Kansas Geological Survey

Open File Report 2002-25G

Information Sheets and Supplementary Documents

By

M. A. Townsend, D. O. Whittemore, D. P. Young, G. Hecox, P. A. Macfarlane,
M. A. Sophocleous, and R. W. Buddemeier

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Kansas Geological Survey Open File Report 2002-25G

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The University of Kansas, Lawrence, KS 66047: (785) 864-3965; www.kgs.ukans.edu

KGS OFR 2002-25G. Information Sheets and Supplementary Documents

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1 Introduction

This report contains supporting and supplementary information documentes relating to the design, conduct, and output of the projects reported on in the overall OFR 2002-25 series.

The technical content (section 2) consists of the seven information sheets developed by the KGS for the Ogallala aquifer management and technical committes. These sheets were developed in response to specific questions or requests from the committees or committee staff, and are intended to provide brief summaries understandable by a lay audience. These information sheets are included since they document work performed under the contract, and contain pertinent information related to the Ogallala-High Plains aquifer. They also present possible issues and parameters for further consideration in subunit delineation and the development of potential management options. They are presented as originally distributed, and have not been edited to conform to subsequent findings.

Information sheet 2.1 relates primarily to report part 25B; 2.2 relates to 25B and 25C; 2.3 relates to 25D and 25F; 2.4 relates to 25C; 2.5 relates to 25F and 25D. Information sheets 2.6 and 2.7 are responses to questions about issues not directly addressed by the contract reports.

Section 3 contains excerpts from the Ogallala committee report, providing information on the motivation for identification and prioritization of aquifer subunits as an approach to managing the watrer resources in areas of present or potential depletion.

Section 4 presents copies of the two contracts under which the reports were generated and some of the work discussed was supported.

2 Technical information sheets developed in response to committee requests

2.1 Recharge- Recharge amounts (accuracy, precision, uncertainty)

1. Focused question: What is the amount of annual recharge to a selected region?

2. General applications question: What is the reliability and utility of recharge estimates for water resource planning and management?

Summary responses:

1. Recharge values are necessarily estimates, based on some combination of model-based calculations with observations of other variables (such as groundwater elevation, stream baseflow, precipitation, soil moisture, etc.). As such, they represent estimates of the relatively long-term average amount of water that penetrated below the rooting zone.

In Kansas, the most widely accepted regional recharge estimate is that prepared by the USGS. This has been used, for example, by KGS in preparing the relevant sections of the High Plains Atlas. Based on the USGS maps, the western third of Kansas can be estimated to have a total (including aquifer and non-aquifer) area of about 30,000 sq. mi., and an average annual recharge of about one inch -- with lower values in the west and higher in the east. This would correspond very approximately to 1.6 million AF/year. However, the 'recharge' that appears to occur where there is no aquifer and little or no groundwater use is of no real resource significance. That can be somewhat refined by looking, for example, at the recharge estimates for the total areas of the GMDs, or for those parts of the GMDs that have relatively low saturated thickness and therefore might be priority management areas. Considering only the GMD areas brings the recharge estimate down by factor of 3; considering only the areas depleted or at risk reduces the total by a factor of about 10.

Western GMDs, Recharge estimates from High Plains Atlas (MAF/yr) based on USGS				
	GMD4	GMD1	GMD3	Total
Total Recharge	0.16	0.05	0.33	0.54
Where ST<50’	0.04	0.03	0.06	0.13

However, even these refined figures may be of little significance in management by aquifer subunits defined on the basis of hydrology and water use. This is because the rates of groundwater flow and exchange are slow, and recharge on one side of a GMD -- or a county, or even perhaps a township -- will not have a noticeable effect on the other side for decades or longer. Estimating specific recharge values at the subunit level are subject to the problems discussed below.

2. Recharge is an important process, and an important concept in water resource management. Its estimates provide important constraints on, and general inventories of, water availability. However, it is one of the most variable, uncertain, and difficult hydrologic

parameters to measure or calculate accurately. Recharge values generally do not make good practical management tools, for the following reasons:

a. Time lags and variations -- in relatively arid regions with thick unsaturated zones, recharge may occur in only a few years per decade, and the water may be delayed up to decades in its progress from the surface to the water table. By contrast, alluvial valleys in the same region will be much more responsive.

b. Recharge is sensitive to land use, treatment and cover -- and therefore subject to change as farming practices, urbanization, etc., change.

c. Even without human intervention, recharge quite variable over space, even at the field scale.

d. Recharge is dependent not only on climate parameters such as precipitation and average water balance, but on the details such as the timing, frequency and intensity of rainfall -- which studies have shown have changed significantly over past decades.

e. Because of the above relationships and uncertainties, estimated recharge values not only change as a result of actual recharge change, but also are subject to alteration as measurements and models evolve.

Comments and general information:

An appreciation of the magnitude of ground-water recharge and of the factors controlling it is critically important to general water resource planning and management. Not only do the approximate values provide some boundaries for the possible ranges of sustainable use, but knowledge of the mechanisms and controls can lead to land use and other management techniques that can enhance or protect natural recharge, or identify areas or aquifer subunits most likely to have significant replenishment rates.

Because of variability and uncertainty in the absolute magnitudes of recharge, however, it is generally more practical to manage groundwater on the basis of direct measurements of use and supply (for example, pumping, stream discharge, and water level or saturated thickness) within a framework based on the approximate values for recharge.

2.2 GMD #1 Water Balance

The approach to the water balance was to quantify the volume of groundwater withdrawn from the GMD1 groundwater system over the period from 1990-1999 and compare that to the volume of water that may be accounted for by various forms of recharge and storage depletion. The time period was selected because these are the 10 years for which the groundwater use data were compiled for the document "An Atlas of the Kansas High Plains Aquifer" (the Atlas; Schloss, et al, 2000). Once the various variables were identified and quantified the water balance is simply a comparison of the water removed and the water inflow plus storage depletion. The basic equation used is:

The variables required for use in the water balance were compiled from various public datasets and databases and are summarized in Table 1.

After all of the variables required to conduct the water balance were compiled, a statistical evaluation was conducted to check for outliers and anomalous values. For purposes of the water balance, it was decided to perform the water balance calculations using the arithmetic average, minimum and maximum values for each of the Table 1 Inflow variables (Table 2).

Table 1. Water balance variables and data sources.

