Kansas Geological Survey

Data, Research, and Technical Support for Ogallala-High Plains Aquifer Assessment, Planning, and Management

An overview report of fiscal year 2003 activities by the Kansas Geological Survey supported by the Ogallala Aquifer Support Study of the Kansas Water Plan

By

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

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1. Introduction

This report documents the activities and accomplishments of the Kansas Geological Survey funded by the Ogallala Aquifer Support Study of the Kansas Water Plan during Fiscal Year (FY) 2003. Although it is a relatively small program, it exerts high leverage in that it permits KGS to respond promptly to developing needs for information and technical support relating to groundwater resources, and it provides a topical focus that facilitates linking together ongoing activities and other funded projects in a synergistic fashion.

Accordingly, the report makes reference to a number of shared or overlapping activities that have been shaped by or integrated with the Ogallala Aquifer Support Study even though substantial portions of their funding were derived from other sources.

The sections that follow address four major activity areas and topical results: development and expansion of online data and information resources; aquifer subunit characterization; recharge and flow changes along rivers crossing the Ogallala aquifer; and potential impacts of past land use and recharge rates on the water quality of the Ogallala-High Plains Aquifer.

As and example of both the prompt technical support aspect of the effort, and of the regional scale hydrologic context and issues, we conclude this introductory section with a summary of responses to queries on issues of groundwater flow and interstate issues.

During the period when Groundwater Management District No. 3 was considering closing townships in the southern part of its district to further appropriation of water, a question arose by individuals in southwest Kansas as to whether there was substantial movement of ground water from the Ogallala-High Plains aquifer from Kansas into Oklahoma. The concern was related to whether pumping of the aquifer in Oklahoma had caused appreciably greater declines in the water levels of the aquifer than in southwest Kansas. To answer the question, a map (Figure 1.1) was prepared for the DWR and the KWO based on water-level data assembled by Woods and Sophocleous (2001, 2002) for the High Plains aquifer in southwest Kansas and in Oklahoma for counties along the Kansas-Oklahoma line. The Kansas data they used are from the KGS-DWR annual water-level network and the Oklahoma data are from the Oklahoma Water Resources Board. They averaged the data for a three-year period (1999-2001) to decrease the amount of variability due to fluctuations in individual wells that might not fit the overall trend for a particular year.

The water-level elevation contours on Figure 1.1 indicate that the predominant direction of regional ground-water flow along the area surrounding the Kansas-Oklahoma state line is from west to east. The direction of ground-water flow is perpendicular to the contour lines. The regional flow direction primarily reflects the regional gradient in the land-surface elevation. Although there are some bends in the contours, such that the directions in ground-water flow are locally to the east-southeast (a gradient with part of its component towards Oklahoma) and east-northeast (a gradient with part of its component towards Kansas), the bends tend to average out such that there is no substantial flow from either state to the other.

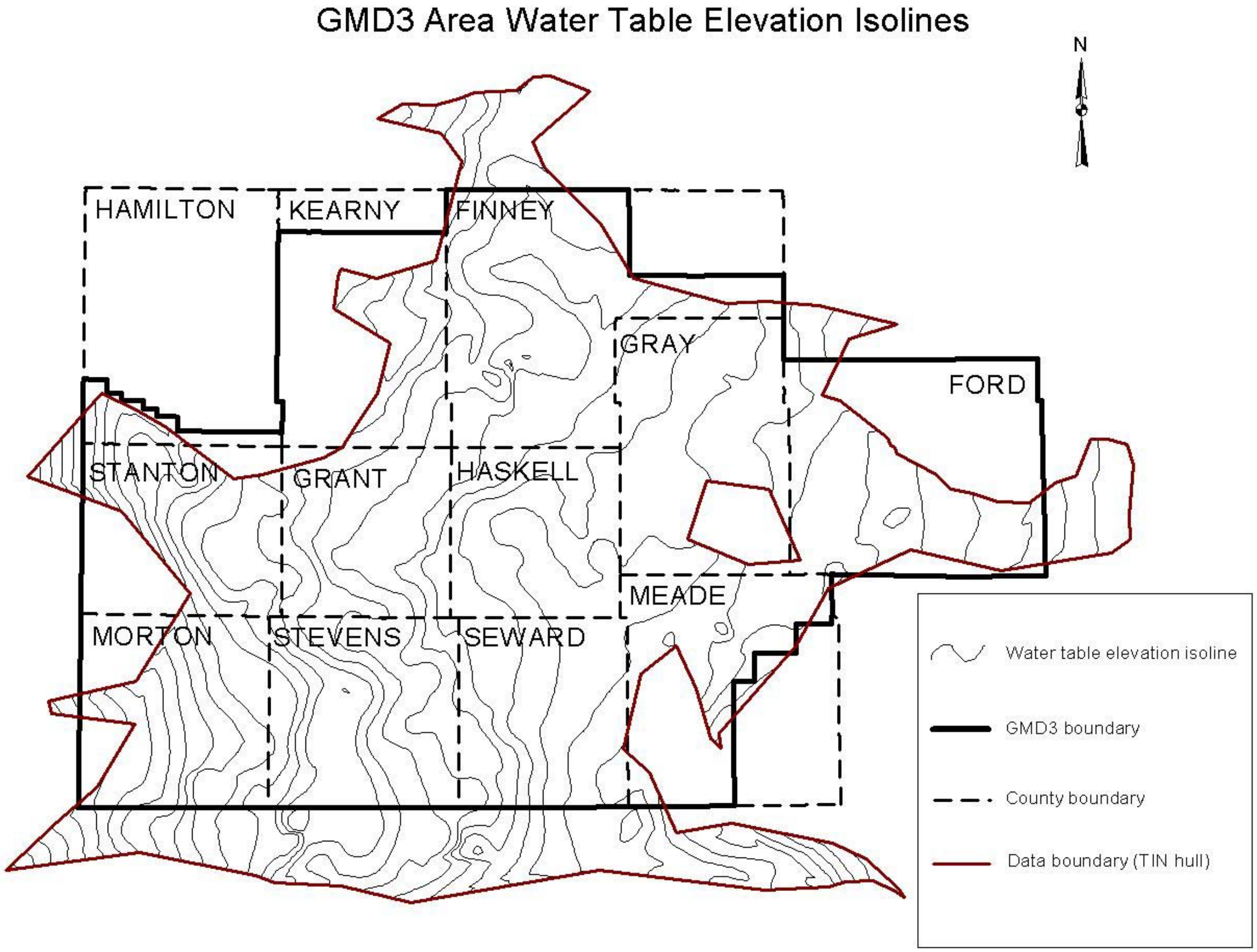


Figure 1.1. Elevation isolines for the water-level surface in the Ogallala-High Plains aquifer in southwest Kansas based on averages for 1999-2001 data from Kansas and adjoining counties in Colorado and Oklahoma (from Woods and Sophocleous, 2001). The interval between isolines is 50 ft.

