U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
CITY OF WICHITA, KANSAS

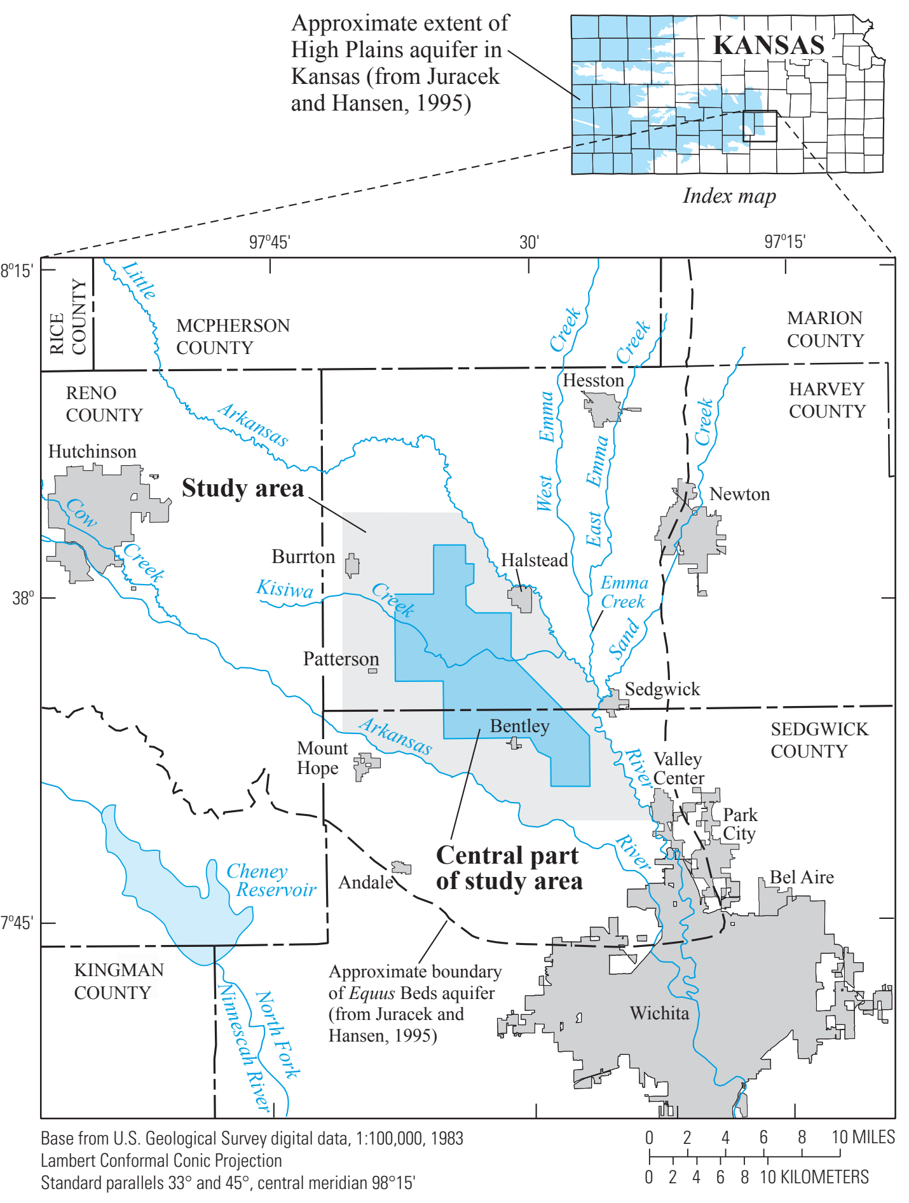
SCIENTIFIC INVESTIGATIONS MAP 3159
Status of groundwater levels and storage volume in the *Equus* Beds aquifer
Hansen, C.V., 2011, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, July 2010

