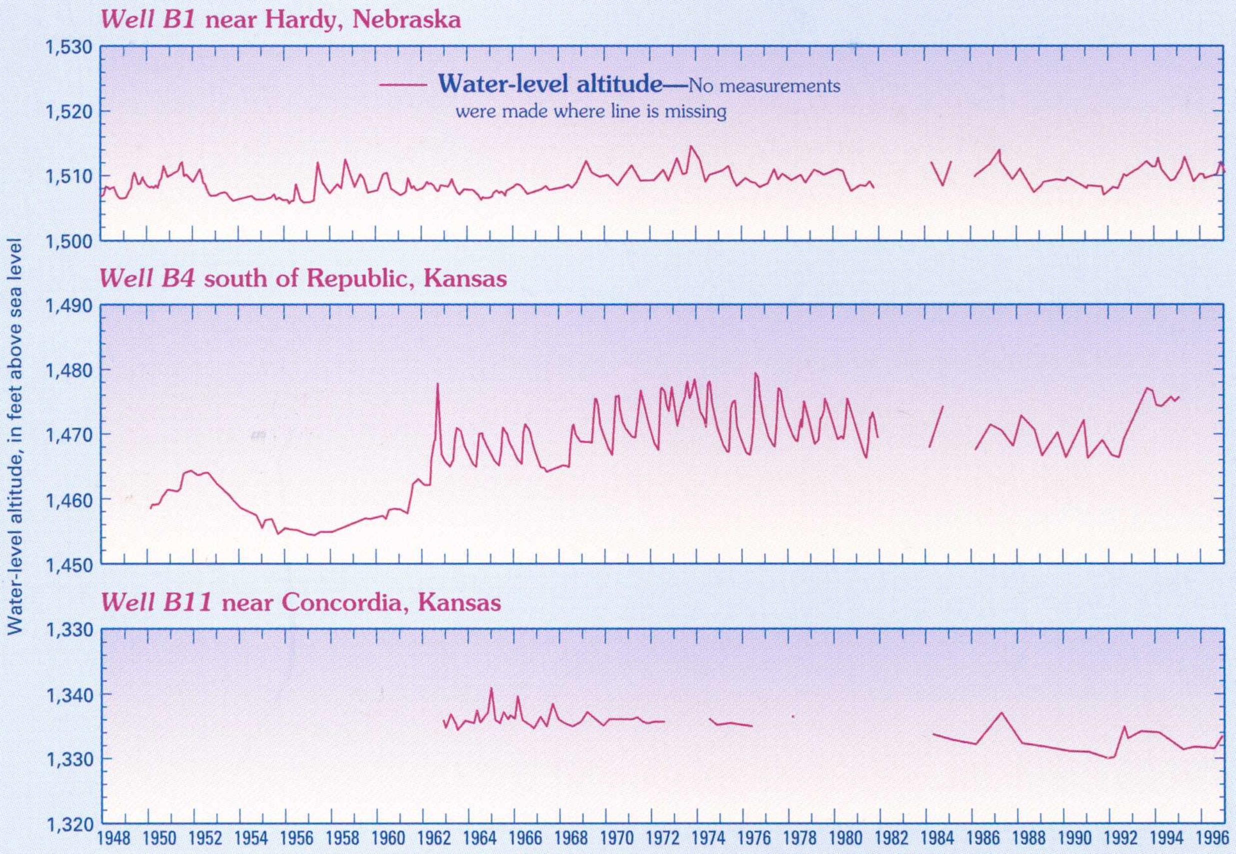
Prepared in cooperation with the
KANSAS WATER OFFICE

Water-Table Conditions, Aquifer Properties, and Streambed Permeability Along the Republican River From Near Hardy, Nebraska, to Concordia, Kansas

Water-Resources Investigations Report 98–4162



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By C.V. Hansen

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Lawrence, Kansas
1998

U.S. Department of the Interior
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per day per foot [$(ft^3/d)/ft$]	0.0929	cubic meter per day per meter
cubic foot per second (ft^3/d)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per foot (ft/ft)	0.3048	meter per meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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.

Water-Table Conditions, Aquifer Properties, and Streambed Permeability Along the Republican River From Near Hardy, Nebraska, to Concordia, Kansas

By Cristi V. Hansen

Abstract

The two principal water-bearing units in the Republican River Valley and the Kansas Bostwick Irrigation District in north-central Kansas are the alluvial aquifer in the Republican River Valley and the Grand Island Formation north of White Rock and Dry Creeks. Water-level data collected from about 130 wells during August and December 1996 were used to construct water-table maps. These maps, along with previously published water-table maps for the summer of 1942, June and July 1963, and spring 1977 and long-term hydrographs for 19 wells, were used to describe the ground-water system and changes that have occurred through time.

The water table slopes gently down the Republican River Valley from an altitude of about 1,510 feet above sea level near Hardy, Nebraska, to less than 1,350 feet near Concordia, Kansas, or about 5 feet per mile. In addition, the water table generally slopes steeply into the valley from the adjacent uplands on the east and west.

Although there are many historic and spatial gaps in the water-level data, there are no apparent large, widespread, long-term water-level declines in the alluvial aquifer despite the substantial increase in ground-water withdrawals since the 1950's. Even the large decrease in long-term Republican River flow since the completion of Harlan County Dam has not caused a large decrease in alluvial aquifer water levels. Some water-table declines may have occurred between the 1960's and 1990's in the Grand Island Formation east of the Republican River Valley and in the alluvial aquifer south of Scandia, Kansas. Most hydrographs of wells in the western upland loess deposits show an increase in water levels during the late 1950's and early 1960's that relate to the development of irrigation using imported surface water by the Kansas Bostwick Irrigation District.

Transmissivity of the alluvial aquifer in the Republican River Valley derived from 42 previously published aquifer and specific-capacity tests and 52 well-completion specific-capacity tests ranged from 260 to 44,000 feet squared per day, with a median of about 10,000 feet squared per day. Transmissivities tended to be larger in the south part of the study area and toward the middle of the valley at least in part because these areas contain coarser alluvial deposits with greater thickness.

Estimated Republican River streambed hydraulic-conductivity values ranged from 0.18 foot per day, characteristic of silt, to about 10 feet per day, characteristic of clean medium-grained sand. Streambed seepage probably tends to be less in the northern part of the study area where the vertical hydraulic conductivity is on the order of 0.1 to 1 foot per day and greater in the southern part of the study area where vertical hydraulic conductivity may approach 10 feet per day.

INTRODUCTION

Following the droughts and floods of the 1930's, the Bureau of Reclamation (BOR, U.S. Department of the Interior) and U.S. Army Corps of Engineers began construction of a series of dams and surface-water irrigation networks intended to reduce flooding and to provide water for agriculture in the Republican River Basin (U.S. Army Corps of Engineers, 1967; Bureau of Reclamation, 1985a). The Kansas Bostwick Irrigation District (KBID), whose structures were built by BOR and which began full operation during 1958, receives most of its water from requested releases from Harlan County Dam in Nebraska (fig. 1). Harlan County Dam, which was completed in November 1951, generally does not release water unless it is requested by an irrigation district or precipitation is plentiful. The releases for KBID flow down the Republican River and are diverted at Guide Rock, Nebraska, into the Courtland Canal (diversion dam completed in 1952), which transports the water to KBID north of White Rock Creek and Lovewell Reservoir in Kansas (fig. 1). Lovewell Reservoir, which was completed in September 1957, generally does not release water unless it is requested by KBID or precipitation is plentiful. Water released from Lovewell Reservoir for use by KBID is distributed by a network of canals that begin just upstream from the U.S. Geological Survey (USGS) streamflow-gaging station on White Rock Creek at Lovewell (site 2, fig. 1). The lands irrigated by KBID in the 4-year study area, which includes the drainage basin of that part of the Republican River from near Hardy, Nebraska, to Concordia, Kansas, are mainly on the uplands west of the Republican River Valley and in the valley from about 4 mi northwest of to about 6 mi south of Republic, Kansas (fig. 1).

Outside of KBID, water users depend on surface water from the Republican River or one of its tributaries, or on ground water. All the surface-water sources in the 4-year study area, even the Republican River, have been known to have zero flow during periods of scant precipitation—for example, August 9–19, 1934, at USGS streamflow-gaging stations on the Republican River near Hardy, Nebraska (site 1, fig. 1), and at Scandia, Kansas (site 3, fig. 1). Although the Republican River became a regulated stream in about 1952, at times during the 1952–57 and 1988–92 droughts the mean daily discharge of the Republican River near Hardy, Nebraska (site 1, fig. 1), at Concordia, Kansas (site 5, fig. 1), and downstream from the study area at Clay Center, Kansas (fig. 1), has been less than 20 ft^3/s (data on file with USGS in Lawrence, Kansas). This much-reduced streamflow may prevent the Republican River from being a reliable source of water for some uses during periods of drought (Hansen, 1997). Even if the streamflow in the Republican River were adequate at all times for all uses, it would not be economically feasible for most users to transport water from the river to a point of use that is more than a short distance from the river. Therefore, most water users in the 4-year study area that are not in KBID or within a short distance of the Republican River must rely on ground water as their source.

Extensive development of the ground-water resource in the 4-year study area did not begin until the 1952–57 drought (fig. 2*A*). The increase in wells seen during about 1964–72 (fig. 2*A*) are mainly large-capacity irrigation wells; this increase may be due in part to the availability of rolling sprinklers that allowed irrigation of terrain that previously was unsuitable for irrigation. An abrupt increase in the number of wells during 1975–77 (fig. 2*A*) may be due mostly to an amendment (Kansas law K.S.A. 82a–728) to the Kansas Water Appropriations Act (K.S.A. 82a–701 *et seq.*) that, beginning on May 1, 1978, made it illegal to divert water for any nondomestic purpose without a water-appropriation permit from the Kansas Department of Agriculture, Division of Water Resources (DWR) (Lane Letourneau, Division of Water Resources, written commun., 1997) and partly to moderate drought conditions during 1975–76.

In 1991, during the drought of 1988–92, flow in the Republican River decreased below the minimum desirable streamflow (MDS) requirement at Concordia, Kansas (established by Kansas law K.S.A. 82a–703a); this caused the DWR to attempt to increase the amount of streamflow in the Republican River by prohibiting about 100 junior permit holders from pumping water from the streams and hydraulically connected alluvium in the Republican River Valley in Cloud, Jewell, and Republic Counties during January through June 1992.

DWR instituted a moratorium on permits for new ground- and surface-water diversions in the Republican River Valley beginning in March 1990 because of concern regarding Republican River flow. Although the moratorium ended in April 1993 when new basin-wide water-appropriation regulations for the Republican River [K.A.R. 5–3–11 (b) (9)] went into effect, no

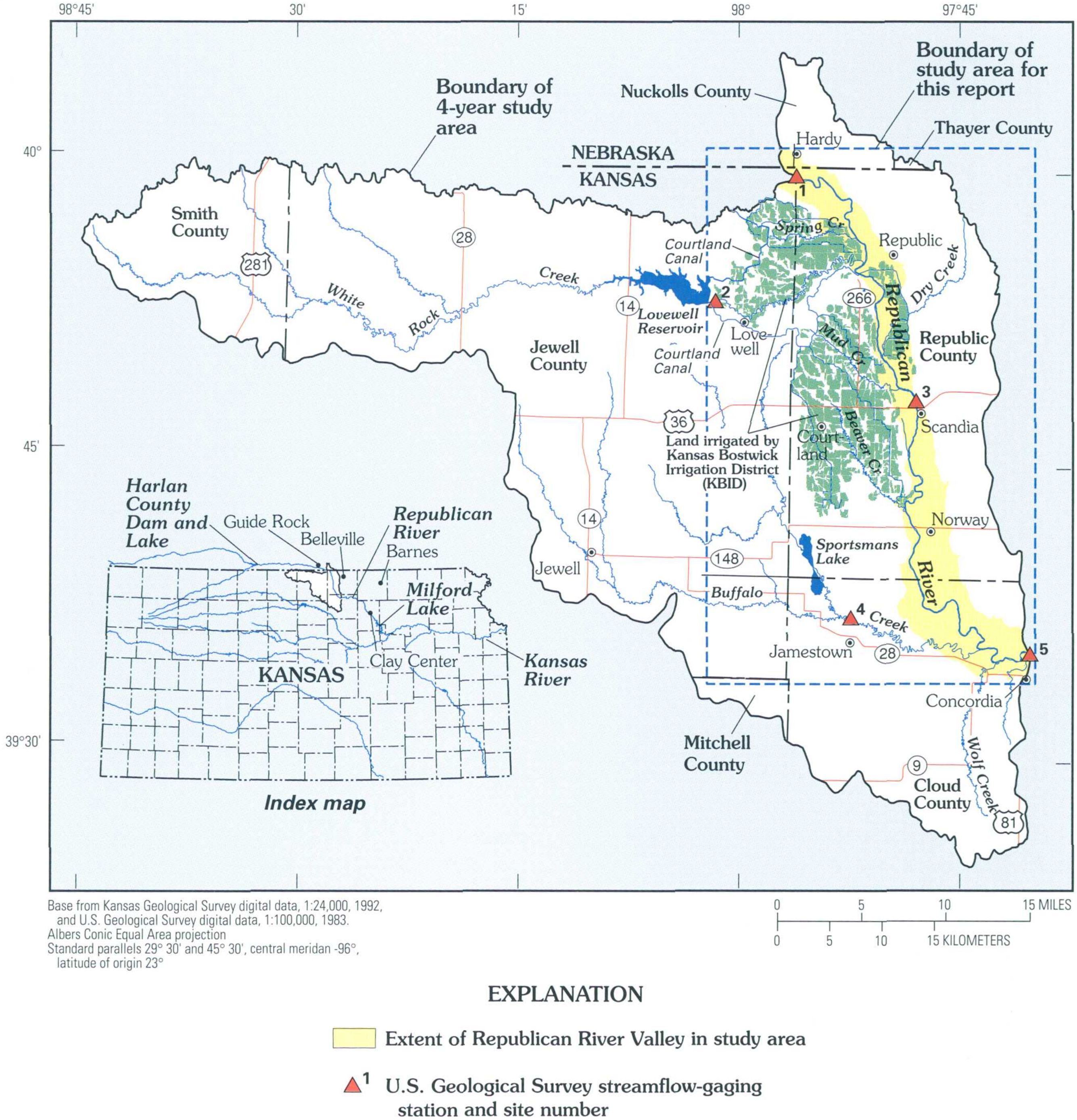


Figure 1. Location of study area.

new permits have been approved since then because, according to these new regulations, all ground and surface water in the Republican River Valley was already fully appropriated (Matt Scherer, Division of Water Resources, written commun., 1998).