2. Online Data and Information Dissemination and Processing

The Ogallala Aquifer Support Study has been a core element of continued KGS development of capabilities to support groundwater resource assessment and management efforts (Buddemeier et al. 2003). Not only are conventional reports and maps being augmented and disseminated by internet-based products, but improved online data access and selection, combined with easy visualization in the form of graphs and maps, also make databases more easily used. Analytical tools such as geospatial clustering have been coupled with an expanded database of section-level geohydrologic and water use data (see Section 3 of this report for examples of applications).

The KGS Geohydrology Section has developed web pages to disseminate data and information related to the High Plains/Ogallala aquifer (http://www.kgs.ku.edu/HighPlains/), specifically including the results of the Ogallala-High Plains Aquifer Support Study. FY 2002 study reports (KGS OFR 2002-29A-G) are posted on a new page specifically addressing issues relevant to the western Kansas (Ogallala) portion of the High Plains aquifer (http://www.kgs.ku.edu/HighPlains/OHP/index.htm). FY 2003 and subsequent reports will be posted as they are completed. These Portable Document Format (PDF) files are publicly accessible and may be viewed, downloaded and printed.

Primary activities in FY 2003 consisted of providing improved access to and easier processing of water-level and associated data, with particular emphasis on the tools and data appropriate to aquifer subunit definition (see Section 3). A major addition to the web site in FY 2003 was an upgrade to the KGS High Plains Aquifer Section-Level Database (http://www.kgs.ukans.edu/HighPlains/data.htm: *link to Section-Level Data*), described by Young et al. (2003). The database includes information on aquifer characteristics, estimated recharge rates, projections on the useable lifetime of the aquifer, land cover, water rights and more. Datasets were updated to reflect the most recent water level measurements, and new variables depicting the density of groundwater use were added.

In addition to additional data and variables, the web interface was given expanded capabilities consistent with the tools and features of the revised WIZARD water level database website (Wilson 2003). The website enables users to access and download section-level data directly and dynamically from the Oracle database. As data are added to the database, the data automatically become available through the web site. A user may select the geographic extent from which they will retrieve section-level data from the following categories: Groundwater Management District (GMD), Public Land Survey System (PLSS; Township and Range), County Name, or a Latitude/Longitude box. Special features include basic statistics, histograms, correlation matrix, calculator, data download, and an option to download an ArcView shape file of the PLSS sections. Neither the database nor the web site are static, but will continue to evolve as more data are added, the needs of the Kansas water community evolve, and user feedback is addressed.

An example of the synergy achieved by the project is that this refinement and expansion of the section-center database has also expanded the technical offerings of the High Plains Aquifer Information Network (**HIPLAIN;** www.hiplain.org), which is a joint venture between the Kansas Geological Survey (KGS) and Kansas State University (KSU) with partial support from the Kansas Water Resources Research Institute (KWRRI). **HIPLAIN** is devoted to providing a user-friendly web network with access to information, references, links, maps, data, and data-analysis tools concerning the High Plains aquifer, and will also provide links to future products and information developed by Ogallala Technical Support activities at KGS.

3. Aquifer Subunit Characterization

In support of the state's program of developing aquifer subunit designations as a management tool, various activities were undertaken. These included continued coordination with the developers of the geospatial clustering tools used successfully to data (LOICZView and the successor prototype application, DISCO), tests of both tools and analytical approaches to the identification of GMD1 aquifer subunits, and extensive cooperative studies with GMD4 that provided significant overlap with the objectives of the Ogallala Aquifer Support study.

GMD1 experimental studies

Aquifer subunit identification tests using the section-level KGS database (see section 2) were carried out with the cooperation of the GMD1 manager. The major findings are listed below.

(1) Unsupervised clustering and supervised clustering using the expert judgment of the manager in identifying "type localities" to serve as examples of particular environments, uses, or problems gave similar results in terms of overall patterns. This finding both reinforces the utility of local knowledge in identifying potential subunits, and provides general validation of the use of management experience in identifying characteristics and possible distinctions in the aquifer.

(2) The GMD1 region was used to test the "fuzzy clustering" tool being developed within DISCO, the successor to the LOICZView geospatial clustering tool. The encouraging results suggest that this will be a very useful approach to dealing with the uncertainties and need for incorporation of non-hydrologic considerations into final designations of aquifer subunits.

(3) Following the extreme dry conditions and heavy pumping in 2002, very few regions of GMD1 were not showing very limited lifetimes based on the 2003 water levels. Because of the need to average water levels over multiple years this finding needs to be refined with subsequent measurements, but highlights the dynamic nature of classifications based on short-term data.

Aquifer subunit characterization in Northwest Kansas

A study of the groundwater flow system in the High Plains aquifer in northwest Kansas and small portions of eastern Colorado and southern Nebraska is ongoing as part of a Ph.D. dissertation research program (Hecox, 2003). This effort has provided an integration and extension of the cooperative GMD4-KGS study to characterize the two distinct areas within the district, one considered "stressed" (in Sheridan County), and a "safe" area (in Sherman County). Water levels are being collected from two detailed study areas, historical water level, precipitation, crop production and water use data have been compiled and analyzed, and a groundwater model has been developed for the area. The data collection program has observed daily barometric pressure-related water level fluctuations of up to 1 foot, drawdown in irrigation wells during the irrigation season between 20 to 70 feet, and recovery of water levels from irrigation season pumping of 6 to 7 months. Recovery histories provide insight into the uncertainties in the results of the annual water level measurement program. Univariate and multivariate statistical analyses and groundwater modeling evaluations have been performed to determine key variables controlling nonpumping and pumping groundwater levels and rates of level decline. The statistically significant variable for explaining nonpumping mid-winter water levels is simply ground surface elevation. The key variables for determining the pumping water levels are pumping rates of individual wells, hydraulic conductivity, specific yield, and saturated thickness. The statistically significant variables for explaining water level declines are ground surface elevation, water use, recharge, and saturated thickness. Some of the specific results are summarized below.

1. Detailed water level change characterization: In cooperation with the staff of GMD-4, detailed water level data collection on the High Plains aquifer continued in Sherman and Sheridan Counties. The program consists of the operation of three continuous recorders and monthly measurements of water levels in 26 wells in the two study areas. The data have been analyzed to assess the water level recovery rates, pumping water levels and drawdowns, and determine overall water level measurement uncertainties. Summary plots of the data are presented in Figures 3.1, 3.2, and 3.3. As presented in Figure 3.3, the observed drawdowns range between 20 and 70 feet with averages of 49 feet in Sherman County and 41 feet in Sheridan County. When saturated thickness decreases to less than the necessary drawdown in a given well, the well yield will start to decline.