	Variable	Water Balance Use	Data Source
Outflow	Reported Groundwater Use	Groundwater Outflow	**wuse_90_99_raw2.dbf. Compiled by Brownie Wilson from DWR water use reports.**
Inflow	Irrigation Return Flow	Irrigation returns	**Calculated as percentage of irrigation water use: 15% of flood irrigation and 5% of sprinkler irrigation.**
	Area of GMD 1 evaluated	Storage depletion Recharge inflow	**Secpols coverage file, variable is *Acres.* This is an ArcInfo file available through KGS.**
	Specific yield	Storage depletion	**Secpols coverage file, variable is *Spec_yld.***
	Water level decline rate	Storage depletion	**Secpols coverage file, variable is *Acres.***
	Natural recharge rate	Recharge	**Secpols coverage file, variable is *Usgs_recharge.***
	Hydraulic conductivity	Groundwater inflow	**Secpols coverage file, variable is *Acres.***
	Hydraulic gradients	Groundwater inflow	**Secpols coverage file, variable is *Acres.***
	Saturated thickness	Groundwater inflow	**Secpols coverage file, variable is *Acres.***
	Cross-sectional width	Groundwater inflow	**Measurement across *Hp_saturated* polygon.**
	Steam flow	Surface water infiltration	**USGS database at** http://ks.water.usgs.gov/ for Smokey Hill and Ladder Creek

Table 2. Groundwater variables and values used in water balance calculations

Variable	Units	Min	Max	Mean	Relative Uncertainty
Specific Yield	fraction	0.10	0.25	0.17	Low
Annual rate of water level change	feet/year	-2.17	1.85	-0.42	Low
USGS Recharge	in/year	0.50	0.70	0.53	Moderate
Area of GMD 1	acres	–	–	1,026,000	Negligible
Hydraulic gradient	foot/foot	–	–	0.002	Low
Hydraulic conductivity	feet/day	–	–	100	Moderate
Saturated Thickness	feet	–	–	80	Moderate
Cross-sectional width of flow path	feet	–	–	64,000	Low
Inflow from Recharge	Acre-feet	428,000	599,000	453,000	Moderate
Inflow from Storage Depletion	Acre-feet	431,000	1,077,000	733,000	Low
Groundwater Inflow from west (total in 10 years)	Acre-feet	90,000	90,000	90,000	Moderate

The Outflow variable, Reported Groundwater Use, is presented on Figure 1, along with irrigated acres and calculated irrigation return flow volumes. For the Outflow variable, it was decided that the Reported Use volume would be treated as a maximum Outflow value and an arbitrary 75% of the Reported Use would be used as a minimum possible Outflow volume for illustration purposes.

The results of the water balance are presented on Table 2 and Figure 2. It is concluded that the available data for the GMD 1 area, with all of the inherent variability and uncertainty discussed in such data, could be used to develop a reasonable understanding of the groundwater flow conditions in this area. A reasonable dataset is available to begin development of quantitative groundwater resource management tools for the GMD 1 area.

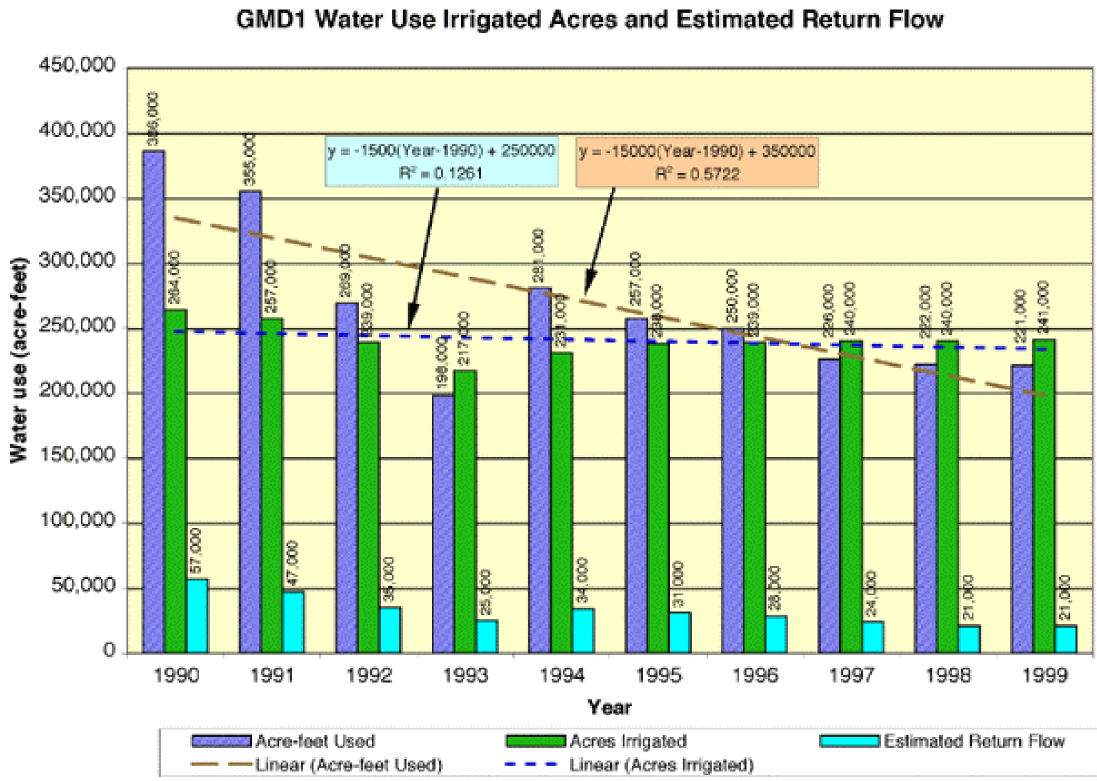


Figure 1. Groundwater use, irrigated acres, and irrigation return flow volumes.

Table 3. Water balance results

	Production Volume		***Inflow Volumes***		
Variable	Reported Use (AF)	Minimum Use (AF)	Average Inflow (AF)	Minimum Inflow (AF)	Maximum Inflow (AF)
Groundwater Use	2,665,000	1,999,000			
Storage Depletion			733,000	431,000	1,077,000
USGS Recharge			453,000	428,000	599,000
Irrigation Return Flow			323,000	162,000	646,000
Ladder Creek streamflow			34,000	10,000	140,000
Groundwater inflow			90,000	90,000	90,000
Total Volumes	2,665,000	1,999,000	1,543,000	1,121,000	2,552,000
Water Balance Inflow Deficit (Acre-feet)			1,122,000	1,545,000	113,000
Water Balance Inflow Deficit (%)			42	58	4

