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Streamflow Characteristics and Trends at Selected Streamgages in Southwest and South-Central Kansas

Scientific Investigations Report 2015–5167

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Rattlesnake Creek, Stafford County, Kansas. Photograph provided by Ryan Waters, Kansas Department of Wildlife, Parks and Tourism.

Back cover. Upper right: *Etheostoma cragini* (Arkansas darter). Photograph provided by Ryan Waters, Kansas Department of Wildlife, Parks and Tourism.
Center: East Branch Kiowa Creek, Comanche County, Kansas. Photograph by Greg Kramos, U.S. Fish and Wildlife Service.
Lower left: *Etheostoma cragini* (Arkansas darter). Photograph provided by Ryan Waters, Kansas Department of Wildlife, Parks and Tourism.

Front and back cover background photograph: Salt Fork Arkansas River, Comanche County, Kansas. Photograph by Greg Kramos, U.S. Fish and Wildlife Service.

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

[Inch/Pound to International System of Units]

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Acknowledgments

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Streamflow Characteristics and Trends at Selected Streamgages in Southwest and South-Central Kansas

By Kyle E. Juracek

Abstract

Historical data for nine selected streamgages in southwest and south-central Kansas were used in an assessment of streamflow characteristics and trends. This information is required by the U.S. Fish and Wildlife Service and the Kansas Department of Wildlife, Parks and Tourism to assist with the effective management of *Etheostoma cragini* (Arkansas darter) habitats and populations in the State. Changing streamflow conditions, such as a reduction or elimination of streamflow, may adversely affect the Arkansas darter. Priority basins for the Arkansas darter represented by the selected streamgages include the Cimarron River, Rattlesnake Creek, the North Fork Ninnescah River, the South Fork Ninnescah River, the Medicine Lodge River, and the Chikaskia River.

Streamflow conditions were assessed using annual streamflow characteristics computed for the period of record for each of the selected streamgages. Specific streamflow characteristics computed were mean discharge, mean base flow, 90th-percentile flow, 10th-percentile flow, minimum 7-day mean flow, minimum 28-day mean flow, number of days of flow less than 1 cubic foot per second, and number of zero-flow days.

Two of the priority basins had statistically significant decreases in annual mean discharge during the period of record. In the Cimarron River Basin, there was a pronounced multidecadal decrease in the magnitude and variability of annual mean discharge. Concurrently, the percentage of the annual mean discharge that was contributed by base flow increased. In the Rattlesnake Creek Basin, there was a pre-1985 decrease in annual mean discharge. Typically, in these two basins, significant decreases were indicated for mean base flow, 90th-percentile flow, 10th-percentile flow, minimum 7-day mean flow, and minimum 28-day mean flow. No significant trend in annual mean discharge was indicated for the North Fork Ninnescah, South Fork Ninnescah, Medicine Lodge, and Chikaskia River Basins. For the Medicine Lodge and Chikaskia River Basins as well as the downstream part of the South Fork Ninnescah River Basin, a significant increase in mean base flow and 10th-percentile flow was indicated. Also, for the latter two basins, a significant increase was indicated for minimum 7-day mean flow.

Factors investigated to explain long-term trends in annual mean discharge, or lack thereof, included precipitation and groundwater withdrawals. Annual precipitation in the study area varied substantially from 1951 to 2013 with no pronounced long-term trend. Thus, a precipitation-related explanation for the significant decrease in annual mean discharge in the Cimarron River and Rattlesnake Creek Basins was not supported. Because the most pronounced decreases in annual mean discharge were in the basin with the largest groundwater-level declines (that is, the Cimarron River Basin), both in terms of magnitude and areal extent, it is likely that groundwater withdrawals were a primary, if not dominant, causative factor.

The occurrence of extremely low-flow (less than 1 cubic foot per second) and zero-flow days varied by basin and year. Typically, such days occurred in the summer and autumn for all basins.

Introduction

The *Etheostoma cragini* (Arkansas darter) (hereafter referred to as “darter”) is listed as a threatened fish species by the State of Kansas. At the Federal level, it currently (2015) is a candidate species for listing. A primary threat to the survival of the darter is loss of habitat caused by changing streamflow conditions. Specifically, a reduction or elimination of streamflow caused by various factors (for example, decreased precipitation, increased temperature and evapotranspiration associated with climate change, groundwater withdrawals, land-use and land-management changes, change in runoff conditions) may adversely and perhaps irreversibly affect the remaining darter populations in the State (Eberle and Stark, 2000; Falke and others, 2011; Hoagstrom and others, 2011). Habitats of particular interest are located in southwest and south-central Kansas. Priority basins identified by the U.S. Fish and Wildlife Service (USFWS) and the Kansas Department of Wildlife, Parks and Tourism (KDWPT) include the Cimarron River Basin (especially downstream from 101° west longitude), the Rattlesnake Creek Basin, the North Fork Ninnescah River Basin upstream from Cheney Reservoir, the South Fork Ninnescah River Basin, the Chikaskia River Basin (especially upstream from 37°15′ north latitude), and the Medicine Lodge River Basin (fig. 1).

To provide some of the information needed for the effective management of darter habitats and populations in Kansas, the U.S. Geological Survey (USGS), in cooperation with the USFWS and KDWPT, began a 1.5-year study in 2014 to assess streamflow at nine selected USGS streamgage sites. The assessment provides an indication of streamflow conditions and changes for the priority basins in southwest and south-central Kansas.

Purpose and Scope

The purpose of this report is to present the results of the USGS study to assess streamflow characteristics and trends at nine selected USGS streamgage sites in southwest and south-central Kansas. Various streamflow characteristics were computed and compared for the period of record for each site. As part of the assessment, precipitation and groundwater withdrawals (as evidenced by groundwater-level changes) were evaluated to potentially explain changes in streamflow.

Results presented in this report will provide some of the information needed by the USFWS and KDWPT to enable better informed and more effective management of darter habitats and populations in Kansas. Specifically, the assessment provides multidecadal information at multiple sites that will contribute to an improved understanding of how streamflow conditions have changed in the areas of interest. Nationally, the methods and results presented in this report provide guidance and perspective for future studies concerned with the issue of streamflow-related habitat change.

Study Area Description

The study area in southwest and south-central Kansas includes all or part of the basins for the Cimarron River, Rattlesnake Creek, North Fork Ninnescah River, South Fork Ninnescah River, Medicine Lodge River, and Chikaskia

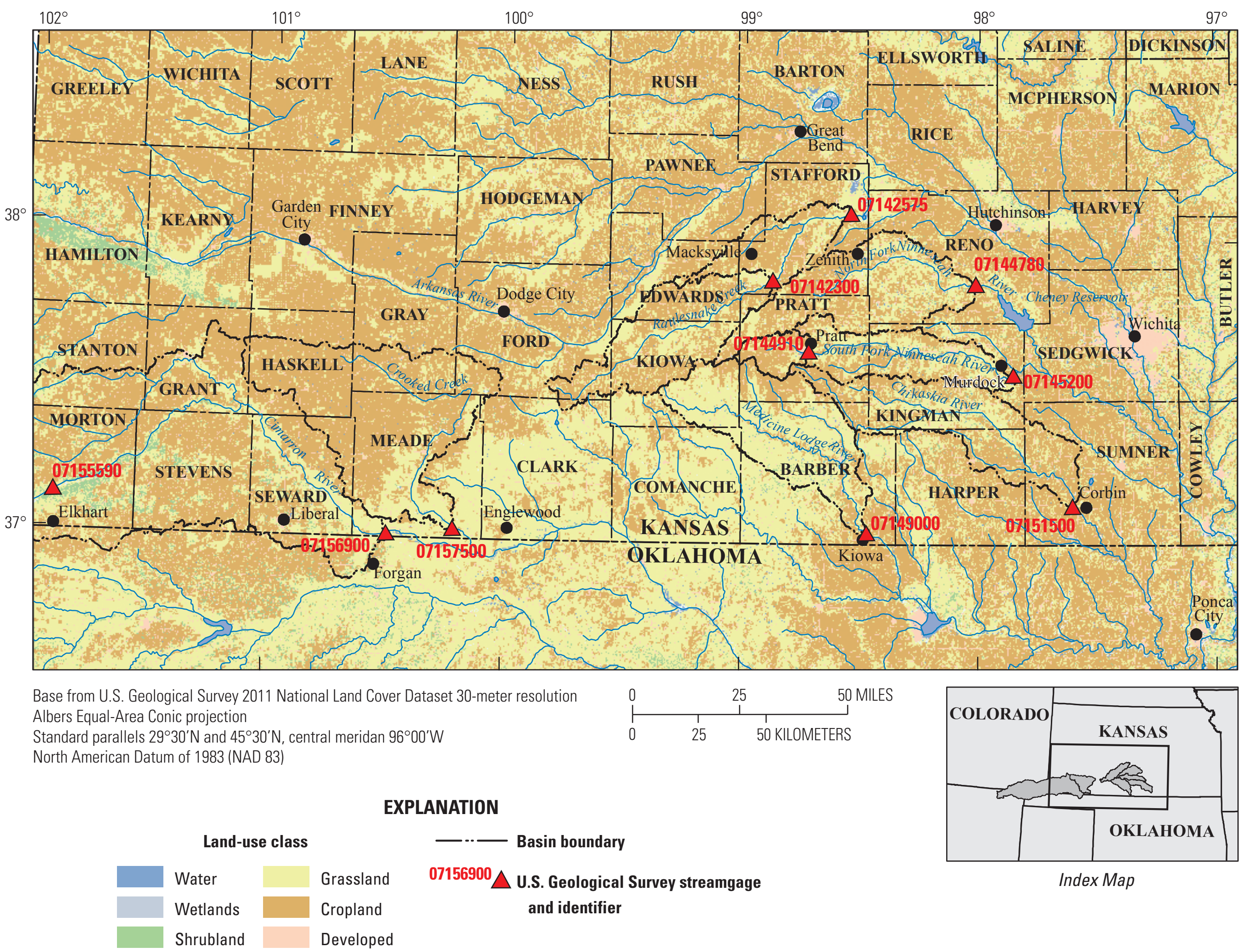

Figure 1. Basin boundaries, selected U.S. Geological Survey streamgages, and land use (2011), southwest and south-central Kansas.

River (fig. 1). Average annual precipitation in the study area increases from about 15 to 20 inches (in.) in the west to about 30 in. in the east (Sophocleous, 1998; High Plains Regional Climate Center, 2014). Land use in the basins mostly is a mix of cropland and grassland (fig. 1) (Jin and others, 2013).

In the study area, the High Plains aquifer underlies all or most of the basins of the Cimarron River, Rattlesnake Creek, North Fork Ninnescah River, and South Fork Ninnescah River; however, the aquifer is not present in much of the Medicine Lodge and Chikaskia River Basins (fig. 2). Extensive use of groundwater from the aquifer, primarily for irrigated agriculture, began in the 1950s and continues to the present (Kansas Water Resources Board, 1958, 1960; Gutentag and others, 1984; Kenny and Juracek, 2013). Groundwater withdrawals from the aquifer, far in excess of natural recharge, have caused declines in groundwater levels (Gutentag and others, 1984; Young and others, 2005). Groundwater withdrawals for irrigation are the primary cause of groundwater-level changes in the aquifer (Young and others, 2005; Whittemore and others, 2015). In much of the Cimarron River Basin (of which Crooked Creek is a subbasin), groundwater levels have declined 50 to 150 feet (ft) or more. Declines of 10 to 25 ft or more have occurred in upstream parts of the basins of Rattlesnake Creek, the North Fork Ninnescah River, and the South Fork Ninnescah River (McGuire, 2014) (fig. 2).