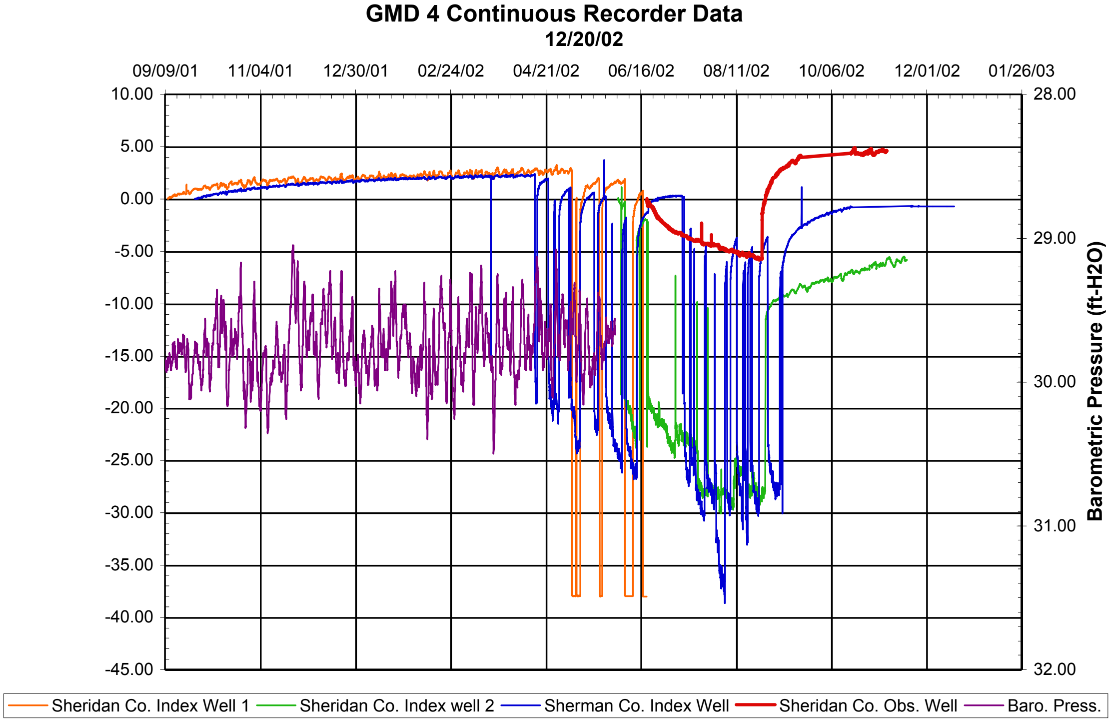


Figure 3.1. Continuous recorder data from three wells in Sheridan County and one well in Sherman County.

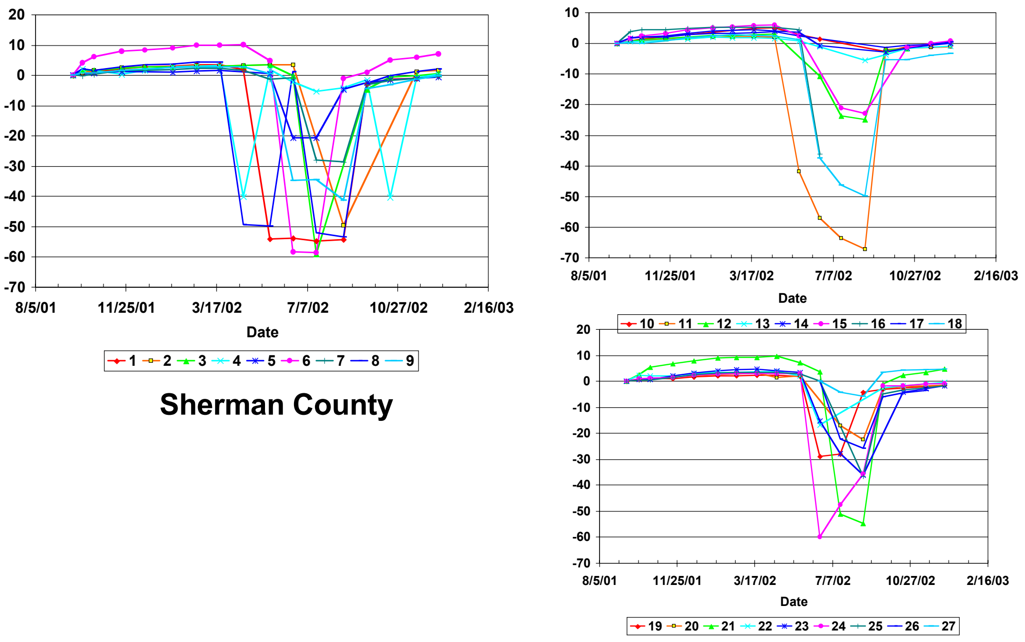
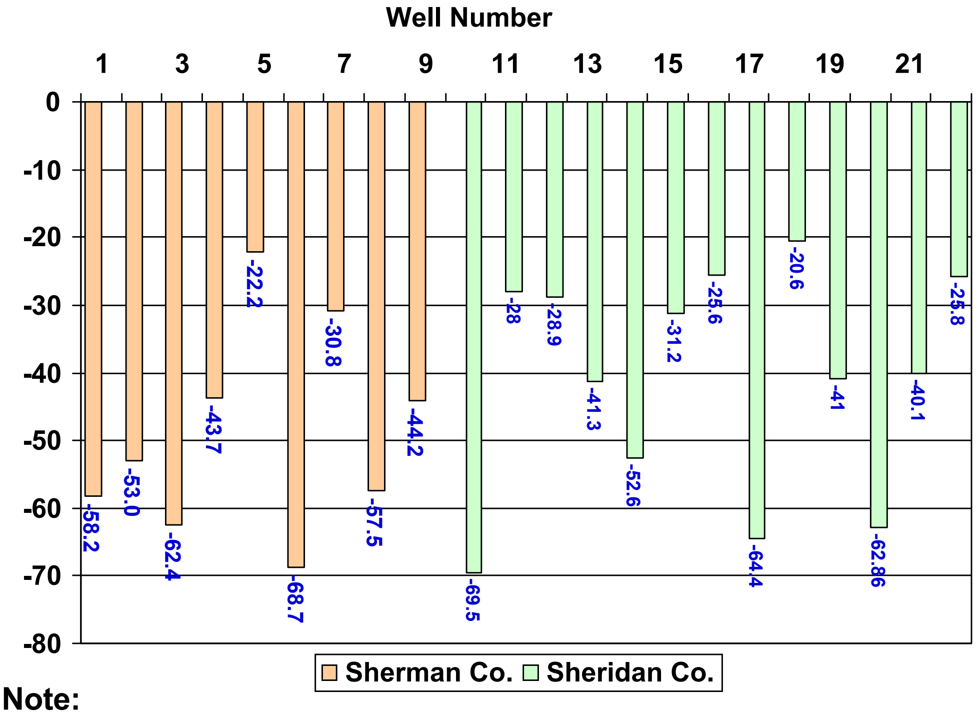


Figure 3.2. Monthly water level data from the Sherman and Sheridan County study areas.



