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Status of groundwater levels and storage volume in the *Equus* Beds aquifer
Hansen, C.V., 2012, Status of groundwater levels and storage volume in the *Equus* Beds aquifer near Wichita, Kansas, July 2011

Abstract

The part of the *Equus* Beds aquifer in southwestern Harvey County and northwestern Sedgwick County was developed to supply water to the city of Wichita and for irrigation in south-central Kansas. The 165 square-mile study area represents about 12 percent of the 1,400 square-mile *Equus* Beds aquifer and accounts for about one-third of the withdrawals from the aquifer. Water-level and storage-volume decreases that began with the development of the aquifer in the 1940s reached record to near-record lows in January 1993. Since 1993, generally higher water levels and partial storage-volume recoveries have been recorded in the aquifer.

Potentiometric maps of the shallow and deep layers of the aquifer show flow in both aquifer layers is generally from west to east. The July 2011 water-level altitudes in the shallow aquifer layer ranged from a high of about 1,470 feet in the northwest corner of the study area to a low of about 1,330 feet in the southeast corner of the study area; water-level altitudes in the deep aquifer layer ranged from a high of about 1,445 feet on the west edge of the study area to a low of about 1,340 feet in the southeast corner of the study area. In the northwest part of the study area, water-levels can be more than 60 feet higher in the shallow layer than in the deep layer of the *Equus* Beds aquifer. Measured water-level changes for August 1940 to July 2011 ranged from a decline of 43.22 feet to a decline of 0.17 feet and averaged 12.45 feet. The largest August 1940 to July 2011 water-level changes of 30 feet or more occurred in the northern part of the study area centered about 2 and 4 miles east of Burrton, Kansas.

The change in storage volume from August 1940 to July 2011 in the study area was a decrease of about 209,000 acre-feet. This volume represents a recovery of about 46,000 acre-feet, or only about 18 percent of the storage volume previously lost between August 1940 and January 1993. The largest post-1993 storage-volume recovery to date in the study area was about 161,300 acre-feet in July 2010. The approximately 115,000 acre-feet decrease in storage volume from July 2010 to July 2011 in the study area represents a depletion of about 71 percent of storage volume previously recovered from January 1993 to July 2010; about 105,000 acre-feet of this decrease occurred between January and July 2011. Most of this depletion probably is because of decreased recharge from precipitation that at 9.26 inches for January through July 2011 was less than one-half of normal and increased irrigation pumpage associated with less-than-normal precipitation; city pumpage probably was less than average. For the study area, irrigation pumpage for 2011 was estimated at about 42,700 acre-feet and 2011 city pumpage was estimated at about 21,400 acre-feet.

The approximately 29,900 acre-feet decrease in storage volume from July 2010 to July 2011 in the central part of the study area represents a depletion of about 31 percent of the storage volume previously recovered from January 1993 to July 2010. A major factor in the greater percentage retention of the January 1993 to July 2010 recovery in the central part of the study area is the decreased city pumpage as part of Wichita's Integrated Local Water Supply Plan.

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 was 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. Since 1940, the U.S. Geological Survey (USGS), in cooperation with the city of Wichita, has monitored 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; this report documents these changes to July 2011.

In 1993, the city of Wichita adopted the Integrated Local Water Supply Plan (ILWSP) to ensure an adequate water supply for the city through 2050 and as part of its effort to effectively manage the part of the *Equus* Beds aquifer it uses (City of Wichita, [2007] and 2008; Warren and others, 1995). ILWSP uses several strategies to do this including (a) greater reliance on other sources of water from outside the study area (for example, the Bentley Wellfield south of the Arkansas River, Cheney Reservoir on the North Fork of the Ninnescah River, and the Wichita's Local Wellfield at the confluence of the Arkansas and Little Arkansas Rivers), (b) encouraging conservation, and (c) developing the Aquifer Storage and Recovery (ASR) project with an artificial-recharge capacity of as much as 100 million gallons a day. The ASR project also is designed to help protect the part of the aquifer used by the city from the encroachment of oilfield brines near Burrton and saline water from the Arkansas River. In 2007, the city of Wichita began using Phase 1 of the *Equus* Beds 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]). For Phase 1, the water pumped directly from the Little Arkansas River is treated to reduce sediment and remove atrazine before being recharged to the aquifer through recharge basins; water pumped from wells in the riverbank does not receive additional treatment before being recharged to the aquifer through recharge wells (Debra Ary, city of Wichita, written commun., 2012).

Purpose and Scope

The purpose of this report is to describe the status of the groundwater levels and storage volume in a part of the *Equus* Beds aquifer northwest of Wichita in July 2011 as compared with predevelopment (before large-scale withdrawals began in September 1940) groundwater levels and to update changes in aquifer storage since 1940. Maps of related groundwater-level measurements and water-level changes are presented. Two hydrographs of groundwater levels were selected to show historical water-level variations. Information in this report can be used to document and improve understanding of the effects of climate, water use, and water-resource management practices on water supplies in the *Equus* Beds aquifer, an important source of water for the city of Wichita and the surrounding area.

Acknowledgments

The author acknowledges the invaluable assistance of Debra Ary of the city of Wichita and Tim Boese of *Equus* Beds Groundwater Management District No. 2 (GMD2). Their technical reviews contributed to improved technical and editorial clarity of the report. Appreciation also is expressed to the city of Wichita for the water-level measurements at the *Equus* Beds historic monitoring wells.

Technical reviews by USGS employees Donald Wilkison and Walter Aucott contributed to improved technical and editorial clarity of the report.