Introduction

Beginning in the 1940s, the Wichita well field was developed in the *Equus* Beds aquifer in southwestern Harvey County and northwestern Sedgwick County to supply water to the city of Wichita, which has been the largest city in Kansas since the mid-1940s (Williams and Lohman, 1949; Gibson, 1998; U.S. Census Bureau, 2010). In addition to supplying drinking water for Wichita, the other primary use of water from the *Equus* Beds aquifer is crop irrigation in this agriculturally-dominated part of south-central Kansas (Rich Eubank, Kansas Department of Agriculture, Division of Water Resources, oral commun., 2008). The decline of water levels in the aquifer were noted soon after the development of the Wichita well field began (Williams and Lohman, 1949). As water levels in the aquifer decline, the volume of water stored in the aquifer decreases and less water is available to supply future needs. For many years the U.S. Geological Survey (USGS), in cooperation with the city of Wichita, has monitored these changes in water levels and the resulting changes in storage volume in the *Equus* Beds aquifer as part of Wichita's effort to effectively manage this resource. In 2007, the city of Wichita implemented Phase I of the *Equus* Beds Aquifer Storage and Recovery (ASR) project to increase the long-term sustainability of the *Equus* Beds aquifer through large-scale artificial recharge (City of Wichita, [2007?]). The ASR project uses water from the Little Arkansas River—either pumped from the river directly or from wells in the riverbank that obtain their water from the river by induced infiltration—as the source of artificial recharge to the *Equus* Beds aquifer (City of Wichita, [2007?]).

Hydrogeology of the Study Area

The approximately 165 square-mile (mi²) study area is located northwest of Wichita, Kansas in Harvey and Sedgwick Counties (fig. 1). It is bounded on the southwest by the Arkansas River and on the northeast by the Little Arkansas River. The land surface in the study area typically slopes gently toward the major streams from an altitude of about 1,495 feet (ft) in the northwest to a low of about 1,295 ft in the southeast. The central part of the study area (fig. 1), which covers about 55 mi², is the historic center of pumping in the study area. The central part of the study area includes wells used to supply water to the city of Wichita and many wells used for irrigation (Kansas Department of Agriculture, Division of Water Resources, unpublished data, 2010).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic Projection
Standard parallels 33° and 45°, central meridian 98°15'

Figure 1. Location of study area near Wichita, south-central Kansas (modified from Aucott and Myers, 1998).

The *Equus* Beds aquifer consists of Quaternary-age deposits in the study area. Quaternary-age deposits in the study area primarily are alluvial deposits with some dune sand and loess (Myers and others, 1996). The alluvial deposits, known locally as the *Equus* beds, are as much as 250 ft thick in the study area (Leonard and Kleinschmidt, 1976). The *Equus* beds primarily consist of sand and gravel interbedded with clay or silt, but locally may consist primarily of clay with thin sand and gravel layers (Lane and Miller, 1965a; Myers and others, 1996). The middle part of the *Equus* beds generally has more fine-grained material than the lower and upper parts (Lane and Miller, 1965b, Myers and others, 1996). The approximately 700-ft-thick Permian-age Wellington Formation underlies the *Equus* beds in the study area and forms the bedrock confining unit below them (Bayne, 1956; Myers and others, 1996).

The *Equus* Beds aquifer is the easternmost extension of the High Plains aquifer in Kansas (Stullken and others, 1985; Hansen and Aucott, 2001). The *Equus* Beds aquifer is an important source of water because of the generally shallow depth to the water table, the large saturated thickness, and generally good water quality. Near the Arkansas River and in the western part of the study area, the water table can be less than 10 ft below land surface. Farther from the Arkansas River and near the Little Arkansas River, the water table can be at a greater depth (as much as 50 ft below land surface in July 2010), depending on the altitude of the land surface and the amount of water-level decline that has been caused by groundwater withdrawals. The saturated thickness of the *Equus* Beds aquifer within the study area ranges from about 75 ft near the Little Arkansas River to almost 250 ft near the Arkansas River where the lowest areas of the underlying bedrock surface occur (Spinazola and others, 1985). The *Equus* Beds aquifer is considered to be an unconfined aquifer, but the presence of clay layers has resulted in semiconfined conditions in some areas (Spinazola and others, 1985; Stramel, 1967). Storage volume (the amount of water available for use) of the *Equus* Beds aquifer in the study area in 2006 was estimated at about 2,100,000 acre-feet (acre-ft) (Hansen, 2007).

