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January 1999 Kansas Water Levels and Data Related to Water-level Changes

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Water levels measured in January 1999 generally showed more declines and fewer rises in region I (southwest), a slight tendency toward water-level decline in region II (west-central) and in region III (northwest), and a tendency toward water-level rise in region V (south-central) except in the westernmost counties. The 1999 measurements showed an average water-level decline of 0.31 ft (9.4 cm) from the 1998 measurements compared to an average rise of 0.15 ft (4.6 cm) during the 1997–98 period. The strong pattern of increasing water-level decline in the western portions of region V is probably caused by decreased recharge resulting from less precipitation in this area in 1998. The single largest rise in water level was 31.6 ft (9.63 m), and the largest decline was 27.4 ft (8.35 m) for the wells in this report. Annual water-level declines outnumbered rises 61% to 39%, compared to 51% rises and 48% declines in the 1998 report. Regional breakdowns of the data indicate that more areas experienced declining water levels and that fewer areas experienced rising water levels in region I. The western portion of region II showed larger areas with declines, and the eastern portion showed relatively stationary water levels with localized areas of rise and decline. Region III generally showed a trend of decline but to a lesser extent than in 1997–98. In region V, where the water table is relatively shallow, a marked increase in the total area of water-level decline occurred in the western portion of the region while a general tendency toward rise with localized areas of decline occurred over the remainder of the region. Small, localized areas of water-level rise greater than 2 ft were observed in both the western and eastern edges of region V.

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.

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 99–5 entitled *1999 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, published by the Kansas Geological Survey in 1993.

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

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. Heavy rain over a short period will eventually exceed the soil's ability to absorb and transmit water and produce 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 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 groundwater 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 groundwater regions (fig. 1). 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 High Plains 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 they contain fewer wells and no laterally extensive major aquifers.

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. 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

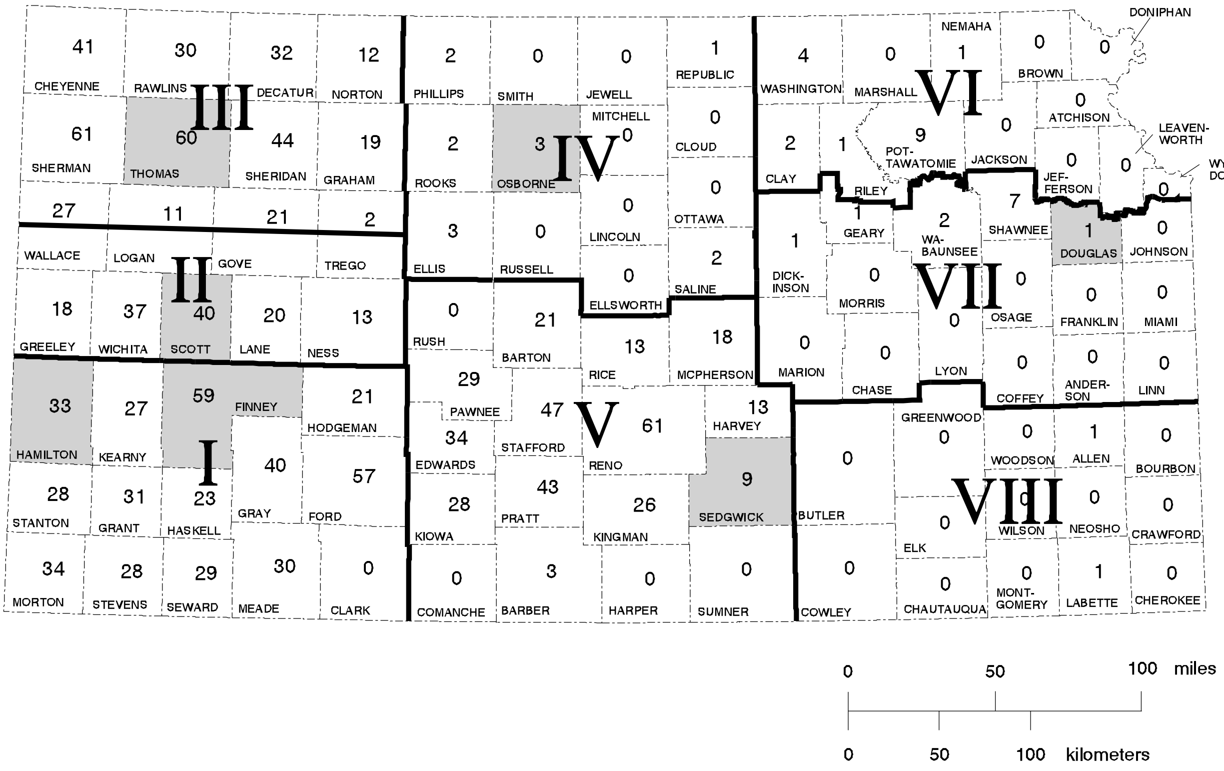


FIGURE 1—Number of ground-water level observation wells measured in each county for the 1999 water-level census. Shaded counties are those for which precipitation graphs and well hydrographs are presented in the text.

expressed as the annual total for the preceding calendar year at a specific location in the general vicinity of the 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, 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 major stream courses. The thickness of the alluvial deposits varies according to the amount of downcutting and sedimentation by streams.

The hydrograph of well 12S–20E–07CBC–01 (fig. 2) 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 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

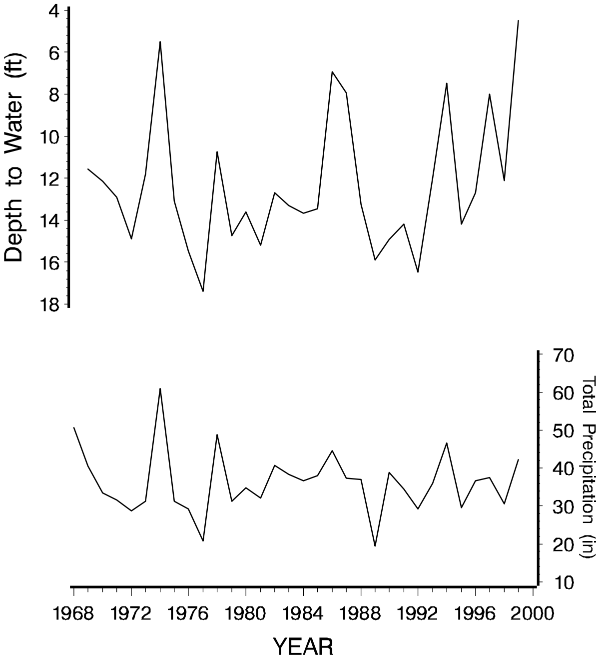


FIGURE 2—Depth to water in Douglas County, well 12S–20E–07–CBC–01 [29 ft (8.8 m) deep; alluvial aquifer], and precipitation at Topeka WSFO airport (station 14816706).

