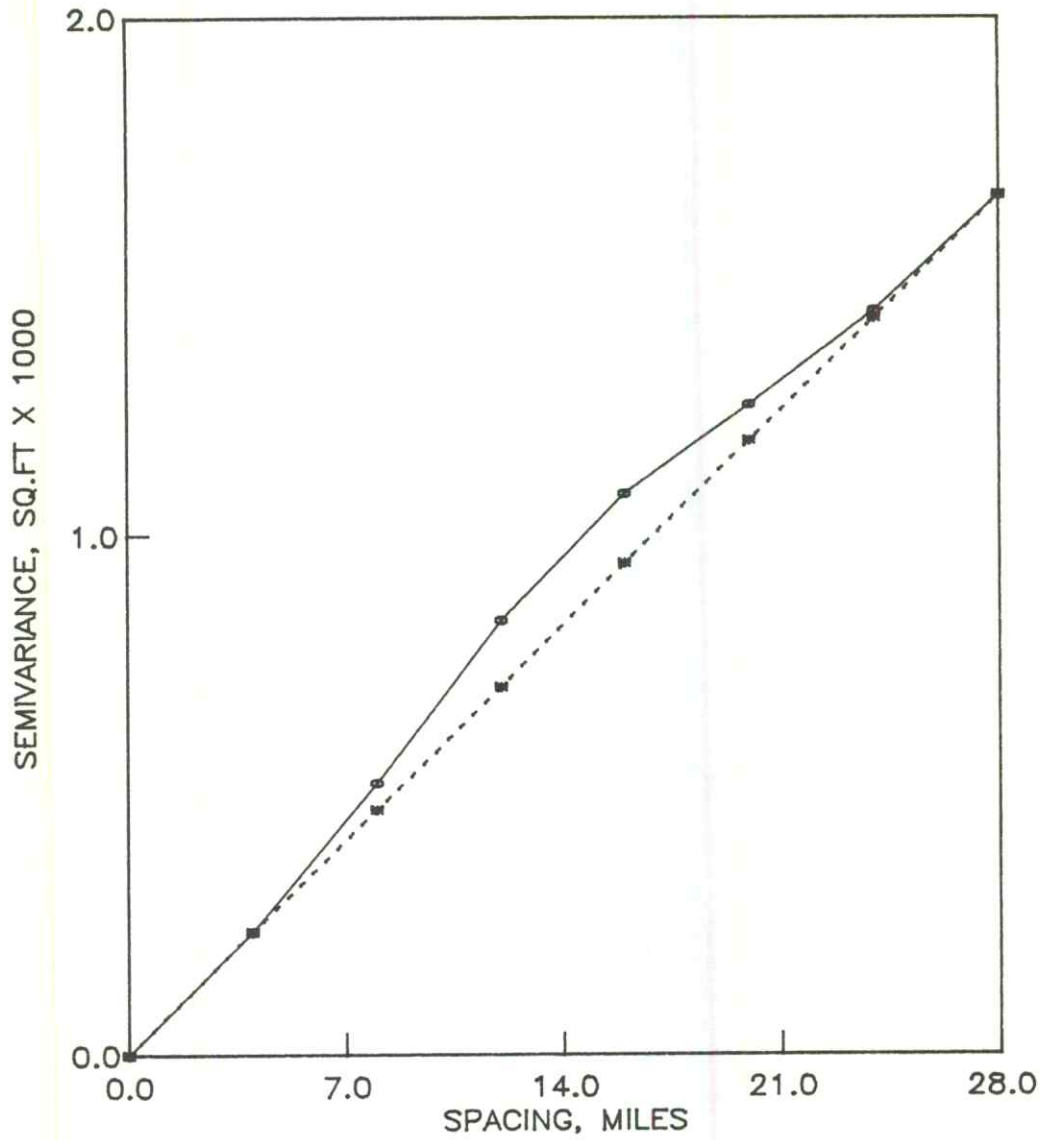
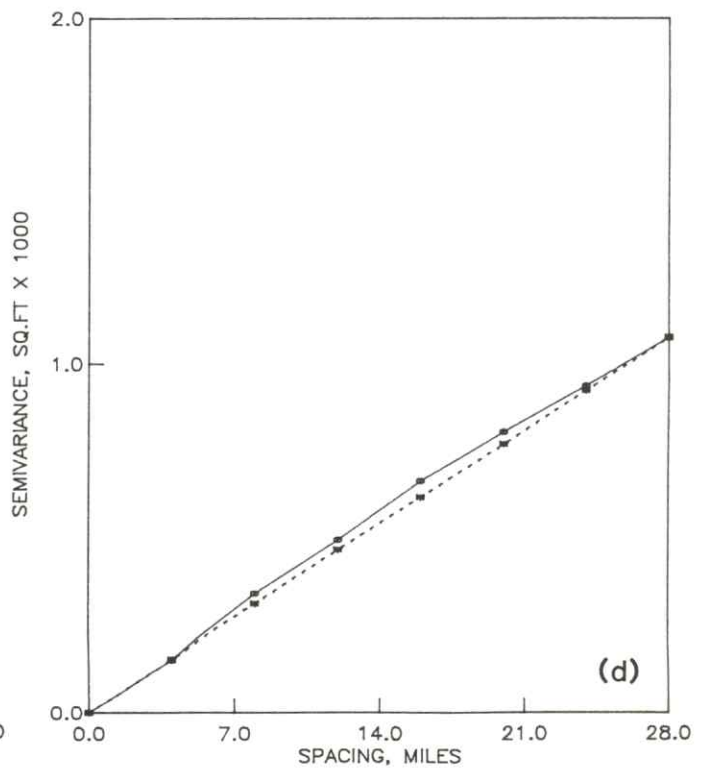
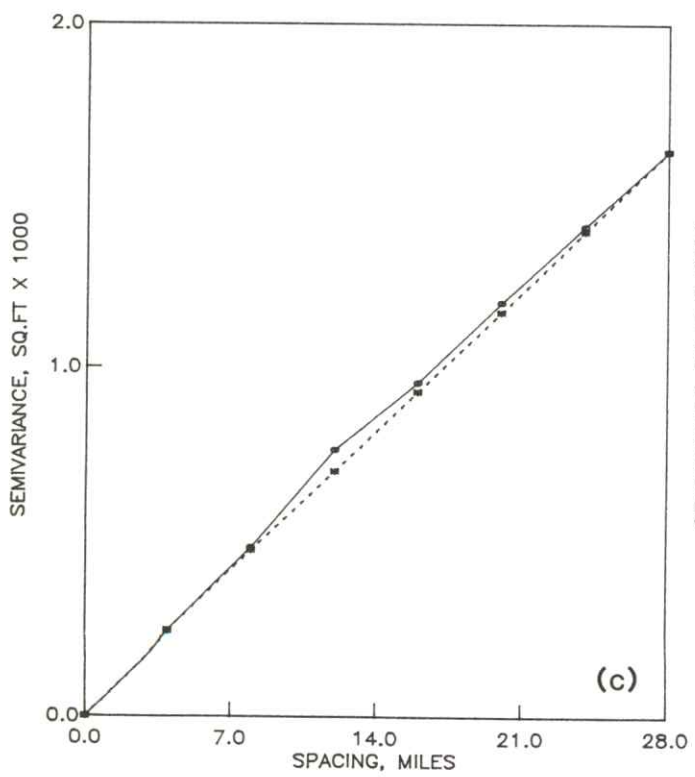
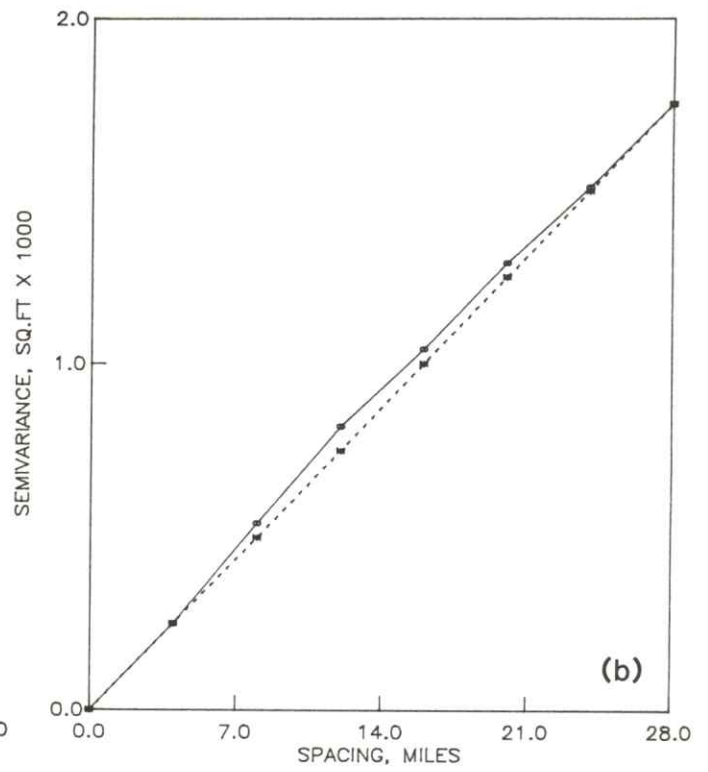
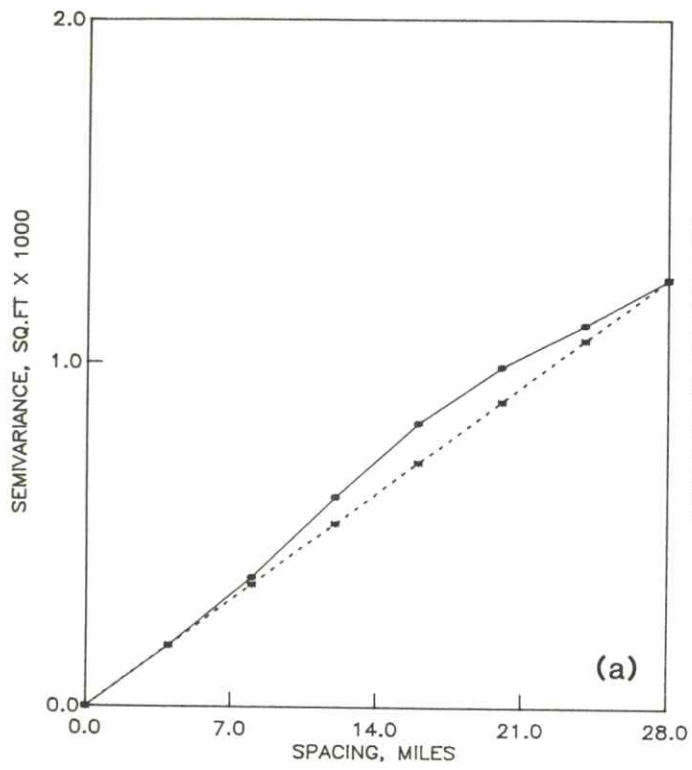


FIGURE A.5. Average semivariance of residuals from a first-degree polynomial drift for all traverses.

FIGURE A.6. Semivariances of residuals from a second-degree polynomial drift of water table elevations in the High Plains aquifer. (a) Semivariance of residuals along traverse NS. (b) Semivariance of residuals along traverse SWNE. (c) Semivariance of residuals along traverse NWSE. (d) Average semivariance of residuals along east-west traverses.



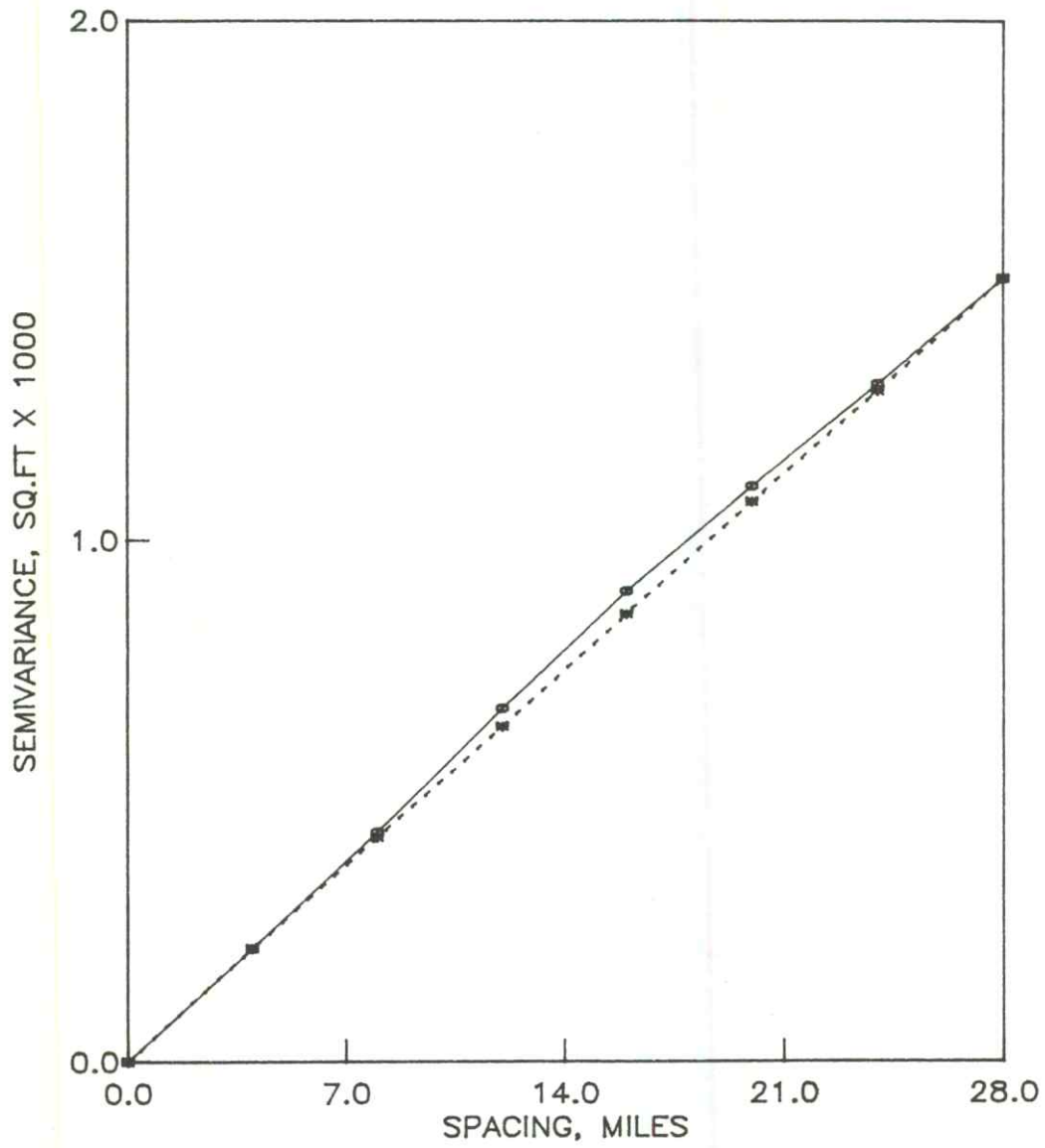


FIGURE A.7. Average semivariance of residuals from a second-degree polynomial drift for all traverses.

APPENDIX B

STATISTICAL TABLES

B.1 Selected patterns used in the tables

Pattern is a nominal variable which refers to different configurations of objects, which in this case are the sample elements or observation well locations. A pattern involves distances among the elements in the set, here arranged in two dimensions. Some patterns have unique characterizations; for example, there is only one way to arrange elements in a square pattern. All square patterns are the result of scaling, rotation, or translation of the one basic type. In contrast, a random pattern has only a statistical definition, as there are an infinite number of possible configurations that fit the description of randomness.

Utility computer programs were prepared to generate sample element patterns covering the entire range of possible patterns (Olea, 1982a, Appendix B). From these, 14 patterns grouped into 7 categories were selected, as shown in Figure B.1.

1. Regular
 - a. Hexagonal
 - b. Square
 - c. Triangular

2. Orthogonal regular traverses
 - d. Intersection every 2 points
 - e. Intersection every 8 points

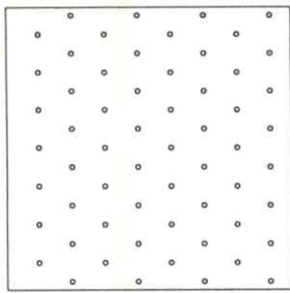
3. Stratified
 - f. Hexagonal
 - g. Square

4. h. Random

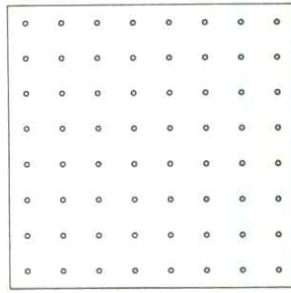
5. Bisymmetrical
 - i. Random
 - j. Regular clusters

6. Regular clusters
 - k. Sixteen points per cluster
 - l. Four points per cluster

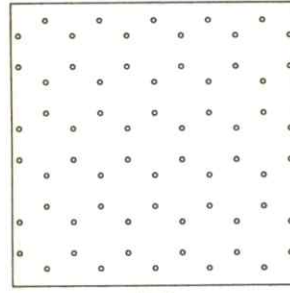
7. Clustered
 - m. One cluster
 - n. Five clusters



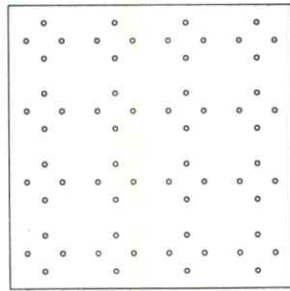
(a)



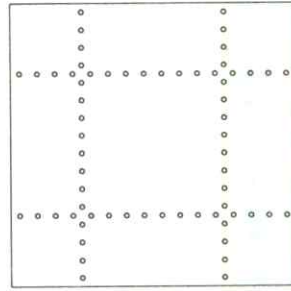
(b)



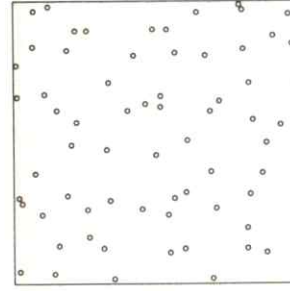
(c)



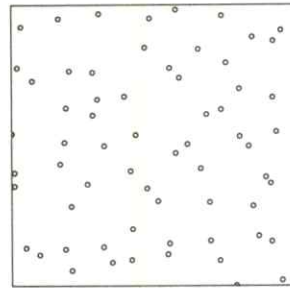
(d)



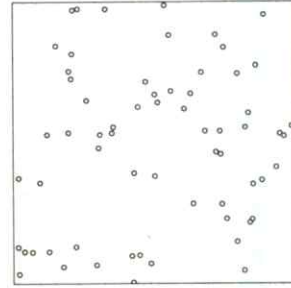
(e)



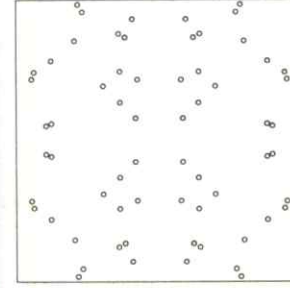
(f)



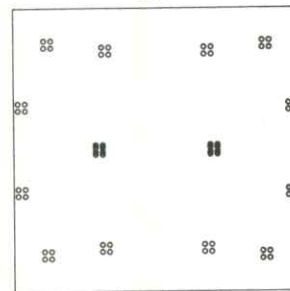
(g)



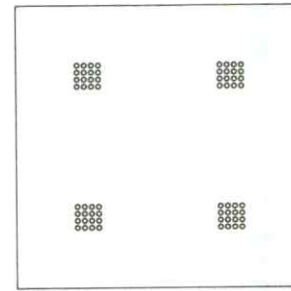
(h)



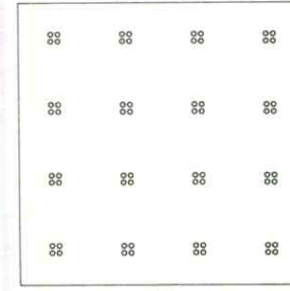
(i)



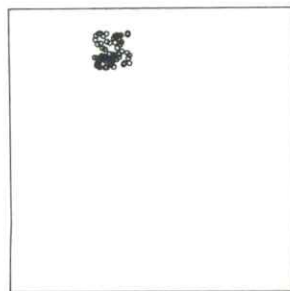
(j)



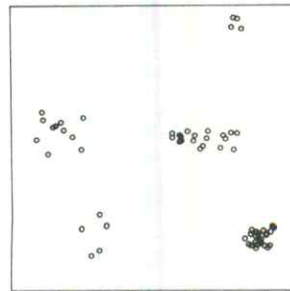
(k)



(l)



(m)

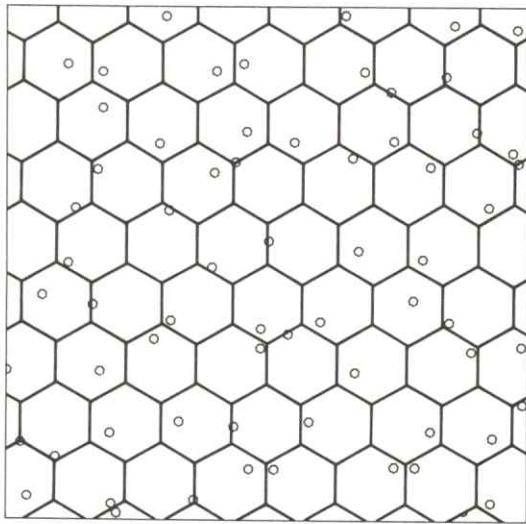


(n)

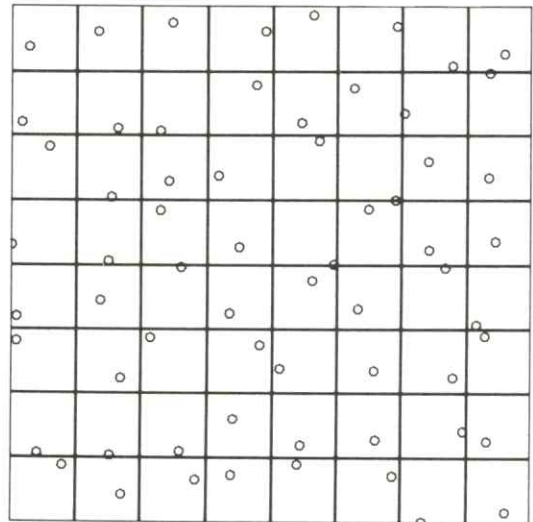
Categories 1 and 2 are uniquely defined. The remaining patterns are representative examples from among an infinite set of possibilities. It can be proven that the three patterns shown as Figure B.1a-c are the only regular configurations which can be formed in a two-dimensional space (Matérn, 1960, p. 74).

Stratified sampling is a selection procedure in which the sample space is divided into mutually exclusive partitions and an element is then randomly taken from every partition (Ripley, 1981, p. 19-22). Figure B.2 illustrates stratified sampling of a two-dimensional space partitioned into squares and into hexagons. The randomly selected points are the same as in Figure B.1f and B.1g.

FIGURE B.1. Sample element patterns investigated in this study. Patterns (a) through (c) are regular, (d) and (e) consist of orthogonal regular traverses, (f) and (g) are stratified, (h) is a random pattern, (i) and (j) are bisymmetrical, and (k) through (n) are clustered patterns.



(a)



(b)

FIGURE B.2. Sampling mechanism for stratified patterns. (a) One point is selected randomly from inside each hexagon. (b) One point is selected randomly from inside each square.

B.2 Sampling tables

The following tables contain values of average standard error and maximum standard error assuming the sample elements and the estimated value have the same support. The sampling density is one point per square mile (0.39 point/km²) and the semivariogram is linear with unit slope.

