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CITY OF WICHITA, KANSAS

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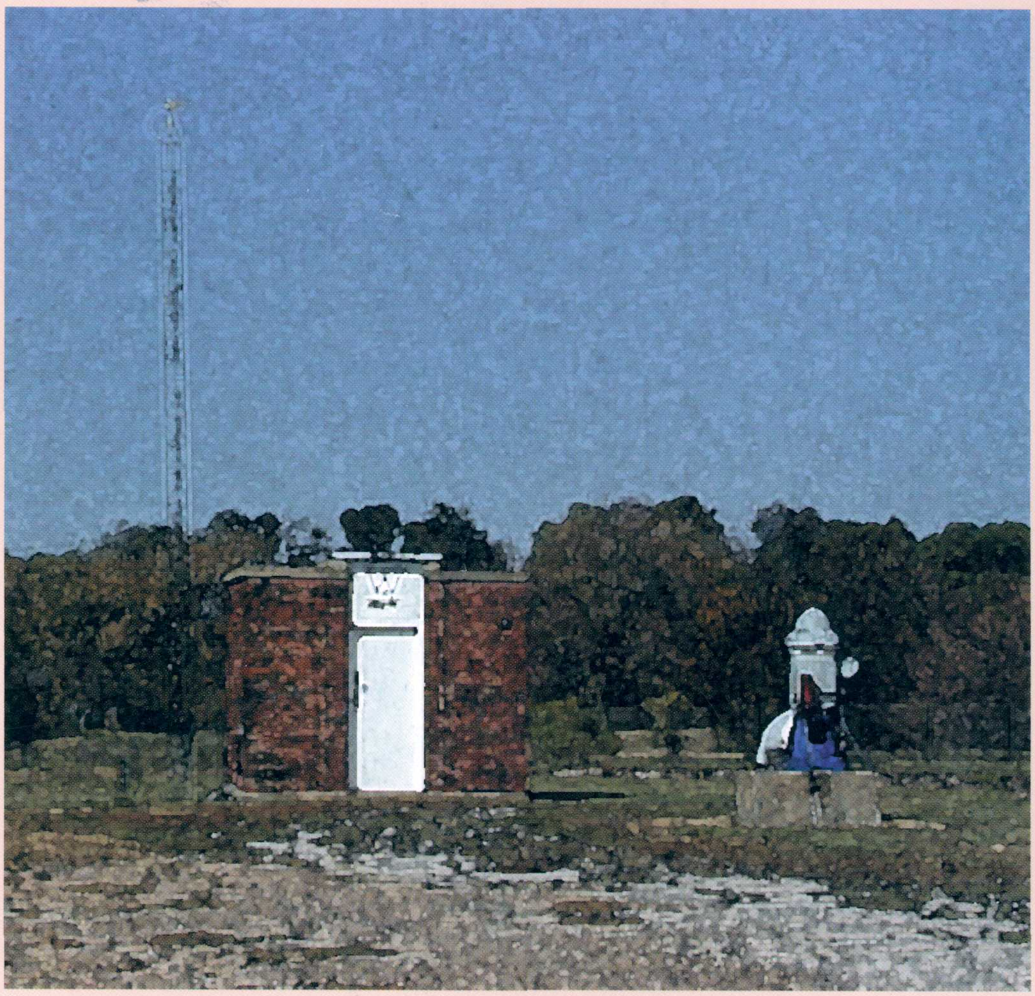
Status of Ground-Water Levels and Storage Volume in the Wichita Well Field Area, South-Central Kansas, 1998–2000

Water-Resources Investigations Report 00–4267



U.S. Department of the Interior
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Cover photograph: Wichita well field public-supply well 4
(taken by Trudy Bennett, U.S. Geological Survey, Wichita, Kansas).

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By CRISTI V. HANSEN and WALTER R. AUCOTT

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Lawrence, Kansas
2001

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
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Building 810, Federal Center
Box 25286
Denver, CO 80225–0286

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
degree Fahrenheit (°F)	([1])	degree Celsius
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

[1]Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$
$$°F = 9/5\ (°C) + 32.$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Status of Ground-Water Levels and Storage Volume in the Wichita Well Field Area, South-Central Kansas, 1998–2000

By Cristi V. Hansen *and* Walter R. Aucott

Abstract

The Wichita well field was developed in the *Equus* Beds aquifer northwest of Wichita, Kansas, to supply water to the city beginning in 1940. Ground-water pumping from the well field caused water levels to decline in a large part of the area. Irrigation pumpage in the well field area, which increased greatly in the 1970's and 1980's, contributed to the declining water levels.

During January 2000, the direction of ground-water flow in the *Equus* Beds aquifer in the well field area was generally from west to east as has been the case since prior to development of the aquifer. The maximum water-level decline since 1940 for the period January 1998 to January 2000 was 36.48 feet in July 1998 in the northern part of the well field. Although cumulative water-level changes from January 1998 to January 2000 in the well field area typically were less than 5 feet, rises of 5 to 10 feet were common in the central and southeastern parts of the well field. The recovery of water levels and aquifer storage volumes, which began in 1993, generally continued during January 1998 to January 2000. The recovery of storage volume from a low of -255,000 acre-feet in the well field area in January 1993 to -126,000 acre-feet in January 2000 represents about a 51-percent recovery of the storage-volume depletion that occurred from August 1940 to January 1993. Decreased city pumpage and other factors have contributed to the rising water levels and increasing aquifer storage volume in the well field area.

INTRODUCTION

The Wichita well field was developed in the *Equus* Beds aquifer to supply water to the city of Wichita in south-central Kansas (fig. 1). On September 1, 1940, pumping began from 25 wells in the well field (Stramel, 1956), and by 1959, there were 55 wells in use (Stramel, 1967). Ground-water pumpage from the well field has caused water levels to decline in a large part of the study area (study area shown in fig. 1). Much of the water-level decline occurred from 1940 to early 1957 (Stramel, 1967). Ground-water pumpage for irrigation in the Wichita well field area also increased substantially in the 1970's and 1980's and contributed to the water-level declines (Myers and others, 1996; Aucott and Myers, 1998). Although most of the water-level declines can be attributed to ground-water pumpage, climatic conditions and thus recharge to the *Equus* Beds aquifer also have affected water levels and the volume of ground water in storage.

The *Equus* Beds Groundwater Management District No. 2 was formed in 1975 to manage ground-water supplies in the area (Aucott and Myers, 1998). The District works with municipal and agricultural users to manage pumpage from the aquifer using the "aquifer safe-yield principle," which limits ground-water pumpage to the annual amount of ground-water recharge as noted in *Equus* Beds Groundwater Management District No. 2 (1995).

In 1965, the city of Wichita began using water from Cheney Reservoir (Stramel, 1967) in addition to water from the *Equus* Beds aquifer. Since 1995

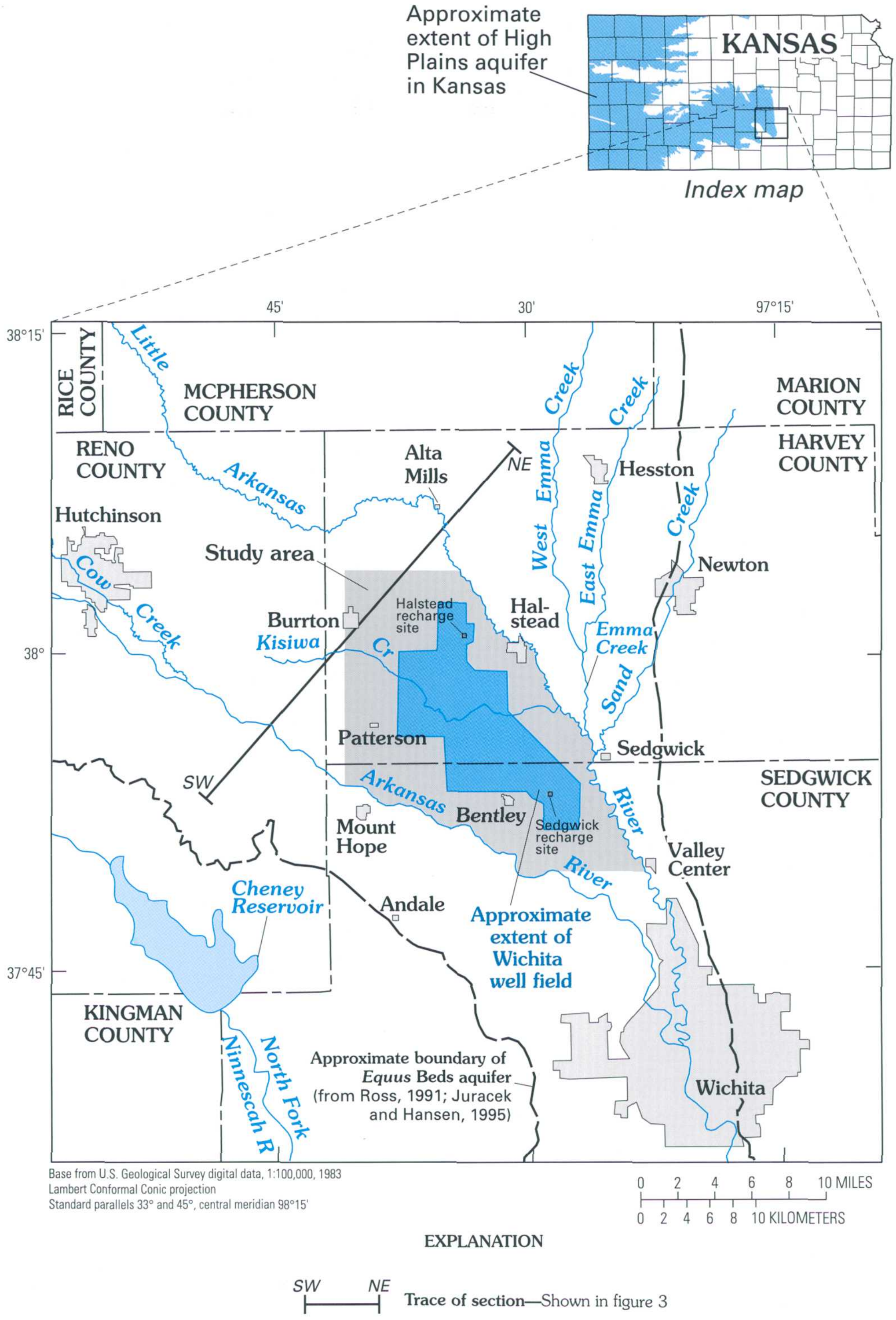


Figure 1. Location of study area and Wichita well field, south-central Kansas (modified from Aucott and Myers, 1998).

(Warren and others, 1995), the city of Wichita, in cooperation with *Equus* Beds Groundwater Management District No. 2 (Halstead, Kansas), Bureau of Reclamation (U.S. Department of the Interior), U.S. Geological Survey (USGS), U.S. Environmental Protection Agency, various Kansas State agencies, Burns and McDonnell Engineering Consultants (Kansas City, Missouri), and Mid-Kansas Engineering Consultants (Wichita, Kansas), has been investigating the potential for using artificial ground-water recharge in the well field area to meet future water-supply needs and to help protect the aquifer from the intrusion of saltwater from natural and anthropogenic sources to the northwest and southwest. Because of the social and economic importance of ground-water resources and because of the changes that artificial recharge is expected to bring to the aquifer, the city of Wichita entered into a cooperative agreement with the USGS to document historical hydrologic conditions, their changes, and the probable causes of these changes in the Wichita well field area (study area shown in fig. 1); to develop a baseline condition for evaluating the effects of artificial recharge on ground-water levels in the aquifer; and to periodically review changes in the ground-water system.

The USGS and the city of Wichita have worked cooperatively since 1940 in evaluating the *Equus* beds ground-water system and its interaction with streams in the area to further the understanding of the entire hydrologic system and to provide information to improve local decisionmaking. The understanding gained from this cooperative study of the *Equus* beds hydrologic system can contribute to the wise management of water resources where similar hydrologic conditions exist in other parts of the United States and foreign lands.

Purpose and Scope

The purpose of this report is primarily to describe the status of ground-water levels and storage volume in the Wichita well field area of the *Equus* Beds aquifer during January 1998 to January 2000. The report addresses water levels and storage in relation to predevelopment (1940) conditions and updates historical information related to changes in the aquifer since 1940. Maps of ground-water-level measurements and water-level changes are presented. Two hydrographs of ground-water levels were selected to show historical water-level variations. Historical water-use and climate information also are presented. The information in this report can be used to monitor 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 Wichita and the surrounding area.

Description of Study Area

The study area (fig. 1) includes 165 mi^2 and is located in Harvey and Sedgwick Counties, northwest of Wichita, Kansas. The study area is in the Arkansas River section of the Central Lowlands physiographic province (Schoewe, 1949). There is little topographic relief in the study area. For the most part, the land surface slopes gently toward the major streams in the area. The study area is bounded on the southwest by the Arkansas River and on the northeast by the Little Arkansas River. The Wichita well field covers approximately 55 mi^2 and is located within the study area (fig. 1).

South-central Kansas has a continental climate that is characterized by large variations in seasonal temperatures, moderate precipitation, and windy conditions. Long-term daily mean temperatures for 1961–90 range from 30.6 ^{o}F in January to 79.6 ^{o}F in July (National Oceanic and Atmospheric Administration, 1997). The long-term annual mean precipitation for 1940–99 at weather stations near the study area (at Hutchinson, Mount Hope, Newton, Sedgwick, and Wichita) is 30.87 in. (National Oceanic and Atmospheric Administration, 1997–2000) (fig. 2*A*). Most of this precipitation occurs during spring and summer.

