Hansen, C.V., 2009, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, January 2009

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 (Williams and Lohman, 1949). In addition to supplying drinking water to the largest city in Kansas, the other primary use of water from the *Equus* Beds aquifer is to irrigate crops in this agriculture-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 began using Phase I of the *Equus* Beds Aquifer Storage and Recovery (ASR) project for large-scale artificial recharge of the *Equus* Beds aquifer. 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, 2009).

Hydrogeology of the Study Area

The study area (fig. 1) includes about 165 square miles (mi²) and is located in Harvey and Sedgwick Counties northwest from Wichita, Kansas. The study area is bounded on the southwest by the Arkansas River and on the northeast by the Little Arkansas River. There is little topographic relief in the study area. For the most part, the land surface slopes gently toward the major streams in the study area. 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.

Quaternary deposits occur throughout the study area primarily as alluvial deposits. These alluvial deposits, known locally as the *Equus* beds, are as much as 250 feet (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 deposits generally has more fine-grained material than the lower and upper parts (Lane and Miller, 1965b, Myers and others, 1996). The Wellington Formation of Permian age underlies the Quaternary deposits in the study area and forms the bedrock confining unit below these deposits; it is about 700 ft thick (Bayne, 1956). In the study area, the *Equus* Beds aquifer consists of the *Equus* beds deposits.

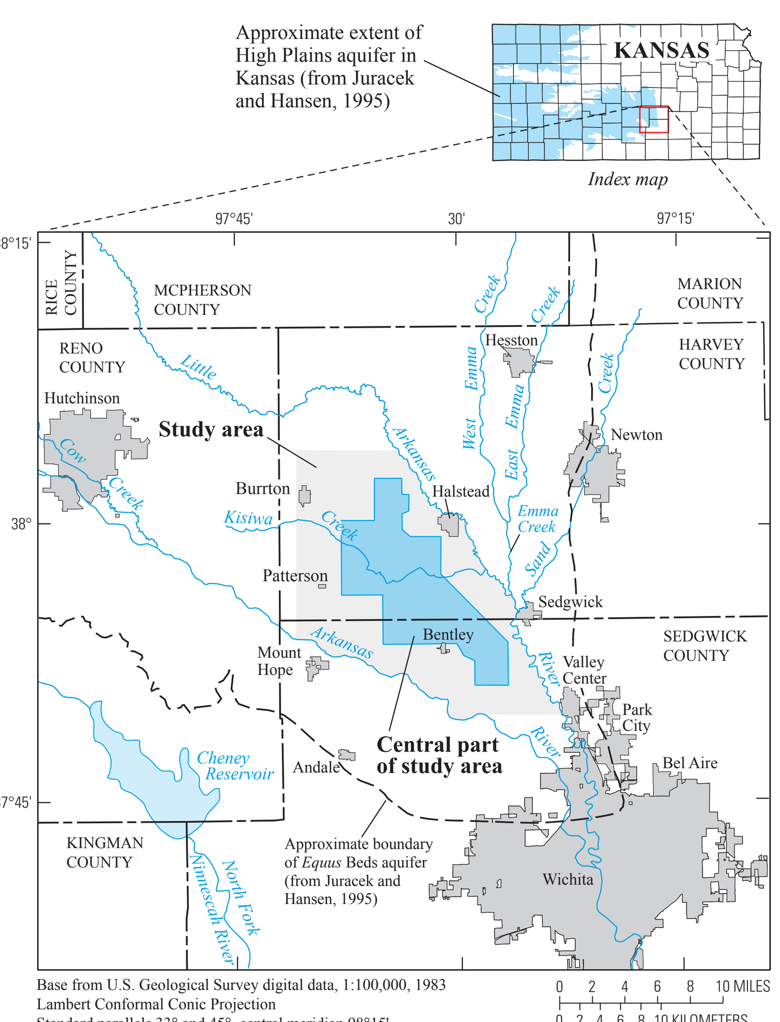

Figure 1. Location of study area near Wichita, south-central Kansas (modified from Aucott and Myers, 1998).