These circumstances were accompanied by increasing concern about water resources of the area. In 1994, a 4-year study was begun to identify and quantify the interaction of the surface- and ground-water systems within the Republican River Valley from near Hardy, Nebraska, to Concordia, Kansas (fig. 1), especially during drought conditions similar to those of March 1988 through June 1992. The results of this study are intended to improve the understand-

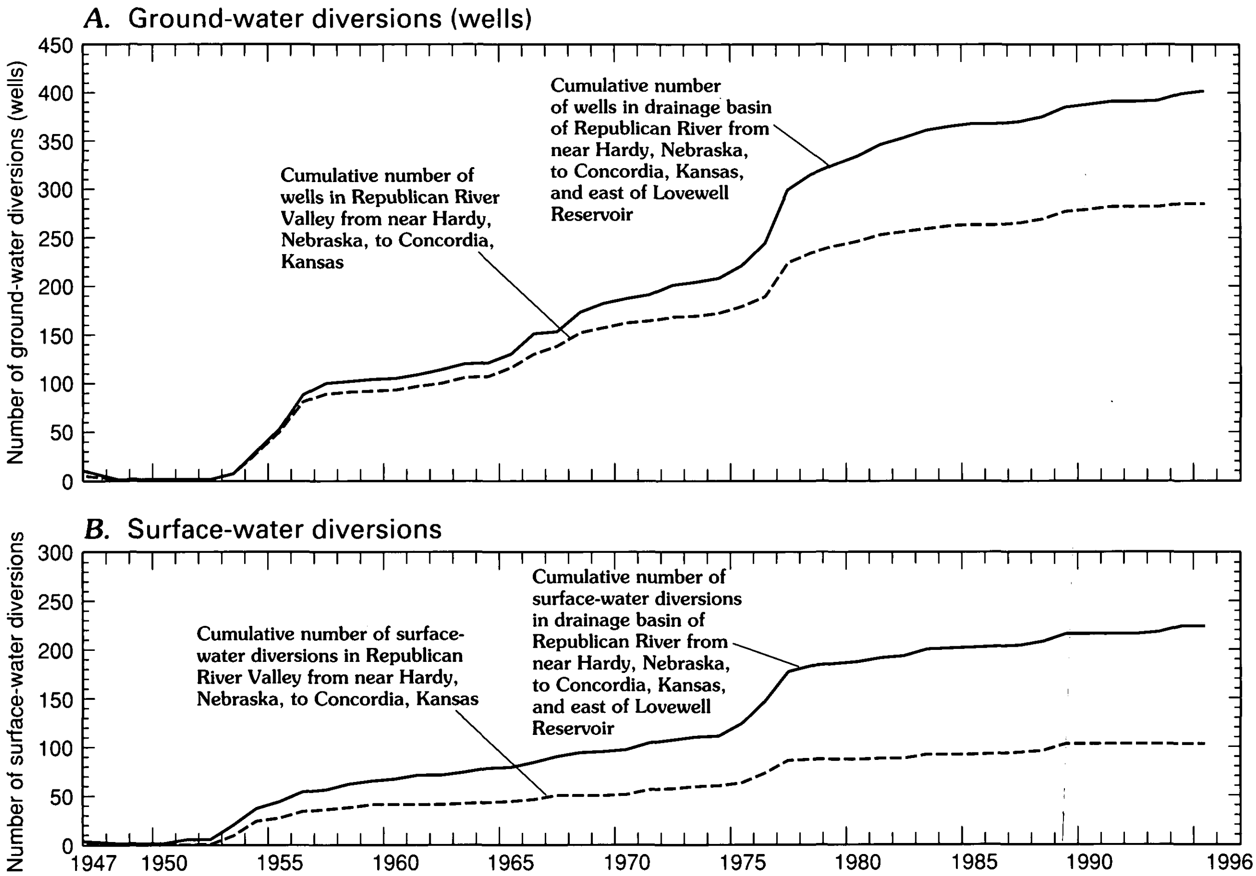


Figure 2. Cumulative number of *(A)* ground- and *(B)* surface-water diversions in the drainage basin and valley of the Republican River from near Hardy, Nebraska, to Concordia, Kansas, 1947–95 (based on diversion data from Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas).

ing of how both the surface- and ground-water systems affect the amount of streamflow in the Republican River. This study was performed by the USGS in cooperation with the Kansas Water Office (KWO) and was supported in part by the Kansas State Water Plan Fund.

Part of the 4-year study addressed the condition of the water table, the alluvial aquifer, and other aquifers along the Republican River Valley. The most recent hydrologic studies in the vicinity of the 4-year study area (Missouri Basin States Association, 1982; Bureau of Reclamation, 1985, 1996; Spruill, 1985) depended on data that now (1998) are about 20 to 35 years old (Fader, 1968; Dunlap, 1982). Although some ground-water-level data are collected on a regular basis in KBID by KBID and in an area of about 80 mi^2 north of the city of Republic (fig. 1) by DWR, no coordinated, systematic collection of ground-water-level data for the entire area in the vicinity of the Republican River from near Hardy, Nebraska, to Concordia, Kansas, has been done since 1977. New ground-water-level and aquifer-properties data collected or estimated throughout this area can be used to define current conditions and compared with data from earlier studies to identify areas and changes in conditions that may have occurred since the previous studies.

Purpose and Scope

The purpose of this report is to document seasonal and long-term changes in water-table conditions along the Republican River in the study area. In addition, information is included in this report on selected properties of the alluvial aquifer in the Republican River Valley and on streambed permeability of the Republican River in the study area.

Ground-water-level data collected for this study during August and December 1996 were used to define recent water-table conditions; some data from outside the Republican River Valley were collected and used to improve the definition of the water table in the alluvial aquifer. The water-table maps constructed from the data collected during 1996 were compared with those from previously published reports to identify changes in conditions that have occurred; long-term water-table hydrographs were used as supplements to the water-table maps for describing and interpreting the changes seen in the maps.

Specific-capacity data and previously published aquifer tests were used to estimate the transmissivity of the alluvial aquifer. Data on the permeability of the streambed of the Republican River were collected during this study at the same time as the ground-water levels in August and December 1996.

Description of Study Area

The area for the 4-year study includes that part of the Republican River drainage basin between the USGS streamflow-gaging stations near Hardy, Nebraska, and at Concordia, Kansas (fig. 1); the drainage area is about 1,155 mi^2. The study area for this report is much smaller, about 494 mi^2, and is limited to those parts of the 4-year study area in eastern Jewell, western Republic, and northwestern Cloud Counties in Kansas and extreme southeastern Nuckolls County and southwestern Thayer County in Nebraska (fig. 1). The study area for this report includes the Republican River Valley, the uplands east of the valley, and the part of the uplands west of the valley and east of Lovewell Reservoir where the KBID exists (fig. 1).

The study area is in the Plains Border section of the Great Plains physiographic province, which is characterized by submature to mature dissected plateaus (Fenneman, 1931). The major geographic features in the study area are the Republican River, its valley, and the flat to gently rolling uplands that are to the east and west of the valley and about 200 to 250 ft above the valley floor. The Republican River in the study area is 42.7 mi long between the gaging stations near Hardy, Nebraska, and at Concordia, Kansas. The valley in the study area is about 34 mi long and about 1.2 to 4.5 mi wide. White Rock and Buffalo Creeks (fig. 1) are the two main tributaries in the study area; other important tributaries are Spring, Mud, Beaver, and Wolf Creeks (from north to south) west of the Republican River and Dry Creek east of the river (fig. 1). Lovewell Reservoir on White Rock Creek is used for storage of irrigation water, flood control, and recreation. Sportsmans Lake (fig. 1), which drains into Buffalo Creek, is regulated by the Kansas Department of Wildlife and Parks for use by waterfowl and for recreation. About 40,000 irrigable acres are within the KBID in the study area; however, not all acres are irrigated every year.

Climate is of great importance in the study area as most of the area's economy is dependent on raising crops and livestock. The climate of the study area is subhumid (Kansas Water Resources Board, 1961, p. 27). Precipitation in the study area is quite variable; recorded annual precipitation at the long-term weather station at Belleville, Kansas, has varied from 12.49 in. in 1934 to 55.06 in. in 1993 with an annual average (1931–96) of 29.66 in. (National Climatic Data Center, 1997b) (fig. 3*A*). This variability and lack of precipitation during some years (fig. 3A) have led to poor crop yields or crop failures in the study area. The increased availability of water for irrigation due to developments such as the operation of the KBID, rolling sprinkler systems, and larger, more efficient pumps, has moderated, but not eliminated, many of the adverse effects of drought on the local economy.

The largest yielding water-bearing units in the study area are the Quaternary-age alluvial aquifer in the Republican River Valley and the Pleistocene-age Grand Island Formation north of White Rock and Dry Creeks (table 1, fig. 4). Although generally not capable of yielding water in quantities as large as these major water-bearing units, the Pleistocene-age loess deposits beneath the KBID on the uplands west of the Republican River Valley and the Cretaceous-age bedrock units are important because of their effect on the overlying ground-water system.

The alluvial and terrace deposits of Pleistocene and Holocene age, collectively referred to in this report as the alluvial aquifer, consist of unconsolidated clay, silt, coarse sand, and medium-to-coarse gravel (table 1); these deposits generally become coarser with depth. The Pleistocene-age alluvial and terrace deposits were laid down in channels eroded into the bedrock in the valleys of the Republican River and its major tributaries (fig. 4). The Holocene-age alluvium was laid down in channels eroded into the Pleistocene-age deposits. The alluvial aquifer is a major source of municipal and irrigation water because it can support large-capacity wells; yields of as much as 2,000 gal/min of water have been reported by well drillers (water-well drillers' logs on file with the Kansas Geological Survey, Lawrence, Kansas). Most of the large-capacity wells in the alluvial aquifer are

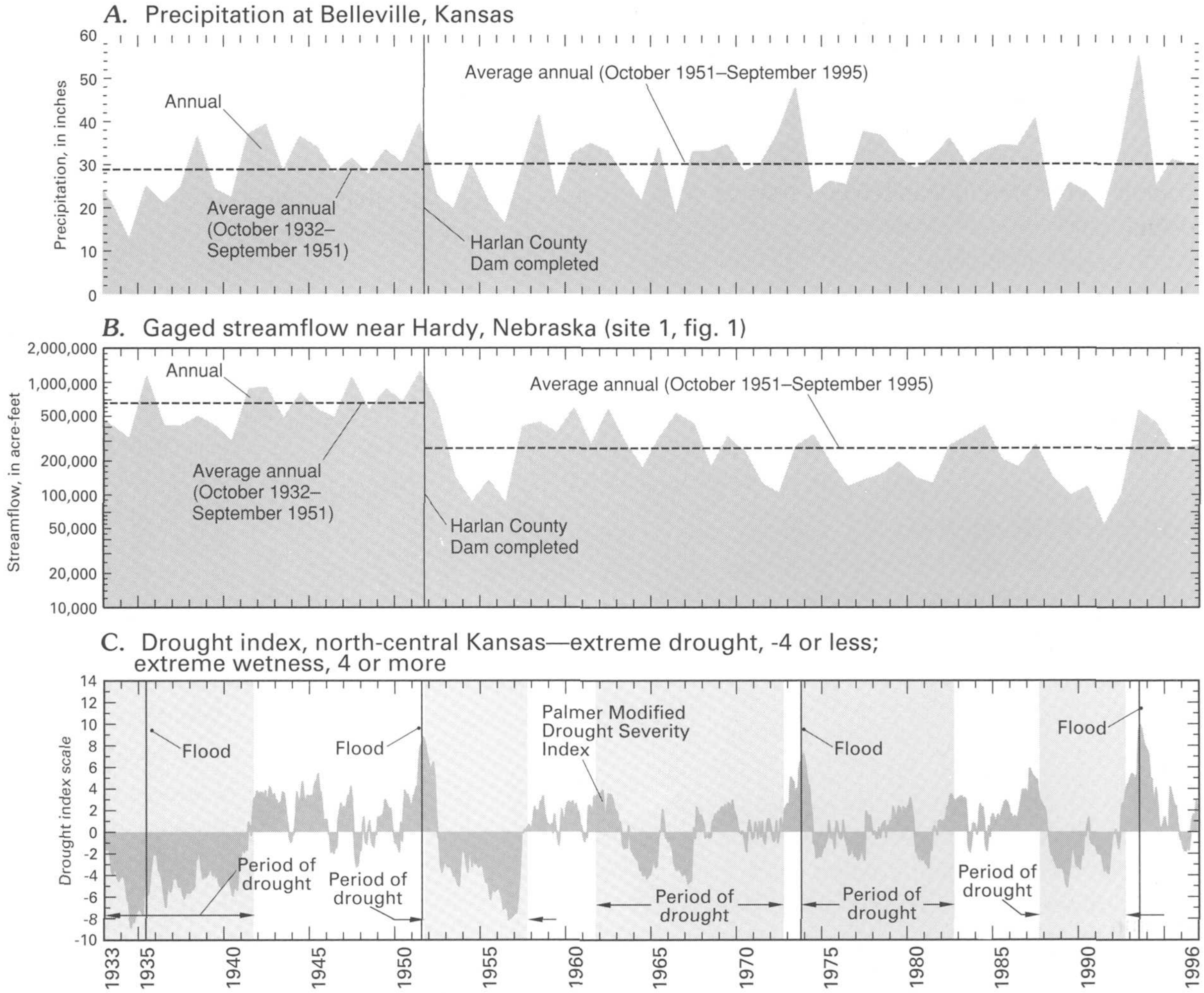


Figure 3. *(A)* Precipitation at Belleville, Kansas, *(B)* gaged streamflow near Hardy, Nebraska, and *(C)* periods of significant droughts and floods in north-central Kansas, 1933–96 (sources: *A*, precipitation data from National Climatic Data Center, 1997b; *B*, streamflow data from U.S. Geological Survey, Lawrence, Kansas, 1997; *C*, droughts and floods from Clement, 1991, and drought indices from National Climatic Data Center, 1997a).

where the KBID is not present, especially in the part of the alluvial aquifer south of Scandia.

The Grand Island Formation, which is also referred to as the Belleville Formation in the study area, consists of unconsolidated Pleistocene-age coarse sand and medium-to-coarse gravel interbedded with silt and clay that were deposited in a channel eroded into the bedrock by the northeastward-flowing ancestral Republican River in northern Jewell and northwestern Republic Counties (Fishel, 1948; Fishel and Leonard, 1955) (table 1). Erosion has removed part or all of these deposits in the present Republican River Valley. The Grand Island Formation can support large-capacity wells; Fishel (1948) and Fader (1968) reported well yields of 2,000 and 1,400 gal/min, respectively, from the Grand Island Formation.

The uplands in the study area, including most of the area in the KBID, are blanketed by a layer of loess; some minor amounts of fluvial deposits are also present in the upland loess deposits (table 1, fig. 4). Most of the upland loess deposits consist of unconsolidated silt and clay with minor amounts of fine sand and gravel of Quaternary age. In most places, the upland loess deposits are above the water table and are unsaturated; however, where these deposits are saturated, as they are in much of the KBID, wells may yield small quantities of water (Bureau of Reclamation, 1985 a,b,c). Water in the upland loess beneath the KBID generally is perched because in most places the base of the loess deposits are about 100 ft above the alluvial aquifer in the Republican River Valley and are underlain by relatively impermeable rocks of Cretaceous age (table 1, fig. 5).