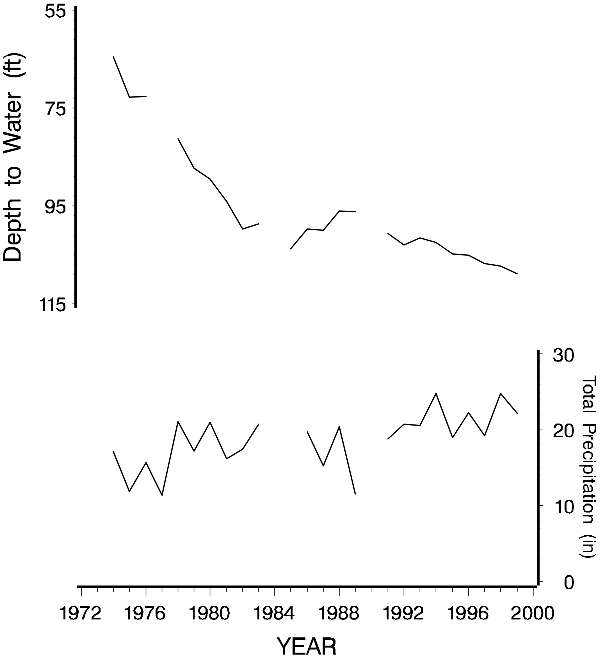


FIGURE 3—Depth to water in Finney County, well 24S–33W–28–DAA–01 [350 ft (107 m) deep; High Plains aquifer], and precipitation at Garden City Experimental Station (station 14298007).

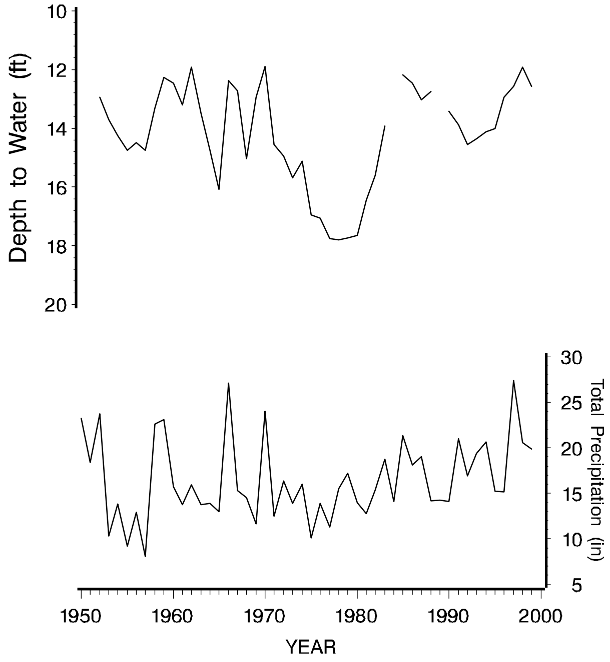


FIGURE 4—Depth to water in Hamilton County, well 23S–43W–21–ABA–01 [29 ft (8.8 m) deep; alluvial aquifer], and precipitation at Syracuse (station 14803807).

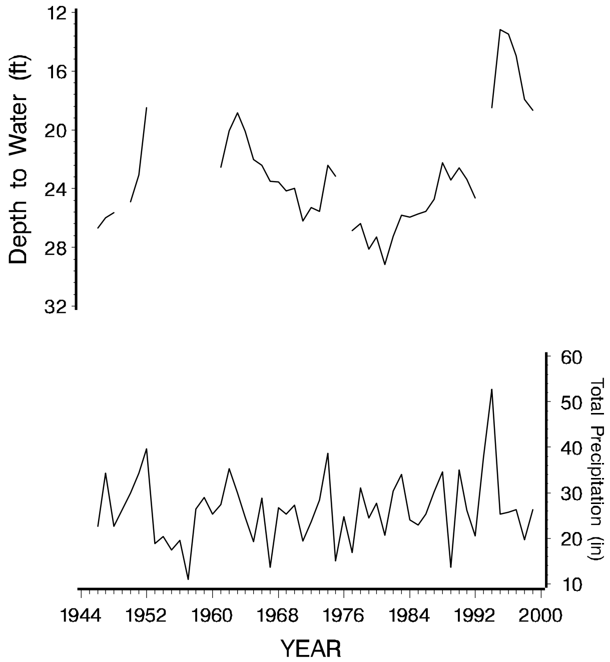


FIGURE 5—Depth to water in Osborne County, well 06S–12W–23–CDC–01 [31.8 ft (9.69 m) deep; unconsolidated Quaternary aquifer–alluvial terrace deposits], and precipitation at Cawker City (station 14137102).

that consist of poorly consolidated sand and gravel of Pleistocene age.

The depth to water for 1999 is 108.9 ft (33.2 m). Compared to the 1940 depth to water of 34 ft (10.4 m) (appendix B, Finney County), the decline of 74.9 ft (22.8 m) represents a decrease of about 21% in saturated thickness. Changes in saturated thickness of this magnitude or greater for the period 1940–1999 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 18.1 inches/yr (46.0 cm/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 in the Quaternary alluvium of the Arkansas River valley. Alluvial aquifer systems consist 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 1999 depth to water of 12.6 ft (3.84 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.

Osborne County, Terrace Deposits of Quaternary Age (QU)

Osborne County contains few observation wells for data collection. 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 the alluvial 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, they interact in various ways that either cancel their effects (e.g., diverting surface water can be less expensive than pumping and is therefore used in its place) or compound their effects (e.g., increased rainfall increases reservoir levels, which allows for more instream releases). The hydrograph is for a shallow well with a shallow water table [at an average depth of 13–28 ft (4.0–8.5 m)] that is located in alluvial terrace deposits of sands, gravels, and clays. 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.

Scott County, High Plains Aquifer (TO)

All the observation wells in Scott County 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 1999 depth to water is 101.2 ft (30.9 m). Compared to the 1940 level [60 ft (18.3 m)] (appendix B, Scott County), the water-level decline is 41.2 ft (12.6 m) and represents a roughly 60% 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.

Sedgwick County, Alluvial Aquifer (QA)

The hydrograph of the observation well 25S–01W–14–DDD–01 (fig. 7) 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

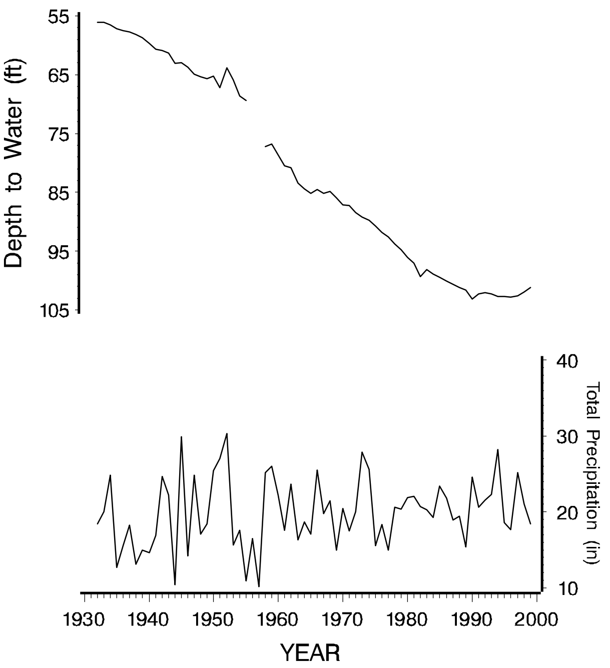


FIGURE 6—DEPTH TO WATER IN SCOTT COUNTY, well 20S–33W–09–BBB–01 [128 ft (39.0 m) deep; High Plains aquifer], and precipitation at Scott City (station 14727104).