Previous Studies

Water-level data have been collected periodically by the city of Wichita in the study area since 1940 and are on file with the USGS in Lawrence, Kansas. Water-level data also have been collected by *Equus* Beds Groundwater Management District No. 2 since 1978 from wells completed in the *Equus* Beds aquifer (*Equus* Beds Groundwater Management District No. 2, 1995). Annual water-level data for the High Plains aquifer (fig. 1), which includes the *Equus* Beds aquifer, have been collected since 1937 by the Kansas Department of Agriculture (Division of Water Resources), the USGS, and the Kansas Geological Survey, and are on file with the USGS in Lawrence, Kansas. These data have been compiled annually for Kansas by the Kansas Geological Survey (Miller and others, 2000). Historical water levels in Kansas, including those in the *Equus* Beds aquifer, are available at URL http://magellan.kgs.ukans.edu/WaterLevels/index.html. Historical and near-real-time data and reports associated with the *Equus* Beds Ground-Water Demonstration Recharge Project (Ziegler and others, 1999) are available at URL http://ks.water.usgs.gov/Kansas/equus/.

Williams and Lohman (1949) and Stramel (1956, 1967) presented water levels and water-level-decline maps for the study area. Ross and others (1997) noted water-level rises in the *Equus* Beds aquifer from 1993 to 1997 and attributed them largely to decreases in withdrawals by the city of Wichita. Aucott and Myers (1998) and Aucott and others (1998) presented water-level decline maps for the study area and discussed the changes in storage volume for selected periods of time. Myers and others (1996) evaluated the hydrologic interaction between the Arkansas River and the *Equus* Beds aquifer in the study area. Water-level data for the *Equus* Beds and High Plains aquifers have been mapped regionally by McGuire and Sharpe (1997) and McGuire and Fischer (1999).

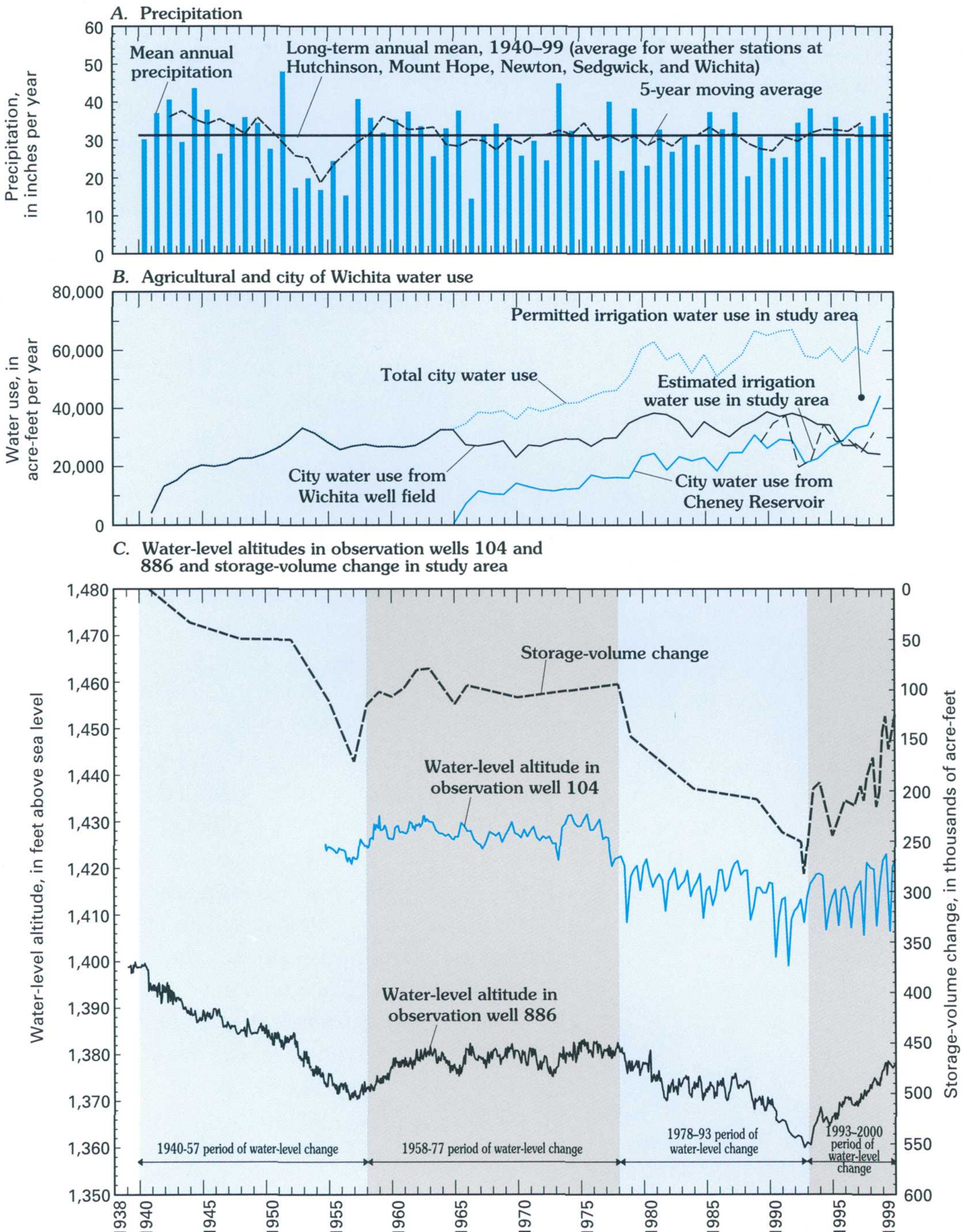


Figure 2. Relation of *(A)* precipitation, *(B)* water used for irrigation in study area and by city of Wichita, and *(C)* water-level altitudes in observation wells 104 and 886 and *Equus* Beds aquifer storage-volume change in study area (modified from Aucott and others, 1998). Source: *(A)* precipitation data from National Oceanic and Atmospheric Administration (1997–2000); *(B)* water-use data from Stramel (1956, 1967), Gerald T. Blain (city of Wichita, written commun., 1997), Joan Kenny (U.S. Geological Survey, written commun., 2000), and Brownie Wilson (Kansas Water Office, written commun., 2000); *(C)* water-level altitude data from Stramel (1956, 1967) and from data collected by city of Wichita and on file with U.S. Geological Survey, Lawrence, Kansas. Locations of observation wells are shown in figures 4–18.

GEOLOGY AND GROUND WATER

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 ft thick in the study area (fig. 3). The *Equus* beds consist primarily 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. The Wellington Formation is about 700 ft thick (Bayne, 1956) and consists of three members—the lower

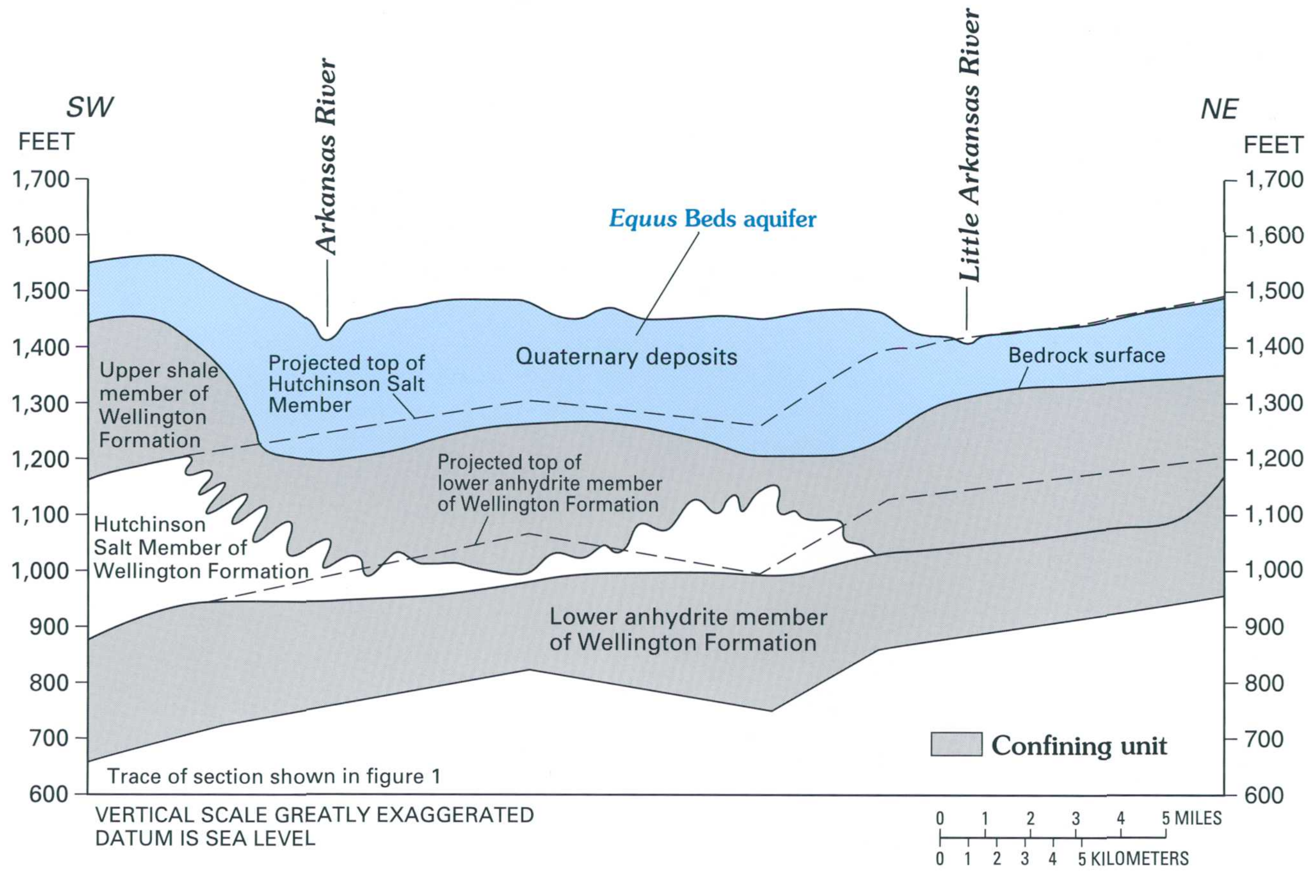


Figure 3. Generalized geologic section (from Leonard and Kleinschmidt, 1976; Myers and others, 1996).

anhydrite member, about 200 ft thick; the Hutchinson Salt Member, about 300 ft thick; and the upper shale member, about 200 ft thick (Myers and others, 1996). Dissolution of the Hutchinson Salt Member has resulted in subsidence of the overlying upper shale member, formation of low areas in the bedrock surface, and concurrent accumulation of alluvial deposits that now compose the *Equus* Beds aquifer (fig. 3) (Myers and others, 1996).

The *Equus* Beds aquifer is the easternmost extension of the High Plains aquifer in Kansas (Stullken and others, 1985). The extent of the High Plains aquifer (Juracek and Hansen, 1995) was used to delineate the *Equus* Beds aquifer in Harvey, Marion, and Reno Counties and in Sedgwick County to the north of Wichita (fig. 1). The *Equus* beds continue south of Wichita in the Arkansas River Valley (Stramel, 1967) but typically are thinner to the south of Wichita (Lane and Miller, 1965a). Therefore, the extent of the alluvial deposits in the Arkansas River Valley (Ross, 1991) was used to delineate the extent of the *Equus* Beds aquifer in this area (fig. 1).

The *Equus* beds are an important source of ground water because of the generally shallow depth to the water table, the large saturated thickness, and the generally good water quality. Near the Arkansas River, the water table may be as little as 10 ft below land surface. Farther from the 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 ground-water withdrawals. The maximum saturated thickness of the *Equus* Beds aquifer within the study area, almost 250 ft, is near the course of the Arkansas River and corresponds to the lowest areas of the underlying bedrock surface (fig. 3).

GROUND-WATER LEVELS

Extensive information is available to describe hydrologic conditions in the study area. Water-level data have been collected periodically from more than 100 wells by city of Wichita personnel using standard water-level measurement techniques similar to USGS methods described in Stallman (1971). Data collection began just prior to the beginning of city pumpage from the well field in 1940; water levels in most wells have been measured quarterly. These data are stored by the city in paper and electronic form and by the USGS in electronic form.

Ground-water-level declines can result from pumpage, decreased recharge resulting from less-than-average precipitation, and other factors. Droughts, such as occurred during 1952–56 and 1988–92 (fig. 2*A*), tend to decrease the amount of recharge available and increase the demand for and thus pumpage of ground water (fig. 2*B*), resulting in increased water-level declines (fig. 2*C*). Periods of greater-than-average rainfall, such as occurred in 1957–62 (fig. 2*A*), tend to increase the amount of recharge available and decrease the demand for and thus pumpage of ground water (fig. 2*B*), resulting in water-level rises (fig. 2*C*). If these water-level declines or rises are large enough, they may locally alter the direction of ground-water flow.

Aucott and Myers (1998) identified four noteworthy periods of water-level change (fig. 2*C*): 1940–57, the initial water-level-decline period when pumpage began in the well field and includes a phase of accelerated declines in the mid-1950's coinciding with drought conditions; 1958–77, a period of general equilibrium with relatively stable city pumpage and water levels and with increasing irrigation pumpage that became significant in the late 1970's; 1978–93, another period of water-level declines associated with increased city and irrigation pumpage due to increased demands and drought conditions; and 1993 to present (2000), a period of water-level rises associated with generally greater-than-average precipitation and decreased city pumpage.

The first two periods have been well documented by Aucott and Myers (1998) and will not be described in this report. Description of the two more recent periods (1978–93 and 1993–2000) is facilitated by the use of hydrographs of water levels in wells 104 and 886 (fig. 2*C*). The hydrograph of well 104 serves as a representative descriptor of irrigation effects outside of the well field; the hydrograph of well 886 serves as a representative descriptor of historical water-level changes in an area of maximum water-level decline near the historic center of the Wichita well field.

The period of water-level declines during 1978 to 1993 ended with record low water levels in most wells, including wells 104 and 886 (fig. 2*C*). These low water levels, which coincided with the 1988–92 drought (fig. 2*A*), were caused by the resulting decrease in recharge to the *Equus* Beds aquifer and increase in city and irrigation pumpage (fig. 2*B*).