Table 1. Generalized section of geologic units in study area and their hydrologic characteristics (modified from Fader, 1968; Bureau of Reclamation, 1985 a,b,c)

System	Series	Rock unit	Terms used in this report	Maximum thickness (feet)	Physical character	Water supply
Quaternary	Holocene	Alluvium	Alluvial aquifer	130	Unconsolidated clay, silt, sand, and gravel occurring along major streams.	Yields small to large quantities of water depending on thickness of deposits.
	Pleistocene	Undifferentiated alluvial and terrace deposits		125	Clay, silt, sand, and gravel, stream deposited; coarser materials generally in lower part of deposit.	Yields large quantities of water to wells.
		Undifferentiated eolian and fluvial deposits	Upland loess deposits	100	Loess, silt, clay, and minor amounts of sand and gravel of eolian and fluvial origin. Mantles upland areas.	Most of the deposits lie above the water table. Yields small quantities of water to wells where saturated.
		Grand Island Formation	Grand Island Formation (Belleville Formation)	120	Cross-bedded, locally derived sand and gravel. In buried river channel of ancestral Republican River in northern Jewell and northwestern Republic Counties.	Yields moderate to large quantities of water to wells.
Cretaceous	Upper	Niobrara Formation	Bedrock	400	Light- to dark-gray chalk and chalky shale. Bentonite beds occur throughout.	Relatively impermeable. May yield very small quantities of water from secondary openings (fractures, faults, and so forth).
		Carlile Shale		300	Clayey and chalky shale, chalky limestone, and thin sandy zone at top.	Yields little or no water to wells.
		Greenhorn Limestone		90	Alternating beds of calcareous shale and chalky limstone. Thin bentonite beds at bottom.	Yields little or no water to wells.
		Graneros Shale		40	Noncalcareous fissile shale and clay.	Yields little or no water to wells.
	Lower	Dakota Formation		350	Clay, shale, silt, and sandstone. Sandstone is lenticular and may exhibit cross bedding.	Yields small to large quantities of water to wells. High chloride content locally and in lower part of unit.

Below the unconsolidated Quaternary-age deposits are shale, chalk, limestone, and sandstone of Cretaceous age (table 1, fig. 5). These rocks generally crop out where erosion has removed the overlying Quaternary-age deposits, which is mainly along the edges of the valleys of the Republican River and its tributaries, with progressively older rocks at or near the surface from northwest to southeast. The Cretaceous-age rocks, collectively referred to as bedrock in this report, are relatively impermeable when compared with the Quaternary-age deposits above them. The bedrock generally yields little or no water to wells, although the Dakota Formation may yield large quantities of water to wells where the sandstone lenses are coarser

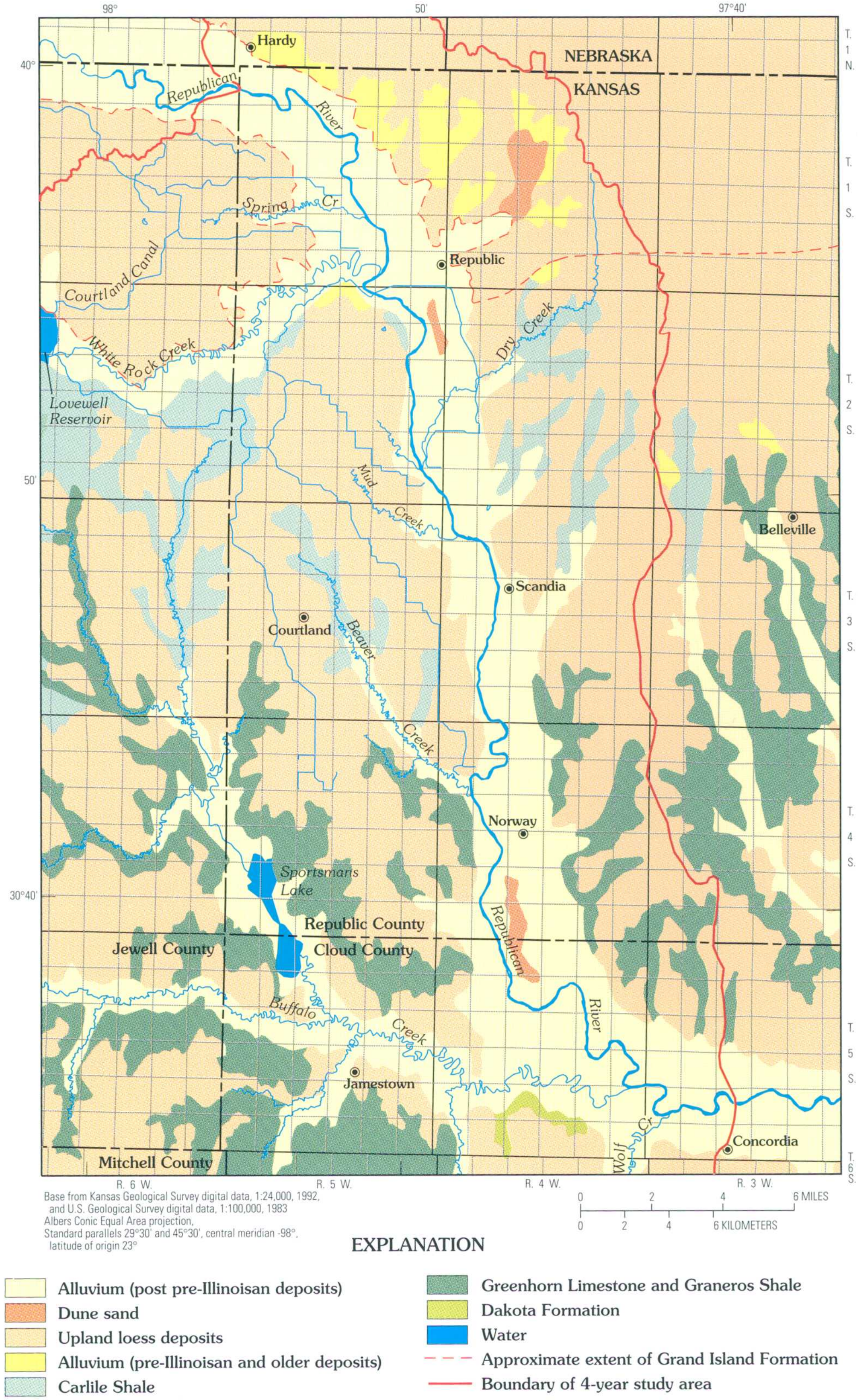


Figure 4. Generalized near-surface geology of study area (surficial geology modified from 1992 digitized version of Ross, 1991; extent of Grand Island Formation modified from Bureau of Reclamation, 1985c, plate 1, and Kansas State Board of Agriculture, Division of Water Resources Administrative Policy and Procedure No. 90–6, as amended March 9, 1993).

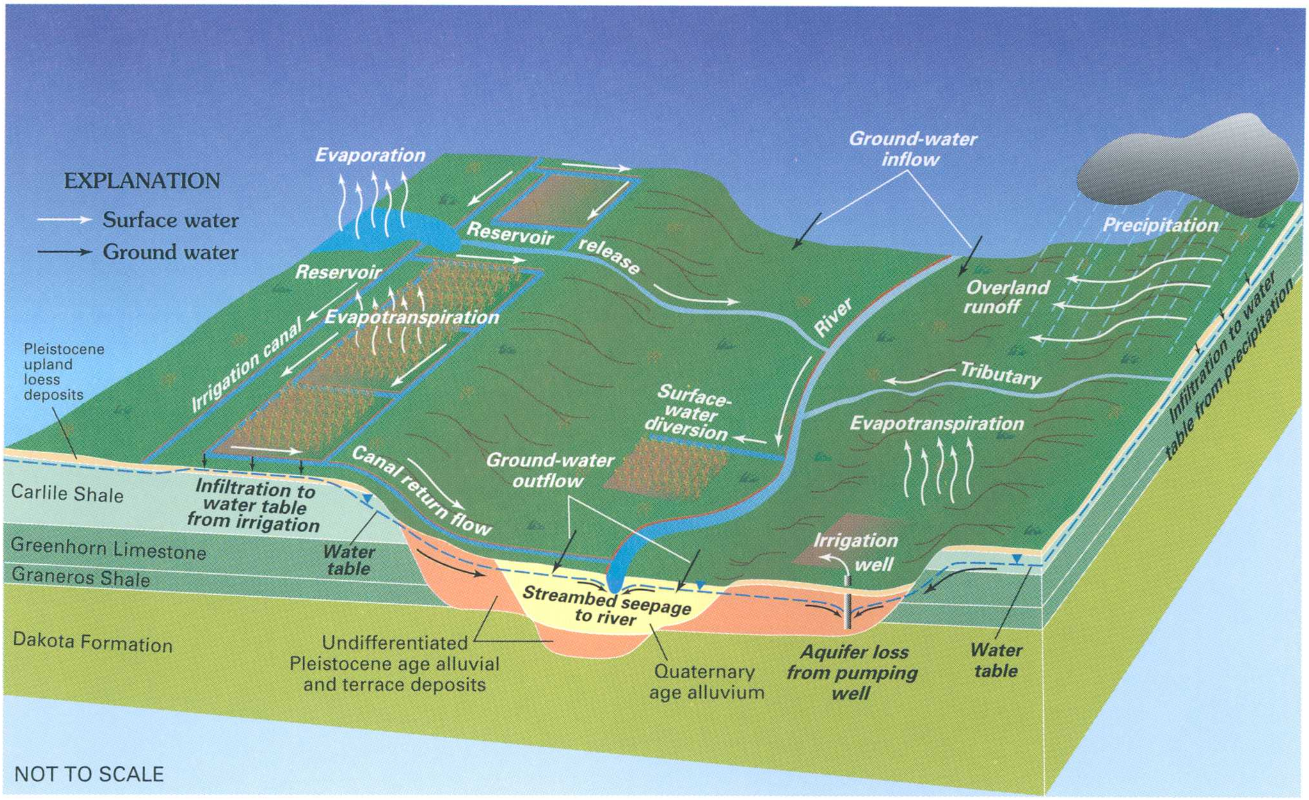


Figure 5. Hydrologic system in study area.

grained and less well cemented (Bureau of Reclamation, 1985a,b,c). The quality of water in the bedrock can range from suitable to unsuitable for most uses, with suitable water generally available where the bedrock is at or near the surface (Bureau of Reclamation, 1985a,b,c). Unsuitable water from the Dakota Formation has infiltrated into the alluvial aquifer in northwestern Cloud County, causing some wells to be abandoned (Fader, 1968) and restricting development of large-capacity wells in the area.

Within the study area, precipitation is the main source of water to the hydrologic system. Precipitation may fall directly into surface-water bodies; move by overland flow into tributaries, canals, or the Republican River; or infiltrate into the ground where it may be used by plants or continue down to the water table (fig. 5). Evaporation from water bodies and the land surface and evapotranspiration by plants remove water from the hydrologic system within the study area.

Within parts of the study area, there can be movement of water (interaction) between the ground- and surface-water parts of the hydrologic system. Most of this interaction takes place along the Republican River, although similar situations on a smaller scale can occur along the tributaries and canals in the study area. Usually the Republican River is a gaining stream—that is, the ground water flows into the river from the alluvial aquifer because the water table is higher than the water level in the stream (fig. 5). At times, this situation may be reversed, and the Republican River becomes a losing stream—that is, water flows from the river to the alluvial aquifer because the water table in the aquifer is lower than the water level in the river. This situation generally occurs mostly during periods of high streamflow but also can occur during extreme low-flow periods.

Well-Numbering Systems

The data used in this report came from a variety of sources, each of which uses a modification of the Bureau of Land Management's system of land subdivision. Figure 6 shows the two systems used for the data presented in this report—one for USGS and BOR data bases and one for water-well drillers' logs. In Kansas, all townships are referenced as south of the Kansas-Nebraska State line, all ranges are referenced as east or west of the sixth principal meridian (approximately 97°20'), and all sections are numbered

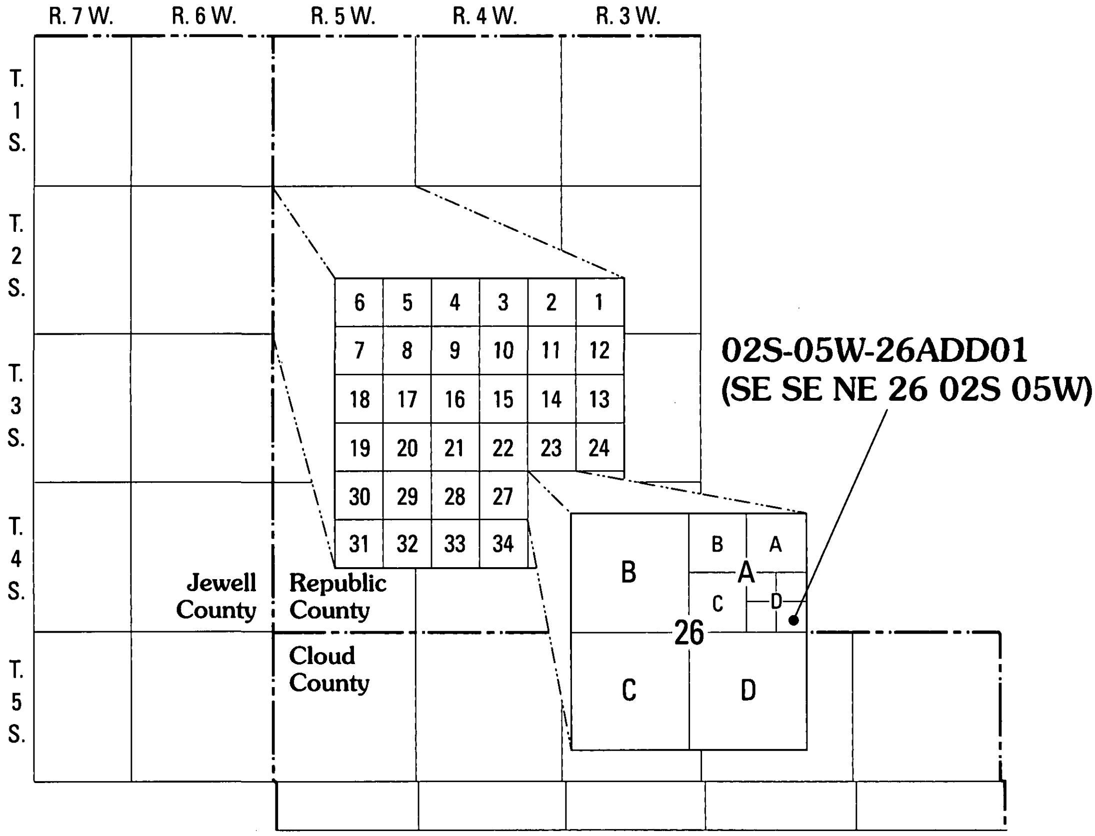


Figure 6. Well-numbering systems. The well shown is the first well inventoried in SE1/4SE1/4NE1/4 sec. 26, T. 2 S., R. 5 W., or, using an abbreviated description from water-well drillers' logs, SE SE NE 26 02S 05W.

between 1 and 36 and follow the standard pattern shown in figure 6. The USGS and BOR data bases add a two-digit sequence number to the well identification.

Previous Studies

During the last 70 years, there have been many reports published on the geology and hydrology of all or parts of the study area. The geology of the study area was originally described in reports for Cloud and Republic Counties by Wing (1930) and for Jewell County by Fishel and Leonard (1955); the description of the geology of Cloud County was enhanced by Bayne and Walters (1959). Wing (1930) included short sections on the availability of ground- and surface-water supplies in Cloud and Republic Counties.