Note:

Sherman Co. Average drawdown = 49 ft

Sheridan Co. Average drawdown = 41 ft

Figure 3.3. Observed drawdowns in the Sherman and Sheridan County detail study wells.

2. Clustering of aquifer regional characteristis: A statistical cluster analysis was conducted on the GMD4 area to define areas of hydrogeologic similarity for the High Plains aquifer. Five distinct areas were identified and are presented in Figure 4. Two areas have declining water levels, two areas have rising water levels, and one area has steady water levels in the time period from 1991–2001.

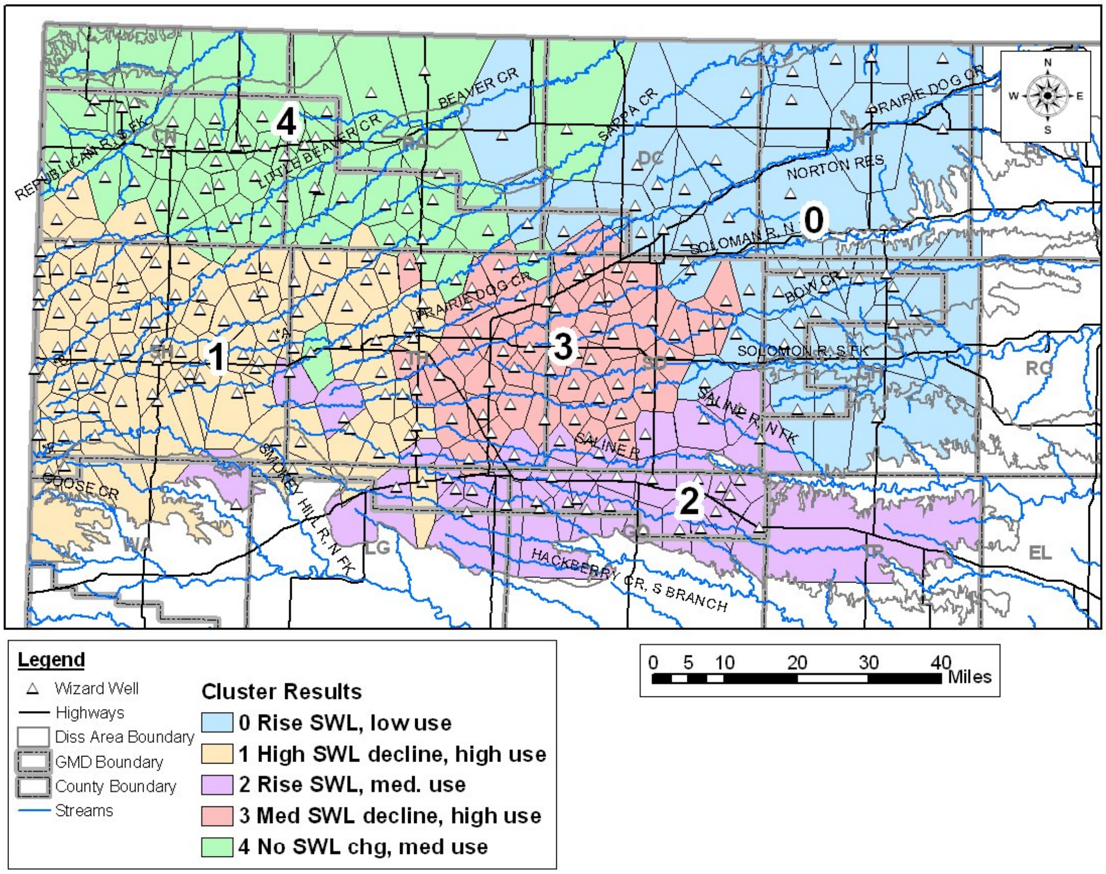


Figure 3.4. Hydrogeologically similar areas in and around GMD4 defined using K-means clustering using the program LoiczView (Maxwell, 2002).

3. Other work: The groundwater use data for the High Plains aquifer in the eight counties in northwest Kansas was compiled and evaluated. The water use data for the individual wells in the WIMAS™ database was compiled into a geodatabase for use in GIS applications and groundwater modeling. Furthermore, using a regression relationship between annual water use and precipitation and the well permit data from Kansas and Colorado, historical estimated use for the individual wells was developed. A groundwater flow model for the region has been developed and calibrated as part of the dissertation research, and will be reported on separately.

Township-scale analysis of aquifer lithology

Macfarlane and Hecox (2003) have initiated the use of available WWC5 logs (http://magellan.kgs.ukans.edu/WaterWell/index.html) to refine the definition and characterization of hydrogeologic aquifer subunits, which can provide primary input to the water agencies developing management tools to help extend the useable life of the Ogallala portion of the High Plains aquifer in Kansas. These water-well completion records have been required for submission to the Kansas Department of Environment since 1975. The driller's log is a description of the sediments observed in the drill cuttings that are returned to surface as the borehole for the well is being drilled. Currently, the database contains thousands of WWC-5 records for the Ogallala region and is potentially the most valuable source of information available for aquifer subunit analysis; however, the logs are typically prepared by individuals who are not trained in geology, so log quality and accuracy can be highly variable and require professional evaluation and interpretation.