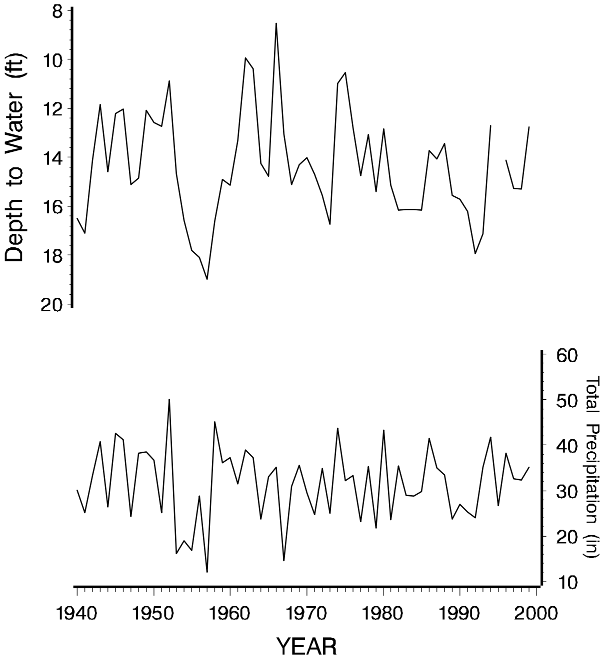


FIGURE 7—DEPTH TO WATER IN SEDGWICK COUNTY, well 25S–01W–14–DDD–01 (30 ft [9.8 m] deep; alluvial aquifer), and precipitation at Mount Hope (station 14553908).

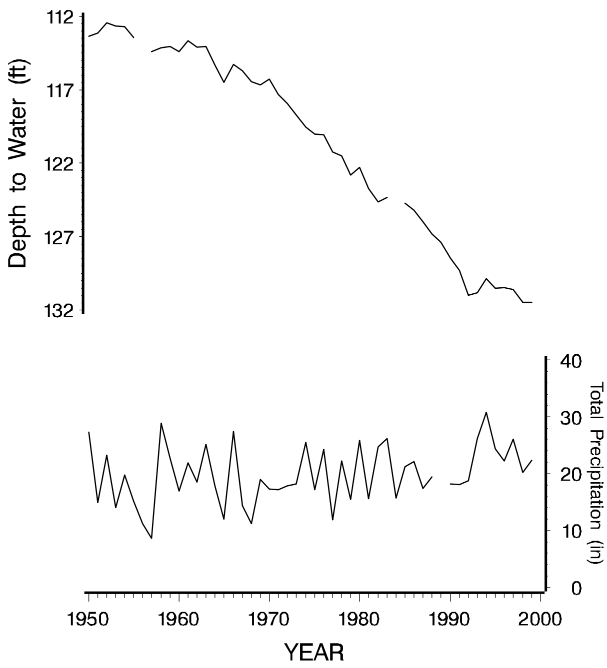


FIGURE 8—Depth to water in Thomas County, well 08S–34W–01–BAC–01 [175 ft (53.3 m) deep; High Plains aquifer], and precipitation at Colby 1 SW (station 14169901).

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.

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 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 131.5 ft (40.1 m) in 1999. This drop in water level represents an 11% 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.

Regional Change in Water Levels

The state of Kansas has been divided into eight hydrologic regions (see fig. 1). In regions IV, VI, VII, and VIII, the water-level data are too sparse to lend themselves to regional analysis. 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 gray shades 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. This criterion is in variance with that used in previous reports in which no wells screened in alluvial aquifers were used outside of region V. Analysis has shown that the most significant effect of this change in well-selection criteria has been to reduce the size of the areas with little or no data on some of the maps in figs. 9–12.

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. Although the average decline of water levels between 1998 and 1999 is small, the average decline since predevelopment of 52.3 ft (15.9 m) is still relatively large. 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, Hamilton, and Finney counties, where saturated thickness has decreased by over 50% (see fig. 9B).

Annual changes in water level (table 3) for Region I show an average decline of 1.1 ft (34 cm) this year, compared with 0.1 ft (3 cm) last year. Declines in water levels were observed in 80% of the wells reported, compared to 55% last year. The average water-level change for this region is statistically significant (table 3). The annual change map for 1998–99 (fig. 9C) shows a marked increase in the total area of declines when compared to the 1997–98 period. Areas of greater than 5-ft (1.5-m) decline have increased significantly and can be found in numerous counties throughout region I. Areas of decline greater than 10 ft (3 m) can be found in southeastern Stevens County. An exception to this trend of decline can be found in Morton and northern Stevens counties, where areas of decline have become smaller and areas of rise have increased in size. Rises greater than 5 ft (1.5 m) are confined to a small area in west-central Finney and east-central Kearny counties. These observations indicate an overall trend of decline to a greater extent than in 1997–98 over most of the region.

TABLE 2—CHANGE IN WATER LEVEL (ft), predevelopment to present, for reported wells in region I.

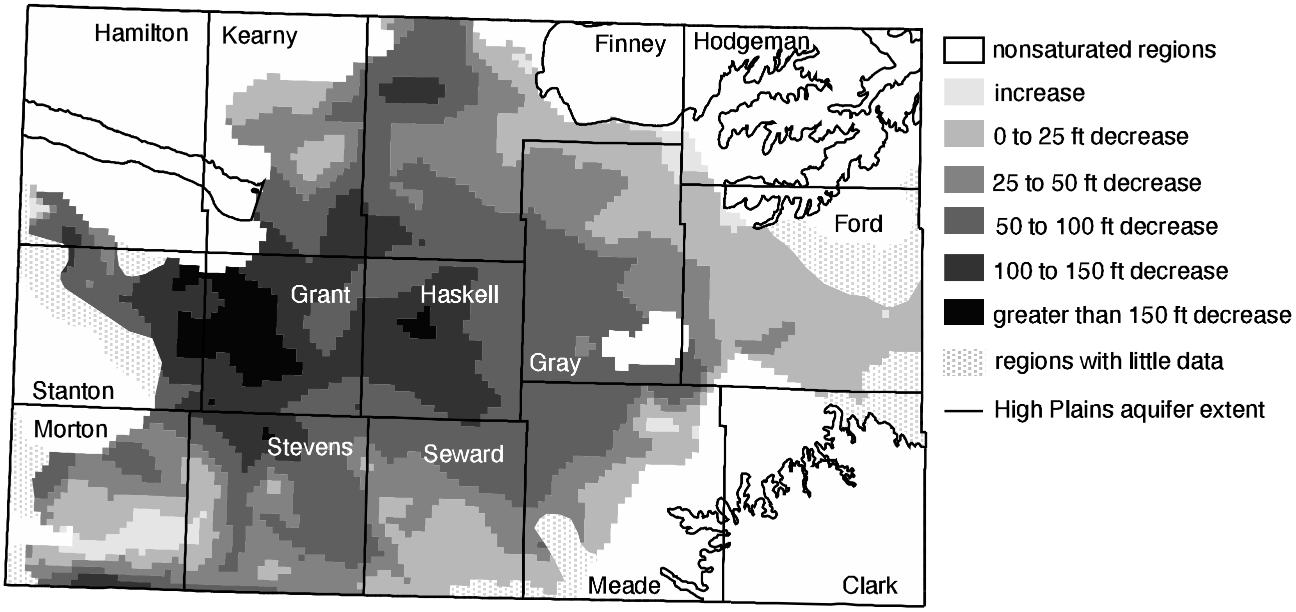
Year	Average change	Number of wells	Largest rise	Largest decline
1993	–48.0	331	19.8	210.4
1994	–49.4	327	19.8	207.9
1995	–49.6	302	19.6	212.0
1996	–53.4	307	18.6	216.9
1997	–52.2	304	19.9	218.9
1998	–51.4	303	20.1	216.8
1999	–52.3	296	19.3	218.0

TABLE 3—ANNUAL CHANGE IN WATER LEVEL (ft), for reported wells in region I.