In 1993, the period of general water-level rise—seen in both wells 104 and 886—began with greater-than-average precipitation (fig. 2*A*). Generally greater-than-average precipitation and thus increased recharge since 1993 may account for part of the rise in water levels of about 10 ft in well 104, based on measurements during the nonpumping season. The resulting water levels are similar to levels observed in well 104 in the late 1970's (fig. 2*C*). Irrigation pumpage in the study area, which was less than or similar to city pumpage during 1989–97, was greater than city pumpage in 1998 (fig. 2*B*) and may account for the consistently large seasonal water-level variations in well 104. An important factor in the water-level rise in well 886 was decreased city pumpage from the well field that accompanied increased city reliance on Cheney Reservoir as a water-supply source (Ross and others, 1997) (fig. 2*B*). As a result, city pumpage from the well field went from being greater than one-half to about one-third of Wichita's water usage during 1993–98 (fig. 2*B*). This shifting of water sources was a part of the city of Wichita's Integrated Local Water Supply Plan (Warren and others, 1995).

Irrigation water-use amounts reported prior to 1989 are not plotted in figure 2*B* because of incomplete reporting of water-use data before 1989 (Lane Letourneau, Kansas Department of Agriculture, Division of Water Resources, oral commun., August 2, 2000). Estimated irrigation water use in the study area in 1998 was less than what is permitted by the State of Kansas (fig. 2*B*); thus, increased irrigation water use in the study area could become a factor during dry years.

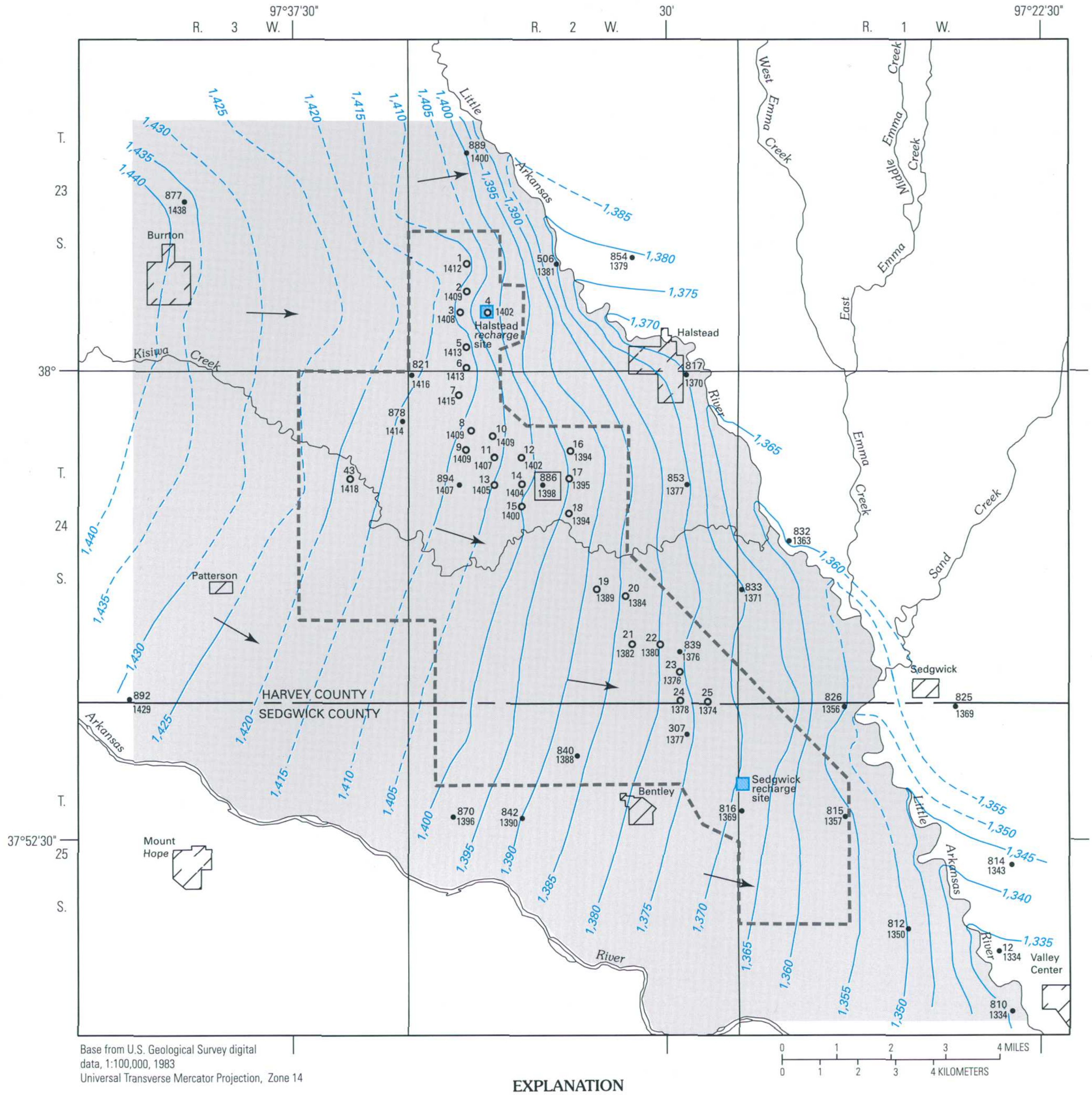
The use of hydrographs along with the use of water-level-altitude and water-level-change maps and changes in storage volume can provide a more complete picture of changes in hydrologic conditions than the use of just one of these graphical tools. Hydrographs of individual wells are important for indicating changes at a specific time and can be used to infer the effects of water-level changes at that location. Such effects could include dewatered shallow wells or increased pumping costs to lift water from greater depths. Water-level-altitude maps show the gradient and direction of ground-water flow over a large area at a particular time. A single water-level-altitude map cannot indicate the distribution and extent of areas affected by water-level declines or rises. However, water-level-change maps can be used to illustrate the areal distribution and extent of water-level declines and rises. Changes in storage volume, which are derived from water-level-change maps and represent a decrease (or increase) in the ground-water resource available for use, are a good measure of the cumulative effect of pumping and climatic conditions on the aquifer.

Water-level-altitude maps for August 1940, October 1992, and January 2000 (figs. 4–6) were constructed from available water-level data to illustrate water-level conditions in the study area during predevelopment, maximum decline, and current periods. Prior to pumpage from the Wichita well field in 1940, near-predevelopment conditions existed for the *Equus* Beds aquifer in the study area (Williams and Lohman, 1949; Aucott and Myers, 1998). The August 1940 water-level-altitude map from Aucott and Myers (1998) (fig. 4) shows that ground water flowed generally from west to east and discharged to the Little Arkansas River. Water-level-altitude maps by Aucott and Myers (1998) and Aucott and others (1998) indicate that, following the beginning of development, ground-water flow remained from west to east but that between the well field and the Little Arkansas River and in the vicinity of Halstead and Sedgwick, the flow generally became more southerly and more parallel to the river.

During the period of maximum decline as illustrated by the October 1992 water-level-altitude map (fig. 5), ground water continued to flow mainly from west to east. However, in some parts of the area between the well field and the Little Arkansas River, declines had altered the water-level gradient sufficiently such that ground water generally flowed from northeast to southwest, that is from near the Little Arkansas River toward the well field. By January 1997, water levels recovered enough so that ground-water flow again was from west to east with ground-water flow between the well field and the Little Arkansas River generally parallel or toward the river (Aucott and others, 1998); this ground-water flow pattern has continued into January 2000 (fig. 6).

Water-level-change maps were constructed from available water-level data to show changes between August 1940 (predevelopment) and October 1992 (fig. 7), between August 1940 and January 1993 (fig. 8), between August 1940 and quarter-year intervals from January 1998 to January 2000 (figs. 9–17), and between January 1993 and January 2000 (fig. 18). In constructing these maps, if a 1940 water-level measurement did not exist for a well in the study area, a value was interpolated from the August 1940 water-level-altitude map (Aucott and Myers, 1998); figure 4 shows wells with August 1940 water-level measurements. The August 1940–October 1992 and the January 1993–January 2000 periods were selected as representative, respectively, of maximum water-level decline and cumulative water-level changes since the period of maximum decline. The month of January was selected for each year to provide comparable conditions with minimal effect from seasonal factors.

The shapes of the water-level-change contours since August 1940 for the period January 1998 to January 2000 (figs. 9–17) are similar to those published for recent years (Aucott and others, 1998; Aucott and Myers, 1998). Comparisons of figures 9–17 show the annual cycle of water-level declines and rises that generally occur in the study area. Typically, the largest water-level declines occur during summer when irrigation and city pumpage are greatest. This is shown most distinctly by the appearance of areas with water-level declines of 30 ft or more on the July 1998 and July 1999 maps of water-level changes since 1940 (figs. 11 and 15). The maximum water-level decline since August 1940 for the period January 1998 to January 2000 was 36.48 ft in July 1998 at well 1 in the northern part of the well field (fig. 11). As consumption of water by vegetation and humans decrease following the summer months, so does irrigation and city pumpage, resulting in water-level rises that can continue into the following spring. The maps of water-level changes since August 1940 for the period January 1998 to January 2000 show these water-level rises as the decrease in the size of the areas with declines of 20 ft or more and the disappearance of the areas with declines of 30 ft or more during the months of October, January, and April (figs. 9, 10, 12–14, 16, and 17). As the warmer weather of summer again causes water consumption to increase, this annual cycle of seasonal water-level declines and rises begins again. Unusually wet or dry climatic conditions or changes in ground-water pumpage strategies may modify this annual cycle. For example, drought conditions and increases in irrigation or city pumpage may result in a cumulative decline in ground-water levels; greater-than-average precipitation and decreases in irrigation or city



EXPLANATION

Study area

—1,375— — Water-level contour—Shows altitude of water level, August 1940. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

Approximate boundary of Wichita well field

Approximate direction of ground-water flow

Artificial recharge demonstration site

886 / 1398 — Well hydrograph shown in figure 2

1 / 1412 — Observation well in vicinity of city of Wichita supply well

854 / 1379 — Other observation well

Well number shown above symbol; water-level altitude, in feet above sea level, shown below.

Water-level measurements were made by city of Wichita personnel.

Figure 4. Water-level altitudes in *Equus* Beds aquifer in vicinity of Wichita well field for August 1940 (from Aucott and Myers, 1998).

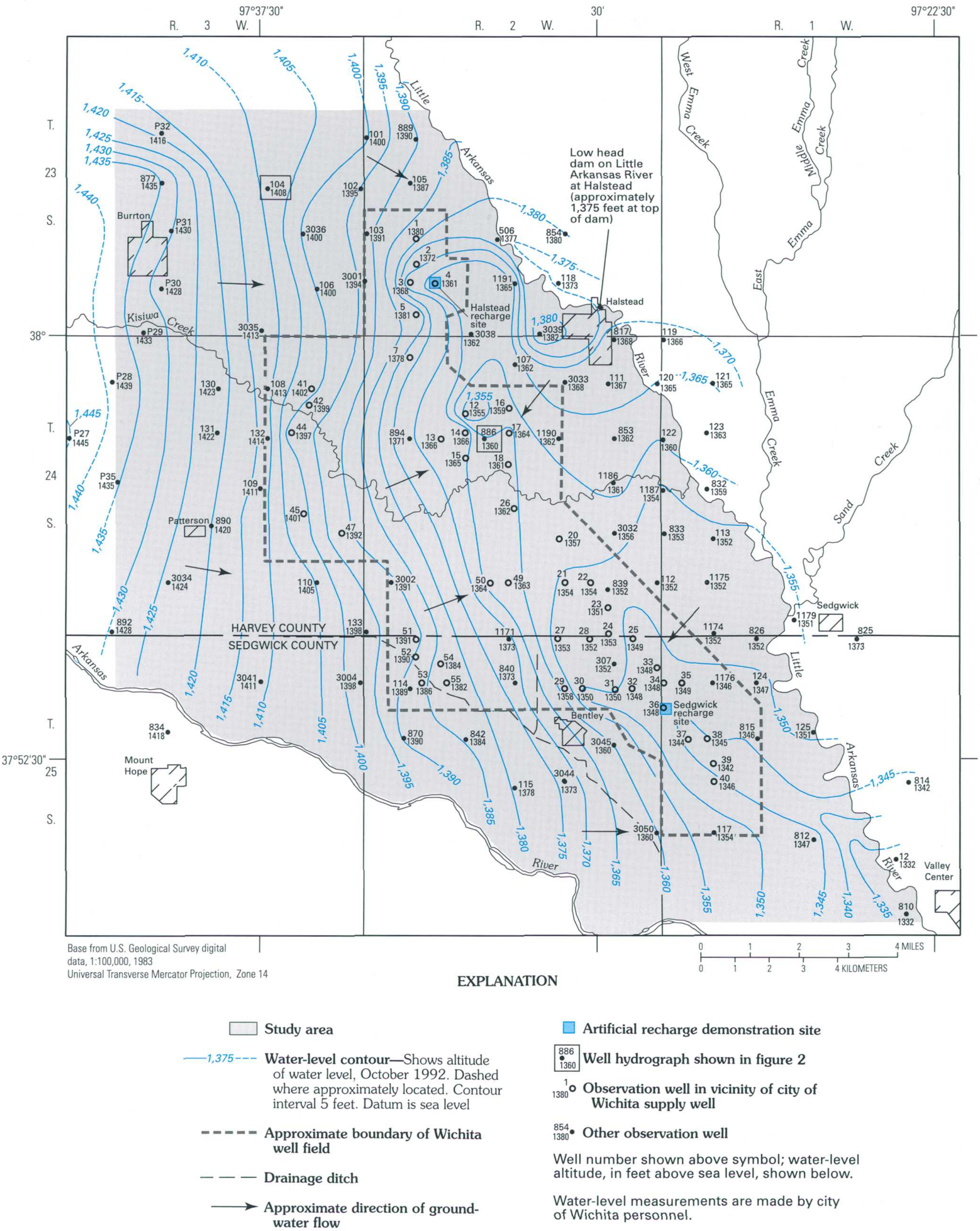
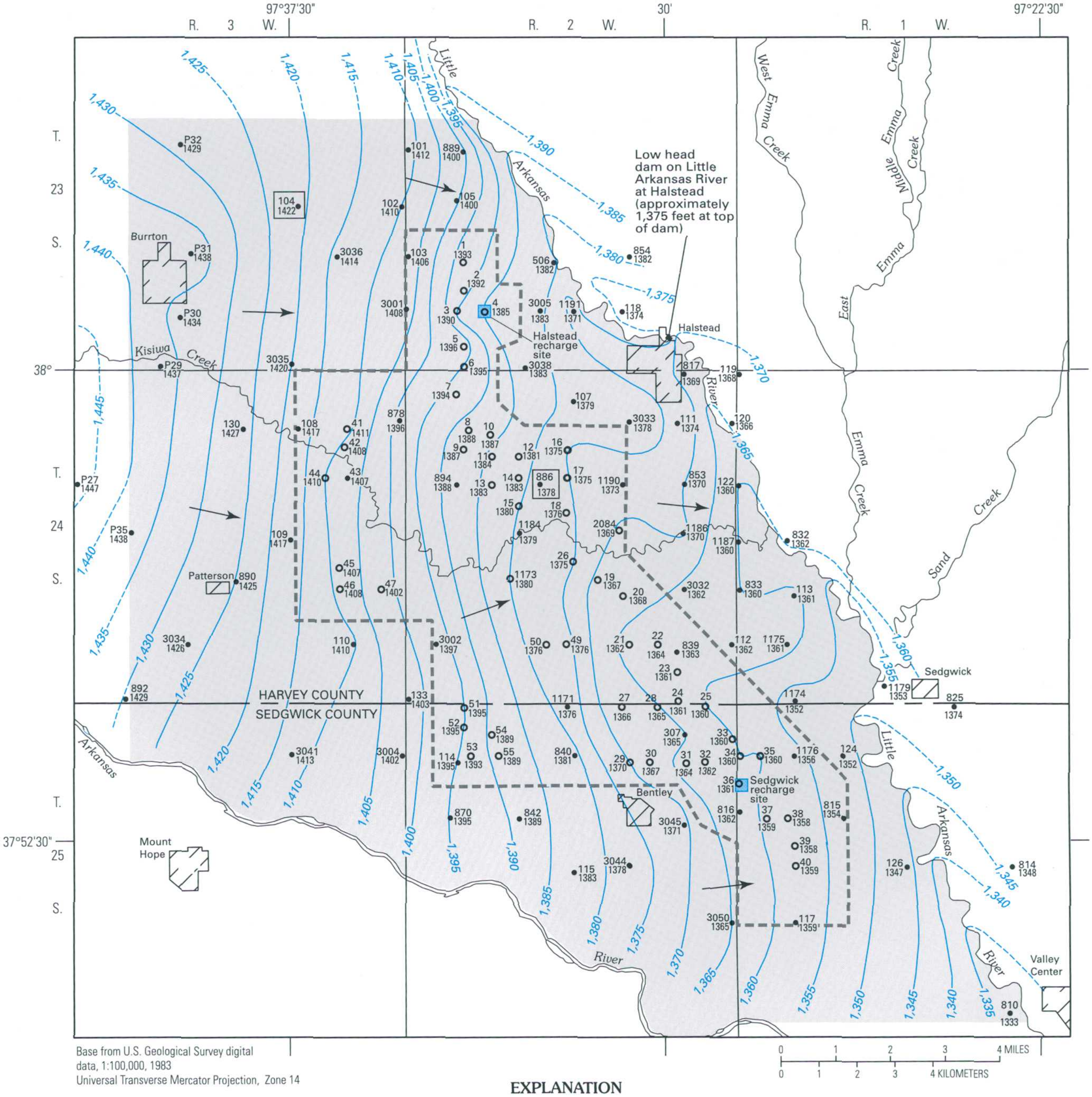