An initial study (1) evaluated the quality of the WWC-5 driller's logs and (2) used the WWC-5 driller's logs and the sample logs contained in the Kansas Geological Survey county bulletins to develop a township-scale understanding of the Ogallala aquifer in two study areas within the Northwest Kansas Groundwater Management District (see discussion of KGS-GMD4 cooperative study). One study area was selected in Sheridan County (eastern area) and one in eastern Sherman and western Thomas counties (western area). Of the more than 1,000 WWC-5 records from the two study areas, a total of 250 were selected for use on the basis of log quality and accuracy. Clay/silt, sand, and sand & gravel thickness were tabulated from the driller's log in each selected WWC-5 record and used to examine the statistical and spatial distribution of permeable deposits within the Ogallala in the two study areas. The results showed that, with suitable evaluation, the WWC5 database can substantially refine understanding of the Ogallala aquifer. For example, the total thickness of Ogallala aquifer sediments was found to be greater in the western than in the eastern study areas. The pilot study found that the coarse sediment fraction constitutes approximately 40% of the upper half of the Ogallala aquifer in both study areas, but that in the western study area a greater percentage of the lower half of the Ogallala is the coarse fraction than in the eastern area. Maps of the sand, sand + gravel, and coarse fraction percentage and thickness were develop and compared to the buried bedrock valleys in the bedrock surface beneath the Ogallala. Caliche and calcium-carbonate- and silica-cemented zones appear to be slightly more prevalent in the lower half of the Ogallala than in the upper half.

4. Recharge and Flow Changes along Rivers Crossing the Ogallala-High Plains Aquifer

In fiscal year 2003, the Kansas Geological Survey (KGS) continued evaluation of recharge and flow changes along rivers crossing the Ogallala-High Plains aquifer as a part of Ogallala aquifer support studies. During fiscal year 2002, the emphasis was on recharge along the upper Arkansas River corridor in southwest Kansas (Whittemore, 2002a). In fiscal year 2003, the KGS conducted an overview of the primary recharge and flow changes in the Arkansas River compared to other major rivers crossing the High Plains aquifer in the Great Plains, including the Cimarron River. The KGS initiated an evaluation of the flow changes in the Cimarron River relative to water-level declines in the Ogallala-High Plains aquifer in southwest Kansas. This evaluation will continue as an activity of the fiscal year 2004 studies for Ogallala aquifer technical support.

The overview of recharge and flow changes in rivers crossing the High Plains aquifer in the Great Plains included a comparison of the Arkansas River in southwestern Kansas to the Canadian River in the panhandle of Texas, the Beaver River in the panhandle of Oklahoma, the Cimarron River in the western portion of the Oklahoma panhandle and in southwestern Kansas, the Republican River in northwestern Kansas and southern Nebraska, the South Platte River in the northeastern corner of Colorado and in western Nebraska, and the North Platte River in western Nebraska (Whittemore, 2002b). Portions of all of these rivers have experienced declines in annual flows during the last few decades where they cross the High Plains aquifer. The comparison shows that the river with the greatest decrease in flow and increase in recharge to the underlying High Plains aquifer during the last few to several decades in the Great Plains is the Arkansas River.

Before the onset of high-volume, consumptive pumping of ground water, rivers crossing and originating within the extent of the High Plains aquifer generally gained flow downstream from ground-water discharge. Although water consumption from reservoirs has decreased flow in some rivers, declines in ground-water levels from pumping have now substantially decreased the discharge to most of the rivers. Water-level declines in the aquifer in southwest Kansas have become large enough that ground water no longer usually discharges to a substantial portion of the Arkansas River. A large amount of Arkansas River flow crossing the western extent of the High Plains aquifer now recharges the alluvial aquifer and then leaks to the underlying Ogallala-High Plains aquifer. During years of low flow from Colorado and below average precipitation in Kansas, such as in 2002, a substantial stretch of the river becomes dry. The dry sections extended farther to the east than in the past, into part of the High Plains aquifer in south-central Kansas during the summer of 2002 and have remained dry through the first half of 2003. Although no channel recharge is present in the dry sections, leakage continues from the alluvium to the High Plains aquifer along a substantial stretch of the river. Lower water levels in the alluvial aquifer following dry periods allow greater capture of high river flows from Colorado.

Ground-water table declines have also caused long-term flow decreases in the Cimarron and Beaver rivers that originate mainly within the extent of the High Plains aquifer. The water-level declines have led to increases in streambed recharge during substantial precipitation events along upstream stretches of the rivers that no longer have perennial flow. Projection of future water-level declines in the High Plains aquifer based on continued present and possible additional water use suggest that selected sections of the South Platte and Canadian rivers might reverse from gaining to losing just as has the Arkansas River.

Prior to ground-water development, the surface of the ground-water table in the aquifer along the Cimarron River was relatively near the bottom of the river channel along the entire length of the river in Kansas, in comparison with the substantial depth of the water table below the river in Stevens, Grant, Haskell, and northwest Seward counties in 2003. A cross section in McLaughlin (1946) along the river from the Colorado-Kansas line to the Kansas-Oklahoma line indicates that the ground-water table in the summers of 1941 and 1942 was above the river channel in southwest Morton, south-central Grant, most of the channel in Seward, and in southwestern Meade County. The water-table level was very close to the channel in eastern Morton to northwestern Stevens counties, and below the channel in part of Stevens County and from southeastern Grant through the southwest corner of Haskell to the northwesternmost part of Seward counties. A graph in McLaughlin (1946) based on streamflow measurements in 1942 and 1943 showed that the river generally lost flow from near Elkhart to the northwest part of Seward County and gained flow from northwest Seward to southwest Meade County. A map of water-table contours for the Ogallala-High Plains aquifer in 1940 (Byrne and McLaughlin, 1948) indicates that the change from a ground-water level below to above the river channel was located in the northwest part of T. 32 S., R. 33 W in northwest Seward County. This is approximately the same vicinity as the start of the perennial portion of the river indicated on the USGS Sublette SW topographic quadrangle of 1968 based on aerial photographs of 1966.

The mean annual flows of the Cimarron River have declined at the current USGS gaging stations in southwest Morton County near Elkhart and in southeast Meade County north of Forgan, Oklahoma (Figures 4.1 and 4.2). The flow of the river in southeast Meade County during 2000-2002 was less than half of that during 1966-1969. The decline in the difference in the flow between southwest Morton and southeast Meade counties (Figure 4.3) represents an increase in recharge from the river across the Ogallala-High Plains aquifer from near Elkhart downstream into northwest Seward County and a decrease in the ground-water discharge from the aquifer to the river from northwest Seward to southwest Meade counties.