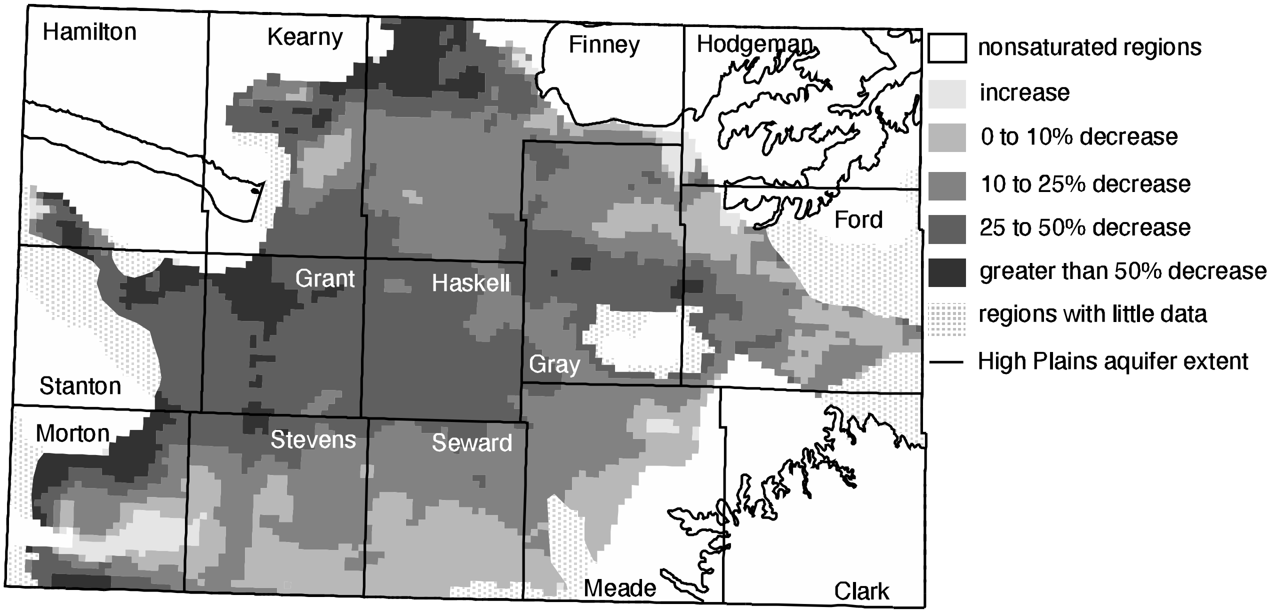
Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of wells with decline[a]	Is change statistically significant?
1993–1994	–0.1	415	43.1	21.5	34	66	no
1994–1995	–2.2	385	9.6	29.9	17	82	yes
1995–1996	–1.6	387	20.0	20.2	24	76	yes
1996–1997	–0.3	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

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.

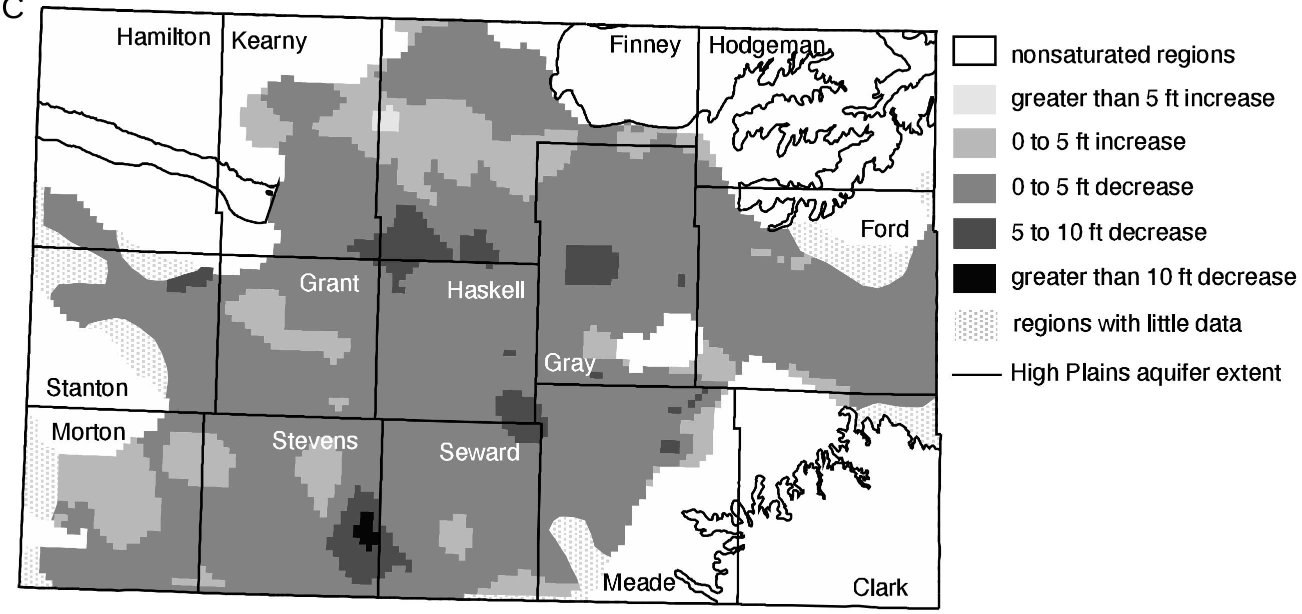
9A


Hamilton
Kearny
Finney
Hodgeman
Ford
Grant
Haskell
Gray
Stanton
Morton
Stevens
Seward
Meade
Clark
nonsaturated regions
increase
0 to 25 ft decrease
25 to 50 ft decrease
50 to 100 ft decrease
100 to 150 ft decrease
greater than 150 ft decrease
regions with little data
High Plains aquifer extent

9B


Hamilton
Kearny
Finney
Hodgeman
Ford
Grant
Haskell
Gray
Stanton
Morton
Stevens
Seward
Meade
Clark
nonsaturated regions
increase
0 to 10% decrease
10 to 25% decrease
25 to 50% decrease
greater than 50% decrease
regions with little data
High Plains aquifer extent

9C


Hamilton
Kearny
Finney
Hodgeman
Ford
Grant
Haskell
Gray
Stanton
Morton
Stevens
Seward
Meade
Clark
nonsaturated regions
greater than 5 ft increase
0 to 5 ft increase
0 to 5 ft decrease
5 to 10 ft decrease
greater than 10 ft decrease
regions with little data
High Plains aquifer extent