Hydrogeology of the Study Area

The approximately 165 square-mile (mi^2) 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 study area represents about 12 percent of the 1,400 mi^2 *Equus* Beds aquifer and about one-third of the pumpage from the aquifer occurs in the study area (Kansas Department of Agriculture, 2011). Pumpage from the *Equus* Beds aquifer in the study area is dominated by irrigation and city use. Total pumpage from the study area in 2010 (latest year for which data are available) was about 51,700 acre-feet (acre-ft), of which about 31,100 acre-ft was for irrigation, about 20,100 acre-ft was Wichita city pumpage, and about 500 acre-ft was for other uses (Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011)

The central part of the study area (fig. 1), which covers about 55 mi^2 or about one-third of the study area, 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, unpub. data, 2011). Total pumpage from the central part of the study area in 2010 (latest year for which data are available) was about 29,000 acre-ft, of which about 8,700 acre-ft was for irrigation, about 20,100 acre-ft was Wichita city pumpage, and about 200 acre-ft was for other uses (Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011).

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 covers about 1,400 mi^2 in Kansas, or about 5 percent of the approximately 30,900 mi^2 covered by the High Plains aquifer in Kansas (fig. 1). 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.

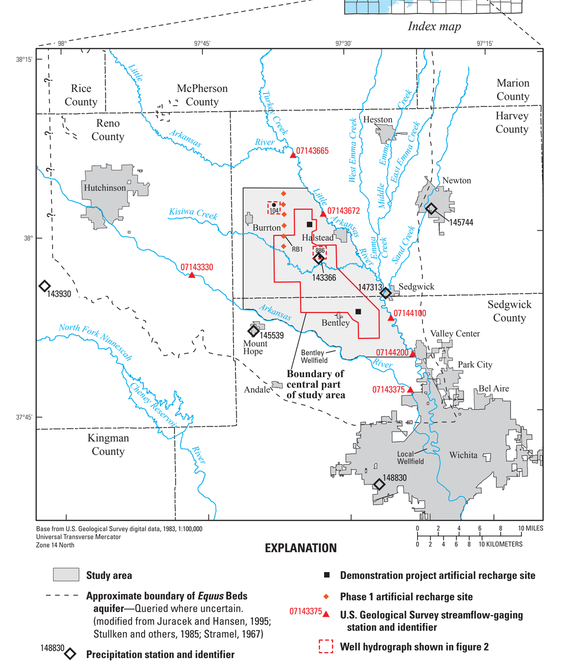

Figure 1. Location of study area near Wichita, south-central Kansas (modified from Aucott and Myers, 1998).

The *Equus* Beds aquifer primarily consists of Quaternary-age alluvial deposits, locally known as the *Equus* beds, with some dune sand and loess (Myers and others, 1996). The alluvial deposits 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). 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-ft (Hansen, 2007).

Near the Arkansas River and in the western part of the study area, the water table in the *Equus* Beds aquifer 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 (about 50 ft below land surface in July 2011), 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). These semiconfined conditions may have resulted in the substantial water-level and water-quality differences seen between the shallow and deep parts of the *Equus* Beds aquifer in some parts of the study area (Stramel, 1956; Ziegler and others, 2010). These substantial differences, along with a need to monitor the effects of artificial recharge on the shallow and deep parts of the aquifer, led to the construction for this report of separate potentiometric-surface maps of the shallow and deep layers of the aquifer.

Methods

Aquifer Layers

For the purposes of this report, wells completed and screened in the *Equus* Beds aquifer were assigned to either the shallow or deep aquifer layer. These layer assignments were based on *Equus* Beds Groundwater Management District No. 2 (GMD2) aquifer zone designations and on well completion and screen depths. GMD2 has identified up to four aquifer zones (designated AA, A, B, and C, in order of increasing depth) within the *Equus* Beds aquifer where there are competent clay layers separating them (Tim Boese, *Equus* Beds Groundwater Management District No. 2, written commun., 2009). The A, B, and C zones are similar to the upper, middle, and lower aquifer units defined by Myers and others (1996) and previously discussed in the "Hydrogeology of the Study Area" section. GMD2 monitoring wells generally are in clusters (closely spaced wells screened to different depths) with each well screened in a different aquifer zone. For this report, wells designated by GMD2 as completed in zones A or C were assigned to the shallow or deep aquifer layers, respectively; no wells designated as completed in zones AA or B were used in this study. The city of Wichita monitors clusters of historic and index monitoring wells. The shallower well in each historic or index well cluster was assumed to be in and assigned to the shallow aquifer layer; the deeper well in each cluster was assumed to be in and assigned to the deep aquifer layer. Ziegler and others (2010) used a depth of 80 ft as the dividing point between the shallow and deep parts of the *Equus* Beds aquifer. An analysis of the GMD2 and city of Wichita well clusters in the study area shows about 90 percent of the GMD2 zone A wells and shallower historic and index wells were completed and screened to a depth of 80 ft or less, and about 90 percent of the GMD2 C zone wells and deeper historic and index wells were completed and screened to a depth of greater than 80 ft. This indicates that the use of the 80-ft depth as the dividing point between aquifer layers was reasonable when assigning the city of Wichita historic monitoring wells not in clusters into either the shallow or deep layer of the *Equus* Beds aquifer and no other information was available.

Water Levels

Groundwater levels were measured from July 8 through August 1, 2011, at 156 historic monitoring wells, 76 index wells, 49 GMD2 monitoring wells, and 2 ASR Phase 1 monitoring wells. The historic monitoring 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 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 layers of the aquifer (Andrew Ziegler, U.S. Geological Survey, oral commun., September 2003). The GMD2 monitoring wells were installed for GMD2 or are existing wells used by GMD2 to monitor the *Equus* Beds aquifer. The ASR Phase 1 monitoring wells were installed to monitor the effects of recharge around the six ASR Phase 1 artificial recharge sites; only two of the wells around recharge site RB1 were measured in July 2011.