Figure 5. Water-level altitudes in *Equus* Beds aquifer in vicinity of Wichita well field for October 1992.



EXPLANATION

- Study area
- 1,375 — Water-level contour—Shows altitude of water level, January 2000. Dashed where approximately located. Contour interval 5 feet. Datum is sea level
- Approximate boundary of Wichita well field
- Approximate direction of ground-water flow
- Artificial recharge demonstration site
- 886 / 1378 Well hydrograph shown in figure 2
- 1 / 1393 Observation well in vicinity of city of Wichita supply well
- 854 / 1382 Other observation well

Well number shown above symbol; water-level altitude, in feet above sea level, shown below.

Water-level measurements were made by city of Wichita personnel.

Figure 6. Water-level altitudes in *Equus* Beds aquifer in vicinity of Wichita well field for January 2000.

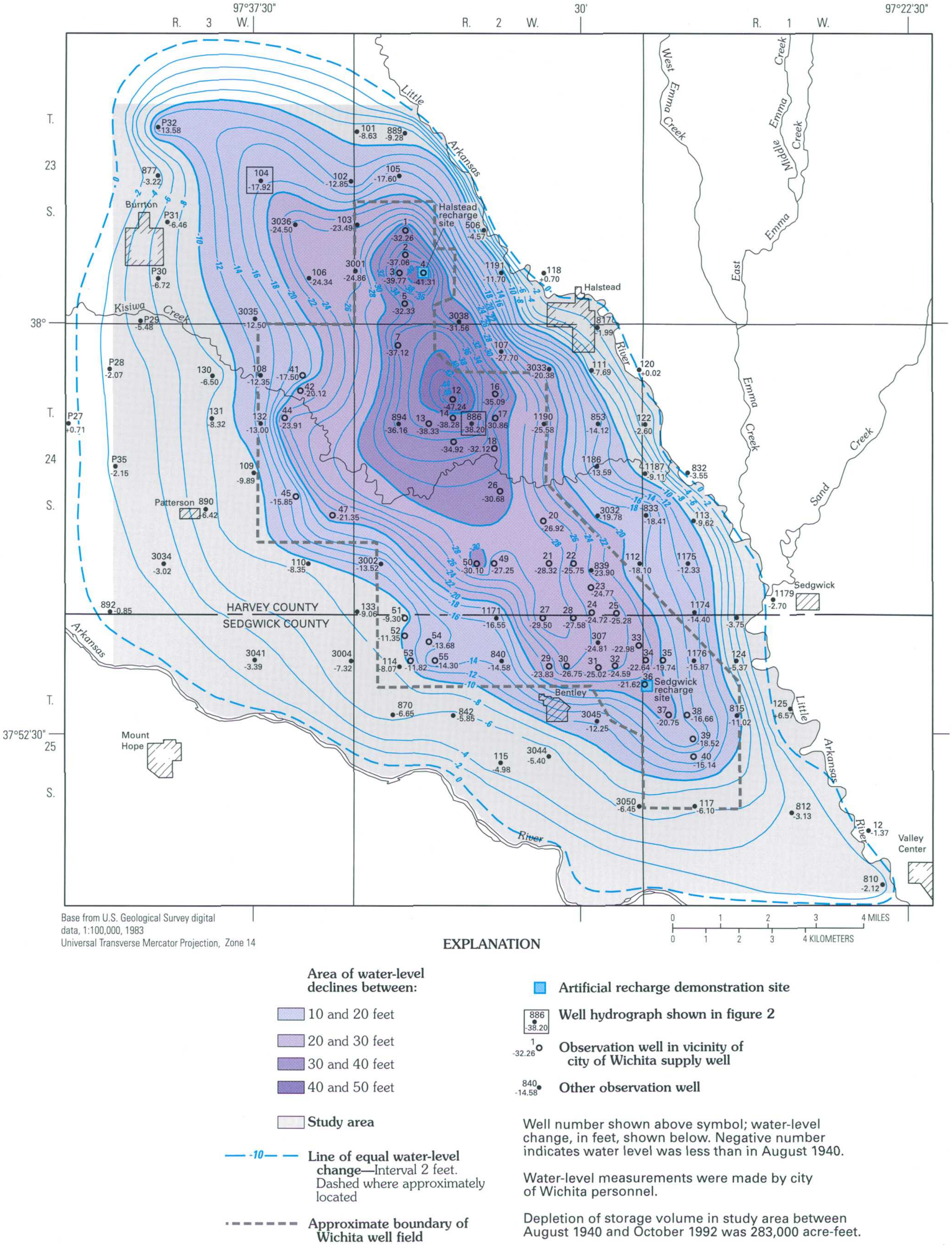
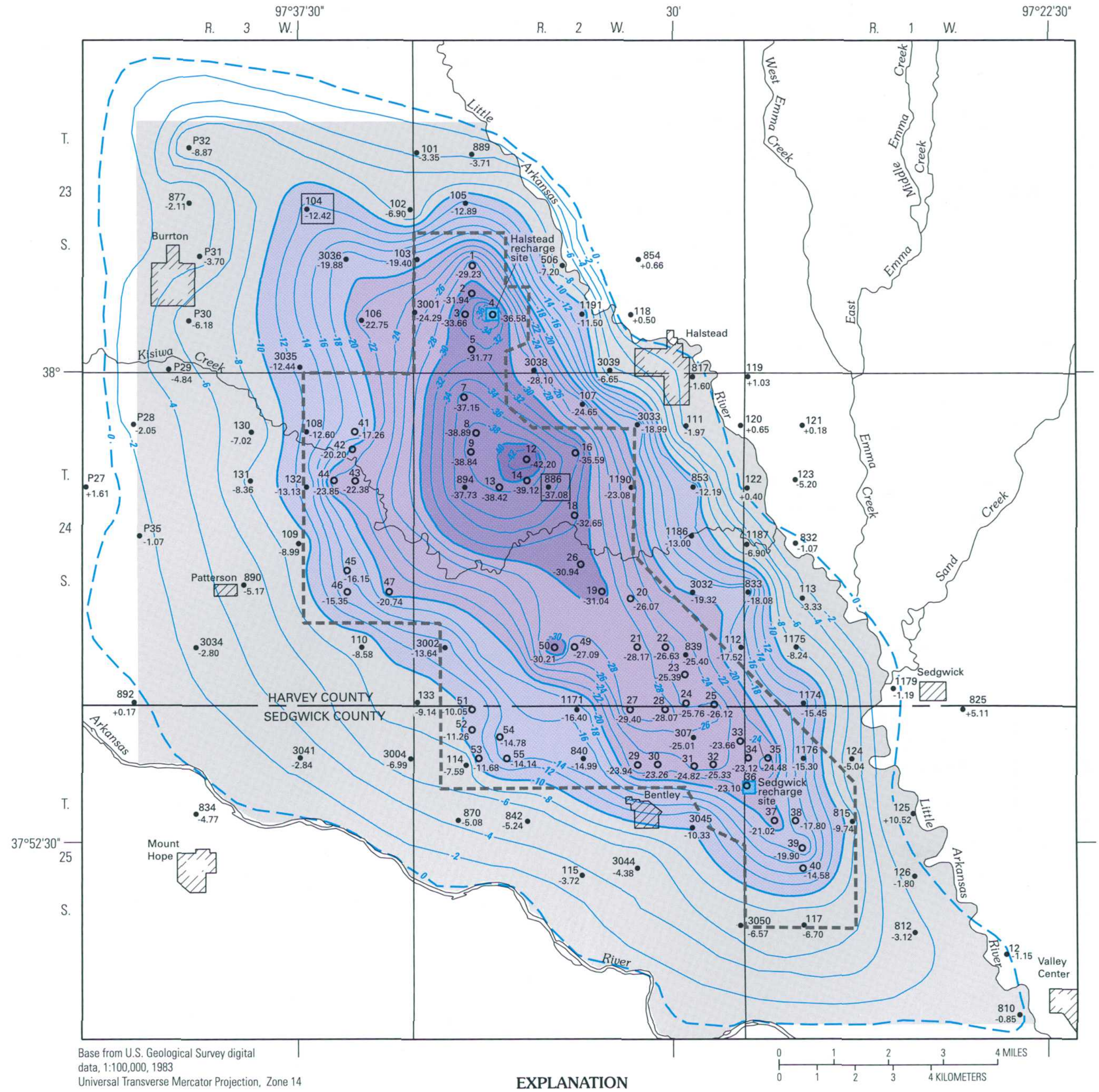


Figure 7. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–October 1992.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet
- 30 and 40 feet
- 40 and 50 feet

