Kansas Geological Survey

Technical Series 19

January 2002 Kansas Water Levels and Data Related to Water Level Changes

by

John J. Woods and Marios A. Sophocleous

January 2004

Abstract

Water levels measured in January 2002 generally showed slightly fewer declines and slightly fewer rises than those measured in January 2001, except in the south-central region, where slightly more declines were observed. The 2002 measurements (a total of 1,370 in all) showed an average water-level decline of 0.91 ft (27.7 cm) for the 2001-2002 period compared to an average decline of 1.26 ft (38.4 cm) during the 2000-2001 period. The single largest rise in water level was 10.2 ft (3.11 m) and the largest decline was 14.4 ft (4.39 m) for the wells in this report. Annual water-level declines outnumbered rises 73% to 26% compared to 80% declines and 20% rises in the 2001 report. Regional breakdowns of the data indicate a continuing trend of decline in region I, a slight shift toward less decline in region II, a marked shift toward less decline in region III, and a slight shift toward more decline in most of region V with water-level rises occurring in the northwestern portion. More specifically, water-level declines occurred in nearly all of region I, but appreciably large areas of rise occurred mainly in Kearny, Finney, and Morton counties. In region II, the total area of decline decreased in Greeley and Wichita and increased in Scott and Lane counties. The total area of rise greater than 1 ft in region II decreased relative to the 2001 measurements, while the total area of relatively stationary water levels increased. The total area of water-level decline in region III markedly decreased during 2001-2002, while the total area of relatively stationary water levels and rises increased. In region V (south central region), where the water table is relatively shallow, a slight increase in the total area of water-level decline occurred over most of the region, while significant areas of water-level rise occurred over most of the region.

Introduction

In this report, we summarize hydrologic data from the cooperative program of ground-water-level measurements in Kansas along with suitable supplementary data from other sources. This program is carried out jointly by the Kansas Geological Survey and the Kansas Department of Agriculture's Water Resources Division and involves water-level measurements on a network of approximately 1,400 wells. The U.S. Geological Survey publishes a compilation of water-resources data annually on a water-year basis (October 1–September 30) (see the list of references in appendix A). This Kansas Geological Survey report presents the annual water-level data in the context of both recent and long-term water-level changes to provide information on the ground-water resources of the state.

Appendix A is a list of publications containing ground-water-level data for Kansas. Appendix B contains information on well locations and characteristics, past and present water-level measurements, trends in the measurements, and other information on water resources. To make this information more understandable, we provide in the text that follows some basic definitions and descriptions of the occurrence of ground water in Kansas, a discussion of the relationship between precipitation and ground water, and tables and maps summarizing the long- and short-term changes in water levels in selected areas of the state. Appendix C lists those wells previously reported that are not contained in this report because of a lack of recent data. Wells that have not been measured for three consecutive years or wells that have been taken out of service have been eliminated from this report.

Areal information in this report is generalized and regional in nature and should not be used in place of site-specific data collection for decisions concerning local ground-water conditions.

Data-collection Program

Most of the wells in the water-level-measurement program are measured annually, some are measured quarterly, and a few are equipped with continuous recorders. For continuously recorded wells, depth-to-water values are picked from the record at specific times, typically one value per month. Because many of the wells are used for irrigation or are in areas of major irrigation pumpage, the annual measurement program is timed for mid-winter to maximize the recovery of water levels from seasonal pumping. The nominal time of measurement is January, but for logistical reasons, some of the wells are measured in December of the preceding year or in February of the reporting year. Because of this, the current water-level report presents data collected before the irrigation season of the present year and includes measurements taken from December through February. In this report, the shallowest depth-to-water measurement made during this three-month period was chosen as the measurement for the current year at each well. This is assumed to be the most recovered depth-to-water measurement. A discussion of data-acquisition methods can be found in KGS Open-file Report 2002–1 entitled *2002 Annual Water Level Raw Data Report for Kansas*.

Ideally, the data should provide a snapshot of regional water levels undisturbed by pumping or other influences. In practice, recovery of local water levels from pumping depends on several factors, including the local hydrogeology, the schedule of pumping, the volume of irrigation water pumped during the preceding season, and the proximity of high-capacity industrial or municipal wells that are pumped year round. Other factors can also influence the apparent water levels, such as changes in barometric pressure or the method of measurement. An apparent change in water level for a particular well during a one-year period may reflect only temporary deviations from the fully equilibrated water table. Because of these uncertainties, any assessment of trends should be based on a comparison of changes that occur over a period of several years or that emerge as a consistent geographic pattern involving a number of wells.

Aquifers and Ground-water Occurrence

Bedrock or unconsolidated sediments that have a sufficiently large number of interconnected pores to contain substantial amounts of extractable water are defined as aquifers. In Kansas, most of the regional aquifers occur in the western and south-central portions of the state. Because these areas receive relatively little rainfall, ground water is extensively used. Fewer ground-water resources are found in eastern Kansas, and surface water is used for many water supplies. For a general overview of the aquifers in Kansas, we refer readers to *Kansas Ground Water*, Educational Series 10, and Chapter 1 (Water resources of Kansas-A Comprehensive Outline) in Bulletin 239 (*Perspectives on Sustainable Development of Water Resources in Kansas*), published by the Kansas Geological Survey in 1993 and 1998, respectively.

Aquifers are more commonly known by popular or geographic names that may or may not coincide with the names of the formations that make up the aquifer.

Throughout Kansas, stream and river systems flow over unconsolidated Quaternary alluvial deposits that may be locally important sources of ground water, forming stream-aquifer systems. Depending on the conditions in the stream and in the aquifer, considerable interchange of water between the subsurface and the stream may occur. The High Plains aquifer consists of the Ogallala Formation and associated Quaternary deposits in western Kansas and the Quaternary alluvial deposits of the Equus Beds and Great Bend Prairie in south-central Kansas. The Dakota is a regional bedrock aquifer in western and central Kansas that consists of sandstones in the Dakota and Kiowa Formations and in the Cheyenne Sandstone. In southeastern Kansas, the major bedrock aquifer is the Ozark aquifer, which consists of solution cavities and fractures in Ordovician and Cambrian limestone and dolomite formations. In northeastern Kansas, Pennsylvanian sandstones in the Lawrence and Stranger Formations are a locally important source of ground water for small municipal and domestic users.

The tables in appendix B contain abbreviated designations of the geologic units that make up the aquifers. These abbreviations, along with descriptions of the geologic units and the aquifers with which they are associated, are listed below.

TABLE 1. Abbreviations and descriptions of geologic unit codes used in this report.

Symbol	Description	Aquifer name
QA	Quaternary alluvium	alluvial
KD	Cretaceous Dakota and Kiowa Formations and Cheyenne Sandstone	Dakota
KN	Cretaceous Niobrara Chalk	
KJ	Lower Cretaceous/Upper Jurassic undifferentiated	Dakota/Morrison
PL	Pennsylvanian Lawrence and Stranger Formations	Douglas Group
TO/QU	Tertiary Ogallala Formation/ Quaternary undifferentiated	High Plains
JM	Jurassic Morrison Formation	Morrison
OU	Ordovician undifferentiated	Ozark

Factors Influencing Infiltration, Recharge, and Water-level Fluctuations

Most aquifer systems are recharged primarily by the percolation of infiltrated precipitation that moves downward through the soil zone to the water table. Recharge also may result from downward seepage from water bodies at the earth's surface.

Infiltration of water through the soil is affected by a number of interrelated factors. The intensity and duration of precipitation affect this rate. Moderate rainfall over an extended period favors infiltration and deep percolation. Heavy rain over a short period will eventually exceed the soil's ability to absorb and transmit water, and will produce appreciable surface runoff. Drainage patterns within a watershed and local topography also affect infiltration rates. In general, steep slopes favor rapid surface runoff, and gentle slopes retain water longer, favoring infiltration. However, extremely flat terrain often develops tight surface soils that impede infiltration. Land use, agricultural practices, and vegetation also influence the balance between appreciable surface runoff, recharge, and evaporation.

The rate of recharge also varies with the permeability and thickness of the soil and other earth materials, which the water must infiltrate to reach the zone of saturation. Relatively rapid downward movement commonly occurs where the soils contain a greater proportion of sand and silt than clay. However, even in areas where the soil zone is dominated by sand, thin clay layers may significantly retard the downward movement of recharge.

The major factors that cause water-level fluctuations in an aquifer are the volume, rate, and timing of ground-water pumping in the area and the rate of replenishment by local recharge or regional flow. If the annual ground-water pumpage from an aquifer exceeds its replenishment, the elevation of the water table will decline. Likewise, if the annual pumpage is less than or equal to the amount of water that can be supplied by local recharge or regional flow, the water table will rise or remain unchanged. The response of a deep water table to recharge events may be delayed for years or decades (such as in much of northwestern and southwestern Kansas). In contrast, a shallow water table in permeable sediments may respond rapidly to recharge events.

Hydrographs and Precipitation Graphs

For this report, the state is divided into eight ground-water regions (fig. 1A). Regional tables and maps depict ground-water-level changes in the major aquifers of the central and western parts of the state. Regions I, II, and III cover the Ogallala aquifer and coincide approximately with the areas of Groundwater Management Districts 3, 1, and 4, respectively. Region V covers the Great Bend Prairie and Equus Beds regions and is roughly coincident with the combined areas of Groundwater Management Districts 2 and 5. No tables or maps are included for the remaining four regions because few wells in these areas are measured on an annual basis. The statewide distribution of wells measured during this reporting period is indicated in fig. 1B.

Hydrographs are plots of the depth to water or the water-level elevation in a given well as a function of time. These graphs are used to portray long-term changes in ground-water levels and short-term fluctuations resulting from recharge or pumpage. In this section, we present several representative well hydrographs and local rainfall records for various aquifers and geographic regions. The hydrographs in figs. 2–8 contain historical information regarding precipitation and water-table fluctuations in Douglas, Finney, Hamilton, Osborne, Scott, Sedgwick, and Thomas counties. Precipitation is measured at stations with complete records that are reasonably close to the well at which measurements are taken. The station number consists of an 8-digit code consisting of a 2-digit state code followed by a 4-digit chronological index number followed by a 2-digit geographic division number. The increases in ground-water usage and the associated declines in the water table in some counties are demonstrated on several of the graphs.

In viewing the graphs in figs. 2–8, it is important to remember that rainfall and water levels are represented by two different types of measurements. The precipitation is expressed as the annual total for the preceding calendar year at a specific location in the general vicinity of the

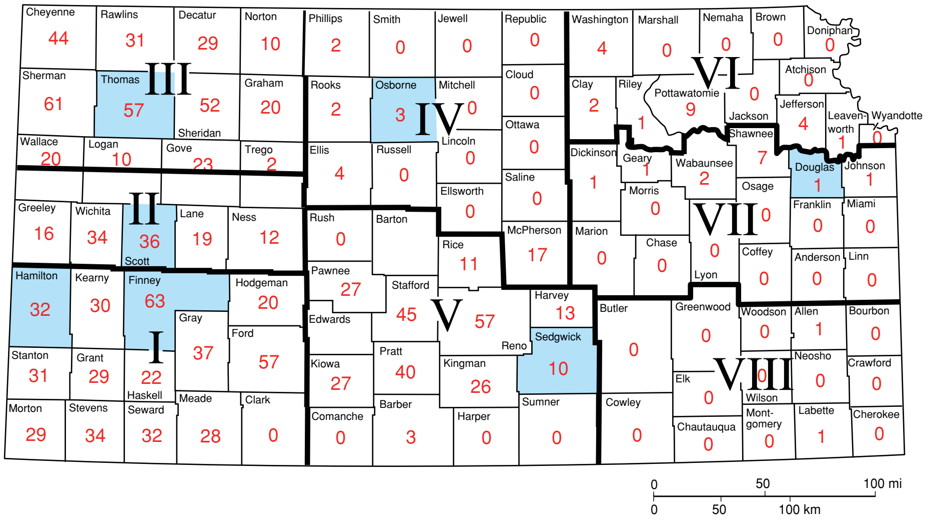

FIGURE 1A. Number of ground-water-level observation wells measured in each county for the 2002 water-level census. Shaded counties are those for which precipitation graphs and well hydrographs are presented in the text.