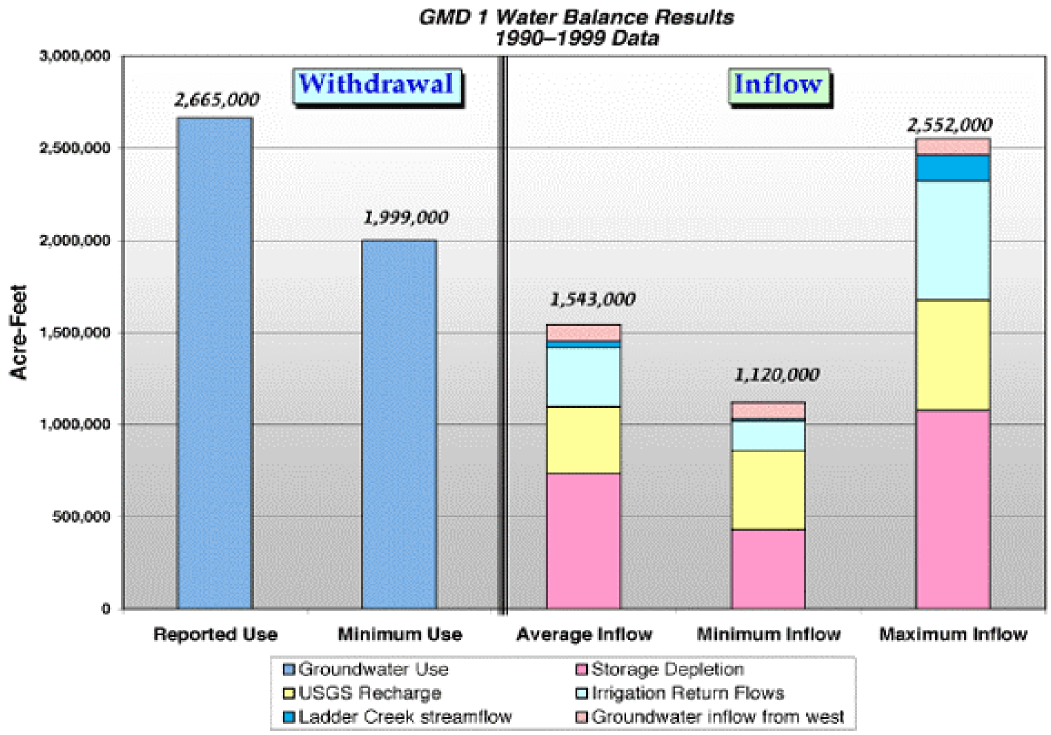


Figure 2. Water balance results for GMD-1.

2.3 Quality (accuracy, precision, uncertainty) of water level measurements

1. Focused question: What is the quality of the annual measurements of depth to water?

2. General applications question: What is the reliability and utility of water level change information derived from these measurements?

Summary responses:

1. The field measurements of the annual water level program have been developed and tested, and are applied, under a rigorous program of quality control that includes standardized procedures, training and cross-checks for technical staff, and statistical analysis of the measurements. The original procedure design, and the results of annual assessments, are published in a series of reports available from the KGS. The specific depth-to-water measurements and their recording are of high quality, and subject to continuing review and monitoring to maintain that quality. In practical terms, this means that the large majority of the measurements are within 0.1' of the "true" values of depth to water at the time and place measured.

2. The utility of these high-quality point measurements of depth-to-water depends on how well they can be used to calculate the net change of elevation in the water table over an extended area. An underlying assumption is that the depth-to-water measurements can be used to represent the absolute elevation of a fully-recovered, equilibrium water table. This is an approximation that has numerous uncertainties:

a. The standardized measurement period in early January is significantly before many of the wells have recovered fully from pumping -- either in the measurement well or in the surrounding region -- during the previous irrigation season. The recovery is not only incomplete, but its extent varies from year to year. At specific sites, this can introduce 'noise' into the record that is on the scale of feet.

b. Related to factor (a) is the point that well selection in the program to date has not taken into consideration distance to other wells that may affect how well the measurement represents a regional equilibrium. This is a particular issue in the case of municipal and industrial wells that may be pumping during the period of measurement.

c. The water table elevation is calculated by combining precise depth-to-water measurements with land elevation values that are, in most cases, estimated from a topographic map and necessarily have uncertainties comparable to the map contour intervals (plus or minus 2-3 feet). This does not affect comparisons of water levels at the same well, but it introduces significant uncertainties in comparing levels at different wells, especially when a measurement well is replaced in the network.

These compound uncertainties have been recognized and reflected in the standard caution in the KGS Technical Series publications on annual water levels, that individual annual and local changes should not be considered reliable but that trends observed over a period of years and areas observed by multiple wells can be used with confidence. Additional comments are presented below.

Comments and general information:

Recent expanded interest in assessing, managing, and conserving the Ogallala aquifer resources place demands on the water level data base which the measurement system was not designed to meet. KGS, with contributing support from KWO, KDA, and individual GMDs, has an ongoing program to review and assess options for improving the interpretations of existing measurements and for identifying potential improvements in the program (see, for example, KGS Open-file Report 2000-29B, viewable at http://www.kgs.ukans.edu/HighPlains/2000-29B/Decdir.htm)

There are a significant number of cost-effective steps that can be taken to not only improve future measurements, but also retrospectively improve our interpretation of existing data. These need not be accomplished for the entire aquifer at once, but can be phased in on the basis of selected case studies or priority areas. Among the more promising possibilities are:

a. GPS elevation surveys of present and past measurement wells would improve the accuracy of comparisons between wells, retrospectively as well as in the future.

b. Detailed comparison of the water use, water level and water budget data that has recently been made possible by electronic database assembly and access improvements has the potential to greatly improve our interpretation of the degree of recovery and general reliability of individual well measurements.

c. Use of water level recording devices, at least on selected sub-regional index wells, will provide a basis for design and interpretation of measurements in the future, as well as insights into past observations.

d. Where recording is not a convenient option, manual measurements can be scheduled and/or performed on the basis of knowledge of local pumping practices and potential interferences in a given aquifer subunit, with individual subunits measured as late in the recovery season as possible to better approximate the equilibrium water table.

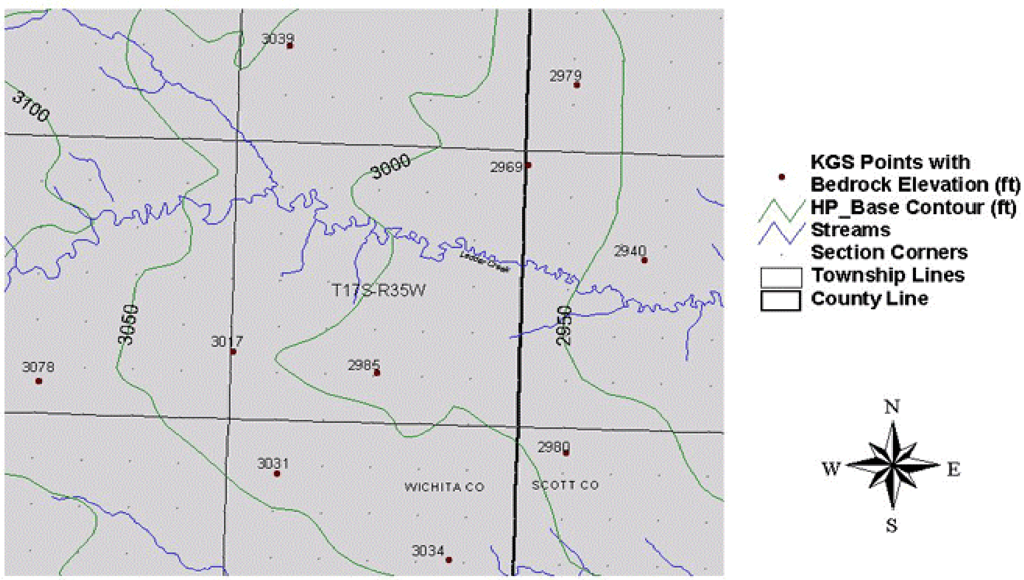
e. Well selection criteria can be modified to consider not only additional hydrologic considerations (e.g., to minimize potential interference), but also specific management needs and priorities in designated aquifer subunits.