Methods

Streamflow characteristics and trends were examined for the period of record for nine USGS streamgages situated in the priority basins of southwest and south-central Kansas (fig. 1, table 1). The available streamflow data used for this study were collected as part of the USGS national streamgaging network using standard USGS methods (Turnipseed and Sauer, 2010). Near real-time and historical streamflow data for the

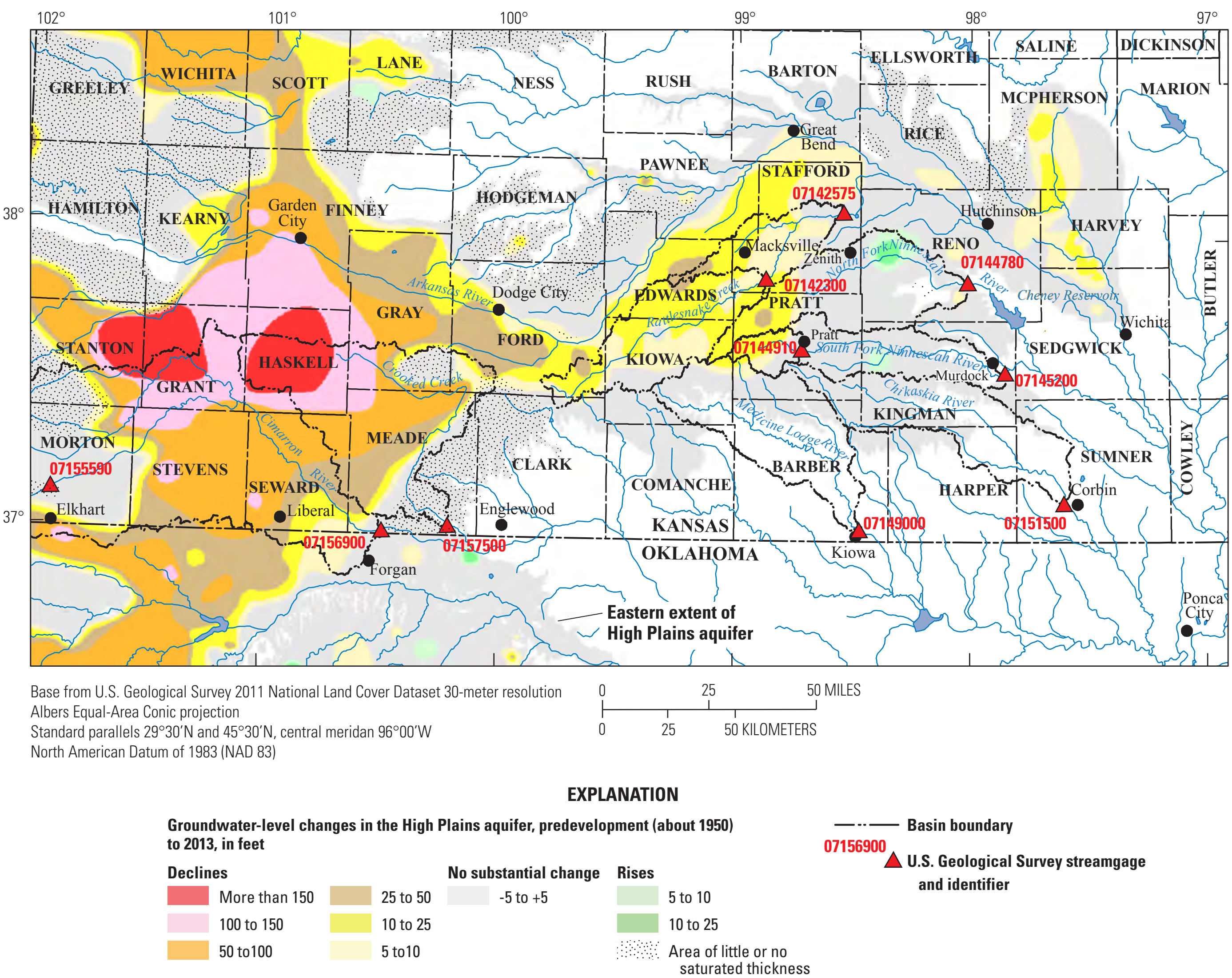

Figure 2. Groundwater-level changes in the High Plains aquifer, predevelopment to 2013. (Source: McGuire, 2014).

Table 1. Nine U.S. Geological Survey streamgages in the priority basins used in this study to examine streamflow characteristics and trends.

[USGS, U.S. Geological Survey; mi², square miles]

USGS streamgage number (fig. 1)	USGS streamgage name	Drainage area[1,2] (mi^2)	Percentage of drainage area overlying the High Plains aquifer	Period of record
07142300	Rattlesnake Creek near Macksville, Kansas	723	100	1960–2013
07142575	Rattlesnake Creek near Zenith, Kansas	1,077	100	1974–2013
07144780	North Fork Ninnescah River above Cheney Reservoir, Kansas	797	93	1966–2013
07144910	South Fork Ninnescah River near Pratt, Kansas	122	100	1981–2013
07145200	South Fork Ninnescah River near Murdock, Kansas	597	90	1951–2013
07149000	Medicine Lodge River near Kiowa, Kansas	885	42	1939–2013
07151500	Chikaskia River near Corbin, Kansas	815	49	1951–2013
07156900	Cimarron River near Forgan, Oklahoma	6,593	70	1966–2013
07157500	Crooked Creek near Englewood, Kansas	1,416	100	1943–2013

[1]Drainage area computed using the watershed boundary dataset component of The National Map (U.S. Geological Survey, 2010).

[2]Substantial parts of the Rattlesnake Creek, North Fork Ninnescah River, South Fork Ninnescah River, Cimarron River, and Crooked Creek Basins may be noncontributing.

nine streamgages are available from the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2014).

For each streamgage, annual streamflow characteristics were computed for each water year (October 1 to September 30) during the period of record using daily mean streamflow values downloaded from NWIS (U.S. Geological Survey, 2014). Specific streamflow characteristics computed were mean discharge, mean base flow, 90th-percentile flow, 10th-percentile flow, minimum 7-day mean flow, minimum 28-day mean flow, number of days of flow less than 1 cubic foot per second (ft^3/s), and number of zero-flow days. Annual mean base flow was computed as the average of daily mean base flow values that were estimated using a base flow-separation technique as described by Wahl and Wahl (1995). The annual 90th-percentile flow is the daily mean streamflow value that is greater than 90 percent of all daily values for a given year. The annual 10th-percentile flow is the daily mean streamflow value that 10 percent of all daily values are less than for a given year.

Determination of the annual minimum 7- and 28-day mean flows involved two steps. First, for each day of the water year, the mean 7- and 28-day flows were computed. Each day represents the end of the 7- or 28-day period for which the means were computed. Second, the mean 7- and 28-day flows were compared to determine the minimum 7- and 28-day mean flows for each water year.

To assess the effects of natural and human factors on streamflow, information on precipitation and groundwater withdrawals was used. Spatially averaged annual precipitation estimates for the basins of the nine selected USGS streamgages were derived from Parameter-elevation Relationships on Independent Slopes Model (PRISM) monthly precipitation data for 1951 through 2013. The PRISM data are based on available data from precipitation stations and interpolation with a sophisticated model that incorporates various physical factors including location and elevation (Daly and others, 2008). Information on groundwater withdrawals was derived from a map of groundwater-level changes (predevelopment to 2013) for the High Plains aquifer (McGuire, 2014). For this report, although specific data on groundwater withdrawals are not used, the variable groundwater-level declines in the basins since predevelopment (fig. 2) are considered indicative of variable amounts of groundwater withdrawals.

Trends were assessed by computing the coefficient of determination (R^2) and *p*-value from linear regression analysis using Microsoft Excel® software. The R^2 indicates the extent to which a dependent variable can be predicted by an independent variable using regression. The R^2 values range from 0, which indicates that none of the variance is explained, to 1, which indicates that all of the variance is explained. In this report, an R^2 value greater than 0.5 is considered a strong relation, 0.25 to 0.5 a moderate relation, and less than 0.25 a weak relation. The *p*-value indicates the statistical significance of a trend. The *p*-value is a probability that measures the "believability" of the null hypothesis (in this case, no trend). The smaller the *p*-value, the greater the evidence for rejection of the null hypothesis (Helsel and Hirsch, 1992). In this study, a trend was considered statistically significant if the *p*-value was less than or equal to 0.05. Throughout the report, statistically significant trends are simply referred to as "significant."

Streamflow Characteristics and Trends

In this section, results of the streamflow analyses for the nine selected streamgages are presented. The order of presentation generally is west to east across the priority basins. From west to east, groundwater withdrawals from the High Plains aquifer generally decrease and annual precipitation increases. Note that the terms discharge, streamflow and flow are used interchangeably.

Cimarron River near Forgan, Oklahoma

During the period of record (1966 to 2013) at the Cimarron River near Forgan, Oklahoma, streamgage (station 07156900, fig. 1, table 1) (hereafter referred to as "Forgan"), there was a pronounced decrease in the magnitude and variability of annual mean discharge (fig. 3). Most of the decrease in magnitude occurred prior to 1985. From the mid-1980s to the late 1990s, annual mean discharge was relatively stable. Subsequently, annual mean discharge again decreased in magnitude. Overall, the variability of annual mean discharge decreased from a pre-1980 range of about 60 to 140 ft^3/s to a post-2000 range of about 20 to 35 ft^3/s. The overall decrease in magnitude of annual mean discharge was significant (table 2). Likewise, there was a significant decrease in annual mean base flow (table 2) during the period of record (fig. 3). Concurrently, the percentage of the annual mean discharge that was annual mean base flow increased (fig. 3). Since 1980, typically about 80 to 90 percent of the annual mean discharge was contributed by base flow. Young and others (2005) determined that, in response to groundwater-level declines, the location where perennial flow in the Cimarron River begins in Seward County, Kansas, has migrated downstream about 15 miles.

The decrease in discharge magnitude and variability during the period of record at Forgan was evidenced by several other streamflow characteristics. Annual 90th-percentile flows decreased from about 120 ft^3/s to about 30 ft^3/s (fig. 4). Annual

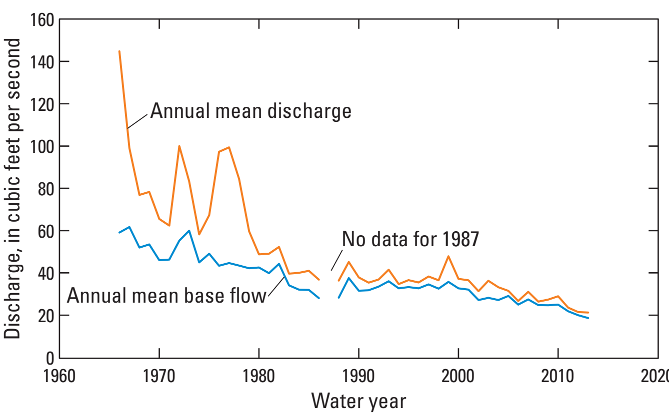

Figure 3. Variation in annual mean discharge and annual mean base flow at the Cimarron River near Forgan, Oklahoma, streamgage (station 07156900), 1966–2013.

10th-percentile flows decreased from about 50 ft^3/s to less than 20 ft^3/s (fig. 4). Thus, during the period of record, the magnitude of both high and low flows decreased. Pronounced decreases also were apparent for the annual minimum 7-day and 28-day mean flows (fig. 5). During the period of record, the minimum 7- and 28-day mean flows decreased from about 40 to 10 ft^3/s and about 50 to 10 ft^3/s, respectively. For each of these four characteristics, the decrease was significant (table 2).

Given the importance of flow availability for darter habitat, the annual occurrence of extreme low flows was investigated. At Forgan, there were no days with a mean flow less than 1 ft^3/s and no zero-flow days during the period of record; however, about 125 river miles upstream at the discontinued USGS streamgage Cimarron River near Elkhart, Kansas (station 07155590, period of record 1971 to 2013; fig. 1), zero-flow days were typical and occurred 81 percent of the time (U.S. Geological Survey, 2014). The discrepancy in flow conditions is indicative of the increased contribution of base flow to the Cimarron River between the two streamgages.

Crooked Creek near Englewood, Kansas

At the Crooked Creek near Englewood, Kansas, streamgage (station 07157500, fig. 1, table 1) (hereafter referred to as "Englewood"), there was a pronounced decrease in the magnitude and variability of annual mean discharge (fig. 6) during the period of record (1943 to 2013). The decrease in magnitude was significant (table 2) and mostly occurred prior to 1980. The pre-1980 annual mean discharge ranged from about 10 ft^3/s to nearly 180 ft^3/s and exceeded 40 ft^3/s about 30 percent of the time. After 1975, variability decreased and the annual mean discharge was consistently less than 20 ft^3/s with a mean of about 10 ft^3/s. The observed decrease in annual mean base flow during the period of record was significant (table 2). Typically, annual mean base flow was about 10 ft^3/s or less after 1975 (fig. 6). The percentage of the annual mean discharge that was annual mean base flow increased from a pre-1960 range of about 15 to 50 percent to a post-1990 range of about 60 to 90 percent.

The annual 90th-percentile flows decreased in magnitude and variability during the period of record at Englewood (fig. 7), and the decrease in magnitude was significant (table 2). Prior to 1980, annual 90th-percentile flows ranged from about 15 ft^3/s to more than 300 ft^3/s. After 1980, annual 90th-percentile flows only varied between about 5 and 35 ft^3/s. For the annual 10th-percentile flows, changes were neither apparent nor significant because these flows frequently were at or near zero throughout the period of record (fig. 7, table 2).