TABLE B.1
SAMPLING EFFICIENCY INDICES AT UNIT LINEAR SEMIVARIOGRAM SLOPE,
UNIT DENSITY, AND 32 NEAREST NEIGHBORS

Pattern	Average Std. Error			Maximum Std. Error		
	0	1	2	0	1	2
Hexagonal	0.63	0.63	0.63	0.72	0.72	0.72
Square	0.64	0.64	0.64	0.74	0.74	0.74
Triangular	0.66	0.66	0.66	0.80	0.80	0.80
Traverses every 2 points	0.68	0.68	0.68	0.89	0.89	0.89
Hexagonal strati- fication	0.69	0.69	0.69	0.86	0.86	0.86
Square strati- fication	0.69	0.69	0.69	0.91	0.91	0.91
Random	0.71	0.71	0.71	1.05	1.05	1.05
Bisymmetrical random	0.72	0.72	0.72	0.98	0.98	0.98
Traverses every 8 points	0.81	0.81	0.84	1.23	1.23	1.45
Four points per regular cluster	0.83	0.83	0.84	0.99	0.99	1.00
Five clusters	0.98	0.99	1.06	1.33	1.49	2.33
Bisymmetrical clusters	1.03	1.03	1.11	1.22	1.22	1.38
Sixteen points per regular cluster	1.13	1.17	1.53	1.51	1.85	5.13
One cluster	2.19	5.01	61.50	2.94	8.27	148.00

TABLE B.2

POINTS OF NO ADDITIONAL RETURN ON SAMPLING EFFICIENCY INDICES BY
INCREASING THE NUMBER OF NEAREST NEIGHBORS

Pattern	Average Std. Error Drift			Maximum Std. Error Drift		
	0	1	2	0	1	2
Hexagonal	3	5	10	3	5	10
Square	4	5	10	10	10	14
Triangular	8	8	11	11	12	12
Traverses every two points	12	12	20	14	15	26
Hexagonal stratification	6	6	16	7	8	25
Square stratification	8	8	18	10	11	30
Random	12	12	32+	12	14	32+
Bisymmetrical random	8	8	32+	20	28	32+
Traverses every 8 points	28	32+	32+	28	32+	32+
Four points per regular cluster	12	12	32+	22	28	32+
Five clusters	32+	32+	32+	32+	32+	32+
Bisymmetrical clusters	20	20	32+	26	28	32+
Sixteen points per regular cluster	32+	32+	32+	32+	32+	32+
One cluster	32+	32+	32+	32+	32+	32+

TABLE B.3

MINIMUM NUMBER OF NEAREST NEIGHBORS REQUIRED TO SOLVE THE
UNIVERSAL KRIGING SYSTEM OF EQUATIONS

Pattern	Drift		
	0	1	2
Hexagonal	1	3	6
Square	1	3	7
Triangular	1	3	7
Traverses every two points	1	3	9
Hexagonal stratification	1	3	6
Square stratification	1	3	6
Random	1	3	6
Bisymmetrical random	1	3	9
Traverses every eight points	1	5	9
Four points per regular cluster	1	3	9
Five clusters	1	3	6
Bisymmetrical clusters	1	5	12
Sixteen points per regular cluster	1	5	9
One cluster	1	3	7

TABLE B.4
 AVERAGE STANDARD ERROR
 THE DRIFT IS A CONSTANT
 UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	<u>Number of nearest neighbors</u>								
	1	2	3	4	6	8	12	16	32
Hexagonal	0.83	0.67	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Square	0.86	0.68	0.65	0.64	0.64	0.64	0.64	0.64	0.64
Triangular	0.88	0.74	0.69	0.68	0.67	0.66	0.66	0.66	0.66
Orthogonal traverses every 2 points	0.92	0.78	0.73	0.71	0.70	0.69	0.69	0.68	0.68
Hexagonal stratification	0.90	0.76	0.72	0.70	0.69	0.69	0.69	0.69	0.69
Square strati- fication	0.90	0.78	0.72	0.71	0.70	0.69	0.69	0.69	0.69
Random	0.93	0.82	0.78	0.76	0.73	0.72	0.72	0.71	0.71
Bisymmetrical random	0.95	0.82	0.78	0.75	0.73	0.72	0.72	0.72	0.72
Orthogonal traverses every 8 points	1.08	0.99	0.95	0.93	0.88	0.86	0.84	0.83	0.81
Four points per regular cluster	1.11	1.03	0.99	0.97	0.87	0.86	0.83	0.83	0.83
Five clusters	1.27	1.21	1.17	1.14	1.12	1.08	1.05	1.03	0.98
Bisymmetrical clusters	1.37	1.30	1.28	1.27	1.20	1.19	1.06	1.04	1.03
Sixteen points per regular cluster	1.49	1.39	1.37	1.36	1.35	1.32	1.27	1.24	1.13
One cluster	2.26	2.25	2.24	2.23	2.22	2.22	2.20	2.20	2.19

TABLE B.5
 AVERAGE STANDARD ERROR
 FIRST-DEGREE POLYNOMIAL DRIFT
 UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	<u>Number of nearest neighbors</u>							
	3	4	5	6	8	12	16	32
Hexagonal	0.65	0.64	0.63	0.63	0.63	0.63	0.63	0.63
Square	0.66	0.65	0.64	0.64	0.64	0.64	0.64	0.64
Triangular	0.80	0.69	0.67	0.67	0.66	0.66	0.66	0.66
Orthogonal traverses every 2 points	1.02	0.77	0.72	0.70	0.69	0.69	0.68	0.68
Hexagonal stratification	1.47	0.74	0.70	0.69	0.69	0.69	0.69	0.69
Square strati- fication	1.81	0.75	0.71	0.70	0.69	0.69	0.69	0.69
Random	1.91	0.96	0.82	0.77	0.73	0.72	0.71	0.71
Bisymmetrical random	21.92	0.84	0.77	0.74	0.72	0.72	0.72	0.72
Orthogonal traverses every 8 points	--	--	1.24	1.14	1.02	0.88	0.83	0.81
Four points per regular cluster	1.99	1.56	1.09	1.01	0.92	0.83	0.83	0.83
Five clusters	3.69	2.71	2.20	1.98	1.60	1.33	1.18	0.99
Bisymmetrical clusters	--	--	2.50	2.24	1.93	1.18	1.07	1.03
Sixteen points per regular cluster	--	--	2.96	2.75	2.29	1.83	1.62	1.17
One cluster	148.00	33.87	19.74	13.92	9.17	7.15	6.31	5.01

TABLE B.6
 AVERAGE STANDARD ERROR
 SECOND-DEGREE POLYNOMIAL DRIFT
 UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	<u>Number of nearest neighbors</u>						
	6	7	8	9	12	16	32
Hexagonal	0.68	0.67	0.66	0.65	0.63	0.63	0.63
Square	--	0.67	0.67	0.66	0.64	0.64	0.64
Triangular	--	0.77	0.72	0.69	0.66	0.66	0.66
Orthogonal traverses every 2 points	--	--	--	0.76	0.71	0.69	0.68
Hexagonal stratification	1.55	0.86	0.77	0.74	0.70	0.69	0.69
Square strati- fication	3.27	0.90	0.78	0.74	0.71	0.70	0.69
Random	26.71	1.42	1.06	0.88	0.77	0.74	0.71
Bisymmetrical random	--	--	--	0.85	0.76	0.73	0.72
Orthogonal traverses every 8 points	--	--	--	1.69	1.30	1.16	0.84
Four points per regular cluster	--	--	--	1.11	1.02	0.95	0.84
Five clusters	88.99	17.76	12.80	9.68	4.90	2.71	1.07
Bisymmetrical clusters	--	--	--	--	9.92	1.62	1.11
Sixteen points per regular cluster	--	--	--	12.94	7.25	4.78	1.53
One cluster	--	2214.00	936.00	547.00	275.00	171.00	61.50

TABLE B.7

MAXIMUM STANDARD ERROR
 THE DRIFT IS A CONSTANT
 UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	<u>Number of nearest neighbors</u>								
	1	2	3	4	6	8	12	16	32
Hexagonal	1.11	0.84	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Square	1.19	0.88	0.80	0.75	0.75	0.75	0.74	0.74	0.74
Triangular	1.32	1.14	0.98	0.88	0.81	0.81	0.80	0.80	0.80
Orthogonal traverses every 2 points	1.50	1.27	1.14	1.05	0.93	0.91	0.90	0.89	0.89
Hexagonal stratification	1.30	1.07	1.02	0.94	0.87	0.86	0.86	0.86	0.86
Square strati- fication	1.42	1.26	1.06	0.97	0.93	0.92	0.91	0.91	0.91
Random	1.48	1.34	1.34	1.23	1.16	1.06	1.06	1.05	1.05
Bisymmetrical random	1.60	1.45	1.33	1.32	1.05	1.00	0.99	0.99	0.98
Orthogonal traverses every 8 points	2.01	1.94	1.80	1.76	1.31	1.39	1.29	1.24	1.23
Four points per regular cluster	1.60	1.50	1.41	1.40	1.17	1.12	1.00	1.00	0.99
Five clusters	1.83	1.82	1.75	1.74	1.70	1.67	1.64	1.46	1.33
Bisymmetrical clusters	1.92	1.83	1.83	1.83	1.76	1.76	1.40	1.39	1.22
Sixteen points per regular cluster	2.19	2.06	2.06	2.05	2.05	1.90	1.90	1.74	1.51
One cluster	2.99	2.98	2.98	2.98	2.97	2.96	2.96	2.95	2.94

TABLE B.8

MAXIMUM STANDARD ERROR
FIRST-DEGREE POLYNOMIAL DRIFT
UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	<u>Number of nearest neighbors</u>							
	3	4	5	6	8	12	16	32
Hexagonal	0.73	0.73	0.72	0.72	0.72	0.72	0.72	0.72
Square	0.84	0.75	0.75	0.75	0.75	0.74	0.74	0.74
Triangular	1.47	0.93	0.83	0.81	0.81	0.80	0.80	0.80
Orthogonal traverses every 2 points	2.45	1.40	1.02	0.94	0.91	0.90	0.89	0.89
Hexagonal stratification	15.39	1.30	0.89	0.87	0.86	0.86	0.86	0.86
Square strati- fication	23.01	1.75	0.99	0.93	0.92	0.91	0.91	0.91
Random	19.74	3.26	1.84	1.58	1.11	1.06	1.05	1.05
Bisymmetrical random	307.00	3.02	1.36	1.14	1.00	0.99	0.99	0.98
Orthogonal traverses every 8 points	--	--	2.58	2.21	1.77	1.45	1.25	1.23
Four points per regular cluster	3.94	2.38	2.11	1.87	1.54	1.00	1.00	0.99
Five clusters	12.35	11.76	5.33	5.23	4.24	3.26	2.28	1.49
Bisymmetrical clusters	--	--	6.04	5.12	4.22	2.26	1.98	1.22
Sixteen points per regular cluster	--	--	5.80	5.48	4.17	3.72	2.90	1.85
One cluster	793.00	118.00	98.19	46.45	18.47	12.55	10.13	8.27

TABLE B.9
 MAXIMUM STANDARD ERROR
 SECOND-DEGREE POLYNOMIAL DRIFT
 UNIT DENSITY AND UNIT LINEAR SEMIVARIOGRAM SLOPE

Pattern	Number of nearest neighbors						
	6	7	8	9	12	16	32
Hexagonal	0.78	0.76	0.76	0.74	0.72	0.72	0.72
Square	--	0.79	0.78	0.77	0.75	0.74	0.74
Triangular	--	1.07	0.99	0.87	0.80	0.80	0.80
Orthogonal traverses every 2 points	--	--	--	1.27	0.97	0.90	0.89
Hexagonal stratification	39.91	1.57	1.14	1.07	0.90	0.87	0.86
Square strati- fication	93.17	3.07	1.42	1.12	0.96	0.93	0.91
Random	2690.00	11.60	7.90	2.03	1.32	1.15	1.05
Bisymmetrical random	--	--	--	1.96	1.25	1.07	0.98
Orthogonal traverses every 8 points	--	--	--	8.84	4.48	3.27	1.45
Four points per regular cluster	--	--	--	1.67	1.43	1.22	1.00
Five clusters	986.00	142.00	101.00	101.00	32.87	12.30	2.33
Bisymmetrical clusters	--	--	--	--	107.00	10.03	1.38
Sixteen points per regular cluster	--	--	--	33.47	23.71	12.10	5.13
One cluster	--	10425.00	8763.00	1956.00	815.00	535.00	148.00

APPENDIX C

SAMPLING DESIGN EXAMPLE

Problem:

Find the best non-regular sampling procedure for the High Plains aquifer which will produce estimates of the water table elevation having an average standard error of 10.8 feet (3.3 m). Border effects will be ignored.

Solution:

From Algorithm 2.1

1. The results of the structural analysis are given in Appendix A. The relevant results are:
 - a. $\omega = 60 \text{ feet}^2 \text{ per mile}$ ($3.5 \text{ m}^2/\text{km}$)
 - b. The drift model is a first degree polynomial within a neighborhood which is 28 miles (45 km) in diameter.
2. From the statement of the problem, the sampling efficiency index is the average standard error.
3. From Table B.1, the non-regular patterns with lowest average standard error are the stratified patterns. A hexagonal stratification is preferred over a square stratification as the former offers a lower maximum standard error. The value $I(1,1)$ is 0.69 feet (0.21 m).
4. From the statement of the problem, $I(\omega, \rho)$ is equal to 10.8 feet (3.3 m).
5. From equation 2.4 and the steps above

$$\begin{aligned}\rho &= 60^2 \left[\frac{0.69}{10.8} \right]^4 \\ &= 0.06 \text{ point per square mile}\end{aligned}$$

6. The number of points inside a 28 mile (45 km) diameter at a density of 0.06 point per square mile ($0.023 \text{ point}/\text{km}^2$) is

$$\begin{aligned}N &= \frac{\pi d^2}{4} \rho \\ &= \frac{3.14159 \times 28^2 \times 0.06}{4} \\ &= 36 \text{ points}\end{aligned}$$

7. From Table B.3, the minimum number of nearest neighbors required to solve the universal kriging system of equations is 3, which is an order of magnitude smaller than the number of points that can be contained inside the neighborhood for which structural analysis models are valid.
8. From Table B.2, the point of no return is 6.
9. Since the 36 points that can be placed inside the structural analysis neighborhood is a larger number than the point of no return, 6 nearest neighbors should be used in the solution of the universal kriging system of equations.

Hence, the best irregular sample pattern for the water table elevation in the High Plains aquifer is a hexagonal stratified pattern. Except near the edges of the aquifer, a sampling density of 0.06 point per square mile (0.023 point/km^2) assures an average standard error of 10.8 feet (3.3 m). The number of sample elements to be used in the universal kriging system of equations should be 6.

APPENDIX D

DISTANCE INDEX

The distance index is a measure of randomness in a two-dimensional process. Let us consider a sample of n points. Each point will have a nearest neighbor which is some distance r_i away. The average distance to the nearest neighbor, \bar{r} , is defined as

$$\bar{r} = \frac{1}{n} \sum_{i=1}^n r_i \quad (\text{D.1})$$

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

$$\bar{r}_E = \frac{1}{2\sqrt{\rho}} \quad (\text{D.2})$$

where ρ is the density of the pattern expressed as the number of sample elements per unit of area.

The distance index R is the ratio of the observed average distance to the nearest neighbor to the value expected for a random pattern:

$$R = \bar{r} / \bar{r}_E \quad (\text{D.3})$$

The distance index R can vary between zero, for a cluster in which all sample elements occur at the same location, to a maximum value of 2.149, for a regular hexagonal pattern such as Figure B.1a.

APPENDIX E

AVAILABLE OBSERVATION WELLS

E.1 High Plains aquifer wells

A total of 1749 observation wells, shown in Plates 1 and 2, were measured without problems during the period December 1980 to March 1981 in the High Plains aquifer. Data on wells 1 to 1646 were gathered by either the Division of Water Resources of the State Board of Agriculture, the City of Wichita, or the United States Geological Survey and available from computer files maintained by the USGS. Information on the remaining 103 wells was provided by Kansas Groundwater Management District No. 2.

Variables listed in the appendix include:

- L.S.E. - Land surface elevation above sea level, feet
- DEPTH - Depth to the water table below the land surface, feet
- ELEV. - Water table elevation above sea level, feet

The location of 1135 of these wells following a hexagonal stratification are shown on Plates 3 and 4. The remaining 614 wells, marked by asterisks in the list, are excess observation wells in the hexagonal stratified sampling plan and are posted on Plate 5.

COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.			
1 - BARTON	185 15W 28CCC	3	1912.5	21.0	1891.5	136 - FINNEY	225 32W 8ACB	1	2884.0	76.4	2807.6 *	271 - FORD	275 24W 9ACD	1	2448.0	20.6	2427.4 *
2 - BARTON	195 13W 8BAD	1	1855.0	20.8	1834.3	137 - FINNEY	225 32W 21CCDC	1	2903.0	114.2	2878.8 *	272 - FORD	275 24W 12CCC	1	2434.0	8.6	2425.4 *
3 - BARTON	195 13W 33BDB	1	1838.0	9.5	1838.0	138 - FINNEY	225 33W 33BDB	1	2903.0	94.2	2808.8 *	273 - FORD	275 24W 16BDB	1	2515.0	75.5	2439.5 *
4 - BARTON	195 14W 6BBB	1	1895.0	10.0	1875.9	139 - FINNEY	225 33W 12CCDC	1	2903.0	120.5	2781.5 *	274 - FORD	275 24W 19ABA	1	2546.0	8.6	2447.6 *
5 - BARTON	195 14W 29DDB	1	1895.0	27.7	1867.3	140 - FINNEY	225 33W 32CCB	1	2923.0	165.3	2757.8 *	275 - FORD	275 24W 22BDB	1	2535.0	95.9	2438.1 *
6 - BARTON	205 11W 6CCC	1	1704.0	10.4	1777.6	141 - FINNEY	225 34W 10AAA	1	2933.0	109.8	2823.2 *	276 - FORD	275 24W 26DAA	1	2512.0	87.7	2424.3 *
7 - BARTON	205 12W 33AC	1	1799.0	7.6	1791.4	142 - FINNEY	225 34W 26ADD	1	2928.0	146.6	2761.4 *	277 - FORD	275 24W 34CCD	1	2548.0	110.3	2437.7 *
8 - BARTON	205 12W 6AAC	1	1822.0	9.6	1812.6	143 - FINNEY	225 34W 32CCB	1	2983.0	175.2	2807.8 *	278 - FORD	275 25W 1DBB	1	2497.0	43.5	2453.5 *
9 - BARTON	205 13W 17BDC	1	1816.0	15.5	1798.8	144 - FINNEY	235 27W 12CCDC	1	2618.0	61.1	2556.9 *	279 - FORD	275 25W 9ACA	1	2546.0	17.3	2482.8 *
10 - BARTON	205 13W 17BDC	1	1876.0	17.3	1858.7	145 - FINNEY	235 27W 22DAB	1	2654.0	89.0	2565.0 *	280 - FORD	275 25W 14DCA	1	2560.0	94.2	2465.8 *
11 - BARTON	205 13W 24DCB	1	1850.0	19.8	1830.3	146 - FINNEY	235 28W 22DCD	1	2729.0	74.7	2654.3 *	281 - FORD	275 25W 19DAA	1	2633.0	132.1	2509.9 *
12 - BARTON	205 14W 13DBD	1	1880.0	20.3	1859.7 *	147 - FINNEY	235 28W 34DCD	1	2738.0	91.7	2646.3 *	282 - FORD	275 25W 20AAA	1	2598.0	114.3	2483.7 *
13 - BARTON	205 14W 22DCB	1	1897.0	14.4	1882.6	148 - FINNEY	235 29W 34DCD	1	2772.0	89.3	2682.7 *	283 - FORD	275 25W 22BDC	1	2582.0	106.1	2475.9 *
14 - BARTON	205 15W 24D	1	1915.0	14.7	1900.3	149 - FINNEY	235 30W 14CAC	1	2846.0	66.8	2779.2 *	284 - FORD	275 25W 25BDB	1	2574.0	113.5	2460.5 *
15 - CHEYENNE	25 40W 28DAA	1	3452.0	113.5	3338.5	150 - FINNEY	235 30W 19CCB	1	2862.0	84.9	2737.0 *	285 - FORD	275 25W 28BDB	1	2613.0	248.0	2486.0 *
16 - CHEYENNE	25 41W 27BDD	1	3620.0	201.0	3419.0	151 - FINNEY	235 31W 35CCC	1	2875.0	110.6	2766.4 *	286 - FORD	275 25W 31DCA	1	2646.0	163.8	2482.2 *
17 - CHEYENNE	25 42W 14DDB	1	3693.0	232.5	3460.5	152 - FINNEY	235 32W 11ADC	1	2942.0	142.2	2794.8 *	287 - FORD	275 26W 1ABD	1	2562.0	55.0	2507.0 *
18 - CHEYENNE	35 37W 19BCC	1	3468.0	228.8	3239.2 *	153 - FINNEY	235 32W 18CCD	1	2878.0	113.1	2764.9 *	288 - FORD	275 26W 4ACB	1	2623.0	95.9	2527.1 *
19 - CHEYENNE	35 37W 21DDB	1	3422.0	218.2	3209.3	154 - FINNEY	235 32W 19CCB	1	2876.0	111.5	2764.5 *	289 - FORD	275 26W 5CAC	1	2642.0	106.1	2535.9 *
20 - CHEYENNE	35 37W 31ADD	1	3381.0	201.4	3179.6 *	155 - FINNEY	235 32W 22DAB	1	2862.0	144.4	2778.6 *	290 - FORD	275 26W 11DCC	1	2629.0	134.1	2494.9 *
21 - CHEYENNE	35 39W 20DCC	1	3450.0	141.8	3308.2	156 - FINNEY	235 32W 31CCD	1	2876.0	101.6	2774.4 *	291 - FORD	275 26W 18ABA	1	2678.0	127.9	2550.1 *
22 - CHEYENNE	35 39W 24DDB	1	3505.0	220.0	3285.0	157 - FINNEY	235 33W 10CCC	1	2880.0	125.9	2754.1 *	292 - FORD	275 26W 21AAA	1	2695.0	168.1	2526.9 *
23 - CHEYENNE	35 39W 32BDB	1	3490.0	154.2	3335.8 *	158 - FINNEY	235 33W 17BDB	1	2904.0	147.7	2756.3 *	293 - FORD	275 26W 28AAC	1	2710.0	186.9	2523.1 *
24 - CHEYENNE	35 40W 9BAA	2	3358.0			159 - FINNEY	235 33W 26ABB	1	2890.0	125.1	2764.9 *	294 - FORD	275 26W 31BDB	1	2718.0	170.3	2547.7 *
25 - CHEYENNE	35 40W 35AAC	1	3445.0	101.1	3343.9	160 - FINNEY	235 33W 28CCB	1	2904.0	138.3	2763.7 *	295 - FORD	275 26W 34BDB	1	2679.0	158.4	2518.6 *
26 - CHEYENNE	35 41W 16AAC	1	3570.0	134.3	3435.7	161 - FINNEY	235 34W 11DCC	1	2931.0	171.6	2764.9 *	296 - FORD	285 21W 10CCA	1	2378.0	50.9	2307.1 *
27 - CHEYENNE	35 41W 33ABB	1	3596.0	173.5	3420.5	162 - FINNEY	235 34W 90BB	1	2951.0	148.6	2802.4 *	297 - FORD	285 21W 10DCA	1	2349.0	9.1	2307.9 *
28 - CHEYENNE	35 42W 4AAA	1	3727.0	231.1	3495.9	163 - FINNEY	235 34W 14BDC	1	2940.0	150.9	2789.1 *	298 - FORD	285 21W 11C	1	2345.0	42.5	2302.5 *
29 - CHEYENNE	45 37W 14ABB	1	3405.0			164 - FINNEY	235 34W 17CCC	1	2974.0	152.4	2821.6 *	299 - FORD	285 21W 12ACD	1	2327.0	34.8	2292.2 *
30 - CHEYENNE	45 37W 25DCA	1	3374.0	151.1	3222.9	165 - FINNEY	235 34W 21CCD	1	2973.0	90.8	2782.2 *	300 - FORD	285 21W 14CAC	1	2400.0	91.5	2308.5 *
31 - CHEYENNE	45 38W 4ACC	1	3509.0	215.4	3293.6	166 - FINNEY	235 34W 28DCA	1	2962.0	146.0	2815.0 *	301 - FORD	285 21W 21AAA	1	2378.0	58.4	2318.6 *
32 - CHEYENNE	45 38W 20CCC	1	3485.0	155.6	3329.4	167 - FINNEY	245 31W 11DAA	1	2821.0	129.5	2752.5 *	302 - FORD	285 21W 21BAA	1	2412.0	96.1	2316.0 *
33 - CHEYENNE	45 39W 21ADC	1	3491.0	185.9	3305.3 *	168 - FINNEY	245 31W 27CCB	1	2883.0	129.0	2754.0 *	303 - FORD	285 21W 24AAC	1	2370.0	79.9	2290.1 *
34 - CHEYENNE	45 39W 27CAA	1	3520.0	206.8	3319.2 *	169 - FINNEY	245 31W 31BDC	1	2794.0	18.0	2776.0 *	304 - FORD	285 21W 25ABB	1	2365.0	70.5	2294.5 *
35 - CHEYENNE	45 39W 18CAB	1	3530.0	156.9	3373.1	170 - FINNEY	245 32W 30AC	1	2881.0	103.6	2777.4 *	305 - FORD	285 21W 27BAB	1	2405.0	93.4	2311.6 *
36 - CHEYENNE	45 39W 27CAA	1	3502.0	135.4	3366.6	171 - FINNEY	245 32W 34CCB	1	2881.0	90.8	2782.2 *	306 - FORD	285 21W 33ACD	1	2400.0	99.1	2308.5 *
37 - CHEYENNE	45 40W 28BDB	1	3520.0	125.1	3394.9	172 - FINNEY	245 32W 35CCB	1	2800.0	20.5	2779.5 *	307 - FORD	285 22W 5ADD	1	2375.0	117.3	2352.7 *
38 - CHEYENNE	45 41W 16DAA	1	3403.0			173 - FINNEY	245 32W 29AC	1	2850.0	57.0	2793.0 *	308 - FORD	285 22W 12CAC	1	2405.0	58.9	2346.1 *
39 - CHEYENNE	45 41W 25BCC	1	3571.0	142.1	3428.7	174 - FINNEY	245 32W 35DD	1	2811.0	41.1	2769.9 *	309 - FORD	285 22W 16BAB	1	2421.0	64.0	2347.0 *
40 - CHEYENNE	45 41W 31ACA	1	3552.0	98.7	3453.3 *	175 - FINNEY	245 33W 9CCD	1	2865.0	65.2	2799.8 *	310 - FORD	285 22W 32BAB	1	2445.0	131.9	2353.1 *
41 - CHEYENNE	45 42W 26BDB	1	3487.8	18.6	3469.2 *	176 - FINNEY	245 33W 14BCC	1	2881.0	38.8	2815.2 *	311 - FORD	285 22W 35BDB	1	2448.0	110.1	2338.0 *
42 - CHEYENNE	45 42W 15DDB	1	3397.0	152.1	3244.9	177 - FINNEY	245 33W 17DCA	1	2867.0	86.5	2805.5 *	312 - FORD	285 23W 4ADD	1	2465.0	249.2	2393.8 *
43 - CHEYENNE	45 38W 13BAD	1	3390.0			178 - FINNEY	245 33W 18BDB	1	2878.0	50.7	2827.3 *	313 - FORD	285 23W 18BAB	1	2547.0	133.4	2413.6 *
44 - CHEYENNE	45 38W 22ACB	1	3437.0	77.5	3312.5	179 - FINNEY	245 33W 19BDB	1	2928.0	99.8	2828.2 *	314 - FORD	285 23W 24ABB	1	2465.0	93.2	2371.8 *
45 - CHEYENNE	45 38W 22ACB	1	3437.0	77.5	3312.5	180 - FINNEY	245 33W 21BDC	1	2915.0	113.5	2801.5 *	315 - FORD	285 23W 33BAC	1	2518.0	113.9	2401.1 *
46 - CHEYENNE	45 38W 26BDB	1	3460.0	117.7	3342.3	181 - FINNEY	245 33W 22BCC	1	2888.0	77.8	2802.2 *	316 - FORD	285 24W 6DAB	1	2598.0	155.5	2442.5 *
47 - CHEYENNE	45 39W 11CCB	1	3530.0	152.6	3377.4	182 - FINNEY	245 33W 23CCB	1	2910.0	92.5	2812.2 *	317 - FORD	285 24W 8DCC	1	2578.0	137.0	2441.0 *
48 - CHEYENNE	45 39W 18CCC	1	3640.0	216.1	3413.9	183 - FINNEY	245 33W 28DAA	1	2886.0	94.1	2791.9 *	318 - FORD	285 24W 9CCB	1	2574.0	137.0	2441.0 *
49 - CHEYENNE	45 39W 25DCA	1	3533.0	152.1	3400.9	184 - FINNEY	245 33W 29DAA	1	2920.0	114.2	2805.8 *	319 - FORD	285 24W 11BCC	1	2554.0	133.5	2420.5 *
50 - CHEYENNE	45 40W 4CCB	1	3653.0			185 - FINNEY	245 33W 30CCB	1	2932.0	97.2	2834.8 *	320 - FORD	285 24W 18DCA	1	2581.0	128.9	2452.1 *
51 - CHEYENNE	45 40W 15ACB	1	3650.0	226.2	3421.8	186 - FINNEY	245 33W 31BDB	1	2923.0	94.5	2828.5 *	321 - FORD	285 24W 29DDB	1	2565.0	131.8	2432.1 *
52 - CHEYENNE	45 40W 27BBA	1	3658.0	204.2	3453.8	187 - FINNEY	245 33W 32CCB	1	2910.0	92.9	2837.1 *	322 - FORD	285 24W 31BDB	1	2570.0	137.0	2433.0 *
53 - CHEYENNE	45 41W 12ADC	1	3679.0	211.9	3467.1 *	188 - FINNEY	245 33W 31DCA	1	2913.7	81.1	2838.6 *	323 - FORD	285 24W 32BDB	1	2636.0	168.8	2472.5 *
54 - CHEYENNE	45 41W 20DAA	1	3640.0	225.4	3516.6	189 - FINNEY	245 33W 32DAA	1	2928.0	113.4	2814.6 *	324 - FORD	285 25W 28BDB	1	2576.0	203.6	2436.0 *
55 - CHEYENNE	45 42W 4AAB	1	3515.0			190 - FINNEY	245 33W 34CAC	1	2910.0	116.8	2793.2 *	325 - FORD	285 25W 6AAB	1	2643.0	147.1	2495.9 *
56 - CHEYENNE	45 42W 14CCB	1	3687.0	153.5	3533.5	191 - FINNEY	245 34W 18BDB	1	2894.0	81.6	2812.4 *	326 - FORD	285 25W 10ADD	1	26		

COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.						
406.-	GRANT	285 37W 30BBD	1	3097.0	218.7	2878.3	541.-	HAMILTON	265 41W 36CCC	1	3270.0	49.0	3221.0	676.-	HASKELL	295 32W 16DAA	1	2915.0	241.2	2673.8
407.-	GRANT	285 38W 7BBB	1	3134.0	215.7	2918.3	542.-	HAMILTON	265 42W 10BB	2	3405.0	105.0	3300.0	677.-	HASKELL	295 32W 19CCC	1	2923.4	271.6	2651.8
408.-	GRANT	285 38W 12CBC	1	3087.0	185.8	2901.2	543.-	HAMILTON	265 42W 17CB	1	3458.0	161.7	3296.3	678.-	HASKELL	295 32W 22BBB	1	2917.0	238.9	2678.1
409.-	GRANT	285 38W 12DCB	1	3080.0	180.8	2899.2	544.-	HAMILTON	265 42W 22DCB	1	3412.0	152.2	3259.8	679.-	HASKELL	295 32W 26CBC	2	2895.0	245.9	2649.1
410.-	GRANT	285 38W 17AAA	1	3112.0	210.8	2901.2	545.-	HAMILTON	265 42W 25CB	1	3405.0	202.7	3309.3	680.-	HASKELL	295 33W 5ACA	1	2963.0	299.4	2663.6
411.-	GRANT	295 35W 10CC	1	3015.0	273.6	2741.4	546.-	HARVEY	235 2W 1396A	1	1396.1	9.1	1396.9	681.-	HASKELL	295 33W 11BBC	1	2953.0	312.7	2640.3
412.-	GRANT	295 35W 7CBD	1	3036.0	262.5	2773.5	547.-	HARVEY	235 2W 18BBB	1	1440.1	33.1	1407.0	682.-	HASKELL	295 33W 28BBC	1	2963.0	285.3	2677.7
413.-	GRANT	295 35W 28ACC	1	2975.0	236.9	2738.1	548.-	HARVEY	235 2W 18DDC	1	1441.0	25.3	1394.5	683.-	HASKELL	295 34W 2ABR	1	2971.0	284.2	2686.8
414.-	GRANT	295 36W 4DBB	1	3055.0	256.1	2798.9	549.-	HARVEY	235 2W 19CCC	1	1434.4	31.1	1403.3	684.-	HASKELL	295 34W 9CBB	1	3001.0	297.5	2703.5
415.-	GRANT	295 36W 19CBC	1	2990.0	187.0	2808.0	550.-	HARVEY	235 2W 23CC5	1	1393.5	10.8	1382.8	685.-	HASKELL	295 34W 11ADD	1	2961.0	278.3	2682.7
416.-	GRANT	295 37W 8CBA	1	3065.0	221.5	2843.5	551.-	HARVEY	235 2W 27CCC	1	1386.1	16.8	1369.3	686.-	HASKELL	295 34W 24BCC	1	2963.0	282.2	2680.8
417.-	GRANT	295 37W 29BBA	1	3094.5	250.6	2843.9	552.-	HARVEY	235 2W 27DDC	1	1388.9	15.4	1373.5	687.-	HASKELL	295 34W 36CCC	1	2976.0	280.5	2655.0
418.-	GRANT	295 38W 8CCC	1	3154.0	207.9	2946.1	553.-	HARVEY	235 2W 28ABA	1	1379.9	17.3	1379.6	688.-	HASKELL	305 31W 6BBB	1	2879.0	272.0	2652.0
419.-	GRANT	295 38W 20DCB	1	3139.0	143.5	2995.0	554.-	HARVEY	235 2W 28DDC	1	1426.0	50.0	1376.0	689.-	HASKELL	305 31W 15ABB	1	2852.0	231.8	2620.2
420.-	GRANT	295 38W 22CBB	1	3113.0	111.7	2922.3	555.-	HARVEY	235 2W 29BBB	1	1431.0	33.5	1397.5	690.-	HASKELL	305 31W 24BBB	1	2853.0	201.0	2632.0
421.-	GRANT	295 38W 35CCD	1	3124.0	164.0	2960.0	556.-	HARVEY	235 2W 29CCD	1	1429.3	49.3	1380.0	691.-	HASKELL	305 31W 33BBB	1	2835.0	214.8	2620.2
422.-	GRANT	305 35W 20BCC	1	3020.0	288.8	2731.2	557.-	HARVEY	235 2W 29DDC	1	1426.3	51.6	1374.7	692.-	HASKELL	305 32W 11BBB	1	2885.0	248.1	2636.9
423.-	GRANT	305 35W 19BCD	1	3004.0	193.7	2810.3	558.-	HARVEY	235 2W 30CCC	1	1434.4	29.8	1404.6	693.-	HASKELL	305 32W 17BCC	1	2910.0	268.3	2641.7
424.-	GRANT	305 36W 18BB	1	2973.0	203.3	2769.7	559.-	HARVEY	235 2W 30DDC	2	1432.8	49.9	1383.2	694.-	HASKELL	305 32W 22BBB	1	2876.0	239.7	2636.3
425.-	GRANT	305 36W 6BBC	1	3075.0	258.3	2816.7	560.-	HARVEY	235 2W 31DDC	1	1431.0	46.6	1384.1	695.-	HASKELL	305 32W 31BAB	1	2906.0	259.8	2646.2
426.-	GRANT	305 36W 74AB	1	2991.0	218.7	2834.7	561.-	HARVEY	235 2W 32CCB	1	1431.0	41.1	1381.0	696.-	HASKELL	305 33W 6DBB	1	2986.0	293.4	2692.6
427.-	GRANT	305 36W 16DAB	1	3027.0	192.4	2834.6	562.-	HARVEY	235 2W 32CCC	1	1431.0	42.4	1388.6	697.-	HASKELL	305 33W 10CC	1	2965.0	256.5	2722.5
428.-	GRANT	305 36W 25CBB	1	2901.5	54.3	2846.7	563.-	HARVEY	235 2W 33CCD	1	1421.4	46.7	1374.7	698.-	HASKELL	305 34W 5BBB	1	3006.0	306.9	2710.7
429.-	GRANT	305 36W 32BCC	1	3064.0	161.5	2902.5	564.-	HARVEY	235 2W 34CCD	1	1437.5	13.7	1384.8	699.-	HASKELL	305 34W 16BBB	1	2983.0	369.3	2722.7
430.-	GRANT	305 37W 2BAA	2	3102.0	287.7	2814.3	565.-	HARVEY	235 3W 4BBB	1	1444.0	42.1	1401.9	700.-	HASKELL	305 34W 30ADD	2	2843.0	91.2	2751.8
431.-	GRANT	305 37W 30CB	1	3090.0	257.9	2872.9	566.-	HARVEY	235 3W 4BBB	1	1444.0	42.1	1401.9	701.-	HODGEMAN	218 21W 21BCC	1	2134.0	46.4	2087.6
432.-	GRANT	305 37W 10DCB	1	3096.0	219.2	2876.8	567.-	HARVEY	235 3W 17DDC	2	1453.0	14.4	1448.6	702.-	HODGEMAN	218 21W 21BCC	1	2134.0	46.4	2087.6
433.-	GRANT	305 37W 20CBC	1	3125.0	200.6	2924.4	568.-	HARVEY	235 3W 21CCC	1	1448.0	31.1	1434.9	703.-	HODGEMAN	225 21W 2BCC	1	2122.0	42.1	2079.9
434.-	GRANT	305 38W 30CC	1	3147.0	172.3	2917.6	569.-	HARVEY	235 3W 23BBB	1	1447.6	30.1	1417.6	704.-	HODGEMAN	225 21W 60CC	1	2138.0	32.6	2105.4
435.-	GRANT	305 38W 30ACA	1	3152.0	141.5	3010.5	570.-	HARVEY	235 3W 23DDC	1	1440.7	30.8	1409.9	705.-	HODGEMAN	225 22W 13CCC	1	2152.0	29.7	2122.3
436.-	GRAY	245 28W 18CC	1	2697.0	74.1	2622.9	571.-	HARVEY	235 3W 24AAA	1	1435.7	31.4	1404.4	706.-	HODGEMAN	225 22W 23DDC	1	2159.0	26.2	2132.8
437.-	GRAY	245 27W 16ABB	1	2654.0	65.1	2588.9	572.-	HARVEY	235 3W 22AAA	1	1445.0	8.6	1432.8	707.-	HODGEMAN	225 22W 27BCC	1	2085.0	28.8	2138.8
438.-	GRAY	245 28W 10ADD	1	2743.0	102.7	2640.3	573.-	HARVEY	235 3W 32CCD	1	1405.0	7.7	1437.3	708.-	HODGEMAN	225 26W 31CCD	1	2621.0	71.3	2549.7
439.-	GRAY	245 28W 31DD	1	2754.0	125.4	2628.6	574.-	HARVEY	235 3W 34DDC	1	1438.0	19.9	1418.1	709.-	HODGEMAN	245 21W 20CBB	1	2348.0	78.8	2269.2
440.-	GRAY	245 28W 36ACA	1	2720.0	96.9	2623.1	575.-	HARVEY	235 3W 36BBB	1	1436.6	27.1	1409.5	710.-	HODGEMAN	245 23W 3CCC	1	2422.0	56.2	2365.8
441.-	GRAY	245 29W 16DAA	1	2787.0	112.4	2674.6	576.-	HARVEY	245 1W 5CCB	1	1474.6	47.9	1366.7	711.-	HODGEMAN	245 24W 20CCC	1	2511.0	64.3	2446.7
442.-	GRAY	245 29W 18CCB	1	2814.0	127.9	2692.9	577.-	HARVEY	245 1W 6BBB	1	1498.6	51.3	1388.4	712.-	HODGEMAN	245 24W 20CCC	1	2511.0	64.3	2446.7
443.-	GRAY	245 30W 18CB	1	2809.0	91.5	2711.5	578.-	HARVEY	245 1W 7DDC	1	1398.4	32.5	1365.9	713.-	KEARNY	225 35W 23CCD	1	3025.0	126.0	2899.0
444.-	GRAY	245 30W 80CC	1	2859.0	138.1	2720.9	579.-	HARVEY	245 1W 18BBB	1	1382.7	19.8	1362.8	714.-	KEARNY	235 35W 5ACC	1	3096.0	149.0	2947.0
445.-	GRAY	245 30W 15CCC	1	2846.0	131.4	2714.6	580.-	HARVEY	245 1W 19AAA	1	1382.3	19.9	1362.4	715.-	KEARNY	235 35W 12CCC	1	3009.0	159.4	2849.6
446.-	GRAY	255 27W 33ABB	1	2728.0	148.8	2579.2	581.-	HARVEY	245 1W 19BBB	1	1373.9	14.6	1359.3	716.-	KEARNY	235 35W 29DCC	2	3023.0	174.0	2949.0
447.-	GRAY	255 27W 34BB	1	2728.0	148.8	2579.2	582.-	HARVEY	245 1W 19BBB	1	1373.9	14.6	1359.3	717.-	KEARNY	235 36W 4CBB	1	3117.0	143.0	3039.4
448.-	GRAY	255 29W 14ABB	1	2776.0	131.0	2645.3	583.-	HARVEY	245 1W 29BBB	1	1379.9	21.8	1358.0	718.-	KEARNY	235 36W 32BBB	1	3034.0	236.8	2997.2
449.-	GRAY	255 30W 20BCC	1	2734.0	169.7	2717.1	584.-	HARVEY	245 1W 30DDC	1	1375.5	14.5	1361.0	719.-	KEARNY	235 37W 4ACB	1	3281.0	189.0	3092.0
450.-	GRAY	255 30W 22ACD	1	2722.0	22.1	2699.9	585.-	HARVEY	245 1W 32CCC	1	1375.3	15.4	1359.9	720.-	KEARNY	235 37W 28BCC	1	3303.0	257.9	3045.1
451.-	GRAY	265 27W 13BBC	1	2567.0	3.8	2563.2	586.-	HARVEY	245 1W 33DDC	1	1370.9	17.2	1353.6	721.-	KEARNY	235 37W 36BAB	1	3263.0	252.8	3010.2
452.-	GRAY	265 27W 27DDC	1	2612.0	48.5	2563.5	587.-	HARVEY	245 2W 18BB	1	1387.5	17.5	1370.1	722.-	KEARNY	245 35W 9CCC	1	2998.0	50.6	2947.5
453.-	GRAY	265 28W 10ACC	1	2642.0	26.6	2562.2	588.-	HARVEY	245 2W 20CC	1	1384.6	17.3	1368.4	723.-	KEARNY	245 35W 13CCC	2	2944.0	23.7	2917.3
454.-	GRAY	265 29W 35CCC	1	2742.0	92.0	2650.0	589.-	HARVEY	245 2W 22CC	1	1399.0	23.5	1375.5	724.-	KEARNY	245 35W 25CCC	1	2982.0	28.2	2944.3
455.-	GRAY	265 30W 17AD	1	2799.0	87.1	2711.9	590.-	HARVEY	245 2W 20CC	1	1399.0	23.5	1375.5	725.-	KEARNY	245 35W 22CCC	2	2962.0	28.6	2935.2
456.-	GRAY	265 30W 24DDC	1	2754.0	76.7	2677.3	591.-	HARVEY	245 2W 3CBB	1	1414.9	40.7	1374.2	726.-	KEARNY	245 36W 15BCC	1	3074.0	107.7	2966.3
457.-	GRAY	275 27W 7ADC	1	2686.0	91.8	2594.2	592.-	HARVEY	245 2W 5ABA	1	1463.6	68.4	1395.2	727.-	KEARNY	255 35W 28AA	1	2990.0	91.1	2898.9
458.-	GRAY	275 27W 10CBB	1	2754.0	117.8	2689.4	593.-	HARVEY	245 2W 6BCC	1	1428.9	36.7	1392.1	728.-	KEARNY	255 35W 17AAA	1	2995.0	82.3	2912.7
459.-	GRAY	275 27W 25CCD	1	2732.0	181.6	2550.4	594.-	HARVEY	245 2W 8BBB	1	1428.5	37.9	1391.7	729.-	KEARNY	255 36W 11BCC	1	3005.0	103.8	2901.3
460.-	GRAY	275 28W 5AAA	1	2707.0	82.5	2624.5	595.-	HARVEY	245 2W 8BBA	2	1420.8	35.8	1385.1	730.-	KEARNY	255 36W 11CBB	1	3005.0	103.8	2901.3
461.-	GRAY	275 28W 30CCA	1	2738.0	95.4	2642.6	596.-	HARVEY	245 2W 8BCC	2	1419.8	32.9	1386.9	731.-	KEARNY	255 36W 18CC	1	3033.0	30.5	3002.5
462.-	GRAY	275 29W 9DA	1	2749.0	88.8	2660.2	597.-	HARVEY	245 2W 8BBC	2	1417.8	33.6	1384.2	732.-	KEARNY	255 36				

COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.						
811-	LANE	175 29W 28DCD	1	2810.0	75.8	2734.2 *	946-	PRATT	295 11W 29AAD	1	1849.0	60.6	1788.4	1081-	SCOTT	175 34W 25DBB	1	3092.0	135.5	2956.5
812-	LANE	175 29W 36BAA	1	2784.0	83.8	2700.2	947-	PRATT	295 12W 20CCD	1	1907.0	104.8	1802.3	1082-	SCOTT	175 34W 28BCA	1	3138.0	125.7	3012.3 *
813-	LANE	175 30W 5AAC	1	2877.0	118.5	2758.5 *	948-	PRATT	295 12W 22BAC	1	1868.0	66.6	1801.3	1083-	SCOTT	185 31W 20ABA	1	2951.0	79.1	2871.9
814-	LANE	175 30W 13CCB	1	2846.0	88.9	2757.1	949-	PRATT	295 13W 31CAA	1	1893.0	31.6	1861.4	1084-	SCOTT	185 31W 24BCB	1	2913.0	75.5	2837.5
815-	LANE	185 27W 13CCC	1	2674.0	86.0	2588.0	950-	PRATT	295 14W 17DBD	1	2012.0	98.9	1913.1	1085-	SCOTT	185 31W 27ABA	1	2930.0	69.6	2860.4 *
816	LANE	185 29W 40AD	1	2801.0	65.5	2735.5	951-	PRATT	295 15W 22CAA	1	2035.0	86.3	1948.7	1086-	SCOTT	185 31W 28BCA	1	2980.0	111.1	2868.9
817-	LANE	185 30W 2AAA	1	2849.0	86.6	2762.4	952-	PRATT	295 15W 18ADA	1	2050.0	91.5	1958.5	1087-	SCOTT	185 32W 20CCB	1	2958.0	91.4	2866.6
818-	LOGAN	115 32W 4AA	1	3059.0	111.7	2947.3 *	953-	RAWLINS	19 33W 29CCC	1	2992.0	114.0	2878.0	1088-	SCOTT	185 32W 30CCB	1	3008.0	120.9	2887.1 *
819-	LOGAN	115 32W 19AAB	1	3073.0	102.9	2970.1	954-	RAWLINS	25 31W 30CAD	1	2665.0	20.3	2644.7	1089-	SCOTT	185 33W 5CCC	1	3041.0	65.0	2944.7
820-	LOGAN	115 36W 6ADD	2	3380.0	162.5	3217.5 *	955-	RAWLINS	25 32W 14DCA	1	2723.0	23.2	2699.8	1090-	SCOTT	185 33W 11ABB	1	2981.0	108.4	2872.4
821	LOGAN	115 36W 60BB	2	3386.0	172.6	3213.4	956-	RAWLINS	25 32W 20DCD	1	2735.0	15.4	2719.6	1091-	SCOTT	185 33W 15DDC	1	2920.0	102.8	2856.0
822-	LOGAN	155 37W 29AAA	1	3420.0	34.2	3385.8	957-	RAWLINS	25 33W 13ABB	1	3178.0	152.6	3025.4	1092-	SCOTT	185 33W 20DCD	1	3034.0	98.4	2935.6 *
823-	MEADE	305 26W 4CCB	1	2525.0	45.7	2479.4	958-	RAWLINS	25 33W 34CAA	1	3064.0	31.0	3039.0	1093-	SCOTT	185 33W 26ADD	2	2952.0	73.9	2878.1 *
824-	MEADE	305 26W 7BBB	1	2541.0	60.8	2480.2 *	959-	RAWLINS	25 36W 13DDC	1	3286.0	190.5	3095.5 *	1094-	SCOTT	185 33W 34AAB	1	2960.0	72.2	2887.8
825-	MEADE	305 26W 17BBC	1	2520.0	41.1	2478.9 *	960-	RAWLINS	25 36W 15DCD	1	3334.0	213.4	3120.6	1095-	SCOTT	185 33W 35AAA	1	2939.0	60.9	2878.1 *
826-	MEADE	305 26W 31CBC	1	2485.0	31.7	2453.3	961-	RAWLINS	25 36W 18CCB	1	3380.0	230.0	3150.0	1096-	SCOTT	185 34W 1CCB	1	3094.0	121.3	2972.8 *
827-	MEADE	305 27W 40DD	1	2576.0	70.6	2505.4 *	962-	RAWLINS	25 36W 36BAA	1	3263.0	176.7	3086.3	1097-	SCOTT	185 34W 3CCB	1	3148.0	113.3	3034.7
828-	MEADE	305 27W 22CCD	1	2511.0	9.2	2501.8	963-	RAWLINS	35 33W 30CCD	1	2823.0	30.5	2792.5	1098-	SCOTT	185 34W 9CCD	2	3133.0	109.9	3023.1 *
829-	MEADE	305 27W 23ABB	1	2531.0	42.9	2488.1 *	964-	RAWLINS	35 33W 8CCD	1	2855.0	27.9	2827.1	1099-	SCOTT	185 34W 18BBB	1	3154.0	113.1	3040.9 *
830-	MEADE	305 27W 32DDC	1	2475.0	8.9	2466.1 *	965-	RAWLINS	35 34W 3ABB	1	2882.0	15.9	2866.1	1100-	SCOTT	185 34W 25BBB	1	3092.0	110.0	2981.3 *
831-	MEADE	305 28W 29AA	1	2660.0	115.6	2544.4	966-	RAWLINS	35 34W 26BAC	1	2900.0	14.9	2885.1	1101-	SCOTT	185 34W 30DDC	1	3154.0	125.4	3028.6 *
832-	MEADE	305 28W 17ABB	1	2697.0	128.2	2575.8	967-	RAWLINS	35 34W 33BCB	1	2945.0	18.5	2925.0	1102-	SCOTT	185 34W 34BCB	1	3202.0	131.1	3012.0
833-	MEADE	305 29W 10CC	1	2728.0	130.8	2597.2	968-	RAWLINS	35 36W 11CCB	1	3301.0	249.7	3172.5	1103-	SCOTT	195 32W 40BB	1	2942.0	35.1	2906.9
834-	MEADE	305 29W 23CAD	1	2744.0	167.5	2576.5	969-	RAWLINS	35 36W 14CCB	1	3332.0	225.1	3110.5	1104-	SCOTT	195 32W 6CCB	1	2937.0	65.7	2871.3 *
835-	MEADE	305 29W 28BBB	1	2758.0	168.0	2590.0 *	970-	RAWLINS	35 36W 17CCC	1	3375.0	210.9	3164.1	1105-	SCOTT	195 32W 32ACB	1	2984.0	83.4	2900.6
836-	MEADE	305 29W 32BBB	1	2756.0	163.0	2593.0	971-	RAWLINS	45 31W 16ABD	1	2761.0	13.0	2748.0	1106-	SCOTT	195 32W 60BB	1	3021.0	63.5	2957.5
837-	MEADE	305 29W 12CCB	1	2813.0	202.4	2676.6 *	972-	RAWLINS	45 31W 25DDC	1	2755.0	18.7	2736.1	1107-	SCOTT	195 33W 11DDC	1	2920.0	70.4	2887.6
838-	MEADE	305 30W 28ABB	1	2803.0	177.6	2625.4	973-	RAWLINS	45 33W 18BAA	1	3068.0	155.0	2980.0	1108-	SCOTT	195 33W 25DDC	1	2964.0	104.5	2895.5
839-	MEADE	315 26W 30BBB	1	2516.0	100.1	2415.9	974-	RAWLINS	45 33W 28DCA	1	3125.0	155.9	2969.1	1109-	SCOTT	195 33W 24ABB	1	2943.0	61.6	2887.4 *
840-	MEADE	315 27W 20AAA	2	2466.0	31.1	2434.9	975-	RAWLINS	45 34W 33CCB	1	3160.0	119.7	3040.3	1110-	SCOTT	195 33W 25DCD	1	2959.0	89.7	2863.3 *
841-	MEADE	315 28W 10BBC	1	2643.0	151.6	2511.4	976-	RAWLINS	45 35W 6DCD	1	3252.0	154.8	3097.3	1111-	SCOTT	195 33W 34CCC	1	2962.0	97.0	2865.0
842-	MEADE	315 29W 25AA	2	2698.0	176.4	2588.0	977-	RAWLINS	45 35W 13DAD	1	3002.0	16.4	2985.6	1112-	SCOTT	195 34W 16AAB	1	3065.0	28.2	3006.8
843-	MEADE	315 29W 10AAA	1	2741.0	154.7	2586.4	978-	RAWLINS	45 35W 17DAB	1	3172.0	19.6	3172.4	1113-	SCOTT	195 34W 19CCD	1	3138.0	125.8	3012.2
844-	MEADE	315 30W 16BBC	1	2770.0	172.4	2597.6	979-	RAWLINS	45 36W 6BBB	1	3370.0	190.0	3180.0	1114-	SCOTT	195 34W 34BBB	1	3088.0	118.1	2969.9 *
845-	MEADE	325 28W 4ADD	1	2546.0	70.9	2475.1	980-	RAWLINS	55 31W 10DDA	1	2820.0	45.7	2774.3	1115-	SCOTT	205 31W 14CCB	1	2863.0	38.9	2824.1
846-	MEADE	325 28W 14CCB	1	2430.0	8.9	2421.1	981-	RAWLINS	55 31W 20CCA	1	2865.0	37.4	2827.6	1116-	SCOTT	205 32W 70BCA	1	2939.0	79.3	2859.7 *
847	MEADE	325 29W 31CC	1	2719.0	118.2	2525.8	982-	RAWLINS	55 31W 23DDC	1	2950.0	122.1	2827.9	1117-	SCOTT	205 32W 30CCD	1	2917.0	83.9	2833.0
848-	MEADE	325 29W 27AAB	1	2688.0	145.8	2542.2	983-	RAWLINS	55 32W 14DDC	1	3020.0	130.0	2889.0	1118-	SCOTT	205 32W 32CCD	1	2920.0	101.0	2827.9 *
849-	MEADE	325 30W 9CCC	1	2764.0	184.6	2579.4	984-	RAWLINS	55 33W 29BDB	1	3042.0	20.0	3022.0	1119-	SCOTT	205 33W 9BBB	1	2973.0	97.1	2875.9 *
850-	MEADE	325 30W 28BBC	1	2759.0	201.1	2557.9	985-	RAWLINS	55 34W 1BBB	1	3137.0	116.0	3021.0	1120-	SCOTT	205 33W 26BBB	1	2938.0	98.8	2839.2 *
851-	MEADE	325 30W 35CAD	1	2728.0	181.6	2546.4	986-	RAWLINS	55 34W 28ADC	1	3207.0	135.1	3071.9	1121-	SCOTT	205 33W 35DBA	1	2929.0	88.4	2840.5 *
852-	MEADE	325 30W 29BBC	1	2731.0	16.5	2554.8	987-	RAWLINS	55 35W 10CCD	1	3267.0	167.6	3099.4	1122-	SCOTT	205 34W 2DBC	1	3015.0	84.1	2930.9
853-	MEADE	325 30W 36AAB	1	2463.0	246.3	2361.5	988-	RAWLINS	55 36W 21BCD	1	3220.0	20.0	3200.0	1123-	SCOTT	205 34W 15BAA	1	3060.0	105.0	2955.0
854-	MEADE	325 30W 35CCB	1	2684.0	164.4	2519.6	989-	RENO	225 8W 31BAA	1	1675.0	10.0	1554.6	1124-	SCOTT	205 34W 25DBB	1	3064.0	74.6	2882.6
855-	MEADE	345 30W 22CCB	1	2675.0	194.5	2480.5	990-	RENO	225 8W 90BB	1	1620.0	31.5	1638.5	1125-	SEDIWICK	255 1W 3AAA	1	1383.2	8.7	1374.5
856-	MEADE	345 30W 27BBB	2	2660.0	190.2	2469.8 *	991-	RENO	225 8W 23DAD	1	1651.0	27.8	1623.2	1126-	SEDIWICK	255 1W 5AAA	1	1367.8	13.9	1353.9
857-	MEADE	355 30W 10CCA	1	2393.0	25.0	2368.0	992-	RENO	225 8W 33CCD	1	1658.0	7.0	1651.0	1127-	SEDIWICK	255 1W 5CCC	1	1375.0	18.8	1356.2 *
858-	MORTON	315 42W 29ABB	1	3531.0	180.8	3150.2	993-	RENO	225 9W 38BD	1	1712.0	35.2	1676.8	1128-	SEDIWICK	255 1W 5DDC	1	1370.7	19.2	1351.5
859-	MORTON	315 42W 29AAB	1	3510.0	107.6	3407.6	994-	RENO	225 9W 17BAA	1	1712.0	19.6	1712.4	1129-	SEDIWICK	255 1W 50DD	1	1330.6	15.5	1359.9 *
860-	MORTON	315 43W 3CB	1	3609.0	63.0	3546.0	995-	RENO	225 10W 2DCC	1	1736.0	10.7	1725.3 *	1130-	SEDIWICK	255 1W 50DD	1	1382.6	23.3	1359.2 *
861-	MORTON	315 43W 20CCB	1	3653.0	100.7	3552.3	996-	RENO	225 10W 8BBB	1	1764.0	15.9	1748.1	1131-	SEDIWICK	255 1W 7BAA	1	1381.0	24.8	1356.2 *
862-	MORTON	315 42W 21ABB	1	3342.0	189.6	3152.4	997-	RENO	225 10W 40AAA	1	1775.0	11.3	1763.7	1132-	SEDIWICK	255 1W 7CCC	1	1383.0	24.7	1358.3 *
863	MORTON	325 41W 15CCD	1	3360.0	21.5	3338.5	998-	RENO	235 6W 31DCB	1	1577.0	31.0	1546.0	1133-	SEDIWICK	255 1W 7DCC	1	1380.0	20.7	1359.9 *
864-	MORTON	325 42W 14CCC	1	3500.0	113.2	3386.8	999-	RENO	235 7W 1ABB	1	1585.0	14.0	1567.0	1134-	SEDIWICK	255 1W 7ECC	1	1386.0	12.0	1360.7 *
865-	MORTON	325 43W 17DCC	1	3626.0	73.7	3552.3	1000-	RENO	235 7W 5ABA	1	1623.0	26.8	1596.2	1135-	SEDIWICK	255 1W 7FCC	1	1383.0	15.1	1344.9
866-	MORTON	325 39W 16ABB	1	3234.0	76.5	3157.5	1001-	RENO	235 7W 13DDC	1	1604.0	52.6	1551.4	1136-	SEDIWICK	255 1W 7AAA	1	1370.0	28.7	1351.4 *
867-	MORTON	335 40W 27CCD	1	3308.0	86.2	3221.8	1002-	RENO	235 7W 26BBB	1	1607.0	37.4	1569.6 *	1137-	SEDIWICK	255 1W 7BBB	1	1378.0	20.9	1357.1 *
868	MORTON	335 41W 3AAD	1	3425.0	142.3	3282.7	1003-	RENO	235 8W 18AAD											

COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.	COUNTY	WELL NUMBER	L.S.E.	DEPTH	ELEV.			
1216-	SEWARD	355 33V 1888A	2707.0	181.4	2525.6	1351-	STAFFORD	215 12W 10CDD	1 1845.0	24.8	1820.2	1486-	THOMAS	65 34W 17CB	1 3261.0	157.8	3103.2
1217-	SEWARD	355 33V 16BBA	2838.0	116.6	2721.4	1352-	STAFFORD	215 13V 18CB	1 1857.0	15.9	1841.1	1487-	THOMAS	65 35W 2CDD	1 3245.0	130.1	3114.2
1218-	SEWARD	355 34V 10BBB	2912.0	74.5	2837.5	1353-	STAFFORD	215 13V 13ADB	1 1866.0	17.4	1848.6	1488-	THOMAS	65 35W 26ACB	1 3300.0	158.4	3145.6
1219-	SHERIDAN	65 27W 30CD	2560.0	34.9	2525.1	1354-	STAFFORD	215 13W 27BDD	2 1877.0	19.0	1867.4	1489-	THOMAS	65 36W 6BCDD	1 3468.0	154.9	3217.1
1220-	SHERIDAN	65 27W 28BBA	2586.0	23.8	2567.1	1355-	STAFFORD	215 14W 24AC	1 1926.0	17.4	1907.3	1490-	THOMAS	65 36W 11ACB	1 3360.0	170.3	3189.7
1221-	SHERIDAN	65 27W 19CDB	2610.0	30.8	2579.2	1356-	STAFFORD	215 14W 32BAC	1 1949.0	25.8	1923.2	1491-	THOMAS	65 36W 30DCB	1 3417.0	154.5	3262.5
1222-	SHERIDAN	65 27W 27BCC	2716.0	159.4	2556.6	1357-	STAFFORD	225 11W 78BB	1 1785.0	5.4	1779.6	1492-	THOMAS	65 36W 40DCB	1 3334.0	101.6	3326.4
1223-	SHERIDAN	65 28W 28ADD	2682.0	46.8	2635.2	1358-	STAFFORD	225 12W 58BD	1 1870.0	21.3	1848.7	1493-	THOMAS	75 32W 7ACA	1 3056.0	78.5	2977.5
1224-	SHERIDAN	65 29W 10DCB	2823.0	131.1	2691.9	1359-	STAFFORD	225 12W 30BDD	1 1872.0	16.5	1855.5	1494-	THOMAS	75 32W 13ACA	1 3037.0	120.0	2917.0
1224-	SHERIDAN	75 29W 24ABD	2737.0	102.8	2688.7	1360-	STAFFORD	225 12W 36BDD	2 1827.0	16.4	1821.6	1495-	THOMAS	75 33W 78DA	1 3203.0	165.7	3037.3
1226-	SHERIDAN	65 29W 32CDA	2828.0	104.5	2723.5	1361-	STAFFORD	225 13W 5CB	1 1905.0	16.2	1888.8	1496-	THOMAS	75 33W 21DCB	1 3141.0	116.7	3024.3
1227-	SHERIDAN	65 30W 18CBA	2720.0	22.8	2757.2	1362-	STAFFORD	225 13W 12CAC	1 1885.0	20.0	1864.9	1497-	THOMAS	75 33W 35ADD	1 3145.0	150.3	2994.7
1228-	SHERIDAN	65 30W 13BAA	2873.0	126.7	2748.3	1363-	STAFFORD	225 13W 29DAD	1 1902.0	16.8	1885.2	1498-	THOMAS	75 34W 88BB	1 3224.0	99.1	3124.9
1229-	SHERIDAN	65 30W 14CDD	2884.0	120.9	2774.8	1364-	STAFFORD	225 14W 7AAC	1 1957.0	24.3	1932.6	1499-	THOMAS	75 34W 25AAA	1 3167.0	114.8	3052.2
1230-	SHERIDAN	65 30W 24DCD	2898.0	136.2	2759.8	1370-	STAFFORD	225 14W 14CBA	1 1930.0	19.2	1910.8	1500-	THOMAS	75 34W 26BDD	1 3177.0	109.6	3067.5
1231-	SHERIDAN	75 26W 6AAB	2634.0	129.8	2504.2	1366-	STAFFORD	225 14W 29BBA	1 1953.0	21.2	1931.8	1501-	THOMAS	75 35W 9CCD	1 3315.0	120.6	3185.4
1232-	SHERIDAN	75 26W 12BAC	2659.0	98.4	2460.6	1367-	STAFFORD	225 14W 35DDB	1 1930.0	26.3	1903.7	1502-	THOMAS	75 36W 17CCD	1 3417.0	145.2	3271.8
1233-	SHERIDAN	75 26W 15BDD	2622.0	142.2	2479.8	1368-	STAFFORD	235 11W 28BB	1 1789.0	3.7	1785.3	1503-	THOMAS	75 36W 35CB	1 3341.0	88.9	3252.0
1234-	SHERIDAN	75 26W 19BCC	2625.0	123.3	2501.7	1369-	STAFFORD	235 11W 28BB	1 1802.0	23.1	1778.9	1504-	THOMAS	85 31W 30CD	1 3003.0	130.3	2872.2
1235-	SHERIDAN	75 26W 28CAB	2634.0	154.5	2479.5	1370-	STAFFORD	235 12W 70BD	1 1859.0	9.1	1849.9	1505-	THOMAS	85 31W 20CD	1 3026.0	114.7	2911.3
1236-	SHERIDAN	75 26W 24BDD	2639.0	127.0	2460.0	1371-	STAFFORD	235 12W 22BCC	1 1853.0	14.9	1838.5	1506-	THOMAS	85 32W 7BAA	1 3110.0	119.7	2998.9
1237-	SHERIDAN	75 28W 8BDC	2808.0	160.6	2647.4	1372-	STAFFORD	235 12W 36BCC	1 1849.0	17.9	1831.1	1507-	THOMAS	85 32W 12DCB	1 3057.0	113.6	2943.4
1238-	SHERIDAN	75 28W 19BBA	2800.0	147.1	2652.9	1373-	STAFFORD	235 13W 8CCB	1 1895.0	11.8	1883.2	1508-	THOMAS	85 32W 27DAB	1 3078.0	115.6	2962.4
1239-	SHERIDAN	75 28W 21ABD	2774.0	156.0	2618.0	1374-	STAFFORD	235 13W 16CCA	1 1886.0	13.8	1872.2	1509-	THOMAS	85 33W 2CDA	1 3141.0	145.8	2995.2
1240-	SHERIDAN	75 28W 31ABA	2725.0	139.3	2585.7	1375-	STAFFORD	235 13W 30CB	1 1906.0	12.3	1893.7	1510-	THOMAS	85 33W 7AAB	1 3144.0	155.3	3058.7
1241-	SHERIDAN	75 29W 24BDD	2838.0	149.8	2671.0	1376-	STAFFORD	235 14W 18CB	1 1897.0	18.4	1897.8	1511-	THOMAS	85 33W 36BBA	1 3116.0	140.5	3018.5
1242-	SHERIDAN	75 29W 21ABD	2860.0	149.8	2710.2	1377-	STAFFORD	235 14W 15ADD	1 1927.0	9.0	1918.1	1512-	THOMAS	85 34W 18AC	1 3179.0	123.7	3055.3
1243-	SHERIDAN	75 29W 27CCD	2869.0	177.1	2691.9	1378-	STAFFORD	235 14W 30BBB	1 1988.0	38.3	1949.8	1513-	THOMAS	85 34W 6CB	1 3266.0	137.8	3128.2
1244-	SHERIDAN	75 29W 30ABA	2886.0	151.9	2734.7	1379-	STAFFORD	245 11W 14CAB	1 1813.0	30.8	1782.2	1514-	THOMAS	85 34W 23CDB	1 3232.0	174.3	3057.7
1245-	SHERIDAN	85 26W 14DAA	2398.0	16.4	2381.6	1380-	STAFFORD	245 11W 17DDB	1 1833.0	23.0	1810.0	1515-	THOMAS	85 36W 18ABA	2 3428.0	128.2	3299.7
1246-	SHERIDAN	85 26W 16CDD	2447.0	36.0	2411.0	1381-	STAFFORD	245 12W 17CAB	1 1891.0	21.9	1885.1	1516-	THOMAS	85 36W 26BDD	1 3199.0	88.2	3110.8
1247-	SHERIDAN	85 27W 11DCD	2504.0	10.4	2493.6	1382-	STAFFORD	245 12W 34AC	1 1880.0	20.2	1857.3	1517-	THOMAS	95 31W 22ABD	1 2990.0	84.8	2905.2
1248-	SHERIDAN	85 27W 33BDD	2554.0	19.9	2534.1	1383-	STAFFORD	245 13W 7BDC	1 1925.0	21.1	1903.9	1518-	THOMAS	95 32W 98DA	1 3043.0	76.8	2966.2
1249-	SHERIDAN	85 28W 9ABC	2822.0	136.0	2630.0	1384-	STAFFORD	245 13W 16ACA	1 1915.0	20.1	1894.9	1519-	THOMAS	95 32W 27CDB	1 3076.0	117.0	2959.0
1250-	SHERIDAN	85 29W 1DCB	2824.0	148.6	2677.2	1385-	STAFFORD	245 13W 30BCC	1 1936.0	14.0	1921.9	1520-	THOMAS	95 33W 15ACC	1 3135.0	129.2	3005.8
1251-	SHERIDAN	85 29W 29BAC	2843.0	98.4	2745.6	1386-	STAFFORD	245 13W 36DDB	1 1907.0	21.9	1885.1	1521-	THOMAS	95 33W 32CAA	1 3061.0	187.0	3174.0
1252-	SHERIDAN	85 30W 11CCD	2941.0	177.8	2764.0	1387-	STAFFORD	245 14W 17AAC	1 1982.0	28.8	1953.1	1522-	THOMAS	95 33W 30CAA	1 3216.0	201.3	3014.7
1253-	SHERIDAN	85 30W 13DAA	2891.0	139.8	2752.1	1388-	STAFFORD	245 14W 31BDD	1 1988.0	20.2	1977.9	1523-	THOMAS	95 33W 35AAD	1 3145.0	152.8	2993.2
1254-	SHERIDAN	85 30W 30ABC	2962.0	127.8	2834.2	1389-	STAFFORD	245 15W 8CCD	1 2034.0	15.0	2019.0	1524-	THOMAS	95 34W 12ADA	1 3199.0	155.4	3042.6
1255-	SHERIDAN	95 27W 12CCD	2678.0	110.3	2567.7	1390-	STAFFORD	245 15W 10BAB	1 2024.0	24.6	1999.4	1525-	THOMAS	95 35W 32DAA	1 3061.0	187.0	3174.0
1256-	SHERIDAN	95 27W 19DCC	2750.0	128.5	2621.5	1391-	STAFFORD	245 15W 32BAC	1 2044.0	22.1	2021.9	1526-	THOMAS	105 11W 26AAA	1 3206.0	176.1	2880.3
1257-	SHERIDAN	95 28W 4BCC	2877.0	127.0	2770.0	1392-	STAFFORD	245 16W 17CDB	1 1770.0	11.4	1758.6	1527-	THOMAS	105 32W 3CAA	1 3091.0	120.4	2970.6
1258-	SHERIDAN	95 28W 6CCB	2691.0	8.3	2682.7	1393-	STAFFORD	255 11W 23DD	1 1796.0	15.0	1780.9	1528-	THOMAS	105 32W 29DCB	1 3064.0	93.9	2970.1
1259-	SHERIDAN	95 29W 17BAB	2854.0	99.4	2754.6	1394-	STAFFORD	255 12W 17CAA	1 1892.0	26.2	1865.8	1529-	THOMAS	105 33W 30BC	1 3145.0	148.5	2996.5
1260-	SHERIDAN	95 29W 26BAA	2869.0	136.4	2726.6	1395-	STAFFORD	255 12W 24DDB	1 1840.0	13.3	1826.7	1530-	THOMAS	105 33W 19CDB	1 3161.0	104.8	3056.3
1261-	SHERIDAN	95 30W 3AAB	2933.0	140.0	2790.0	1396-	STAFFORD	255 12W 32CCA	1 1876.0	4.6	1871.4	1531-	THOMAS	105 33W 27BB	1 3119.0	104.0	3015.0
1262-	SHERIDAN	95 30W 16CDA	2882.0	60.5	2821.5	1397-	STAFFORD	255 13W 38BB	1 1932.0	20.5	1913.1	1532-	THOMAS	105 34W 13CDB	1 3229.0	186.5	3039.5
1263-	SHERIDAN	105 28W 22DAA	2681.0	28.9	2662.1	1398-	STAFFORD	255 13W 40BDB	1 1920.0	33.4	1898.9	1533-	THOMAS	105 36W 36ACC	1 3359.0	171.8	3187.2
1264-	SHERIDAN	105 28W 20DAA	2681.0	28.9	2662.1	1399-	STAFFORD	255 13W 16AAC	1 1940.0	28.2	1911.8	1534-	TREGO	125 23W 20CCC	1 2373.6	20.4	2353.2
1265-	SHERIDAN	105 29W 20CCC	2776.0	13.7	2762.3	1400-	STAFFORD	255 13W 30CCA	1 1965.0	20.1	1944.9	1535-	WALLACE	118 38W 35CCC	2 3372.0	140.1	3231.9
1266-	SHERIDAN	105 30W 8DCC	2930.0	104.9	2825.1	1401-	STAFFORD	255 13W 33CDB	1 1930.0	10.5	1919.5	1536-	WALLACE	118 42W 8DCC	1 3953.0	107.4	3845.6
1267-	SHERIDAN	105 30W 17BAD	2895.0	68.8	2826.7	1402-	STAFFORD	255 14W 44AD	1 1969.0	14.1	1954.9	1537-	WALLACE	135 42W 10BAC	1 3710.0	39.1	3730.9
1268-	SHERIDAN	85 31W 9BCC	2824.0	163.2	2764.0	1403-	STAFFORD	255 14W 30FDD	1 1949.0	16.9	1949.9	1538-	WALLACE	145 38W 21DCD	1 3538.0	81.8	3456.2
1269-	SHERIDAN	85 31W 7BBA	3304.0	5.5	3294.5	1404-	STAFFORD	255 15W 11BCC	1 2020.0	13.2	2006.8	1539-	WALLACE	145 38W 29CCC	1 3543.0	93.2	3449.8
1270-	SHERIDAN	65 37W 16CDD	3476.0	172.9	3287.1	1405-	STAFFORD	255 15W 29BDD	1 2034.0	10.6	2023.4	1540-	WALLACE	145 39W 36CDB	1 3576.0	136.1	3439.9
1271-	SHERIDAN	65 37W 19ABD	3460.0	160.9	3315.1	1406-	STANTON	275 39W 28BB	1 3217.0	85.6	3131.4	1541-	WALLACE	145 40W 29ABA	1 3702.0	167.3	3534.7
1272-	SHERIDAN	65 38W 9ABD	3510.0	164.3	3345.8	1407-	STANTON	275 39W 23AC	2 3144.0	180.5	2963.5	1542-	WALLACE	145 41W 18DCB	1 3778.0	144.0	3636.0
1273-	SHERIDAN	65 38W 20AC	3407.0	14.8	3392.3	1408-	STANTON	275 39W 27DDB	1 3153.0	216.6	2936.4	1543-	WALLACE	145 41W 22BBB	1 3729.0	120.6	3608.4
1274-	SHERIDAN	65 39W 9DDB	3385.0	15.5	3417.5	1409-	STANTON	275 39W 34DD	1 3153.0	216.6	2936.4	1544-	WALLACE	145 41W 28DCA	1 3760.0	151.6	3608.4
1275-	SHERIDAN	65 40W 10AAC	3474.0	160.4	3480.6	1410-	STANTON	275 41W 31CCB	2 3402.0	230.5	3171.5	1545-	WALLACE	145 41W 30DCC	1 3798.0	176.5	3621.5
1276-	SHERIDAN	65 40W 30DCC	3618.0	164.8	3553.2	1411-	STANTON										