Water levels in the historic monitoring wells were measured by city of Wichita personnel; water levels in the index wells and GMD2 monitoring wells were measured by GMD2 personnel. Water levels in the Phase 1 monitoring wells are collected by the USGS using multi-sensor monitors that continuously collect physical properties, including water-level altitude. Water levels in the other monitoring wells were measured by GMD2. All agencies used standard water-level measurement techniques that are similar to USGS methods described in Cunningham and Schalk (2011). The historic monitoring well data are on file, in paper and electronic form, with the city of Wichita's Public Works and Utilities Department in Wichita, Kansas; the index and GMD2 monitoring 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, 2011); and well data collected by the USGS are stored in the USGS's National Water Information System (NWIS) database (U.S. Geological Survey, 2011b). All the water-level data used in this report also are stored in NWIS. The quality of the water-level data for each well was evaluated by examining hydrographs of all the water levels available for the well. Where the July 2011 data looked questionable, the data provider was questioned about the values and any corrections provided were applied. The measured water levels can be affected by pumping at nearby wells; as a result, the interpretation made using these water levels also will show the effects of these nearby pumping wells.

Water-Level Altitudes

The July 2011 water-level altitudes depicted in the potentiometric-surface maps of the shallow and deep layers of the *Equus* Beds aquifer were calculated by subtracting the depth to water below land surface in a well from the altitude of land surface at the well. Land-surface altitudes are those stored for the wells in NWIS or WIZARD or determined from the National Elevation Dataset (U.S. Geological Survey, 2009). Monitoring wells used in this report were divided into two groups to describe differences between the water levels in the shallow and deep layers of the aquifer. The well was assigned to the shallow or deep layer of the *Equus* Beds aquifer based on the layer in which the bottom of the well's casing or screened interval occurred (as described in the "Aquifer Layers" section). The 196 wells assigned to the shallow layer of the aquifer range in depth from 7 to 101 ft in depth, with about 96 percent of the wells 80 ft or less in depth. The 87 wells assigned to the deep layer of the aquifer range in depth from 76 to 285 ft in depth with about 97 percent of the wells greater than 80 ft in depth.

Average daily surface-water-altitude measurements from data collected by sensors at six USGS streamflow-gaging stations on the Arkansas and Little Arkansas Rivers (fig. 1) were used to estimate the surface-water altitude along these streams. These measurements were used along with the groundwater-level measurements in the construction of the potentiometric-surface map of the shallow *Equus* Beds aquifer layer created for this report. Because the groundwater-level measurements used for the shallow aquifer layer were collected over several weeks, each streamflow-gaging station's average surface-water altitude for the day at the midpoint of the groundwater-level measurement period was used (U.S. Geological Survey, 2011b).

The July 2011 surface-water and groundwater-level altitudes were plotted on the potentiometric-surface map of their assigned aquifer layer and manually contoured. Where well clusters exist, the difference between water levels in the shallow and deep aquifer layers commonly was less than 2 ft (less than one-half of the 5-ft contour interval used for the potentiometric maps) in the same well cluster. Therefore, where water-level data did not exist for one layer but did exist for the other layer and the surrounding well clusters indicated the water-level differences between the shallow and deep layers were small, the data from the other aquifer layer were used as supplemental data to guide the placement of the potentiometric-surface contours. The locations of points of groundwater diversions and the 2010 water-use associated with these points (Kansas Department of Agriculture, Division of Water Resources, unpub. data, May 2011) also were used to guide the location of the contours.

Water-Level Change

The water-level change at a well since August 1940 was determined by subtracting the depth to water below land surface in July 2011 from the depth to water below land surface at the same well in August 1940. All wells used for the water-level change maps were historic monitoring wells or index wells. Of the 148 wells used for the water-level change map, 135 are in the shallow layer of the aquifer. Only 37 of the 148 wells used for the water-level change map 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 2011 water-level-change values for the measured wells were plotted on the map and manually contoured.

Storage-Volume Change

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, has been the basis of many historical computations, 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 2011 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. Thiessen 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 Thiessen polygon multiplied by the water-level-change value associated with the Thiessen 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 Thiessen 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 2011 was calculated as the change in storage volume for August 1940 to July 2011 minus the change in storage volume for August 1940 to January 1993.

Precipitation

Precipitation for the study area for 2010 and 2011 was estimated as the arithmetic average of precipitation for the five Cooperative weather stations in or near Halstead, Hutchinson, Mount Hope, Newton, and Wichita (station numbers 143366, 143930, 145539, 145744, and 148830, respectively; fig. 1). Values for normal precipitation currently (2011) used by the National Oceanic and Atmospheric Administration (NOAA) are the averages for 1981–2010 (National Oceanic and Atmospheric Administration, 2011c). Standard normal (annual or monthly) precipitation data for weather stations in or near Hutchinson, Mount Hope, Newton, and Wichita, the representative normal precipitation data for the weather station near Sedgwick (Cooperative station number 147313; fig. 1), and the pseudonormal precipitation data for the weather station near Halstead reported by NOAA were averaged to determine the normal precipitation for the study area. Standard normal precipitation values were not available for either the Sedgwick or Halstead weather station because collection of precipitation data at Sedgwick was discontinued in 2004 and precipitation data were not collected at Halstead before 2001. As described by NOAA, a representative normal is "scaled or based on filled values to be representative of the full period of record" for stations where the observed record is incomplete (National Oceanic and Atmospheric Administration, 2011d). A pseudonormal is based on linear combinations of the normals from neighboring stations and is used where the station's record is missing data, commonly because the station did not begin until after the start of the normal period (National Oceanic and Atmospheric Administration, 2011b). Normal annual precipitation for the study area is about 32.14 inches (in.). This is similar to the long-term (1940–2010) average annual precipitation of 31.52 in. that was estimated for the study area by Hansen and Aucott (2010). Average study-area precipitation for January through July 2011 was about 9.26 in. (National Oceanic and Atmospheric Administration, 2011e, 2011f, and 2011g; Kansas State Research and Extension, 2011; and Mary Knapp, State Climatologist, written commun., August 11, 2011), which was less than one-half of the January through July study-area normal of 20.43 in. (National Oceanic and Atmospheric Administration, 2011c).

Groundwater Levels and Storage Volume

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 and rises is reflected in the annual fluctuations in the water levels in wells shown in figure 2. The consistently large seasonal water-level fluctuations (commonly from 5 to 20 ft) in well 104 probably are caused by nearby agricultural-irrigation pumpage.