Study area

Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

886 -37.08 **Well hydrograph shown in figure 2**

1 -29.23 **Observation well in vicinity of city of Wichita supply well**

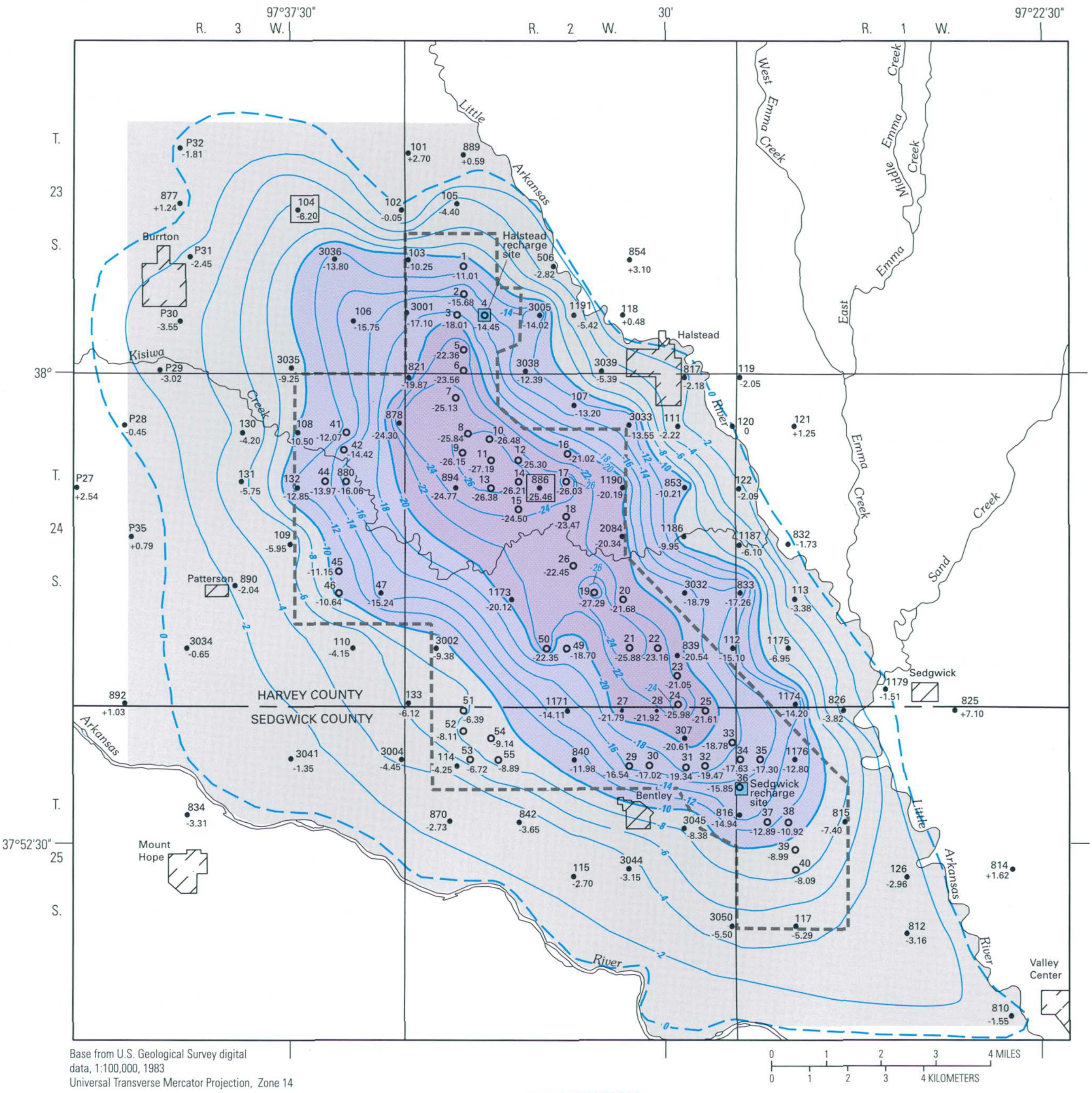
854 +0.66 **Other observation well**

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and January 1993 was 255,000 acre-feet.

Figure 8. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–January 1993 (modified from Aucott and Myers, 1998).



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet

Study area

Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

Well hydrograph shown in figure 2 (886, -25.46)

Observation well in vicinity of city of Wichita supply well (1, -11.01)

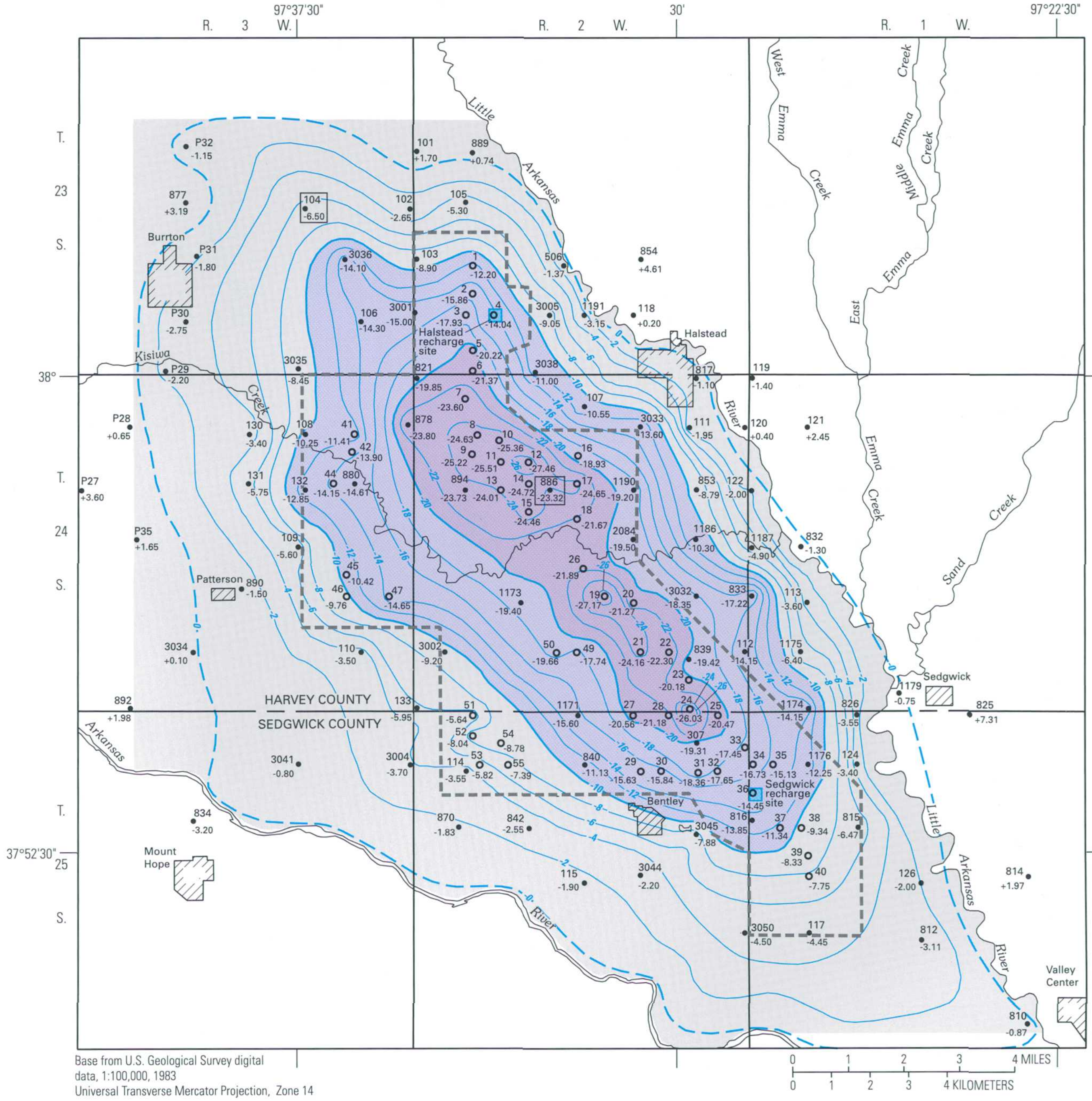
Other observation well (854, +3.10)

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and January 1998 was 176,000 acre-feet.

Figure 9. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–January 1998 (modified from Aucott and Myers, 1998).



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet

Study area

Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

Well hydrograph shown in figure 2 (886 / -23.32)

Observation well in vicinity of city of Wichita supply well (1 / -12.20)

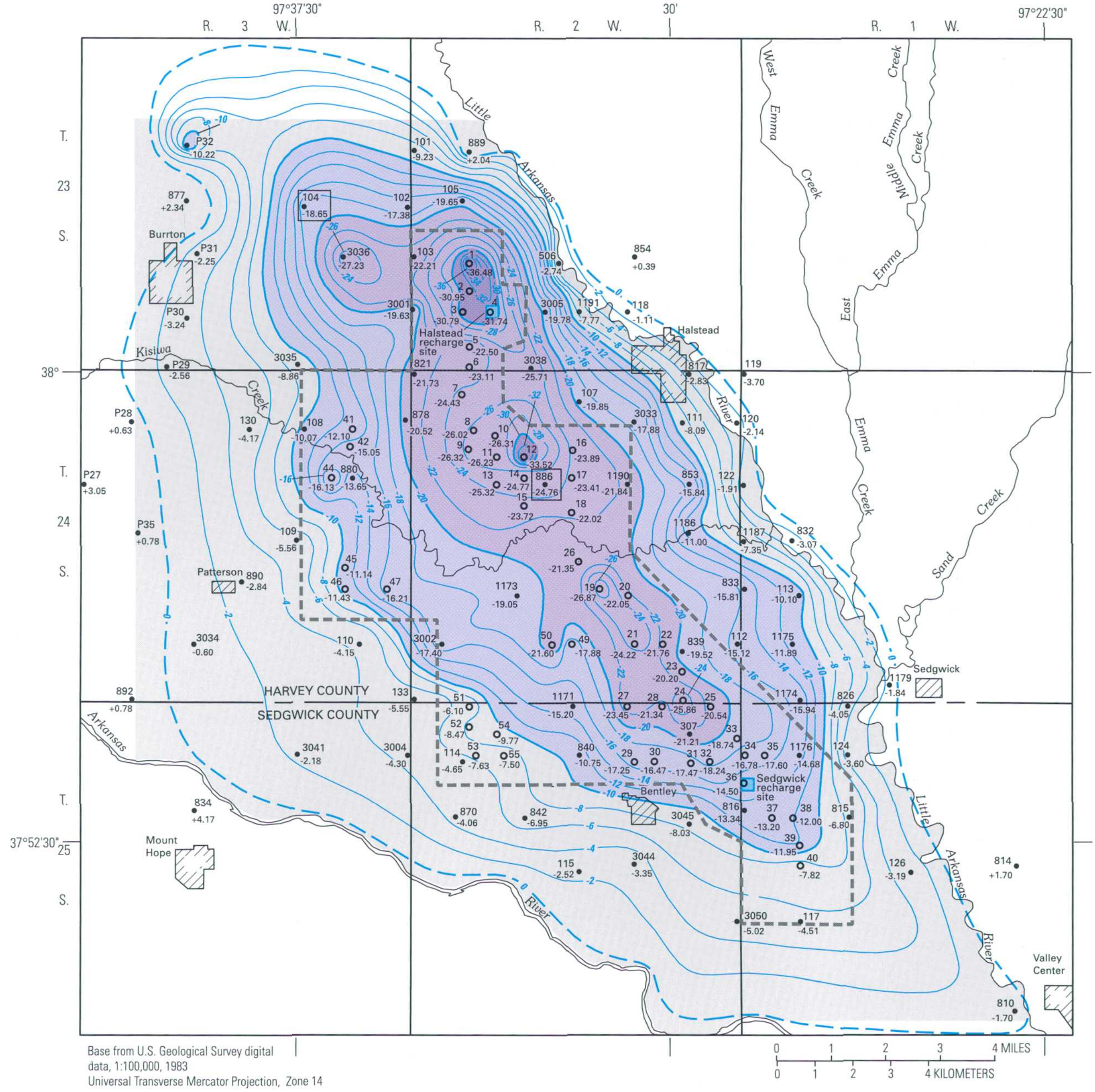
Other observation well (854 / +4.61)

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and April 1998 was 167,000 acre-feet.

Figure 10. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–April 1998.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet
- 30 and 40 feet
- **Study area**

—— -10 —— **Line of equal water-level change**—Interval 2 feet. Dashed where approximately located

- - - - - - **Approximate boundary of Wichita well field**

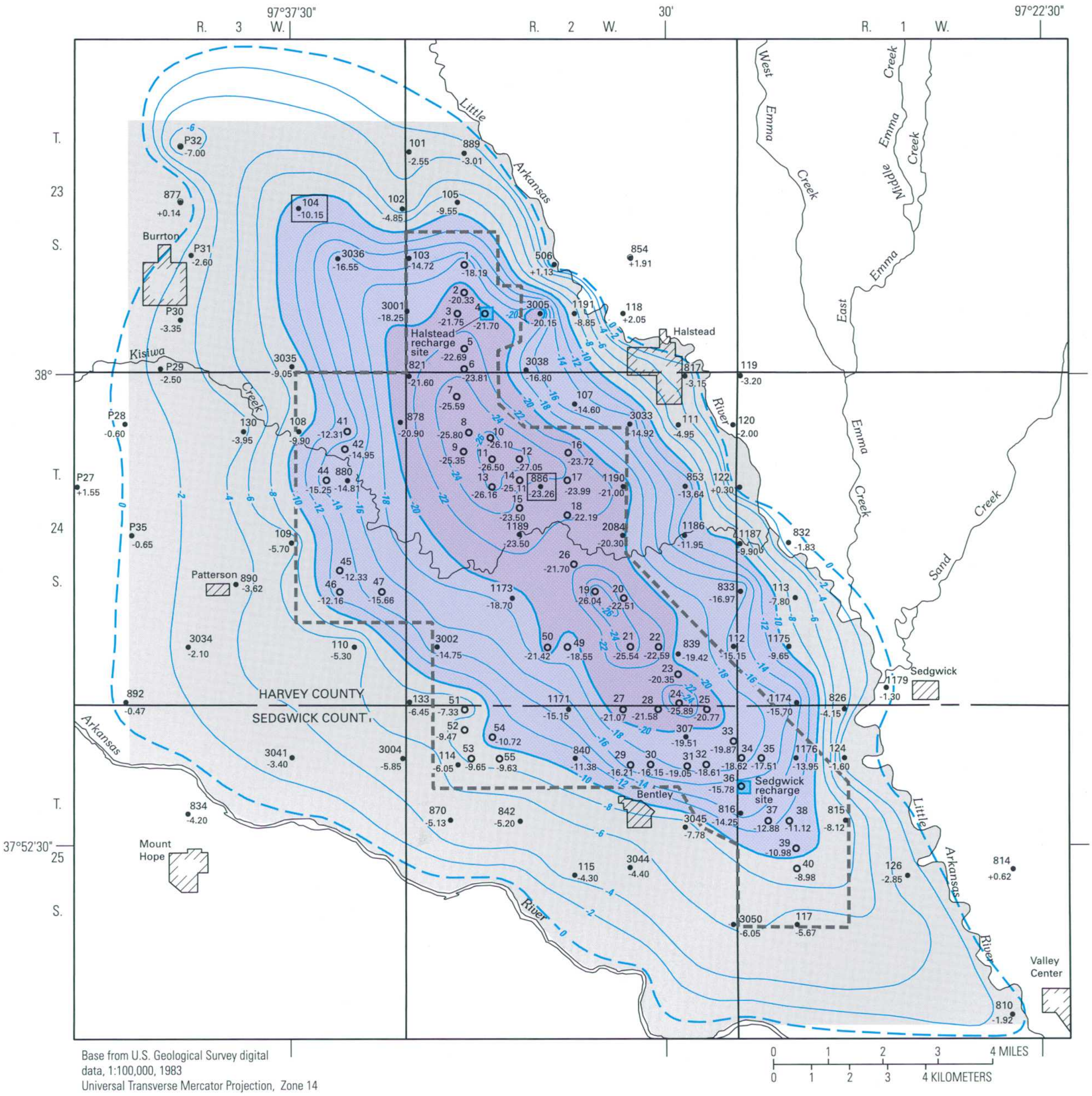
- **Artificial recharge demonstration site**
- 886 / -24.76 **Well hydrograph shown in figure 2**
- 1 / -36.48 **Observation well in vicinity of city of Wichita supply well**
- 854 / +0.39 **Other observation well**

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and July 1998 was 216,000 acre-feet.