COUNTY	WELL NUMBER	L. S. E.	DEPTH	ELEV.
1621.-	WICHITA	18S 36W 150AD	1 3235.0	87.3 3147.7
1622.-	WICHITA	18S 36W 180DC	1 3295.0	128.3 3166.7 *
1623.-	WICHITA	18S 36W 36CCC	1 3219.0	78.1 3140.9
1624.-	WICHITA	18S 37W 3BBB	1 3315.0	136.0 3179.0 *
1625.-	WICHITA	18S 37W 3CCC	1 3352.0	147.1 3204.9
1626.-	WICHITA	18S 37W 19AAD	1 3370.0	142.5 3227.5
1627.-	WICHITA	18S 37W 21BBB	1 3360.0	155.4 3204.6 *
1628.-	WICHITA	18S 37W 34RBB	1 3320.0	100.7 3219.3 *
1629.-	WICHITA	18S 37W 36ABB	1 3301.0	106.0 3195.0
1630.-	WICHITA	18S 38W 2RCC	1 3414.0	153.1 3260.9
1631.-	WICHITA	18S 38W 8RBD	1 3432.0	127.8 3304.2
1632.-	WICHITA	18S 38W 12BCC	1 3401.0	157.4 3243.6 *
1633.-	WICHITA	18S 38W 23BAB	1 3340.0	43.5 3296.5
1634.-	WICHITA	18S 38W 31DBC	1 3450.0	120.6 3329.4
1635.-	WICHITA	18S 38W 360DD	1 3374.0	82.8 3291.2
1636.-	WICHITA	19S 35W 1AAA	1 3165.0	114.5 3050.5 *
1637.-	WICHITA	19S 35W 8BBB	1 3217.0	96.3 3120.7
1638.-	WICHITA	19S 35W 29BCB	1 3139.0	36.3 3102.7
1639.-	WICHITA	19S 36W 15BAA	1 3236.0	78.4 3157.6
1640.-	WICHITA	19S 37W 22AAB	1 3330.0	107.0 3223.0
1641.-	WICHITA	19S 38W 18DCC	1 3456.0	123.9 3332.0
1642.-	WICHITA	19S 38W 26CCB	1 3408.0	107.4 3300.6
1643.-	WICHITA	19S 38W 31CBC	1 3463.0	141.7 3321.3
1644.-	WICHITA	20S 36W 14ADD	1 3225.0	97.4 3127.6
1645.-	WICHITA	20S 37W 29CCB	1 3359.0	110.4 3248.6
1646.-	WICHITA	20S 38W 33BBA	1 3424.0	141.2 3282.8
1647.-	HARVEY	22S 2W 5CBD	1 1468.0	46.0 1422.0 *
1648.-	HARVEY	22S 2W 22ACC	1 1430.0	8.3 1421.7
1649.-	HARVEY	22S 2W 29BBA	1 1445.0	20.8 1424.2
1650.-	HARVEY	22S 3W 20CD	1 1450.0	36.0 1414.0
1651.-	HARVEY	22S 3W 17AAB	1 1447.0	32.2 1414.9
1652.-	HARVEY	22S 3W 29BAD	1 1430.0	12.7 1417.3 *
1653.-	HARVEY	22S 3W 35AAA	1 1420.0	11.4 1408.6 *
1654.-	HARVEY	23S 1W 19AAC	1 1420.0	30.6 1389.4
1655.-	HARVEY	23S 1W 29BBA	1 1403.0	21.6 1381.4
1656.-	HARVEY	23S 2W 4ADC	1 1434.0	37.3 1396.8
1657.-	HARVEY	23S 2W 20BAC	1 1428.0	40.4 1387.6 *
1658.-	HARVEY	23S 2W 22CCD	1 1395.0	16.0 1379.0 *
1659.-	HARVEY	23S 3W 6DDD	1 1495.0	70.8 1424.2 *
1660.-	HARVEY	23S 3W 14AAC	1 1450.0	35.7 1414.3 *
1661.-	HARVEY	23S 3W 16CAC	1 1456.0	27.8 1428.3 *
1662.-	HARVEY	23S 3W 32CDA	1 1446.0	9.7 1436.3 *
1663.-	HARVEY	23S 3W 32DCB	1 1446.0	10.1 1435.9 *
1664.-	HARVEY	24S 1W 5AAD	1 1393.0	26.1 1366.9
1665.-	HARVEY	24S 1W 5ADD	1 1393.0	24.2 1368.8 *
1666.-	HARVEY	24S 1W 19RBC	1 1383.0	19.7 1363.3 *
1667.-	HARVEY	24S 1W 22BCC	1 1390.0	27.6 1364.4 *
1668.-	HARVEY	24S 2W 12CCC	1 1385.0	18.9 1366.1 *
1669.-	MCPHERSON	18S 3W 30CCC	1 1515.0	109.6 1405.4 *
1670.-	MCPHERSON	18S 3W 32BCC	1 1512.0	106.1 1405.9
1671.-	MCPHERSON	18S 4W 21CCC	1 1412.0	9.2 1402.8
1672.-	MCPHERSON	18S 4W 35BAB	1 1515.0	112.4 1402.6 *
1673.-	MCPHERSON	19S 1W 32DAC	1 1590.0	47.6 1542.4
1674.-	MCPHERSON	19S 3W 6CAC	1 1495.0	90.1 1404.9 *
1675.-	MCPHERSON	19S 3W 17BBD	1 1507.0	102.0 1405.0 *
1676.-	MCPHERSON	19S 3W 18CCB	1 1498.0	89.5 1408.5 *
1677.-	MCPHERSON	19S 3W 31BBA	1 1494.0	84.6 1409.4
1678.-	MCPHERSON	19S 4W 1CCD	1 1511.0	106.0 1405.0
1679.-	MCPHERSON	19S 4W 3DBD	1 1498.0	92.2 1405.8 *
1680.-	MCPHERSON	19S 4W 9ADA	1 1491.0	80.5 1410.5
1681.-	MCPHERSON	19S 4W 15AAC	1 1494.0	84.5 1409.5 *
1682.-	MCPHERSON	19S 4W 22CDD	1 1481.0	78.4 1402.6 *
1683.-	MCPHERSON	19S 4W 23DAA	1 1490.0	82.8 1402.2 *
1684.-	MCPHERSON	19S 4W 27ABA	1 1485.0	79.1 1405.9 *
1685.-	MCPHERSON	19S 4W 35BBB	1 1486.0	80.4 1407.6 *
1686.-	MCPHERSON	20S 1W 8BAA	1 1567.0	30.7 1536.3 *
1687.-	MCPHERSON	20S 1W 17DBC	1 1555.0	29.0 1526.0
1688.-	MCPHERSON	20S 1W 22BBB	1 1527.0	11.5 1515.5
1689.-	MCPHERSON	20S 1W 29DDD	1 1530.0	20.0 1509.9
1690.-	MCPHERSON	20S 3W 18BCA	1 1485.0	64.1 1420.9
1691.-	MCPHERSON	20S 3W 22CCC	1 1478.0	46.8 1431.2 *
1692.-	MCPHERSON	20S 3W 29BBB	1 1473.0	35.5 1437.5
1693.-	MCPHERSON	20S 3W 30BBA	1 1476.0	51.9 1424.1 *
1694.-	MCPHERSON	20S 3W 32ADD	1 1470.0	42.6 1427.4 *
1695.-	MCPHERSON	20S 4W 1RBD	1 1496.0	80.2 1415.8 *
1696.-	MCPHERSON	20S 4W 11CDB	1 1476.0	57.8 1418.2 *
1697.-	MCPHERSON	20S 4W 12ACA	1 1491.0	79.6 1413.4 *
1698.-	MCPHERSON	20S 4W 15BCD	1 1474.0	48.8 1423.2 *
1699.-	MCPHERSON	20S 4W 27DAC	1 1467.0	38.8 1428.2
1700.-	MCPHERSON	21S 2W 12RBB	1 1503.0	13.3 1489.7
1701.-	MCPHERSON	21S 2W 19BDA	1 1471.0	49.1 1421.9
1702.-	MCPHERSON	21S 2W 28BCD	1 1467.0	36.2 1430.8
1703.-	MCPHERSON	21S 2W 36ABD	1 1475.0	13.3 1461.7
1704.-	MCPHERSON	21S 3W 29AAA	1 1475.0	40.9 1434.1
1705.-	MCPHERSON	21S 3W 6CBB	1 1464.0	42.5 1421.5 *
1706.-	MCPHERSON	21S 3W 8DBD	1 1462.0	36.9 1425.1
1707.-	MCPHERSON	21S 3W 22RBB	1 1450.0	31.3 1418.8 *
1708.-	MCPHERSON	21S 3W 33BCC	1 1461.0	51.8 1409.2
1709.-	MCPHERSON	21S 4W 3ABBB	1 1456.0	26.6 1429.4 *
1710.-	MCPHERSON	21S 4W 13DCD	1 1445.0	23.8 1421.2 *
1711.-	MCPHERSON	21S 4W 26CCA	1 1445.0	30.1 1414.9
1712.-	RENO	22S 4W 24BCC	1 1452.0	33.3 1418.7
1713.-	RENO	22S 4W 32BCC	1 1510.0	15.9 1494.1
1714.-	RENO	23S 4W 3BAB	1 1470.0	8.8 1461.2
1715.-	RENO	23S 4W 24AAA	1 1467.0	14.0 1453.0
1716.-	RENO	23S 4W 30BAA	1 1491.0	9.4 1481.6
1717.-	RENO	23S 4W 31CAC	1 1486.0	7.5 1478.5 *
1718.-	RENO	24S 4W 1ABC	1 1460.0	7.5 1452.5 *
1719.-	RENO	24S 4W 1BAD	1 1460.0	7.6 1452.4
1720.-	RENO	24S 4W 5CCA	1 1480.0	8.0 1472.0
1721.-	RENO	24S 4W 14DAB	1 1455.0	9.6 1445.4
1722.-	RENO	24S 4W 16DDC	1 1467.0	9.7 1457.3 *
1723.-	RENO	24S 4W 25BAC	1 1448.0	6.5 1441.5 *
1724.-	RENO	24S 4W 31ADC	1 1485.0	28.9 1456.1
1725.-	RENO	24S 4W 33BCD	1 1467.0	17.9 1449.1 *
1726.-	RENO	24S 5W 8RBD	1 1530.0	29.5 1500.5 *
1727.-	RENO	24S 5W 10CCA	1 1509.0	24.4 1484.6 *
1728.-	RENO	24S 5W 20BBD	1 1550.0	38.1 1511.9 *
1729.-	RENO	24S 5W 24RBD	1 1487.0	14.5 1472.5 *
1730.-	RENO	24S 6W 14ABD	1 1540.0	14.5 1525.5 *
1731.-	RENO	25S 4W 2ABB	1 1449.0	9.0 1440.0
1732.-	SEDGWICK	25S 1W 7ACA	1 1377.0	24.0 1353.0 *
1733.-	SEDGWICK	25S 1W 10CCC	1 1365.0	20.1 1345.4 *
1734.-	SEDGWICK	25S 1W 28DBA	1 1364.0	14.4 1349.6 *
1735.-	SEDGWICK	25S 1W 30DBB	1 1368.0	13.3 1354.7
1736.-	SEDGWICK	25S 2W 16DDB	1 1390.0	6.5 1383.5
1737.-	SEDGWICK	25S 2W 23DCA	1 1379.0	10.6 1368.4 *
1738.-	SEDGWICK	25S 3W 15CCC	1 1428.0	22.3 1405.7 *
1739.-	SEDGWICK	25S 3W 28CCB	1 1440.0	34.3 1405.7 *
1740.-	SEDGWICK	26S 1W 5AAC	1 1360.0	12.3 1347.7 *
1741.-	SEDGWICK	26S 1W 12BAC	1 1341.0	16.8 1324.2
1742.-	SEDGWICK	26S 1W 15DBC	1 1342.0	13.3 1328.7 *
1743.-	SEDGWICK	26S 1W 31CCD	1 1370.0	40.8 1329.2 *
1744.-	SEDGWICK	26S 2W 3ABB	1 1376.0	11.1 1364.9 *
1745.-	SEDGWICK	26S 2W 8AAB	1 1397.0	32.4 1364.6 *
1746.-	SEDGWICK	26S 2W 13ACD	1 1360.0	11.8 1348.2 *
1747.-	SEDGWICK	26S 2W 19CAA	1 1400.0	35.5 1364.5 *
1748.-	SEDGWICK	26S 2W 23ABD	1 1371.0	23.8 1347.2 *
1749.-	SEDGWICK	26S 3W 2AAA	1 1409.0	22.2 1386.8 *

E.2 Wells in aquifers other than the High Plains aquifer

The following is a listing of observation wells penetrating aquifers other than the High Plains aquifer.

Perched aquifers without specific names were designated by a letter for the purposes of this report, e.g. SAND DUNE "A". Wells in small rivulets were named after the closest creeks of which they are tributaries.