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 35.4 ft (10.8 m), with the largest decline equal to 83.2 ft (25.4 m). Water-level declines since the predevelopment period (fig. 10A) exceed 50 ft (15 m) in many areas, 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 1998. The depth-to-bedrock in region II is 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 total water reserves than is the case in the High Plains 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 (18.2 cm) in the 1998–99 period, a statistically significant change (table 5). The percentage of wells exhibiting a decline was more than the percentage of wells exhibiting a rise (59% vs. 41%). As fig. 10C indicates, the total area of greater than 1-ft (0.3-m) decline has increased markedly in Wallace, Greeley, and Wichita counties during the current period relative to 1997–98. In contrast, the total area of declines greater than 1 ft (0.3 m) has changed little in Scott and Lane counties relative to 1997–98. The total area of greater than 1-ft (0.3-m) rise has decreased relative to the 1997–98 period, primarily in Wichita, Greeley, and Wallace counties. Areas of greatest decline are in southern Wallace County. No areas of rise greater than 4 ft (1.2 m) occurred. These observations indicate an overall trend of significant water-level decline in the westernmost part of the region and relatively stationary water levels with local areas of rise and decline in the eastern and central parts of the 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
1993	−34.0	89	4.1	86.5
1994	−32.4	107	5.2	83.9
1995	−34.2	111	2.5	84.7
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

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?
1993–1994	+0.9	109	7.7	5.5	66	33	yes
1994–1995	−1.1	131	5.4	10.1	24	76	yes
1995–1996	−0.9	134	6.6	14.6	31	69	yes
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

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 9 (opposite page)—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 1999. (B) Change in saturated thickness (%), predevelopment to 1999. (C) Annual water-level change (ft), 1998–99.

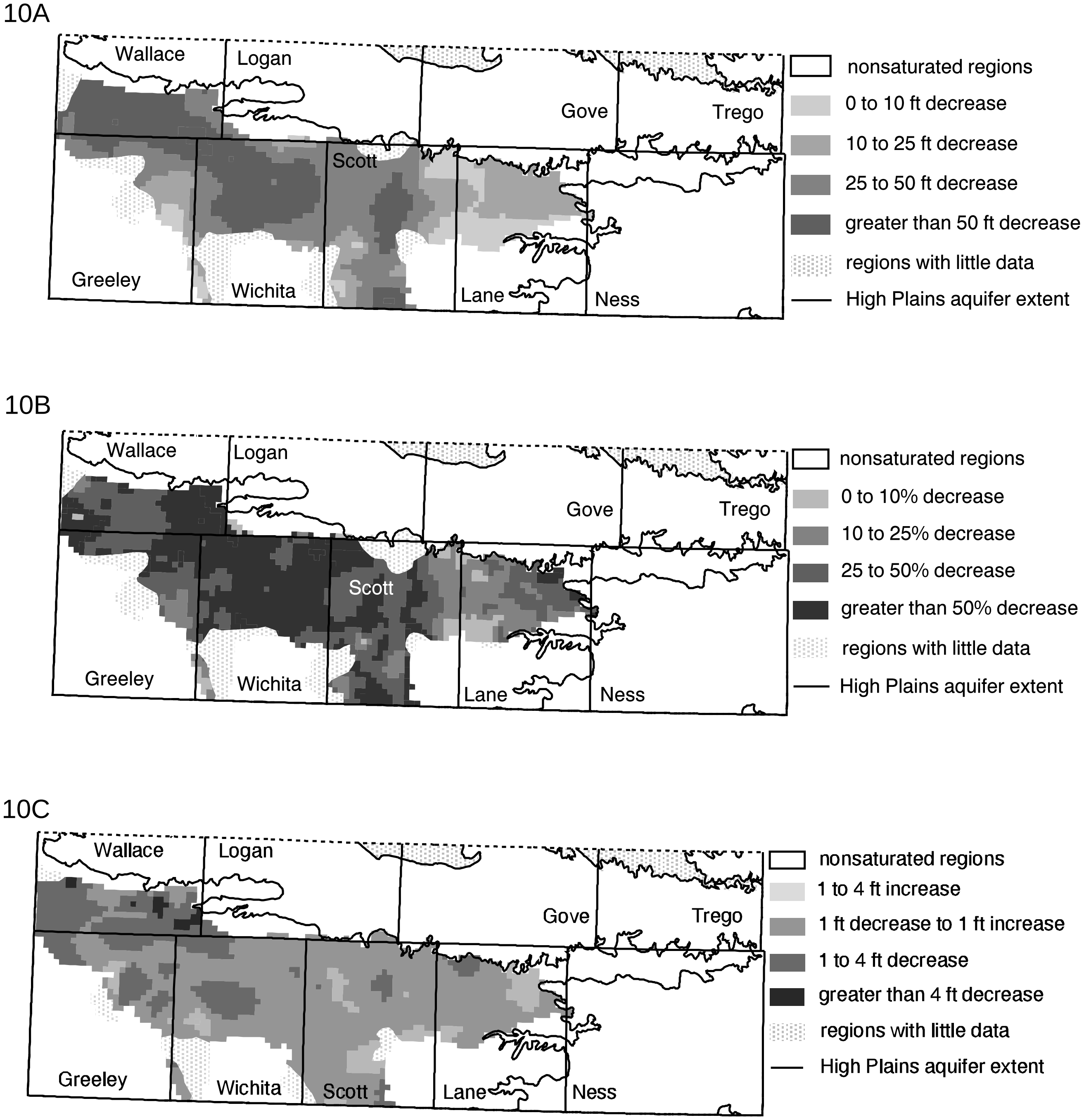


FIGURE 10—GROUND-WATER CHANGES IN THE AREA OF THE HIGH PLAINS AQUIFER IN REGION II, WEST-CENTRAL KANSAS. See fig. 11 for adjacent areas to the north and fig. 9 for adjacent areas to the south. (A) Generalized water-level changes (ft), predevelopment to 1999. (B) Change in saturated thickness (%), predevelopment to 1999. (C) Annual water-level change (ft), 1998–99.

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 14.4 ft (4.39 m), with the largest decline equal to 66.9 ft (20.4 m). The largest areas of declines greater than 25 ft (7.5 m) in water level (fig. 11A) and 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 1999 average annual change in water level was a decline of 0.1 ft (3 cm) (table 7), which is statistically insignificant. This average annual decline was slightly less than that of the 1997–98 period, which was 0.3 ft (9 cm). The percentage of wells with a decline in water level during 1998–99 was 61%, while the percentage of wells with a rise was 39% compared to 69% showing a decline and 30% showing a rise in the 1997–98 period. Figure 11C shows that the total area of declines greater than 1 ft (0.3 m) has significantly decreased in the current period relative to 1997–98. This trend seems to be most prevalent in Cheyenne, Sherman, Thomas, and northern Logan counties. In contrast, the total area of greater than 1-ft (0.3-m) decline has increased in Sheridan County. From fig. 11C one also can see that declines greater than 5 ft (1.5 m) were observed in relatively small, localized areas in southwestern Rawlins, in Sheridan, and in north-central Gove counties. Unlike the 1997–98 period, no areas of declines greater than 10 ft (3 m) were observed in region III. The largest areas with rises greater than 5 ft (1.5 m) were observed in northwestern Rawlins, southeastern Thomas, northeastern Logan, and southwestern Sheridan counties. These observations, taken as a whole, indicate an overall trend of decline throughout most of the region with significant localized areas of water-level rise. This trend of decline is to a lesser extent than in the 1997–98 period. In the analysis of these maps, no comparison was made for Decatur and Norton counties because numerous wells drilled in alluvial sediments were included this year in these counties that had not been included in previous years. In fig. 11C it can be seen that inclusion of these wells resulted in a drastic reduction in the areas of sparse data.