2.4 Bedrock – Preliminary Analysis of Bedrock Surface Estimates and Data Sources

A preliminary analysis of available bedrock elevation estimates was undertaken in a randomly-chosen township in GMD1. The selected township is T17S-R35W in Wichita County.

The USGS Base of High Plains (HP_Base) contours were compared with the KGS point data used to create the bedrock surface used in the High Plains Atlas (Fig. 1). Also, a limited amount of readily-available point data was compiled and compared with the USGS contours and KGS point data (Fig. 2). The only additional data sources used in this initial exercise were WWC-5 forms and the county bulletin (Prescott et al., 1954).

Fig 1. USGS HP_Base Contours and KGS Bedrock Point Data in and Around T17S-R35W

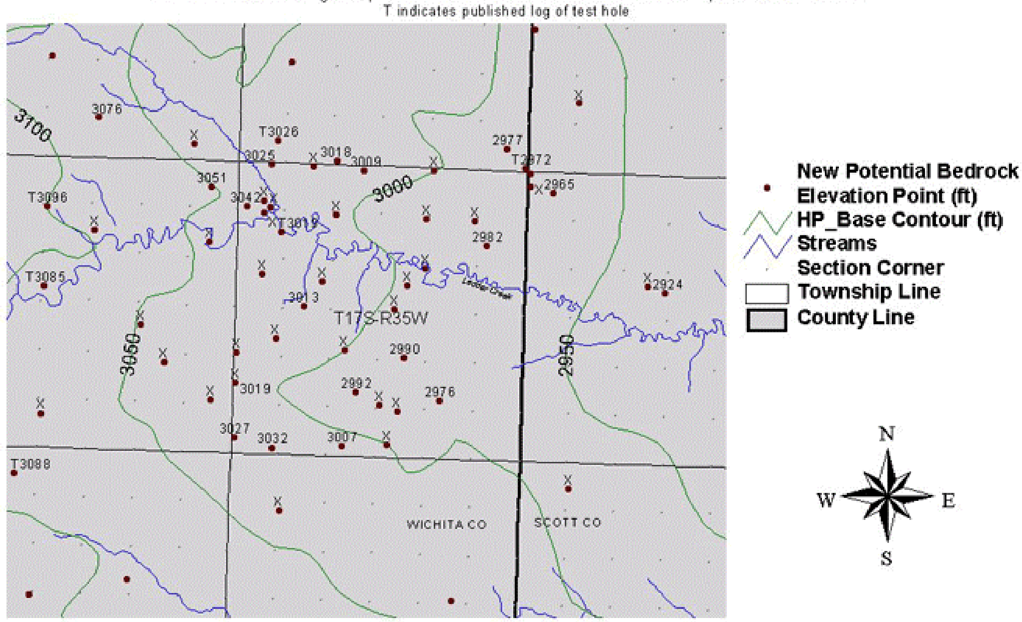


- The USGS Base of High Plains (HP_Base) map provides 50-ft interval contours developed from 1:500,000-scale source information. USGS point data for the HP_Base contour map are not available.

- KGS bedrock elevation point data (used for HP Atlas bedrock surface) were obtained from the KGS WIZARD (Water Information Storage and Retrieval Database). However, not all bedrock data available from WIZARD were used.

Fig 2. Potential Additional Bedrock Elevation Points in and Around T17S-R35W

X indicates location on log was questionable and/or surface elevation could not be picked with confidence
T indicates published log of test hole



- Generally, the both the WIZARD points and the additional point data agreed well with the USGS contours. Point density was improved substantially by using additional data. Potentially, the bedrock surface could be mapped with a contour interval of 25 ft or less, but no significant changes in the present average values would be expected *in this area*.
- Other untapped sources of bedrock data could further refine the bedrock surface and reduce uncertainties. Potential sources include: GMDs and other agencies, local drillers and landowners, Kansas Department of Transportation files, oil and gas logs, and other published and unpublished data.
- Surveyed locations and elevations of selected wells, especially using a high-accuracy Global Positioning System (GPS), would improve the absolute accuracy of bedrock surface, as well as water table estimates.

REFERENCES

Prescott, G.C., Branch, J.R., and Wilson, W.W. (1954). Geology and ground-water resources of Wichita and Greeley counties, Kansas. Kansas Geological Survey Bulletin 108.

2.5 Monitoring Well Network

In 1982 the USGS water level monitoring network was evaluated by the KGS staff to determine the "optimum" sampling design and needed enhancements to minimize the number of wells needing to be measured and to minimize the standard error of the water level measurement (Olea, 1982). The work was done using the 1795 water-level wells in use at that time.

- The error in the water level for the High Plains aquifer uses the average of the water-level values from the whole water-level network.
- There is no separation of areas based on variation in hydrology, geology, or geography.
- A hexagonal monitoring network was found to be the most efficient method of well placement (figure 1).

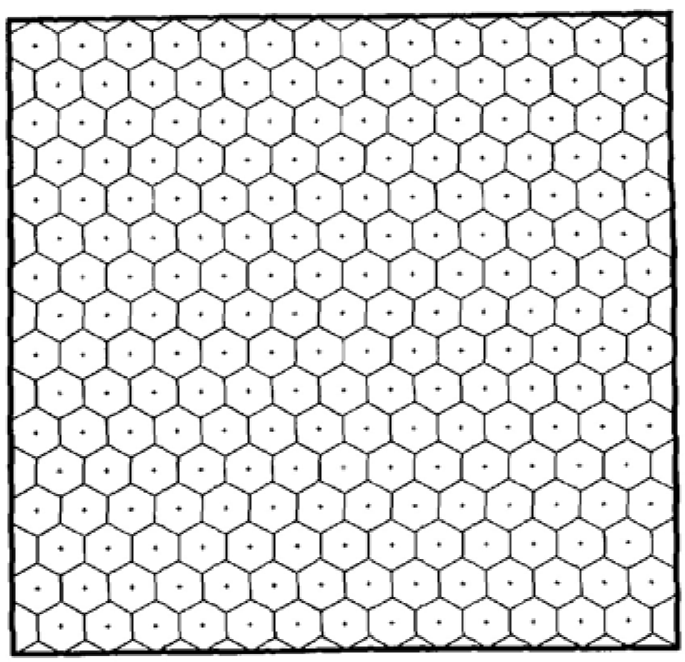


Figure 1. Hexagonal pattern used to place one observation well inside each polygon, which is 16 square miles in area.