The ground-water system in the study area before major ground-water development, which began in 1952, was described for Republic and northern Cloud County by Fishel (1948) and for Jewell County by Fishel and Leonard (1955). Bayne and Walters (1959) updated the description of the ground-water system for all of Cloud County to the period between the beginning of major ground-water development and the beginning of full operation of the KBID in 1958.

Concerns about the ground- and surface-water resources in the lower Republican River Basin in Kansas were discussed in a 1961 report by the Kansas Water Resources Board (1961). Fader (1968) updated the description of the ground-water system to conditions in the early 1960's for the parts of northern Cloud, eastern Jewell, and western Republic Counties that are in or near the Republican River Valley. The ground-water system for the entire Republican River Basin was described under 1977–78 conditions by Dunlap (1982). Spruill (1985) described the condition of the surface-water system in 1982 for part of the Republican River Valley that is in Kansas and upstream from Norway. In 1994, under contract to KWO, Water Resources Management, Inc. (1994) completed a study of stream depletion in the surface-water system of the lower Republican River.

Since 1981, there have been several comprehensive studies of the Republican River Basin that include the study area. In 1982, the Missouri Basin States Association (1982a,b) made a comprehensive study of the surface- and ground-water systems in the Missouri Basin. BOR has completed two comprehensive studies—the first, in 1985, was a water-management study of the ground- and surface-water systems of the Republican River Basin that included the results of a numerical ground-water flow model (Bureau of Reclamation, 1985a,b,c); the second, in 1996, was a resource-management study of the ground- and surface-water systems in the Republican River Basin that emphasized the part of the surface-water system administered by BOR (Bureau of Reclamation, 1996).

Although they are not compiled and published in a formal report, several agencies have collected ground-water-level data in the study area; some of these data have been used in the studies previously mentioned. BOR, with the assistance of KBID, has been collecting ground-water-level data within the KBID on a periodic basis since about 1955. From about 1950 to about 1978, BOR collected ground-water-level data on a periodic basis in their formerly proposed Scandia Unit (surface-water irrigation district), which was in the Republican River Valley between Scandia and Concordia, Kansas. Few, if any, water levels have been measured in the Republican River Valley south of Scandia during the last 20 years. On a periodic basis since about 1992, the DWR has been collecting ground-water-level data in the Grand Island Formation in northwestern Republic and northeastern Jewell Counties.

Acknowledgments

Several agencies provided data used in this study. KBID provided data about water use and discharge from the irrigation district during 1975–95, a map of the extent of the irrigation district, and explained and clarified how the irrigation district operates. BOR provided water-level measurements and well data for the monitoring wells in the KBID area and the formerly proposed Scandia Unit, and water-use and discharge data from KBID during 1958–75. DWR provided annual water-use data for ground- and surface-water diversions in Kansas. Also used were water-well drillers' logs filed with the Kansas Department of Health and Environment and the Kansas Geological Survey during 1975–95. David Leib and Thomas Stiles of KWO periodically reviewed the study results and offered helpful suggestions.

WATER-TABLE CONDITIONS

Hydrographs of water-table wells located along two sections in the study area are presented in figures 7 and 8, with the traces of the sections shown in figure 9. These hydrographs were created from water-level measurements made by BOR, DWR, or USGS in 19 water-table wells in or near the Republican River Valley and the KBID in the uplands west of the valley. These 19 wells were selected from about 500 wells as those with the longest and most complete records that also best illustrate long-term water-table conditions in the Republican River Valley and in the uplands west of the valley. The frequency of measurements varied from well to well and from year to year, and not all wells were measured in all years.

The water-table maps presented in this report consist of three previously published maps (figs. 9–11) for summer 1942 (Fishel, 1948), June and July 1963 (Fader, 1968), and spring 1977 (Dunlap, 1982) and two maps constructed for this study (figs. 12 and 13) using water-level data collected during August 5–8 and December 9–11, 1996. The summer 1942 and June and July 1963 water-table maps are published at a scale of 1:126,720 (2 mi = 1 in.), are based on a relatively large number of data points, and have a 10-ft contour interval; the August and December 1996 maps also were constructed at this scale with a 10-ft contour interval. The spring 1977 water-table map is published at a scale of 1:250,000, is based on relatively few data points, and has more generalized contours with a 20-ft contour interval. Some of the apparent differences between maps may be due more to the differences in data density, contour interval, and original map scale than to real changes in water table. Also, the authors of water-table maps prior to 1996 may not have used or had available the U.S. Geological Survey's Concordia and Smith Center 1:100,000-scale topographic quadrangles to guide the shape and location of the water-table contours.

The August and December 1996 water-table maps were constructed from ground-water levels measured in approximately 130 existing water wells in or near the Republican River Valley in the study area. Where possible, wells used in previous studies (Fishel, 1948; Fader, 1968; Dunlap, 1982) or already in the USGS National Water Information System (NWIS) were selected for measurement. Unfortunately, most wells

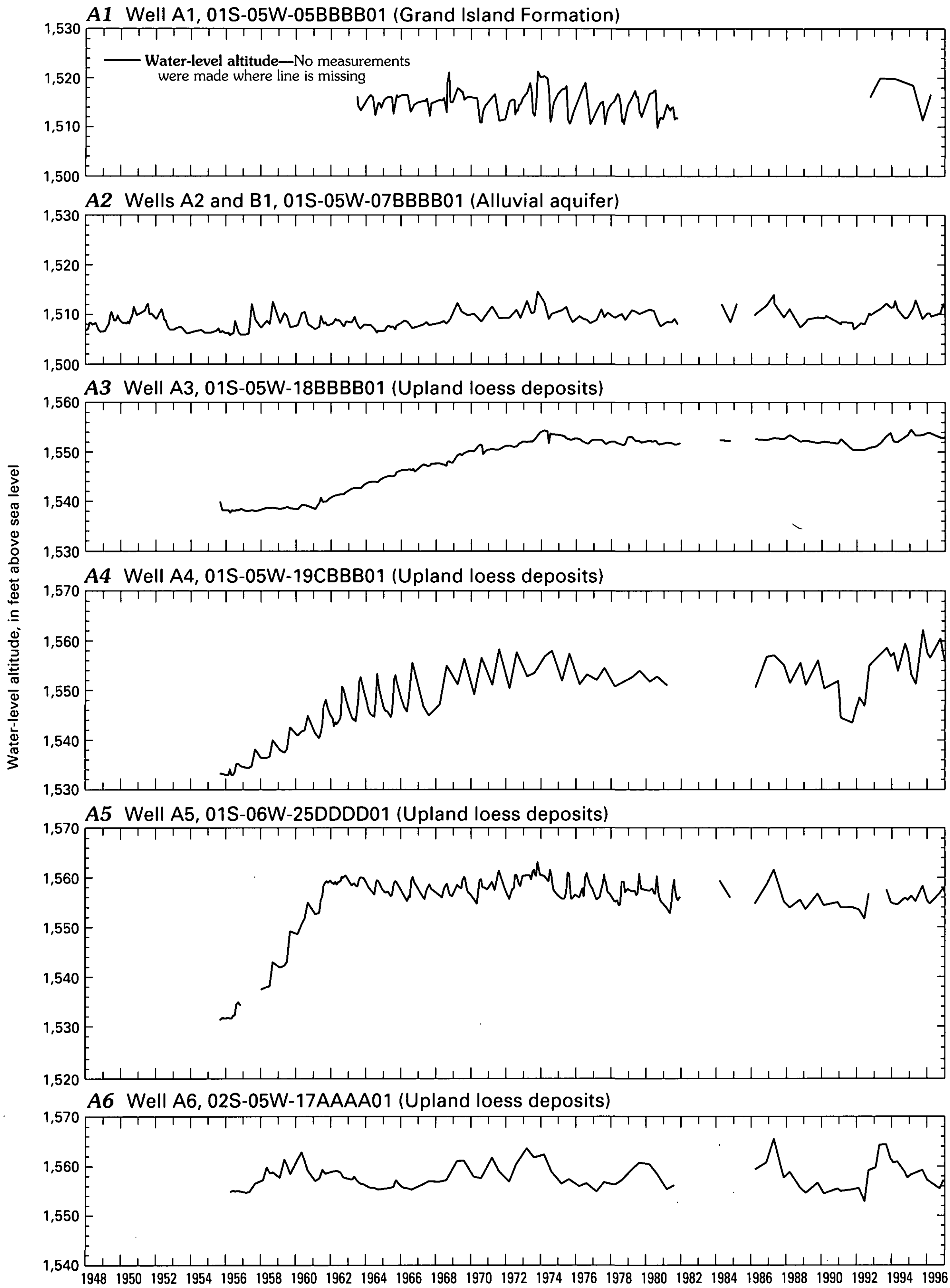


Figure 7. Water-table hydrographs along section *A–A'* through the Kansas Bostwick Irrigation District (data from Bureau of Reclamation, Grand Island, Nebraska; U.S. Geological Survey, Lawrence, Kansas; and Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas). Location of wells shown in figure 9.

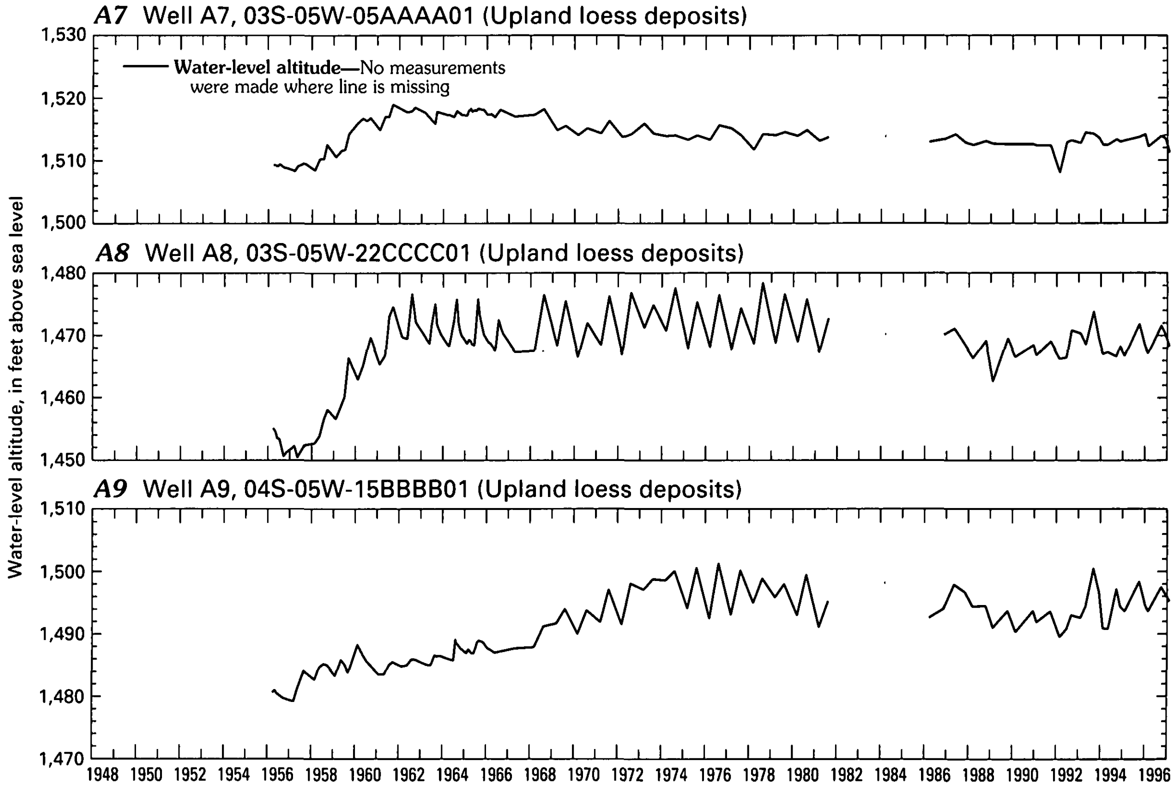


Figure 7. Water-table hydrographs along section *A–A′* through the Kansas Bostwick Irrigation District (data from Bureau of Reclamation, Grand Island, Nebraska; U.S. Geological Survey, Lawrence, Kansas; and Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas)—Continued. Location of wells shown in figure 9.

with previously published data or with data in NWIS could not be measured in 1996, with the exception of KBID and DWR monitoring wells. Monitoring, irrigation, or public-supply wells were selected in preference to other types of wells because their construction and use generally allow for easier access and accurate measurements. Not all of the selected wells could be accessed during each measurement period. Standard methods (U.S. Geological Survey, 1980) were used to measure the depth to water and to the bottom of each well. The contours of the U.S. Geological Survey's Concordia and Smith Center 1:100,000-scale topographic quadrangles were used to guide the shape and location of the August and December 1996 water-table contours.

Summer 1942

The water-table map for summer 1942 (fig. 9; Fishel, 1948, plate 8) is thought to reflect predevelopment conditions—that is, conditions before regulation of the river, development of large-scale surface-water irrigation, and installation of large-capacity irrigation wells. The data used for this map are almost exclusively from domestic and stock wells and test holes; only one irrigation well was used to construct the map (Fishel, 1948); most of the water levels were measured in June and July 1942. The drought of 1929–41 (Clement, 1991; fig. 3*C*) ended the year before the ground-water levels used to construct this map were measured. During 1942, precipitation was above the long-term (October 1931–September 1951) average for the period before the completion of Harlan County Dam in late 1951 (fig. 3*A*). Streamflow in the Republican River near Hardy, Nebraska, also was slightly above the long-term average (October 1931–September 1951) (fig. 3*B*).