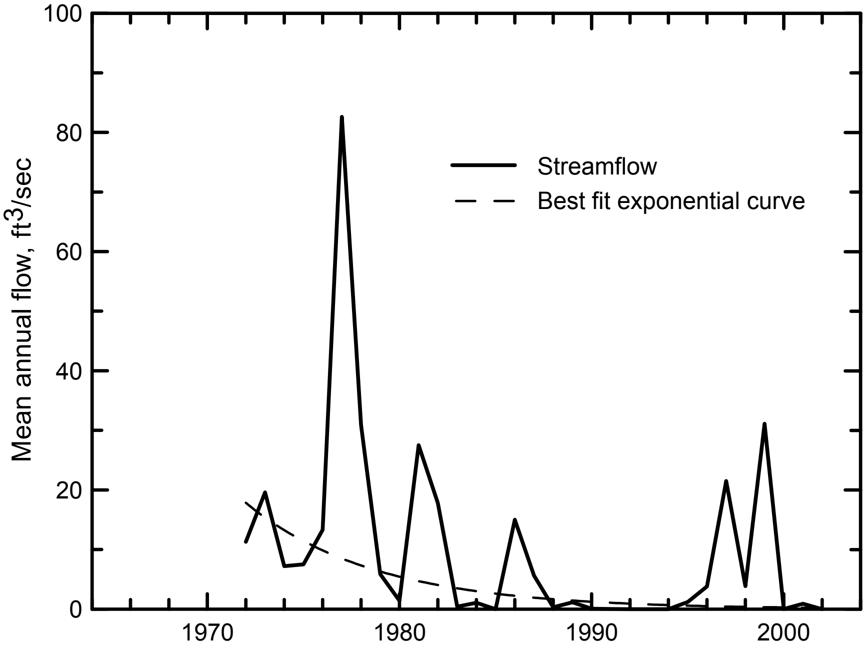


Figure 4.1. Mean annual flow of Cimarron River near Elkhart Kansas during 1972-2002 (USGS data).

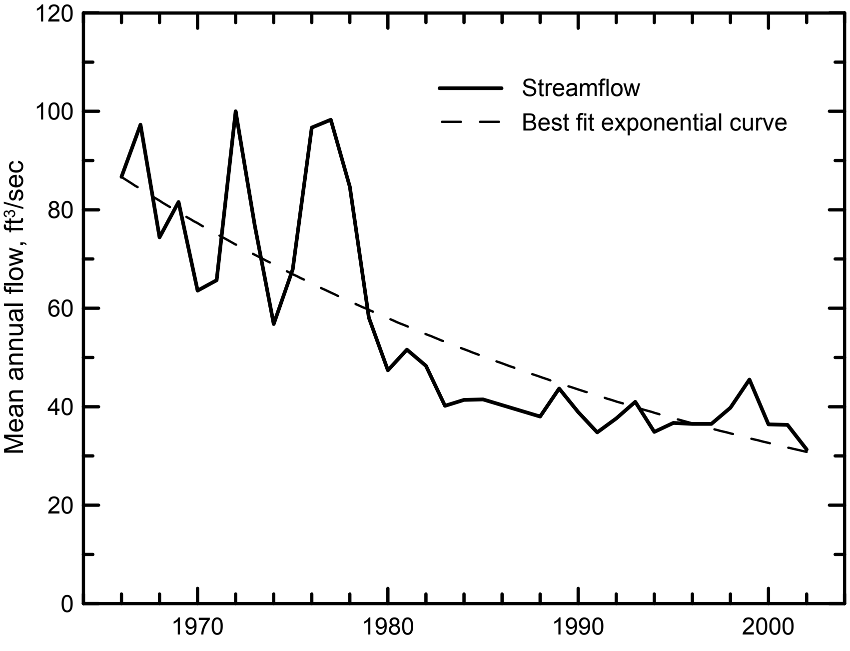


Figure 4.2 Mean annual flow of Cimarron River north of Forgan, Oklahoma during 1966-2002 (USGS data).

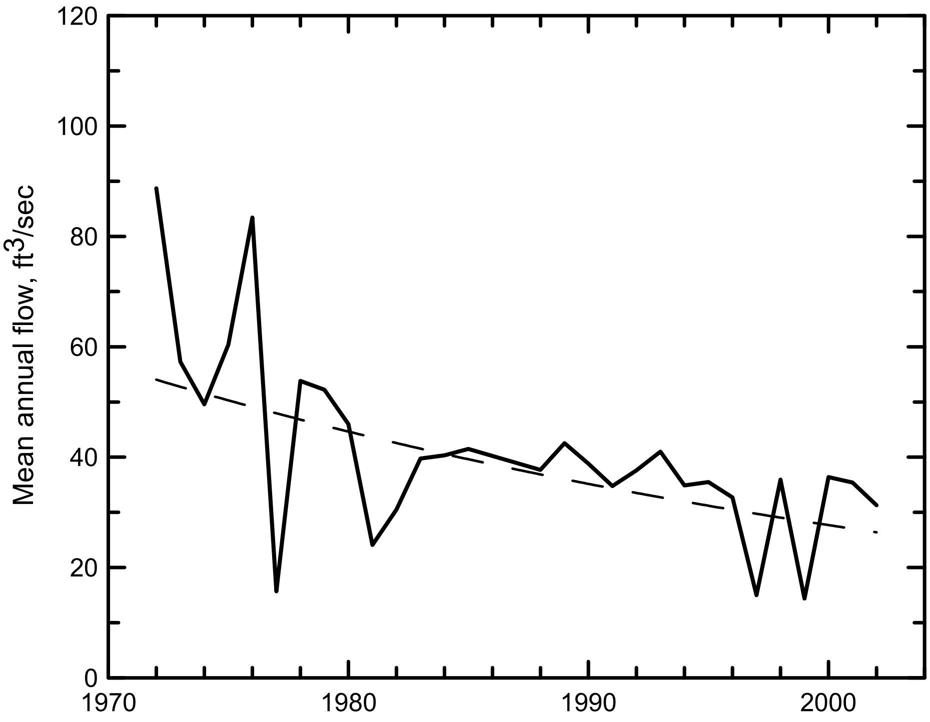


Figure 4.3. Mean annual flow of Cimarron River north of Forgan, Oklahoma minus the flow near Elkart, Kansas (USGS data).

The decline in the water table of the Ogallala-High Plains aquifer along the Cimarron River corridor is the main cause of the decrease in river flow. Gutentag et al. (1981) described substantial water-level drops in the aquifer in southwest Kansas through the 1960's to 1975. A discharge survey that they conducted in November 1974 indicated that the point where flow began in the Cimarron River was approximately in the center of T. 32 S., R. 33 W., a distance of about 3-4 channel miles downstream of the beginning of perennial flow on the 1968 USGS topographic map. The location where the ground-water levels in the aquifer change from below to above the river channel (and thus, the start of perennial flow) has migrated another 11-12 channel miles downstream from the 1974 survey to just southeast of the center of the county, based on KGS and DWR measurements in annual network wells within 2.5 miles of the river (Table 4.1). This location is near the old town of Arkalon in the southwest part of T. 33 S., R. 32. W. McLaughlin (1942) cited data from the USGS that the mean daily discharge of the Cimarron River near Arkalon in 1938-1939 was 42.3 ft^3/sec. Today, this is the area where the river would be expected to begin its perennial flow based on the water-level data.