Figure 11. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–July 1998.



EXPLANATION

Area of water-level declines between:

10 and 20 feet

20 and 30 feet

Study area

—10— — **Line of equal water-level change**—Interval 2 feet. Dashed where approximately located

- - - - - - **Approximate boundary of Wichita well field**

Artificial recharge demonstration site

886 / -23.26 **Well hydrograph shown in figure 2**

1 / -18.19 **Observation well in vicinity of city of Wichita supply well**

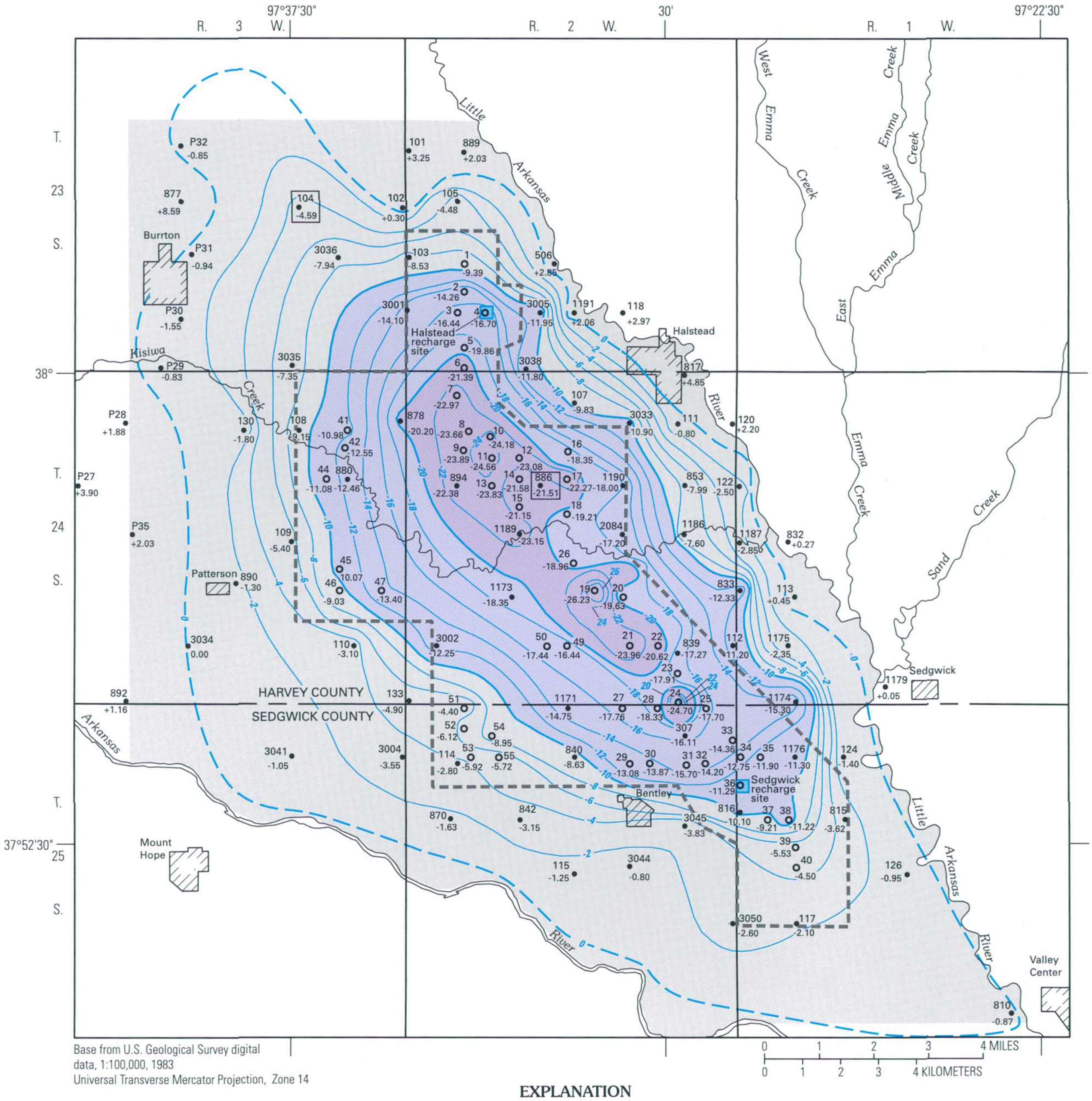
854 / +1.91 **Other observation well**

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and October 1998 was 201,000 acre-feet.

Figure 12. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–October 1998.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet

Study area

Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

Well hydrograph shown in figure 2 (886, -21.51)

Observation well in vicinity of city of Wichita supply well (1, -9.39)

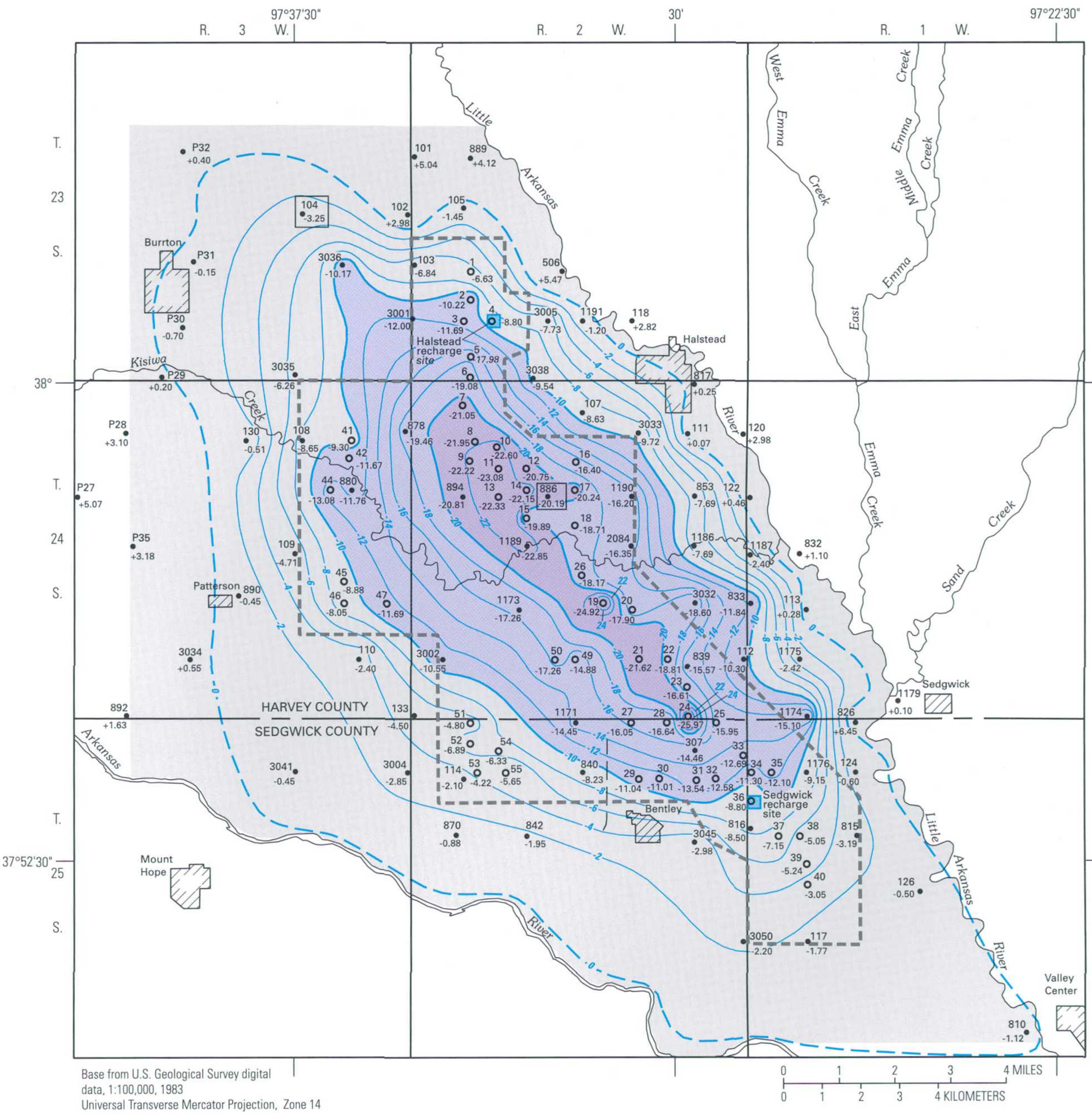
Other observation well (842, -3.15)

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and January 1999 was 142,000 acre-feet.

Figure 13. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–January 1999.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet
- Study area

Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

Well hydrograph shown in figure 2 (886 / -20.19)

Observation well in vicinity of city of Wichita supply well (1 / -6.63)

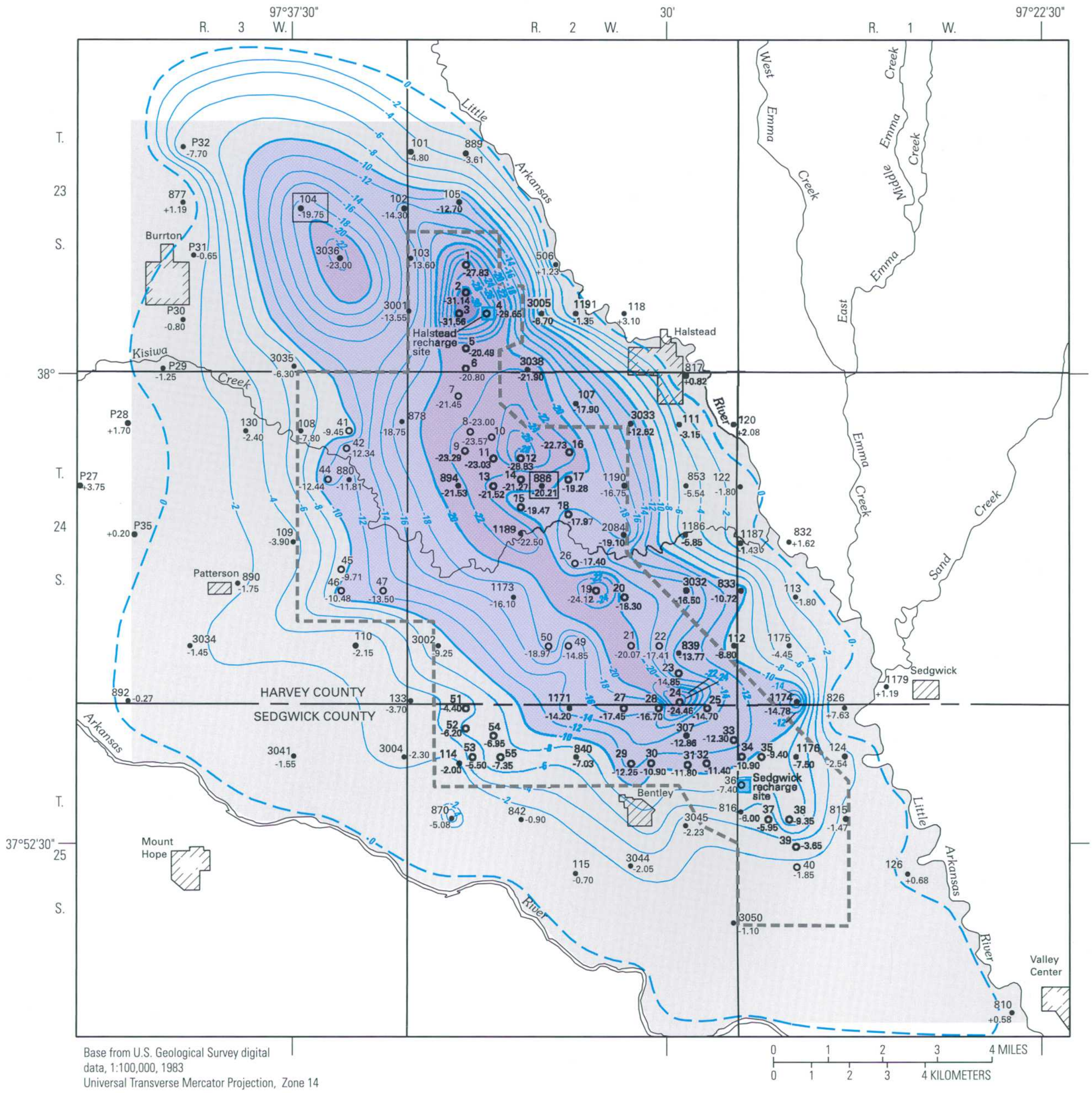
Other observation well (842 / -1.95)

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and April 1999 was 126,000 acre-feet.