Prior to 1975, the annual minimum 28-day mean flow at Englewood was somewhat more variable than the post-1975 period (fig. 8); however, a similar temporal pattern was not evident for the annual minimum 7-day mean flow (fig. 8). Throughout the period of record, the annual minimum 7- and 28-day mean flows generally were less than 10 ft^3/s and typically were less than 4 ft^3/s. For both streamflow characteristics, a significant trend was not indicated (fig. 8, table 2).

The annual occurrence of extremely low-flow (less than 1 ft^3/s) and zero-flow days varied considerably at Englewood during the period of record. The annual number of extremely low-flow days typically varied between 0 and 60 (fig. 9*A*); however, in six years (1952, 1954, 1956, 2011, 2012, 2013) there were more than 80 such days. The annual number of zero-flow days typically varied between 0 and 50 (fig. 9*B*). Between 1980 and 2010, zero-flow days rarely occurred. Extremely low-flow and zero-flow days most commonly occurred at Englewood during the months of June, July, August, and September.

Table 2. Results of trend tests for annual streamflow characteristics for the nine selected U.S. Geological Survey streamgages in southwest and south-central Kansas.

[E, standard scientific notation for exponent]

Streamflow characteristic	*p*-value	Trend
Cimarron River near Forgan, Oklahoma (station 07156900)		
Mean discharge	1.48E-12	negative
Mean base flow	7.69E-19	negative
90th-percentile flow	3.84E-16	negative
10th-percentile flow	5.25E-14	negative
Minimum 7-day mean flow	6.79E-10	negative
Minimum 28-day mean flow	1.80E-13	negative
Crooked Creek near Englewood, Kansas (station 07157500)		
Mean discharge	9.60E-06	negative
Mean base flow	5.42E-04	negative
90th-percentile flow	2.42E-05	negative
10th-percentile flow	5.34E-01	none
Minimum 7-day mean flow	5.28E-01	none
Minimum 28-day mean flow	4.20E-01	none
Rattlesnake Creek near Macksville, Kansas (station 07142300)		
Mean discharge	9.98E-04	negative
Mean base flow	2.27E-04	negative
90th-percentile flow	3.26E-03	negative
10th-percentile flow	5.43E-05	negative
Minimum 7-day mean flow	2.65E-04	negative
Minimum 28-day mean flow	1.73E-04	negative
Rattlesnake Creek near Zenith, Kansas (station 07142575)		
Mean discharge	7.42E-02	none
Mean base flow	1.16E-02	negative
90th-percentile flow	2.26E-01	none
10th-percentile flow	3.13E-02	negative
Minimum 7-day mean flow	5.00E-02	negative
Minimum 28-day mean flow	4.47E-02	negative
North Fork Ninnescah River above Cheney Reservoir, Kansas (station 07144780)		
Mean discharge	9.62E-01	none
Mean base flow	2.33E-01	none
90th-percentile flow	9.13E-01	none
10th-percentile flow	1.33E-01	none
Minimum 7-day mean flow	7.73E-02	none
Minimum 28-day mean flow	2.42E-01	none
South Fork Ninnescah River near Pratt, Kansas (station 07144910)		
Mean discharge	2.33E-01	none
Mean base flow	1.88E-02	negative
90th-percentile flow	1.25E-01	none
10th-percentile flow	7.65E-02	none
Minimum 7-day mean flow	1.74E-01	none
Minimum 28-day mean flow	2.17E-01	none
South Fork Ninnescah River near Murdock, Kansas (station 07145200)		
Mean discharge	7.34E-01	none
Mean base flow	4.29E-03	positive
90th-percentile flow	3.01E-01	none
10th-percentile flow	2.39E-02	positive
Minimum 7-day mean flow	1.06E-02	positive
Minimum 28-day mean flow	7.18E-02	none
Medicine Lodge River near Kiowa, Kansas (station 07149000)		
Mean discharge	6.41E-01	none
Mean base flow	9.78E-04	positive
90th-percentile flow	6.76E-01	none
10th-percentile flow	2.64E-02	positive
Minimum 7-day mean flow	1.59E-01	none
Minimum 28-day mean flow	1.33E-01	none
Chikaskia River near Corbin, Kansas (station 07151500)		
Mean discharge	1.50E-01	none
Mean base flow	1.74E-03	positive
90th-percentile flow	2.38E-01	none
10th-percentile flow	1.89E-02	positive
Minimum 7-day mean flow	7.71E-03	positive
Minimum 28-day mean flow	8.63E-02	none

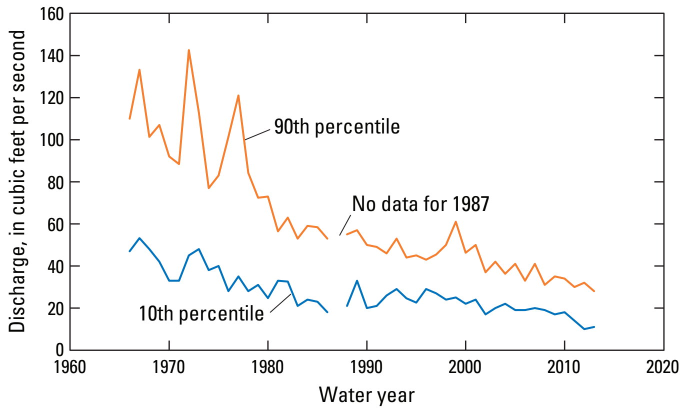

Figure 4. Variation in annual 90th- and 10th-percentile streamflows at the Cimarron River near Forgan, Oklahoma, streamgage (station 07156900), 1966–2013.

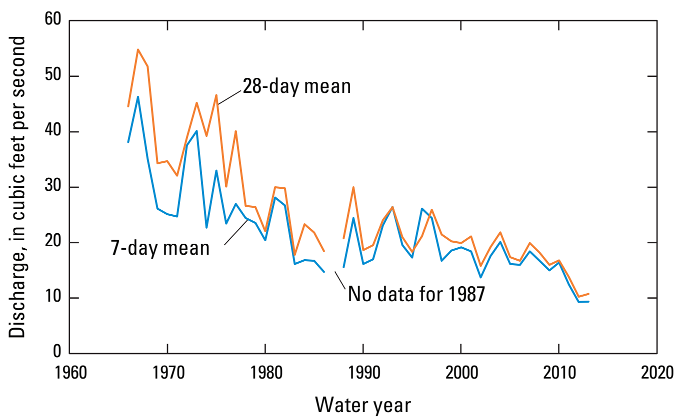

Figure 5. Variation in annual minimum 7-day and 28-day mean flows at the Cimarron River near Forgan, Oklahoma, streamgage (station 07156900), 1966–2013.

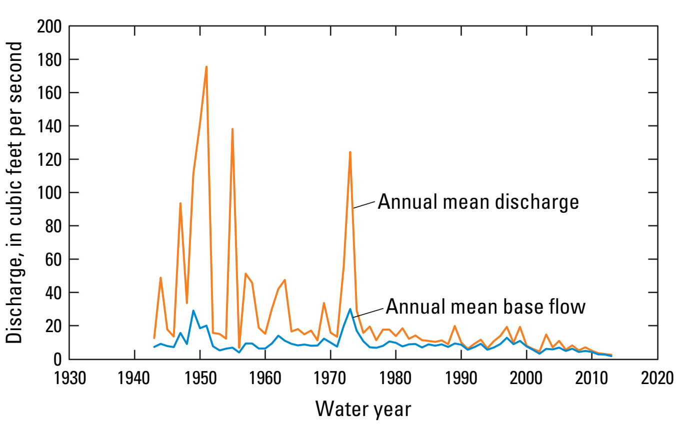

Figure 6. Variation in annual mean discharge and annual mean base flow at the Crooked Creek near Englewood, Kansas, streamgage (station 07157500), 1943–2013.

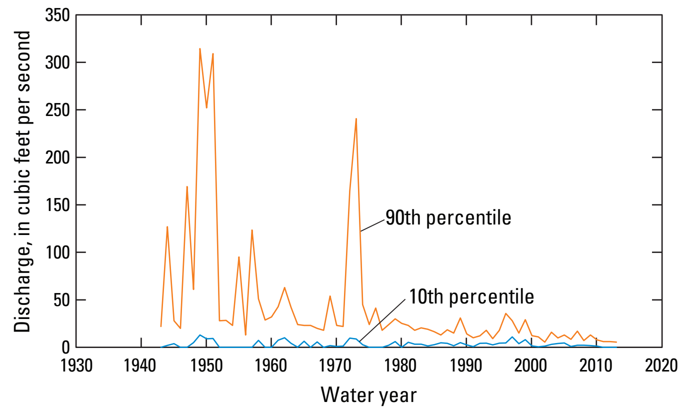

Figure 7. Variation in annual 90th- and 10th-percentile streamflows at the Crooked Creek near Englewood, Kansas, streamgage (station 07157500), 1943–2013.

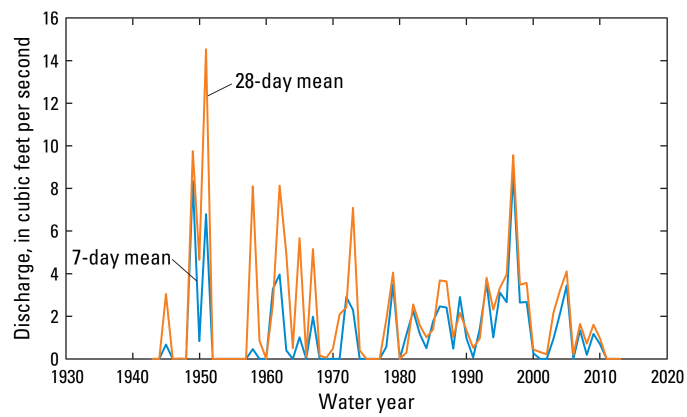

Figure 8. Variation in annual minimum 7-day and 28-day mean flows at the Crooked Creek near Englewood, Kansas, streamgage (station 07157500), 1943–2013.

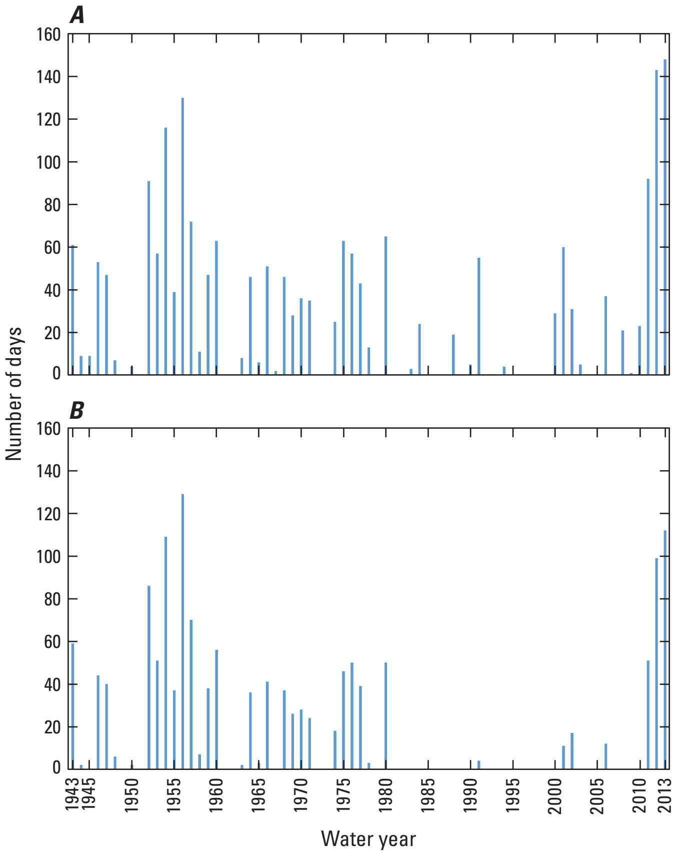

Figure 9. Variation at the Crooked Creek near Englewood, Kansas, streamgage (station 07157500), 1943–2013. *A*, annual number of days with mean discharge less than 1 cubic foot per second. *B*, annual number of zero-flow days.

Rattlesnake Creek near Macksville, Kansas

During the period of record (1960 to 2013) at the Rattlesnake Creek near Macksville, Kansas, streamgage (station 07142300, fig. 1, table 1) (hereafter referred to as "Macksville"), there was a decrease in the magnitude and variability of annual mean discharge (fig. 10). Prior to 1985, annual mean discharge ranged from about 6 ft^3/s to about 110 ft^3/s. After 1985, annual mean discharge ranged from nearly 0 to about 35 ft^3/s. Observed decreases in both annual mean discharge and annual mean base flow were significant during the period of record (table 2). The percentage of the annual mean discharge that was annual mean base flow varied considerably from year to year with no pronounced trend. Typically, annual mean base flow accounted for 40 to 90 percent of the annual mean discharge.