- The values in Table 1 indicate that there is not a large difference in average standard error between a straight hexagonal pattern and a stratified hexagonal and stratified square pattern (figure 2).
- The stratified pattern means that one available sampling point is selected to represent the space within the hexagon surrounding a point. If more than one point falls within a given hexagon only one of those points is used.

- The results of the study indicated that due to cost considerations and the desire to use existing wells with long-term records a stratified hexagonal or square pattern would improve the sampling grid that existed (figure 2).
- The standard error in the existing water level measurement program is ± 10 ft.

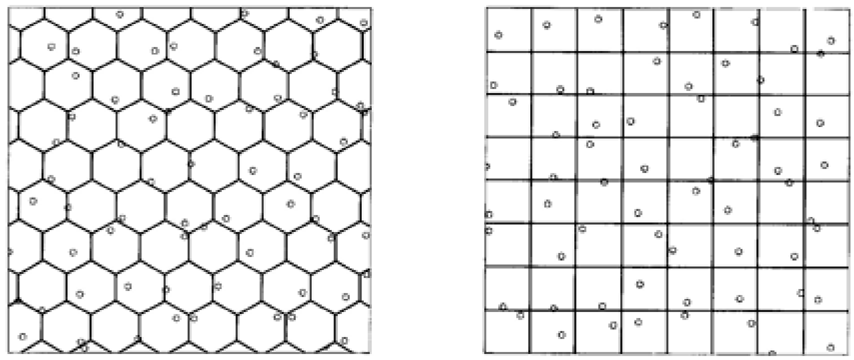


Figure 2. Sampling mechanism for stratified patterns. (a) One point is selected randomly from inside each hexagon. (b) One point is selected randomly from inside each square.

Table 1. Sampling Efficiency Indices for Different Sampling Patterns

Pattern	Average Std. Error	Maximum Std Error
Hexagonal	0.63	0.72
Square	0.64	0.74
Triangular	0.66	0.80
Hexagonal Stratification	0.69	0.86
Square Stratification	0.69	0.86

If the state of Kansas wishes to design and drill a monitoring well network for water level measurements the hexagonal pattern clearly has the lowest standard error and is most efficient (figure 1, table 1). However, if the desire is to decrease the standard error of the actual measurements and increase the level of accuracy in the estimation of the water table, the number of wells that would be needed in such a pattern becomes quite large (figure 3). The cost of drilling such a large number of wells also becomes a factor.

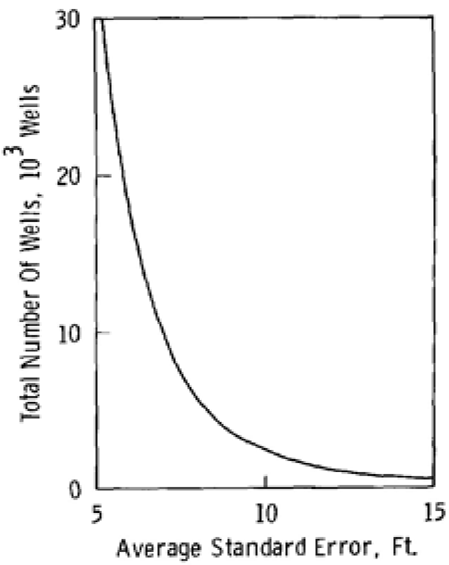


Figure 3. Network size as a function of level of accuracy in the estimation of water-table elevations in the High Plains aquifer in Kansas. Sampling is assumed to follow a hexagonal stratification.

The above discussion assumes that each new measurement point is perfect and that no known information exists between the two points. This is obviously not correct. One idea has been proposed to divide the High Plains area into "like subunits" in order to maximize similarities of hydrology and geology.

- The error in water level measurements would be typical of that area and would not use the "average error" calculated for the whole High Plains aquifer.
- Subunits could be selected by "intuitive" observation, such as northern Kansas with GMD4 and GMD1 areas, southwest Kansas (GMD3), and south-central Kansas (GMDs 2 and 5) or by use of the clustering technique as illustrated by Brownie Wilson's work.
- The error in the water level measurements would increase dramatically in southwest Kansas because of the large variation in areas with declining water levels
- The error would probably decrease in south-central and northern Kansas areas.
- Developing a monitoring network utilizing the subdivisions would probably result in a varying number of wells to be installed within each sub-area. This kind of analysis has not been done at present.
- The advantage of establishing a monitoring net by sub-area is that it would permit more efficient use of information within each sub-area for selecting future areas for drilling.

2.6 Review of USGS Water Quality Report

Below is a review of the U.S. Geological Survey's water quality study of the High Plains aquifer, for consideration by the Ogallala Aquifer Management Advisory Committee. Results of this study have made it into recent news reports, noting that nitrate and other contaminants have been detected in the Ogallala aquifer.

Litke, D. W., 2001, Historical Water-Quality Data for the High Plains Regional Ground-Water Study Area in Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 1930-98. USGS Water-Resources Investigations Report 00-4254,65 p.

The report is an overall compilation of water-quality data from the High Plains states being investigated in the USGS NAWQA (**Na**tional **W**ater **Q**uality **A**ssessment) program. Evaluation of the data was done on a subunit basis or time interval basis rather than by state boundaries. The aquifer subunits pertinent to Kansas include:

- Ogallala North (includes northern Kansas and parts of Nebraska, Wyoming, and Colorado)
- Ogallala Central (includes west-central and southwest Kansas as well as Oklahoma and northern Texas),
- Kansas Quaternary deposits (south-central Kansas), and
- Valley-fill alluvium (includes Platte River, Republican River, and Arkansas River).

The report evaluated nitrate, dissolved solids, pesticides and other constituents as major categories of interest. My review is of the analysis of nitrate, dissolved solids, and atrazine. The USGS analysis of nitrate and dissolved solid concentration changes with time is based on data from all aquifer units lumped together.

<u>Nitrate</u>

The U.S. EPA drinking water standard for nitrate is 10 mg/L. Where levels are above this amount, the water may cause health problems for infants or young animals.

From 1930 to 1998 an increasing trend in nitrate values was observed:

- Valley-fill alluvial deposits -1.5 ppm in 1930 to 5.5 ppm by 1998.
- Kansas Quaternary deposits - 3.5 ppm in 1940s to 4.5 by 1998.
- Central Ogallala - general range of 2 ppm during the 1940s to 1998.
- Northern Ogallala –1.8 in1930s to 3.5 ppm by 1998.