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 from January 1993 to January 2011, higher water levels have been recorded in the *Equus* Beds aquifer 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, 2009a, 2009b, 2011a, 2011b). City pumpage from the aquifer in the study area during 1993 through 2010 averaged about 23,300 acre-ft per year compared to an average of 32,100 acre-ft per year for 1965 (when Wichita began supplementing water from the *Equus* Beds aquifer with water from Cheney Reservoir) through 1992 (Hansen and Aucott, 2010; Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011). Pumpage for agricultural irrigation, which averaged about 30,100 acre-ft per year for 1993 through 2010 and 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; Hansen and Aucott, 2010); thus, decreased pumpage for agricultural irrigation likely contributed to the higher water levels only in years of greater-than-normal precipitation. 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, 2011b) through January 2011. Phase 1 artificial recharge through July 2011 totaled about 2,900 acre-ft (U.S. Geological Survey, 2011a).

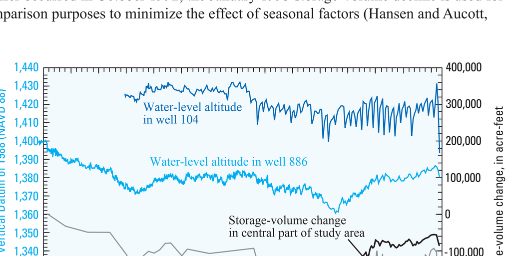

Figure 2. Water-level altitudes in monitoring wells 104 and 886 and *Equus* Beds aquifer storage-volume change in the study area and the central part of the study area (water-level-altitude data are from Stramel (1956, 1967) and data collected by city of Wichita that are on file with U.S. Geological Survey in Lawrence, Kansas; storage-volume changes are from Stramel (1956, 1967), Aucott and Myers (1998), Aucott and others (1998), Hansen and Aucott (2010), Hansen (2011a, 2011b), and unpublished data on file with U.S. Geological Survey in Lawrence, Kansas). Locations of monitoring wells are shown in figures 1 and 5.

Potentiometric Surfaces of the Shallow and Deep Aquifer Layers, July 2011

The potentiometric-surface contours of the shallow and deep layers of the *Equus* Beds aquifer (figs. 3 and 4, respectively) indicate movement of water in the aquifer is generally from west to east across the area. Hachured areas indicate cones of depression that likely are related to pumping wells and present exceptions to the generally easterly flow pattern. Water-level altitudes in the shallow aquifer layer range from a high of about 1,470 ft in the northwest corner of the study area to a low of about 1,330 ft in the southeast corner of the study area. Water-level altitudes in the deep aquifer layer range from a high of about 1,445 ft on the west edge of the study area to a low of about 1,340 ft near the southeast corner of the study area. Where the potentiometric-surface contours bow out to the west (for example, in the middle of T. 24 S. R. 2 W. on fig. 3) or are hachured (for example, near wells 4B, 21B, and IW23A on fig. 3 and near wells 42D, 46D, and 50D on fig. 4), they indicate areas where the water levels are lower than in the surrounding area, probably because of pumping at nearby wells. Potentiometric contours in the northwest part of the study area are oriented differently in the shallow (fig. 3) and deep (fig. 4) layers of the aquifer and the water-level altitudes in the shallow layer are up to 60 ft higher than those in the deep layer of the aquifer. These differences probably are caused by thicker clay layers in this area reducing the hydraulic connection between the shallow and deep layers of the aquifer. No obvious effects of artificial recharge can be seen on the potentiometric surfaces of either of the shallow or deep aquifer layers (figs. 3 and 4), probably because no artificial recharge had occurred at any of the ASR Phase 1 sites since November 2010 (U.S. Geological Survey, 2011a).

Where water-levels in the shallower wells differ from those in the deeper wells in the same cluster, they indicate there is a vertical component of flow within the aquifer. A downward vertical gradient is indicated where the water levels are higher in the shallower wells than in the deeper wells within a cluster; an upward vertical gradient is indicated where the water levels are lower in the shallower wells than in the deeper wells within a cluster. Within 19 of the 81 clusters in the study area, the water-level differences in July 2011 between the shallower and deeper wells were 1 ft or less and probably do not indicate a substantial vertical component of flow; within 3 of the 81 clusters, the July 2011 water levels in the shallower wells were from 1 to 2 ft lower than those in the deeper wells. However, within 59 of the 81 clusters in the study area, the water levels in the shallower wells were more than 1 ft higher than those in the deeper wells, indicating that a downward component of flow in the aquifer may have been common during July 2011. In 32 of the 81 clusters in the study area, the water levels ranged from about 6 to about 61 ft higher in the shallower wells than in the deeper wells in July 2011. These larger differences indicate that at these clusters the two aquifer layers probably are not well connected. If nearby wells pump from only one aquifer layer, the water-level differences between wells within a cluster may be greater than if the nearby wells were not pumping.

Water-Level Changes, August 1940 to July 2011

Water-level changes from August 1940 to July 2011 are shown in figure 5. Water levels were measured in the historic monitoring wells by city of Wichita personnel from July 25 through 27, 2011, and on August 1, 2011; water levels were measured in the index wells by GMD2 personnel on July 21 and 22, 2011. Water-level changes from August 1940 to July 2011 ranged from a decline of 43.22 ft at well 1B in the central part of the study area to a decline of 0.17 ft at well P27A near the west edge of the study area of the study area (fig. 5). The average August 1940 to July 2011 water-level change for the wells shown in figure 5 was a decline of about 12.45 ft (table 1). No obvious effects of artificial recharge are documented at the Phase 1 sites in this report, probably because before July 2011, artificial recharge last occurred in November 2010 (U.S. Geological Survey, 2011a). Water-level declines of 10 ft or more occurred in much of the central part of the study area and in T. 24 S. R. 1 W.; declines of 30 ft or more occurred in the northern part of the of the study area centered about 2 miles (mi) northeast and 4 mi east of Burrton, Kansas (fig. 5). These declines likely were caused by reduced recharge from decreased precipitation and by pumping in the area.