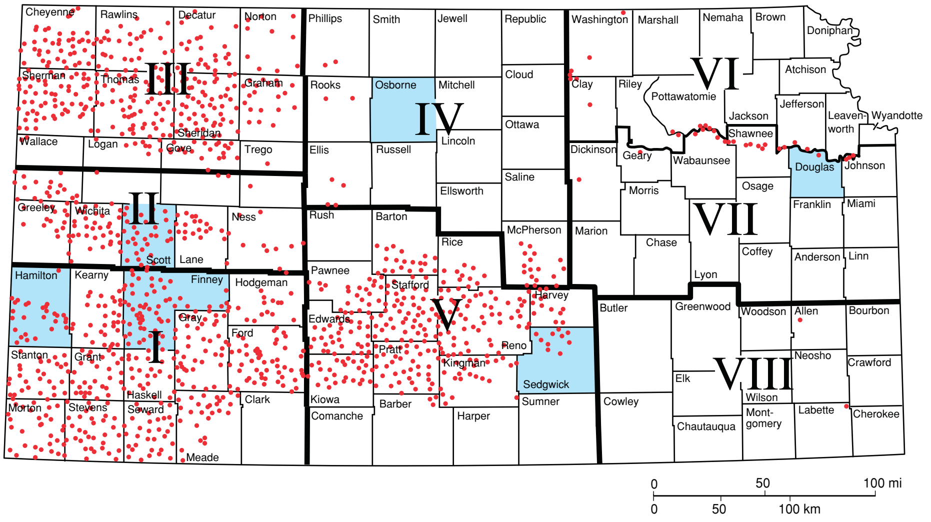

FIGURE 1B. Distribution of ground-water-level observation wells measured for the 2002 water-level census.

well. The corresponding depth-to-water measurement is taken at a single point in time, before the onset of irrigation, usually early in the year. Although the graphs are a reasonable way to compare the available data, no direct correspondence exists between the plots. The relationship is only theoretical, because of the importance of the timing of precipitation events to the recharge process. For example, a wet spring season may have less influence on next year's water level than a single storm event closer to the time of water-level measurement.

Some of the graphs in figs. 2–8 display discontinuous lines. The breaks indicate years during which the data-collecting agencies encountered sampling problems, resulting in no data having been reported in the desired time interval. No attempt is made to connect these data points because of the variable and seasonal nature of the natural processes. Lines joining two points do not accurately represent the behavior of the water table between sampling observations. In all of the hydrographs, measurements were plotted primarily for the months of December or January.

The figures demonstrate that the deeper aquifers in more arid regions do not show rapid responses to recharge events because of the greater thickness of the unsaturated zone and the low recharge rate. Water levels in shallow aquifers, however, respond more rapidly to recharge. This is particularly true where surface water and ground water commonly interact.

Douglas County, Alluvial Aquifer (QA)

The observation well in fig. 2, for Douglas County (see also fig. 1B), is screened in the Kansas River alluvium. In this area, alluvial deposits are the primary geologic unit for water usage and yield water of good quality and moderate quantity. The alluvium consists of unconsolidated clay, sand, and gravel located along the river's course. The thickness of the alluvial deposits varies according to the cumulative amount of downcutting and sedimentation by streams.

The hydrograph of the Douglas County well 12S–20E–07CBC–01 (figs. 2 and 1B) illustrates a relatively prompt response of the water table to precipitation. This is probably because of the shallow depth of the water table, relative proximity of the well to the river, the types of sediment through which the water moves, and the small volume of ground water pumped in the area.

Finney County, High Plains Aquifer (QU, TO)

Most of the observation wells in Finney County (fig. 1B) are screened in the High Plains aquifer. The depth to bedrock (bottom of the aquifer) at well 24S–33W–28DAA–01 (fig. 3) is 386 ft (118 m), and the well is screened in deposits that consist of poorly consolidated sand and gravel of Pleistocene age.

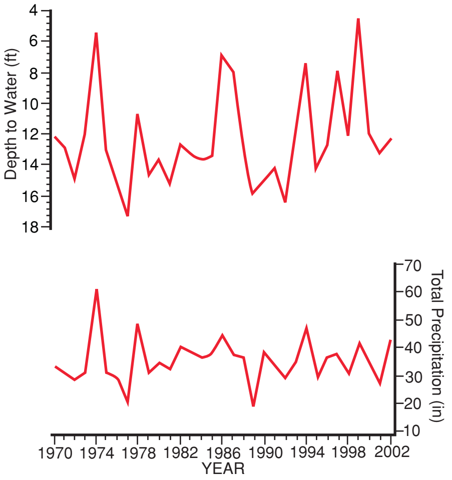

FIGURE 2. Depth to water in Douglas County, well 12S-20E-07-CBC-01 [29 ft (8.8 m) deep; alluvial aquifer], and precipitation at Topeka WSFO (Weather Station Forecast Office) airport (station 14816706).

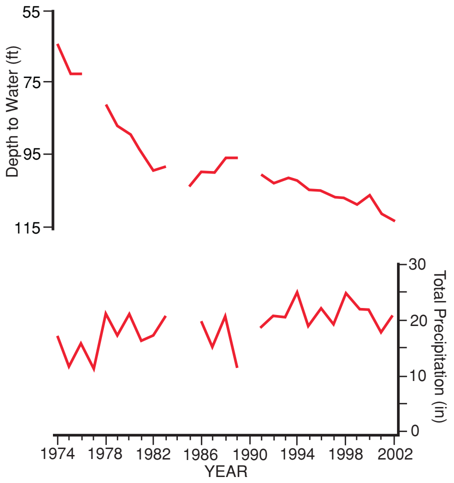

FIGURE 3. Depth to water in Finney County, well 24S-33W-28-DAA-01 [350 ft (107 m) deep; High Plains aquifer], and precipitation at Garden City Experiment Station (station 14298007).

The depth to water for 2002 is 113.2 ft (34.5 m). Compared to the 1940 depth to water of 34 ft (10.4 m) (Appendix B, Finney County), the decline of 79.2 ft (24.1 m) represents a decrease of about 22% in saturated thickness. Changes in saturated thickness of this magnitude or greater for the period 1940–2001 are typical of the High Plains aquifer in Finney County.

Figure 3 illustrates the lack of effect of precipitation recharge on the water table in the High Plains aquifer and the prominent effect of ground-water pumping on the water table in the area. As the graph indicates, precipitation has fluctuated over time with an average annual total of 18.3 inches/yr (46.5cm/yr).

Hamilton County, Alluvial Aquifer (QA)

The aquifers used in Hamilton County are associated with various geologic units (KJ, TO, QU, QA). The hydrograph (fig. 4) is for well 23S–43W–21–ABA–01 (fig. 1B) in the Quaternary alluvium of the Arkansas River valley. This aquifer system consists of unconsolidated sand and gravel at relatively shallow depths. The depth to bedrock at the well is 29 ft (8.8 m), with a 1940 depth to water of 15 ft (4.6 m) and a 2002 depth to water of 13.4 ft (4.08 m). This local increase in saturated thickness is reasonable for an alluvial aquifer because the water level fluctuates in response to recharge from the Arkansas River and from rainfall events. However, aquifer systems such as the High Plains and Dakota aquifers in Hamilton County show steady, long-term declines in water levels. This is the result of ground-water withdrawals that exceeded natural recharge. Some wells in the area show declines in excess of 70 ft (21 m) since predevelopment, as shown in appendix B.

The hydrograph (fig. 4) for well 23S–43W–21–ABA–01 shows some relationship between precipitation and water levels. Large-scale and variable local irrigation-pumping can influence these relationships. In addition, precipitation, water use, and releases from the John Martin reservoir in Colorado influence streamflow in the Arkansas River over a much larger area than that represented by the single precipitation gauge.

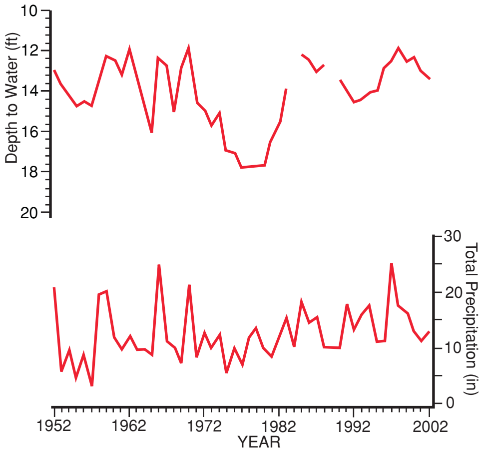

FIGURE 4. Depth to water in Hamilton County, well 23S-43W-21-ABA-01 [29 ft (8.8 m) deep; alluvial aquifer], and precipitation at Syracuse (station 14803807).

Osborne County, Terrace Deposits of Quaternary Age (QU)

Osborne County contains few observation wells for data collection (fig. 1B). The major aquifers in this county are the Dakota (KD) and the terrace deposits of Quaternary age (QU). The hydrograph of the observation well 06S–12W–23–CDC–01 is presented in fig. 5. The well is in terrace deposits along the North Fork Solomon River.

The combined effects of recharge, ground-water pumping, releases from upstream reservoirs, and surface-water irrigation on yearly changes in water level influence the hydrograph. Precipitation patterns drive these factors directly or indirectly. In turn, these factors interact in various ways that either cancel their influence (e.g., diverting surface water can be less expensive than pumping and is therefore used in its place) or compound it (e.g., increased rainfall increases reservoir levels, which allows for more instream releases). The well is completed in terrace deposits consisting of sand, gravel, and clay and has a shallow water table [with an average depth to water of 13–28 ft (4.0–8.5 m)]. These permeable materials allow the water table to respond more rapidly to local recharge and changes in the stream-channel water level. A comparison of figs. 2 and 5 supports these conclusions. The well in fig. 2 also is an alluvial well, but it is not subject to fluctuations resulting from variable local releases and irrigation. Thus, depth to water and precipitation in fig. 2 show greater correspondence than in fig. 5.

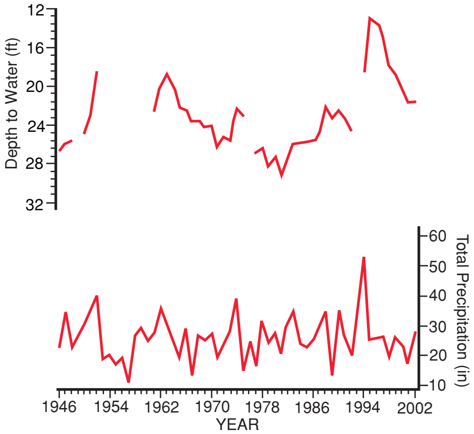

FIGURE 5. Depth to water in Osborne County, well 06S-12W-23-CDC-01 [31.8 ft (9.69 m) deep; unconsolidated Quaternary aquifer-alluvial terrace deposits], and precipitation at Cawker City (station 14137102).

Scott County, High Plains Aquifer (TO)

All the observation wells in Scott County (fig. 1B) are screened in the Ogallala Formation (TO). In this area, the High Plains aquifer consists of the Ogallala Formation, which is composed of sand, gravel, silt, and clay and overlain by Pleistocene loess deposits of sand, silt, and clay. Well 20S–33W–09BBB–01 is used for the hydrograph (fig. 6), and it penetrates 128 ft (39.0 m) to the bottom of this aquifer.

The 2002 depth to water is 102.2 ft (31.2 m). Compared to the 1950 level [60 ft (18.3 m)] (appendix B, Scott County), the water-level decline is 42.2 ft (12.9 m) and represents approximately a 62% decrease in saturated thickness for this period, which is typical of the High Plains aquifer in Scott County.