Methods

From July 1 through July 22, 2010, water levels were measured in 114 historic observation wells and 38 areal index wells. The historic observation wells have been used by the city of Wichita for monitoring water levels in the *Equus* Beds aquifer for years, many since the 1940s (Stramel, 1956). The areal index wells were installed in 2001 and 2002 to monitor the effects of artificial recharge on the water quality and water levels in the *Equus* Beds aquifer and to determine if there are water-quality differences between the shallow and deep parts of the aquifer (Andrew Ziegler, U.S. Geological Survey, oral commun., September 2003). Water levels in the historic observation wells were measured by city of Wichita personnel; water levels in the areal index wells were measured by *Equus* Beds Groundwater Management District No. 2 (GMD2) personnel. Both agencies used standard water-level measurement techniques that are similar to USGS methods described in Stallman (1971). The historic observation well data are on file, in paper and electronic form, with the city of Wichita's Water and Sewer Department in Wichita, Kansas; the areal index well data collected by GMD2 are stored in the Kansas Geological Survey's (KGS's) Water Information and Storage and Retrieval Database (WIZARD) (Kansas Geological Survey, 2010). The water-level data used in this report from the historic monitoring wells and the areal index wells also are stored by the USGS in the National Water Information System (NWIS) database (U.S. Geological Survey, 2010b).

Precipitation for the study area for 2010 was estimated as the arithmetic average of precipitation for the five weather stations in or near Halstead, Hutchinson, Mount Hope, Newton, and Wichita (fig. 1). Values for normal precipitation currently (2010) used by the National Oceanic and Atmospheric Administration are the averages for 1971–2000 (National Oceanic and Atmospheric Administration, 2002). Normal (annual or monthly) precipitation for weather stations at Sedgwick, Hutchinson, Mount Hope, Newton, and Wichita was used to determine normal precipitation for the study area. Because precipitation data were not collected at Halstead before 2001, normal precipitation data from the nearby Sedgwick station were used instead. Collection of precipitation data at Sedgwick was discontinued in 2004, thus this station could not be used for the 2010 arithmetic average precipitation. Normal annual precipitation for the study area is about 31.35 inches (in.). This is similar to the long-term (1940–2009) average annual precipitation of 31.52 in. that was estimated for the study area by Hansen and Aucott (2010).

The water-level change since August 1940 at a well was determined by subtracting the depth to water below land surface in July 2010 from the depth to water below land surface at the same well in August 1940. Of the 152 wells used in this report, only 35 had measured water levels for August 1940. If an August 1940 water-level measurement did not exist for a well in the study area, one was estimated from the August 1940 water-level altitude map of Stramel (1956) as modified by Aucott and Myers (1998). The August 1940 to July 2010 water-level-change values for the measured wells were plotted on the map and manually contoured.

Change in storage volume for the purposes of this report is defined as the change in saturated aquifer volume multiplied by the specific yield of the aquifer. Specific yield is the ratio of (1) the volume of water a rock or soil will yield by gravity to (2) the volume of rock or soil (Lohman and others, 1972). A specific yield of 0.2 has been used to compute the changes in storage volume in the *Equus* Beds aquifer since Stramel (1956) first computed storage volume for the aquifer. The use of a specific yield of 0.2 was retained in this report because, as noted by Hansen and Aucott (2001), it is within the range of most estimates of specific yield, and because there is no general agreement on an average value of specific yield for the *Equus* Beds aquifer in the study area.

The change in storage volume from August 1940 to July 2010 was computed using computer-generated Thiessen polygons (Thiessen, 1911) that were based on the measured water-level changes at wells and the manually drawn lines of equal water-level change. Theissen polygons apportion the water-level change at each well and the estimated value at points representing the lines of equal water-level change to the area around the wells and points. The volume of storage change was computed by summing the area of each Theissen polygon multiplied by the water-level-change value associated with the Theissen polygon, and then multiplied by the specific yield. To determine the storage-volume change since August 1940 in the whole study area and in the central part of the study area, the computation was done for the Theissen polygons within each of these areas.

Changes in storage volume for periods that do not begin with August 1940 were calculated as the difference between changes in storage volume for August 1940 to the beginning of the selected time period, and for August 1940 to the end of the selected time period. For example, the change in storage volume for January 1993 to July 2010 was calculated as the change in storage volume for August 1940 to July 2010 minus the change in storage volume for August 1940 to January 1993.

Groundwater Levels and Storage Volume, July 2010

Groundwater-level declines can result from a combination of factors, with the primary factors in the study area being pumpage and decreased recharge resulting from less-than-normal precipitation. Droughts and other periods of less-than-normal precipitation tend to decrease the amount of recharge available and increase demand for, and thus pumpage of, groundwater, resulting in increased water-level declines. Periods of greater-than-normal rainfall tend to increase the amount of recharge available and decrease the demand for, and thus pumpage of, groundwater, resulting in water-level rises. If the water-level declines or rises are large enough, they may locally alter the direction of groundwater flow. An annual cycle of water-level declines and rises generally occurs in the study area. Typically, the largest water-level declines occur during the summer or fall when agricultural-irrigation and city pumpage are greatest (Aucott and Myers, 1998). This cycle of annual water-level declines is reflected in the annual fluctuation in the water levels in wells shown in figure 2. The consistently large seasonal water-level variations (commonly from 5 to 20 ft) in well 104 probably are caused by agricultural-irrigation pumpage.