The water table slopes gently down the valley from an altitude of about 1,510 ft above sea level near Hardy, Nebraska, to less than 1,350 ft near Concordia, Kansas, or about 5 ft/mi (fig. 9). In addition, the water table slopes steeply into the valley from the adjacent uplands on the east and west, and a water-table divide is shown by the 1,520-ft contour northeast of the valley near the city of Republic. The more pronounced

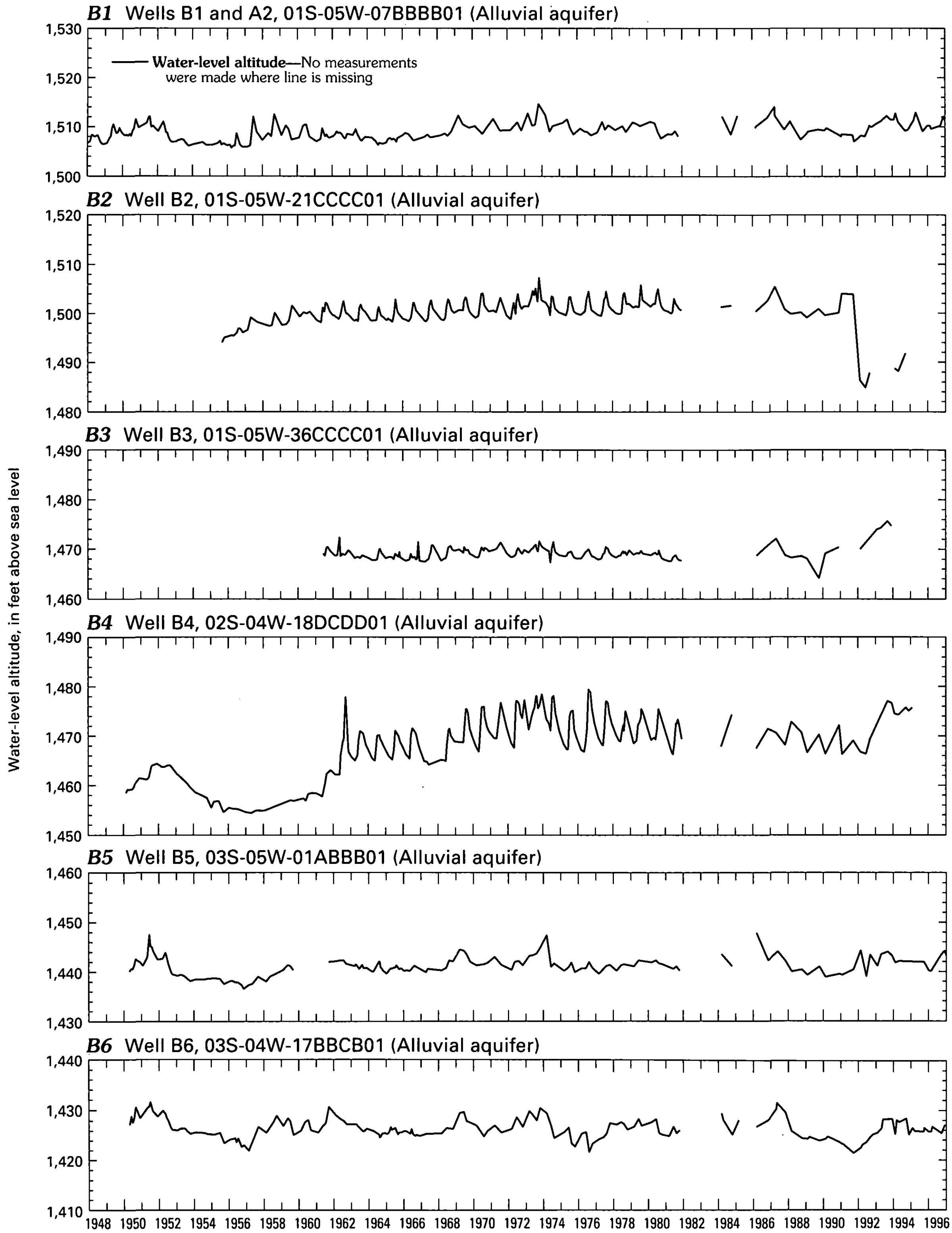


Figure 8. Water-table hydrographs along *B–B'* in the Republican River Valley (data from Bureau of Reclamation, Grand Island, Nebraska; U.S. Geological Survey, Lawrence, Kansas; and Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas). Location of wells shown in figure 9.

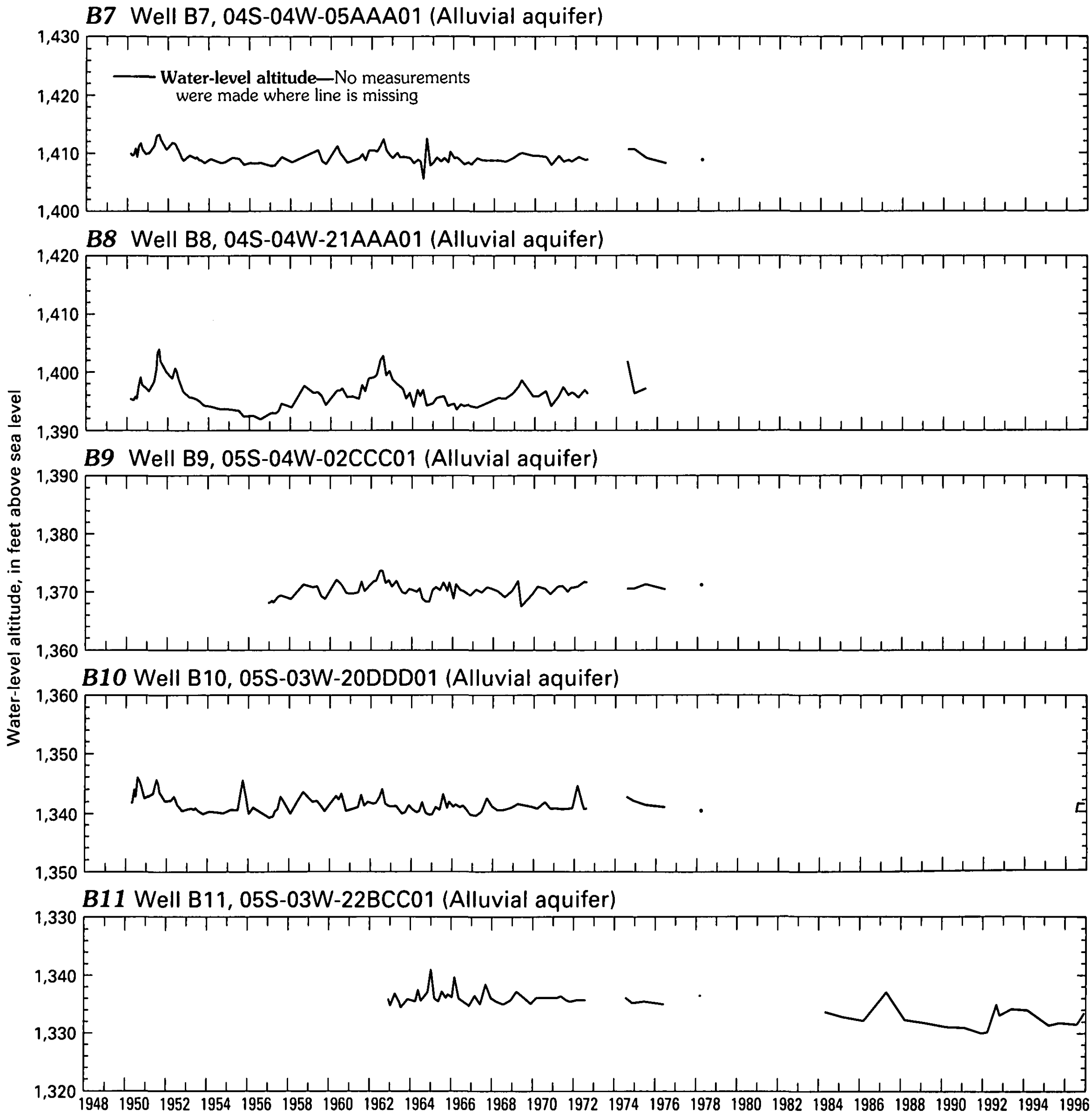
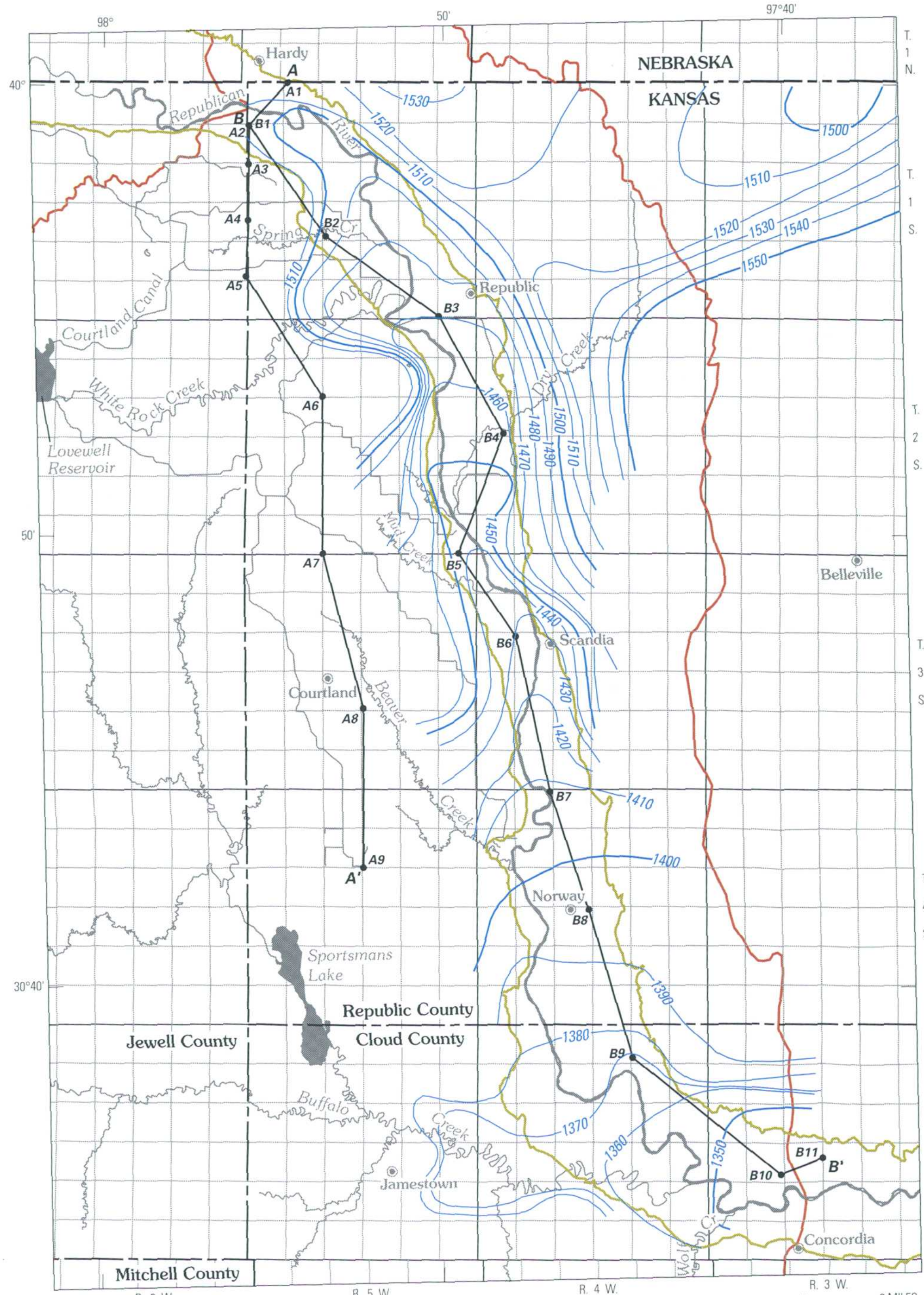


Figure 8. Water-table hydrographs along *B–B'* in the Republican River Valley (data from Bureau of Reclamation, Grand Island, Nebraska; U.S. Geological Survey, Lawrence, Kansas; and Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas)—Continued. Location of wells shown in figure 9.

curvature of water-table contours upstream from Scandia suggest a greater aquifer-to-river gradient than is indicated by contours downstream from Scandia. This difference in aquifer-to-river gradient may be due in part to the fact that, according to cross sections and logs of test holes in Fishel (1948), the alluvial aquifer north of Scandia generally is finer grained and less than 40 ft thick, whereas south of Scandia the alluvial aquifer generally is coarser grained and about 80 to 100 ft thick.

June and July 1963

The water-table map for June and July 1963 (fig. 10; Fader, 1968, plate 3) is based on ground-water levels measured about 5 years after KBID went into full operation in 1958. These water-level measurements were made in many observation and irrigation wells; no domestic or stock wells were measured for this map. Most of the irrigation wells are in



Base from Kansas Geological Survey digital data, 1:24,000, 1992, and U.S. Geological Survey digital data, 1:100,000, 1983
Albers Conic Equal Area projection,
Standard parallels 29°30' and 45°30', central meridian -98°, latitude of origin 23°

EXPLANATION

—1350— **Water-table contour**—Shows altitude of water table. Contour interval 10 feet. Datum is sea level

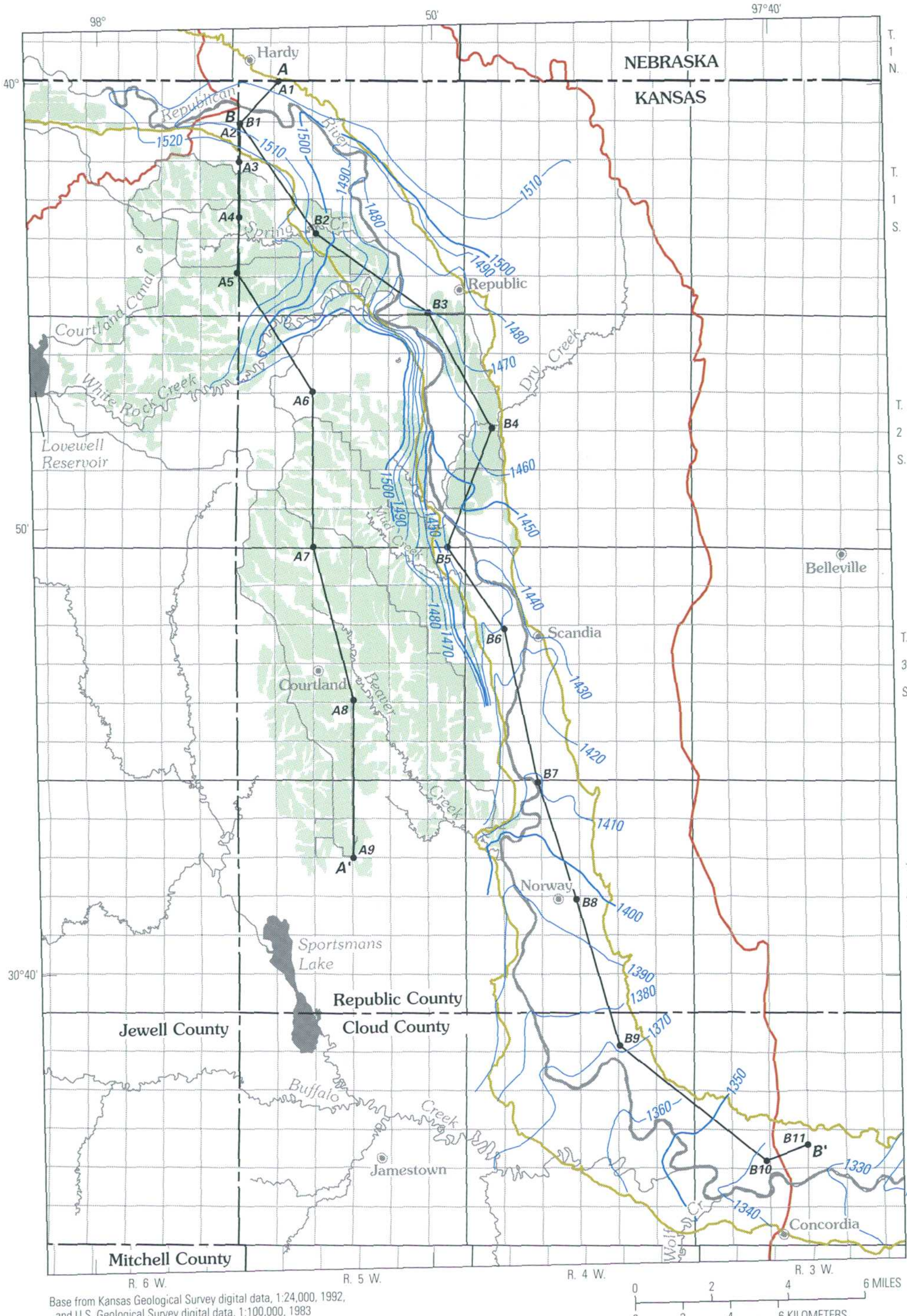
Boundary of 4-year study area

Boundary of Republican River Valley

A—A' **Trace of section**—For water-table hydrographs shown in figures 7 and 8

A9• **Well**—Number is well identification used in figures 7 and 8

Figure 9. Water table in and adjacent to the Republican River Valley in study area, summer 1942 (modified from Fishel, 1948, plate 8).