  The range of reported nitrate values and number of samples evaluated:
- Northern Ogallala – less than 1.1 to greater than 8.9 ppm (1,787 samples)

- Central Ogallala – less than 0.6 to greater than 5.6 ppm (1,468 samples)
- Kansas Quaternary deposits – less than 0.1 to greater than 15.7 ppm (302 samples)
- Valley-fill alluvium – less than 0.1 to greater than 20 ppm (2,544 samples)

These values indicate the wide variability present in the High Plains aquifer depending upon such factors as depth to water, well construction, land use, fertilizer use, and type of well use (municipal, irrigation, industrial, etc.). The higher values indicate that throughout the High Plains (not just in Kansas) there is a potential for nitrate problems.

- Land use was a significant factor in the Kansas Quaternary deposits and the Ogallala Central areas (as well as other parts of the study area).
    - Nitrate concentrations were smaller under rangeland than under agricultural areas (no values were given in the text).
- Irrigation intensity showed a significant but weak relationship in areas with shallow water table (Kansas Quaternary deposits).
    - Irrigation intensity was not correlated with nitrate values in either the Ogallala north or central areas.

Salinity

A recommended secondary standard for total dissolved solids (salinity) is 500 mg/L. Above this level water hardness; chemical deposits; corrosivity; colored water; staining; and salty taste may be noticed in the water.

- Variable salinity occurs throughout the entire High Plains aquifer.
- The range of dissolved solids in the Kansas Quaternary deposits and Ogallala central area was between 300 and 350 ppm from 1930s to 1998
- The alluvial areas and the northern part of the Quaternary deposits had a range of values from 501 to 1,000 ppm prior to 1980.
- After 1980 more hot spots of salinity values greater than 1,000 ppm occurred.
- Land use evaluation showed that urban areas in the three Ogallala areas had larger dissolved solids concentrations that the other units.
- Areas such as the Arkansas River valley have higher dissolved solids and sulfate concentrations than other portions of Kansas.
- The underlying Cretaceous units in Kansas caused larger dissolved solids concentrations in those areas than in other portions of the High Plains aquifer.

Pesticides

- About 75% of pesticide data came from sites in Nebraska and central Kansas
- Atrazine detections were larger in areas of agricultural land that produced corn or sorghum

- Shallow aquifers, such as the Platte River alluvium in Nebraska, were most susceptible to pesticide contamination
- Pesticides were detected in the deeper High Plains aquifer but not as frequently as in the shallower portion of the aquifer.
    - Presence of pesticides in the deeper aquifer indicates that contamination pathways exist and may pose a potential future problem.

Summary

- Overall the report indicates that contamination of the High Plains aquifer has occurred primarily due to agricultural practices over the years.
- Certain parts of the High Plains aquifer in Kansas (mostly areas with shallow water tables) have nitrate above the drinking water limit and increasing salinity problems at present.
- The presence of nitrate and pesticide in the deeper portions of the aquifer (including parts of Kansas) indicate that pathways exist for future movement of contaminants into the aquifer.
- The slow movement of water through the unsaturated zone to the ground-water table indicates that the potential for long-term contamination exists.

2.7 Question of blending of oil and gas brine with Ogallala aquifer water

During the June 28, 2001 meeting, one of the members of the Ogallala Management Advisory Committee raised the issue of using brine from oil and gas production and blending it with Ogallala ground water to extend the life of the aquifer. The following document reports the typical salinity levels (both chloride and total dissolved solids concentrations) in oil and gas brines in western Kansas and in the Ogallala portion of the High Plains aquifer. These values were used to calculate the volumes of brine and Ogallala aquifer water that would bring mixtures of the two waters to recommended standards for drinking water and upper limits for use of irrigation water.

Chemical Characteristics of Oil and Gas Brines in Western Kansas

Oil and gas brines in western Kansas are sodium–chloride type waters. Chloride is the dissolved constituent in highest concentration in the brines. Sulfate concentration in the brines is typically around one tenth or lower of the chloride concentration. The typical chloride concentration ranges from about 19,000 mg/L (close to that of seawater) up to 100,000 mg/L. (A mg/L is essentially the same as a ppm in freshwater but is slightly greater than a ppm in brine due to the greater density of the brine than of freshwater.) The typical concentration of total dissolved solids (TDS) ranges from 35,000 mg/L (close to that of seawater) up to 160,000 mg/L. Some brine in the deep Arbuckle Group can have chloride concentrations as low as about 10,000 mg/L and TDS contents as low as 20,000 mg/L. Some brine in other formations can have chloride and TDS concentrations as high as 200,000 mg/L and 340,000 mg/L, respectively. For comparison, seawater contains chloride and TDS contents of 19,400 mg/L and 35,800 mg/L, respectively.

Chemical Characteristics of Ground Waters in the Ogallala Aquifer

Ground waters in the Ogallala portion of the High Plains aquifer in western Kansas are usually fresh and are calcium, magnesium–bicarbonate in chemical type. Chloride and TDS concentrations are typically in the ranges 5-50 mg/L and 250-600 mg/L, respectively. The chloride and TDS contents average approximately 20 mg/L and 380 mg/L, respectively, if the ground waters affected by saline Arkansas River water are not included.

Water for Drinking and Irrigation Use

The recommended standards for drinking use are 250 mg/L for chloride and 500 mg/L for TDS concentration. Although the chloride level that different crops can withstand ranges depending on the crop and soil type, concentrations greater than about 350 mg/L begin to cause reductions in yield. The usual definition of the division between freshwater and saline water, 1,000 mg/L TDS content, is the effective upper limit of sodium–chloride type water that can be used for irrigation water use before yield reductions occur. Crops can withstand greater concentrations of sulfate and TDS in sodium–sulfate type water than of chloride and TDS in sodium–chloride type water.

Blending of Brines and Ogallala Aquifer Water

The amount of oil and gas brine that could be blended with ground water from the Ogallala aquifer to produce a mixture that could still be used would depend on the chemistry of both the brine and the aquifer water. The chemical type of water that would result from blending of a brine and Ogallala aquifer water to produce a mixture at a use limit would range from calcium, sodium–bicarbonate, chloride to sodium–chloride, depending on the amount of brine in the mixture. Table 1 lists the volume percentages of brine and Ogallala water in various blends based on different ranges of typical brine chemistry, average Ogallala composition, and water-use limits.

The volume percentage of Ogallala aquifer water that would be necessary to dilute oil and gas brine to a usable level ranges from about 98% to over 99.1% of the mixture. The volumes are mainly dependent on the chloride and TDS concentrations in the starting Ogallala water and the salinity of the brine. For illustration, it would take about 100 acre-ft or more of average water from the Ogallala aquifer to dilute one acre-ft of average oil and gas brine to a usable level. The volume of brine that could contaminate fresh Ogallala ground water to over limits recommended for use ranges from less than 2% to as low as less than 0.1% of the mixture. This shows why a small volume of oil brine can contaminate a large amount of freshwater. The unit usually used by the petroleum industry for volumes of oil and saltwater is the barrel, which is equivalent to 42 gallons. There are 7,758 barrels in an acre-ft of water. The amount of an average oil and gas brine from western Kansas that would contaminate an acre-ft of fresh Ogallala ground water to chloride and TDS levels greater than recommended for use would usually be less than 100 barrels.