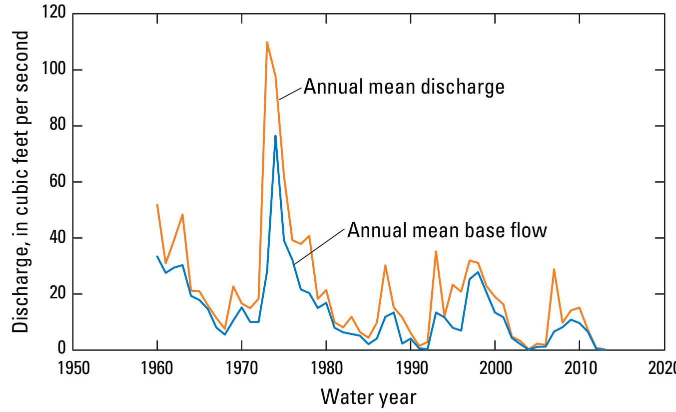

Figure 10. Variation in annual mean discharge and annual mean base flow at the Rattlesnake Creek near Macksville, Kansas, streamgage (station 07142300), 1960–2013.

The annual 90th- and 10th-percentile flows also decreased in magnitude and variability during the period of record at Macksville (fig. 11). For the 90th-percentile flows, the pre-1985 range was about 10 to 140 ft^3/s, whereas the post-1985 range was about zero to 55 ft^3/s. After 1985, the 10th-percentile flows were at or near zero in 19 of 29 years. The decrease for both streamflow characteristics during the period of record was significant (table 2).

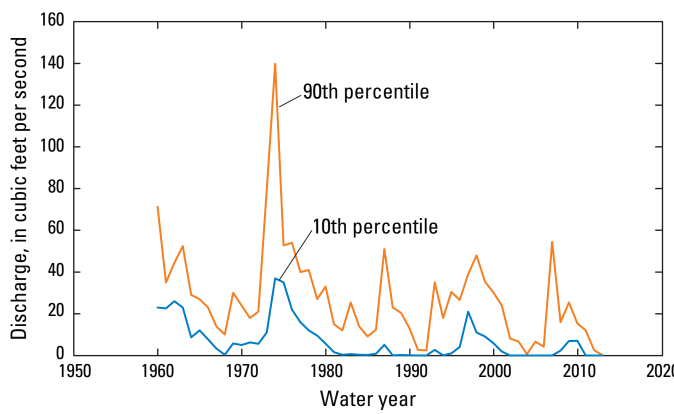

Figure 11. Variation in annual 90th- and 10th-percentile streamflows at the Rattlesnake Creek near Macksville, Kansas, streamgage (station 07142300), 1960–2013.

Annual minimum 7-day and 28-day mean flows were similar during the period of record, and both exhibited more variability before 1985 (fig. 12). The pre-1985 and post-1985 ranges for the minimum 7- and 28-day mean flows were 0 to about 35 ft^3/s and 0 to about 20 ft^3/s, respectively. Typically, the post-1985 minimum 7- and 28-day mean flows were less than 5 ft^3/s and frequently were at or near zero. During the period of record, a significant decrease was indicated for both streamflow characteristics (table 2).

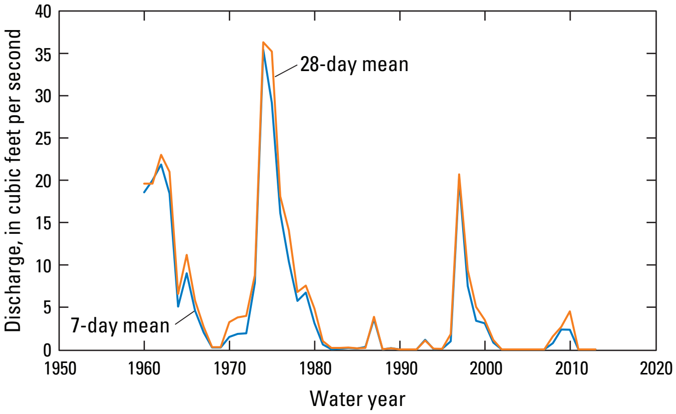

Figure 12. Variation in annual minimum 7-day and 28-day mean flows at the Rattlesnake Creek near Macksville, Kansas, streamgage (station 07142300), 1960–2013.

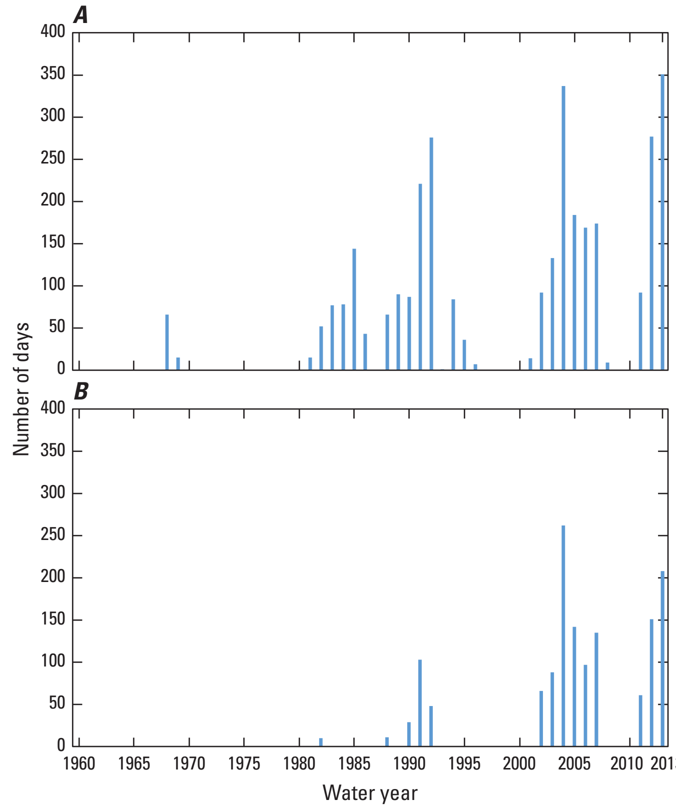

Figure 13. Variation at the Rattlesnake Creek near Macksville, Kansas, streamgage (station 07142300), 1960–2013. *A*, annual number of days with mean discharge less than 1 cubic foot per second. *B*, annual number of zero-flow days.

At Macksville, days with extremely low flow (less than 1 ft^3/s) or zero flow were rare before 1980 (fig. 13). Since 1980, such days have been a frequent occurrence. During the 20 years prior to 1980, extremely low-flow days only occurred in 2 years; however, since 1980, extremely low-flow days occurred in 26 of 33 years. Moreover, since 1980, 19 years had more than 50 days with extremely low flow (fig. 13*A*). No zero-flow days occurred before 1980. After 1980, zero-flow days occurred in 14 of 33 years. Since 2000, 9 of 13 years had more than 50 zero-flow days and 5 years had more than 100 zero-flow days (fig. 13*B*). Although extremely low-flow and zero-flow days occurred in all months, they most commonly occurred in July, August, September, October, and November.

Rattlesnake Creek near Zenith, Kansas

The Rattlesnake Creek near Zenith, Kansas, streamgage (station 07142575, fig. 1, table 1) (hereafter referred to as “Zenith”), is located about 68 stream miles downstream from the Macksville streamgage (fig. 1). The drainage basin at Zenith is about 354 square miles (49 percent) larger than at Macksville (table 1).

At Zenith, the annual mean discharge decreased from 1974 to 1985. After 1985, the annual mean discharge fluctuated generally between about 5 and 80 ft^3/s with no pronounced trend (fig. 14). An exception was 1993 when the annual mean discharge was about 185 ft^3/s. Overall, for the period of record (1974 to 2013), a significant trend in annual mean discharge was not indicated (table 2). For annual mean base flow, which was characterized by considerable year-to-year variability, a significant negative (downward) trend was indicated for the period of record (table 2). The most pronounced decrease in annual mean base flow occurred prior to 1985 (fig. 14). The percentage of the annual mean discharge that was annual mean base flow also was characterized by substantial year-to-year variability. Typically, annual mean base flow accounted for 40 to 80 percent of the annual mean discharge.

The historical pattern indicated for the annual mean discharge also was apparent for the annual 90th- and 10th-percentile flows (fig. 15). After 1985, the 90th-percentile flows ranged between about 10 and 240 ft^3/s and typically were less than 100 ft^3/s. Concurrently, the 10th-percentile flows ranged between zero and about 35 ft^3/s with a mean of 8 ft^3/s. During the period of record, a significant trend was not indicated for the 90th-percentile flows; however, a significant decrease was indicated for the 10th-percentile flows (table 2).

The annual minimum 7-day and 28-day mean flows also decreased from 1974 to 1985 and subsequently fluctuated (fig. 16). During the period of record, the minimum 7- and 28-day mean flows typically were similar. After 1985, the minimum 7- and 28-day mean flows ranged from zero to 30 ft^3/s and were less than 5 ft^3/s in 21 of 29 years. For both streamflow characteristics, a significant decrease was indicated during the period of record (table 2).

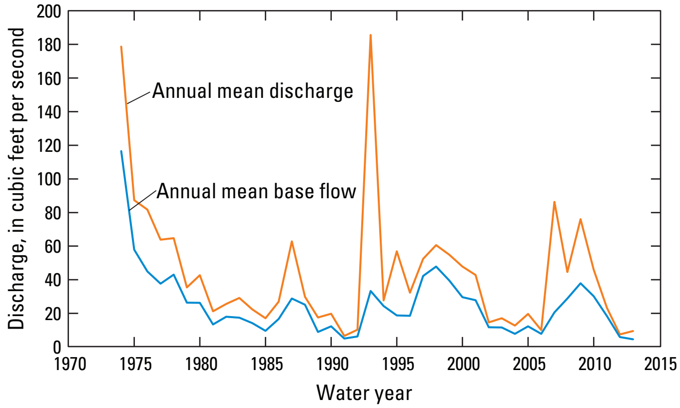

Figure 14. Variation in annual mean discharge and annual mean base flow at the Rattlesnake Creek near Zenith, Kansas, streamgage (station 07142575), 1974–2013.

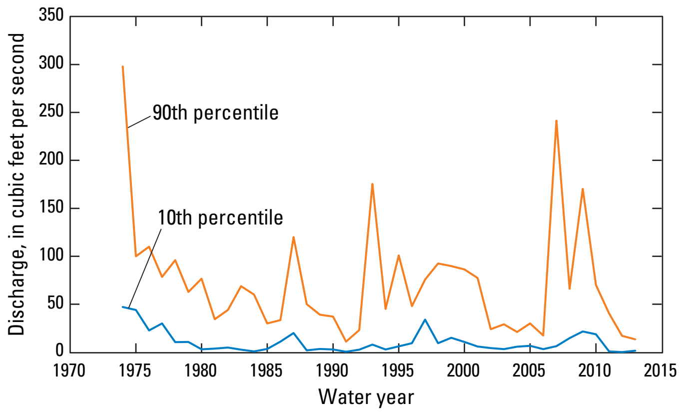

Figure 15. Variation in annual 90th- and 10th-percentile streamflows at the Rattlesnake Creek near Zenith, Kansas, streamgage (station 07142575), 1974–2013.

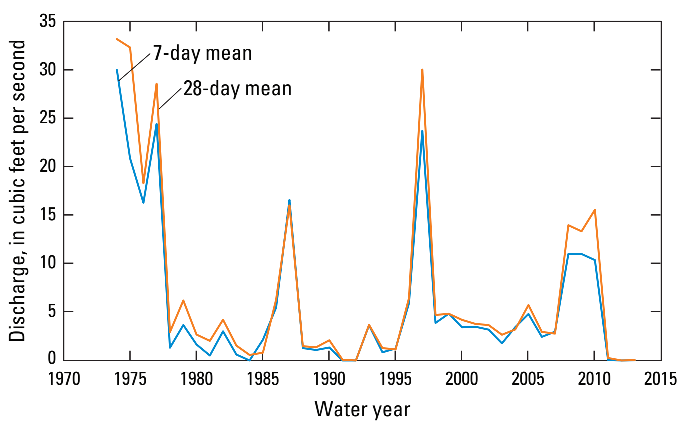

Figure 16. Variation in annual minimum 7-day and 28-day mean flows at the Rattlesnake Creek near Zenith, Kansas, streamgage (station 07142575), 1974–2013.