The *Equus* Beds aquifer is the easternmost extension of the High Plains aquifer in Kansas (Stulken and others, 1985; Hansen and Aucott, 2001). The *Equus* Beds aquifer is an important source of groundwater because of the generally shallow depth to the water table, the large saturated thickness, and generally good water quality. Near the Arkansas River, the water table may be as little as 10 ft below land surface. Farther from the Arkansas River and near the Little Arkansas River, the water table is at a greater depth, 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 semi-confined 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

The January 2009 water-level measurements were collected during January 2 to 30, 2009, from 113 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 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) and are available at the following URL: *http://www.kgs.ku.edu/Magellan/WaterLevels/index.html* 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 and are available at the following URL: *http://waterdata.usgs.gov/ks/nwis*

The water-level change since August 1940 at a well was determined by subtracting the depth to water below land surface in January 2009 from the depth to water below land surface at the same well in August 1940. Of the 151 wells used in this report, 38 had measured water levels for August 1940 and 113 did not. 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 January 2009 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. 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 January 2009 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 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 January 2009 was calculated as the change in storage volume for August 1940 to January 2009, minus the change in storage volume for August 1940 to January 1993.

Groundwater Levels and Storage Volume, January 2009

Groundwater-level declines can result from a combination of factors, with the primary factors being pumpage and decreased recharge resulting from less-than-average precipitation. Droughts and other periods of less-than-average 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-average 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 in well 104 probably are caused by agricultural-irrigation pumpage.

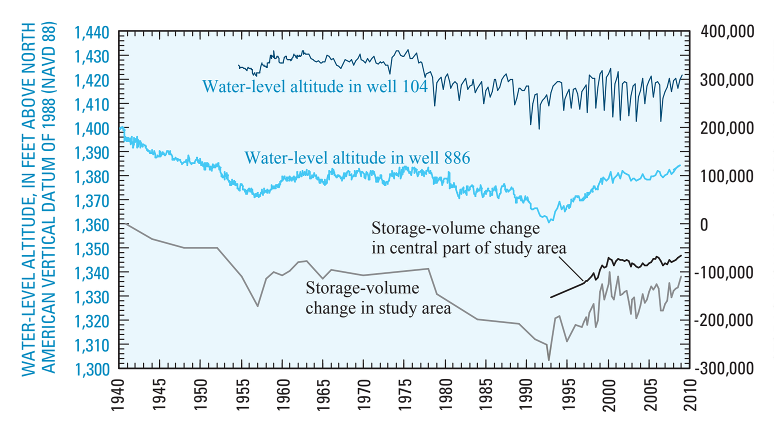

Figure 2. Water-level altitudes in observation wells 104 and 886 and *Equus* Beds aquifer storage-volume change since 1940 to January 2009 in the study area and the central part of the study area (water-level-altitude data from Stramel (1956, 1967), and from data collected by city of Wichita, *Equus* Beds Groundwater Management District No. 2, and on file with U.S. Geological Survey. Location of observation wells is shown in figure 3. Storage-volume changes from Stramel (1956, 1967), Aucott and Myers (1998), Aucott and others (1998), Hansen and Aucott (2001, 2004), Hansen (2007, 2009), and data on file with U.S. Geological Survey in Lawrence, Kansas).

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 on these comparisons (Hansen and Aucott, 2001). Recent reports have shown that since January 1993, the *Equus* Beds aquifer has been experiencing higher water levels because of near-average to greater-than-average precipitation and decreased city pumpage (Aucott and Myers, 1998; Hansen and Aucott, 2001, 2004; 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-average precipitation and increase in years of average to less-than-average precipitation (Hansen, 2007); thus, decreased pumpage for agricultural irrigation likely contributed to the higher water levels only in years of greater-than-average precipitation. Water levels in wells in the study area have continued to remain relatively high, indicating this period of higher water levels that began in 1993 continued through January 2009 (fig. 2). Large-scale artificial recharge by the city of Wichita, which began in 2007, probably also has contributed to the continuation of these higher water levels.