The water-level changes and the low and variable annual rainfall shown in the hydrograph (fig. 6) bear no observable relationship. This is consistent with other studies that indicate that average annual recharge is on the order of 0.25 inch/yr (0.6 cm/yr) and that the time required for water to move from the surface to the water table in some locations is more than 30 years. Clearly, the dominant effect is the decline in the water table resulting from ground-water pumping.

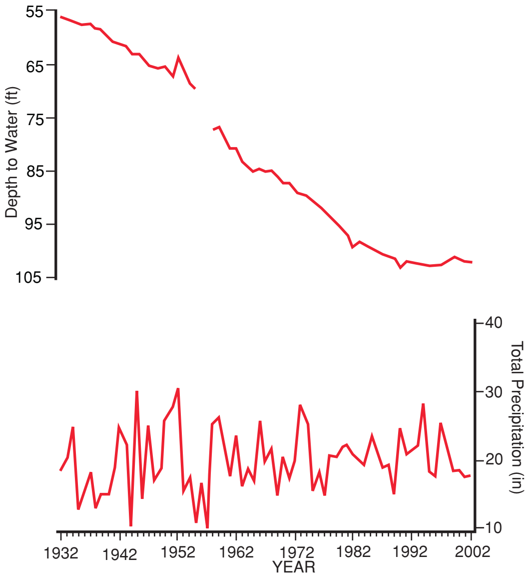

FIGURE 6. Depth to water in Scott County, well 20S-33W-09-BBB-01 [128 ft (39.0 m) deep; High Plains aquifer], and precipitation at Scott City (station 14727104).

Sedgwick County, Alluvial Aquifer (QA)

The hydrograph of the observation well 25S–01W–14–DDD–01 (figs. 7 and 1B) is representative of ground-water conditions in Sedgwick County and is screened in the Arkansas River alluvium. The hydrograph illustrates the effect of recharge on changes in water level on a yearly basis. Because this well is shallow and located in alluvial terrace deposits with an average water-table depth of 15–20 ft (4.6–6.1 m), the depth to water is greatly influenced by recharge from the river and infiltrating precipitation.

A comparison of fig. 7 with figs. 2 and 5 shows that the Sedgwick County well is more similar to the Douglas County well in the Kansas River alluvium (fig. 2). Unlike the well in Osborne County (fig. 5), the wells in Sedgwick and Douglas counties are subject to streamflow regimes and are less affected by local flow regulation.

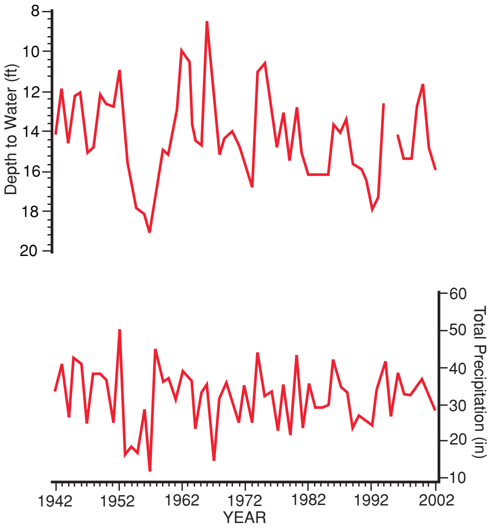

FIGURE 7. Depth to water in Sedgwick County, well 25S-01W-14-DDD-01 [alluvial aquifer], and precipitation at Mount Hope (station 14553908).

Thomas County, High Plains Aquifer (TO)

The primary aquifer in Thomas County is the High Plains, which consists of the Ogallala Formation in this area. The Ogallala is composed of sand, gravel, silt, and clay and is overlain by Pleistocene loess. The distribution of measured wells in Thomas County is shown in fig. 1B. The depth to bedrock at observation well 08S–34W–01–BAC–01 is 270 ft (82.3 m). The depth to water in this well has increased from 113 ft (34.4 m) below land surface in 1950 to 134.3 ft (40.9 m) in 2002. This drop in water level represents a 14% decrease in saturated thickness since predevelopment.

As in the hydrograph for Scott County (fig. 6), the hydrograph in fig. 8 shows no obvious correspondence between total annual rainfall and the depth to the water table. In this part of Kansas, the water table in the High Plains aquifer is much deeper than it is elsewhere in the state. This deep water table combined with thick, overlying, unsaturated sediments and low annual rainfall results in long time-lags between rainfall and recharge. The long-term imbalance between ground-water withdrawal and replenishment is evident from the decline of water levels over a 50-year period with relatively stable amounts of precipitation.

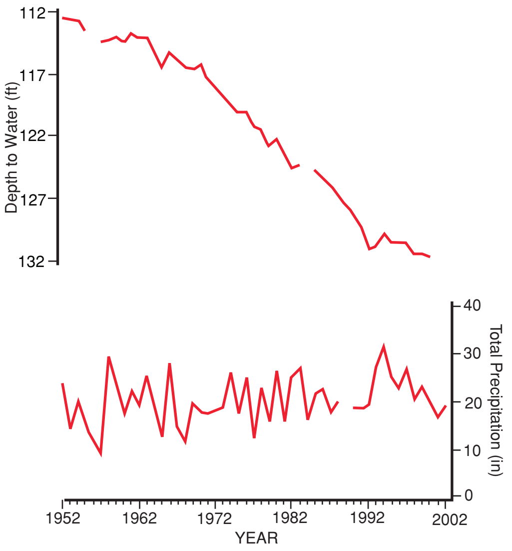

FIGURE 8. Depth to water in Thomas County, well 08S-34W-01-BAC-01 [175 ft (53.3 m) deep; High Plains aquifer], and precipitation at Colby 1 SW (station 14169901).

Regional Change in Water Levels

As mentioned previously, the state of Kansas has been divided into eight hydrologic regions (see fig. 1A). In regions IV, VI, VII, and VIII, the water-level data are too sparse to lend themselves to regional analysis (fig. 1B). For each of the remaining four regions that contain major portions of the High Plains aquifer, two types of water-level change are presented in this section. Each is based on the measured depths to water reported in appendix B. Because the amount of water available and the elevation of the water table both decrease as the depth to water increases, changes are discussed in terms of change in water level, or elevation of the water table.

Because wells are normally measured in the same month in each sample year, this provides a benchmark for short-term changes, and differences between successive annual measurements are reported as the annual change. Long-term effects are represented by changes since the predevelopment period. The predevelopment water level represents conditions before ground water in that region was used extensively and is usually taken as a specific year in the range 1940–1950, depending on the availability of early data for the region.

Tables 2–9 summarize regional changes in water level since the predevelopment period and during the past seven years. Figures 9–12 are divided into three maps each, depicting the spatial distribution of water-level and saturated-thickness changes in the High Plains aquifer. Part A of each figure displays a generalized interpretation of the absolute vertical change in water level from the assigned predevelopment period to the present. Part B shows a generalized interpretation of the percentage change in the saturated thickness of the aquifer from predevelopment to present. Finally, part C shows the generalized change in water level since the last annual sample. The areal extent of the High Plains aquifer is shown as an outline on each map, and except for fringe areas, generally coincides with the shaded regions. On each map, an average value of the variable (water-level change or percent change in saturated thickness) is determined for each section in a township. The sections are then classified into different intervals according to their specific average values. For example, all sections with an average decline of water level since predevelopment between 25 to 50 ft (7.6–15.2 m) are shaded the same color and assigned to the interval that is labeled 25 to 50 ft decrease, and so forth. The classification schemes are based on the range of possible values, are limited as to the total number of classes, and therefore may vary from one region to another. It also must be kept in mind that the general intensities of colors may differ from one annual report to the next. In this report, we have indicated areas of sparse data in figs. 9–12.

For the production of figs. 9–12, not every well listed in the tables of appendix B was used. Wells drilled in any formations of type KD, KN, JM, KJ, PL and OU (even in combination with any other type) were not used because these formations are not considered part of the High Plains aquifer system. Wells drilled in formations of type QA were included in all regions (if not in combination with any of the types mentioned immediately above) unless these wells were believed to be part of "perched" alluvial systems. There were seven wells drilled in these perched sediments in this report that had 2002 measurements.

Statistical analysis is an important tool for understanding observed patterns of ground-water data. This report employs a statistic to help describe the behavior of annual water-level changes. Tables 3, 5, 7, and 9 report the results of a "paired t-test" on the difference between each successive annual depth-to-water measurement for each well. This statistic, the average of all annual water-level changes, is tested to determine whether that difference is large enough to indicate that a "statistically significant" change has occurred. Statistical significance relates the value of a statistic with the probability of observing that calculated value. It is often measured by the "p-value." This quantity reports the probability of encountering a larger value than was calculated from the sample of data. A 5% level of significance is commonly used as an indication of statistical significance (this convention is followed in this report). This means that the p-value must be less than 0.05 (5%) to indicate statistical significance. In other words, there is less than a 5% risk that the statistic could be larger, by random chance. This is commonly accepted as sufficient evidence of a statistically significant result. However, there remains a 1 in 20 (5%) chance that this relationship is not significant. Conversely, if statistical significance is rejected because of a large p-value, a possibility always remains that the difference is nonetheless real.

Region I: Southwestern Kansas

Table 2 shows the changes in regional water levels since predevelopment in the High Plains aquifer for this region. From this table, one can see that the average decline from predevelopment to 2002, 55.6 ft (16.9 m), is quite large. Furthermore, the map in fig. 9A shows large areas of decline of greater than 100 ft from predevelopment ground-water levels in parts of Stanton, Grant, Haskell, Stevens, Kearny, and Finney counties. Because of the large original saturated thickness of the High Plains aquifer in this area, substantial reserves of ground water still exist. There are limited areas, primarily in Grant, Stanton, Morton, and Finney counties, where saturated thickness has decreased by more than 50% (see fig. 9B).

Annual changes in water level (table 3) for Region I show an average decline of 1.7 ft (52 cm) this reporting year, compared with 2.2 ft (67 cm) last year. Declines in water levels were observed in 85% of the wells reported, compared to 88% last year. The average water-level change for this region is statistically significant (table 3). The annual change map for 2001–2002 (fig. 9C) shows water-level declines of at least 0 to 5 ft over most of the region. Furthermore, as in 2000-2001, there were significant areas of decline greater than 5 ft (1.5 m), and some small areas of decline greater than 10 ft (3 m). The largest areas of 5 to 10 ft decline were observed in southeastern Stevens and southeastern Haskell counties, where small areas of 10-ft or greater decline were observed. The largest areas of water-level rise were found in northeastern Kearney, northwestern Finney, and in northeastern Morton counties. Smaller areas of water-level rise were observed in Grant, Ford, Stanton, and Stevens counties. These observations indicate a continuation of a trend of a water-level decline over most of the region during 2001-2002. Possible explanations for this trend are the summer 2000 and 2001 heat wave and drought, which may have led to increased water use in the region during 2000 and 2001.

TABLE 2. Change in water level (ft), predevelopment to present, for reported wells in region I.

Year	Average change	Number of wells	Largest rise	Largest decline
1996	–53.4	307	18.6	216.9
1997	–52.2	304	19.9	218.9
1998	–51.4	303	20.1	216.8
1999	–52.3	296	19.3	218.0
2000	–51.9	283	18.5	218.1
2001	–54.3	281	15.8	220.8
2002	–55.6	274	17.1	219.4

TABLE 3. Annual change in water level (ft), for reported wells in region I.

Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of well with decline[a]	Is change statistically significant?
1996–1997	–0.3	423	20.0	21.1	43	57	no
1997–1998	–0.1	442	19.1	30.2	45	55	no
1998–1999	–1.1	438	31.6	12.6	19	80	yes
1999–2000	–0.8	432	21.9	15.7	36	64	yes
2000–2001	–2.2	431	5.2	27.5	11	88	yes
2001–2002	–1.7	438	10.2	14.2	15	85	yes

a. The percentage of wells with water-level rises and the percentage of wells with water-level declines will not always sum to 100. Each year it is possible that a small number of wells will remain at the same level as the previous year.