Precipitation during January 2011 through July 2011 at the five weather stations in and near the study area (Halstead, Hutchinson, Mount Hope, Newton, and Wichita; fig. 1) ranged from about 6.66 in. at Hutchinson to about 12.65 in. at Wichita and averaged about 9.26 in. (National Oceanic and Atmospheric Administration, 2011e, 2011f, and 2011g; Kansas State Research and Extension, 2011; and Mary Knapp, State Climatologist, written commun., August 11, 2011). Average precipitation in the study area for January 2011 through July 2011 was 9.26 in., less than one-half of the study-area normal of 20.43 in. for January through July (National Oceanic and Atmospheric Administration, 2011c). In addition, July 2011 precipitation in the study area, which averaged 0.74 in., only was about 21 percent of the July study-area normal of 3.56 in.; precipitation in July ranged from 0.18 in. at Hutchinson to 1.45 in. at Wichita (National Oceanic and Atmospheric Administration, 2011c, 2011e, and 2011f; Mary Knapp, State Climatologist, written commun., August 11, 2011).

Pumpage in the part of the study area outside the central part of the study area tends to be dominated by irrigation, whereas city pumpage tends to dominate the central part of the study area (Hansen and Aucott, 2010). For example, in the part of the study area outside the central part of the study area in 2010, the latest year for which pumpage data were available, irrigation pumpage was about 22,300 acre-ft, no city pumpage occurred, and pumpage for other uses totaled about 500 acre-ft; within the central part of the study area in 2010, irrigation pumpage was about 8,700 acre-ft, city pumpage about 20,100 acre-ft, and pumpage for other uses totaled about 200 acre-ft. In figure 5, therefore, the area of decline of 30 ft or more that is centered outside the central part of the study area likely was caused by irrigation pumpage and the area of decline of 30 ft or more within the central part of the study probably was mostly caused by city pumpage.

Table 1 includes average water-level changes for the wells used to make the water-level change maps associated with the storage-volume changes that are also shown in table 1. Water-level changes since August 1940 are larger declines in the central part of the study area than in the whole study area (table 1). However, the changes since January 1993, January 2007, January 2010, and January 2011 shown in table 1 are larger rises or smaller declines in the central part of the study area than in the whole study area. The comparison of the August 1940 to July 2010 average water-level changes to those for August 1940 to January 2011 and August 1940 to July 2011 indicate that much of the water-level decline since July 2010 occurred during January 2011 to July 2011 (table 1).

Storage-Volume Change, July 2011

Storage-volume change is greatly affected by irrigation and city pumpage. Commonly, only about one-third of irrigation pumpage from the *Equus* Beds aquifer in the study area occurs within the central part of the study area and the other two-thirds occurs outside of it; all city pumpage from the *Equus* Beds aquifer generally occurs within the central part of the study area (Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011). Therefore, changes in city pumpage have more effect in the central part of the study area and changes in irrigation pumpage have more effect in the rest of the study area.

Study Area

The storage volume of water in the *Equus* Beds aquifer decreased in the study area from August 1940 to July 2011 by about 209,000 acre-ft (fig. 2, table 1). The storage volume in the study area in July 2011 was about 115,000 acre-ft less than in July 2010, and about 105,000 acre-ft less than in January 2011 (table 1), indicating about 90 percent of the storage-volume decrease from July 2010 to July 2011 occurred in 2011 (table 1). Storage-volume generally decreases from January to July; however the January 2011 to July 2011 decrease is almost an order of magnitude larger than the 1997 through 2010 January to July average storage-volume change of about 13,000 acre-ft. Storage-volume amounts in July 2011 were similar to those seen in the mid-1980s and mid-1990s (fig. 2).

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 2011 represents a recovery of 46,000 acre-ft (table 1) or only about 18 percent of storage volume lost between August 1940 and January 1993. Between January 1993 and July 2010, when the largest post-1993 recorded recovery to date occurred, about 161,300 acre-ft of storage volume had been recovered in the study area (table 1); this represents a recovery of about 63 percent of the storage volume lost between August 1940 and January 1993. These recoveries were attributed by Hansen and Aucott (2010) and Hansen (2011) to the approximately 50 percent decrease in city pumpage as a part of Wichita's ILWSP and to decreased irrigation pumpage and increased recharge associated with greater than normal precipitation in most years. The approximately 2,800 acre-ft of water that was artificially recharged to the aquifer by the city of Wichita through the six Phase 1 recharge sites (fig. 3) from March 2007 to July 2010 was only a minor factor in the January 1993 to July 2010 storage-volume recovery (U.S. Geological Survey, 2011a).

The approximately 115,000 acre-ft decrease in storage volume in the study area from July 2010 to July 2011 represents a depletion of about 71 percent of storage volume previously recovered from January 1993 to July 2010, with about 105,000 acre-ft of that depletion occurring from January 2011 through July 2011 (table 1).