Days with extremely low flow (less than 1 ft^3/s) or zero flow were an infrequent occurrence during the period of record at Zenith. Only 5 years (1984, 1991, 1992, 2011, and 2012) had more than 30 days of extremely low flow (fig. 17*A*). Only 2012 had more than 30 zero-flow days (fig. 17*B*). Extremely low-flow and zero-flow days typically occurred in August, September, and October.

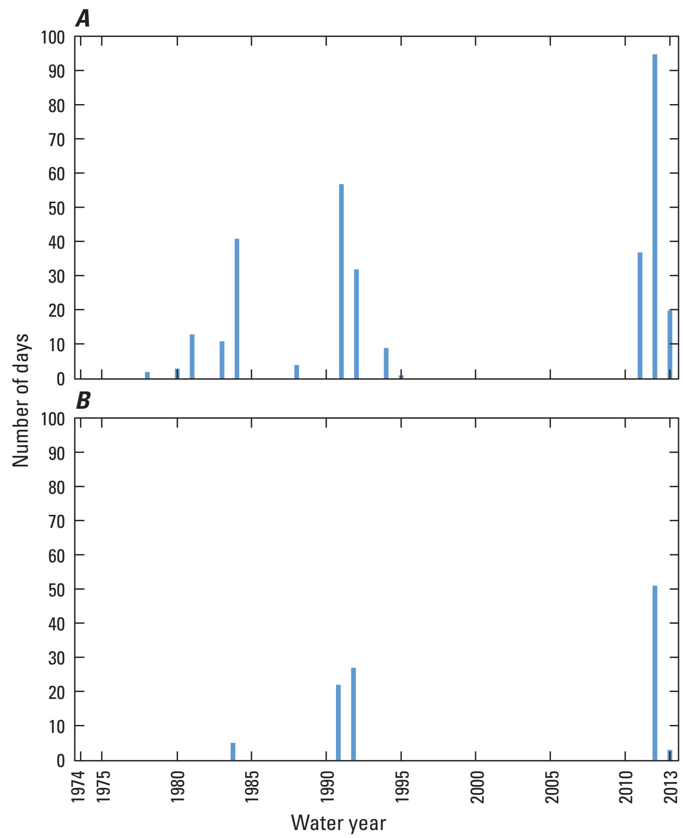

Figure 17. Variation at the Rattlesnake Creek near Zenith, Kansas, streamgage (station 07142575), 1974–2013. *A*, annual number of days with mean discharge less than 1 cubic foot per second. *B*, annual number of zero-flow days.

North Fork Ninnescah River above Cheney Reservoir, Kansas

During the period of record (1966 to 2013) at the North Fork Ninnescah River above Cheney Reservoir, Kansas, streamgage (station 07144780, fig. 1, table 1) (hereafter referred to as "Ninnescah"), there was not a significant trend in annual mean discharge or annual mean base flow (fig. 18, table 2); however, prior to 2000, the variability in annual mean discharge was greater. Before 2000, annual mean discharge ranged from about 50 ft^3/s to about 390 ft^3/s and exceeded 250 ft^3/s five times. After 2000, annual mean discharge ranged from about 50 ft^3/s to about 220 ft^3/s and typically was less than 160 ft³/s. Annual mean base flow during the period of record ranged between about 35 and 125 ft³/s. Typically, annual mean base flow accounted for 30 to 75 percent of the annual mean discharge.

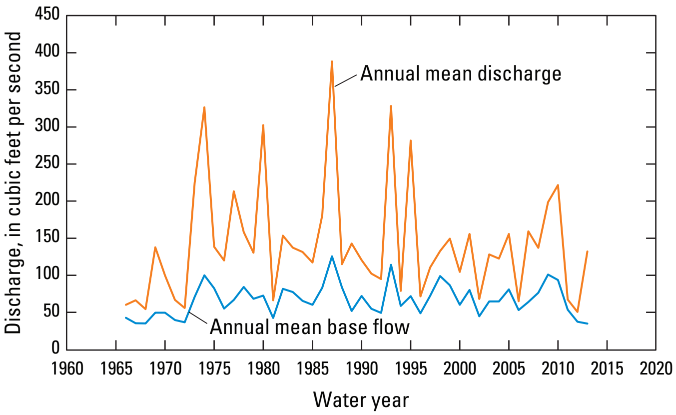

Figure 18. Variation in annual mean discharge and annual mean base flow at the North Fork Ninnescah River above Cheney Reservoir, Kansas, streamgage (station 07144780), 1966–2013.

For the annual 90th- and 10th-percentile flows, a significant trend was not indicated (fig. 19, table 2). During the period of record, the 90th-percentile flows ranged from about 100 ft³/s to about 600 ft³/s and typically were less than 350 ft³/s. Concurrently, the 10th-percentile flows ranged from about 4 ft³/s to about 90 ft³/s and frequently were less than 30 ft³/s.

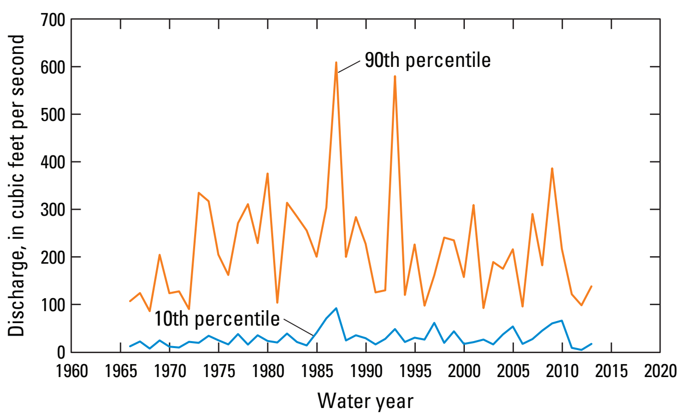

Figure 19. Variation in annual 90th- and 10th-percentile streamflows at the North Fork Ninnescah River above Cheney Reservoir, Kansas, streamgage (station 07144780), 1966–2013.

A significant trend was not indicated for the annual minimum 7-day and 28-day mean flows at Ninnescah during the period of record (fig. 20, table 2); however, there was a notable increase in variability beginning in the mid-1980s. From 1966 to the early 1980s, the minimum 7- and 28-day mean flows varied between zero and about 25 ft³/s. Subsequently, the minimum 7- and 28-day mean flows varied between zero and about 100 ft³/s with 7 years having minimum mean flows greater than 30 ft³/s.

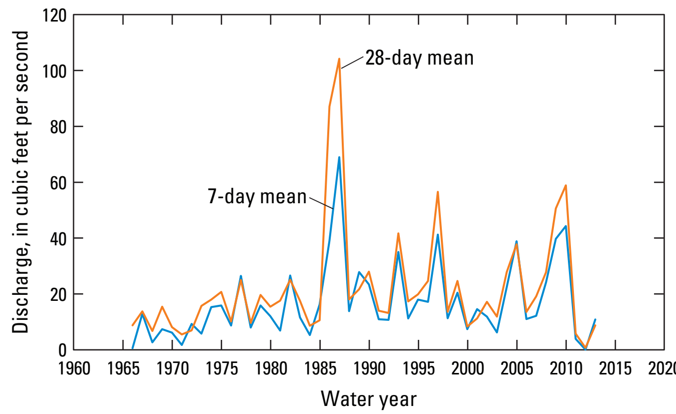

Figure 20. Variation in annual minimum 7-day and 28-day mean flows at the North Fork Ninnescah River above Cheney Reservoir, Kansas, streamgage (station 07144780), 1966–2013.

At Ninnescah, days with extremely low flow (less than 1 ft³/s) or zero flow were a rare occurrence. Extremely low flows were measured only in 1966 (7 days), 1968 (1 day), and 2012 (20 days). Zero-flow days were measured only in 1966 (1 day) and 2012 (5 days).

South Fork Ninnescah River near Pratt, Kansas

At the South Fork Ninnescah River near Pratt, Kansas, streamgage (station 07144910, fig. 1, table 1) (hereafter referred to as "Pratt"), annual mean discharge exhibited pronounced year-to-year variability during the period of record (1981 to 2013) with no significant trend (fig. 21, table 2); however, following the peak year of 1997, there was a possible negative trend. Typically, annual mean discharge ranged between 10 and 30 ft³/s. For annual mean base flow, which averaged about 9 ft³/s, a significant decrease was indicated during the period of record (fig. 21, table 2). Annual mean base flow typically accounted for 40 to 80 percent of the annual mean discharge.

The annual 90th- and 10th-percentile flows at Pratt were characterized by year-to-year variability with no significant trend (fig. 22, table 2). During the period of record, the 90th- and 10th-percentile flows averaged about 18 and 6 ft³/s, respectively.

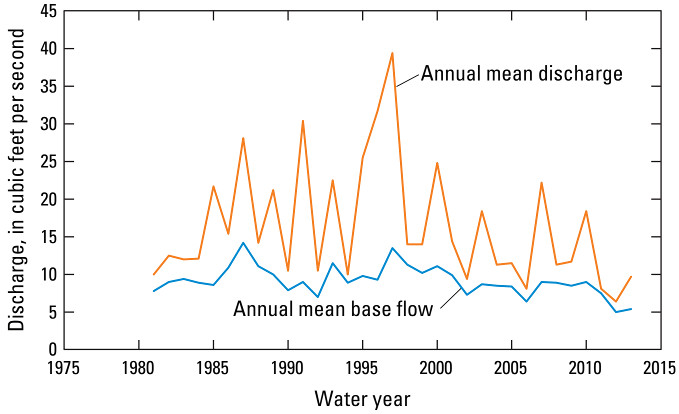

Figure 21. Variation in annual mean discharge and annual mean base flow at the South Fork Ninnescah River near Pratt, Kansas, streamgage (station 07144910), 1981–2013.

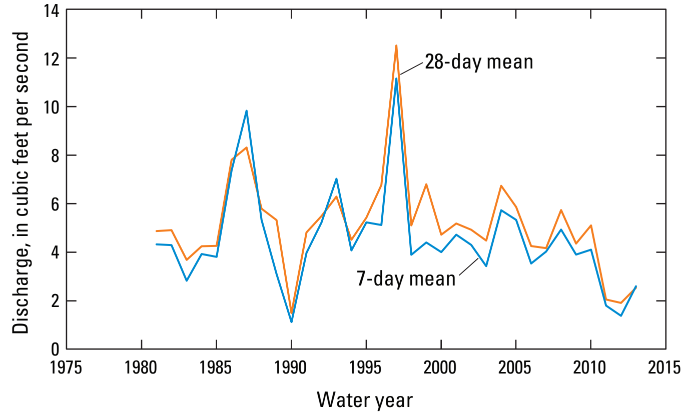

Figure 23. Variation in annual minimum 7-day and 28-day mean flows at the South Fork Ninnescah River near Pratt, Kansas, streamgage (station 07144910), 1981–2013.

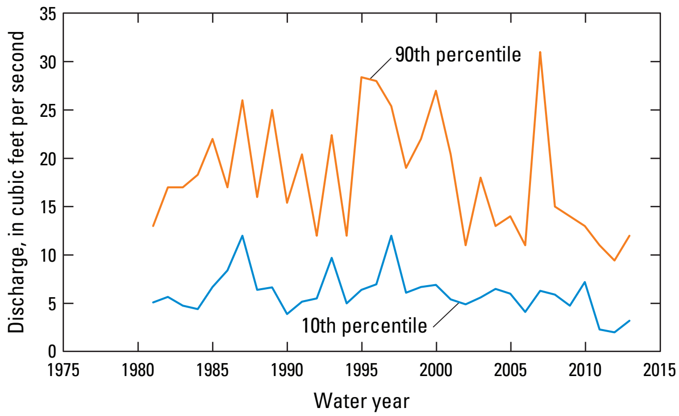

Figure 22. Variation in annual 90th- and 10th-percentile streamflows at the South Fork Ninnescah River near Pratt, Kansas, streamgage (station 07144910), 1981–2013.

The annual minimum 7-day and 28-day mean flows were variable with no significant trend during the period of record (fig. 23, table 2). With few exceptions, the minimum 7-day and 28-day mean flows ranged between 2 and 7 ft^3/s. Days with extremely low flow (less than 1 ft^3/s) were rare at Pratt as only three such days were recorded in 1990. No zero-flow days occurred during the period of record.

South Fork Ninnescah River near Murdock, Kansas

The South Fork Ninnescah River near Murdock, Kansas, streamgage (station 07145200, fig. 1, table 1) (hereafter referred to as "Murdock"), is located about 67 river miles downstream from the Pratt streamgage (fig. 1). The drainage basin at Murdock is about 475 square miles (389 percent) larger than at Pratt (table 1).