COUNTY	WELL NUMBER	AQUIFER	COUNTY	WELL NUMBER	AQUIFER
1.- ALLEN	24S 18E 28CDD	1 ALLUVIUM IN NEOSHO RIVER VALLEY	96.- HODGEMAN	24S 23W 26CCB	1 DAKOTA
2.- BARBER	31S 15W 19BDB	1 PERMIAN DEPOSITS	97.- JACKSON	6S 15E 27BAB	1 GLACIAL DEPOSITS
3.- BARBER	32S 11W 30BBA	1 ALLUVIUM IN MEDICINE R. VALLEY	98.- JEFFERSON	11S 16E 25CBA	1 ALLUVIUM IN KANSAS RIVER VALLEY
4.- BARBER	32S 12W 4DBC	1 ALLUVIUM IN MEDICINE R. VALLEY	99.- JEFFERSON	11S 17E 21ADA	1 ALLUVIUM IN KANSAS RIVER VALLEY
5.- BARBER	33S 11W 28CBB	1 ALLUVIUM IN MEDICINE R. VALLEY	100.- JEFFERSON	11S 17E 27BBC	1 ALLUVIUM IN KANSAS RIVER VALLEY
6.- BARBER	34S 15W 17ADA	1 ALLUVIUM IN SALT FORK VALLEY	101.- JEFFERSON	11S 18E 8DAC	1 ALLUVIUM IN KANSAS RIVER VALLEY
7.- BARBER	35S 15W 11CB	1 PERMIAN DEPOSITS	102.- JEFFERSON	11S 18E 20ACC	1 ALLUVIUM IN KANSAS RIVER VALLEY
8.- BOURBON	25S 24E 36AAC	1 CAMBRIAN-ORDOVICIAN DEPOSITS	103.- JEFFERSON	11S 19E 27BCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
9.- CHEROKEE	34S 25E 13BAC	1 CAMBRIAN-ORDOVICIAN DEPOSITS	104.- JEFFERSON	11S 19E 29CCA	1 ALLUVIUM IN KANSAS RIVER VALLEY
10.- CHEYENNE	1S 38W 2CDC	1 ALLUVIUM IN REPUBLICAN R. VALLEY	105.- JOHNSON	11S 23E 33BDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
11.- CHEYENNE	1S 38W 8DCC	1 ALLUVIUM IN REPUBLICAN R. VALLEY	106.- JOHNSON	12S 22E 21CCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
12.- CHEYENNE	1S 38W 30BDC	1 ALLUVIUM IN REPUBLICAN R. VALLEY	107.- JOHNSON	12S 22E 25BCCB	1 ALLUVIUM IN KANSAS RIVER VALLEY
13.- CHEYENNE	1S 39W 25CBC	1 ALLUVIUM IN REPUBLICAN R. VALLEY	108.- JOHNSON	12S 22E 29BBD	1 ALLUVIUM IN KANSAS RIVER VALLEY
14.- CHEYENNE	2S 39W 27BBB	1 ALLUVIUM IN REPUBLICAN R. VALLEY	109.- KINGMAN	27S 6W 16CCB	1 ALLUVIUM IN SMOOTS CREEK VALLEY
15.- CHEYENNE	3S 40W 22BCA	1 ALLUVIUM IN REPUBLICAN R. VALLEY	110.- LABETTE	31S 21E 15CCC	2 ALLUVIUM IN NEOSHO RIVER VALLEY
16.- CHEYENNE	3S 40W 28CBB	1 ALLUVIUM IN REPUBLICAN R. VALLEY	111.- LEAVENWORTH	12S 22E 21BCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
17.- CLAY	6S 1E 2BCD	1 ALLUVIUM IN REPUBLICAN R. VALLEY	112.- LEAVENWORTH	12S 22E 22CAA	1 ALLUVIUM IN KANSAS RIVER VALLEY
18.- CLAY	6S 2E 29DAC	1 ALLUVIUM IN REPUBLICAN R. VALLEY	113.- LOGAN	13S 35W 23BCC	1 ALLUVIUM IN SMOKY HILL R. VALLEY
19.- CLAY	8S 2E 2CCA	1 ALLUVIUM IN REPUBLICAN R. VALLEY	114.- LOGAN	13S 36W 20CCB	1 ALLUVIUM IN SMOKY HILL R. VALLEY
20.- CLOUD	5S 2W 1BAC	1 DAKOTA	115.- MARION	17S 3W 4BBB	1 ALLUVIUM IN SMOKY HILL R. VALLEY
21.- CRAWFORD	29S 23E 24DBA	1 CAMBRIAN-ORDOVICIAN DEPOSITS	116.- MARION	17S 5W 7CBB	1 ALLUVIUM IN SMOKY HILL R. VALLEY
22.- CRAWFORD	30S 24E 19ADD	1 CAMBRIAN-ORDOVICIAN DEPOSITS	117.- MARION	17S 5W 25AAA	1 ALLUVIUM IN SMOKY HILL R. VALLEY
23.- DOUGLAS	12S 19E 13ADA	1 ALLUVIUM IN KANSAS RIVER VALLEY	118.- MORTON	31S 41W 7CDD	1 MESOZOIC DEPOSITS
24.- DOUGLAS	12S 20E 7CBC	1 ALLUVIUM IN KANSAS RIVER VALLEY	119.- MORTON	31S 41W 31CBB	1 MESOZOIC DEPOSITS
25.- DOUGLAS	12S 20E 17CCB	1 ALLUVIUM IN KANSAS RIVER VALLEY	120.- MORTON	31S 43W 14DDC	1 LOWER CRETACEOUS DEPOSITS
26.- DOUGLAS	12S 20E 35CDD	1 ALLUVIUM IN KANSAS RIVER VALLEY	121.- NESS	18S 21W 25AAB	1 ALL. IN UPPER WALNUT CREEK VALLEY
27.- DOUGLAS	13S 20E 1BCC	1 ALLUVIUM IN KANSAS RIVER VALLEY	122.- NESS	18S 21W 31CAA	1 ALL. IN UPPER WALNUT CREEK VALLEY
28.- DOUGLAS	13S 20E 2BDD	2 ALLUVIUM IN KANSAS RIVER VALLEY	123.- NESS	18S 24W 36ABD	1 ALL. IN UPPER WALNUT CREEK VALLEY
29.- DOUGLAS	13S 20E 11BAA	1 ALLUVIUM IN KANSAS RIVER VALLEY	124.- NESS	18S 25W 33BBC	1 ALL. SOUTH FORK WALNUT CREEK VALLEY
30.- DOUGLAS	15S 19E 15AAD	1 IRELAND SANDSTONE	125.- NESS	18S 26W 6BAB	2 ALL. MIDDLE FORK WALNUT CREEK VALLEY
31.- EDWARDS	23S 19W 22CCC	1 DAKOTA	126.- NESS	19S 23W 1CCB	1 DAKOTA
32.- ELLSWORTH	17S 9W 21BCC	1 DAKOTA	127.- NESS	19S 23W 8CBB	1 ALL. IN UPPER WALNUT CREEK VALLEY
33.- ELLSWORTH	17S 9W 21BCC	2 ALLUVIUM IN LOST CREEK VALLEY	128.- NESS	20S 22W 35BCC	1 ALLUVIUM IN PAWNEE RIVER VALLEY
34.- ELLSWORTH	17S 9W 28CBB	1 DAKOTA	129.- NESS	20S 23W 32CDA	1 ALLUVIUM IN PAWNEE RIVER VALLEY
35.- ELLSWORTH	17S 9W 31AAB	1 DAKOTA	130.- NESS	20S 26W 7BDC	1 ALLUVIUM IN HACKBERRY CREEK VALLEY
36.- FINNEY	21S 29W 36CCB	1 ALLUVIUM IN PAWNEE RIVER VALLEY	131.- OSBORNE	6S 12W 23CDD	1 ALL. IN NORTH FORK SOLOMON R. VALLEY
37.- FINNEY	21S 34W 14DBB	1 NIOBRARA	132.- OSBORNE	7S 15W 10CCC	1 ALL. IN SOUTH FORK SOLOMON R. VALLEY
38.- FINNEY	22S 27W 14ADC	1 DAKOTA	133.- POTTAWATOMIE	9S 11E 31DCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
39.- FINNEY	22S 34W 8CBC	1 NIOBRARA	134.- POTTAWATOMIE	9S 11E 32ADC	1 ALLUVIUM IN KANSAS RIVER VALLEY
40.- FINNEY	25S 33W 3BCC	1 SAND DUNE "A"	135.- POTTAWATOMIE	9S 11E 34CAB	1 ALLUVIUM IN KANSAS RIVER VALLEY
41.- FORD	25S 22W 7ACA	1 DAKOTA	136.- POTTAWATOMIE	9S 11E 35DDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
42.- FORD	25S 23W 11CCC	1 DAKOTA	137.- POTTAWATOMIE	10S 8E 12CBB	1 ALLUVIUM IN KANSAS RIVER VALLEY
43.- FORD	25S 23W 12BBB	1 DAKOTA	138.- POTTAWATOMIE	10S 8E 14CBA	1 ALLUVIUM IN KANSAS RIVER VALLEY
44.- FORD	25S 23W 14ADD	1 DAKOTA	139.- POTTAWATOMIE	10S 10E 10DBC	1 ALLUVIUM IN KANSAS RIVER VALLEY
45.- FORD	25S 23W 25CCC	1 DAKOTA	140.- POTTAWATOMIE	10S 11E 1CBC	1 ALLUVIUM IN KANSAS RIVER VALLEY
46.- FORD	25S 23W 32DBB	1 DAKOTA	141.- POTTAWATOMIE	10S 11E 3BCA	1 ALLUVIUM IN KANSAS RIVER VALLEY
47.- FORD	25S 23W 34CCB	1 DAKOTA	142.- POTTAWATOMIE	10S 11E 4ACB	1 ALLUVIUM IN KANSAS RIVER VALLEY
48.- FORD	25S 23W 35DAD	1 DAKOTA	143.- RENO	23S 4W 16BBB	1 SAND DUNE "D"
49.- FORD	25S 23W 35DDB	1 DAKOTA	144.- RENO	25S 8W 19ADB	1 ALLUVIUM IN SILVER CREEK VALLEY
50.- FORD	25S 23W 36BDA	1 DAKOTA	145.- RENO	26S 6W 13BAB	1 ALL. NINNESCAH R. TRIB. VALLEY
51.- FORD	25S 25W 29CAD	1 DAKOTA	146.- RENO	26S 8W 9ABA	1 ALLUVIUM IN GOOSE CREEK VALLEY
52.- FORD	25S 26W 19BDB	1 DAKOTA	147.- REPUBLIC	1S 3W 9C	1 UNDIFFERENTIATED QUATERNARY DEPOSITS
53.- FORD	25S 26W 20ABC	1 DAKOTA	148.- REPUBLIC	1S 4W 15AAA	1 UNDIFFERENTIATED QUATERNARY DEPOSITS
54.- FORD	26S 22W 8DDC	1 DAKOTA	149.- RICE	18S 10W 24BBB	1 DAKOTA
55.- FORD	26S 22W 18ACA	1 DAKOTA	150.- RILEY	10S 7E 34BAA	2 ALLUVIUM IN KANSAS RIVER VALLEY
56.- FORD	26S 23W 10DAD	1 DAKOTA	151.- RILEY	10S 7E 35DBB	1 ALLUVIUM IN KANSAS RIVER VALLEY
57.- FORD	26S 23W 10DBC	1 DAKOTA	152.- RILEY	10S 8E 23CDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
58.- FORD	26S 23W 15ADA	1 DAKOTA	153.- RILEY	10S 9E 17BDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
59.- FORD	27S 23W 24CBB	1 DAKOTA	154.- RILEY	10S 9E 19BBA	1 ALLUVIUM IN KANSAS RIVER VALLEY
60.- GEARY	11S 6E 27CBB	1 ALLUVIUM IN KANSAS RIVER VALLEY	155.- RILEY	11S 7E 1BCC	1 ALLUVIUM IN KANSAS RIVER
61.- GOVE	13S 26W 20CBC	1 ALL. IN HACKBERRY CREEK VALLEY	156.- ROOKS	7S 17W 24BBB	1 ALL. SOUTH FORK SOLOMON R. VALLEY
62.- GRANT	27S 38W 15BBB	1 DAKOTA	157.- ROOKS	7S 19W 23CDB	1 ALL. SOUTH FORK SOLOMON R. VALLEY
63.- GRANT	30S 36W 4ABB	1 DAKOTA	158.- RUSH	18S 20W 19AAD	1 ALL. UPPER WALNUT RIVER VALLEY
64.- HAMILTON	23S 40W 29DDB	1 LOWER CRETACEOUS DEPOSITS	159.- SCOTT	19S 31W 20BAD	1 NIOBRARA
65.- HAMILTON	24S 42W 28DDD	1 MESOZOIC DEPOSITS	160.- SHAWNEE	11S 12E 1ABA	1 ALLUVIUM IN KANSAS RIVER VALLEY
66.- HAMILTON	24S 43W 14CBB	1 MESOZOIC DEPOSITS	161.- SHAWNEE	11S 14E 13BBB	1 ALLUVIUM IN KANSAS RIVER VALLEY
67.- HAMILTON	25S 39W 23BDD	1 MESOZOIC DEPOSITS	162.- SHAWNEE	11S 14E 15ABB	1 ALLUVIUM IN KANSAS RIVER VALLEY
68.- HAMILTON	25S 39W 34DCA	1 MESOZOIC DEPOSITS	163.- SHAWNEE	11S 14E 18CBB	1 ALLUVIUM IN KANSAS RIVER VALLEY
69.- HAMILTON	25S 40W 26BBB	1 MESOZOIC DEPOSITS	164.- SHAWNEE	11S 14E 22CCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
70.- HAMILTON	25S 43W 3ABB	1 MESOZOIC DEPOSITS	165.- SHAWNEE	11S 14E 24BBB	1 ALLUVIUM IN KANSAS RIVER VALLEY
71.- HAMILTON	26S 40W 18BA	1 MESOZOIC DEPOSITS	166.- SHAWNEE	11S 15E 13BCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
72.- HAMILTON	26S 41W 12DCC	1 MESOZOIC DEPOSITS	167.- SHAWNEE	11S 15E 14ADB	1 ALLUVIUM IN KANSAS RIVER VALLEY
73.- HARVEY	23S 3W 12DCC	1 SAND DUNE "B"	168.- SHAWNEE	11S 15E 23DBD	2 ALLUVIUM IN KANSAS RIVER VALLEY
74.- HARVEY	26S 3W 14CCA	1 SAND DUNE "B"	169.- SHAWNEE	11S 15E 24BDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
75.- HARVEY	23S 3W 16BAC	1 SAND DUNE "B"	170.- SHAWNEE	11S 16E 19DDD	1 ALLUVIUM IN KANSAS RIVER VALLEY
76.- HARVEY	23S 3W 24AAD	1 SAND DUNE "B"	171.- SHAWNEE	11S 16E 29ACA	1 ALLUVIUM IN KANSAS RIVER VALLEY
77.- HARVEY	23S 3W 26ABB	1 SAND DUNE "B"	172.- STANTON	28S 42W 32BBB	1 MESOZOIC DEPOSITS
78.- HARVEY	24S 1W 22DDD	1 SAND DUNE "C"	173.- STANTON	29S 41W 31CDD	1 MESOZOIC DEPOSITS
79.- HODGEMAN	21S 26W 35AAC	1 ALL. IN UPPER PAWNEE R. VALLEY	174.- STANTON	29S 43W 33CDB	1 MESOZOIC DEPOSITS
80.- HODGEMAN	22S 22W 4AAA	1 ALL. BUCKNER CREEK TRIBUTARY VALLEY	175.- STANTON	30S 40W 33CCB	1 MESOZOIC DEPOSITS
81.- HODGEMAN	22S 23W 31ADD	1 DAKOTA	176.- STANTON	30S 42W 12ACC	1 MESOZOIC DEPOSITS
82.- HODGEMAN	22S 24W 14BCC	1 DAKOTA	177.- WABAUNSEE	10S 10E 15DCC	1 ALLUVIUM IN KANSAS RIVER VALLEY
83.- HODGEMAN	22S 24W 25DDC	1 DAKOTA	178.- WABAUNSEE	10S 12E 29ADD	1 ALLUVIUM IN KANSAS RIVER VALLEY
84.- HODGEMAN	22S 24W 35DAC	1 DAKOTA	179.- WALLACE	13S 39W 33BBB	1 ALLUVIUM IN SMOKY HILL R. VALLEY
85.- HODGEMAN	23S 22W 7DAA	1 DAKOTA	180.- WASHINGTON	1S 5E 5ADA	1 GLACIAL DEPOSITS
86.- HODGEMAN	23S 23W 18AA	1 ALL. IN BUCKNER CREEK VALLEY	181.- WASHINGTON	4S 2E 14CCC	1 DAKOTA
87.- HODGEMAN	23S 23W 4AAD	1 DAKOTA	182.- WASHINGTON	5S 1E 20ADA	1 DAKOTA
88.- HODGEMAN	23S 23W 4DCA	1 DAKOTA	183.- WASHINGTON	5S 1E 31DDD	1 ALLUVIUM IN REPUBLICAN R. VALLEY
89.- HODGEMAN	23S 24W 11ABB	1 DAKOTA	184.- WYANDOTTE	11S 24E 14BDA	1 ALLUVIUM IN KANSAS RIVER VALLEY
90.- HODGEMAN	23S 24W 11DAA	1 DAKOTA	185.- WYANDOTTE	11S 24E 21DDD	2 ALLUVIUM IN KANSAS RIVER VALLEY
91.- HODGEMAN	23S 24W 28BCC	1 DAKOTA	186.- WYANDOTTE	11S 24E 28BCC	3 ALLUVIUM IN KANSAS RIVER VALLEY
92.- HODGEMAN	23S 25W 22DBB	1 DAKOTA	187.- WYANDOTTE	11S 24E 31DAB	1 ALLUVIUM IN KANSAS RIVER VALLEY
93.- HODGEMAN	23S 26W 7CCC	1 DAKOTA	188.- WYANDOTTE	11S 24E 32ABA	2 ALLUVIUM IN KANSAS RIVER VALLEY
94.- HODGEMAN	24S 23W 6AAB	1 DAKOTA	189.- WYANDOTTE	11S 25E 20BAB	2 ALLUVIUM IN KANSAS RIVER VALLEY
95.- HODGEMAN	24S 23W 13DCC	1 DAKOTA			

E.3 Excess wells per 10-acre tract

Although not exactly in the same location, the following wells are located in the same 10-acre tract as wells in Appendix E.1. The 93 wells listed below are considered redundant and were not used in the study.

COUNTY	WELL NUMBER	COUNTY	WELL NUMBER
1.-	BARTON 18S 15W 28CCC 1	51.-	HARVEY 24S 3W 11AAA 3
2.-	FINNEY 24S 33W 9CCD 2	52.-	HARVEY 24S 3W 11ADD 1
3.-	FINNEY 24S 33W 9CCD 3	53.-	HARVEY 24S 3W 11ADD 3
4.-	FINNEY 24S 33W 18BDB 2	54.-	HARVEY 24S 3W 11DCC 2
5.-	FINNEY 24S 33W 19DBB 2	55.-	HARVEY 24S 3W 11DCC 3
6.-	FINNEY 24S 33W 31ABD 2	56.-	HARVEY 24S 3W 11DDD 2
7.-	FORD 26S 24W 32ADD 2	57.-	HARVEY 24S 3W 11DDD 3
8.-	FORD 26S 24W 32CAB 2	58.-	HARVEY 24S 3W 11DDD 4
9.-	HARVEY 23S 2W 17BBB 2	59.-	HARVEY 24S 3W 17CCC 2
10.-	HARVEY 23S 2W 28ABA 2	60.-	HARVEY 24S 3W 18BBB 2
11.-	HARVEY 23S 2W 29BBB 2	61.-	HARVEY 24S 3W 23DAB 2
12.-	HARVEY 23S 2W 29CBB 2	62.-	HARVEY 24S 3W 23DAB 3
13.-	HARVEY 23S 2W 29CDD 2	63.-	HARVEY 24S 3W 23DDC 2
14.-	HARVEY 23S 2W 30DDD 1	64.-	HARVEY 24S 3W 23DDC 3
15.-	HARVEY 23S 2W 31DDD 1	65.-	HARVEY 24S 3W 24DCC 2
16.-	HARVEY 23S 2W 32CBB 2	66.-	HARVEY 24S 3W 24DCC 3
17.-	HARVEY 23S 2W 32CCC 2	67.-	HARVEY 24S 3W 31DDD 2
18.-	HARVEY 23S 2W 33CCD 2	68.-	HARVEY 24S 3W 31DDD 3
19.-	HARVEY 23S 3W 4BBB 2	69.-	MEADE 31S 26W 30BBB 2
20.-	HARVEY 23S 3W 8DDD 1	70.-	MEADE 32S 29W 27AAB 2
21.-	HARVEY 23S 3W 17DDD 1	71.-	MEADE 32S 30W 35CAD 2
22.-	HARVEY 23S 3W 17DDD 3	72.-	PAWNEE 22S 15W 3AAA 2
23.-	HARVEY 23S 3W 21CCC 2	73.-	PAWNEE 22S 17W 5BCC 1
24.-	HARVEY 23S 3W 32AAA 2	74.-	PRATT 26S 12W 34CDC 2
25.-	HARVEY 23S 3W 32DCC 2	75.-	RENO 24S 4W 13CC 2
26.-	HARVEY 24S 2W 6ADD 1	76.-	SEDGWICK 25S 1W 6CCC 2
27.-	HARVEY 24S 2W 6ADD 3	77.-	SEDGWICK 25S 1W 7BCC 2
28.-	HARVEY 24S 2W 8BAA 1	78.-	SEDGWICK 25S 1W 7BCC 3
29.-	HARVEY 24S 2W 8BBB 1	79.-	SEDGWICK 25S 1W 17CBB 2
30.-	HARVEY 24S 2W 8BCC 1	80.-	SEDGWICK 25S 1W 17CBB 3
31.-	HARVEY 24S 2W 8DBB 2	81.-	SEDGWICK 25S 1W 17CCC 2
32.-	HARVEY 24S 2W 9ADD 2	82.-	SEDGWICK 25S 1W 17CCC 3
33.-	HARVEY 24S 2W 9CBB 2	83.-	SEDGWICK 25S 1W 18AAA 3
34.-	HARVEY 24S 2W 9DDD 2	84.-	SEDGWICK 25S 1W 18ABB 3
35.-	HARVEY 24S 2W 16BAA 2	85.-	SEDGWICK 25S 2W 5BBB 1
36.-	HARVEY 24S 2W 17ABB 2	86.-	SEDGWICK 25S 2W 5BBB 3
37.-	HARVEY 24S 2W 22BCC 2	87.-	SEDGWICK 25S 2W 5BCC 2
38.-	HARVEY 24S 2W 22CDD 2	88.-	SEDGWICK 25S 2W 5BCC 2
39.-	HARVEY 24S 2W 26BBB 2	89.-	SEDGWICK 25S 2W 5DCD 2
40.-	HARVEY 24S 2W 26CCC 1	90.-	SEDGWICK 25S 2W 11BBB 1
41.-	HARVEY 24S 2W 27AAA 1	91.-	SEDGWICK 25S 2W 11CBC 1
42.-	HARVEY 24S 2W 28DAA 1	92.-	SEDGWICK 25S 2W 24DDD 3
43.-	HARVEY 24S 2W 28DAA 2	93.-	SEDGWICK 33S 32W 28CDD 2
44.-	HARVEY 24S 2W 28DCC 2		
45.-	HARVEY 24S 2W 28DCC 3		
46.-	HARVEY 24S 2W 35ADD 1		
47.-	HARVEY 24S 2W 35DDD 1		
48.-	HARVEY 24S 3W 1DDD 2		
49.-	HARVEY 24S 3W 6DDD 2		
50.-	HARVEY 24S 3W 11AAA 1		

E.4 Wells without land surface elevation

Forty wells have measurements that are of no use in a spatial analysis due to the lack of a reported land surface elevation.

COUNTY	WELL NUMBER
1.- CHEYENNE	5S 39W 6DAA 1
2.- CLARK	33S 22W 30CBC 1
3.- COMANCHE	31S 18W 19ACB 1
4.- EDWARDS	25S 16W 31DCC 1
5.- ELLIS	14S 18W 12AAD 1
6.- ELLIS	14S 18W 12ABB 1
7.- ELLSWORTH	17S 9W 20BCD 1
8.- ELLSWORTH	17S 9W 28CBB 2
9.- ELLSWORTH	17S 9W 31AAB 2
10.- ELLSWORTH	17S 9W 31ADC 1
11.- FORD	26S 22W 21DCA 1
12.- FORD	27S 24W 3CDD 1
13.- FORD	27S 24W 4ABC 1
14.- FORD	28S 21W 23DBC 1
15.- FORD	28S 26W 13CAA 1
16.- GRANT	28S 37W 2BBB 4
17.- HARVEY	24S 2W 26DCC 1
18.- KIOWA	28S 19W 10AAC 1
19.- MARION	17S 4E 34AAA 1
20.- OSBORNE	7S 12W 28ABA 1
21.- OSBORNE	7S 15W 8CCC 2
22.- PHILLIPS	4S 18W 23CDC 1
23.- POTTAWATOMIE	9S 11E 19CDB 1
24.- POTTAWATOMIE	9S 11E 27CAA 1
25.- POTTAWATOMIE	10S 12E 7BBC 1
26.- PRATT	27S 12W 12DAA 1
27.- RAWLINS	5S 33W 16CAC 1
28.- REPUBLIC	1S 3W 1CCA 1
29.- RICE	18S 9W 4BCC 1
30.- RICE	18S 9W 4BCC 2
31.- RUSH	18S 18W 22DDD 1
32.- RUSH	18S 20W 14CCC 1
33.- SALINE	16S 2W 18BBB 1
34.- SALINE	16S 3W 23DDD 1
35.- SEDGWICK	25S 1W 18AAA 1
36.- SEDGWICK	25S 1W 18ABB 1
37.- SEWARD	32S 33W 17ABC 1
38.- SHAWNEE	11S 13E 4ADA 1
39.- STAFFORD	25S 13W 7B 1
40.- THOMAS	6S 33W 18CCC 1

E.5 Wells without truly static measurements

The following 20 wells were measured, but because of various types of measurement error or unstable conditions in the well the readings are not considered representative of the actual depth to the water table.

	COUNTY	WELL NUMBER	DEPTH
1.-	DECATUR	5S 30W 35BCB 1	128.82
2.-	GRANT	28S 38W 8BC 1	241.67
3.-	GRANT	29S 37W 3CDB 1	225.38
4.-	GRANT	29S 37W 22AAB 1	152.60
5.-	GRANT	30S 38W 13CCC 1	224.69
6.-	HARVEY	24S 2W 28DDD 1	75.82
7.-	HARVEY	24S 2W 28DDD 3	45.81
8.-	KEARNY	26S 36W 22CCA 1	78.01
9.-	LANE	16S 30W 34DAB 1	130.05
10.-	MORTON	32S 42W 26CDD 1	146.45
11.-	SCOTT	16S 33W 25BCC 1	21.67
12.-	SEDGWICK	25S 2W 2BAA 1	72.28
13.-	SEWARD	31S 34W 18BBB 1	216.94
14.-	SEWARD	32S 32W 19BAB 1	226.83
15.-	SHERIDAN	10S 28W 5DDB 1	118.84
16.-	STANTON	27S 40W 21DAA 1	79.57
17.-	STANTON	27S 40W 25CBC 1	178.05
18.-	STEVENS	32S 39W 2BBB 1	210.58
19.-	THOMAS	10S 31W 29AAB 1	91.06
20.-	THOMAS	10S 34W 1ABA 1	190.55

APPENDIX F

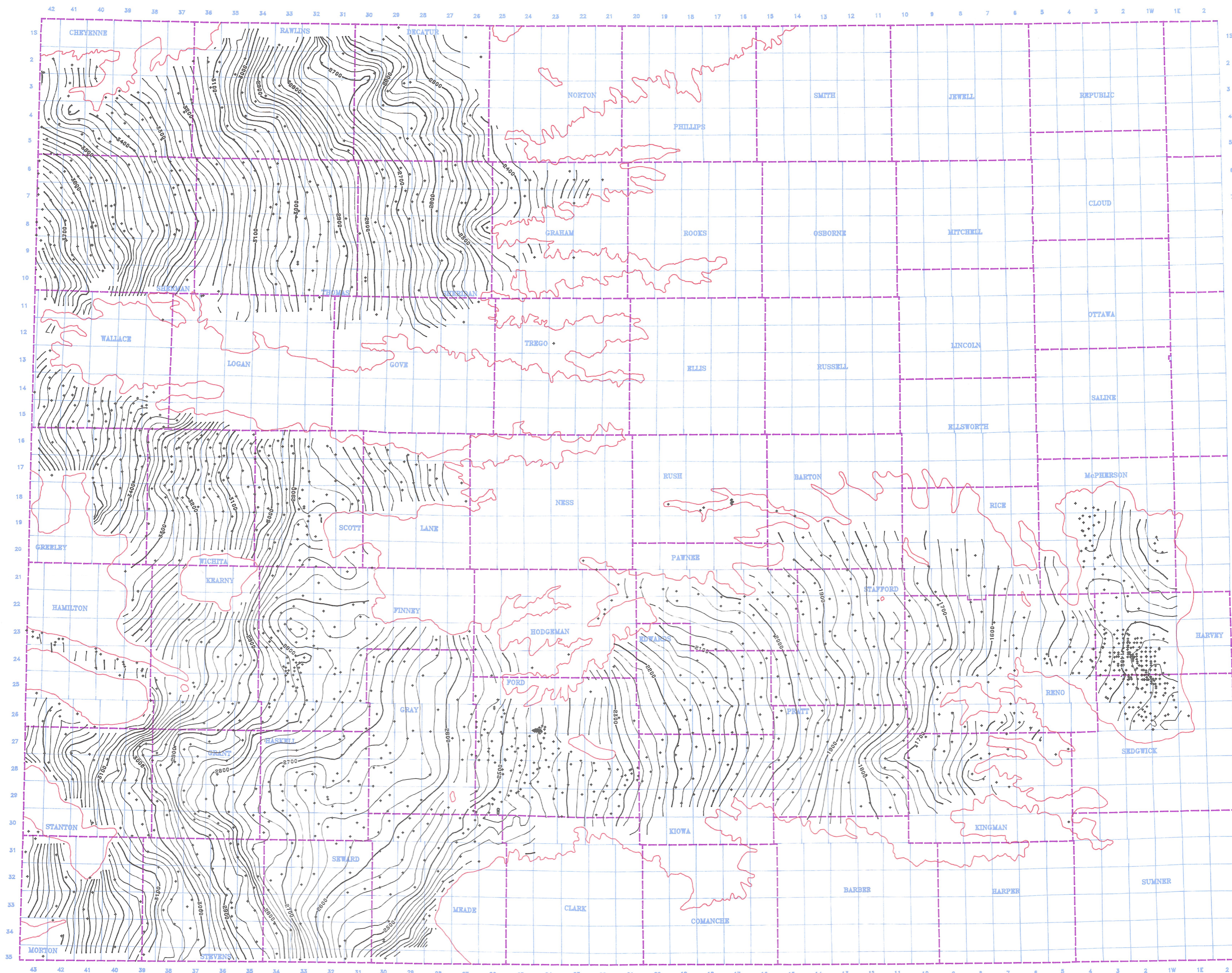
WELL LOCATIONS TO BE INCORPORATED INTO THE NETWORK

Listed below are 660 locations of centers of 16-square-mile (41 km²) regular hexagons. An observation well should be placed inside each hexagon to completely cover the High Plains aquifer with a stratified hexagonal network at a density of one well every 16 square miles (41 km²). The locations are divided into two groups according to the saturated thickness expected at the well location. Those locations that may have less than 40 feet (12.2 m) of saturated thickness are marked with an asterisk. The remaining locations are in areas where more than 40 feet (12.2 m) of saturated thickness is expected.