Figure 14. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–April 1999.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet
- 30 and 40 feet

Study area

-10— **Line of equal water-level change**—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

886 / -20.21 **Well hydrograph shown in figure 2**

1 / -27.83 **Observation well in vicinity of city of Wichita supply well**

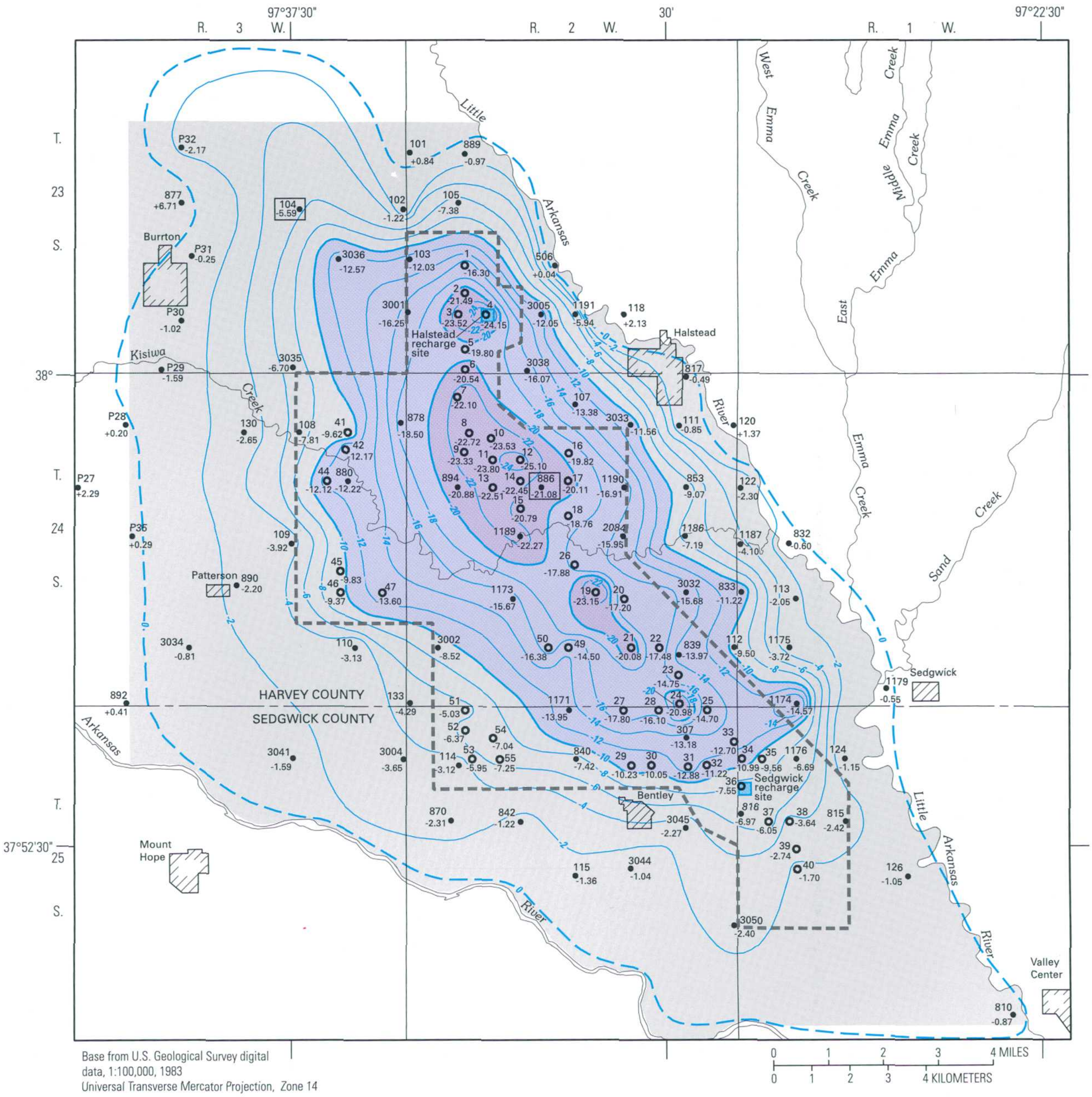
870 / -5.08 **Other observation well**

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and July 1999 was 159,000 acre-feet.

Figure 15. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–July 1999.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet

Study area

-10— Line of equal water-level change—Interval 2 feet. Dashed where approximately located

Approximate boundary of Wichita well field

Artificial recharge demonstration site

886 / -21.08 **Well hydrograph shown in figure 2**

1 / -16.30 **Observation well in vicinity of city of Wichita supply well**

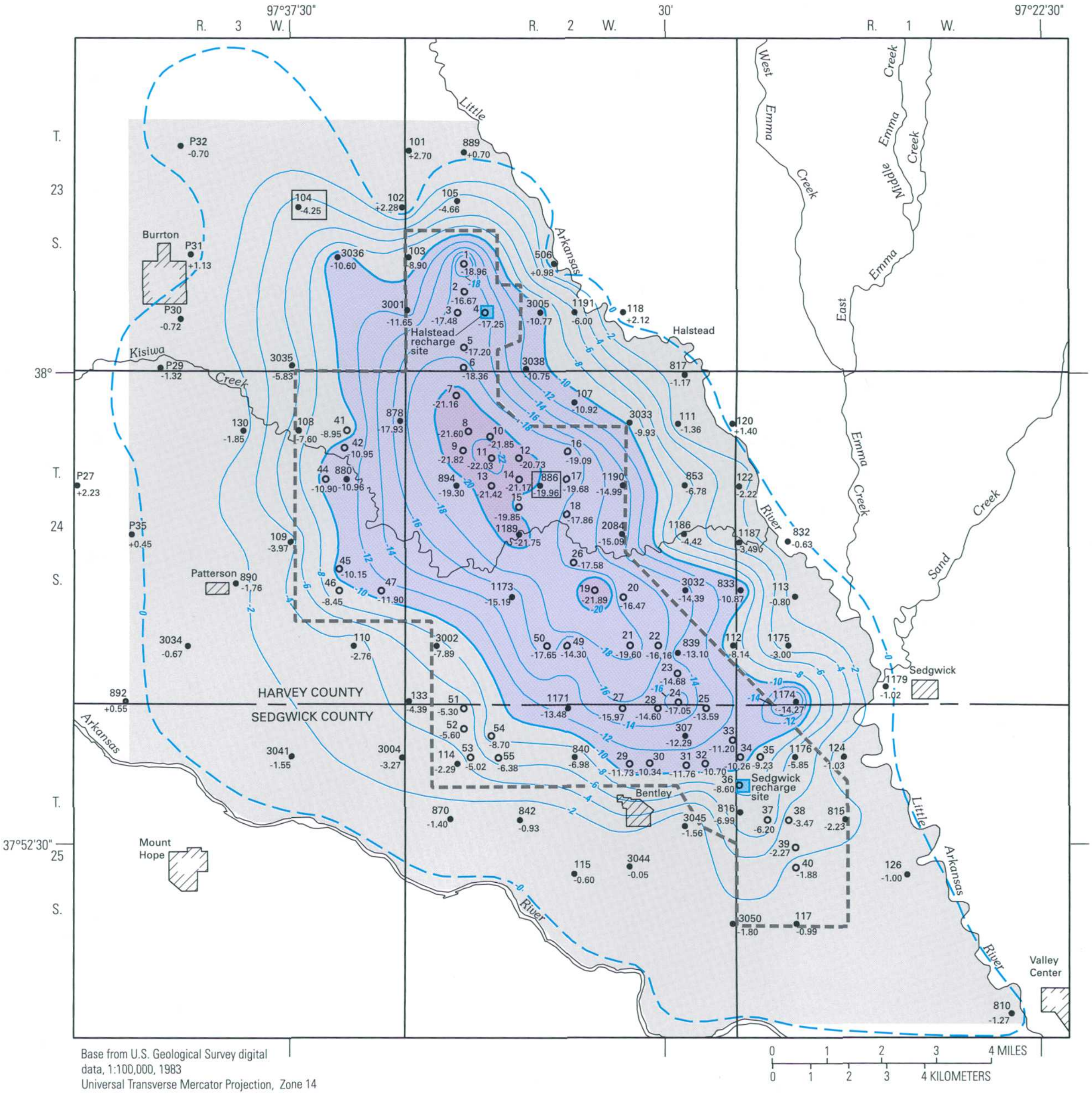
870 / -2.31 **Other observation well**

Well number shown above symbol; water-level change, in feet, shown below. Negative number *indicates water level was less than in August 1940.*

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and October 1999 was 142,000 acre-feet.

Figure 16. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–October 1999.



EXPLANATION

Area of water-level declines between:

- 10 and 20 feet
- 20 and 30 feet
- **Study area**

Line of equal water-level change—Interval 2 feet. Dashed where approximately located.

Approximate boundary of Wichita well field

Artificial recharge demonstration site

Well hydrograph shown in figure 2 (886 / -19.96)

Observation well in vicinity of city of Wichita supply well (1 / -27.83)

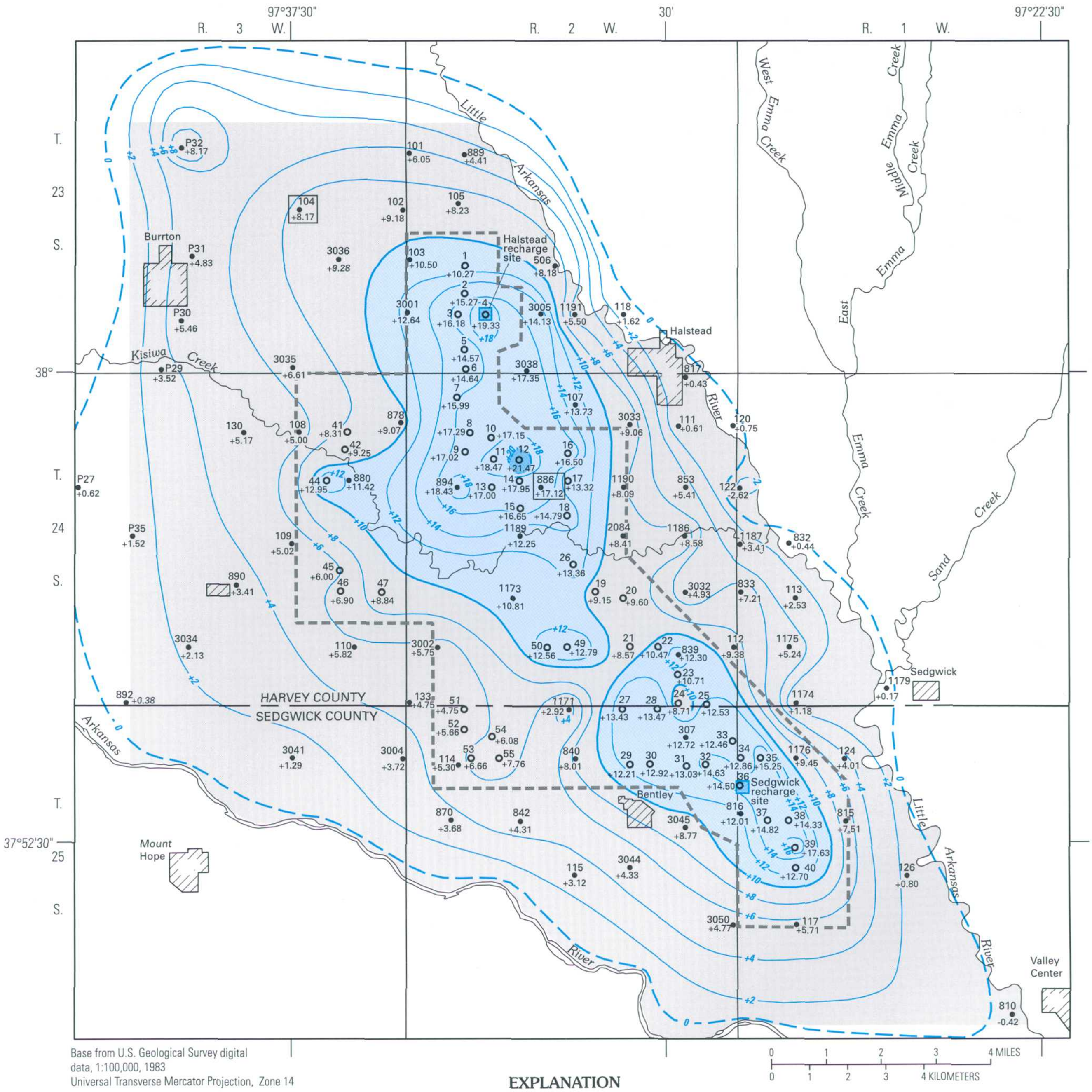
Other observation well (870 / -1.40)

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in August 1940.

Water-level measurements were made by city of Wichita personnel.

Depletion of storage volume in study area between August 1940 and January 2000 was 126,000 acre-feet.

Figure 17. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, August 1940–January 2000.



EXPLANATION

- Area of water-level recovery greater than 10 feet
- Area of water-level recovery greater than 20 feet
- Study area
- +10 — Line of equal water-level change—Interval 2 feet. Dashed where approximately located
- Approximate boundary of Wichita well field
- Artificial recharge demonstration site
- 886 +17.12 Well hydrograph shown in figure 2
- 1 +10.27 Observation well in vicinity of city of Wichita supply well
- 115 +3.12 Other observation well

Well number shown above symbol; water-level change, in feet, shown below. Negative number indicates water level was less than in January 1993.

Water-level measurements were made by city of Wichita personnel.

Figure 18. Water-level change in *Equus* Beds aquifer in vicinity of Wichita well field, January 1993–January 2000.

pumpage may result in a cumulative recovery of ground-water levels.

For most wells in the study area, the seasonal water-level variations during the period January 1998 to January 2000 were larger than the cumulative water-level change from January 1998 to January 2000. The seasonal variations of water levels in wells in the study area commonly were 5 to 10 ft during the period January 1998 to January 2000, whereas cumulative water-level changes from January 1998 to January 2000 generally were less than 5 ft in the wells in the study area. The maximum seasonal water-level variations that occurred during the period January 1998 to January 2000 were 20 to 30 ft from July 1998 to April 1999 or from April 1999 to July 1999 in the northern part of the study area in wells 1, 2, 4, and 102 (compare figs. 11, 14, and 15) and may be the combined result of seasonal irrigation pumpage, renewed city pumpage, and semiconfined aquifer conditions in this part of the study area (Aucott and Myers, 1998).