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

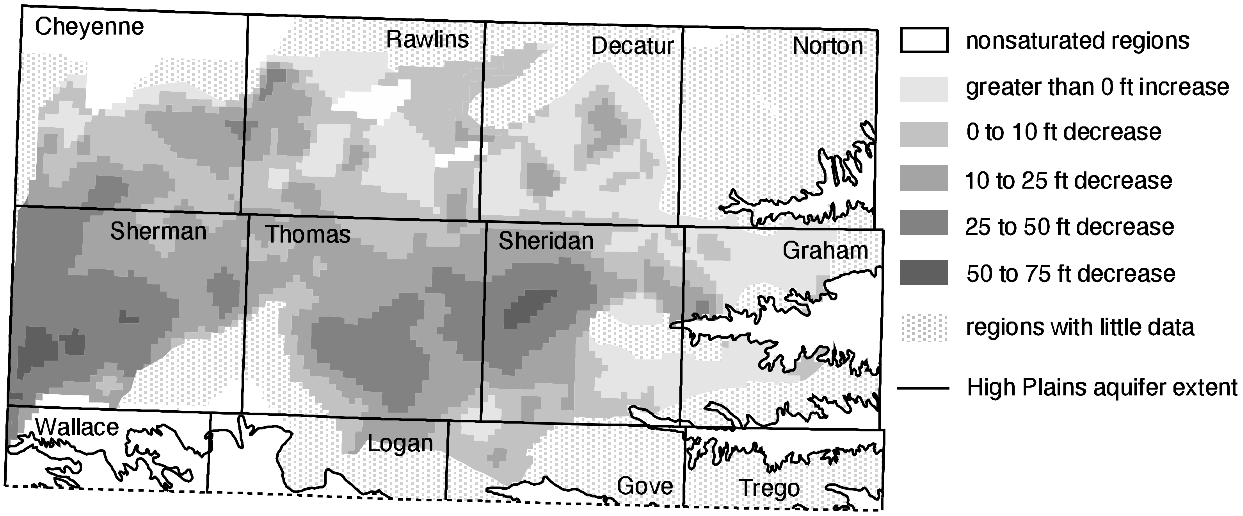
Year	Average change	Number of wells	Largest rise	Largest decline
1993	–13.8	209	6.1	66.6
1994	–12.4	238	8.7	64.8
1995	–13.2	234	22.3	67.1
1996	–14.2	225	23.5	67.8
1997	–14.2	227	21.8	67.4
1998	–14.8	225	10.1	61.5
1999	–14.4	229	15.3	66.9

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

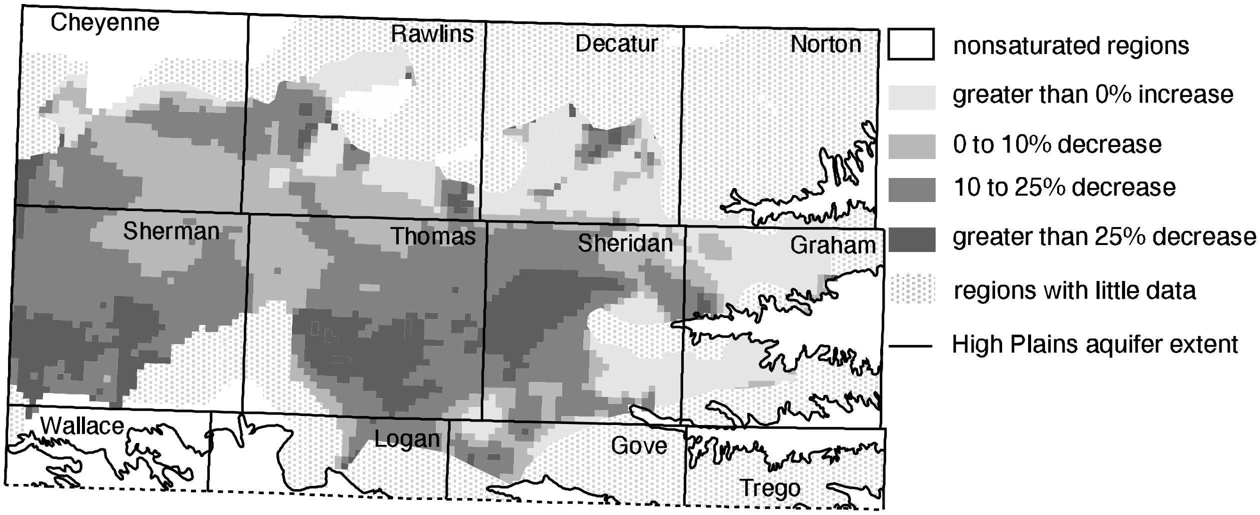
Interval	Average change	Number of wells	Largest rise	Largest decline	Percentage of wells with rise[a]	Percentage of wells with decline[a]	Is change statistically significant?
1993–1994	+1.3	290	15.6	11.3	73	26	yes
1994–1995	–0.5	317	16.2	13.0	34	66	yes
1995–1996	–0.4	306	9.9	17.4	45	54	yes
1996–1997	–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

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.

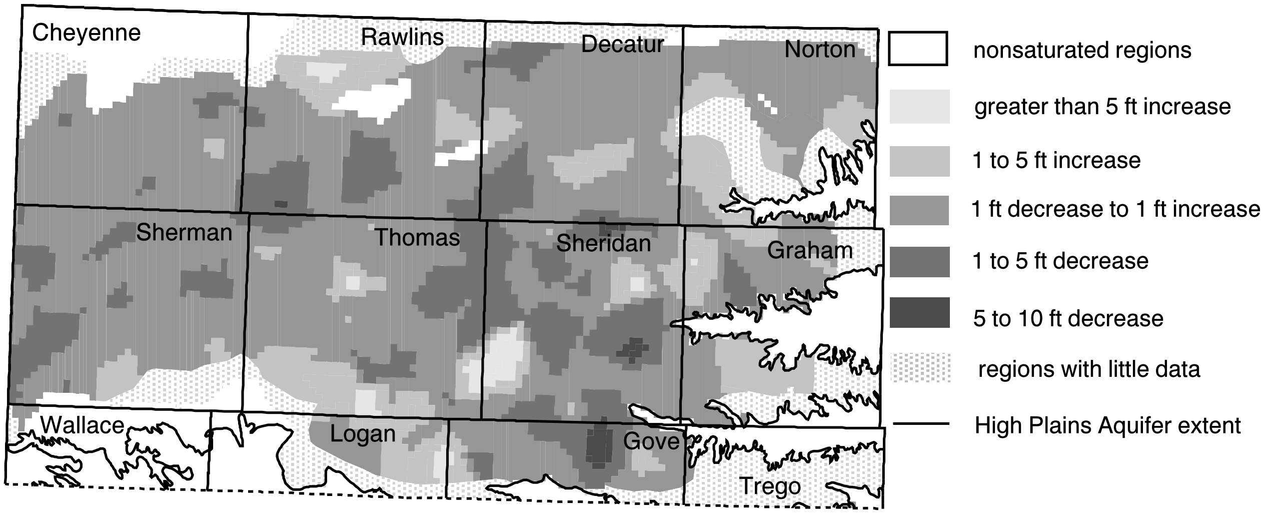
11A


Cheyenne
Rawlins
Decatur
Norton
Sherman
Thomas
Sheridan
Graham
Wallace
Logan
Gove
Trego
nonsaturated regions
greater than 0 ft increase
0 to 10 ft decrease
10 to 25 ft decrease
25 to 50 ft decrease
50 to 75 ft decrease
regions with little data
High Plains aquifer extent