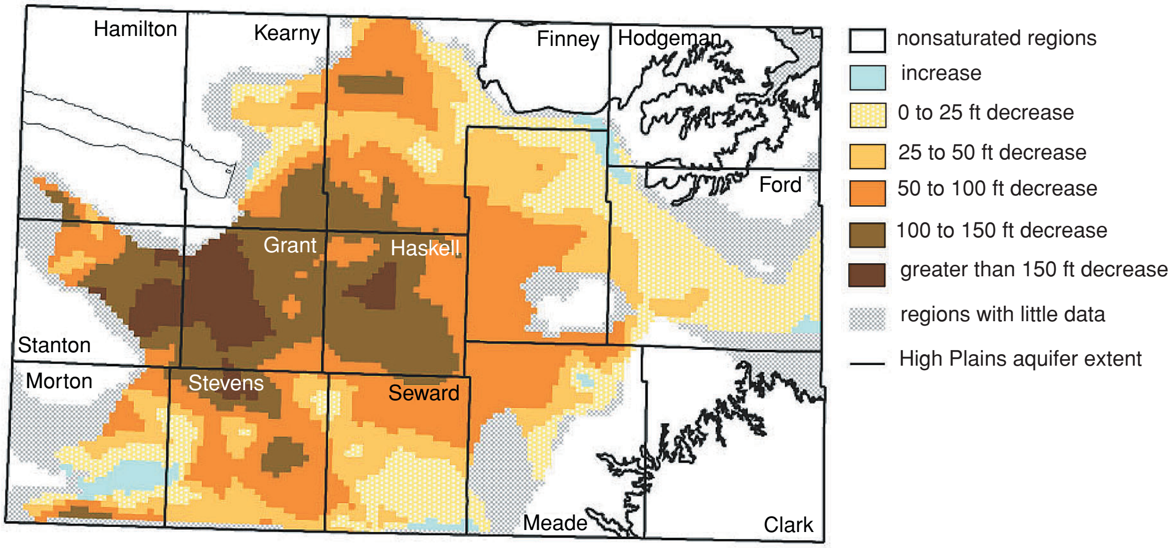

FIGURE 9A. Ground-water changes in the area of the High Plains aquifer in Region I, southwest Kansas. See fig. 10 for adjacent areas to the north, and fig. 12 for adjacent areas to the east. (A) Generalized water-level changes (ft), predevelopment to 2002.

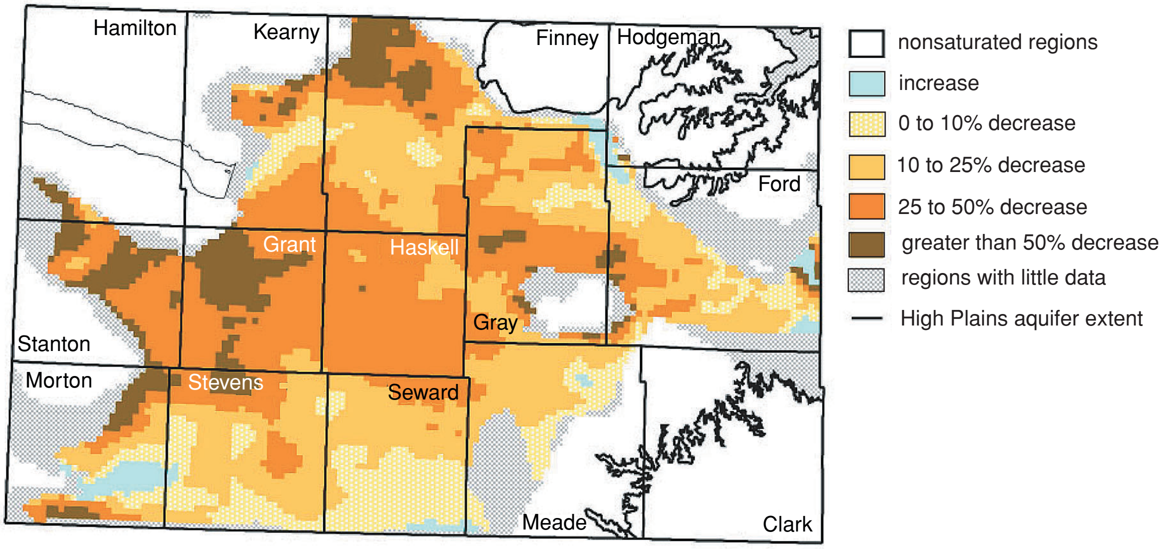

FIGURE 9B. Change in saturated thickness (%), predevelopment to 2002.

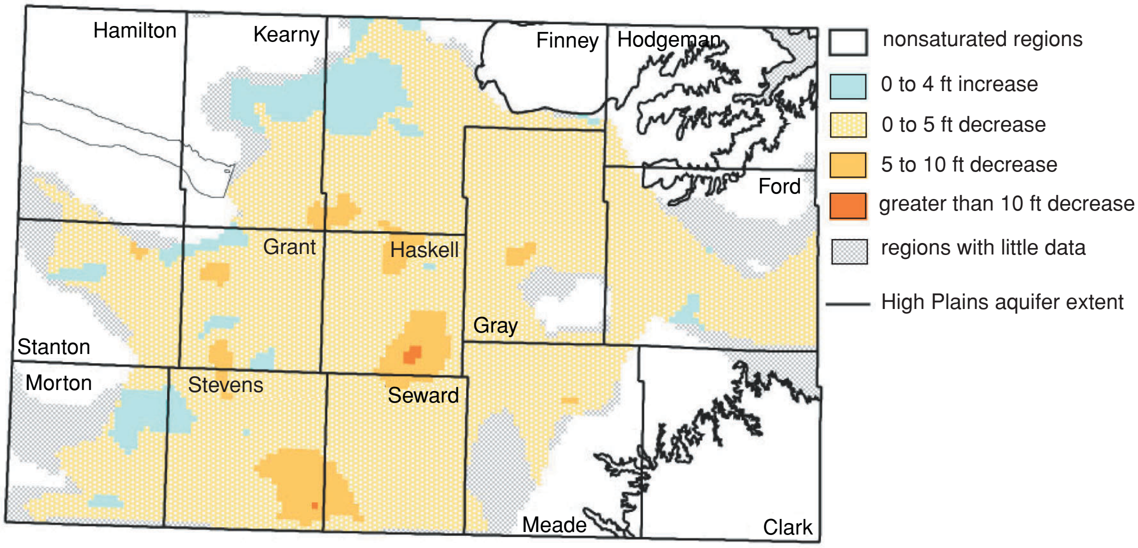

FIGURE 9C. Annual water-level change (ft), 2001-2002.

Region II: West-central Kansas

Region II encompasses Greeley, Wichita, Scott, Lane, and Ness counties as well as the southern half of Wallace, Logan, Gove, and Trego counties. In this region, the High Plains is the primary aquifer. The average decline in water level since predevelopment for reported wells (table 4) has been approximately 34.5 ft (10.5 m), with the largest decline equal to 87.0 ft (26.5 m). Water-level declines since the predevelopment period (fig. 10A) exceed 50 ft (15 m) primarily in Wallace, Greeley, Wichita, and Scott counties. The areal extent of the largest declines seems to be about the same as that observed in 2001. The depth-to-bedrock in region II is generally less than that in regions I and III, consequently, small declines in water-level elevation represent a larger percentage (50% or more in many areas—see fig. 10B) of the original water reserves than is the case in the Ogallala aquifer in regions I and III. The hydrograph for Scott County (fig. 6) illustrates the typical pattern of decline in the region.

Water levels in region II declined by an average of 0.6 ft (18 cm) in the 2001-2002 period, a change that was statistically significant (table 5). The percentage of wells exhibiting a decline was more than the percentage of wells exhibiting a rise (73% vs. 27%). As fig. 10C indicates, the total area of decline greater than 1 ft (0.3 m) has decreased in Greeley and Wichita counties and increased in Lane County relative to the 2000-2001 period. Small areas of greater than 5-ft decline were observed in Wallace, Greeley, and Wichita counties. The total area of rises during the 2001-2002 period decreased relative to that observed in the 2000-2001 period with small areas of water-level rise appearing in Wallace, Greeley, Wichita, and Scott counties. Areas of relatively stable water levels (1-ft (0.3-m) rise to 1-ft decline) increased relative to the 2000-2001 period, especially in Wichita County. These results indicate a slight shift toward fewer declines in region II. Dwindling ground-water resources and the “zero depletion” policy of west-central Groundwater Management District 1 have discouraged excessive use of ground water in this region.

TABLE 4. Change in water level (ft), predevelopment to present, for reported wells in region II.

Year	Average change	Number of wells	Largest rise	Largest decline
1996	–35.3	108	2.8	95.2
1997	–34.8	110	3.0	84.7
1998	–36.7	121	3.1	83.6
1999	–35.4	109	3.2	83.2
2000	–35.3	101	3.1	84.8
2001	–34.3	95	3.2	86.9
2002	–34.5	93	3.4	87.0

TABLE 5. Annual change in water level (ft), for reported wells in region II.

Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of wells with decline[a]	Is change statistically significant?
1996–1997	+0.1	148	15.4	23.1	53	47	no
1997–1998	+0.5	154	25.3	10.7	58	42	no
1998–1999	–0.6	153	5.5	14.8	41	59	yes
1999–2000	–0.3	146	15.2	15.5	36	64	no
2000–2001	–0.5	134	32.0	8.6	22	77	no
2001–2002	–0.6	130	6.4	14.4	27	73	yes

[a] The percentage of wells with water-level rises and the percentage of wells with water-level declines will not always sum to 100. Each year it is possible that a small number of wells will remain at the same level as the previous year.

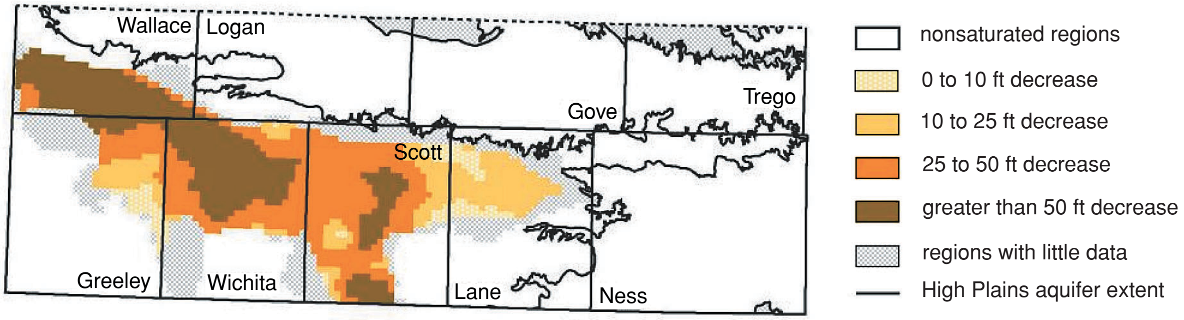

FIGURE 10A. Ground-water changes in the area of the High Plains aquifer in Region II, west-central Kansas. See fig. 11 for adjacent areas to the north, and fig. 9 for adjacent areas to the south. (A) Generalized water-level changes (ft), predevelopment to 2002.