Maximum cumulative water-level changes from January 1998 to January 2000 ranged from a rise of 8.93 ft in well 24 in the southeastern part of the well field to a decline of 7.95 ft in well 1 in the northern part of the well field (compare figs. 9 and 17). Cumulative water-level rises of 5 to 10 ft from January 1998 to January 2000 were common in the central and southeastern parts of the well field (compare figs. 9 and 17). These cumulative water-level rises from January 1998 to January 2000 probably were the result of greater-than-average precipitation (fig. 2*A*) and decreased city pumpage due to increased reliance on water from Cheney Reservoir (fig. 2*B*). Cumulative water-level declines from January 1998 to January 2000 occurred mainly in part of the extreme northern part of the well field and southwestern part of the study area (compare figs. 9 and 17); these declines probably were due to renewed city pumpage in the northern part of the well field and to irrigation pumpage in the southwestern part of the study area.

During January 1998 to January 2000, water levels generally continued to recover from the large declines that had occurred as of January 1993. Water-level rises between January 1993 and January 2000 were as much as 21.47 ft in well 12 near the center of the well-field pumpage (fig. 18). The continued recovery of water levels can be seen in the northern and central part of the well field as an almost doubling in the size of the area with water-level rises of 10 ft or more for the period January 1993 to January 2000 (fig. 18) when compared to the area with rises of 10 ft or more for the period January 1993 to January 1998 as shown in Myers and Aucott (1998). In January 2000, a second area with water-level rises of 10 ft or more appeared in the southern part of the well field (fig. 18).

In 1995, the city of Wichita began investigating the potential for artificial recharge to meet future needs and to help protect the *Equus* Beds aquifer from the intrusion of saltwater from natural and anthropogenic sources to the northwest and southwest (Ziegler and others, 1999). Currently (2000), two artificial recharge demonstration sites are located in the well field near Halstead and Sedgwick (fig. 1). Operation of the Halstead recharge site (fig. 1) began in September 1997. Some indications of the effects of recharge can be seen in water levels in wells near the Halstead recharge site (observation wells near city supply wells 2, 3, and 4). Depths to water in these wells during nonpumping periods typically have been several feet less during periods of artificial recharge than during nonpumping periods before recharge began. In addition, the depths to water in these wells (data on file with the USGS, Lawrence, Kansas) tend to be less than those in nearby wells during nonpumping periods when artificial recharge does occur than during nonpumping periods when artificial recharge does not occur.

STORAGE VOLUME

Changes in storage volume are defined for the purposes of this report as the change in saturated aquifer volume multiplied by the specific yield of the aquifer. The specific yield of the *Equus* Beds aquifer has been estimated by many investigators using a variety of methods; these methods include aquifer tests, laboratory analyses of aquifer samples, lithologic descriptions from drillers' logs, water-balance equations, and parameter estimation for ground-water flow and transport models. Estimates of specific yield from these methods have ranged from less than 0.1 to more than 0.3 with most estimates in the range of 0.15 to 0.2 (Williams and Lohman, 1949; Stramel, 1956, 1967; Kansas Water Resources Board, 1960; Bayne and Ward, 1969; Lohman, 1979; Gutentag and others, 1984; Reed and Burnett, 1985; Spinazola and others, 1985; Stullken and others, 1985; Hansen, 1991; Nathan C. Myers, USGS, written commun., 1996; Cederstrand and Becker, 1998; and David Stous and Patrick Higgins, Burns and McDonnell Engineering

Consultants, written commun., 2000). A specific yield of 0.2 has been used to compute the changes in storage volume in the *Equus* Beds aquifer since the value was first used by Stramel (1956) (Aucott and Myers, 1998). The use of a specific yield of 0.2 was retained in this report because it is within the range of most estimates of specific yield and because there is no general agreement on a single representative value for specific yield of the *Equus* Beds aquifer in the study area.

Changes in storage volume since August 1940, as shown in table 1, were computed using the aquifer volume from areas inside water-level-change contours for selected time periods. Changes in storage volume since January 1993, as shown in table 1, were calculated as the difference between changes in storage volumes for August 1940 to January 1993 and August 1940 to the selected time period. The changes in storage volume computed for both the study and well field areas are shown in table 1.

Aucott and Myers (1998) described the largest ground-water storage-volume depletion computed for the study area as 255,000 acre-ft in January 1993. To minimize the effect of seasonal factors on the change in water levels and storage volume, January measurements were used for year-to-year comparisons; thus water-level data for January 1993 were used to represent the period of maximum decline. However, additional study revealed that the largest measured water-level declines and storage-volume depletion actually occurred in October 1992 and encompassed an area of about 174 mi^2. The largest measured water-level decline was 47.24 ft in well 12 near the center of the well field (fig. 7), and the associated storage-volume depletion was 283,000 acre-ft (table 1). Larger water-level declines and storage-volume depletions likely occurred in August or early September 1992 when irrigation and city pumpage probably were at a maximum; however, no areally comprehensive measurements were available to construct a map of the water-level surface for this time period or to compute total storage-volume depletion for comparison.

The largest storage-volume depletion in the study area since August 1940 for the period January 1998 to January 2000 was 216,000 acre-ft in July 1998 (table 1 and fig. 11). Except for depletions due to seasonal increases in irrigation and city pumpage, storage volume since January 1998 generally has increased. This is a continuation of the storage-volume recovery that is associated with the general rise in ground-water levels that began in 1993 in the study and well field areas. Water-level rises between January 1993 and

Table 1. Storage-volume changes in *Equus* Beds aquifer in Wichita well field area, August 1940–January 2000

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

Time period	Storage-volume change, in acre-feet: Within study area	Storage-volume change, in acre-feet: Within well field area
August 1940–July 1992	-251,000	-148,000
August 1940–October 1992	-283,000	-159,000
August 1940–January 1993	-255,000	-154,000
August 1940–January 1998	-176,000	-110,000
August 1940–April 1998	-167,000	-104,000
August 1940–July 1998	-216,000	-117,000
August 1940–October 1998	-201,000	-113,000
August 1940–January 1999	-142,000	-96,300
August 1940–April 1999	-126,000	-87,000
August 1940–July 1999	-159,000	-92,700
August 1940–October 1999	-142,000	-89,300
August 1940–January 2000	-126,000	-70,600
January 1993–January 1998	[1]+79,000	[1]+44,000
January 1993–January 2000	+129,000	+83,400

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

January 2000 were as much as 21.47 ft in well 12 near the center of the well-field pumpage (fig. 18). The recovery of storage volume (in relation to August 1940) from a low of -255,000 acre-ft in January 1993 to -126,000 acre-ft in January 2000 (table 1) represents about a 51-percent recovery of storage in the study area. Water levels and storage volume in January 2000 were similar to those last seen in the late 1970's (fig. 2*C*). Figure 18 indicates that the water-level rises and resulting storage-volume recovery that occurred in the study area are closely associated with the city well field area and thus with decreases in city pumpage. Other factors such as greater-than-average precipitation (fig. 2*A*) and decreased irrigation pumpage (fig. 2*B*) in some years also contributed to the storage-volume recovery.

SUMMARY

The Wichita well field was developed in the *Equus* Beds aquifer to supply water to the city of Wichita, Kansas. On September 1, 1940, the city began pumping from 25 wells in the well field, and by 1959 there were 55 wells in use. Ground-water pumpage from the well field caused water levels to decline in a large part of the study area. Irrigation pumpage in the study area, which increased greatly in the 1970's and 1980's, contributed to declining water levels. Although most of the water-level declines can be attributed to ground-water pumpage, climatic conditions, and thus recharge to the *Equus* Beds aquifer, also have affected ground-water levels. In 1965, the city of Wichita began using water from Cheney Reservoir in addition to water from the *Equus* Beds aquifer. Since 1995 the city has been investigating the use of artificial recharge in the well field area to meet future water-supply needs and to protect the aquifer from the intrusion of saltwater from natural and anthropogenic sources to the northwest and southwest.

During 1978 to 1993, water-level declines associated with increased city and irrigation pumpage due to increased demands and drought conditions occurred in the study area. Water-level rises associated with generally greater-than-average precipitation and decreased city pumpage from the Wichita well field occurred during the period 1993 to present (2000). An important factor in the decreased city pumpage was increased reliance by Wichita on Cheney Reservoir as a water-supply source; as a result, during 1993–98, city pumpage from the well field went from being greater than one-half to about one-third of Wichita's water usage. The January 2000 water levels represent recoveries to levels similar to those in the late 1970's.

During January 2000, the direction of ground-water flow in the *Equus* Beds aquifer in the study area generally was from west to east, as has been the case since prior to development of the aquifer. The maximum water-level decline since 1940 for January 1998 to January 2000 was 36.48 ft in July 1998 in the northern part of the well field. The seasonal water-level variations in wells in the study area during the period January 1998 to January 2000 commonly were 5 to 10 ft, whereas cumulative water-level changes for the same period generally were less than 5 ft. However, during January 1998 to January 2000, seasonal water-level variations of 20 to 30 ft occurred in the northern part of the study area as a result of seasonal irrigation pumpage, renewed city pumpage, and semiconfined aquifer conditions. Cumulative water-level rises from January 1998 to January 2000 of 5 to 10 ft were common in the central and southeastern parts of the well field. These rises probably were the result of greater-than-average precipitation and decreased city pumpage due to increased reliance on water from Cheney Reservoir. Cumulative water-level declines from January 1998 to January 2000 occurred mainly in part of the extreme northern part of the well field and southwestern part of the study area; these declines probably were due to renewed city pumpage in the northern part of the well field and to irrigation pumpage in the southwestern part of the study area. Some indication of the effects of artificial recharge can be seen in wells near the Halstead recharge site. Depths to water in these wells during nonpumping periods typically have been several feet less during periods of artificial recharge than during nonpumping periods before recharge began.

The largest storage-volume change in the study area since 1940 for the period January 1998 to January 2000 was -216,000 acre-ft in July 1998. Except for depletions due to seasonal increases in irrigation and city pumpage, storage volume in the study area during January 1998 to January 2000 generally continued to recover from a low of -255,000 acre-ft in January 1993 to -126,000 acre-ft in January 2000. This represents about a 51-percent recovery of the storage-volume depletion that occurred from August 1940 to January 1993 and a recovery to volumes similar to volumes that occurred in the late 1970's. This recovery of storage volume is closely associated with decreases in city pumpage, although greater-than-average precipitation and reduced irrigation pumpage in some years also contributed to the recovery.

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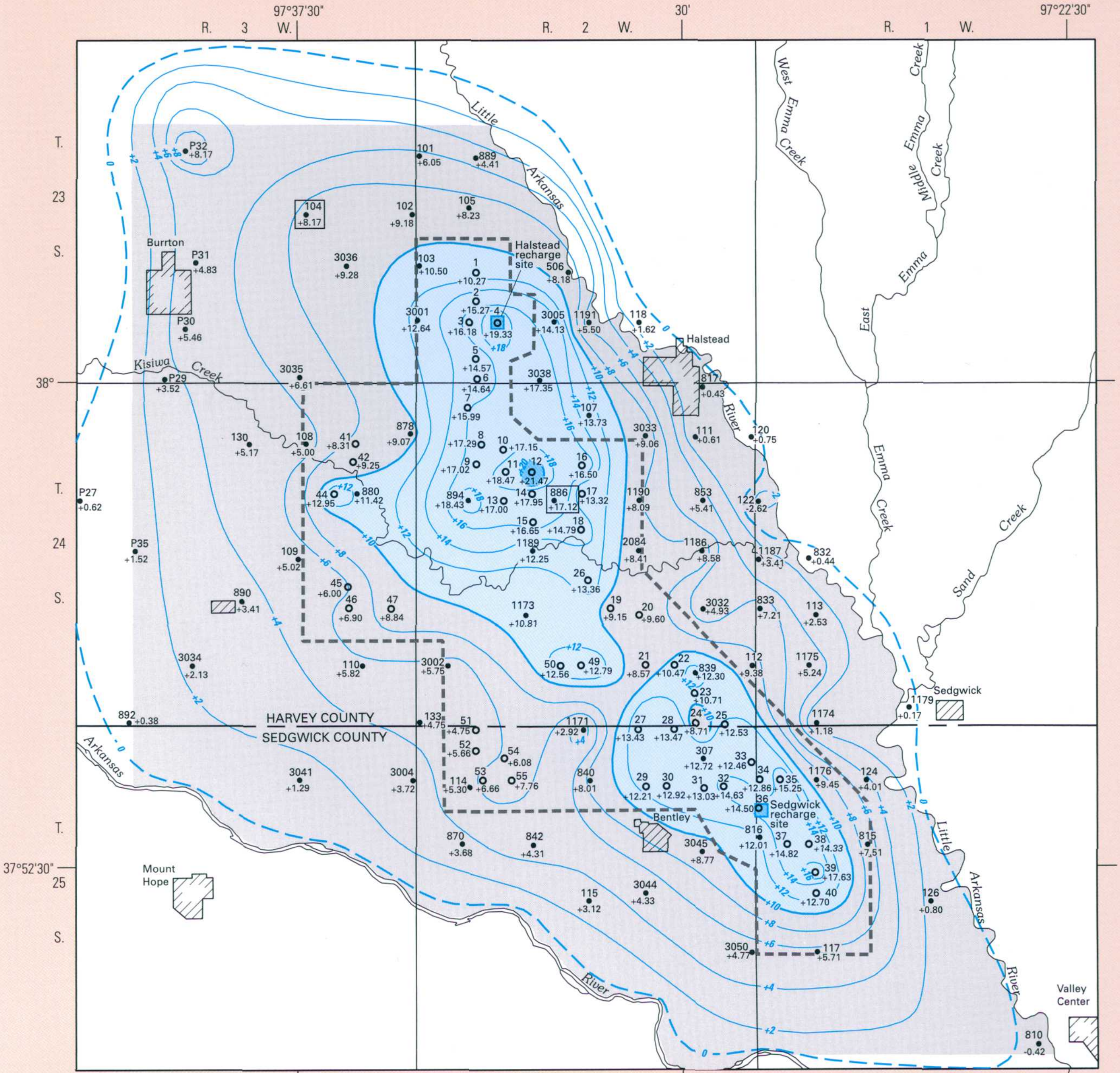

Water-level change in *Equus* Beds aquifer, January 1993–January 2000