At Murdock, annual mean discharge varied considerably during the period of record (1951–2013) with no significant trend (fig. 24, table 2). Generally, annual mean discharge ranged between 100 and 350 ft^3/s. For annual mean base flow, which ranged between about 60 and 165 ft^3/s, a significant increase was indicated during the period of record (fig. 24, table 2). Annual mean base flow typically accounted for 40 to 80 percent of the annual mean discharge. Compared to Pratt, annual mean discharge and annual mean base flow at Murdock were an order of magnitude larger.

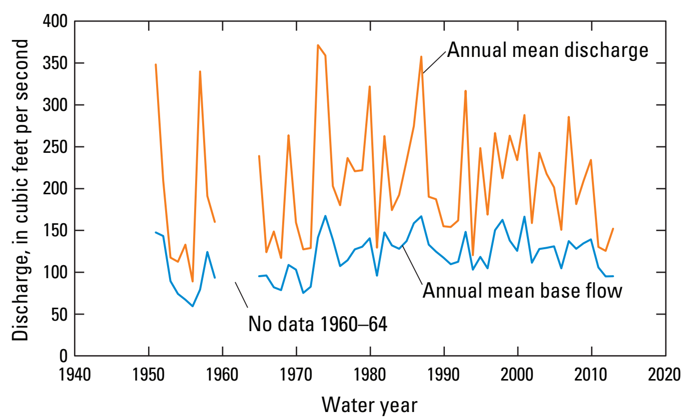

Figure 24. Variation in annual mean discharge and annual mean base flow at the South Fork Ninnescah River near Murdock, Kansas, streamgage (station 07145200), 1951–2013.

The annual 90th- and 10th-percentile flows at Murdock were characterized by year-to-year variability (fig. 25). During the period of record, the 90th-percentile flows ranged from 130 to 675 ft^3/s with a mean of 309 ft^3/s. Concurrently, the 10th-percentile flows ranged from 17 to 136 ft^3/s with a mean of 73 ft^3/s. No significant trend was indicated for the 90th-percentile flows; however, a significant increase was indicated for the 10th-percentile flows (fig. 25, table 2).

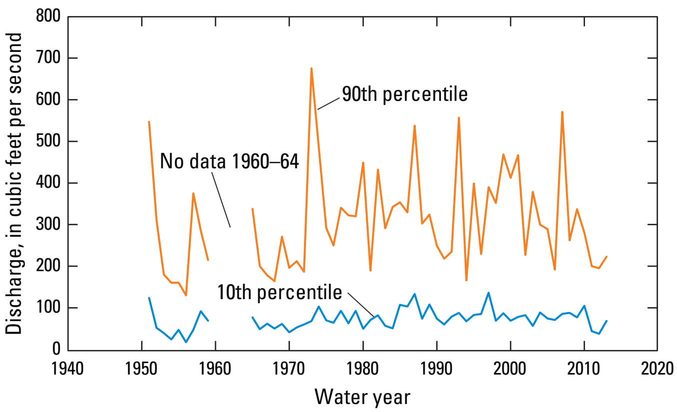

Figure 25. Variation in annual 90th- and 10th-percentile streamflows at the South Fork Ninnescah River near Murdock, Kansas, streamgage (station 07145200), 1951–2013.

During the period of record, the annual minimum 7-day and 28-day mean flows were variable and typically ranged between 20 and 90 ft^3/s (fig. 26). A significant increase was indicated for the minimum 7-day mean flows; however, no significant trend was indicated for the minimum 28-day mean flows (table 2). No extremely low-flow (less than 1 ft^3/s) or zero-flow days occurred during the period of record.

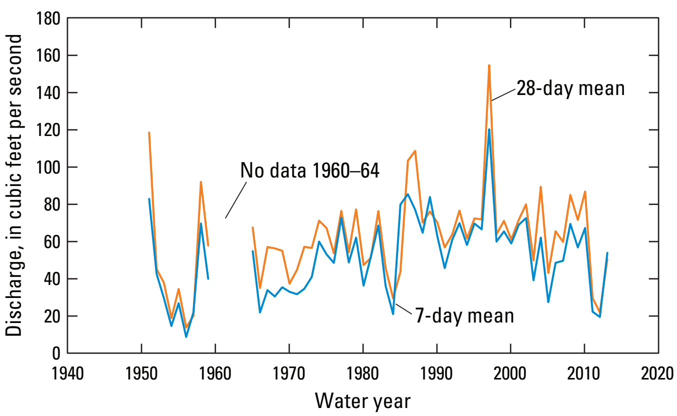

Figure 26. Variation in annual minimum 7-day and 28-day mean flows at the South Fork Ninnescah River near Murdock, Kansas, streamgage (station 07145200), 1951–2013.

Medicine Lodge River near Kiowa, Kansas

At the Medicine Lodge River near Kiowa, Kansas, streamgage (station 07149000, fig. 1, table 1) (hereafter referred to as "Kiowa"), annual mean discharge varied considerably with no significant trend during the period of record (1939 to 2013) (fig. 27, table 2). Annual mean discharge ranged from about 35 ft^3/s in 1964 to nearly 500 ft^3/s in 1949. For the period of record, a significant increase in annual mean base flow was indicated (table 2). Since 1960, annual mean base flow ranged from about 30 ft^3/s to about 180 ft^3/s and typically accounted for 40 to 80 percent of the annual mean discharge.

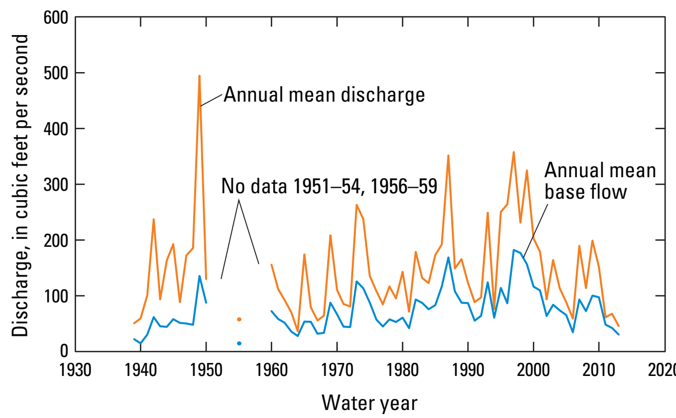

Figure 27. Variation in annual mean discharge and annual mean base flow at the Medicine Lodge River near Kiowa, Kansas, streamgage (station 07149000), 1939–2013.

A significant trend was not indicated for the annual 90th-percentile flows (fig. 28, table 2). During the period of record, the 90th-percentile flows typically ranged between 80 and 400 ft^3/s; however, for 5 years (1949, 1973, 1987, 1997, and 1999), the 90th-percentile flow was about 575 ft^3/s or greater. For the period of record, a significant increase was indicated for the annual 10th-percentile flows (table 2). The 10th-percentile flows ranged from zero to about 140 ft^3/s and typically were less than 50 ft^3/s.

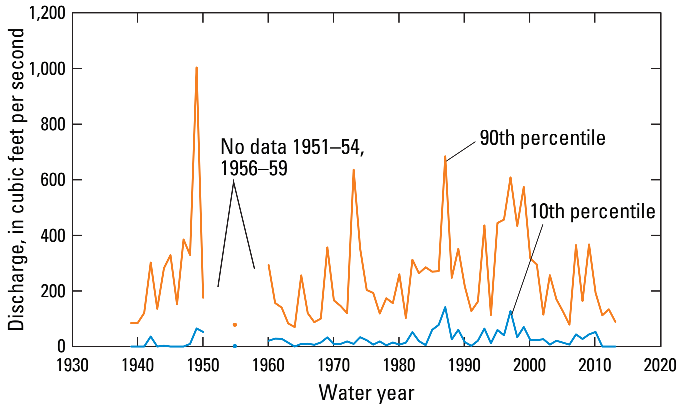

Figure 28. Variation in annual 90th- and 10th-percentile streamflows at the Medicine Lodge River near Kiowa, Kansas, streamgage (station 07149000), 1939–2013.

Since 1960, with the notable exceptions of 1987 and 1997, the annual minimum 7-day and 28-day mean flows generally ranged from zero to 30 ft³/s (fig. 29). During the period of record, a significant trend for these streamflow characteristics was not indicated (table 2).

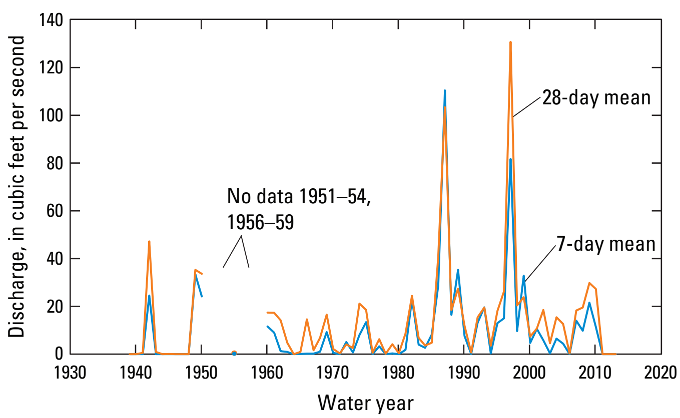

Figure 29. Variation in annual minimum 7-day and 28-day mean flows at the Medicine Lodge River near Kiowa, Kansas, streamgage (station 07149000), 1939–2013.

The occurrence of extremely low-flow (less than 1 ft³/s) and zero-flow days at Kiowa varied during the period of record. Extremely low-flow days were relatively frequent prior to 1960, infrequent between 1960 and 1980, rare between 1980 and 2010, and frequent since 2010 (fig. 30*A*). Zero-flow days had a similar pattern of occurrence (fig. 30*B*). Typically, extremely low and zero-flow days occurred in July, August, September, and October.

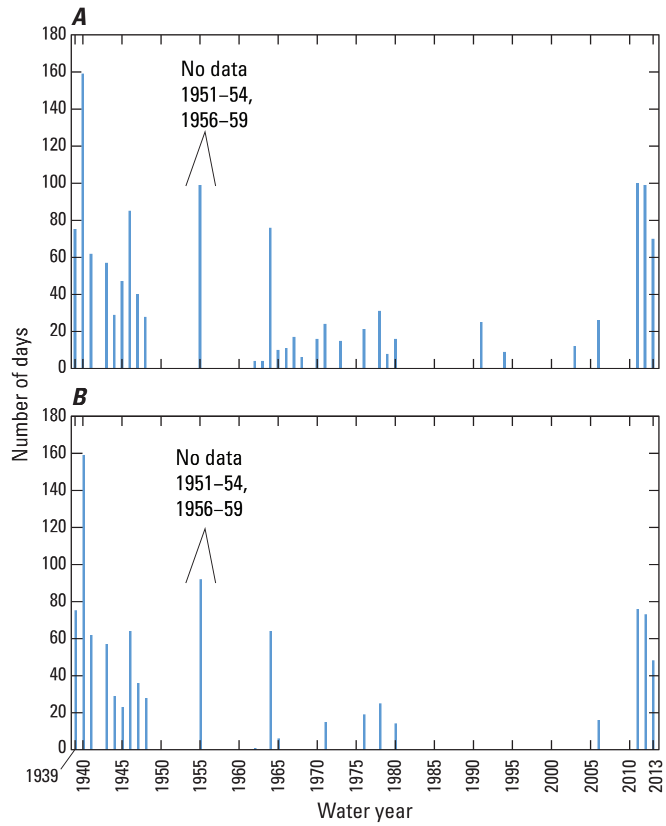

Figure 30. Variation at the Medicine Lodge River near Kiowa, Kansas, streamgage (station 07149000), 1939–2013. *A*, annual number of days with mean discharge less than 1 cubic foot per second. *B*, annual number of zero-flow days.

Chikaskia River near Corbin, Kansas

During the period of record (1951 to 2013) at the Chikaskia River near Corbin, Kansas, streamgage (station 07151500, fig. 1, table 1) (hereafter referred to as "Corbin"), annual mean discharge exhibited substantial year-to-year variability with no significant trend (fig. 31, table 2). Annual mean discharge ranged from 40 ft³/s in 1954 to more than 500 ft³/s in six different years. A significant increase was indicated for annual mean base flow during the period of record (table 2). Annual mean base flow ranged from about 20 ft³/s in the mid-1950s to about 220 ft³/s in 1999. Since the late 1970s, annual mean base flow typically accounted for 30 to 60 percent of the annual mean discharge.