Water-level changes from August 1940 to January 2009 are shown in figure 3. Water levels were measured in the historic observation wells by city of Wichita personnel during January 2 to 12, 2009, and in the areal index wells by GMD2 personnel during January 19 to 30, 2009. Precipitation during January 2 to 12, 2009, was no more than a trace at all five weather stations in and near the study area (Halstead, Hutchinson, Mount Hope, Newton, and Wichita; fig. 1); precipitation ranged from 0.02 to 0.08 inch (in.) at these stations during January 19 to 30, 2009 (Mary Knapp, State Climatologist, written commun. May 2009). Water-level changes from August 1940 to January 2009 ranged from a decline of 25.66 ft at well 14 in the central part of the study area to a rise of 2.80 ft at well P27 just beyond the west edge of the study area (fig. 3). Water-level declines of 20 ft or more occurred in one small area around well 14 in the central part of the study area, probably because of pumping near this well. Surrounding the area of decline of 20 ft or more is a large area of water-level declines of 10 ft or more that covers much of the central part of the study area (where Wichita city wells are located). Water-level declines of 10 ft or more also occurred in a small area around Phase I recharge site RRW-3 in the northern part of the study area (fig. 3). Small water-level rises of less than 3 ft occurred along the western edge of the study area and near the Little Arkansas River. Since March 2007, when Wichita began large-scale artificial recharge, about 2,110 acre-ft of water have been artificially recharged into the aquifer through the six recharge sites shown in figure 3 (Wichita Water Utilities, written commun., 2009). The areas around the Phase I artificial recharge sites do not indicate any obvious effects from artificial recharge, probably because no artificial recharge occurred during January 2009, and only about 1 acre-ft was recharged from November 2008 through January 2009 (Wichita Water Utilities, written commun., 2009).

The change in storage volume in the study area from August 1940 to January 2009 was a decrease of about 111,000 acre-ft (fig. 2, table 1). The storage volume in the study area in January 2009 was about 30,000 acre-ft more than in January 2008, and about 23,000 acre-ft more than in July 2008 (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 January 2009 represents a recovery of about 144,000 acre-ft (table 1) or about 56 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 January 2009 represents a recovery of about 56,000 acre-ft, or about 34 percent of the storage volume previously lost from August 1940 to January 2007. Precipitation in the study area during July 2008 to January 2009 tended to be near normal except for September, when monthly precipitation was about 3 in. above normal in much of the study area (*http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php* accessed May 2009). This near-normal to greater-than-normal precipitation probably contributed to the relatively high water levels, and thus maintenance of the substantial storage-volume recovery following the low levels in January 1993. Artificial recharge probably was an additional factor in the maintenance of the higher water levels and the storage-volume recovery seen in the study area since January 2007.