Base from Kansas Geological Survey digital data, 1:24,000, 1992,
and U.S. Geological Survey digital data, 1:100,000, 1983
Albers Conic Equal Area projection,
Standard parallels 29°30' and 45°30', central meridian -98°,
latitude of origin 23°

EXPLANATION

Later (1993) extent of Kansas Bostwick Irrigation District—Irrigated land

—1350— **Water-table contour**—Shows altitude of water table. Contour interval 10 feet. Datum is sea level

Boundary of 4-year study area

Boundary of Republican River Valley

A—A' **Trace of section**—For water-table hydrographs shown in figures 7 and 8

A9• **Well**—Number is well identification used in figures 7 and 8

Figure 10. Water table in and adjacent to the Republican River Valley in study area, June and July 1963 (modified from Fader, 1968, plate 3).

the valley from near Scandia to Concordia, Kansas (Fader, 1968).

During 1963, precipitation was less than the long-term average (October 1951–September 1995) for the period following the completion of Harlan County Dam (fig. 3*A*), and flow in the Republican River near Hardy, Nebraska, was about the same as the long-term average streamflow for the period following the completion of Harlan County Dam (fig. 3*B*). The water-table contours are similar to those indicated by the summer 1942 map in most areas. The water-table contours on the June and July 1963 map are more closely spaced on the west side of the valley between Republic and Scandia, Kansas, than water-table contours on the summer 1942 map, indicating there may have been a rise in the water table in the western uplands. Although none of the long-term hydrographs of wells in KBID extend back to 1942 (fig. 7), substantial water-table increases of about 10 to 30 ft between the mid-1950's and 1963 are shown in many of the hydrographs of wells in the KBID in the uplands west of the Republican River Valley.

Spring 1977

The water-table map for spring 1977 (fig. 11; Dunlap, 1982, sheet 4) was constructed by the USGS for the BOR as part of a water-management study of the Republican River Basin (Bureau of Reclamation, 1985a,b,c) and is based on ground-water levels measured about 20 years after KBID went into full operation. The ground-water levels used to construct this water-table map were measured during the drought of 1974–82 (Clement, 1991; fig. 3*C*). Although precipitation during 1977 was above the long-term average for the period following the completion of Harlan County Dam (fig. 3*A*), streamflow near Hardy, Nebraska, was only about one-half the long-term average streamflow for the same period (fig. 3*B*). The water-table contours for spring 1977 are similar to those indicated in the maps for spring 1942 and especially for June and July 1963 in most areas. The smaller scale and the fewer number of data points used for the spring 1977 water-table map preclude drawing further conclusions from comparisons of it with the other water-table maps.

August 1996

The water-table map for August 1996 (fig. 12) is based on 116 ground-water-level measurements made during August 5–8, 1996, in observation, irrigation, and a few public-supply wells. Most of the observation wells are used by BOR to monitor ground-water levels in the KBID. The irrigation wells mostly are in the Republican River Valley or in the areas where the Grand Island Formation exists. During 1996, precipitation and flow in the Republican River in the study area were similar to their respective long-term averages for the period (fig. 3*A*) following completion of Harlan County Dam (figs. 3*A* and 3*B*). The water-table contours for August 1996 are similar in most areas to those of maps previously shown in this report. A comparison of the water-table contours on the August 1996 map with the June and July 1963 contours in the Republican River Valley between Scandia and the Republic-Cloud County line shows some indication of a water-table decline near the middle of the valley. Unfortunately, this supposition can not be checked using the long-term hydrographs of wells in the Republican River Valley because of a lack of data.

December 1996

The water-table map for December 1996 (fig. 13) is based on 127 ground-water-level measurements made during December 9–11, 1996, 115 of which also were measured during August 5–8, 1996. Many of the water-level altitudes determined during December 1996 were within 2 to 3 ft of the water-level altitudes determined during August 1996. In the study area during 1996, precipitation and flow in the Republican River were similar to their respective long-term averages for the period following the completion of Harlan County Dam (figs. 3*A* and 3*B*). The water-table contours for December 1996 are similar in most areas to those shown on previous maps in this report, especially the August 1996 map.

Long-Term and Seasonal Changes

Long-term water-level changes greater than the maximum seasonal changes of 12 ft generally have not occurred in the alluvial aquifer in the Republican River Valley in the study area. Some hydrographs of wells in the western upland loess deposits

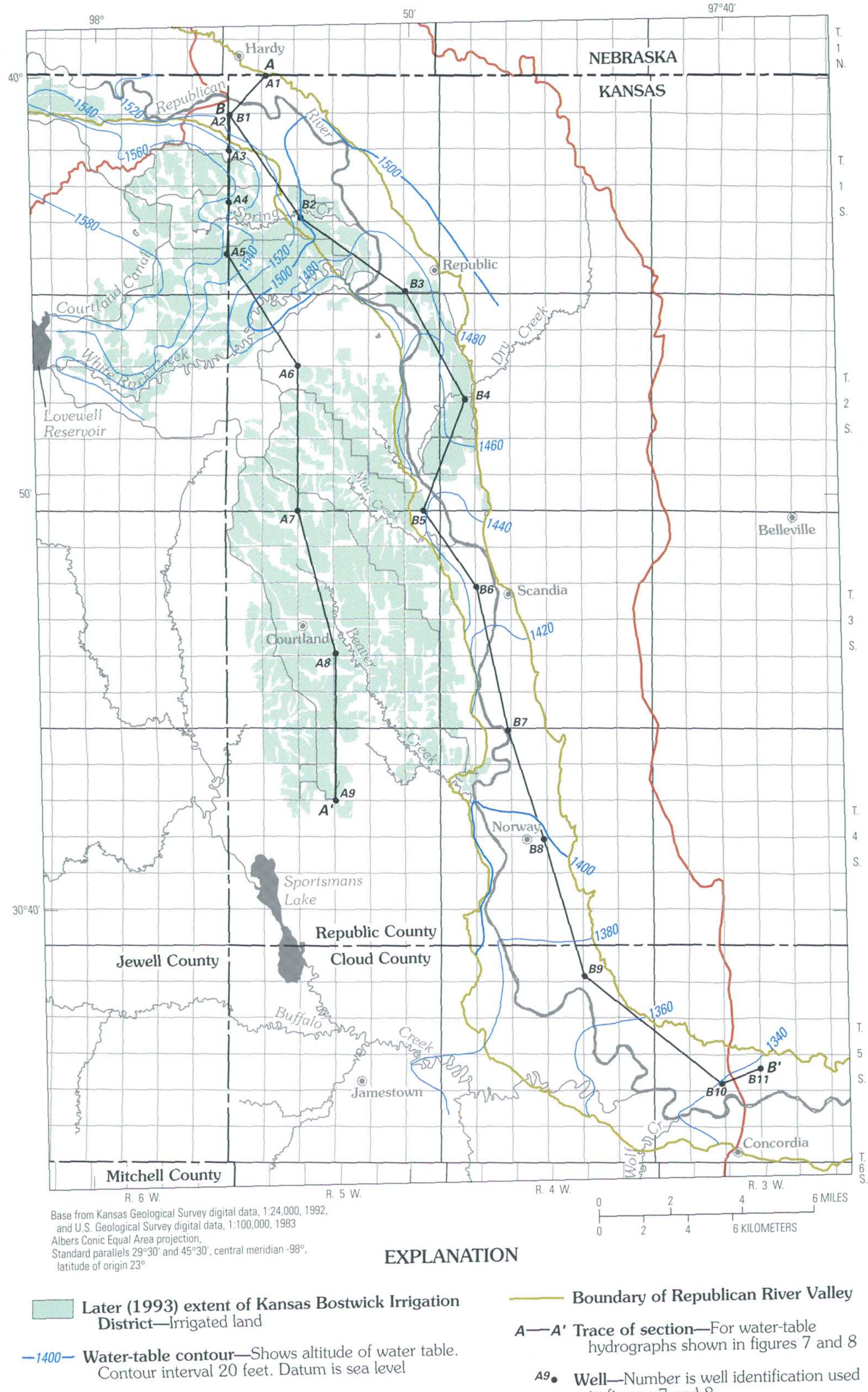
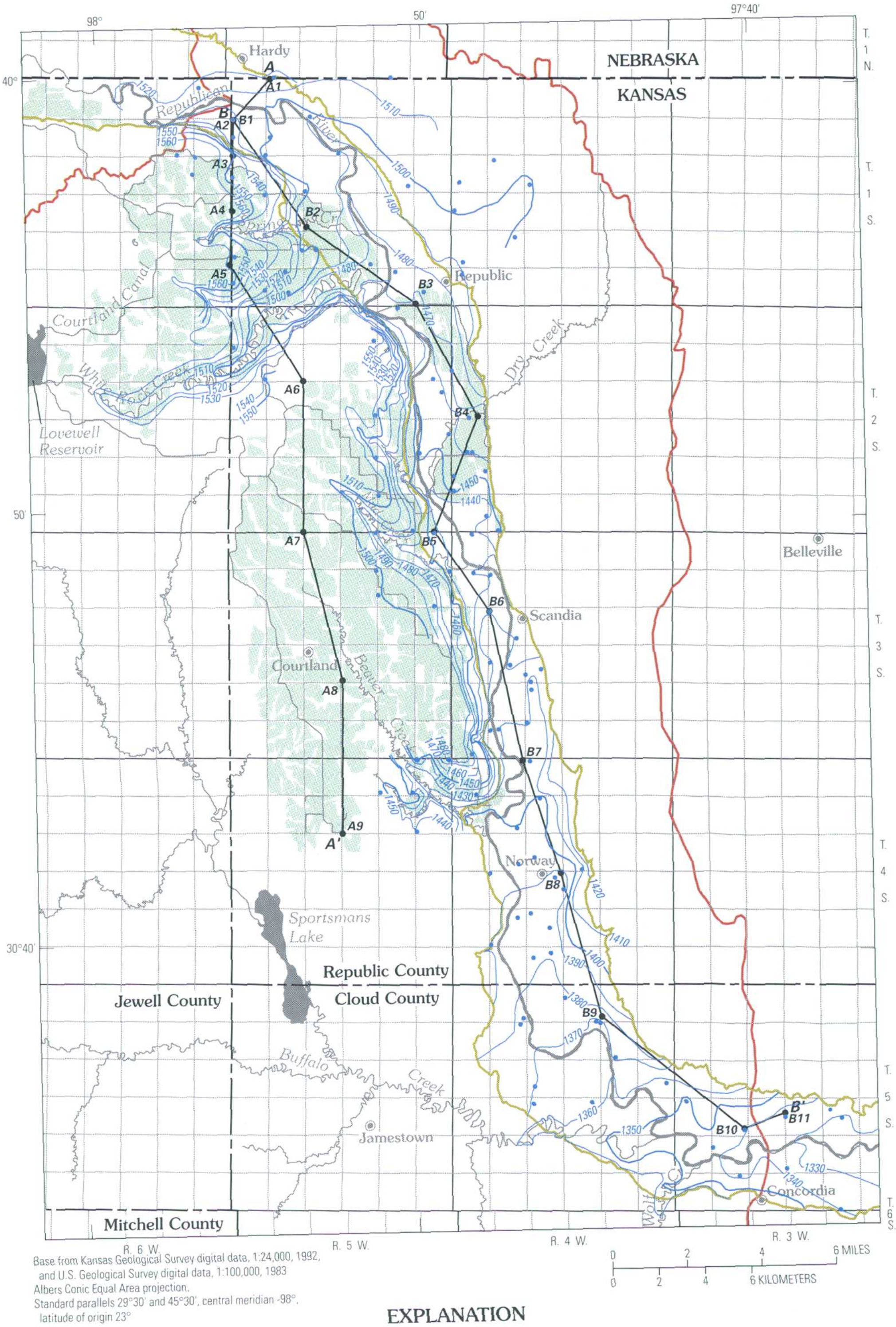


Figure 11. Water table in and adjacent to the Republican River Valley in study area, spring 1977 (modified from Dunlap, 1982, sheet 4).



EXPLANATION

1993 extent of Kansas Bostwick Irrigation District—Irrigated land

—1350— Water-table contour—Shows altitude of water table. Contour interval 10 feet. Datum is sea level

Boundary of 4-year study area

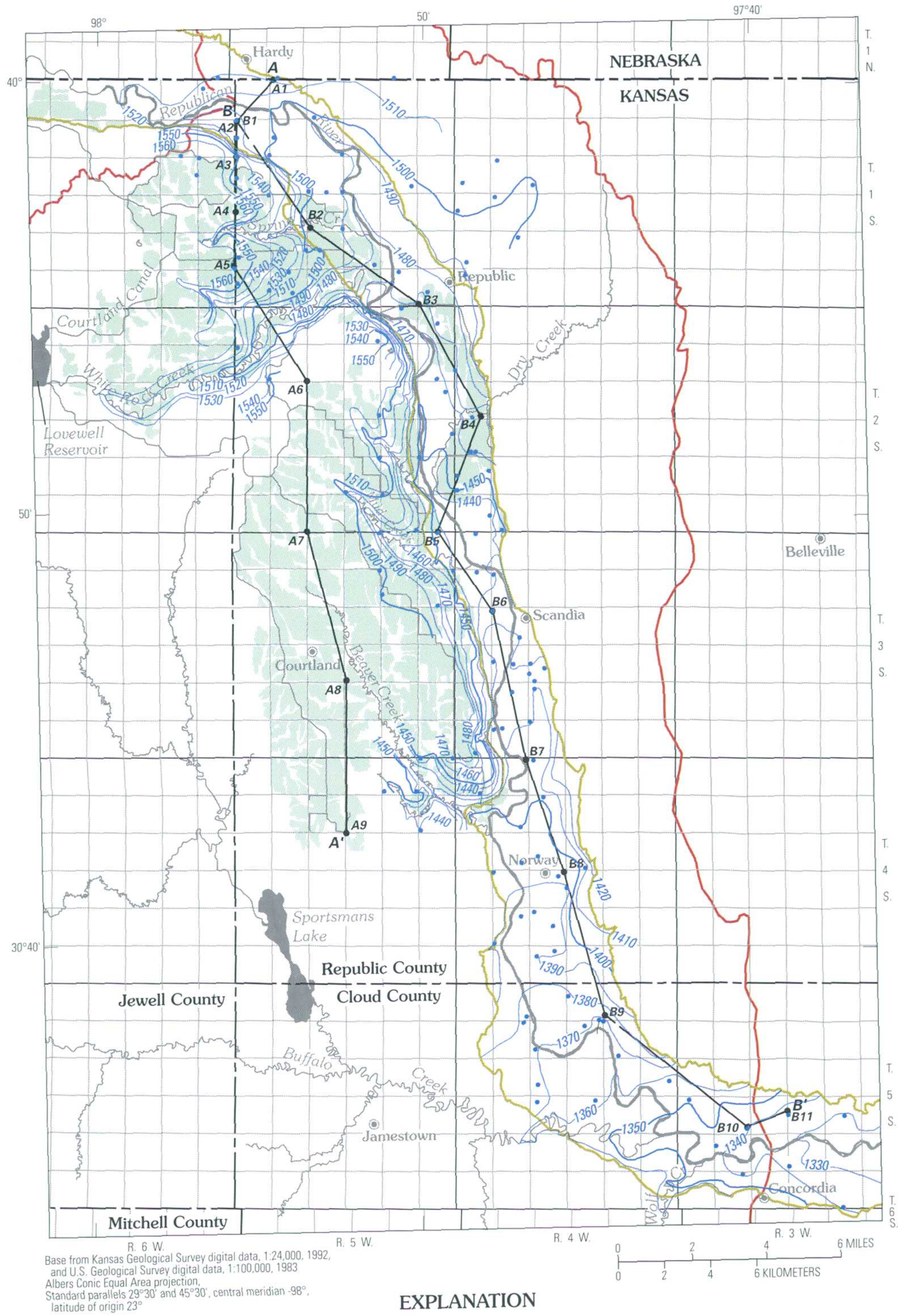
Boundary of Republcan River Valley

A—A' Trace of section—For water-table hydrographs shown in figures 7 and 8

A9 • Well—Number is well identification used in figures 7 and 8

• Well

Figure 12. Water table in and adjacent to the Republican River Valley in study area, August 1996 (data from U.S. Geological Survey, Lawrence, Kansas).