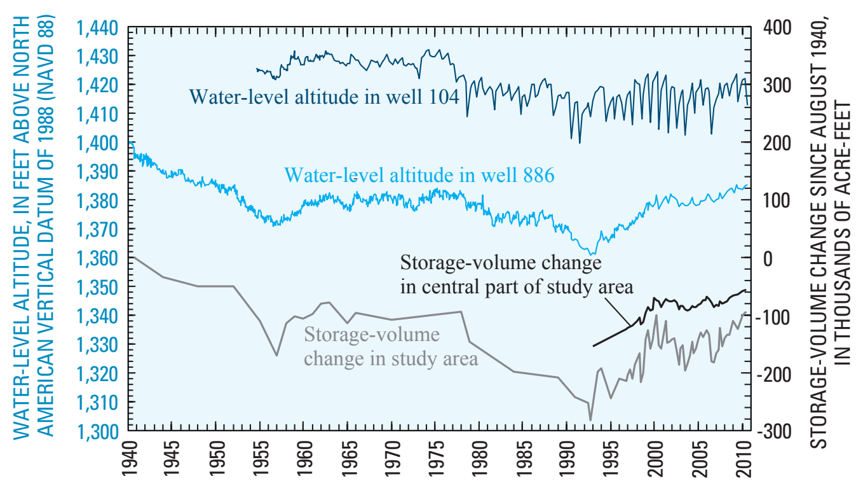


Figure 2. Water-level altitudes in observation wells 104 and 886 and *Equus* Beds aquifer storage-volume change in the study area and the central part of the study area (water-level-altitude data are from Stramel (1956, 1967) and data collected by city of Wichita that are on file with U.S. Geological Survey in Lawrence, Kansas; storage-volume changes are from Stramel (1956, 1967), Aucott and Myers (1998), Aucott and others (1998), Hansen and Aucott (2001, 2004, 2010), Hansen (2007, 2009), and unpublished data on file with U.S. Geological Survey in Lawrence, Kansas). Locations of observation wells are shown in figure 3.

Record to near-record water-level declines in the *Equus* Beds aquifer occurred in October 1992 and January 1993 (Aucott and Myers, 1998; Hansen and Aucott, 2001). Although the maximum recorded decline in storage volume in the *Equus* Beds aquifer occurred in October 1992, the January 1993 storage-volume decline is used for comparison purposes to minimize the effect of seasonal factors (Hansen and Aucott, 2001). Recent reports have indicated that since January 1993, the *Equus* Beds aquifer has been experiencing higher water levels because of near-normal to greater-than-normal precipitation and decreased city pumpage (Aucott and Myers, 1998; Hansen and Aucott, 2001, 2004, 2010; Hansen, 2007). Pumpage for agricultural irrigation, which can vary as much as 40 percent from year to year, tended to decrease in years of greater-than-normal precipitation and increase in years of normal to less-than-normal precipitation (Hansen, 2007); thus, decreased pumpage for agricultural irrigation likely contributed to the higher water levels only in years of greater-than-normal precipitation. Water levels in wells in the study area have continued to remain relatively high (fig. 2), indicating this period of higher water levels that began in 1993 continued through July 2010. Large-scale artificial recharge by the city of Wichita, which began in 2007, probably contributed to the continuation of these higher water levels near the recharge sites (Hansen and Aucott, 2010).