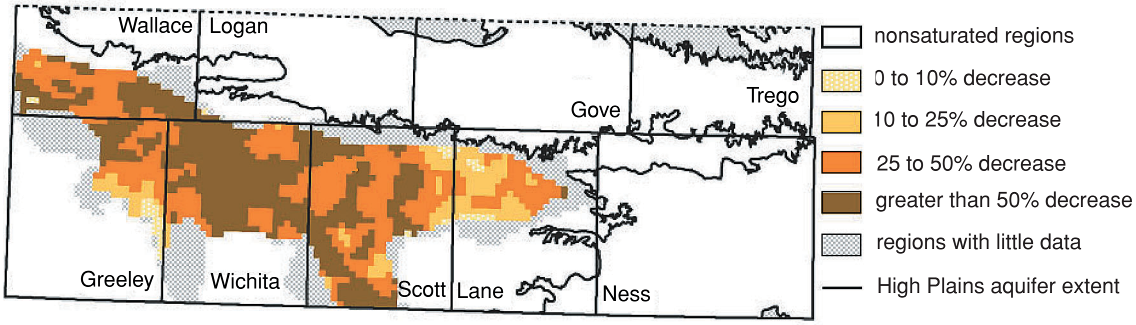

FIGURE 10B. Change in saturated thickness (%), predevelopment to 2002.

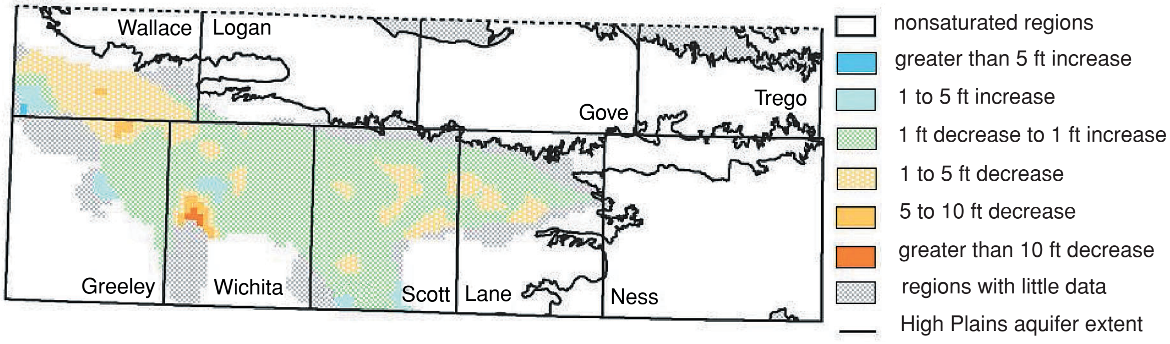

FIGURE 10C. Annual water-level change (ft), 2001-2002.

Region III: Northwestern Kansas

In northwestern Kansas, the High Plains is the primary aquifer. The average water-level change since predevelopment for this region (table 6) was a decline of 16.4 ft (5.0m) with the largest decline equal to 71.7 ft (21.9 m). The largest areas of declines greater than 25 ft (7.6 m) in water level (fig. 11A) and also of declines greater than 25% in saturated thickness (fig. 11B) since predevelopment continue to be in Sherman, Sheridan, and Thomas counties, where well development is greatest. Declines in saturated thickness in this region have not yet reached the 50% level because of the large predevelopment saturated thickness of the aquifer. The hydrograph of the well in Thomas County (fig. 8) illustrates a sustained water-table decline, which is typical for much of the region.

The 2002 average annual change in water level was a decline of 0.3 ft (9.1 cm) (table 7), which is statistically significant. This average annual change was less than that of the 2001–2002 period, which was a decline of 1.1 ft (34 cm). The percentage of wells with a decline in water level during 2001–2002 was 60%, while the percentage of wells with a rise was 40%, compared to 84% showing a decline and 16% showing a rise in the 2000–2001 period. Figure 11C shows a large decrease in the total area of 1-5 ft (0.3-1.5 m) decline relative to the 2000-2001 period. A small area of 5- to 10-ft decline appears on the border between southeastern Thomas County and southwestern Sheridan County. There was a significant increase in the total area of water-level rise, the individual areas being more evenly distributed within the region than in the 2000-2001 period. There was only one significant area of greater than 5-ft (1.5-m) rise, this being in southwestern Cheyenne County. Areas of relatively stationary (1-ft decline to 1-ft rise) water levels greatly increased in the 2001-2002 period relative to the 2000-2001 period. These observations, as a whole, indicate a strong shift toward less water-level decline in most of the region during the 2001-2002 period.

TABLE 6. Change in water level (ft), predevelopment to present, for reported wells in region III.

Year	Average change	Number of wells	Largest rise	Largest decline
1996	–14.2	225	23.5	67.8
1997	–14.2	227	21.8	67.4
1998	–14.8	225	10.1	61.5
1999	–14.4	229	15.3	66.9
2000	–14.6	225	10.2	64.0
2001	–16.1	221	9.5	69.8
2002	–16.4	219	8.5	71.7

TABLE 7. Annual change (ft), for reported wells in region III.

Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of wells with decline[a]	Is change statistically significant?
1996–1997	–0.1	313	8.6	13.8	51	48	no
1997–1998	–0.3	323	18.8	16.1	30	69	no
1998–1999	–0.1	323	19.6	27.4	39	61	no
1999–2000	0.0	330	9.2	8.5	44	56	no
2000–2001	–1.1	330	10.3	8.2	16	84	yes
2001–2002	–0.3	334	10.1	8.9	40	60	yes

a. The percentage of wells with water-level rises and the percentage of wells with water-level declines will not always sum to 100. Each year it is possible that a small number of wells will remain at the same level as the previous year.

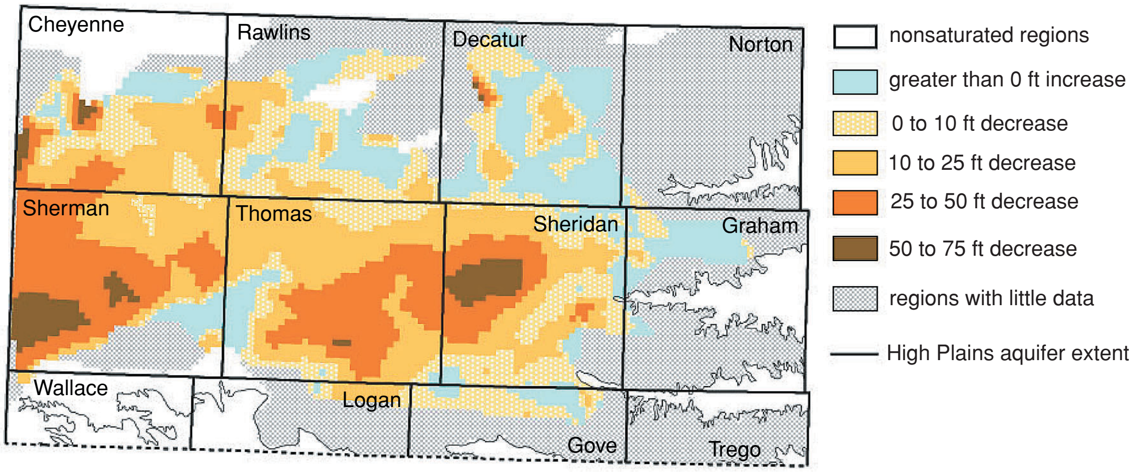

FIGURE 11A. Ground-water changes in the area of the High Plains aquifer in Region III, northwestern Kansas. See fig. 10 for adjacent areas to the south. (A) Generalized water-level changes (ft), predevelopment to 2002.

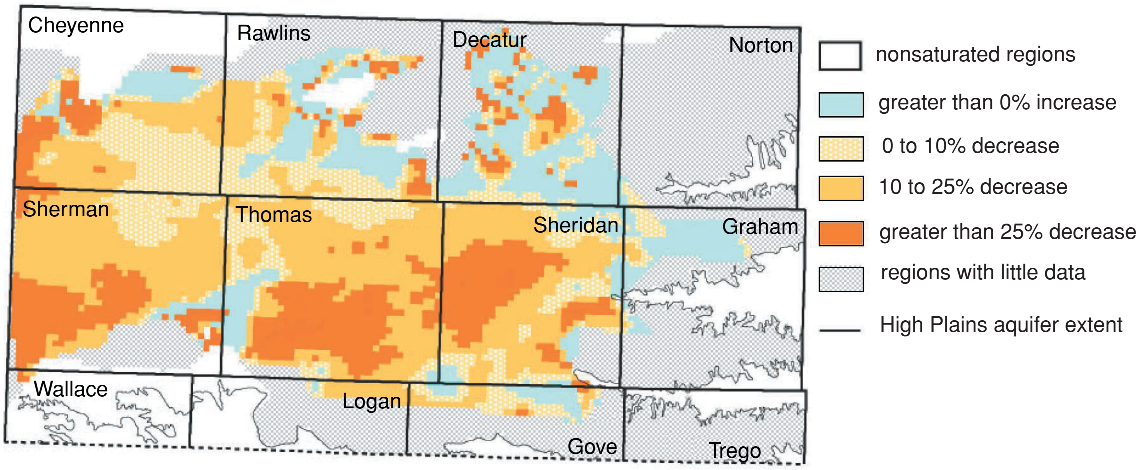

FIGURE 11B. Change in saturated thickness (%), predevelopment to 2002.

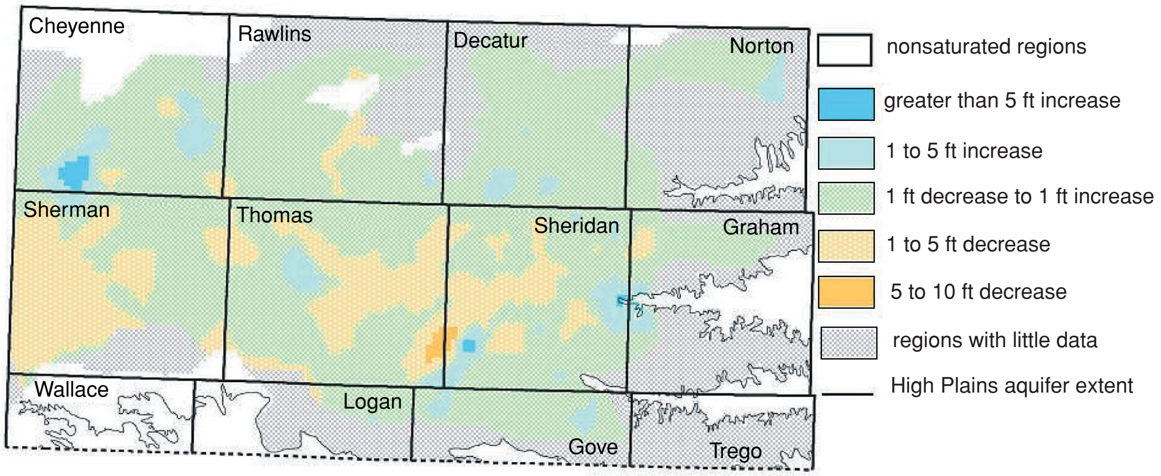

FIGURE 11C. Annual water-level change (ft), 2001-2002.

Region V: South-central Kansas

The south-central region of Kansas is located east of the easternmost extension of the Ogallala formation. In this region the primary geologic unit used for groundwater supply is Quaternary alluvium. As table 8 shows, the average change since predevelopment has been a decline of 2.9 ft (88 cm), which is much smaller than the average change in other western regions. Significant areas of water-level decline greater than 10 ft (3 m) and saturated-thickness decline greater than 10% (figs. 12A and 12B) continue to appear in Edwards and Pawnee counties and, to a lesser extent, in Stafford, Kiowa, Pratt, Barton, Rice, Reno, Harvey, and McPherson counties. Water-table elevations higher than the predevelopment value by 0–10 ft (0–3 m) were observed primarily in Stafford, Reno, Kingman, Pratt, Kiowa, Harvey, and Edwards counties.