COUNTY	WELL LOCATION	COUNTY	WELL LOCATION	COUNTY	WELL LOCATION	COUNTY	WELL LOCATION
1.- BARBER	30S 11W 10CCC	91.- EDWARDS	23S 20W 20BBD *	181.- GRAY	25S 30W 4BBA	271.- KIOWA	29S 19W 33DBD
2.- BARBER	30S 12W 8DDC *	92.- EDWARDS	23S 20W 36BDB *	182.- GRAY	26S 28W 5BBC	272.- KIOWA	29S 20W 8BCC
3.- BARBER	30S 12W 24DBB *	93.- EDWARDS	24S 19W 10BCD *	183.- GRAY	26S 29W 15CDA	273.- KIOWA	29S 20W 31DAD
4.- BARBER	30S 13W 23CCC *	94.- EDWARDS	24S 20W 8DBA *	184.- GRAY	26S 30W 1CAD	274.- KIOWA	30S 18W 7CAA *
5.- BARBER	31S 10W 2BDD	95.- EDWARDS	24S 20W 24CAB *	185.- GRAY	27S 28W 35AAC	275.- KIOWA	30S 18W 23CCC *
6.- BARBER	31S 10W 18CBA *	96.- EDWARDS	24S 20W 32DDA	186.- GRAY	27S 29W 34BBD	276.- KIOWA	30S 19W 28ABB
7.- BARBER	31S 11W 4ACC *	97.- EDWARDS	25S 20W 13BBD	187.- GRAY	28S 27W 33CAD *	277.- KIOWA	30S 20W 11DDA
8.- BARTON	17S 11W 29CDD *	98.- EDWARDS	25S 20W 29AAD *	188.- GRAY	28S 28W 23ACD	278.- KIOWA	30S 20W 20CCC
9.- BARTON	18S 11W 12BBA *	99.- EDWARDS	26S 20W 26BDD	189.- GRAY	28S 28W 31DDA	279.- LANE	16S 27W 26ADB *
10.- BARTON	18S 11W 20BBC *	100.- ELLIS	13S 20W 32AAA *	190.- GRAY	28S 29W 22BBD	280.- LANE	18S 27W 20BBB
11.- BARTON	18S 11W 36BBD	101.- FINNEY	21S 31W 25DAB	191.- GRAY	29S 28W 11DCB *	281.- LANE	18S 29W 13CDA *
12.- BARTON	18S 12W 10ABD *	102.- FINNEY	21S 33W 29ACB	192.- GRAY	29S 29W 10BCD	282.- LANE	18S 29W 33BBB *
13.- BARTON	18S 12W 34BDD	103.- FINNEY	21S 34W 6BBB *	193.- GREELEY	16S 42W 18AAA *	283.- LANE	18S 30W 22AAA *
14.- BARTON	18S 13W 1ABA *	104.- FINNEY	21S 34W 30BCC *	194.- GREELEY	17S 42W 6ADD *	284.- LOGAN	11S 32W 1AAD
15.- BARTON	18S 13W 9CBB *	105.- FINNEY	22S 31W 6DAB	195.- GREELEY	17S 42W 30DDA *	285.- LOGAN	11S 32W 25AAD
16.- BARTON	18S 13W 24ACB	106.- FINNEY	22S 31W 31AAB	196.- GREELEY	18S 40W 22ABA *	286.- LOGAN	11S 33W 2ACD
17.- BARTON	19S 11W 8CCA	107.- FINNEY	22S 33W 36BAB	197.- GREELEY	18S 42W 1CCC *	287.- LOGAN	11S 33W 18ACC
18.- BARTON	19S 11W 24CCB	108.- FINNEY	23S 28W 8AAD *	198.- GREELEY	18S 42W 20BCC *	288.- LOGAN	11S 33W 26ABA *
19.- BARTON	19S 12W 22CDD	109.- FINNEY	23S 29W 2BBB *	199.- GREELEY	18S 42W 35AAC	289.- LOGAN	11S 34W 3BBB *
20.- BARTON	19S 14W 11BCD	110.- FINNEY	23S 29W 7BCC *	200.- GREELEY	19S 39W 20ACD *	290.- LOGAN	11S 34W 28ADD
21.- BARTON	19S 14W 35CCC	111.- FINNEY	24S 31W 7ACA	201.- GREELEY	19S 40W 10ACA	291.- LOGAN	11S 35W 5BAA *
22.- BARTON	19S 15W 9DCC *	112.- FINNEY	25S 32W 16AAD	202.- GREELEY	19S 42W 7DBB *	292.- LOGAN	11S 35W 13BBD *
23.- BARTON	20S 13W 13BCC	113.- FINNEY	26S 32W 13ADD	203.- GREELEY	19S 42W 23CAA *	293.- LOGAN	11S 35W 29RDD *
24.- CHEYENNE	2S 37W 2AAC *	114.- FORD	25S 21W 5BBD *	204.- GREELEY	20S 39W 26AAD *	294.- LOGAN	11S 36W 15ACC *
25.- CHEYENNE	2S 37W 18DDA	115.- FORD	25S 21W 14ACD *	205.- HAMILTON	21S 39W 15ACD *	295.- LOGAN	12S 32W 4CBB *
26.- CHEYENNE	2S 37W 26ACD	116.- FORD	25S 21W 29BDB *	206.- HAMILTON	23S 40W 1DDB *	296.- LOGAN	12S 32W 13DDA *
27.- CHEYENNE	2S 38W 4ADB *	117.- FORD	25S 23W 25ACD *	207.- HAMILTON	24S 41W 7AAC	297.- LOGAN	12S 32W 28CCC *
28.- CHEYENNE	2S 38W 27CCC	118.- FORD	25S 24W 18CAD *	208.- HARPER	31S 7W 5CBA *	298.- LOGAN	12S 33W 6ACD
29.- CHEYENNE	2S 39W 13BBA *	119.- FORD	25S 24W 26BCC *	209.- HARPER	31S 7W 14DDB *	299.- LOGAN	12S 33W 14ACB *
30.- CHEYENNE	2S 40W 30CCC *	120.- FORD	25S 26W 5BCC	210.- HARPER	31S 8W 15CAA *	300.- LOGAN	12S 33W 30DDD *
31.- CHEYENNE	3S 37W 31AAA	121.- FORD	26S 22W 4DAB *	211.- HARPER	31S 9W 1ACC *	301.- LOGAN	12S 34W 15CCB *
32.- CHEYENNE	3S 38W 22BBD	122.- FORD	26S 22W 28BDB *	212.- HARPER	31S 9W 17ADD *	302.- LOGAN	12S 35W 1HDD
33.- CHEYENNE	3S 39W 1DCC	123.- FORD	26S 23W 6DDC *	213.- HARPER	31S 9W 25DBB	303.- LOGAN	12S 35W 17CAA *
34.- CHEYENNE	4S 37W 19DAA	124.- FORD	26S 23W 14DDA *	214.- HARVEY	22S 1W 7DBB *	304.- LOGAN	12S 35W 25CCC *
35.- CHEYENNE	4S 41W 12ADD	125.- FORD	26S 25W 29CCC	215.- HARVEY	22S 1W 23DCC *	305.- LOGAN	12S 36W 3ACC *
36.- CHEYENNE	5S 38W 3BBB	126.- FORD	26S 25W 1DDB *	216.- HARVEY	22S 1W 31DDD *	306.- LOGAN	13S 32W 1DDC *
37.- CLARK	30S 21W 15BBD	127.- FORD	27S 21W 6CCA *	217.- HASKELL	27S 32W 16CAD	307.- LOGAN	13S 33W 2DDB *
38.- CLARK	30S 22W 16BBA *	128.- FORD	27S 21W 14CCC *	218.- HASKELL	27S 34W 3CAA	308.- LOGAN	14S 36W 19CCA *
39.- CLARK	30S 23W 18ABB *	129.- FORD	28S 26W 19ACB	219.- HASKELL	27S 34W 34BBD	309.- LOGAN	14S 37W 21ACD *
40.- CLARK	30S 24W 28AAD *	130.- FORD	29S 23W 35DDD	220.- HASKELL	30S 33W 26ABB	310.- LOGAN	15S 25W 17DBA *
41.- CLARK	30S 25W 13BBD *	131.- FORD	29S 24W 34CCA *	221.- HOGEMAN	22S 24W 20CB *	311.- LOGAN	15S 35W 25BDD *
42.- CLARK	30S 25W 29ACC	132.- GOVE	11S 26W 14BCC	222.- HOGEMAN	22S 24W 18CCA *	312.- LOGAN	15S 36W 26BBB *
43.- CLARK	31S 24W 1AAC *	133.- GOVE	11S 28W 2ABC	223.- HOGEMAN	22S 25W 4CAC *	313.- MARION	21S 1E 21CAA *
44.- CLARK	31S 24W 16BCD *	134.- GOVE	11S 28W 18ABC	224.- HOGEMAN	22S 25W 28CDA *	314.- MCPHERSON	18S 3W 8BDA *
45.- CLARK	31S 25W 28AA *	135.- GOVE	11S 28W 26CBA	225.- HOGEMAN	23S 23W 25ACA *	315.- MCPHERSON	18S 3W 24CDD *
46.- COMANCHE	31S 17W 5BBD *	136.- GOVE	11S 29W 28ACD	226.- HOGEMAN	23S 26W 11ABC *	316.- MCPHERSON	19S 1W 18AAC *
47.- COMANCHE	31S 17W 11DAA *	137.- GOVE	11S 30W 13BBD	227.- HOGEMAN	23S 26W 20BCC *	317.- MCPHERSON	19S 2W 3BBA *
48.- COMANCHE	31S 17W 29BDD *	138.- GOVE	11S 31W 14BCC	228.- HOGEMAN	23S 26W 35DDB *	318.- MCPHERSON	19S 2W 27BBD *
49.- COMANCHE	31S 18W 15ACC	139.- GOVE	12S 26W 10AAA *	229.- HOGEMAN	24S 24W 11CBB *	319.- MCPHERSON	19S 3W 13AAC *
50.- COMANCHE	31S 19W 1AAC	140.- GOVE	12S 26W 19BBB *	230.- HOGEMAN	24S 25W 9DBA *	320.- MCPHERSON	19S 4W 6BBB *
51.- COMANCHE	31S 19W 16BCC *	141.- GOVE	12S 26W 34ADD *	231.- KEARNY	21S 38W 13BBA *	321.- MCPHERSON	19S 4W 30BCD *
52.- COMANCHE	31S 19W 25ABD *	142.- GOVE	12S 27W 4CDA *	232.- KEARNY	21S 38W 29ACC *	322.- MCPHERSON	20S 2W 15CAC *
53.- COMANCHE	31S 20W 2BBA *	143.- GOVE	12S 27W 28CDD *	233.- KEARNY	22S 37W 15CCA	323.- MCPHERSON	20S 3W 1ACC
54.- COMANCHE	32S 17W 1ICCB *	144.- GOVE	12S 28W 6DAA *	234.- KEARNY	22S 38W 18CA *	324.- MCPHERSON	20S 5W 33ABD
55.- COMANCHE	32S 17W 17CDD *	145.- GOVE	12S 28W 14DDB *	235.- KEARNY	22S 38W 17CCA *	325.- MCPHERSON	21S 1W 11AAC *
56.- COMANCHE	32S 18W 3DCC	146.- GOVE	12S 28W 30CCC *	236.- KEARNY	22S 38W 25CCD	326.- MCPHERSON	21S 1W 35ACC *
57.- COMANCHE	32S 18W 27DCC *	147.- GOVE	12S 30W 1CBA *	237.- KEARNY	23S 36W 11ACC	327.- MCPHERSON	21S 2W 10BDA *
58.- COMANCHE	32S 19W 13DDB *	148.- GOVE	12S 30W 17CDA *	238.- KEARNY	23S 36W 35CAD	328.- MCPHERSON	21S 5W 21BDD
59.- COMANCHE	33S 19W 1DCC *	149.- GOVE	12S 31W 3DDB *	239.- KEARNY	23S 38W 5DCC	329.- MEADE	30S 28W 26BDA
60.- DECATUR	1S 26W 3BDB *	150.- GOVE	12S 31W 27DDB *	240.- KEARNY	23S 38W 24BAA	330.- MEADE	31S 25W 4ADD
61.- DECATUR	1S 26W 27ADC *	151.- GOVE	13S 30W 5DDB *	241.- KEARNY	23S 38W 32ACC	331.- MEADE	31S 29W 1DAB
62.- DECATUR	1S 27W 5ACB *	152.- GOVE	13S 31W 22ABB *	242.- KEARNY	24S 36W 7DBB	332.- MEADE	33S 29W 14ABA
63.- DECATUR	1S 27W 29CDD	153.- GRAHAM	6S 21W 13ABA	243.- KEARNY	24S 36W 31CCC	333.- MEADE	33S 29W 30ADA
64.- DECATUR	1S 28W 15ACC	154.- GRAHAM	6S 23W 16BDD	244.- KEARNY	24S 37W 22CCB	334.- MEADE	33S 30W 15BBA
65.- DECATUR	1S 29W 25ADA	155.- GRAHAM	6S 24W 2ACC	245.- KEARNY	24S 38W 12CCA	335.- MEADE	34S 28W 16ACC
66.- DECATUR	1S 30W 2ACA	156.- GRAHAM	6S 25W 3BCA	246.- KEARNY	26S 35W 1DBA	336.- MEADE	34S 29W 17BCC
67.- DECATUR	1S 30W 18ACB	157.- GRAHAM	7S 21W 1BBB *	247.- KEARNY	26S 38W 14DCC	337.- MEADE	34S 29W 26DDB
68.- DECATUR	2S 27W 1ADB *	158.- GRAHAM	7S 23W 4DCC	248.- KEARNY	26S 38W 30DAA *	338.- MEADE	35S 28W 4CDA
69.- DECATUR	2S 27W 36ABB	159.- GRAHAM	7S 23W 33ABA *	249.- KINGMAN	29S 5W 32CAD *	339.- MEADE	35S 29W 5CCB
70.- DECATUR	2S 28W 3DBA	160.- GRAHAM	7S 24W 14DAB	250.- KINGMAN	29S 5W 36ACC *	340.- MORTON	31S 39W 17CCA
71.- DECATUR	2S 28W 27DCC *	161.- GRAHAM	7S 24W 30DCC	251.- KINGMAN	29S 6W 7DBB *	341.- MORTON	31S 40W 3DDB *
72.- DECATUR	2S 29W 4BCC	162.- GRAHAM	8S 24W 35ACD *	252.- KINGMAN	29S 6W 28DDB *	342.- MORTON	32S 39W 5CDD
73.- DECATUR	2S 29W 28CDD	163.- GRAHAM	8S 25W 3CCC *	253.- KINGMAN	29S 7W 9CAA *	343.- MORTON	32S 39W 32CAA
74.- DECATUR	2S 30W 6ACB	164.- GRAHAM	9S 21W 21CCC *	254.- KINGMAN	29S 8W 11CAC *	344.- MORTON	32S 41W 12AAC *
75.- DECATUR	2S 30W 30CDD	165.- GRAHAM	9S 21W 36DDD *	255.- KINGMAN	29S 8W 19CDB *	345.- MORTON	32S 42W 20BBB
76.- DECATUR	3S 26W 10BAA	166.- GRAHAM	9S 22W 14CCC *	256.- KINGMAN	29S 9W 9DDB	346.- MORTON	32S 43W 3CAC
77.- DECATUR	3S 26W 34CAA *	167.- GRAHAM	9S 24W 8CCC	257.- KINGMAN	29S 9W 33DCC *	347.- MORTON	32S 43W 34BBD
78.- DECATUR	3S 27W 8AAB	168.- GRAHAM	10S 22W 2BAB *	258.- KINGMAN	29S 10W 23DDB	348.- MORTON	33S 39W 20DCB
79.- DECATUR	3S 27W 32ABC	169.- GRAHAM	10S 23W 4BBD *	259.- KINGMAN	29S 10W 31DDD	349.- MORTON	33S 40W 10DDB
80.- DECATUR	3S 28W 22AAC	170.- GRAHAM	10S 23W 13ADA *	260.- KINGMAN	30S 8W 27DCC *	350.- MORTON	33S 41W 24DCC
81.- DECATUR	3S 30W 19ABA	171.- GRAHAM	10S 24W 14ACC *	261.- KINGMAN	30S 9W 28ACC	351.- MORTON	33S 42W 7ADA
82.- DECATUR	3S 30W 35BDB	172.- GRAHAM	10S 25W 15BBB *	262.- KINGMAN	30S 10W 14ABC	352.- MORTON	33S 42W 22CAB
83.- DECATUR	4S 27W 36DDA	173.- GRANT	27S 35W 29DCC	263.- KINGMAN	30S 10W 30AAA	353.- MORTON	34S 39W 8CCD
84.- DECATUR	4S 29W 9BCC *	174.- GRANT	28S 35W 12ABB	264.- KIOWA	27S 20W 5CBA *	354.- MORTON	34S 41W 13AAD
85.- DECATUR	4S 30W 23ACD *	175.- GRANT	29S 35W 24CAA	265.- KIOWA	28S 16W 34ABB	355.- MORTON	34S 41W 21CDD
86.- DECATUR	5S 27W 25ABD	176.- GRAY	24S 27W 27BBA	266.- KIOWA	28S 18W 23BBB	356.- MORTON	34S 42W 19DDD *
87.- DECATUR	5S 29W 4BBB	177.- GRAY	25S 27W 15BCD	267.- KIOWA	29S 16W 22AAA *	357.- MORTON	35S 39W 5BDD
88.- DECATUR	5S 30W 14BBA	178.- GRAY	25S 28W 17ABB	268.- KIOWA	29S 17W 12ACB *	358.- MORTON	35S 40W 15ACA
89.- EDWARDS	23S 19W 21ADD *	179.- GRAY	25S 28W 25ABC	269.- KIOWA	29S 17W 20ADD *	359.- MORTON	35S 41W 1AAA
90.- EDWARDS	23S 20W 12CAD *	180.- GRAY	25S 29W 27DBB	270.- KIOWA	29S 18W 35BAC *	360.- MORTON	35S 41W 16BBA