The approximately 100 acre-ft of water artificially recharged to the aquifer at the Phase 1 sites (fig. 3) by the city of Wichita from July 2010 to July 2011, none of which occurred in January through July 2011, was too small to counteract these large storage-volume depletions (U.S. Geological Survey, 2011a). Major factors in the July 2010 to July 2011 and January 2011 to July 2011 storage-volume depletions in the study area probably are reduced recharge associated with less-than-normal precipitation and greater-than-average irrigation pumpage that was about 30,100 acre-ft in 2010, the last year for which pumpage data are available (Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011), and was expected to be the greatest on record in 2011 (Tim Boese, GMD2, written commun., 2011). Less-than-average city pumpage, which was about 20,100 acre-ft in 2010 and estimated to be similar in 2011 (Debra Ary, city of Wichita, written commun., January 2012) , while contributing to the depletion, probably was not as important a factor. Irrigation pumpage in 2011 in the study area probably was substantially more than the 1993 through 2010 annual average of about 30,100 acre-ft and probably was a larger part of the decrease in storage volume than in past years. In 2011, about 46,000 acre-ft of irrigation was permitted in the study area and about 70 drought-term applications were made for as much as an additional 17,700 acre-ft (Doug Schemm, Kansas Department of Agriculture, Division of Water Resources, written commun., January 2012). GMD2 expects 2011 irrigation pumpage in the study area to be the largest on record (Tim Boese, GMD2, written commun., 2012); about 90 percent of irrigation pumpage in the study area commonly occurs in May through July (Andrew Lyon, Kansas Department of Agriculture, Division of Water Resources, written commun., July 2010). Irrigation pumpage in the study area in 2011 was estimated at about 42,700 acre-ft, assuming pumpage from previously authorized irrigation permits was equal to the record of 39,200 acre-ft in 2003 (Hansen and Aucott, 2010; Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011), plus an estimated additional 3,500 acre-ft of pumpage from irrigation drought-term permits (Tim Boese, GMD2, written commun., 2012). This estimate of irrigation pumpage does not seem unreasonable as average precipitation in the study area for January through July was only about 9.26 in. for 2011 compared to 16.70 in. for 2003 (Kansas State Research and Extension, 2011; National Oceanic and Atmospheric Administration, 2011a, 2011e, 2011f, and 2011g). The city of Wichita pumpage from the study area for January through July 2011 was about 12,000 acre-ft, (Shelly Bloesser, city of Wichita, written commun., September, 2011); this would be equivalent to an annual pumpage of about 21,400 acre-ft, assuming 56 percent of the annual pumpage occurred during January through July as it has in past years (Megan Schmeltz, city of Wichita, written commun., 2009). If true, city pumpage would be more than the 20,100 acre-ft pumped in 2010 and less than the 1993 through 2010 annual average of 23,300 acre-ft (Hansen and Aucott, 2010, and Kansas Department of Agriculture, Division of Water Resources, unpub. data, 2011), indicating city pumpage probably had less of an effect on the January through July 2011 storage-volume depletion than did irrigation pumpage and reduced recharge from precipitation.

Central Part of Study Area

The change in storage volume in the *Equus* Beds aquifer in the central part of the study area (where Wichita city wells are located) from August 1940 to July 2011 was a decrease of about 85,900 acre-ft (fig. 2, table 1). Storage volume in the central part of the study area in July 2011 was about 28,800 acre-ft less than in January 2011 and about 29,900 acre-ft less than in July 2010 (table 1). From January 1993 to July 2011, storage volume in the central part of the study area increased by about 68,100 acre-ft (table 1) or about 44 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 2011, storage volume in the central part of the study area decreased by about 3,000 acre-ft (table 1). About 68,000 acre-ft of storage volume was recovered in the central part of the study area between January 1993 (when near record low storage volumes occurred) and July 2011, which is more than the 46,000 acre-ft of recovery in the whole study area.

Between January 1993 and July 2010 (when the largest recorded recovery to date occurred) about 98,000 acre-ft of storage volume was recovered in the central part of the study area (table 1). The approximately 29,900 acre-ft decrease in storage volume from July 2010 to July 2011 represents a depletion of about 31 percent of the storage volume previously recovered from January 1993 to July 2010. As noted previously in the "Study Area" section, irrigation pumpage during 2011 likely was greater than the 1993 through 2010 annual average, while city pumpage was probably less than its 1993 through 2010 annual average. The decreases in city pumpage that are part of Wichita's ILWSP (City of Wichita, 2008; Hansen and Aucott, 2010; Warren and others, 1995) probably are a major factor in the larger percentage retention of the January 1993 to July 2010 recovery in the central part of the study area (where city pumpage is concentrated) than in the whole study area.

Table 1. Storage-volume changes and average water-level changes in the *Equus* Beds aquifer near Wichita, south-central Kansas, August 1940 to July 2011.

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

Time period	Study area: Storage-volume changes (acre-feet)	Study area: Average water-level change (feet)	Central part of study area: Storage-volume changes (acre-feet)	Central part of study area: Average water-level change (feet)	Proportion of storage-volume change in the study area that occurred in the central part of the study area (percent)
August 1940 to January 1993	[1]-255,000	-16.07	[1]-154,000	-24.09	60
August 1940 to January 2007	[2]-167,000	-10.42	[2]-82,900	-13.78	50
August 1940 to July 2010	[3]-93,700	-6.72	[3]-56,000	-10.13	60
August 1940 to January 2011	[4]-104,000	-6.99	[4]-57,100	-9.80	55
August 1940 to July 2011	-209,000	-12.45	-85,900	-14.62	41
January 1993 to January 2007	[2]+88,000	6.90	[2]+71,100	11.08	81
January 1993 to July 2010	[3]+161,300	10.20	[3]+98,000	14.19	61
January 1993 to July 2011	+46,000	5.00	+68,100	9.84	148
January 2007 to July 2010	[3]+73,300	3.83	[3]+26,900	3.61	37
January 2007 to January 2011	[4]+63,000	3.52	[4]+25,800	3.98	41
January 2007 to July 2011	-42,000	-1.91	-3,000	-0.84	7
July 2010 to July 2011	-115,300	-5.73	-29,900	-4.35	26
January 2011 to July 2011	-105,000	-5.20	-28,800	-4.83	27

[1] Storage-volume change previously reported by Aucott and Myers (1998).
[2] Storage-volume change previously reported by Hansen and Aucott (2010).
[3] Storage-volume change previously reported by Hansen (2011a).
[4] Storage-volume change previously reported by Hansen (2011b).