Water-level changes from August 1940 to July 2010 are shown in figure 3. Water levels were measured in the historic observation wells by city of Wichita personnel on July 1, 2010, and from July 20 through 22, 2010; water levels were measured in the areal index wells by GMD2 personnel on July 15 and 16, 2010. Water-level changes from August 1940 to July 2010 ranged from a decline of 27.25 ft at well 1 in the northern part of the central part of the study area to a rise of 5.04 ft at well 506 near the Little Arkansas River in the northern part of the study area (fig. 3). Water-level declines of 20 ft or more occurred in the northern part of the central part of the study area, probably because of pumping in this area. Surrounding the area of decline of 20 ft or more is a large area of water-level declines of 10 ft or more (fig. 3). There are two additional areas of water-level declines of 10 ft or more—a large area south of Kisiwa Creek in the central part of the study area and a smaller area in the northwest part of the study area (fig. 3). Water-level rises of less than 3 ft occurred in a large area along the western edge of the study area and in small areas near the Arkansas and Little Arkansas Rivers (fig. 3). These water-level rises probably occurred because of increased natural recharge from excess precipitation. Precipitation in July 2010 at the five weather stations in and near the study area (Halstead, Hutchinson, Mount Hope, Newton, and Wichita; fig. 1) ranged from about 2.77 in. at Wichita to about 9.29 in. at Mount Hope and averaged about 5.70 in. (National Oceanic and Atmospheric Administration, 2010g) with most of the precipitation occurring during July 3 through 6, 2010 (National Oceanic and Atmospheric Administration, 2010g). Precipitation in the study area during July 2010 was about 2 in. or more above normal in much of the study area (National Oceanic and Atmospheric Administration, 2010h). No obvious effects of artificial recharge are documented at the Phase 1 sites in this report, probably because only about 48 acre-ft of artificial recharge occurred in July 2010 and only at the four northern Phase 1 sites (U.S. Geological Survey, 2010a).

The change in storage volume in the study area from August 1940 to July 2010 was a decrease of about 93,700 acre-ft (fig. 2; table 1). Storage volume levels in July 2010 were similar to those seen in the 1970s (fig. 2). The storage volume in the study area in July 2010 was about 6,300 acre-ft more than in January 2010, and about 30,300 acre-ft more than in July 2009 (table 1). From August 1940 (just before Wichita began pumping water from the study area) to January 1993 (when near-record low water levels and storage volumes occurred in the study area because of a combination of drought conditions and increased usage), storage volume decreased by about 255,000 acre-ft in the study area (Aucott and Myers, 1998). The change in storage volume from January 1993 to July 2010 represents a recovery of about 161,300 acre-ft (table 1) or about 63 percent of the storage volume previously lost from August 1940 to January 1993. From August 1940 to January 2007 (when the last set of water-level measurements were made before large-scale artificial recharge began), storage volume decreased by about 167,000 acre-ft (table 1). The change in storage volume from January 2007 to July 2010 represents a recovery of about 73,300 acre-ft, or about 44 percent of the storage volume previously lost from August 1940 to January 2007. Precipitation in the study area during January through July 2010 averaged about 22.85 in., or about 3.47 in. greater than the study-area normal for January through July (National Oceanic and Atmospheric Administration, 2002, 2010a–g). Hansen and Aucott (2011) noted greater-than-normal precipitation contributes to storage-volume recoveries through increased natural recharge and reduced demand for irrigation and city pumpage. Since March 2007, when Wichita began large-scale artificial recharge, about 2,825 acre-ft (about 921 million gallons) of water have been artificially recharged into the aquifer through the six Phase 1 recharge sites shown in figure 3 (U.S. Geological Survey, 2010a). Hansen and Aucott (2010) documented the amount of artificial recharge is relatively small compared to the amount of the city and agricultural-irrigation pumpage from the *Equus* Beds aquifer in the study area for the same period.

Table 1. Storage-volume changes in *Equus* Beds aquifer near Wichita, south-central Kansas, August 1940 to July 2010.

[Data on file with U.S. Geological Survey, Lawrence, Kansas.]

Time period	Storage-volume changes, in acre-feet	
	Study area	Central part of study area
August 1940 to January 1993	[1]-255,000	[1]-154,000
August 1940 to January 2007	[2]-167,000	[2]-82,900
August 1940 to July 2009	[2]-124,000	[2]-64,100
August 1940 to January 2010	[2]-100,000	[2]-57,600
August 1940 to July 2010	-93,700	-56,000
January 1993 to July 2010	+161,300	+98,000
January 2007 to July 2010	+73,300	+26,900
July 2009 to July 2010	+30,300	+8,100
January 2010 to July 2010	+6,300	+1,600

[1] Storage-volume change previously reported by Aucott and Myers (1998).

[2] Storage-volume change previously reported by Hansen and Aucott (2010).