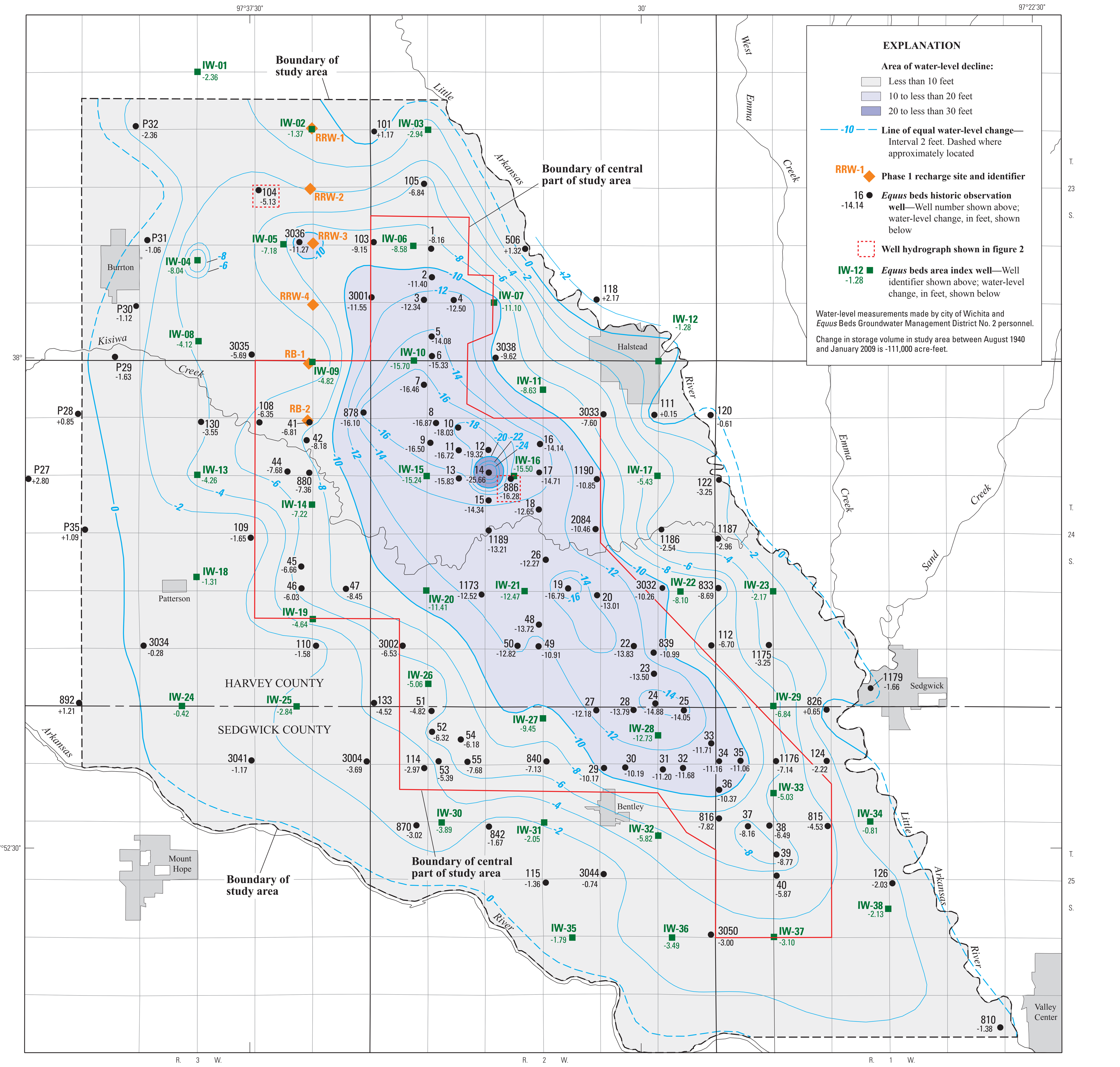

Figure 3. Water-level changes in the *Equus* Beds aquifer in the study area, August 1940 to January 2009.

The change in storage volume in the central part of the study area (where Wichita city wells are located) from August 1940 to January 2009 was a decrease of about 66,600 acre-ft (fig. 2, table 1). Storage volume in the central part of the study area in January 2009 was about 11,800 acre-ft more than in January 2008 and about 4,600 acre-ft more than in July 2008 (table 1). From January 1993 to January 2009, storage volume in the central part of the study area increased by about 87,400 acre-ft (table 1) or about 57 percent of the storage volume previously lost from August 1940 to January 1993. From January 2007 (just before large-scale artificial recharge began) to January 2009, storage volume in the central part of the study area increased by about 16,300 acre-ft or about 20 percent of the storage volume previously lost from August 1940 to January 2007. A comparison of the changes in storage volume for the central part of the study area to those for the study area as a whole indicates that in recent years the recovery has been maintained more consistently in the central part of the study area than in the study area as a whole (fig. 2). This probably is because city pumpage, which occurs in the central part of the study area, has remained less than pre-1993 levels, whereas agricultural-irrigation pumpage, which occurs throughout the study area, has been as much or more than pre-1993 levels in some years (Hansen, 2007). Artificial recharge also probably contributed to the recovery of water levels and storage volume seen in the central part of the study area since January 2007.

Table 1. Storage-volume changes in *Equus* Beds aquifer near Wichita, south-central Kansas, August 1940 to January 2009.

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

Time period	Storage-volume changes, in acre-feet	
	In study area	In central part of study area
August 1940 to January 1993	[1]-255,000	[1]-154,000
August 1940 to January 2007	-167,000	-82,900
August 1940 to January 2008	-141,000	-78,400
August 1940 to July 2008	[2]-134,000	[2]-71,200
August 1940 to January 2009	-111,000	-66,600
January 1993 to January 2009	+144,000	+87,400
January 2007 to January 2009	+56,000	+16,300
January 2008 to January 2009	+30,000	+11,800
July 2008 to January 2009	+23,000	+4,600

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

[2] Storage-volume change previously reported by Hansen (2009).

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)

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.

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