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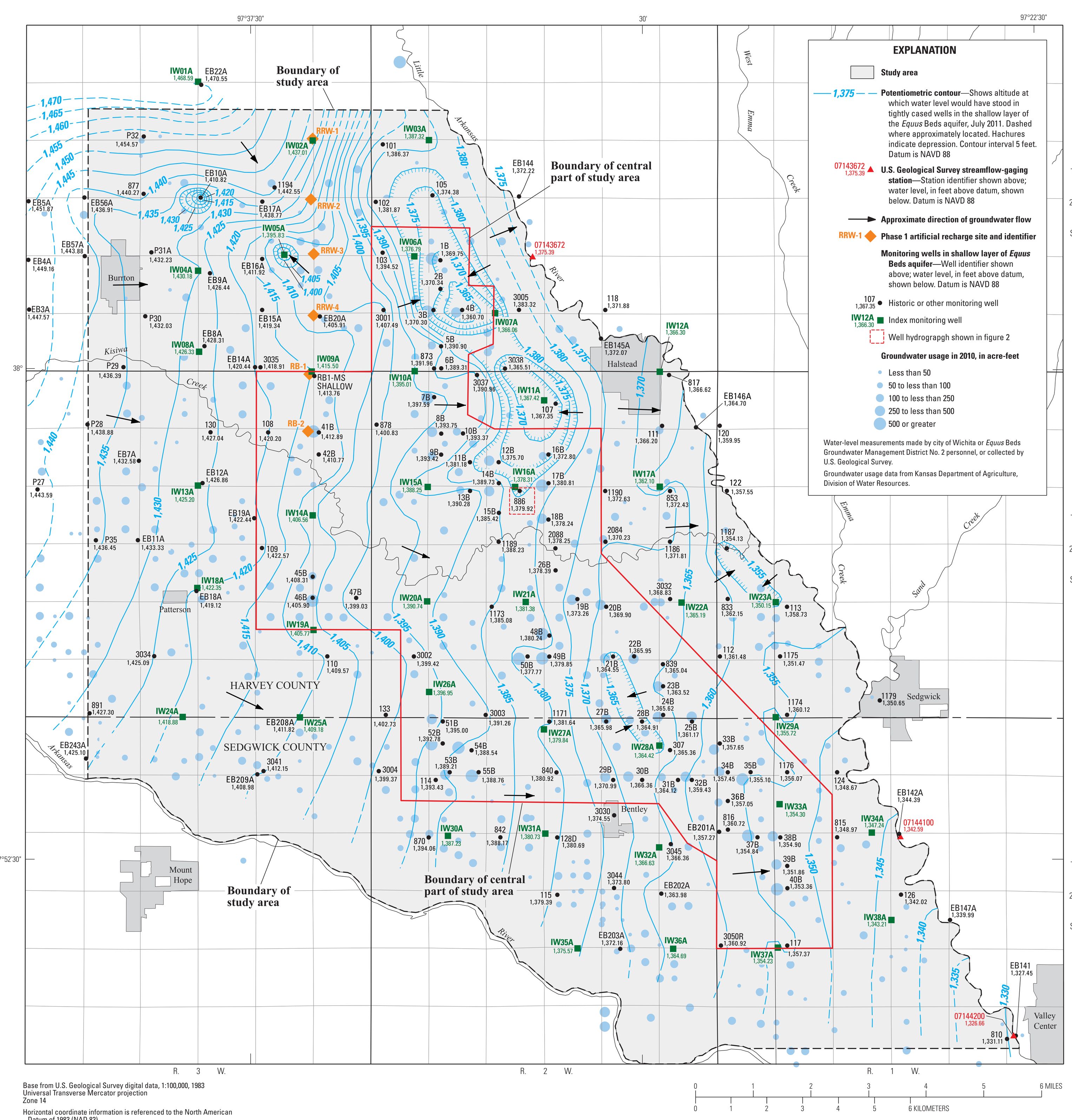

Figure 3. Potentiometric surface of the shallow layer of the *Equus* Beds aquifer, July 2011.