The change in storage volume in the central part of the study area (where Wichita city wells are located) from August 1940 to July 2010 was a decrease of about 56,000 acre-ft (fig. 2; table 1). Storage volume in the central part of the study area in July 2010 was about 8,100 acre-ft more than in July 2009 and about 1,600 acre-ft more than in January 2010 (table 1). From January 1993 to July 2010, storage volume in the central part of the study area increased by about 98,000 acre-ft (table 1) or about 64 percent of the storage volume previously lost from August 1940 to January 1993. From January 2007 (just before large-scale artificial recharge began) to July 2010, storage volume in the central part of the study area increased by about 26,900 acre-ft or about 32 percent of the storage volume previously lost from August 1940 to January 2007. Major factors in the recovery in storage volumes seen in the study area and the central part of the study area (table 1) are increased recharge from greater-than-normal precipitation and planned decreases in city pumpage that are part of Wichita's Integrated Resource Plan (Hansen and Aucott, 2010; Warren and others, 1995); however, part of the recovery may be because city and irrigation pumpage probably decreased in response to greater-than-normal precipitation in the study area during January to July 2010 (National Oceanic and Atmospheric Administration, 2002, 2010g).

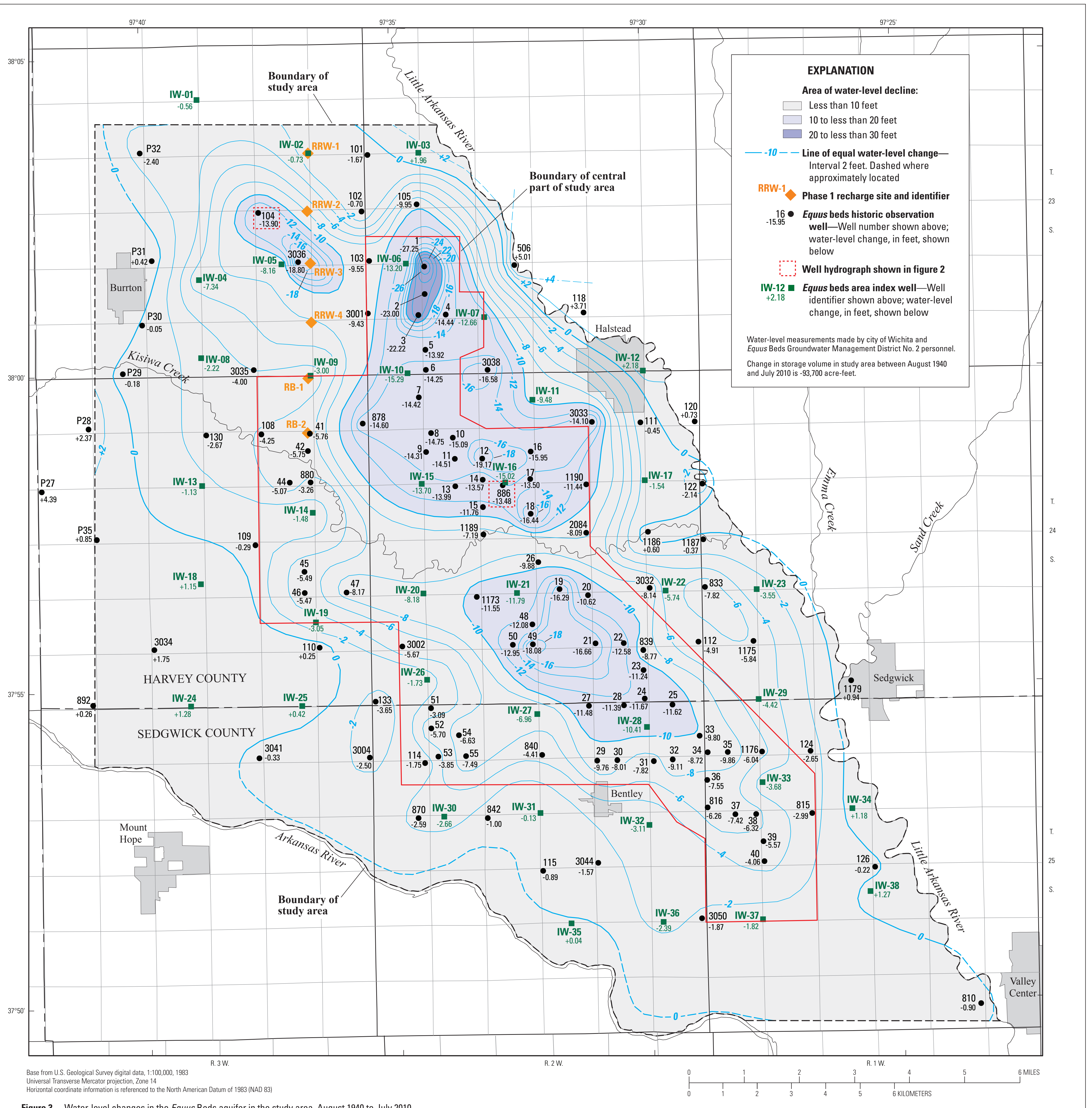
Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi²)	2.590	square kilometer (km²)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m³)
million gallons (Mgal)	3,785	cubic meter (m³)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Figure 3. Water-level changes in the *Equus* Beds aquifer in the study area, August 1940 to July 2010.