Water-level changes in the 2001–2002 period (table 9) had an average decline of 0.6 ft (18 cm) with 74% of the wells exhibiting a decline in water level (compared to 65% during the 2000–2001 period). From fig. 12C, it can be seen that the total area of 0-2-ft decline has increased slightly in 2001-2002 relative to the 2000-2001 period. There also has been a slight increase in the total area of 2-ft or greater decline. Furthermore, there are small areas of 4-6-ft decline in southwest Pratt, southeast Kiowa, northeast Edwards, northeast Reno, northwest Harvey, and southwest McPherson counties, but the total area of declines of 4 ft or greater decreased in 2001-2002 relative to 2000-2001. The total area of water-level rise decreased measurably in the 2001-2002 period relative to 2000-2001, but a general increase in the total area of water-level rise was observed in the northwest part of the region. In addition, there were areas of southwest Stafford and northwest Edwards counties that experienced declines greater than 2 ft during 2001-2002 that had experienced rises during 2000-2001. There were also areas of southern Barton County that experienced rises during 2001-2002 that had experienced declines of 4 ft or greater during 2000-2001. These results indicated a slightly increased trend toward water-level decline over most of the region, but an increased trend toward water-level rise in the northwesternmost portions.

In the central and eastern portions of this area, the freshwater aquifer is underlain by formations containing saltwater, which can move up to replace the freshwater if pumping exceeds recharge. This means that local areas are subject to both water-table declines (reduction of saturated thickness) and upconing of saltwater. Because of this, reporting of water levels alone is not sufficient for determining the availability of usable water.

TABLE 8. Change in water level (ft), predevelopment to present, for reported wells in region V.

Year	Average change	Number of wells	Largest rise	Largest decline
1996	–3.4	220	17.8	32.3
1997	–2.6	219	20.5	32.3
1998	–1.8	216	21.7	32.2
1999	–1.7	213	20.0	32.7
2000	–1.7	207	18.8	33.7
2001	–2.3	206	18.4	33.8
2002	–2.9	201	16.6	34.0

TABLE 9. Annual change in water level (ft) for reported wells in region V.

Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of wells with decline[a]	Is change statistically significant?
1996–1997	+0.6	341	18.3	3.5	64	35	yes
1997–1998	+0.9	351	7.9	5.5	80	19	yes
1998–1999	+0.2	344	6.2	5.7	57	41	yes
1999–2000	–0.1	338	9.8	6.1	41	58	no
2000–2001	–0.5	330	2.5	7.5	35	65	yes
2001–2002	–0.6	323	5.6	5.9	26	74	yes

a. The percentage of wells with water-level rises and the percentage of wells with water-level declines will not always sum to 100. Each year it is possible that a small number of wells will remain at the same level as the previous year.

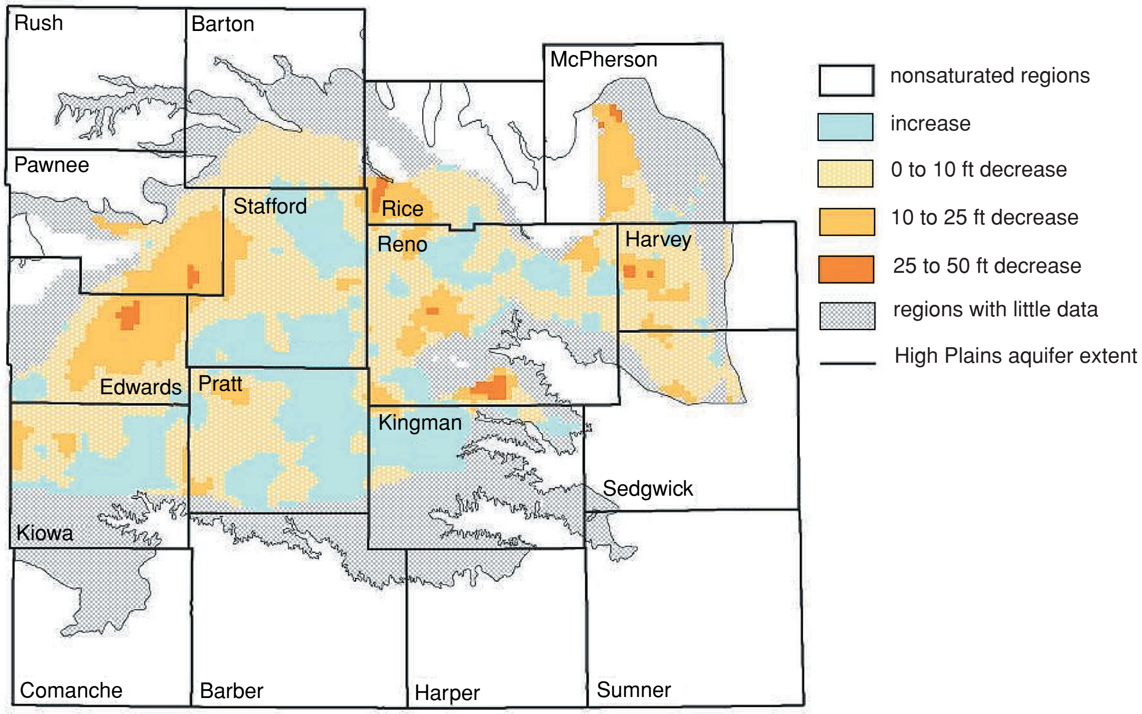

FIGURE 12A. Ground-water changes in the area of the High Plains aquifer in Region V, south-central Kansas. See fig. 9 for adjacent areas to the west. (A) Generalized water-level changes (ft), predevelopment to 2002.

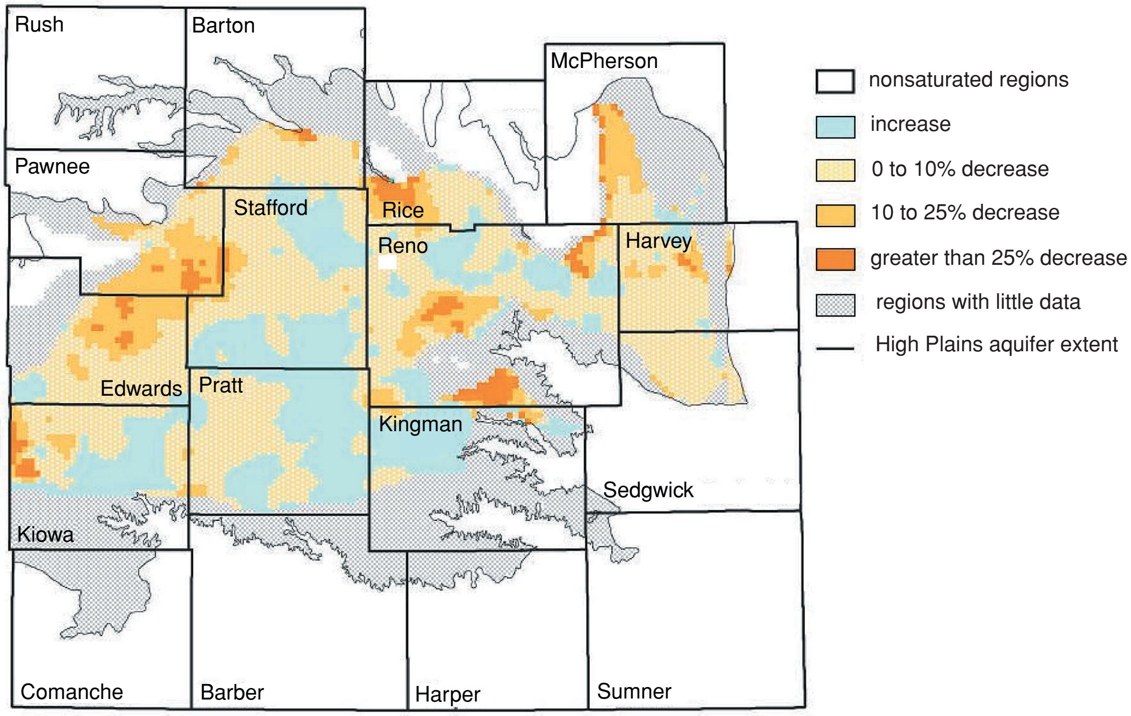

FIGURE 12B. Change in saturated thickness (%), predevelopment to 2002.

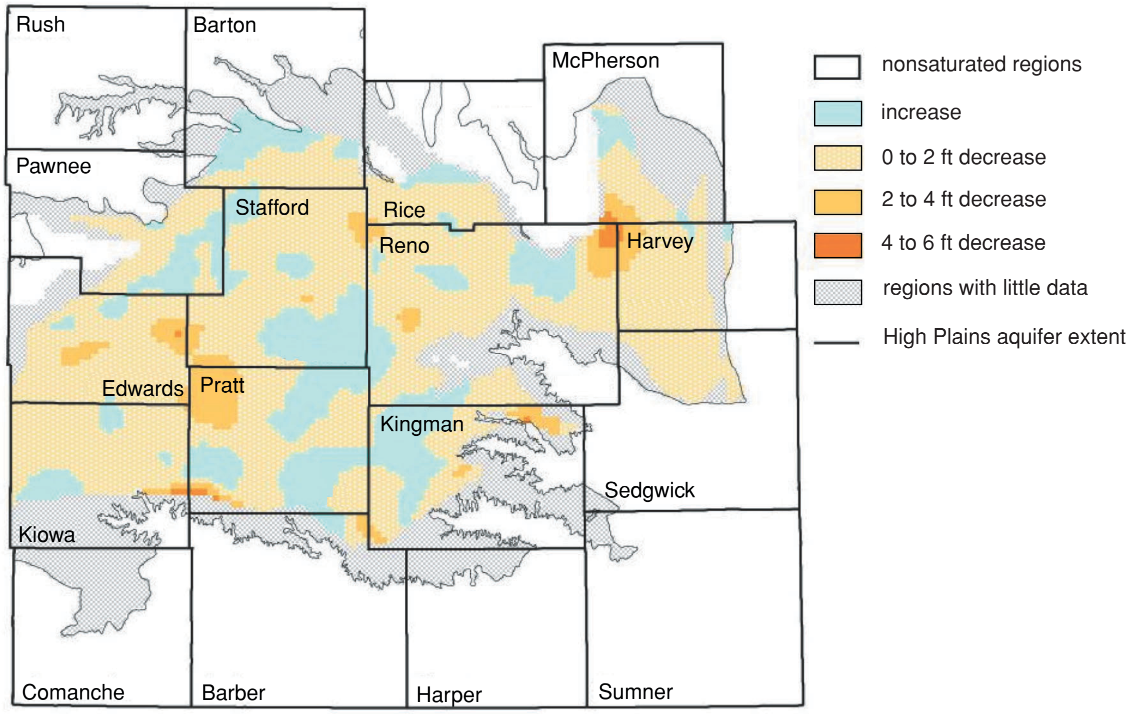

FIGURE 12C. Annual water-level change (ft), 2001-2002.

Appendix A: Publications Containing Ground-water-level Data for Kansas

Records of ground-water-level data for Kansas were published in U.S. Geological Survey Water-Supply Papers for 1935–1971. These water-supply papers are listed in table 10. A series of annual reports that contain records of water-level measurements for Kansas for 1956–1965 have been published in the Kansas Geological Survey bulletins listed in table 11.

Recent Literature of Interest to Users of Water-level Data

In addition to the water-supply papers and bulletins, information of interest to users of water-level data in Kansas can be found in the following recent publications. For literature more than ten years old, refer to earlier issues of this report or to Kansas Geological Survey Open-file Report 90–41a-m entitled *Kansas Water Bibliography through 1989* by J. H. Sorensen, 1990.

1992

Geiger, C. O., Lacock, D. L., Schneider, D. R., Carlson, M. D., and Pabst, B. J., 1992, Water resources data, Kansas, water year 1991: U.S. Geological Survey, Open-file Report 92–90, 130 p.

________, 1992, Water resources data, Kansas water year 1991: U.S. Geological Survey, Water-data Report KS–91–1, 358 p.

Hansen, C. V., Underwood, E. J., Wolf, R. J., and Spinazola, J. M., 1992, Geohydrologic systems in Kansas—Physical framework of the upper aquifer unit of the Western Interior Plains aquifer system: U.S. Geological Survey, Hydrologic Investigations Atlas HA–722–D, 2 sheets, scales 1:1,000,000 and 1:3,000,000.