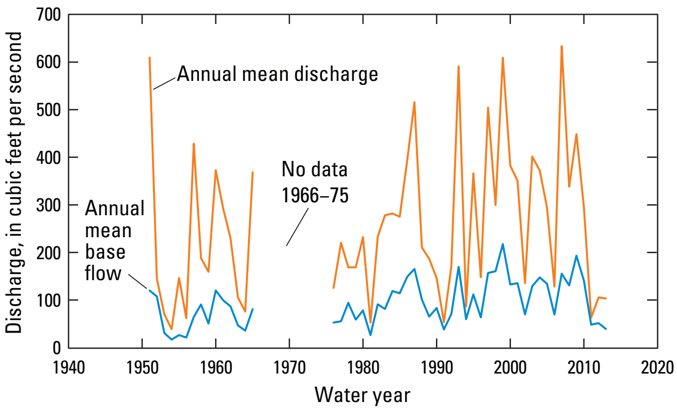

Figure 31. Variation in annual mean discharge and annual mean base flow at the Chikaskia River near Corbin, Kansas, streamgage (station 07151500), 1951–2013.

Pronounced year-to-year variability with no significant trend was exhibited by the annual 90th-percentile flows during the period of record (fig. 32, table 2). Since the late 1970s, the 90th-percentile flows ranged from about 90 ft³/s to more than 1,100 ft³/s. Concurrently, the annual 10th-percentile flows ranged from less than 5 ft³/s to about 130 ft³/s and typically were less than 50 ft³/s. For the period of record, a significant increase was indicated for the 10th-percentile flows (table 2).

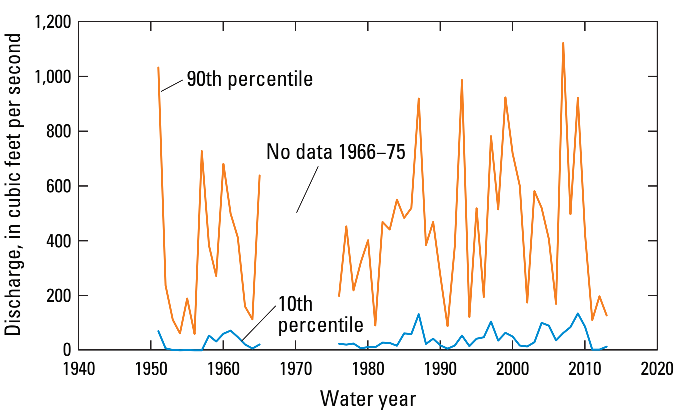

Figure 32. Variation in annual 90th- and 10th-percentile streamflows at the Chikaskia River near Corbin, Kansas, streamgage (station 07151500), 1951–2013.

At Corbin, the annual minimum 7-day and 28-day mean flows were characterized by pronounced year-to-year variability during the period of record (fig. 33). Since the late 1970s, the minimum 7-day mean flows ranged from near zero to about 105 ft³/s. Concurrently, the minimum 28-day mean flows ranged from about 1 ft³/s to about 165 ft³/s. For the period of record, a significant increase was indicated for the minimum 7-day mean flows; however, no significant trend was indicated for the minimum 28-day mean flows (table 2).

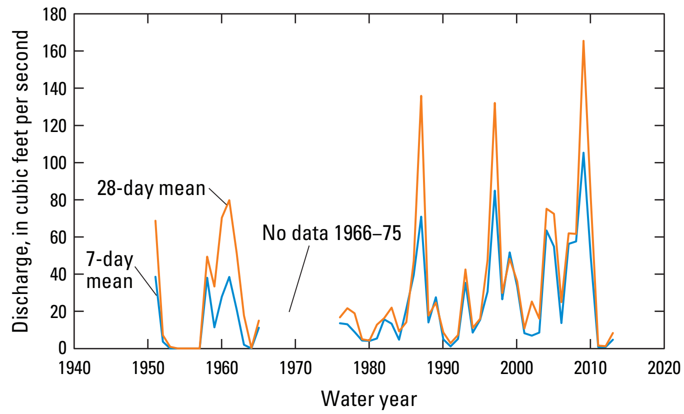

Figure 33. Variation in annual minimum 7-day and 28-day mean flows at the Chikaskia River near Corbin, Kansas, streamgage (station 07151500), 1951–2013.

Days with extremely low flow (less than 1 ft³/s) or zero flow at Corbin primarily occurred during the drought of the mid-1950s (fig. 34). Subsequently, such days have been a rare occurrence.

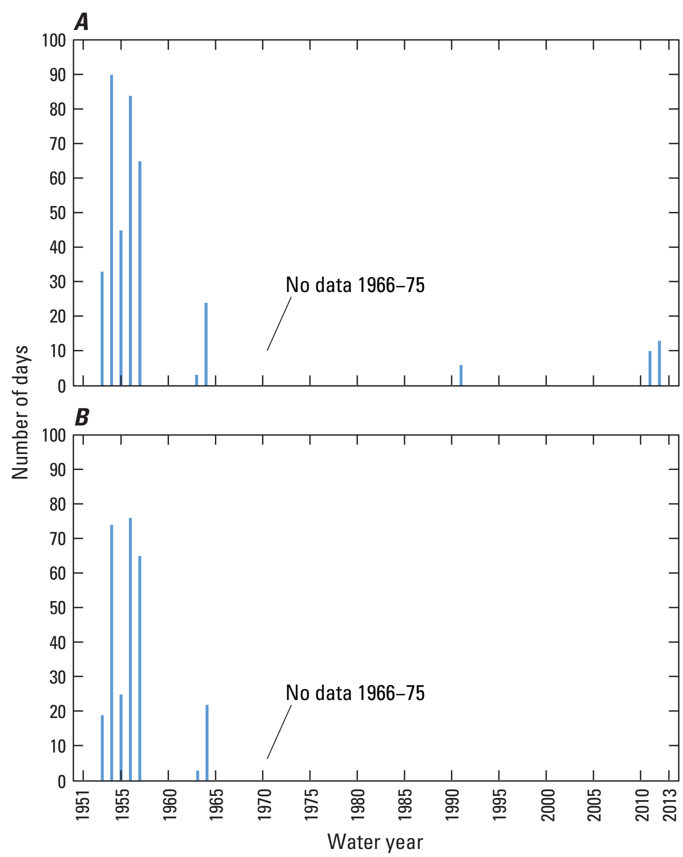

Figure 34. Variation at the Chikaskia River near Corbin, Kansas, streamgage (station 07151500), 1951–2013. *A*, annual number of days with mean discharge less than 1 cubic foot per second. *B*, annual number of zero-flow days.

Effects of Natural and Human Factors on Streamflow

Streamflow in the priority basins is affected by natural and human factors. The primary natural factor is precipitation, which contributes to streamflow directly by surface runoff and indirectly by the processes of infiltration, groundwater recharge, and base flow (Hornberger and others, 1998). Important human factors include groundwater withdrawal for irrigated agriculture and land-management practices (Juckem and others, 2008; Falke and others, 2011; Wang and Hejazi, 2011). These factors were evaluated as possible explanations for the streamflow conditions and trends observed in the priority basins.

Spatially averaged annual precipitation in the priority basins was characterized by substantial year-to-year variability from 1951 to 2013 with no pronounced long-term trends (fig. 35); however, at Murdock, a weak yet significant positive (upward) trend was indicated ($R^2 = 0.08$, p-value = 0.0268). Although a pronounced change in annual precipitation was not evident in the priority basins, it is possible that the delivery of the precipitation changed. For example, a change in the characteristics of the largest storms (size, frequency, duration, or intensity) could, in part, account for changes in the largest streamflows.

The relation between annual precipitation and annual mean discharge for each of the priority basins was statistically evaluated using R^2 and p-values. As described below, the relation varied substantially among the basins.

In the Cimarron River Basin, a long-term (multidecadal) decrease in annual mean discharge was evident particularly at Forgan (fig. 3) and also at Englewood (fig. 6). At both sites, the decrease was significant (table 2). Because there was not a concurrent long-term decrease in annual precipitation in the basin (figs. 35*A* and 35*B*), a precipitation-related explanation for the long-term decrease in discharge was not supported. The relation between discharge and precipitation was virtually nonexistent at Forgan ($R^2 = 0.01$, p-value = 0.628). At Englewood the relation was weak but significant ($R^2 = 0.18$, p-value = 4.94E-4).

In the Rattlesnake Creek Basin, a pre-1985 decrease in annual mean discharge was indicated at Macksville and Zenith (figs. 10 and 14). As in the Cimarron River Basin, there was not a concurrent decrease in annual precipitation in the basin (figs. 35*C* and 35*D*). Thus, a precipitation-related explanation for the pre-1985 decrease in discharge was not supported. For the period of record, there was a significant decrease in annual mean discharge at Macksville but not at Zenith (table 2). The relation between discharge and precipitation was weak yet significant at Macksville ($R^2 = 0.12$, p-value = 9.72E-3) and Zenith ($R^2 = 0.11$, p-value = 3.49E-2).

For the four remaining priority basins, annual mean discharge varied substantially with no pronounced trend (figs. 18, 21, 24, 27, and 31, table 2). The relation between discharge and precipitation, in relative terms, was moderate

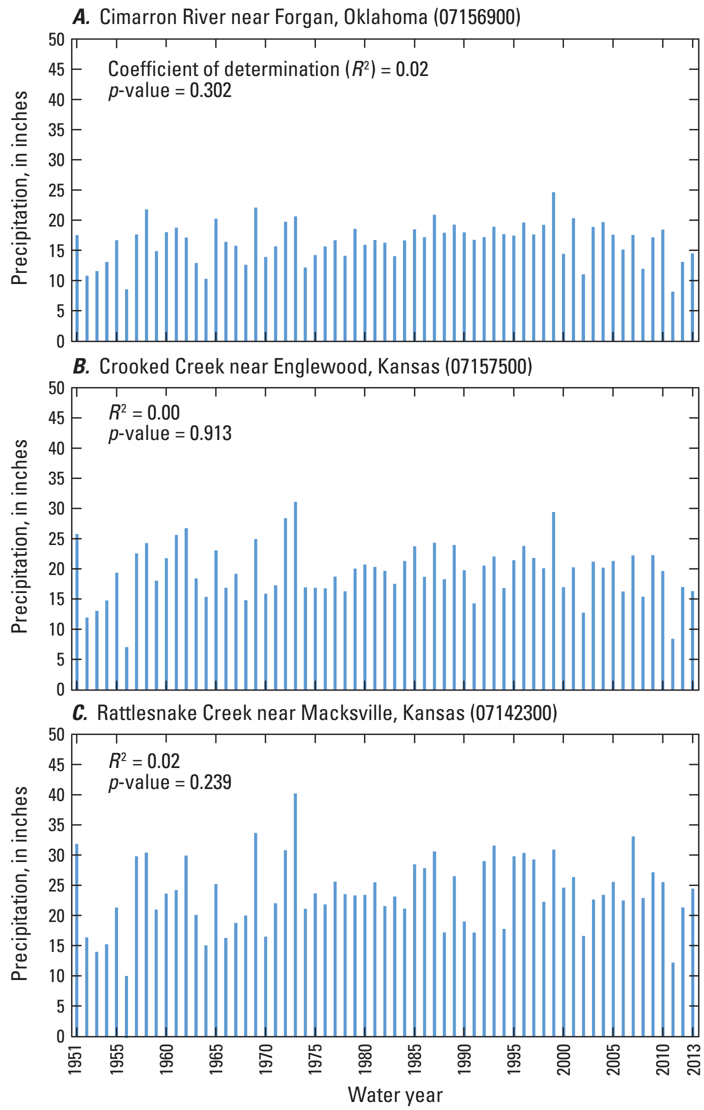

Figure 35. Variation in annual precipitation for the basins of the nine selected U.S. Geological Survey streamgages including the coefficient of determination (R^2) and p-value associated with the relation between precipitation and time. *A*, Cimarron River near Forgan, Oklahoma (07156900). *B*, Crooked Creek near Englewood, Kansas (07157500). *C*, Rattlesnake Creek near Macksville, Kansas (07142300).

and significant at Ninnescah ($R^2 = 0.32$, p-value = 2.38E-5) and Pratt ($R^2 = 0.34$, p-value = 4.05E-4). The relation between discharge and precipitation was relatively strong and significant at Murdock ($R^2 = 0.55$, p-value = 2.48E-11), Kiowa ($R^2 = 0.57$, p-value = 3.36E-11), and Corbin ($R^2 = 0.70$, p-value = 4.26E-15).