Table 4.1 Elevation of water level in DWR-KGS annual network wells within 2.5 miles of the Cimarron River relative to the river channel elevation in Seward and southwestern Meade counties.

Well location and ID	General descriptive location	Well depth ft	Land surface elev. at well ft	Well location relative to Cimarron R	River channel elev. ft	Land surface elev. at well minus river channel elev. ft	Depth to water ft	Date of depth to water	Water level elev. minus river channel elev. ft
31S 34W 18BBB 01	NW corner Seward Co.	375	2951	1.9 mi to W	2778	173	252.3	1/2000	-79
32S 34W 10DAA 01	NW Seward Co.	350	2925.4	2.3 mi to W	2710	215	259.6	1/2003	-45
32S 33W 32DBD 01	NW of center Seward Co.	?	2820	1.6 mi to SW	2660	160	185.8	1/2003	-26
33S 33W 12AAD 01	Center of Seward Co.	140	2626	0.65 mi to W	2612	14	23.8	1/2003	-10
33S 32W 28CDD 02	SE of center Seward Co.	205	2630	1.0 mi to SW	2565	65	62.8	1/2003	3
33S 31W 20ACA 01	SE Seward Co.	418	2750	2.1 mi to NE	2532	218	214.3	1/2003	4
33S 31W 28DDB 01	SE Seward Co.	?	2720	2.5 mi to NE	2510	210	192.8	1/1998	17
35S 30W 10CDA 01	SW corner Meade Co.	260	2420	0.6 mi to NNE	2376	44	26.7	1/2003	17

The hydrographs of the wells in Seward County (Figure 4.4) show the historic declines in the ground-water levels in the Ogallala-High Plains aquifer. In general, the declines in the water levels are greater the farther upstream the location in the river corridor. The water level in the well in the northwest corner of Seward County (31S 24W 18BBB 01 in Figure 4.4) dropped approximately 71 ft from December 1959 to January 2000. (The level in the well could not be measured after 2000 and the well was removed from the network). The water level elevation at this well in December 1958 would have been only about 8 ft below the elevation of the riverbed (see Table 4.1). The water level in the network well in southwest Meade County (located 0.6 mile north of the river) shows a general correlation with the mean annual flow of the Cimarron River (Figure 4.5).

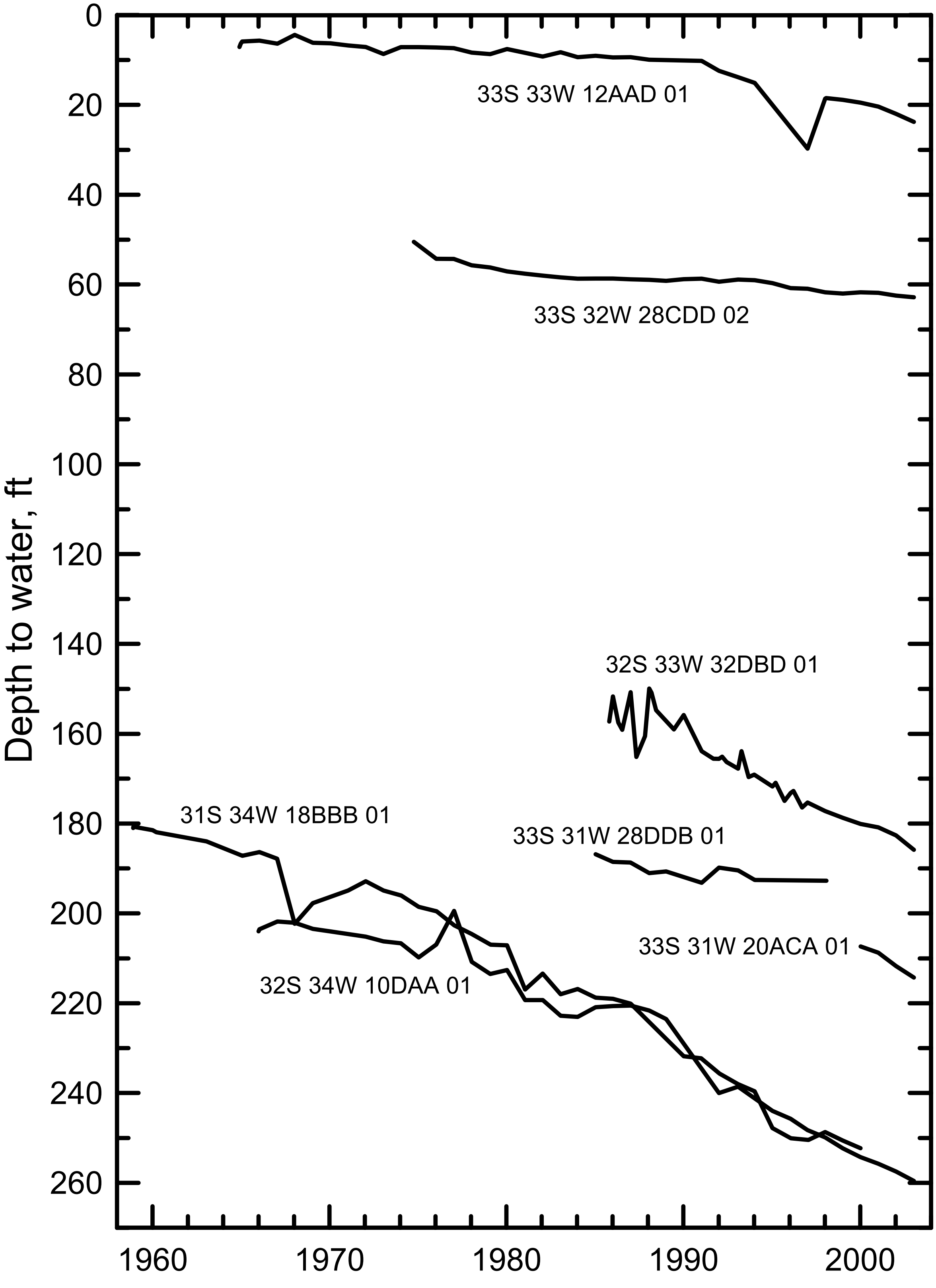


Figure 4.4 Water-level changes in wells within 2.5 miles of Cimarron River in Seward County.