Hansen, C. V., Wolf, R. J., and Spinazola, J. M., 1992, Geohydrologic systems in Kansas—Physical framework of the confining unit in the Western Interior Plains aquifer system: U.S. Geological Survey, Hydrologic Investigations Atlas HA–722–E, 2 sheets, scales 1:1,000,000 and 1:3,000,000.

Spinazola, J. M., Wolf, R. J., and McGovern, H. E., 1992, Geohydrologic systems in Kansas—Physical framework of the Great Plains aquifer system: U.S. Geological Survey, Hydrologic Investigations Atlas HA–722–B, 2 sheets, scales 1:1,000,000 and 1:2,000,000.

Wolf, R. J., McGovern, H. E., and Spinazola, J. M., 1992, Geohydrologic systems in Kansas—Physical framework of the Western Interior Plains confining system: U.S. Geological Survey, Hydrologic Investigations Atlas HA–772–C, 2 sheets, scales 1:1,000,000 and 1:3,000,000.

1993

Buchanan, R., and Buddemeier, R. W., (compilers) 1993, Kansas ground water: Kansas Geological Survey, Educational Series 10, 44 p.

Combs, L. J., Hansen, C. V., and Wolf, R. J., 1993, Geohydrologic systems in Kansas—Geohydrology of the lower aquifer unit in the Western Interior Plains aquifer system: U.S. Geological Survey, Hydrologic Investigations Atlas HA–722–1, 3 sheets, scale 1:1,5000,000.

Hansen, C. V., 1993, Description of geographic-information-system files containing water-resource-related data compiled and collected for Wyandotte County, northeastern Kansas: U.S. Geological Survey, Open-file Report 93–92, 46 p.

Mitchell, J. E., Woods, J., McClain, T. J., and Buddemeier, R. W., 1993, January 1992 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 3, 134 p.

Wolf, R. J., and Helgesen, J. O., 1993, Ground- and surface-water interaction between the Kansas River and associated alluvial aquifer, northeastern Kansas: U.S. Geological Survey, Water-resources Investigations Report 92–4137, 49 p.

1994

Dugan, J. T., McGrath, T., and Zelt, R. B., 1994, Water-level changes in the High Plains aquifer—Predevelopment to 1992: U.S. Geological Survey, Water-resources Investigations Report 94–4027, 56 p.

Mitchell, J. E., Woods, J., McClain, T. J., and Buddemeier, R. W., 1994, January 1993 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 4, 114 p.

Woods, J. J., Mitchell, J. E., Buddemeier, R. W., 1994, January 1994 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 5, 106 p.

1995

Geiger, C. O., Lacock, D. L., Schneider, D. R., Carlson, M. D., and Dague, B. J., 1995, Water-resources data, Kansas water year 1994: U.S. Geological Survey, Water-data Report KS–94–1, 479 p.

Goolsby, D. A., Scribner, E. A., Thurman, E. M., Pomes, M. L., and Meyer, M. T., 1995, Data on selected herbicides and two triazine metabolites in precipitation of the midwestern and northeastern United States, 1990–91: U.S. Geological Survey, Open-file Report 95–0469, 341 p.

Hedman, E. R., and Engel, G. B., 1995, Flow characteristics of selected streams in the Great Plains subregion of the Central Midwest Regional Aquifer System and selected adjacent areas; Kansas and Nebraska, and parts of Colorado, Iowa, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey, Hydrologic Investigations Series HA–708, 3 sheets.

Jordan, P. R., and Stamer, J. K. (eds), 1995, Surface-water-quality assessment of the Lower Kansas River basin, Kansas and Nebraska; analysis of available data through 1986: U.S. Geological Survey, Water-supply Paper 2352–B, 161 p.

Roberts, D. J., and Combs, L. J. (compls.), 1995, Water-resource reports prepared by or in cooperation with the U.S. Geological Survey, Kansas, 1886–1994: U.S. Geological Survey, Open-file Report 95–0120, 122 p.

Southard, R. E., 1995, Flood volumes in the Upper Mississippi River basin, April 1 through September 30, 1993: U.S. Geological Survey, Circular 1120–H, 32 p.

Woods, J. J., Schloss, J. A., and Buddemeier, R. W., 1995, January 1995 water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 8, 138 p.

1996

Bell, R. W., Joseph, R. L., and Freiwald, D. A., 1996, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—Summary of information on pesticides, 1970–1990: U.S. Geological Survey, Water-resources Investigations Report 96–4003, 51 p.

Council of Water Research Directors, 1996, Water research in Kansas, 1994–1995: Kansas Agricultural Experiment Station, Manhattan, KS, 34 p.

Jorgensen, D. G., Helgesen, J. O., Signor, D. C., Leonard, R. B., Imes, J. L., and Christenson, S. C., 1996, Analysis of regional aquifers in the central midwest of the United States in Kansas, Nebraska, and parts of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming—Summary: U.S. Geological Survey, Professional Paper 1414–A, 67 p.

Putman, J. E., Lacock, D. L., Schneider, D. R., Carlson, M. D., and Dague, B. J., 1996, Water resources data, Kansas water year 1995: U.S. Geological Survey, Water-data Report KS–95–1, 488 p.

Tanner, D. Q., 1996, Surface-water-quality assessment of the Lower Kansas River basin, Kansas and Nebraska—Selected metals, arsenic, and phosphorus in streambed sediments of first- and second-order streams, 1987: U.S. Geological Survey, Water-resources Investigations Report 94–4196, 13 p.

Whittemore, D. O., Mingshu, T., and Grauer, J., 1996, Upper Arkansas River corridor study—Inventory of available data and development of conceptual models—A Kansas water plan project: Kansas Geological Survey, Open-file Report 96–19, 83 p.

Woods, J. J., and Schloss, J. A., 1996, January 1996 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 9, 124 p.

1997

McGuire, V. L., and Sharpe, J. B., 1997, Water-level changes in the High Plains aquifer—predevelopment to 1995: U.S. Geological Survey, Water-resources Investigations 97–4081, 2 sheets.

Miller, R. D., Davis, J. C., Laflen, D., Siceloff, J., Bennett, B., Brohammer, M., and Acker, P., 1997, Acquisition activity and raw data report on 1997 annual water measurements; Kansas Geological Survey's portion: Kansas Geological Survey, Open-file Report 97–11, 98 p.

Miller, R. D., Davis, J. C., and Olea, R. A., 1997, Acquisition activity, statistical quality control, and spatial quality control for 1997 annual water level data acquired by the Kansas Geological Survey: Kansas Geological Survey, Open-file Report 97–33, 59 p.

Putnam, J. E., Lacock, D. L., Schneider, D. R., Carlson, M. D., and Dague, B. J., 1997, Water resources data, Kansas water year 1996: U.S. Geological Survey, Water-data Report KS–96–1, 408 p.

Sophocleous, M. [A.], and Sawin, R. S., 1997, Safe yield and sustainable development of water resources in Kansas; level changes: Kansas Geological Survey, Public Information Circular 9, 6 p.

Woods, J. J., Schloss, J. A., and Macfarlane, P. A., 1997, January 1997 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 11, 90 p.

1998

Aucott, W. R., and Myers, N. C., 1998, Changes in ground-water levels and storage in the Wichita well field area, south-central Kansas, 1940–1998: U.S. Geological Survey, Water-resources Investigations 98–4141, 20 p.

Aucott, W. R., Myers, N. C., and Dague, B. J., 1998, Status of ground-water levels and storage in the Wichita well field area, south-central Kansas, 1997: U.S. Geological Survey, Water-resources Investigations 98–4095, 15 p.

Miller, R. D., Davis, J. C., and Olea, R. A., 1998, 1998 Annual water level raw data report for Kansas: Kansas Geological Survey, Open-file Report 98–7, 28 p., 1 cd-rom

Putnam, J. E., Lacock, D. L., Schneider, D. R., and Carlson, M. D., 1998, Water resources data, Kansas water year 1997: U.S. Geological Survey, Water-data Report KS–97–1, 445 p.

Woods, J. J., Schloss, J. A., and Macfarlane, P. A., 1998, January 1998 Kansas water levels and data related to water-level changes: Kansas Geological Survey, Technical Series 12, 92 p.

Sophocleous, M. A. (ed.), 1998, Perspectives on sustainable development of water resources in Kansas: Kansas Geological Survey, Bulletin 239, 239 p.

1999

Cederstrand, J. R., and Becker, M. F., 1999, Digital map of water levels in 1980 for the High Plains aquifer in parts of

Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey, Open-file Report 99-263 [online] http://water.usgs.gov/pubs/of/ofr99-263/

Cederstrand, J. R., and Becker, M. F., 1999, Digital map of predevelopment water levels for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey, Open-file Report 99-264 [online] http://water.usgs.gov/pubs/of/ofr99-264/

Cederstrand, J. R., and Becker, M. F., 1999, Digital map of changes in water levels from predevelopment to 1980 for the High Plains aquifer in part of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey, Open-file Report 99-265 [online] http://water.usgs.gov/pubs/of/ofr99-265/

Miller, R. D., and Davis, J. C., 1999, 1999 annual water-level raw data report for Kansas: Kansas Geological Survey, Open-file Report 1999-5, var. pag.

Myers, N. C., Finnegan, P. J., and Breedlove, J. D., 1999, Analysis of water-level data and ground-water flow modeling at Fort Riley, Kansas: U.S. Geological Survey, Water Resources Investigations 99-4115, 6 p.

Olea, R. A., and Davis, J. C., 1999, Sampling analysis and mapping of water levels in the High Plains aquifer of Kansas: Kansas Geological Survey, Open-file Report 1999-11, 19 p., 1 cdrom

Putnam, J. E., Lacock, D. L., Schneider, D. R., and Carlson, M. D., 1999, Water resources data, Kansas water year 1998: U.S. Geological Survey, Water-data Report KS 98-1, 447 p.

Sophocleous, M. A., and Sawin, R. S., 1997, Safe yield and sustainable development of water resources in Kansas: Kansas Geological Survey, Public Information Circular 9, 6 p.

Woods, J. J., Schloss, J. A., and Macfarlane, P. A., 1999, January 1999 Kansas water-level measurements: Kansas Geological Survey, Technical Series 14, 89 p.

2000

Fischer, B. C., Kollasch, K. M., and McGuire, V. L., 2000, Digital map of water-level changes in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 1980 to 1997: U.S. Geological Survey, Open-file Report 00-096 [online] http://pubs.water.usgs.gov/ofr00-096/

Hansen, C. V., and Aucott, W. R., 2000, Status of ground-water levels and storage volume in the Wichita well field area, south-central Kansas, 1998-2000: U.S. Geological Survey, Water-resources Investigations 00-4267 [online] http://ks.water.usgs.gov/Kansas/pubs/reports/wrir.00-4267.html

Miller, R. D., Davis, J. C., and Laflen, D. R., 2000, Annual water level raw data report for Kansas: Kansas Geological Survey, Open-file Report 2000-10, 19 p., 1 cdrom

Olea, R. A., and Davis, J. C., 2000, Year 2000 sampling analysis and mapping of water levels in the High Plains aquifer of Kansas: Kansas Geological Survey, Open-file Report 2000-13, 8 p.

Olea, R. A., and Davis, J. C., 2000, Year 2000 proposed additions to the High Plains Aquifer Water-level Observation Network: Kansas Geological Survey, Open-file Report 2000-17, 7 p.

Putnam, J. E., Lacock, D. L., Schneider, D. R., and Carlson, M. D., 2000, Water resources data, Kansas water year 1999: U.S. Geological Survey, Water-data Report KS 99-1, 466 p.

2001

Davis, J. C., 2001, Statistical control for Yr. 2001 water-well measurements: Kansas Geological Survey, Open-file Report 2001-2, 23 p.