11B


Cheyenne
Rawlins
Decatur
Norton
Sherman
Thomas
Sheridan
Graham
Wallace
Logan
Gove
Trego
nonsaturated regions
greater than 0% increase
0 to 10% decrease
10 to 25% decrease
greater than 25% decrease
regions with little data
High Plains aquifer extent

11C


Cheyenne
Rawlins
Decatur
Norton
Sherman
Thomas
Sheridan
Graham
Wallace
Logan
Gove
Trego
nonsaturated regions
greater than 5 ft increase
1 to 5 ft increase
1 ft decrease to 1 ft increase
1 to 5 ft decrease
5 to 10 ft decrease
regions with little data
High Plains Aquifer extent

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 ground-water supply is Quaternary alluvium. As table 8 shows, the average change since predevelopment has been a decline of 1.7 ft (52 cm), which is much smaller than the average change in other 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, Rice, Reno, and Kingman counties. Water-table elevations higher than the predevelopment value by 0–10 ft (0–3 m) were observed primarily in Stafford, Reno, Kingman, Pratt, and Kiowa counties.

Water-level changes in the 1998–99 period (table 9) had an average rise of 0.2 ft (6 cm) with 57% of the wells exhibiting an increase in water level (compared to 80% during the 1997–98 period). The total area over which declines occurred during 1998–99 is considerably larger than that observed for the previous period. From fig. 12C, it can be seen that the largest areas of decline were in the westernmost parts of the region (Pawnee, Edwards, and Kiowa counties). The largest annual water-level declines can be seen in south-central Pratt County and in small areas of Edwards and Reno counties. The largest water-level rises are in small areas in northwestern Pratt, south-central Harvey, and north-central Sedgwick counties.

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. The Kansas Geological Survey, Big Bend Groundwater Management District 5, and Equus Beds Groundwater Management District 2 are currently studying the relationship between saltwater and freshwater.

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
1993	–4.3	222	21.1	31.9
1994	–1.7	224	19.4	31.4
1995	–4.0	219	16.9	33.2
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

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?
1993–1994	+2.5	335	13.6	4.7	85	15	yes
1994–1995	–2.4	329	5.2	10.0	6	94	yes
1995–1996	+0.7	322	5.9	9.5	80	19	yes
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

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 11 (opposite page)—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 1999. (B) Change in saturated thickness (%), predevelopment to 1999. (C) Annual water-level change (ft), 1998–99.

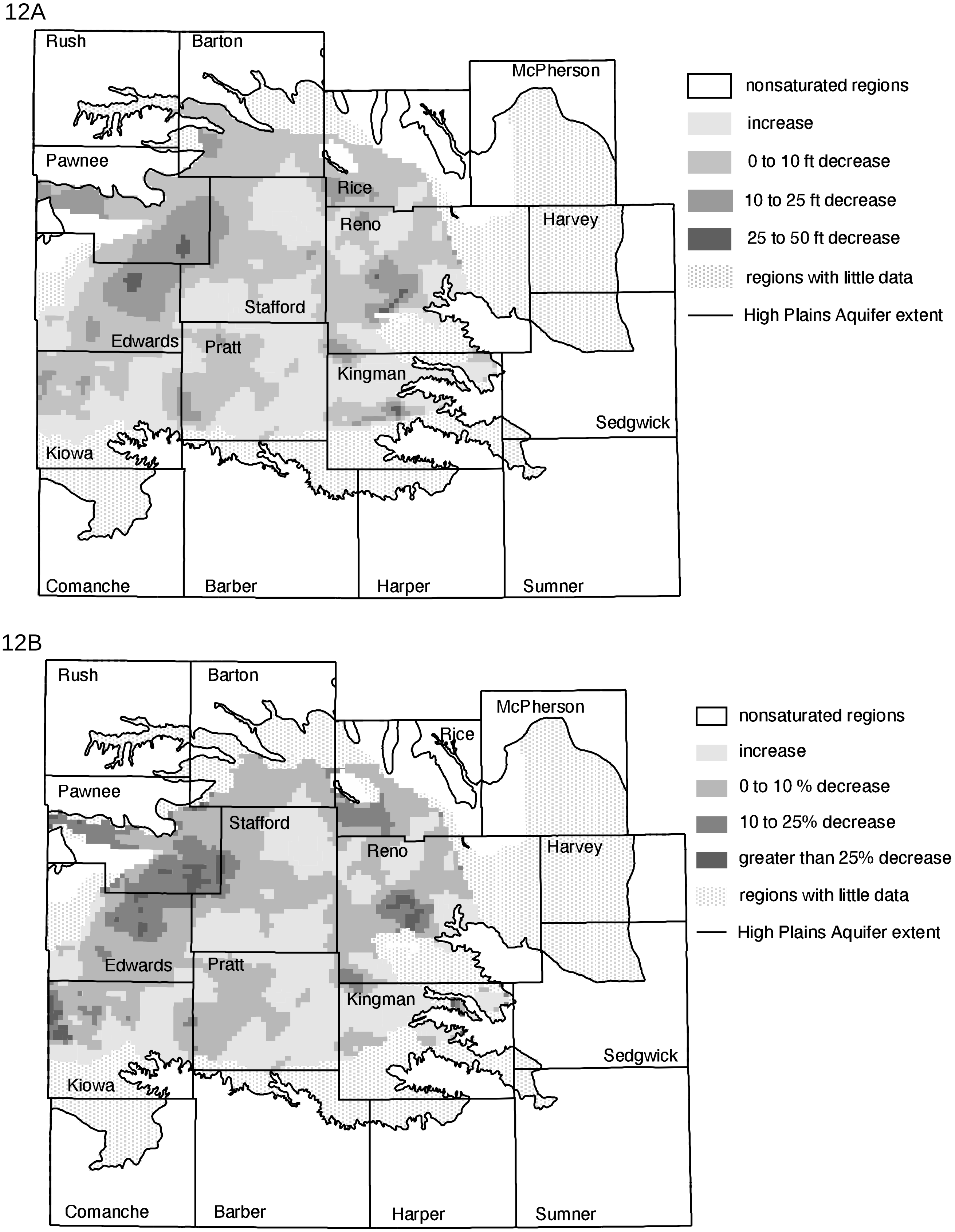
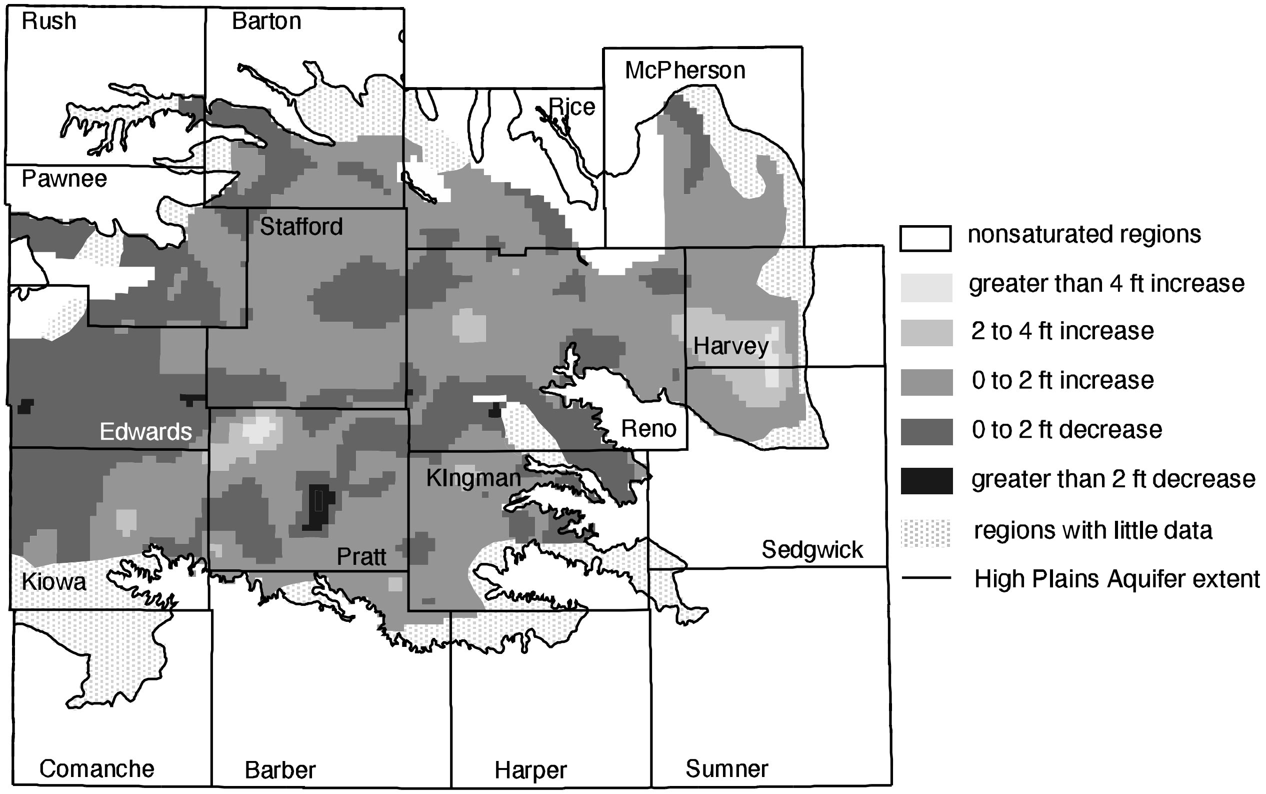