The computations indicate why oil and gas brine in western Kansas would not be a suitable source of water to use to extend the life of the Ogallala aquifer. If marginal quality water were to be used in western Kansas to blend with Ogallala aquifer water, a more appropriate source would be slightly saline water from the Dakota aquifer with a TDS content of 1,000-2,000 mg/L in west-central Kansas.

Table 1. Volumes of Oil and Gas Brine and Ogallala Aquifer Water in Mixtures at Usable Limits for Drinking and Irrigation Use.

Average Ogallala aquifer content, mg/L	Oil and gas brine content, mg/L	Brine and Ogallala water mixture, mg/L	Percent volume of Ogallala water in mixture	Percent volume of brine in mixture	Volume of Ogallala water to dilute one acre-ft of brine, acre-ft	Volume of brine to contaminate one acre-ft of Ogallala water, barrels
Mixtures based on chloride concentration for drinking water use						
20	19,000	250	98.79	1.21	82	95
20	100,000	250	99.77	0.23	434	18
Mixtures based on chloride concentration for irrigation water use						
20	19,000	350	98.26	1.74	57	137
20	100,000	350	99.67	0.33	302	26
Mixtures based on TDS concentration for drinking water use						
380	35,000	1,000	99.65	0.35	288	27
380	160,000	1,000	99.925	0.075	1,329	5.8
Mixtures based on TDS concentration for irrigation water use						
380	35,000	1,000	98.21	1.79	55	141
380	160,000	1,000	99.61	0.39	256	30

3. Relevant excerpts from the report to the Kansas Water Office *"Discussion and Recommendations for long-term management of the Ogallala Aquifer in Kansas"*, by the Ogallala Management Advisory Committee
http:// /www.kwo.org/Reports/ogallala_mgt__rpt_.htm

(Excerpts from the body of the report, section II, Recommendations)

1. ***Delineate the Ogallala Aquifer into aquifer subunits to allow management decisions in areas of similar aquifer characteristics.***

Each Groundwater Management District, and the Division of Water Resources for areas outside of GMDs, should delineate these subunits. The Kansas Geological Survey, Division of Water Resources, Kansas State University, and Kansas Water Office should cooperate and assist through the water planning process.

1. The GMDs and DWR should identify each aquifer subunit in decline or suspected decline and establish water-use goals to extend and conserve the life of the Ogallala Aquifer.

Setting water-use goals in aquifer subunits helps define the enormous challenge of managing this large, extremely valuable resource today and into the future. In areas where ample supplies remain either no reductions will be necessary or modest reductions may be recommended to help extend and conserve the life of the aquifer and reduce stress on nearby subunits. In a subunit with a rapid decline and a short estimated usable lifetime, a more aggressive goal should be set. Assistance programs would be targeted to those areas to help reach the water-use goals. Variables to consider in setting the water-use goal include the estimated volume of water available, recharge, amount of annual water use, estimated usable life of the aquifer, public input and others should be determined by the GMDs and DWR.

2. ***Identify aquifer subunit priorities to extend the life of the aquifer and sustain the vitality of western Kansa****s.*

Base priority on rate of decline, the estimated time before an area must transition to less water use due to declines and the potential socio-economic impact of the decline and other factors. High priority aquifer subunits should be candidates for acquiring additional information necessary to implement plans, assistance programs and/or other actions deemed necessary by the GMDs and DWR. If incentive and voluntary plans are unsuccessful, then strict administration of existing water law should be applied.

(Excerpts from Appendix A to the report, Menu of Options)

II. Management of Aquifer Subunits

A. Develop a protocol to define criteria to a) identify preliminary aquifer subunits, b) establish preliminary water use goals for each subunit, and c) classify aquifer subunits as high, medium, or low priority, using existing data and tools recommended by the Technical Advisory Committee. The GMDs and DWR, with assistance and cooperation from the KWO, KGS, and KSU, are to establish the protocols and report them to the Kansas Water Authority by July 2003. The GMDs, and DWR for Ogallala aquifer areas outside the GMDs, are to identify preliminary aquifer subunits and preliminary water use goals.

B. The GMDs and DWR should set timelines to achieve sections C through H of the management proposal by July 2003. The progress made towards the aquifer subunit goals is to be reported to the Kansas Water Authority every 2 years, beginning in 2004.

C. The GMDs and DWR are to establish criteria to identify aquifer subunits as high, medium, or low priority, and then assign priority to each subunit in their areas. Consider factors such as rate of decline, the estimated time before an area must transition to less water use due to declines, legal (water right) criteria in each subunit, the economics, and potential socio-economic impact of the declines. High priority aquifer subunits would be targeted for additional data if needed, assistance, and possibly enhanced management.

D. Identify aquifer subunits based on aquifer characteristics and other key parameters that can be used in water resource management. Each GMD is to identify the aquifer subunits within their district, and DWR is to identify the Ogallala aquifer subunits outside of the districts. The KGS, DWR, KWO and KSU should cooperate and assist. The Technical Advisory Committee has recommended several tools for delineating aquifer subunits. An aquifer subunit can later be redefined, based on new data or management needs.

E. For high priority aquifer subunits, enhanced water management plans should be considered by the GMDs. These enhancements can be developed with input from water users in the subunit about management approaches outside of strict water administration. The Chief Engineer must determine that these approaches are not in conflict with the water appropriation act and are in the public interest. If GMDs choose not to implement enhanced management plans the Chief Engineer may initiate them in response to the public interest to protect the resource.

F. Analyze additional data as needed to verify high priority aquifer subunit conditions, and as needed for proposed management strategies.

4 Copies of contracts

4.1 KWO-KGS Contract:

OGALLALA AQUIFER SUPPORT STUDY

I. PROJECT TITLE

This contract, effective August 15, 2001, between the Kansas Water Office (KWO) and the University of Kansas Center for Research, Inc. (CRINC, FEIN#480680117, 2385 Irving Hill Road, Lawrence, KS 66044) on behalf of the Kansas Geological Survey (KGS), shall be known as the "Ogallala Aquifer Support Study". All references to this contract shall include this title and the Kansas Water Office contract No. 02-114.

This contract shall be effective for the period of August 31, 2001, through June 30, 2002.

II. KANSAS WATER PLAN REFERENCE

WATER RIGHTS MANAGEMENT SECTION: Implementation of H.S. for S.B. 287 Report Recommendations.

III. KANSAS WATER PLAN 2010 OBJECTIVES

By 2010, reduce water level decline rates within the Ogallala Aquifer and implement enhanced water management in targeted areas.