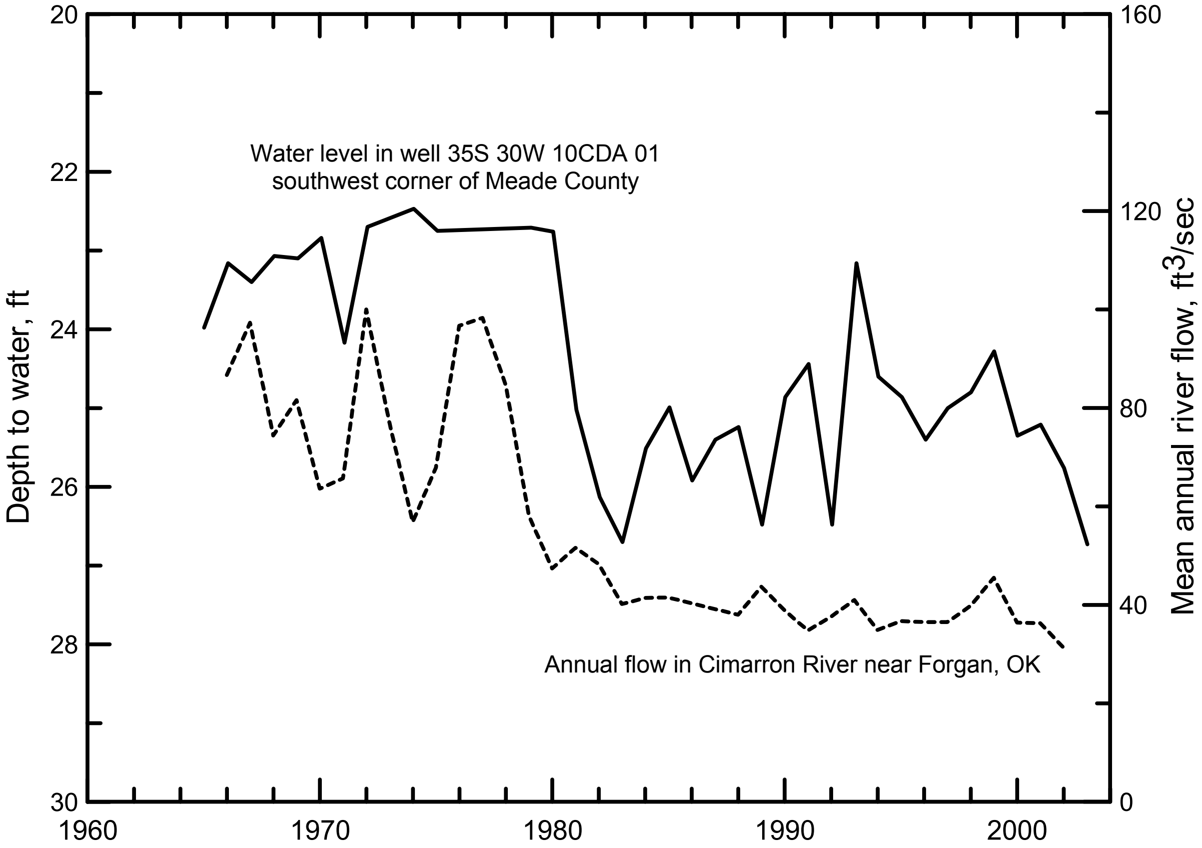


Figure 4.5. Ground-water level in well 35S 30W 10CDA 01 compared to mean annual flow in the Cimarron River north of Forgan, Oklahoma during 1965-2002 (KGS and USGS data).

The relationships among the elevation of the ground-water level, river channel elevation, and river flow will be examined in more detail in Seward and Meade counties, and also in Morton, Stevens, Grant, and Haskell counties as a part of fiscal year 2004 activities for Ogallala aquifer technical support. The evaluation will include an examination of the hydraulic gradient in the ground-water surface in the Cimarron River corridor and the lithology of the Ogallala-High Plains aquifer along the Cimarron River corridor relative to the gradient.

5. Potential Impacts of Past Land Use and Recharge Rates on the Water Quality of the Ogallala-High Plains Aquifer

Quantification of the available remaining water in, the rate of recharge to, and the usable lifetime of the Ogallala-High Plains aquifer in western Kansas has been the main focus of recent studies on the water resources of the aquifer. Although there are some investigations on water quality at specific locations or in subregions of the aquifer, there has been little emphasis on overall water quality. The quality of the remaining water for agricultural, industrial, and drinking supply uses is an issue that deserves attention and further research. The Kansas Geological Survey (KGS) conducted an overview of water-quality impacts related to land use and recharge to identify major quality issues needing future study (Townsend et al., 2002a, 2002b).

Land use in the Ogallala-High Plains aquifer area is dominated by agriculture, a large part of which is irrigated cropland. Water levels and water quality in the Ogallala-High Plains aquifer continue to be impacted by past land uses. KGS site studies and USGS National Water Quality Assessment (NAWQA) program regional studies show that irrigation recharge enhances the movement of contaminants to the water table. Overall increases in nitrate-N (20% - 80%), chloride (11% - 50%), and sulfate (4% - 90%) concentrations and specific conductance (3% - 30%), measured at the same irrigation wells in the 1970s and 1990s indicate movement of contaminants to the water table. The USGS NAWQA study has observed atrazine and its metabolites in soil water and at the water table at monitoring sites. Nitrogen-15 analyses of soil water and ground water indicate that row crop and feedlot agriculture are major sources of contamination.

Recharge estimates and calculated fluxes by both KGS and USGS show that recharge from flood irrigation return flows moves contaminants faster than does natural recharge or center pivot or drip irrigation. Still, the amount of recharge is only a fraction of the amount of water pumped for irrigation. Although irrigation efficiency improvements could result in slower downward movement of contaminated water in the distant future, the current problem is to determine (1) the quantity of contaminated water in transit to the aquifer within the next few decades, and (2) whether the quality of water will sustain current and future demands in the area. Estimates of the quantity of contaminated water are limited by the lack of good recharge estimates for specific portions of the aquifer. Rough estimates can be made but geologic variability in the aquifer thickness and composition prevents accurate site-specific estimates. For more information, see KGS OFR 2002-25B: Best Estimates of Aquifer Recharge: Magnitude and Spatial Distribution (Hecox et al., 2002), which is available from the Ogallala-High Plains Aquifer Information page at http://www.kgs.ukans.edu/HighPlains/OHP/index.htm. Current work by KGS on the lithologic framework of the aquifer in southwest and northwest Kansas will provide data that will help in estimating recharge and areal amounts of contaminated water moving through the unsaturated zone. The quality of water is also variable throughout the aquifer and is most impacted by land uses. A more detailed water-quality and land-use study throughout the High Plains aquifer region will enhance the ability to more accurately identify potential problem areas in the future. Additional information for this section will be made available online on the KGS Ogallala-High Plains aquifer web site as KGS OFR 2002-58:

Potential Impacts of Past Land Use and Recharge Rates on the Ogallala Aquifer: Water Quality Issues in Kansas (Townsend et al., 2002b).

Acknowledgments

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