References

Aucott, W.R., and Myers, N.C., 1998, Changes in ground-water levels and storage in the Wichita well field area, south-central Kansas, 1940–98: U.S. Geological Survey Water-Resources Investigations Report 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 Report 98–4095, 15 p.

Bayne, C.K., 1956, Geology and ground-water resources of Reno County, Kansas: Kansas Geological Survey Bulletin 120, 130 p., available at: *http://www.kgs.ku.edu/General/Geology/Reno/index.html.*

City of Wichita, [2007?], Wichita area future water supply—A model program for other municipalities: Wichita, Kansas, accessed March 24, 2009, at *http://www.wichita.gov/CityOffices/WaterAndSewer/ProductionAndPumping/ASR/FutureWaterSupply.htm.*

Gibson, Campbell, 1998, Population of the 100 largest cities and other urban places in the United States—1790–1990: U.S. Census Bureau, Population Division Working Paper No. 27 accessed January 10, 2010, at *http://www.census.gov/population/www/documentation/twps0027.html.*

Hansen, C.V., 2007, Status of ground-water levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2003–January 2006: U.S. Geological Survey Scientific Investigations Report 2006–5321, 34 p., available at: *http://pubs.usgs.gov/sir/2006/5321/.*

Hansen, C.V., 2009, Status of ground-water levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, July 2009: U.S. Geological Survey Scientific Investigations Map 3075, map scale 1:84,480, available at: *http://pubs.usgs.gov/sim/3075/.*

Hansen, C.V., and Aucott, W.R., 2001, 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 Report 00–4267, 27 p.

Hansen, C.V., and Aucott, W.R., 2004, Status of ground-water levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2000–January 2003: U.S. Geological Survey Water-Resources Investigations Report 03–4298, 36 p., available at: *http://pubs.usgs.gov/wri/wrir034298/.*

Hansen, C.V., and Aucott, W.R., 2010, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2006 to January 2010: U.S. Geological Survey Scientific Information Report 2010–5231, 47 p.

Juracek, K.E., and Hansen, C.V., 1995, Digital maps of the extent, base, top, and 1991 potentiometric surface of the High Plains aquifer in Kansas: U.S. Geological Survey Open-File Report 95–758, map scales 1:500,000 and 1:1,000,000.

Kansas Geological Survey, 2010, WIZARD water-level database: Kansas Geological Survey database accessed August 8, 2010, at *http://www.kgs.ku.edu/Magellan/WaterLevels/index.html.*

Lane, C.W., and Miller, D.E., 1965a, Geohydrology of Sedgwick County, Kansas: Kansas Geological Survey Bulletin 176, 100 p., available at: *http://www.kgs.ku.edu/General/Geology/Sedgwick/index.html.*

Lane, C.W., and Miller, D.E., 1965b, Logs of wells and test holes in Sedgwick County, Kansas: Kansas Geological Survey Special Distribution Publication 22, 175 p.

Leonard, R.B., and Kleinschmidt, M.K., 1976, Saline water in the Little Arkansas River Basin area, south-central Kansas: Kansas Geological Survey Chemical Quality Series 3, 24 p.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms—Revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Myers, N.C., Hargadine, G.D., and Gillespie, J.B., 1996, Hydrologic and chemical interaction of the Arkansas River and the *Equus* Beds aquifer between Hutchinson and Wichita, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 95–4191, 100 p., available at: *http://pubs.er.usgs.gov/publication/wri954191.*

National Oceanic and Atmospheric Administration, 2002, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971–2000, Kansas: Asheville, North Carolina, Climatography of the United States no. 81, 37 p., available at: *http://cdo.ncdc.noaa.gov/climatenormals/clim81/KSnorm.pdf.*

National Oceanic and Atmospheric Administration, 2010a, Climatological data, Kansas, January 2010: Asheville, North Carolina, v. 124, no. 1, 49 p.