EXPLANATION

- 1993 extent of Kansas Bostwick Irrigation District—Irrigated land
- —1350— Water-table contour—Shows altitude of water table. Contour interval 10 feet. Datum is sea level
- Boundary of 4-year study area
- Boundary of Republican River Valley
- A—A' Trace of section—For water-table hydrographs shown in figures 7 and 8
- A9• Well—Number is well identification used in figures 7 and 8
- • Well

Figure 13. Water table in and adjacent to the Republican River Valley in study area, December 1996 (data from U.S. Geological Survey, Lawrence, Kansas).

(wells A3–A5 and A7–A9, fig. 7) show an increase in water levels of 10 to 30 ft during the late 1950's and early 1960's that relate to the development of the KBID and irrigation using imported surface water. This is supported by comparing the locations of contours from the summer 1942, June and July 1963, and August 1996 water-table maps. The water-table maps indicate that some water-level declines probably have occurred between the 1960's and 1990's in the Grand Island Formation east of the Republican River Valley and north of Republic, Kansas, and in the alluvial aquifer south of Scandia, especially on the side of the valley where the river is farthest from the edge of the valley. Only 1 of the 20 long-term hydrographs (well B2, fig. 8) indicated a decline in the water table that exceeded 12 ft, which occurred during 1992–94. A water-level decline of a few feet occurred in well B11 between the 1960's and 1990's, supporting the idea that even though there is a lack of recent same-well data in the south part of the study area, some small declines may have occurred there. Although there are many historic and spatial gaps in the water-level data, there are no apparent large, widespread, long-term water-level declines in the study area despite the substantial increase in ground-water withdrawals since the 1950's. Even the large decrease in long-term Republican River flow since the completion of Harlan County Dam, indicated in figure 3*B*, has not caused a large decline in alluvial aquifer water levels, probably because this large decrease in flow corresponds to a decrease in stream stage of only about 1 ft.

The effects of major hydrologic events on ground-water levels are frequently visible on one or more of the hydrographs (figs. 7 and 8). The droughts of 1952–57, 1962–72, 1974–82, and 1988–92 and the floods of 1951, 1973, and 1993 generally are reflected by the long-term hydrographs.

Many of the hydrographs of wells in the KBID, whether in the Republican River Valley or in the uplands west of the valley, show an annual cycle of seasonal water-table changes of 2 to 12 ft (fig. 7, wells A4, A5, A8, A9; fig. 8, wells B2 and B4). This annual cycle is characterized by an abrupt rise in the water table during the growing season due to increased recharge from the application of imported surface water for irrigation followed by a gradual decline in the water table during the nonirrigation season as the recharge from irrigation drains away. The hydrograph of the well in the Grand Island Formation near Hardy, Nebraska (fig. 7, well A1), shows an opposite annual cycle of seasonal water-table changes that is generally characteristic of ground-water irrigation—an abrupt decline during the growing season when water for irrigation is pumped from the aquifer followed by a gradual rise in the water table during the nonirrigation season as the water table recovers. The Grand Island Formation, unlike the alluvial aquifer, is not hydraulically connected to the Republican River and also may receive less recharge from precipitation because it is covered by loess deposits. As a result, large-capacity wells in the Grand Island Formation may experience larger water-table declines with longer recovery times than if the same wells were in the alluvial aquifer.

Comparison of the water-level measurements from 115 wells used for both the August and December 1996 water-table maps (figs. 12 and 13) indicates the seasonal effects of irrigation. Of the 115 wells, 73 are in the Repubican River Valley, 32 are in the uplands west of the valley, and 10 are in the uplands east of the valley (figs. 12 and 13). Typically, wells in the Republican River Valley downstream from about Scandia and in the uplands east of the valley north of Republic have water-table increases between August and December, which is indicative of areas of ground-water irrigation. Wells in the uplands west of the valley generally experienced water-table declines during those months, which is indicative of areas of irrigation using imported surface water. Some of the largest water-level declines between August and December 1996 occurred in wells in the area between the valley and the uplands to the west where the slope of the land surface is steep and the water-table gradient is large.

AQUIFER PROPERTIES

Transmissivity is the most important and widely used aquifer property that describes the movement of water through an aquifer. Transmissivity is a measure of the capacity of an aquifer to transmit water at the prevailing kinematic viscosity (Heath, 1983). In this report, transmissivity is expressed in feet squared per day. Transmissivity can be used to predict the potential yield of a proposed well for a specified drawdown and to estimate the effect of pumping wells on one another. The transmissivity of an aquifer can be estimated from aquifer-test data. Estimates of transmissivity can also be made from specific-capacity data (Lohman, 1979), although well efficiency, which is independent of transmissivity, affects specific capacity. Specific capacity is the rate of discharge of water from a well divided by the drawdown of water within the well (Lohman and others, 1972). In this report, specific capacity is expressed in cubic feet per day per foot.

Previously published values of transmissivity from 42 wells in the Republican River Valley in or near the study area are shown in figure 14. These values included transmissivity estimated from two aquifer tests made using one and four observation wells (Fader, 1968), five single-well recovery tests (one from Fader, 1968; three from Fishel, 1948—one of which was reanalyzed by Reed and Burnett, 1985), 14 step-drawdown (single well) tests (Fader, 1968), and 22 estimates from specific capacity reported by the well owners (Fader, 1968).

Pumping-test data for 52 wells recorded on water-well completion (WWC5) forms on file at the Kansas Geological Survey (Lawrence, Kansas) and the Kansas Department of Health and Environment (Topeka, Kansas) were used to compute specific capacity and estimate transmissivity; no new wells were constructed or tests made as a part of this study. The data compiled from WWC5 forms included the location of the well, the diameter of the well, the pumping rate (discharge), the length of the pumping period, and the difference in the water level (drawdown) between the beginning and end of the pumping period. A specific yield of 0.2, which had been used by previous investigators (Fader, 1968; Bureau of Reclamation, 1985a,b,c; Hansen, 1991) for the water-bearing units in this area, was used in the procedure to estimate transmissivity.

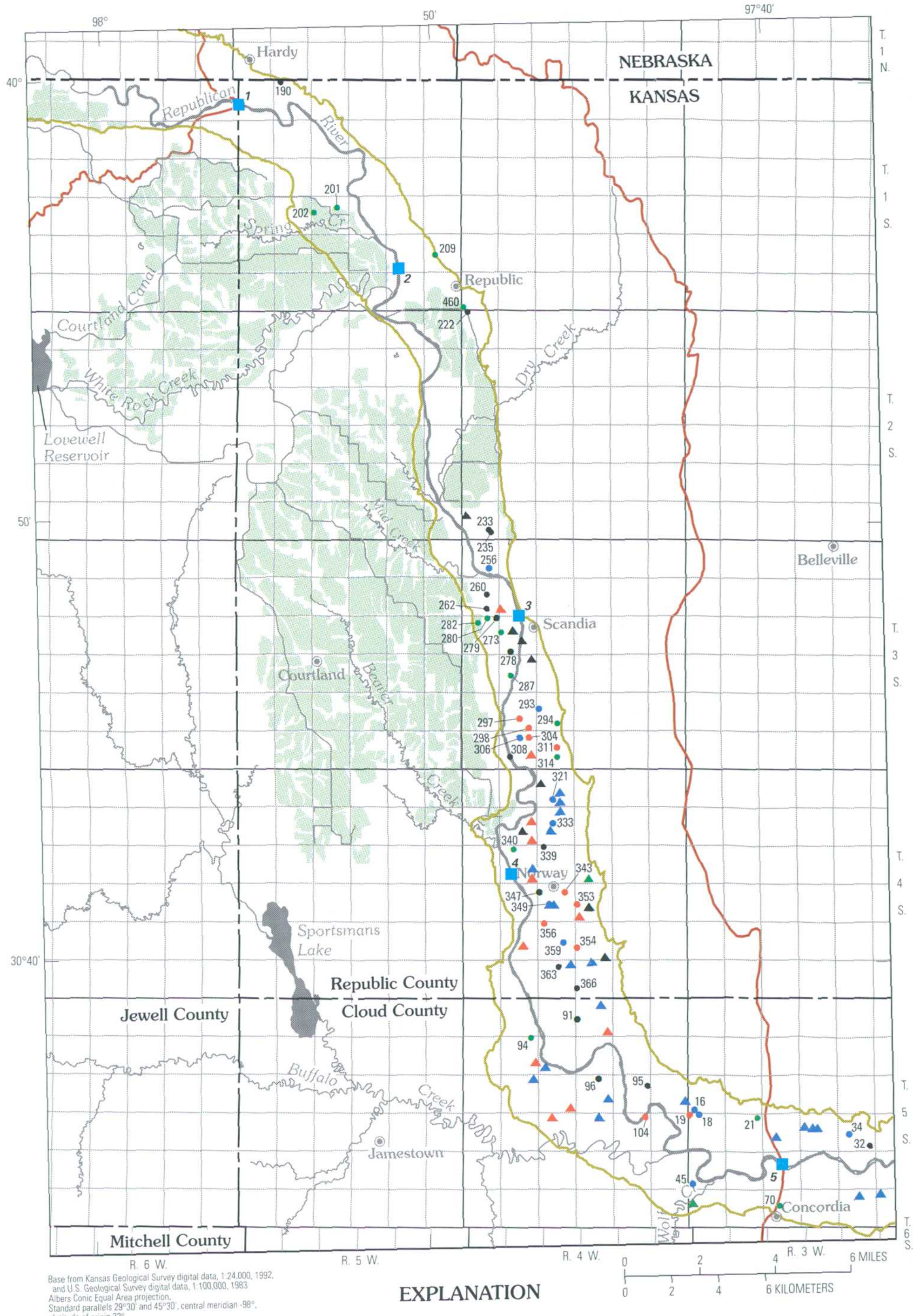
Estimates of transmissivity derived from specific-capacity data are partially dependent on well efficiency, which can be affected by the length of the pumping test, the construction of the well, its development, the character of the screen or casing perforation, and the velocity and length of flow up the casing (Lohman and others, 1972). To reduce the variation in well efficiency caused by these effects, only data from wells with screen diameters of more than 10 in. and pumping rates greater than 100 gal/min were used (table 2).

Transmissivity estimates from published information ranged from about 260 to about 44,000 ft^2/d; transmissivity values estimated as a part of this study ranged from about 1,400 to about 31,000 ft^2/d. The median transmissivity value was about 10,000 ft^2/d for both the published values and those estimated for this study. The transmissivity values estimated for this study (median of 8,300 ft^2/d) tended to be less than published values of transmissivity (median of 14,700 ft^2/d). This may be due in part because a greater percentage of estimates for this study were derived from specific-capacity values, which because they include the effects of well loss, tend to predict lower transmissivity values.

Generally, transmissivity values, whether estimated by this study or from previously published reports, tend to increase to the south from just downstream of the KBID in the Republican River Valley, and tend to be larger in the middle of the valley than at the margins of the valley (fig. 14). This is consistent with hydrogeologic sections by Fishel (1948, plate 5), which show saturated thickness and coarseness of the alluvial aquifer deposits increasing from north to south and generally increasing toward the center of the valley in the study area. Just south of Scandia, there seems to be an area of smaller transmissivity values (fig. 14); this may indicate that the alluvial deposits in this area are thinner or more fine grained. North of Scandia, there are few transmissivity values; most were estimated by this study and are relatively small (fig. 14). The relative scarcity of wells north of Scandia probably is due mainly to the presence of the KBID in this part of the Republican River Valley. Fishel's (1948) hydrogeologic sections show the alluvial deposits have a smaller saturated thickness and are finer grained north of Scandia than south. Therefore, the small transmissivity values north of Scandia in figure 14 may be a reasonable representation of the transmissivity of the alluvial aquifer in this area.

STREAMBED PERMEABILTY

Streambed permeability was estimated from data collected at five sites in the Republican River Valley (fig. 14) using a hydraulic potentiomanometer as described by Lee (1977) and Winter and others (1988). The hydraulic potentiomanometer measures the differences in water pressure (hydraulic head) between the water in the stream and the water in the aquifer below the river. These measurements were used to estimate the vertical hydraulic conductivity of the streambed using Darcy's law as described by Myers and others (1996):



EXPLANATION

1993 extent of Kansas Bostwick Irrigation District—Irrigated land

Boundary of 4-year study area

Boundary of Republican River Valley

5 Streambed permeability measurement site—Number is site number in table 3

Transmissivity—In feet squared per day. Values from published data and estimated from water well data (where well diameter greater than 10 inches, well discharge greater than 100 gallons per minute, and specific yield assumed to be 0.20) Number is well number used in table 2 (estimated values only)

Source and range in transmissivity

Published	Estimated	
▲	●	Greater than 0 - 5,000
▲	●	5,000 - 10,000
▲	●	10,000 - 15,000
▲	●	Greater than or equal to 15,000

Figure 14. Published and estimated transmissivity values and location of streambed-permeability measurement sites in the Republican River Valley in or near study area [sources: published values from Fishel (1948), Fader (1968), and Reed and Burnett (1985); estimated values based on reported water-well data from water-well completion (WWC5) forms on file with Kansas Geological Survey (Lawrence) and Kansas Department of Health and Environment (Topeka)].