COUNTY	WELL LOCATION	COUNTY	WELL LOCATION	COUNTY	WELL LOCATION	COUNTY	WELL LOCATION
361.-	MORTON 35S 42W 2ABD *	451.-	PRATT 29S 12W 36BDD	541.-	SEWARD 31S 31W 24ACC	631.-	TREGO 11S 21W 30BDD *
362.-	MORTON 35S 43W 3BAA *	452.-	PRATT 29S 13W 11BCD	542.-	SEWARD 31S 32W 14CDD	632.-	TREGO 12S 21W 2BDB *
363.-	NESS 16S 21W 9CCA *	453.-	PRATT 29S 13W 19BDB	543.-	SEWARD 31S 34W 17CCA	633.-	TREGO 12S 21W 18DBC *
364.-	NESS 16S 22W 2ABW *	454.-	PRATT 29S 13W 34DDA *	544.-	SEWARD 31S 34W 26DD	634.-	TREGO 12S 22W 4ACC *
365.-	NESS 16S 22W 18AAC *	455.-	PRATT 29S 14W 34BCC	545.-	SEWARD 32S 31W 12CCA	635.-	TREGO 12S 22W 28DCC *
366.-	NESS 16S 23W 15DCC *	456.-	PRATT 29S 15W 32DBA *	546.-	SEWARD 32S 32W 11ACC	636.-	TREGO 12S 23W 7AAA *
367.-	NESS 16S 24W 5DD * *	457.-	RAWLINS 1S 31W 4ADA	547.-	SEWARD 32S 32W 35CAC	637.-	TREGO 12S 23W 23ACD *
368.-	NESS 16S 24W 12CDD *	458.-	RAWLINS 1S 31W 27BB * *	548.-	SEWARD 33S 31W 8DD	638.-	TREGO 12S 24W 22BAR *
369.-	NESS 16S 24W 29AAB *	459.-	RAWLINS 1S 32W 5BCC *	549.-	SEWARD 33S 31W 25ABC	639.-	TREGO 12S 25W 1DCC *
370.-	NESS 16S 24W 36DCC *	460.-	RAWLINS 1S 32W 13BB * *	550.-	SEWARD 33S 32W 7CCA	640.-	TREGO 12S 25W 20ABB *
371.-	NESS 16S 25W 6CC *	461.-	RAWLINS 1S 32W 29BC * *	551.-	SEWARD 33S 34W 12CBB	641.-	TREGO 12S 25W 36AAA *
372.-	NESS 16S 25W 14BCC *	462.-	RAWLINS 1S 33W 15BB * *	552.-	SEWARD 34S 31W 5ADC	642.-	TREGO 13S 21W 31ACC *
373.-	NESS 16S 25W 30BCC *	463.-	RAWLINS 1S 34W 1BD * *	553.-	SEWARD 34S 31W 13DBB	643.-	TREGO 13S 23W 19DCC *
374.-	NESS 16S 26W 9DCC *	464.-	RAWLINS 1S 34W 17BAB *	554.-	SEWARD 34S 32W 15AAD	644.-	TREGO 13S 24W 10BDD *
375.-	NESS 17S 26W 4BAA *	465.-	RAWLINS 1S 34W 25BAB *	555.-	SEWARD 35S 31W 1CCD	645.-	TREGO 13S 25W 8BAA *
376.-	NESS 18S 26W 15BB * *	466.-	RAWLINS 1S 35W 3ADA *	556.-	SEWARD 35S 33W 13ADD	646.-	TREGO 15S 25W 25CCA *
377.-	NORTON 1S 21W 27ADC *	467.-	RAWLINS 1S 35W 18BC * *	557.-	SHERIDAN 6S 26W 13ADD	647.-	WALLACE 11S 39W 4AAD *
378.-	NORTON 1S 22W 4BDB	468.-	RAWLINS 1S 35W 27ADA *	558.-	SHERIDAN 7S 26W 36ABC	648.-	WALLACE 11S 40W 5BBB *
379.-	NORTON 1S 22W 13AAA	469.-	RAWLINS 2S 32W 1BDD *	559.-	SHERIDAN 7S 28W 13ADD	649.-	WALLACE 11S 40W 12CCC *
380.-	NORTON 1S 22W 28ADC	470.-	RAWLINS 2S 33W 3BC * *	560.-	SHERIDAN 7S 30W 15CCC	650.-	WALLACE 11S 40W 29CBB *
381.-	NORTON 1S 23W 6ACA	471.-	RAWLINS 2S 34W 13ACD *	561.-	SHERIDAN 8S 26W 32DBC	651.-	WALLACE 11S 41W 10CDD *
382.-	NORTON 1S 23W 14ACA	472.-	RAWLINS 2S 35W 5ADB *	562.-	SHERIDAN 9S 26W 12BDC	652.-	WALLACE 11S 42W 24DCC *
383.-	NORTON 1S 23W 30ADD	473.-	RAWLINS 2S 35W 6BDB *	563.-	SHERIDAN 9S 26W 20ACD	653.-	WALLACE 12S 42W 29ADD *
384.-	NORTON 1S 24W 15BCC	474.-	RAWLINS 2S 35W 14BCB	564.-	SHERIDAN 9S 29W 31DDB	654.-	WICHITA 18S 38W 33ADD *
385.-	NORTON 1S 25W 25ACD	475.-	RAWLINS 3S 31W 3CCC	565.-	SHERIDAN 10S 26W 1BAB *	655.-	WICHITA 19S 35W 34DDB *
386.-	NORTON 2S 21W 15DDD *	476.-	RAWLINS 3S 31W 33ABC *	566.-	SHERIDAN 10S 26W 17ACD *	656.-	WICHITA 19S 36W 33CCA *
387.-	NORTON 2S 22W 1ADD *	477.-	RAWLINS 3S 32W 5DCC *	567.-	SHERIDAN 10S 27W 3AAA	657.-	WICHITA 19S 37W 31DDB *
388.-	NORTON 2S 22W 16CDD *	478.-	RAWLINS 3S 32W 13CCC *	568.-	SHERIDAN 10S 27W 7CCC	658.-	WICHITA 20S 35W 22DDC *
389.-	NORTON 2S 22W 25DDD *	479.-	RAWLINS 3S 32W 32BDB *	569.-	SHERIDAN 10S 28W 4BBA	659.-	WICHITA 20S 37W 11DCB *
390.-	NORTON 2S 23W 2ADA	480.-	RAWLINS 4S 32W 11AAA *	570.-	SHERIDAN 10S 29W 14ACA	660.-	WICHITA 20S 38W 16AAA
391.-	NORTON 2S 23W 18DDC	481.-	RAWLINS 4S 32W 19ADA	571.-	SHERMAN 7S 38W 32DAA		
392.-	NORTON 2S 23W 35AAB *	482.-	RAWLINS 4S 32W 35ADD *	572.-	SHERMAN 8S 39W 11BDD		
393.-	NORTON 2S 24W 3CCB	483.-	RAWLINS 4S 33W 10ABB	573.-	SHERMAN 9S 37W 10ACC		
394.-	NORTON 2S 24W 27CCC	484.-	RAWLINS 4S 36W 21CDB	574.-	SHERMAN 9S 38W 8DBA		
395.-	NORTON 2S 25W 5BCC	485.-	RAWLINS 5S 32W 17ABA	575.-	SHERMAN 9S 38W 24CAA *		
396.-	NORTON 2S 25W 13CCD	486.-	RAWLINS 5S 32W 32CCA	576.-	SHERMAN 9S 38W 32DCB *		
397.-	NORTON 2S 25W 29CCC	487.-	RAWLINS 5S 35W 30BBB	577.-	SHERMAN 9S 39W 22ADD		
398.-	NORTON 3S 21W 10ABA	488.-	RAWLINS 5S 35W 34DDD	578.-	SHERMAN 10S 37W 3BBB *		
399.-	NORTON 3S 21W 19BCB	489.-	RENO 22S 5W 9CCA	579.-	SHERMAN 10S 38W 13BAD		
400.-	NORTON 3S 22W 9CBC	490.-	RENO 22S 5W 33CCA	580.-	SHERMAN 10S 38W 29ABA *		
401.-	NORTON 3S 22W 33BCB	491.-	RENO 22S 6W 7ACA	581.-	SHERMAN 10S 39W 15AAA *		
402.-	NORTON 3S 23W 7ABC *	492.-	RENO 23S 4W 22DCD	582.-	SHERMAN 10S 39W 19CCC *		
403.-	NORTON 3S 23W 23ACB *	493.-	RENO 23S 5W 21CCA	583.-	SMITH 1S 15W 1ADB *		
404.-	NORTON 3S 23W 31ADD *	494.-	RENO 23S 6W 11DCC	584.-	SMITH 1S 15W 17ACC *		
405.-	NORTON 3S 24W 22BDB *	495.-	RENO 23S 8W 23ACC	585.-	STAFFORD 21S 11W 2ACB		
406.-	NORTON 3S 25W 12BBB	496.-	RENO 24S 6W 26DBA *	586.-	STAFFORD 21S 11W 18DBB		
407.-	NORTON 3S 25W 20BBB	497.-	RENO 24S 8W 11CDD	587.-	STAFFORD 21S 11W 26CAA		
408.-	NORTON 3S 25W 36CDD *	498.-	RENO 25S 4W 27DDD	588.-	STAFFORD 21S 13W 5BDC		
409.-	NORTON 4S 23W 11ABC	499.-	RICE 18S 8W 9CBC	589.-	STAFFORD 22S 11W 15DDD		
410.-	NORTON 4S 23W 19DDD	500.-	RICE 18S 8W 33CCC	590.-	STAFFORD 25S 14W 22CCD		
411.-	NORTON 4S 24W 10CBC	501.-	RICE 18S 9W 7ACD	591.-	STANTON 27S 40W 5ACC		
412.-	NORTON 4S 25W 8CBB *	502.-	RICE 18S 9W 23CBA *	592.-	STANTON 27S 40W 13CAB		
413.-	NORTON 4S 25W 24CAA	503.-	RICE 18S 9W 31CCB	593.-	STANTON 27S 41W 15DDB		
414.-	NORTON 5S 21W 33DDA	504.-	RICE 19S 6W 35BBA	594.-	STANTON 27S 42W 16CBA		
415.-	NORTON 5S 25W 5ABB	505.-	RICE 19S 8W 13ABA *	595.-	STANTON 28S 40W 17DDD		
416.-	NORTON 5S 25W 13ABC	506.-	RICE 19S 8W 29ADA *	596.-	STANTON 28S 41W 34AAD		
417.-	PAWNEE 21S 15W 17DAA	507.-	RICE 19S 9W 14BBB *	597.-	STANTON 29S 40W 24ACD		
418.-	PAWNEE 21S 16W 2BDB *	508.-	RICE 19S 9W 19CCC	598.-	STANTON 29S 40W 32DCB		
419.-	PAWNEE 21S 16W 18BCC *	509.-	RICE 19S 10W 9DDD	599.-	STANTON 29S 41W 23BCC		
420.-	PAWNEE 21S 18W 14AAC *	510.-	RICE 20S 6W 14DCC	600.-	STEVENS 31S 38W 16DDD		
421.-	PAWNEE 22S 18W 2DCB	511.-	RICE 20S 7W 15ACD *	601.-	STEVENS 32S 36W 21BDB		
422.-	PAWNEE 22S 18W 18DDA *	512.-	RICE 20S 8W 1ACC *	602.-	STEVENS 32S 37W 35CAA		
423.-	PAWNEE 22S 18W 35AAC *	513.-	RICE 20S 9W 2BCC	603.-	STEVENS 32S 39W 24BBB		
424.-	PAWNEE 22S 19W 34BBA *	514.-	RICE 20S 9W 18CBB	604.-	STEVENS 34S 36W 28BBB		
425.-	PAWNEE 23S 15W 12CAD	515.-	RICE 20S 9W 27DDD	605.-	STEVENS 34S 37W 19DCC		
426.-	PAWNEE 23S 18W 7ACC *	516.-	RICE 20S 10W 4AAC	606.-	STEVENS 35S 35W 15DDA		
427.-	PHILLIPS 1S 16W 3ADD *	517.-	RICE 20S 10W 28DDB	607.-	STEVENS 35S 36W 1ACC		
428.-	PHILLIPS 1S 16W 18BDD *	518.-	RICE 21S 6W 11ABB *	608.-	STEVENS 35S 36W 16CDB		
429.-	PHILLIPS 1S 17W 4ACB *	519.-	RICE 21S 6W 19AAA	609.-	STEVENS 35S 37W 2BDD		
430.-	PHILLIPS 1S 17W 28DCC *	520.-	RICE 21S 6W 35ABD	610.-	STEVENS 35S 37W 18ACA		
431.-	PHILLIPS 1S 18W 6AAD *	521.-	RICE 21S 8W 29BCC	611.-	STEVENS 35S 38W 4ABD		
432.-	PHILLIPS 1S 18W 14AAD *	522.-	RICE 21S 9W 15DDC	612.-	SUMNER 30S 4W 20BDD *		
433.-	PHILLIPS 1S 18W 29CDB	523.-	ROOKS 9S 17W 30ACC *	613.-	THOMAS 7S 31W 1CCA		
434.-	PHILLIPS 1S 19W 15BCC *	524.-	ROOKS 9S 18W 33DD * *	614.-	THOMAS 7S 32W 27DCC		
435.-	PHILLIPS 1S 20W 1BDB *	525.-	ROOKS 9S 19W 25CCA *	615.-	THOMAS 8S 13W 36AAC		
436.-	PHILLIPS 1S 20W 17ACB *	526.-	ROOKS 9S 20W 27ABA *	616.-	THOMAS 8S 35W 9ABB		
437.-	PHILLIPS 1S 20W 25ACC *	527.-	ROOKS 10S 19W 5BBA *	617.-	THOMAS 8S 35W 33ADC		
438.-	PHILLIPS 2S 17W 1DD * *	528.-	ROOKS 10S 19W 12ABC *	618.-	THOMAS 8S 36W 24BBB		
439.-	PHILLIPS 2S 17W 16DCC *	529.-	ROOKS 10S 19W 20CCA *	619.-	THOMAS 8S 36W 32BCC		
440.-	PHILLIPS 2S 18W 2BDA *	530.-	ROOKS 10S 20W 11CCA *	620.-	THOMAS 9S 31W 36CCD		
441.-	PHILLIPS 2S 18W 18DD * *	531.-	RUSH 18S 16W 11DBB	621.-	THOMAS 9S 34W 7CDB		
442.-	PHILLIPS 2S 19W 3CCC *	532.-	RUSH 18S 16W 17BBD	622.-	THOMAS 9S 34W 31CDC		
443.-	PHILLIPS 2S 19W 27CCC *	533.-	RUSH 18S 17W 4ACD	623.-	THOMAS 9S 36W 12CCC *		
444.-	PHILLIPS 2S 20W 5DCC *	534.-	RUSH 19S 16W 23DDA *	624.-	THOMAS 9S 36W 20DCC *		
445.-	PHILLIPS 2S 20W 13CDD *	535.-	RUSH 19S 16W 32CCA *	625.-	THOMAS 10S 31W 17ABD		
446.-	PHILLIPS 2S 20W 32ABB *	536.-	SCOTT 17S 31W 4RDD	626.-	THOMAS 10S 34W 13ABA		
447.-	PHILLIPS 3S 18W 8BBC *	537.-	SCOTT 17S 32W 14BDD	627.-	THOMAS 10S 34W 30ABA *		
448.-	PRATT 27S 13W 26CCC	538.-	SCOTT 20S 31W 21CCC *	628.-	THOMAS 10S 35W 16ACA		
449.-	PRATT 27S 15W 13CCC	539.-	SEDGWICK 29S 4W 24AAA *	629.-	THOMAS 10S 36W 18BB		
450.-	PRATT 28S 13W 31BAA	540.-	SEDGWICK 29S 4W 17ABB *	630.-	THOMAS 10S 36W 17BBB		

**Kansas Geological Survey
The University of Kansas
Lawrence, Kansas 66044
USA**



HIGH PLAINS AQUIFER, KANSAS

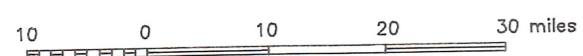
WATER TABLE ELEVATION AS PERCEIVED
BY THE NETWORK OF 1749 WELLS

1982

Ricardo A. Olea

KANSAS GEOLOGICAL SURVEY

Scale 1:1,000,000
1 inch equals approximately 15.78 miles



This map was produced using the facilities of the Automated Cartography Laboratory of the Kansas Geological Survey. Data correction, contouring and projection were performed by computer. Digitizing, editing and production of the reference geographical map were performed using the GIMMAP software developed jointly by the Kansas Geological Survey and the Bureau de Recherches Géologiques et Minières, Orleans, France.

The basic water level information was gathered by the Division of Water Resources, Kansas State Board of Agriculture, United States Geological Survey, City of Wichita and Kansas Groundwater Management District No. 2 during the period December 1980 to March 1981.

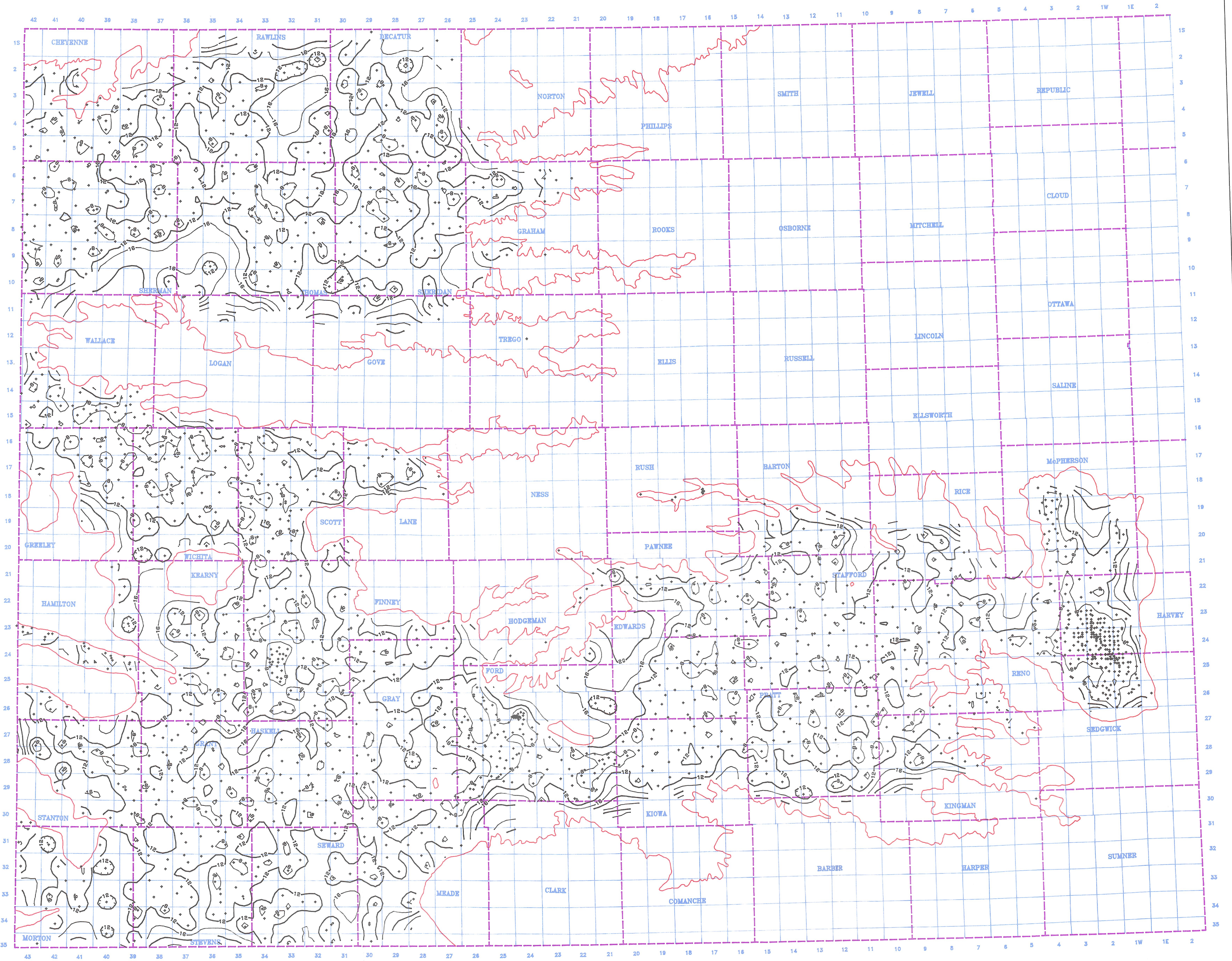
Lambert conformal conic projection with standard parallels of 33N and 45N.

Plate 1

Contour interval 20 feet.

+ Observation well location

— Aquifer boundary



HIGH PLAINS AQUIFER, KANSAS

STANDARD ERROR FOR THE WATER
TABLE ELEVATION AS PERCEIVED
BY THE NETWORK OF 1749 WELLS

1982

Ricardo A. Olea
KANSAS GEOLOGICAL SURVEY

Scale 1:1,000,000
1 inch equals approximately 15.78 miles

10 0 10 20 30 miles

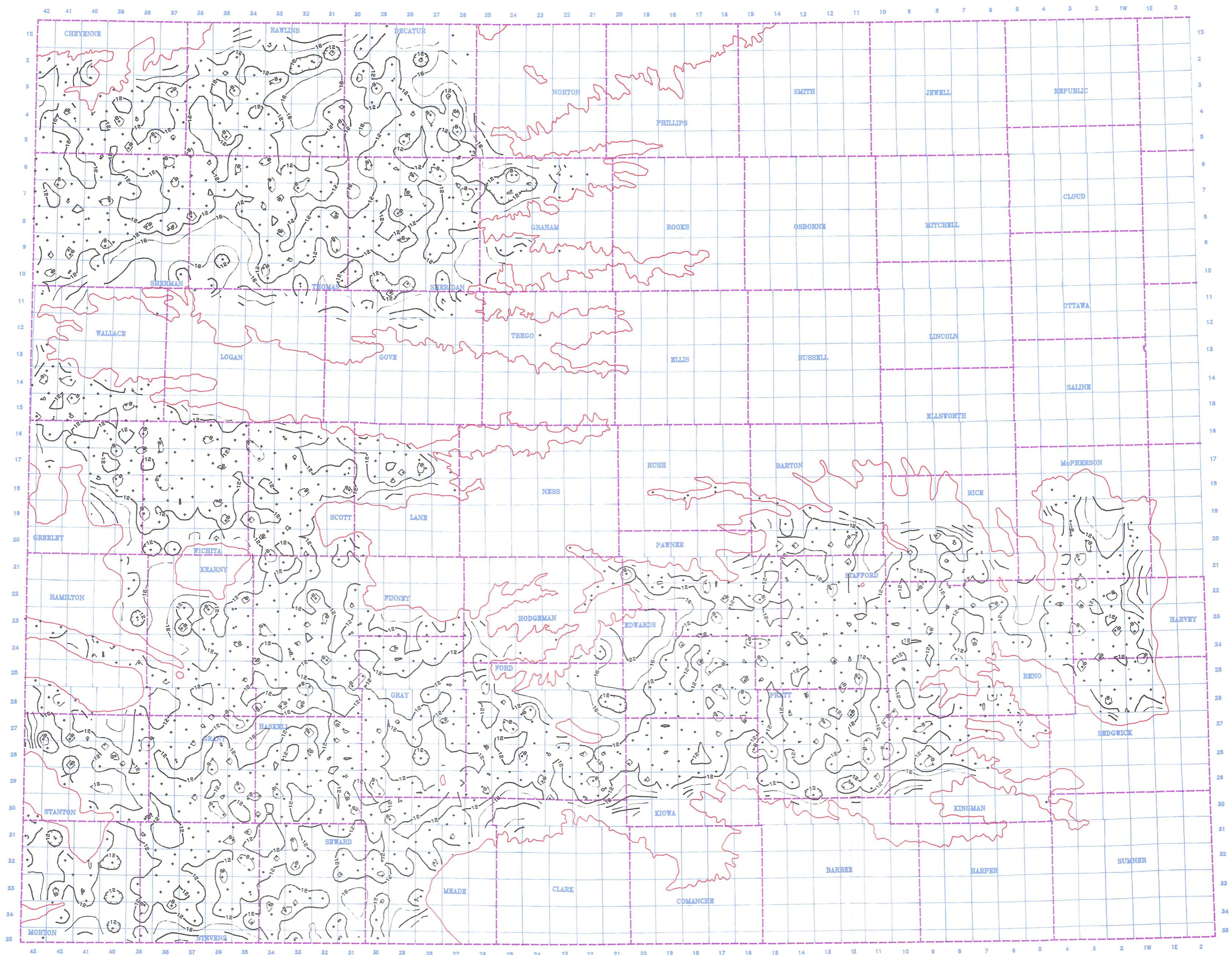
This map was produced using the facilities of the Automated Cartography Laboratory of the Kansas Geological Survey. Data correction, contouring and projection were performed by computer. Digitizing, editing and production of the reference geographical map were performed using the GIMMAP software developed jointly by the Kansas Geological Survey and the Bureau de Recherches Geologiques et Minieres, Orleans, France.

The basic water level information was gathered by the Division of Water Resources, Kansas State Board of Agriculture; United States Geological Survey; City of Wichita and Kansas Groundwater Management District No. 2 during the period December 1980 to March 1981.

Lambert conformal conic projection with standard parallels of 33N and 45N.

Plate 2

Contour interval 4 feet.
+ Observation well location
— Aquifer boundary



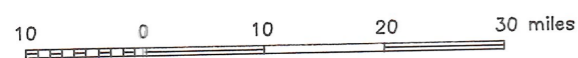
HIGH PLAINS AQUIFER, KANSAS

STANDARD ERROR FOR THE WATER
TABLE ELEVATION AS PERCEIVED
BY THE NETWORK OF 1135 WELLS

1982

Ricardo A. Olea
KANSAS GEOLOGICAL SURVEY

Scale 1:1,000,000
1 inch equals approximately 15.78 miles



This map was produced using the facilities of the Automated Cartography Laboratory of the Kansas Geological Survey. Data correction, contouring and projection were performed by computer. Digitizing, editing and production of the reference geographical map were performed using the GIMMAP software developed jointly by the Kansas Geological Survey and the Bureau de Recherches Géologiques et Minières, Orleans, France.

The basic water level information was gathered by the Division of Water Resources, Kansas State Board of Agriculture; United States Geological Survey; City of Wichita and Kansas Groundwater Management District No. 2 during the period December 1980 to March 1981.

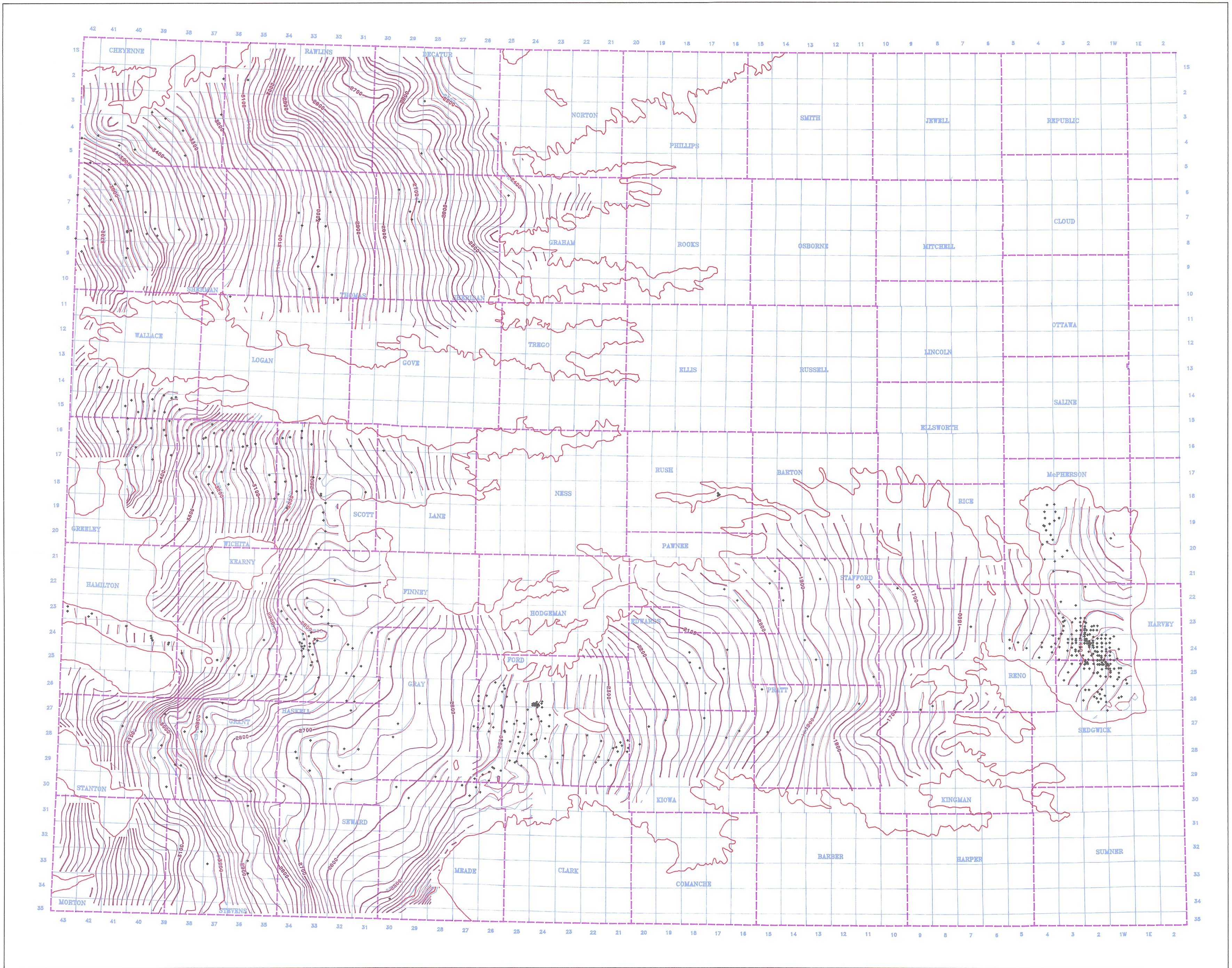
Lambert conformal conic projection with standard parallels of 33N and 45N.

Plate 4

Contour interval 4 feet.

+ Observation well location

— Aquifer boundary



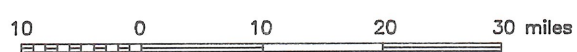
HIGH PLAINS AQUIFER, KANSAS

WATER TABLE COMPARISON. RED CONTOURS ARE
 BASED ON THE 1749 WELL NETWORK AND BLUE
 CONTOURS ON THE 1135 WELL NETWORK.

1982

Ricardo A. Olea
 KANSAS GEOLOGICAL SURVEY

Scale 1:1,000,000
 1 inch equals approximately 15.78 miles



This map was produced using the facilities of the Automated Cartography Laboratory of the Kansas Geological Survey. Data correction, contouring and projection were performed by computer. Digitizing, editing and production of the reference geographical map were performed using the GIMMAP software developed jointly by the Kansas Geological Survey and the Bureau de Recherches Géologiques et Minières, Orleans, France.

The basic water level information was gathered by the Division of Water Resources, Kansas State Board of Agriculture; United States Geological Survey; City of Wichita and Kansas Groundwater Management District No. 2 during the period December 1980 to March 1981.

Lambert conformal conic projection with standard parallels of 35N and 45N.

Plate 5

Contour interval 20 feet.

• Discarded observation wells

— Aquifer boundary