FIGURE 12 (above and next page)—GROUND-WATER CHANGES IN THE AREA OF THE HIGH PLAINS AQUIFER IN REGION V, SOUTH-CENTRAL KANSAS. See fig. 9 for adjacent areas to the west. (A) Generalized water-level changes (ft), predevelopment to 1999. (B) Change in saturated thickness (%), predevelopment to 1999. (C) Annual water-level change (ft), 1998–99.

12C



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 seven 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., 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

Buddemeier, R. W., 1995, Kansas research and data needs, 1995–2000: Kansas Geological Survey, Open-file Report 95–46, 6 p.

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., January 1996 Kansas water-level measurements: Kansas Geological Survey, Open-file Report 96–21, 100 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.

Woods, J. J., and Schloss, J. A., 1997, January 1997 Kansas water-level measurements: Kansas Geological Survey, Open-file Report 97–34, 69 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 Surveym, 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.

TABLE 10—U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPERS.

Year	**Water-Supply Paper Number***
1935	777
1936	817
1937	840
1938	845
1939	886
1940	908
1941	938
1942	946
1943	988
1944	1018
1945	1025
1946	1073
1947	1098
1948	1128
1949	1158
1950	1167
1951	1193
1952	1223
1953	1267
1954	1323
1955	1406
1956	1456
1957–1961	1781
1962–1966	1976
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***
1956	125
1957	131
1958	141
1959	146
1960	153
1961	159
1962	167
1963	173
1964	177
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 can not 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 99–5 entitled *1999 Annual Water Level Raw Data Report for Kansas*.

Column Definitions

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).

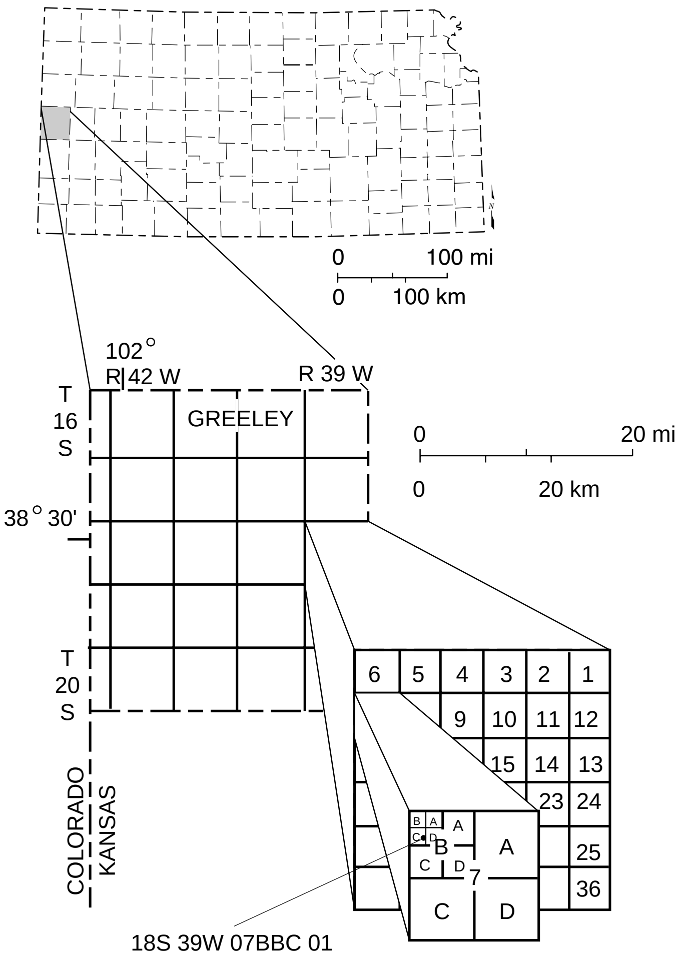


FIGURE 13—LOCATING WELLS USING THEIR LEGAL LOCATION DESIGNATION.

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 significant amounts of water-table data are available.

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 gives the well number as described for column 1.

Column 14 identifies the principal geologic unit or units (up to three) 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:

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