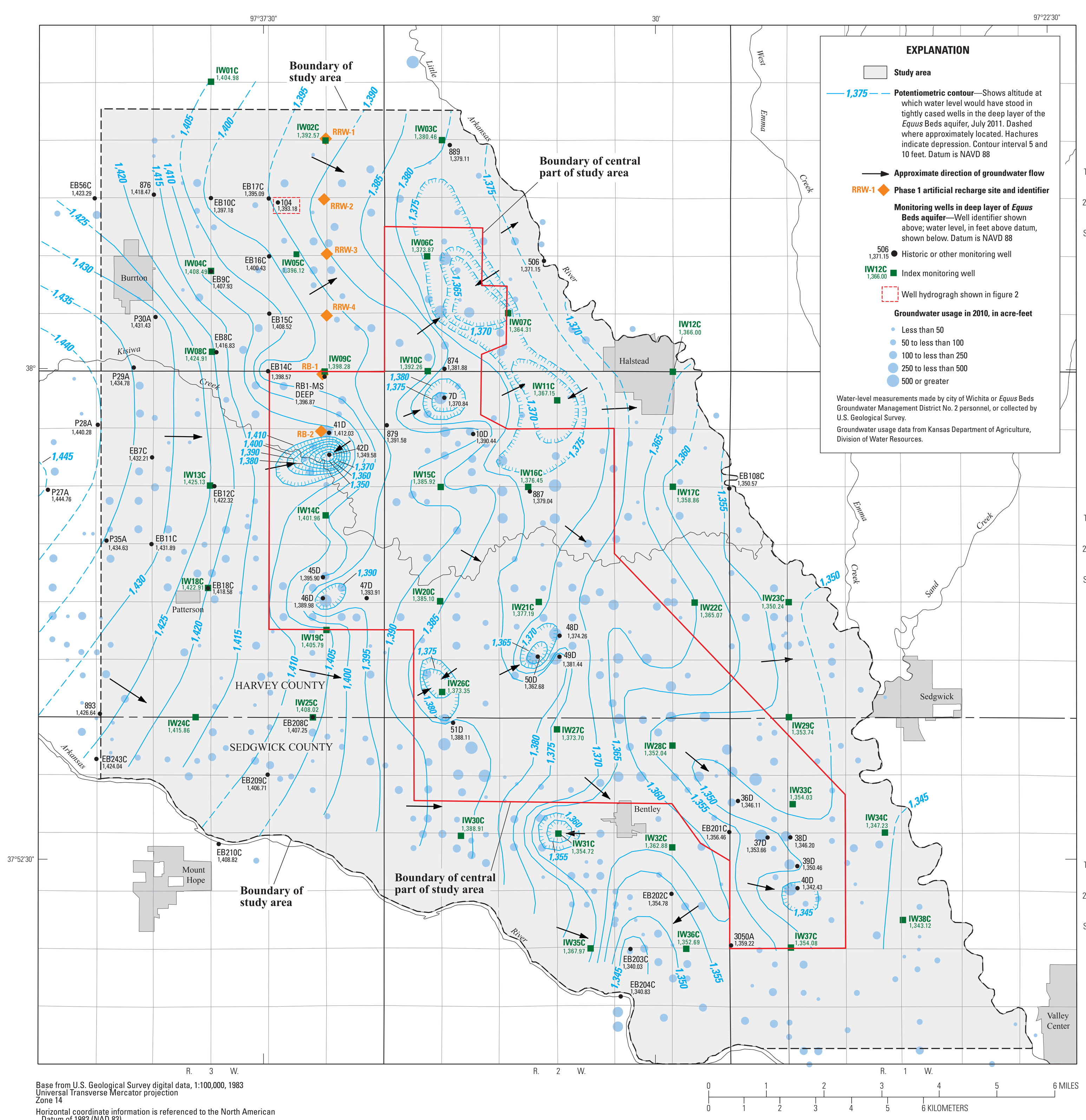

Figure 4. Potentiometric surface of the deep layer of the *Equus* Beds aquifer, July 2011.

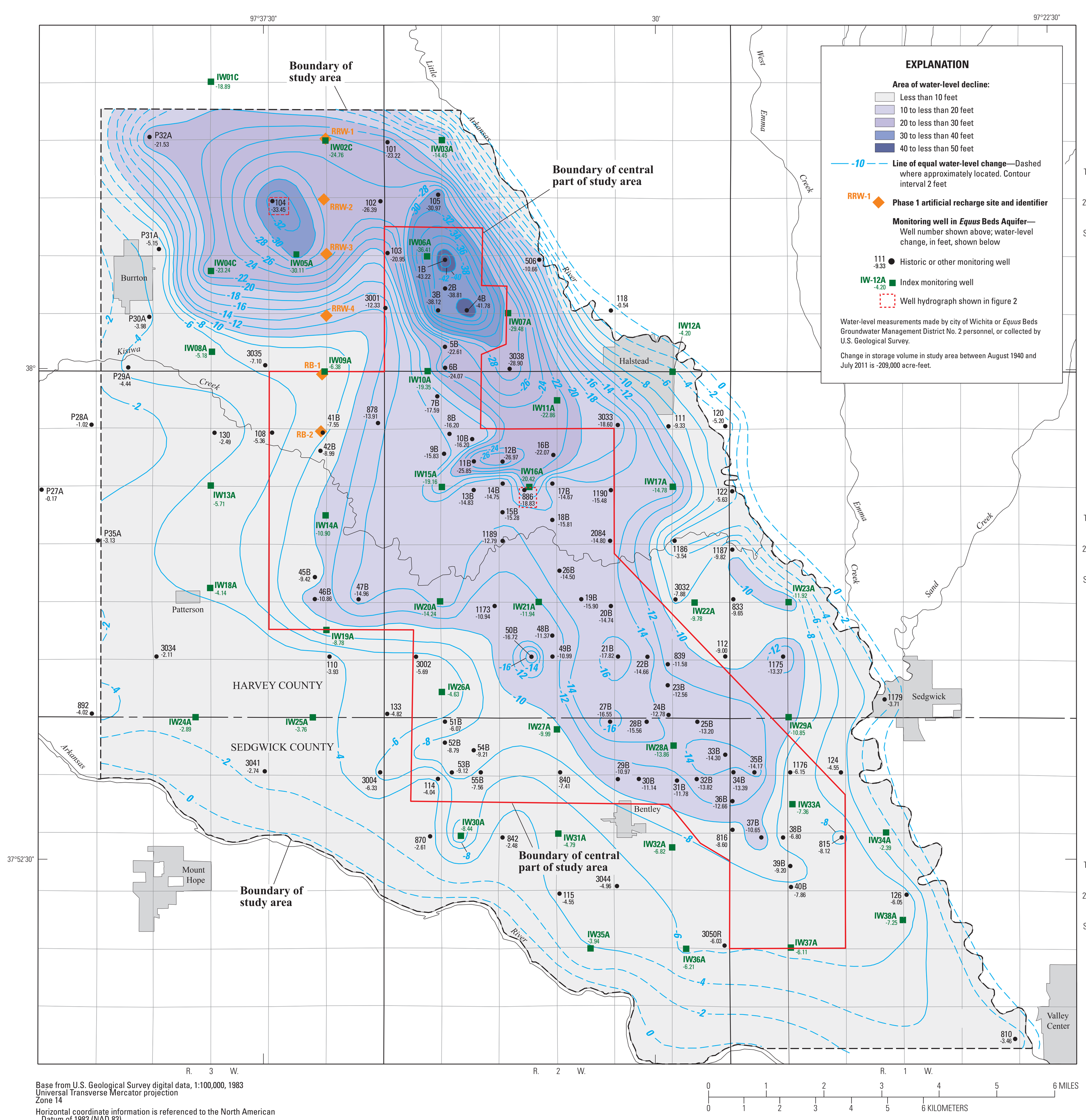

Figure 5. Water-level changes in the *Equus* Beds aquifer in the study area, August 1940 to July 2011.

Status of Groundwater Levels and Storage Volume in the *Equus* Beds Aquifer near Wichita, Kansas, July 2011

By Cristi V. Hansen, 2012

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