Laflen, D. R., and Miller, R. D., 2001, 2001 annual water level raw data report for Kansas: Kansas Geological Survey, Open-file Report 2001-1 [online] http://megallan.kgs.ukans.edu/WaterLevels/CD/index.htm

Olea, R. A., and Davis, J. C., 2001, Year 2001 mapping of water levels in the High Plains aquifer of Kansas and analysis of the monitoring network: Kansas Geological Survey, Open-file Report 2001-6, 49 p.

Putnam, J. E., Lacock, D. L., Schneider, D. R., and Carlson, M. D., 2001, Water resources data, Kansas, water year 2000: U.S. Geological Survey, Water-data Report KS 00-1, 505 p.

2002

Becker, M. F., Bruce, B. W., Pope, L. M., and Andrews, W. J., 2002, Ground-water quality in the central High Plains aquifer, Colorado, Kansas, New Mexico, Oklahoma, and Texas, 1999: U.S. Geological Survey, Water-resources Investigations 02-4112, 64 p.

Davis, J. C., 2002, Statistical quality control for year 2002 water-well measurements: Kansas Geological Survey, Open-file Report 2002-5, 21 p.

Johnson, M. R., Cornwall, J. F., and Landon, M. K., 2002, Digital map of the elevation of the base of the High Plains aquifer in the Republican River basin upstream of Hardy, Nebraska, in parts of Nebraska, Kansas, and Colorado: U.S. Geological Survey, Open-file Report 02-0064; http://water.usgs.gov/pubs/of/ofr02-064

Kansas Geological Survey, 2002, Technical support for Ogallala aquifer assessment, planning, and management, agency edition: Kansas Geological Survey, Open-file Report 2002-25, 1 cd-rom

Laflen, D. R., and Miller, R. D., 2002, 2002 annual water-level raw data report for Kansas: Kansas Geological Survey, Open-file Report 2002-1, 1 cd-rom

Olea, R. A., and Davis, J. C., 2002, Geostatistical analysis and mapping for year 2002 water levels in the High Plains aquifer of Kansas: Kansas Geological Survey, Open-file Report 2002-14, 34 p.

Olea, R. A., Sophocleous, M., and Woods, J. J., 2002, Expansion for the High Plains Aquifer Observation Network of water wells in southwest Kansas: Kansas Geological Survey, Open-file Report 2002-35, 2 p.

Putnam, J. E., Lacock, D. L., and Schneider, D. R., 2002, Water resources data, Kansas water year 2001: U.S. Geological Survey, Water-data Report KS 01 1, 532 p.

Sophocleous, M. A., Kluitenberg, C .J., and Healey, J. M., 2002, Southwestern Kansas High Plains deep vadose zone pilot study to estimate Darcian-based ground-water recharge at three instrumented sites: Kansas Geological Survey, Open-file Report 2001-11, 120 p.

Townsend, M. A., Young, D. P., and Hecox, Gary, 2002, Potential impacts of past land use and recharge rates on the Ogallala aquifer; water-quality issues in Kansas: Kansas Geological Survey, Open-file Report 2002-58, 17 p.

Whittemore, D. O., 2002, Ground-water recharge in the Upper Arkansas River Corridor in southwest Kansas; a supplemental report for technical support for Ogallala aquifer assessment, planning, and management: Kansas Geological Survey, Open-file Report 2002-30, 29 p.

Woods, J. J., and Sophocleous, M. [A.], 2002, January 2001 Kansas water-level measurements: Kansas Geological Survey, Technical Series 17 [online] http://www.kgs.ku.edu/Hydro/Levels/2001/index.html

Woods, J. J., and Sophocleous, M. [A.], 2002, [Set of maps for Southwest Kansas Groundwater Management District]: Kansas Geological Survey, Open-file Report 2001-45, set of 8 water-availability maps, scale 1:300,000

Woods, J. J., and Sophocleous, M. [A.], 2002,[Saturated thickness at section centers in the High Plains aquifer, set of maps for Southwest Kansas Groundwater Management District]: Kansas Geological Survey, Open-file Report 2002-26, 4 sheets, scale 1:300,000

TABLE 10. U.S. Geological Survey Water-supply Papers

Year	**Water-supply Paper Number***	**Year**	**Water-supply Paper Number***
1935	777	1948	1128
1936	817	1949	1158
1937	840		
1938	845	1950	1167
1939	886	1951	1193
		1952	1223
1940	908	1953	1267
1941	938	1954	1323
1942	946	1955	1406
1943	988	1956	1456
1944	1018	1957-1961	1781
1945	1025		
1946	1073	1962-1966	1976
1947	1098	1967-1971	2090

*Can be purchased from the U.S. Geological Survey, Books and Open-file Reports. Federal Center, Box 25425, Denver, CO 80225.

TABLE 11. Kansas Geological Survey Bulletins with water-level measurements

Year	**Bulletin Number***	**Year**	**Bulletin Number***
1956	125	1961	159
1957	131	1962	167
1958	141	1963	173
1959	146	1964	177
1960	153	1965	184

*Can be purchased from the Publications Sales Office, Kansas Geological Survey,
1930 Constant Avenue, Lawrence, KS 66047.

Appendix B: Water-level Data

This appendix contains water-level data for wells in Kansas, arranged in alphabetical order by county. For each county, a table is presented that spans two pages. The nature of the information presented and how to use it is described in the following text.

An apparent anomaly should be noted. A few of the wells are preceded by a plus sign (e.g., +21S–34W–14DBB–01 in Finney County). For these wells, at least one of the water levels listed for the past seven years is below the top of the bedrock. This situation can occur when wells are intentionally drilled into the bedrock to allow for greater yields, or when the top of the bedrock contains fractures that were filled with unconsolidated material from overlying units and therefore can produce substantial amounts of ground water. Another possible explanation of this apparent anomaly is the fact that for many wells, the depth to the top of bedrock is estimated based on data from nearby wells, rather than having been measured or derived from logging data from the subject well.

Each year a series of analyses are performed on the data in this report, and one aspect of those analyses compares the current year's water-level measurement with data from previous years and with data from nearby wells screened in the same aquifer. One of the benefits of these tests is that water levels that seem to have changed significantly from one year to the next can be flagged for more careful analysis of the data-collection and data-processing procedures and of the wells in which the measurements were taken. In rare cases, variations in the water levels from one year to the next cannot be explained and must be considered anomalous. In these instances, publishing the data in a document of this nature is not prudent, and so in the following tables the depth-to-water columns have a few entries showing only an asterisk instead of the observed value. These asterisks are intended to alert readers that measurement data were recorded but were found to be questionable. To obtain the actual measurement data in these cases, we refer readers to KGS Open-file Report 2002–01 by Laflen and Miller (2002) entitled *2002 Annual Water Level Raw Data Report for Kansas* (see previous section for reference).

Column Definitions

On the first page, column 1 contains the well number, which is based on the legal location of the well. Wells in this report are numbered according to a modification of the U.S. Bureau of Land Management system of land subdivision (fig. 13). The legal location is composed of the township, range, and section numbers followed by letters indicating the subdivision of the section in which the well is located. The first letter encloses a 160-acre tract; the second, a 40-acre tract; the third, a 10-acre tract; and the fourth, if present, a 2.5-acre tract. The letters A, B, C, and D designate the tract in a counterclockwise manner, starting in the northeast corner. Therefore, a location described as SW NW NW sec. 7, T. 18 S., R. 39 W. [the SW quarter of the NW quarter of the NW quarter of sec(tion) 7, T(ownship) 18 S(outh), R(ange) 39 W(est)] is translated to 18S–39W–07–BBC. A two-digit number is appended to the location to identify specific wells in cases where there is more than one well in the same tract. If there were two wells in the parcel of land described above, the second well ID would be 18S–39W–07BBC–02.

Column 2 contains the USGS site ID, which is a unique identifier based primarily on the geographic (longitude, latitude) location of the well (fig. 13).

Column 3 gives the well depth measured in feet below the land-surface.

Column 4 gives the depth to water during the base reference (predevelopment) year where that information is available. Depending on the area of the state, the base reference year is 1940, 1944, or 1950. These are the earliest predevelopment years (before significant irrigation withdrawals of ground water) for which a significant amount of water-table data is available.

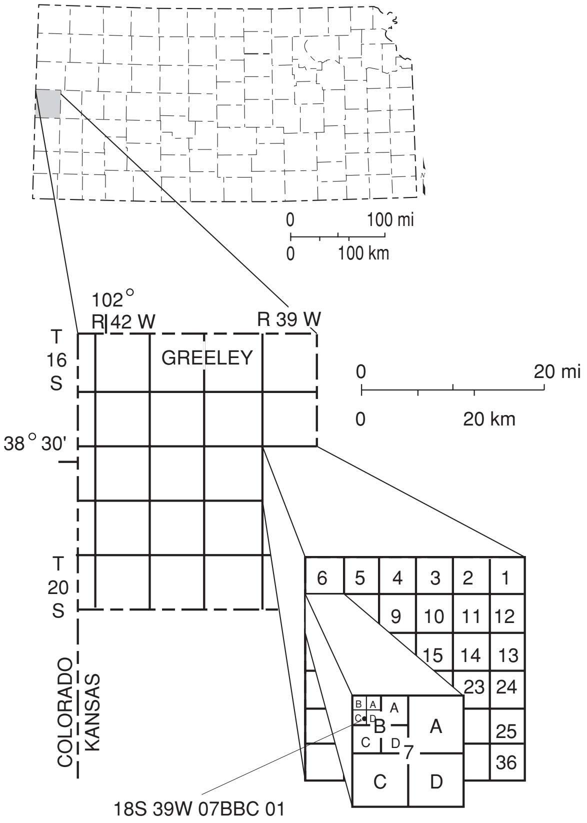

FIGURE 13. Locating wells using their legal location designation.

Column 5 gives the depth to water for the reference year of either 1966 or 1974. Depending on the locale, these years mark the beginning of modern continuous water-level monitoring operations for the major Kansas aquifers.

Columns 6–12 give the depths to water measured in each year (when available) for the current year and the past six years.

Column 13, the leftmost column on page two, gives the well number as described for column 1.

Column 14 identifies the principal geologic unit or units (up to 3) in which the well is screened. Designations for the geologic units in the tables are listed in table 1. In some cases, geologic unit designations are inferred from designations for neighboring wells or the general geology of the area. Where more than one unit designation is given for a single well, the designations indicate that the well was drilled through more than one water-bearing formation or that the geologic units are so similar or in such close proximity that the hydrology at that well may be influenced by more than one unit.

Column 15 gives the land-surface altitude of the well (in feet above mean sea level). By subtracting the depth-to-water from the land-surface altitude, the altitude of the water table can be calculated.

Column 16 presents the depth to bedrock where that is known. The bedrock is assumed to be the consolidated formation at the bottom of the aquifer. The difference between the depth to water and the depth to bedrock is the saturated thickness of the aquifer.

Columns 17–19 give water-level change from the base reference (predevelopment) year, from the reference year (1966 or 1974), and from the preceding year, respectively.

Columns 20 and 21 present the average annual water-level changes between the base reference (predevelopment) year and the current year and between the reference year (1966 or 1974) and the current year, respectively.

Columns 22 and 23 present the saturated thicknesses of the water-bearing formations in the base reference (predevelopment) year and in the present year, respectively. Where the depth to bedrock or the depth to water is not known, no values are given.

Column 24 gives the percentage change in saturated thickness from the base reference (predevelopment) year to present. This is roughly equivalent to the percentage change (in most cases, a depletion) of the original water resource. If we abbreviate "saturated thickness" as ST, the percent change can be calculated using the formula:

$$\%\ \text{change in ST} = 100\times\frac{(\text{present ST} - \text{predevelopment ST})}{(\text{predevelopment ST})}$$

(Appendix B county tables follow on p. 25-90; Appendix C on p. 91-92)