Table 2. Estimated specific-capacity and transmissivity values from wells in Republican River Valley in study area

[Source of data used for estimates: water-well drillers' log data from water-well completion forms on file with Kansas Geological Survey (Lawrence, Kansas) and Kansas Department of Health and Environment (Topeka, Kansas). ft, feet; in., inches; gal/min, gallons per minute; $(ft^3/d)/ft$, cubic feet per day per foot; ft^2/d, feet squared per day]

Well no. (fig. 14)	Location[1] (subdivisions, section, township, range)	Water use[2]	Depth of well (ft)	Casing diameter (in.)	Depth to prepumping water level (ft)	Depth to pumping water level (ft)	Well discharge (gal/min)	Pumping period (minutes)	Date of pumping test (month/day/year)	Specific capacity $[(ft^3/d)/ft]$	Transmissivity (ft^2/d)
					Republic County						
190	NE NW NW 05 01S 05W	I	46.5	16	15	35	800	90	05/24/77	7,700	5,600
201	NE SW NE 21 01S 05W	I	45	16	18	34	500	120	06/25/75	6,000	4,400
202	SW SW NW 21 01S 05W	I	35	16	11	27	200	120	06/26/75	2,400	1,500
209	NW NE SW 25 01S 05W	I	33	16	10	26	500	120	12/02/75	6,000	4,400
222	NE NW NW 06 02S 04W	I	51	16	25.5	34	500	60	06/26/83	11,000	8,200
233	NC SE 31 02S 04W	I	48	16	10	30	840	60	06/03/77	8,100	5,600
235	NW SE SE 31 02S 04W	I	50	16	6	25	1,200	60	03/15/90	12,000	8,800
256	SE 06 03S 04W	I	51	16	8	19	1,500	60	07/14/84	26,000	21,000
260	SE SW NE 07 03S 04W	I	60	16	9	25	1,150	30	08/31/76	14,000	9,400
262	NE SW SE 07 03S 04W	I	46	16	11	40	1,000	480	08/15/90	6,600	5,700
273	SW SW NW 17 03S 04W	I	51	16	10	35	900	90	06/30/76	6,900	4,900
278	SW SE SW 17 03S 04W	I	67	16	10	24	500	360	08/30/90	6,900	5,700
279	NE NE NE 18 03S 04W	I	65	16	11	35	1,000	120	06/26/92	8,000	6,000
280	NE NW NE 18 03S 04W	S	45	16	11	31	395	120	06/22/92	3,800	2,600
282	SE NE NW 18 03S 04W	S	36	16	9	28	450	60	07/15/76	4,600	2,900
287	NW NE SW 20 03S 04W	I	50	16	10	30	500	360	07/12/89	4,800	3,900
293	SW SW NW 28 03S 04W	I	52	16	8	25	2,000	45	05/21/84	23,000	17,000
294	NW NW SW SE 28 03S 04W	I	52	16	18	50	1,000	60	06/26/80	6,000	4,000
297	SW NW SE 29 03S 04W	I	52	16	10	20	1,000	30	11/08/77	19,000	14,000
298	SW SE SE 29 03S 04W	N	47	16	12	30	1,300	60	04/05/79	14,000	10,000
304	SW NE NE 32 03S 04W	I	60	16	12	29	1,200	60	11/17/94	14,000	10,000
306	SW NW NE 32 03S 04W	I	60	16	8	20	1,000	840	07/15/94	16,000	16,000
308	SW NE SW 32 03S 04W	I	68	16	10	30	1,200	30	12/10/76	12,000	7,600
311	SW SW NE 33 03S 04W	I	60	16	22	33	1,000	120	05/27/93	18,000	14,000
314	SW NW SE 33 03S 04W	I	66	16	18	49	1,000	120	05/26/93	6,200	4,500
321	NC NE SE SW 04 04S 04W	I	63	16	27	33	500	660	07/12/89	16,000	15,000
333	SE SE NW 09 04S 04W	I	82	16	15	29	1,500	60	07/20/89	21,000	16,000
339	NE NW NW 16 04S 04W	I	60	16	12	40	1,200	60	04/21/81	8,300	5,700
340	NE NW 17 04S 04W	I	60	16	12	55	500	120	08/28/92	2,200	1,400
343	NC NE 21 04S 04W	I	61	16	18	28	1,000	45	05/15/84	19,000	14,000

Table 2. Estimated specific-capacity and transmissivity values from wells in Republican River Valley in study area—Continued

Well no. (fig. 14)	Location[1] (subdivisions, section, township, range)	Water use[2]	Depth of well (ft)	Casing diameter (in.)	Depth to prepumping water level (ft)	Depth to pumping water level (ft)	Well discharge (gal/min)	Pumping period (minutes)	Date of pumping test (month/day/year)	Specific capacity [(ft³/d)/ft]	Transmissivity (ft²/d)
	Republic County—Continued										
347	NC W2 W2 NW 21 04S 04W	I	60	16	7	27	1,200	30	03/25/85	12,000	7,600
349	NW NE SW 21 04S 04W	I	67	16	26	40	1,500	60	07/18/90	21,000	16,000
353	NW NW SW 22 04S 04W	I	55	16	20	36	1,250	30	07/12/77	15,000	10,000
354	SW NW SW 27 04S 04W	I	56	16	21	37	1,250	30	05/26/77	15,000	10,000
356	NE NW NW 28 04S 04W	I	72	16	18	28	1,000	45	05/11/84	19,000	14,000
359	NE NW SE 28 04S 04W	I	63	16	18	27	1,000	30	03/23/83	21,000	15,000
363	SW NW NE 33 04S 04W	I	50	16	23	40	1,030	60	06/20/80	12,000	8,400
366	W2 W2 SW 34 04S 04W	I	68	16	9	28	1,200	90	05/03/82	12,000	9,300
460	SW SW SW 31 01S 04W	Z	55	16	11	29	450	60	05/06/89	4,800	3,100
	Cloud County										
16	SE SW SW 18 05S 03W	I	63	16	22	30	1,200	30	11/08/77	29,000	21,000
18	NW NE NW 19 05S 03W	I	82	16	12	18	1,250	30	11/05/76	40,000	31,000
19	NW NW NW 19 05S 03W	I	51	16	12	24	1,250	30	09/27/77	20,000	14,000
21	NE NE 20 05S 03W	I	60	16	20	45	650	60	10/30/75	5,000	3,200
32	SE SE 23 05S 03W	I	39	16	24	35	400	60	11/06/75	7,300	6,200
34	NW NE SW 23 05S 03W	I	43	16	7	15	1,050	30	01/25/78	25,000	18,000
45	SW SW 30 05S 03W	I	36	16	12	16	500	60	09/25/75	24,000	19,000
70	SE SE NW 33 05S 03W	P	47	12	21	35	350	720	03/29/82	5,000	4,600
91	NW NW SW 03 05S 04W	I	68	16	9	28	1,200	45	05/11/82	12,000	8,500
94	NW NE NE 08 05S 04W	I	50	16	8	40	1,000	60	05/09/77	6,000	4,000
95	NE SE NE 14 05S 04W	I	64	16	8	30	1,285	60	11/08/75	11,000	8,100
96	NW NE 15 05S 04W	I	53	16	12	35	1,000	60	11/17/75	8,400	5,800
104	NE NE 23 05S 04W	I	45	16	8	16	600	180	04/05/96	14,000	12,000

[1]Water-well locations are reported using a modification of the Bureau of Land Management's system of land subdivision (see fig. 6). In Kansas, all townships are referenced as south of the Kansas-Nebraska State line, all ranges are referenced as east or west of the sixth principal meridian, and all sections are numbered between 1 and 36 and follow the standard pattern. Subdivisions are listed from small to large from left to right and are designated by the following abbreviations: NE, northeast; NW, northwest; SE, southeast; SW, southwest; NC, near center; E2, east half; N2, north half; S2, south half; W2, west half; CE, center of east line; CN, center of north line; CS, center of south line; CW, center of west line; CR, corner—designated by previous subdivision abbreviation.

[2]Water-use abbreviations: I, irrigation; S, feedlot; N, industrial; P, public water supply; Z, other.

$$K = \frac{\left(\frac{V}{t}\right)}{A\left(\frac{dh}{dl}\right)}, \qquad (1)$$

where K = vertical hydraulic conductivity, in feet per day;

V = volume of water flowing between the aquifer and the river measured using the hydraulic potentiomanometer, in cubic feet;

t = elapsed time of test, in days;

A = area of seepage meter of the hydraulic potentiomanometer, 2.77 ft^2;

dh = difference in water level between stream and aquifer measured using the hydraulic potentiomanometer, in feet; and

dl = length of probe of the hydraulic potentiomanometer that is inserted vertically into the streambed, 2 ft.

The data used for estimating streambed permeability were collected in the Republican River during August and December 1996 at the same time as ground-water levels were measured for this study. Discharge of the Republican River also was measured during the streambed-permeability measurements at the five sites. The hydraulic potentiomanometer generally was placed in the streambed near the streambank because flowlines in the adjacent aquifer typically tend to converge near the bank of a stream or lake (Winter, 1976). Table 3 shows the measurements made using the hydraulic potentiomanometer and the estimates of vertical hydraulic conductivity computed from these measurements. Although measurements were made during both August and December 1996 at only two sites, the two estimates of vertical conductivity at each of these two sites are in general agreement. The amount of uncertainty associated with the measurements of streambed permeability is unknown but could be substantial because of many factors such as only 11 measurements were made and only the upper 2 ft of the streambed was measured.

The values of streambed vertical hydraulic conductivity are within the range of hydraulic-conductivity values for silt to clean sand, with the values less than 1 ft/d being characteristic of silt to silty sand and the values greater than 1 ft/d being characteristic of silty sand to clean, medium-grained sand (Heath, 1983). The values of vertical hydraulic conductivity are generally smaller in the northern part of the study area from near Hardy, Nebraska, to Scandia, Kansas, than in the southern part from Norway to Concordia, Kansas, indicating streambed deposits may become coarser and (or) better sorted in the downstream direction. Although the values in table 3 are based only on the passage of water vertically through the top 2 ft of the streambed and the transmissivity values shown in figure 14 apply to the horizontal flow in the entire alluvial aquifer, the pattern of smaller vertical hydraulic-conductivity values in the north and larger values in the south is similar to the pattern of transmissivity as shown in figure 14. These patterns may account in part for the greater aquifer-to-river gradient upstream from Scandia than downstream from Scandia that is indicated by the contours of the water-table maps (figs. 9–13).

Streambed seepage probably tends to be less in the northern part of the study area where the vertical hydraulic conductivity is on the order of 0.1 to 1 ft/d and greater in the southern part of the study area where vertical hydraulic conductivity may approach 10 ft/d. Streambed seepage could be of particular importance during extreme droughts when the hydraulic gradient might be from the stream to the aquifer, and any loss in streamflow could be significant (Hansen, 1998).

SUMMARY

The two principal water-bearing units in the study area, which includes the Republican River Valley and the Kansas Bostwick Irrigation District (KBID) in north-central Kansas, are the alluvial aquifer in the Republican River Valley and the Grand Island Formation north of White Rock and Dry Creeks. Water-level data collected from about 130 wells during August and December 1996 were used to construct water-table maps. These maps, along with previously published water-table maps for the summer of 1942, June and July 1963, and spring 1977, and 19 long-term well hydrographs, were used to describe the ground-water system and changes that have occurred through time. The summer 1942 water-table map reflects conditions prior to development. Significant ground-water development in the study area began during the 1952–57 drought.

The water table slopes gently down the Republican River Valley from an altitude of about 1,510 ft above sea level near Hardy, Nebraska, to less than

Table 3. Estimated vertical hydraulic conductivity of Republican River streambed measured during August and December 1996 in study area

[ft, feet; ft^3, cubic feet; ft^3/d, cubic feet per day; ft/d, feet per day; <, less than; >, greater than; --, not available]

Site no. (fig. 14)	Name of site	Description of location	Date of measurement (month/day)	Difference in water level between stream and aquifer, upward (+) or downward (-) gradient (ft)	Volume of water, increase (+) or decrease (-) (ft^3)	Elapsed time (days)	Total flow, upward (+) or downward (-) (ft^3/d)	Estimated vertical hydraulic conductivity (ft/d)
1	Republican River near Hardy, Nebraska	Right bank under bridge in sandy silt.	08/06	-1.01	-0.0166	0.067	- 0.25	0.18
		About 250 ft upstream from bridge and 20 ft from right bank in medium-grained sand.	12/12	+.015	+ .0004	.042	+.01	.48
		About 250 ft upstream from bridge and 20 ft from right bank in medium-grained sand.	12/12	+.015	+ .0004	.042	+.01	.48
2	Republican River at Republic, Kansas	About 200 ft upstream from bridge, next to left bank in medium-grained sand.	12/10	+.075	+ .0042	.042	+.10	.96
		About 200 ft upstream from bridge and about 30 ft from left bank in medium-grained sand.	12/10	+.03	+ .0035	.042	+.08	1.9
3	Republican River at Scandia, Kansas	About 30 ft upstream from bridge near right bank in medium-grained sand.	12/10	+.01	+ .0004	.042	+.01	.72
		About 10 ft downstream from bridge near right bank in small channel with thin silt layer at top of medium-grained sand.	12/10	+.04	No measureable change	.042	--	--
4	Republican River at Norway, Kansas	Right bank under bridge in silty sand.	08/06	-.14	- .0309	.045	-.69	3.6
		About 10 ft upstream from bridge and 2 ft from left bank in quiet water behind sandbar; silty layer on top of medium-grained sand.	12/10	+.04	+ .0085	.024	+.35	6.3
5	Republican River at Concordia, Kansas	About 10 ft downstream from bridge and 10 ft from left bank in semiliquid sand and silt.	12/11	<+.01	+ .0035	.026	+.14	>10
		About 10 ft downstream from bridge and 20 ft from left bank in semiliquid sand and silt.	12/11	>-.01	- .0011	.026	-.04	>2.9

1,350 ft near Concordia, Kansas, or about 5 ft/mi. In addition, the water table generally slopes steeply into the valley from the adjacent uplands on the east and west. Water-table contours generally indicate a more pronounced aquifer-to-river gradient upstream from Scandia than downstream from Scandia.

Long-term water-level changes greater than the maximum seasonal changes of 12 ft generally have not occurred in the alluvial aquifer in the Republican River Valley. Although there are many historic and spatial gaps in the water-level data, there are no apparent large, widespread, long-term water-level declines in the alluvial aquifer in the valley despite the substantial increase in ground-water withdrawals since the 1950's. Even the large decrease in long-term Republican River flow since the completion of Harlan County Dam has not caused a large decrease in alluvial aquifer water levels. There are some indications from the water-table maps and hydrographs of wells that small water-level declines may have occurred between the 1960's and 1990's in the alluvial aquifer south of Scandia, Kansas. Most hydrographs of wells in the western upland loess deposits show an increase in water levels of 10 to 30 ft during the late 1950's and early 1960's that relate to the development of the KBID and irrigation using imported surface water. The water-table maps indicate some water-level declines probably have occurred between the 1960's and 1990's in the Grand Island Formation east of the Republican River Valley and north of Republic, Kansas.

Transmissivity of the alluvial aquifer in the Republican River Valley derived from 42 previously published aquifer and specific-capacity tests and 52 well-completion specific-capacity tests ranged from 260 to 44,000 ft^2/d, with a median of about 10,000 ft^2/d. Transmissivities tended to be larger in the south part of the study area and toward the middle of the valley at least in part because these areas contain coarser alluvial deposits with greater saturated thickness.

Vertical hydraulic conductivity of the Republican River streambed was estimated using a hydraulic potentiomanometer. Streambed hydraulic-conductivity values ranged from 0.18 ft/d, which is characteristic of silt, to about 10 ft/d, which is characteristic of clean medium-grained sand. Streambed seepage probably tends to be less in the northern part of the study area where the vertical hydraulic conductivity is on the order of 0.1 to 1 ft/d and greater in the southern part of the study area where vertical hydraulic conductivity may approach 10 ft/d.

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