National Oceanic and Atmospheric Administration, 2010b, Climatological data, Kansas, February 2010: Asheville, North Carolina, v. 124, no. 2, 47 p.

National Oceanic and Atmospheric Administration, 2010c, Climatological data, Kansas, March 2010: Asheville, North Carolina, v. 124, no. 3, 48 p.

National Oceanic and Atmospheric Administration, 2010d, Climatological data, Kansas, April 2010: Asheville, North Carolina, v. 124, no. 4, 36 p.

National Oceanic and Atmospheric Administration, 2010e, Climatological data, Kansas, May 2010: Asheville, North Carolina, v. 124, no. 5, 34 p.

National Oceanic and Atmospheric Administration, 2010f, Climatological data, Kansas, June 2010: Asheville, North Carolina, v. 124, no. 6, 34 p.

National Oceanic and Atmospheric Administration, 2010g, Climatological data, Kansas, July 2010: Asheville, North Carolina, v. 124, no. 7, 42 p.

National Oceanic and Atmospheric Administration, 2010h, Kansas—July 2010 monthly departure from normal precipitation: National Weather Service, Advanced Hydrologic Prediction Service, accessed November 10, 2010 at *http://water.weather.gov/precip.*

Spinazola, J.M., Gillespie, J.B., and Hart, R.J., 1985, Ground-water flow and solute transport in the *Equus* beds area, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 85–4336, 68 p., available at: *http://pubs.er.usgs.gov/publication/wri854336.*

Stallman, R.W., 1971, Aquifer-test design, observation and data analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. B–1, p. 14–16, available at: *http://pubs.er.usgs.gov/publication/twri03B1.*

Stramel, G.J., 1956, Progress report on the ground-water hydrology of the *Equus* beds area, Kansas: Kansas Geological Survey Bulletin 119, part 1, 59 p.

Stramel, G.J., 1967, Progress report on the ground-water hydrology of the *Equus* beds area, Kansas 1966: Kansas Geological Survey Bulletin 187, part 2, 27 p.

Stullken, L.E., Watts, K.R., and Lindgren, R.J., 1985, Geohydrology of the High Plains aquifer, western Kansas: U.S. Geological Survey Water-Resources Investigations Report 85–4198, 86 p., available at: *http://pubs.er.usgs.gov/publication/wri854198.*

Theissen, A.H., 1911, Precipitation averages for large areas: Monthly Weather Review, v. 39, p. 1,082–1,084.

U.S. Census Bureau, 2010, Table 4—Annual estimates of resident population for incorporated places in Kansas, April 1, 2000 to July 1, 2009 (SUB–EST2009–04–20): U.S. Census Bureau, Population Division, accessed January 27, 2010, at *http://www.census.gov/popest/cities/SUB-EST2009-4.html.*

U.S. Geological Survey, 2010a, Highlights of *Equus* Beds Groundwater Recharge Project: U.S. Geological Survey, Kansas Water Science Center, accessed November 10, 2010, at *http://ks.water.usgs.gov/studies/equus/equus_hilites.html#HDR1*.

U.S. Geological Survey, 2010b, National Water Information System (NWISWeb): U.S. Geological Survey database accessed October 7, 2010, at *http://waterdata.usgs.gov/ks/nwis/.*

Warren, D.R., Blain, G.T., Shorney, F.L., and Klein, L.J., 1995, IRP—a case study from Kansas: Journal of the American Water Works Association, v. 87, no. 6, p. 57–71.

Williams, C.C., and Lohman, S.W., 1949, Geology and ground-water resources of a part of south-central Kansas, with special reference to the Wichita municipal water supply: Kansas Geological Survey Bulletin 79, 455 p.

Status of Groundwater Levels and Storage Volume in the *Equus* Beds Aquifer near Wichita, Kansas, July 2010

By

Cristi V. Hansen

2011

Suggested citation:
Hansen, C.V., 2011, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, July 2010: U.S. Geological Survey Scientific Investigations Map 3159, 1 sheet.

For more information about USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: *http://www.usgs.gov*

Publishing support provided by:
Rolla Publishing Service Center

For additional information concerning this publication, contact:
Director, USGS Kansas Water Science Center
4821 Quail Crest Place, Lawrence, KS (785) 842–9909

Or visit the Kansas Water Science Center Web Site at:
http://ks.water.usgs.gov