IV. SCOPE OF WORK

Item	Description
1.	**Data Support:** The KGS agrees to collect and provide to the KWO specific data and information regarding the Ogallala Aquifer for the purpose of policy determination by the Management and Technical committees established by the Kansas Water Office.
2.	**Provide preliminary data and information needs as follows:** a. Best estimates of aquifer recharge from a magnitude and spatial sense, including the range of values of the estimates spatially and among scientific sources. b. Identify the potential relationships between saturated thickness and well yield both in magnitude and spatially distribution. c. Data reflecting the relationship between ground water levels, estimated usable lifetime for large volume pumping and water usage and whether that relationship can be represented spatially by a decade representation

	of time for selected water use options that will be identified during the quarterly meetings. d. Data reflecting climatic variations experience of current generation of irrigators as compared to long term climatic variations. e. The appropriate scale of use and precision of data sets identified during the quarterly meetings. f. Other data needs determined by the Ogallala Management and Technical Advisory Committees under the approval of both the KWO and the KGS.

V. DELIVERABLES

The KGS shall submit to the Kansas Water Office, 901 South Kansas Avenue, Topeka, Kansas, 66612-1249, the following items:

Item	Description	Delivery Date
1.	A progress report on items listed in the Scope of Work outlined in Section IV	October 12, 2001 January 11, 2002 April 12, 2002
2.	Final report and posted web page(s) on items listed in the Scope of Work outlined in Section IV	June 30, 2002

VI. COMPENSATION

The Kansas Water Office agrees to pay the KGS a total of $37,500 for the anticipated costs of accomplishing the Scope of Work outlined in Section IV and providing the deliverables listed in Section V. Payments will be made within 30 days, upon receipt of a billing from the KGS under the following schedule, and the receipt and acceptance by KWO of the indicated deliverables listed in Section V. It is understood that this contract is consistent in scope and purpose with the Kansas Department of Agriculture's and Kansas Geological Survey contract, dated June 12, 2001 and the Kansas Geological Survey's water plan fund appropriation from Senate Bill 57.

Item	Deliverable	Payment Amount	Payment Schedule

1.	Upon contract execution	$18,750	August 31, 2001
2.	Satisfactory completion of item 1 in Section V	$9,375	January 11, 2002
3.	Satisfactory completion of this contract.	$9,375	June 30, 2002

VII. COMPLETION OF THE CONTRACT

This contract shall be completed no later than June 30, 2002, unless otherwise modified in writing by mutual agreement of all parties. This contract shall be successfully completed upon review and approval by the Kansas Water Office of all deliverables as described in Section V. All items received may be used by the KWO upon receipt.

VIII. MODIFICATION AND EXTENSION OF CONTRACT

This contract may be modified or extended at any time upon written approval of all parties, but not later than 30 days prior to the aforementioned completion date.

IX. CONTACT PERSONS

The Kansas Geological Survey will be represented by Bill Harrison, Deputy Director and Chief Geologist, (785) 864-2070. The Kansas Water Office will be represented by Earl Lewis, Professional Engineer, (785) 296-0875.

X. KANSAS CONTRACT PROVISIONS ATTACHMENT

The provisions found in Contract Provisions Attachment (Form DA-146a - Attachment B), which is attached hereto, are hereby incorporated in this contract and made a part thereof.

XI. ACKNOWLEDGMENT

All products resulting from this contract shall acknowledge that this contract is funded (in part) by the State Water Plan Fund.

4.2: KDA-KGS Contract

AGREEMENT
Between
THE KANSAS DEPARTMENT OF AGRICULTURE
And
THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH INC.

This agreement is entered into on this _12____, day of June, 2001, by and between THE KANSAS DEPARTMENT OF AGRICULTURE (KDA) and THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.(KUCR) on behalf of the KANSAS GEOLOGIC SURVEY(KGS).

In consideration of the covenants contained herein, KUCR/KGS agrees to collect and provide to KDA specific data regarding the Ogallala aquifer for the purpose of policy determination by Management and Technical committees established by the Kansas Water Office. The specifics for the data required will be established and refined by discussions between the parties at 1 or more coordination meetings to be held in June of 2001.

Preliminary data needs could include; but shall not be limited to:

Best estimates of aquifer recharge from a magnitude and spatial sense, including the range of values of the estimates spatially and among scientific sources.

B. Data related to the relationship between saturated thickness and well yield in magnitude spatially.

C. Data reflecting the relationship between time to deplete and selected water use options, and whether that relationship can be represented spatially by a decade representation of time.

D. Data reflecting climatic variation experience of current generation of irrigators as compared to long term climatic variations.

E. Data reflecting the appropriate balance or interface in scale between basic (data sub-township), basic information(township) and management perspective (community, county, GMD, sub-area of decade) time to deplete.

Both parties recognize that the deliverables of this contract are part of a more extensive project. Both parties agree that this contract may be amended after the coordination meetings outlined above. Any such amendment(s) shall be in writing, shall be formalized by both parties in the same manner as this agreement, and shall be attached to and become a part of this agreement.

4. The time-frame for completion of the deliverables shall be not later than June 30, 2002, unless an alternative date is established to the agreement of both parties.

In consideration of the covenants contained herein, KDA agrees to pay KUCR/KGS as compensation for the performance as specified in this agreement the sum of $37,500. This amount shall be paid in three installments; $18,750, upon execution of this agreement, $9,375 upon 50% completion, and the remaining $9,375 upon satisfactory completion of the project.

TERM OF AGREEMENT. The term of this agreement shall commence upon execution and shall continue through full performance by both parties.

EQUIPMENT. KUCR/KGS shall provide or arrange for all equipment necessary for this project.

RELATIONSHIP OF PARTIES. During the term of this agreement, it is mutually understood by the parties hereto that the KUCR/KGS will be deemed to be an independent contractor and is in no way an employee or agent of KDA.

ASSIGNMENT. Neither this agreement nor the subject matter thereof nor any portion thereof may be sold, assigned or transferred in any manner by the KUCR/KGS, without first obtaining written permission from KDA.

SUCCESSORS IN INTEREST. This agreement shall be binding upon the respective parties, their successors and assigns.

11. **TERMINATION.** Failure by either to perform any of it's duties as specified in this agreement or as specified in further discussion by the parties, shall be sufficient cause for termination of this agreement by KDA. In addition, either party may terminate this agreement upon 30 days notice to the other party. Upon termination of agreement pursuant to this provision, all unexpended funds paid by KDA in the hands of the KUCR/KGS**,** shall be returned to KDA immediately.

1. The provisions contained in Contractual Provisions Attachment form (DA-146a) which is attached hereto, are hereby incorporated in this contract and made a part hereof. Whenever the term State or Agency or words of like effect is used in the form DA-146a, such reference shall be deemed to apply to KDA. The term contractor shall mean the KUCR/KGS.

KANSAS DEPARTMENT OF AGRICULTURE	THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
(Signed- 6-12-01)	*(Signed- 6-08-01)*
Jamie Clover Adams Secretary of Agriculture	Joanne Altieri, Director Contract Negotiations and Research Compliance