Groundwater withdrawals can cause groundwater-level declines that result in decreased contributions of groundwater to streams (that is, base flow) and thus a decrease in, or cessation of, streamflow (Winter and others, 1998; Winter, 2007; Falke and others, 2011). Within a basin, the greater the amount of groundwater withdrawal, the greater the potential will be

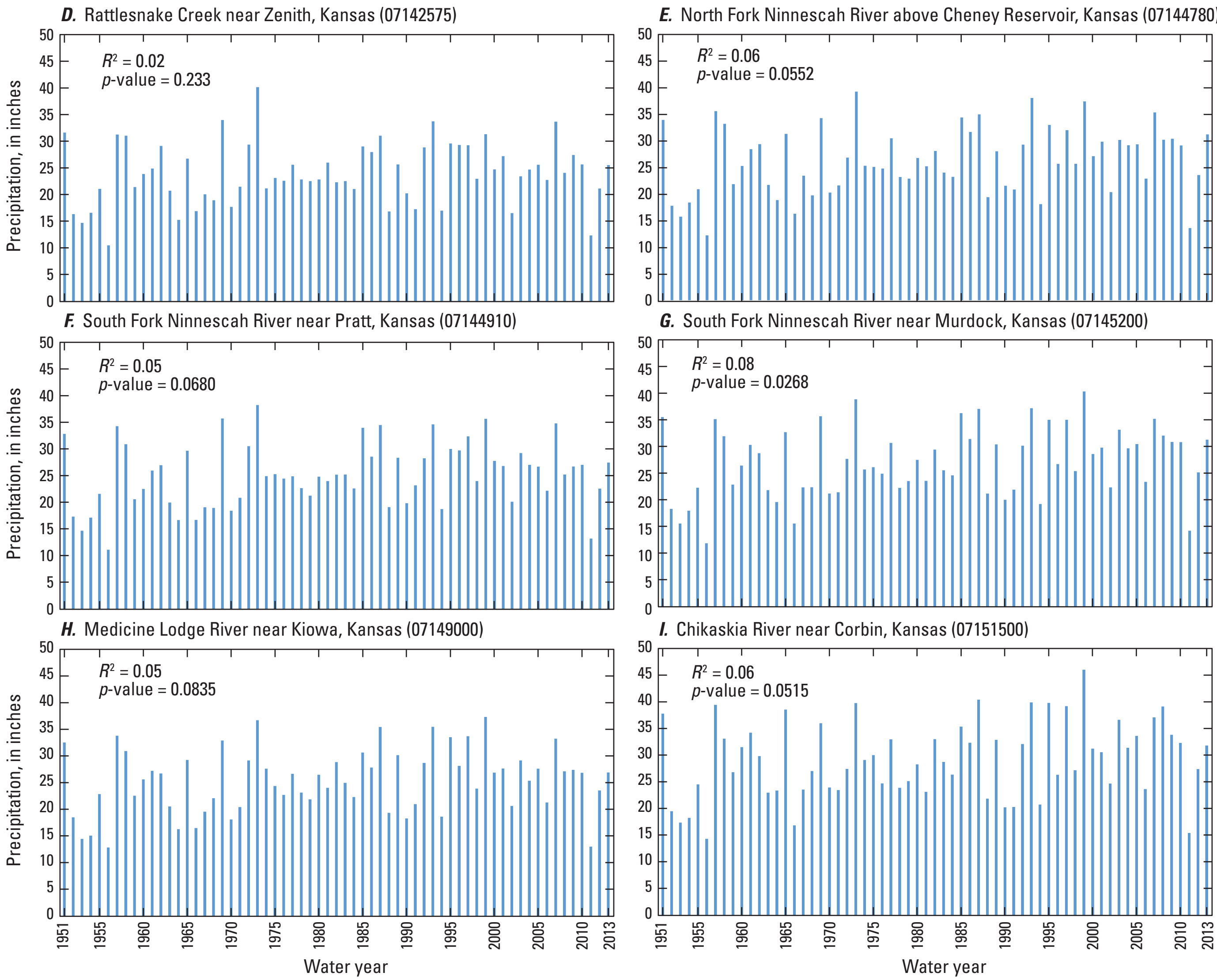

Figure 35. Variation in annual precipitation for the basins of the nine selected U.S. Geological Survey streamgages including the coefficient of determination (R^2) and *p*-value associated with the relation between precipitation and time.—Continued
D, Rattlesnake Creek near Zenith, Kansas (07142575). *E*, North Fork Ninnescah River above Cheney Reservoir, Kansas (07144780). *F*, South Fork Ninnescah River near Pratt, Kansas (07144910). *G*, South Fork Ninnescah River near Murdock, Kansas (07145200). *H*, Medicine Lodge River near Kiowa, Kansas (07149000). *I*, Chikaskia River near Corbin, Kansas (07151500). (Source: Daly and others, 2008)

for a decrease in streamflow. Such a relation was evident in some of the priority basins.

Among the priority basins, the largest groundwater-level changes associated with groundwater withdrawals were in the Cimarron River Basin where extensive areas had groundwater-level declines of 50 to 150 ft or more (fig. 2). Correspondingly, the most pronounced decreases in annual mean discharge, both in terms of magnitude and variability, also were measured in this basin. The significant decreases in annual mean discharge, accompanied by significant decreases in annual mean base flow, were evident throughout the period of record at Forgan and Englewood (figs. 3 and 6, table 2). Previously, Young and others (2005) concluded that groundwater-level declines were the primary cause of long-term flow decreases in the Cimarron River. Dodds and others (2004) attributed the decline in flow of multiple Great Plains streams to groundwater pumping from the High Plains aquifer.

Parts of the Rattlesnake Creek Basin had groundwater-level declines of 10 to 25 ft or more (fig. 2). In this basin, a pre-1985 decrease in annual mean discharge was evident at Macksville and Zenith (figs. 10 and 14) that may have been caused, at least in part, by groundwater-level declines. During the period of record, there was a significant decrease in annual mean discharge at Macksville but not Zenith (table 2). Similar groundwater-level declines occurred in the upstream-most part of the North Fork and South Fork Ninnescah River Basins (fig. 2); however, an associated significant decrease in annual mean discharge was not indicated at Ninnescah (fig. 18, table 2), Pratt (fig. 21, table 2), or Murdock (fig. 24, table 2). At least two possible explanations may, in part, account for the absence of streamflow decreases in these two basins. First, the part of the basin where groundwater-level declines occurred was limited in terms of magnitude and areal extent. Second, any effect of the groundwater-level declines may have been partially offset by groundwater-level increases in the central part of each basin (fig. 2).

Within the Medicine Lodge and Chikaskia River Basins, groundwater-level changes associated with groundwater withdrawals from the High Plains aquifer generally were minimal (fig. 2). Annual mean discharge in these two basins was characterized by substantial year-to-year variability at Kiowa and Corbin with no significant long-term trend (figs. 27 and 31, table 2).

In the priority basins where streamflow has decreased, land-management practices possibly were a contributing factor. For example, in crop production areas, the use of conservation-farming methods (for example, no-till) and more efficient irrigation practices can reduce runoff (Sophocleous, 1998; Aguilar, 2009). Water consumption by *Tamarix* (tamarisk, also known as saltcedar), an introduced invasive species (Brock, 1994), also may be a contributing factor to decreased streamflows; however, the effect of tamarisk on streamflow is debatable (Hultine and others, 2010).

The relation among annual precipitation, groundwater-level changes, and annual mean discharge for the nine selected USGS streamgages is summarized in figure 36. As shown, the most pronounced decreases in annual mean discharge during

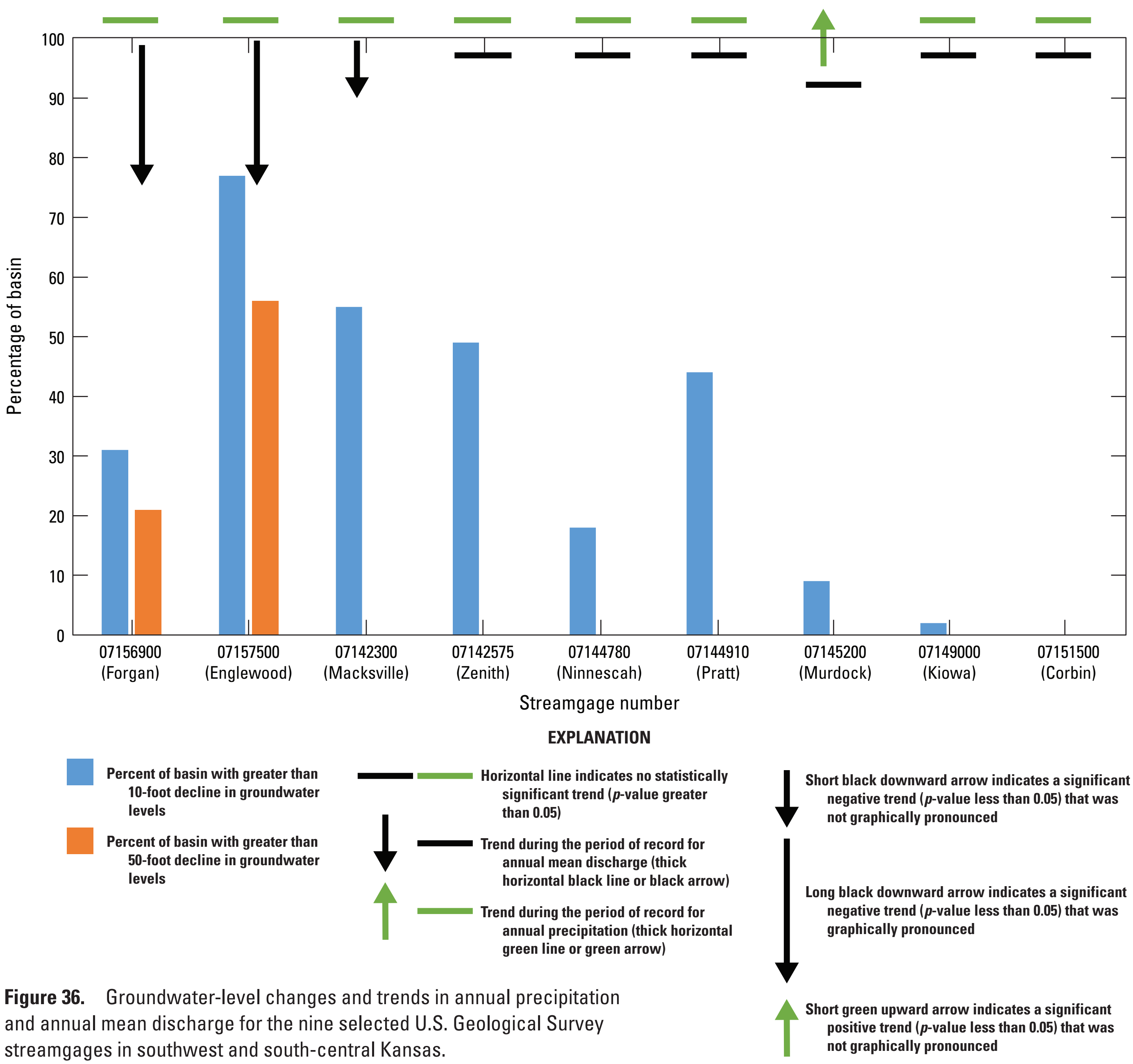

Figure 36. Groundwater-level changes and trends in annual precipitation and annual mean discharge for the nine selected U.S. Geological Survey streamgages in southwest and south-central Kansas.

the period of record occurred at the two streamgages for which the largest groundwater-level declines were measured in the upstream basin; namely, Forgan (Cimarron River) and Englewood (Crooked Creek) (fig. 2). Upstream from Forgan and Englewood, areas with groundwater-level declines in excess of 50 ft covered about 1,412 and 793 square miles, respectively.

Summary and Conclusions

A 1.5-year study by the U.S. Geological Survey, in cooperation with the U.S. Fish and Wildlife Service and the Kansas Department of Wildlife, Parks and Tourism, was begun in 2014 to provide an assessment of streamflow characteristics and trends at nine selected U.S. Geological Survey streamgage sites in southwest and south-central Kansas. The intent of the assessment was to provide some of the information needed to better understand hydrologic conditions in priority basins thereby enabling more effective management of *Etheostoma cragini* (Arkansas darter) habitats and populations in the State. Results of the assessment are summarized below:

1. In the Cimarron River Basin, there was a statistically significant decrease in annual mean discharge during the period of record. Concurrently, the percentage of the annual mean discharge that was contributed by base flow increased.

2. In the Rattlesnake Creek Basin, there was a pre-1985 decrease in annual mean discharge.

3. In the Cimarron River and Rattlesnake Creek Basins, significant decreases typically were indicated for mean base flow, 90th-percentile flow, 10th-percentile flow, minimum 7-day mean flow, and minimum 28-day mean flow during the period of record.

4. In the North Fork Ninnescah, South Fork Ninnescah, Medicine Lodge, and Chikaskia River Basins, no significant trend in annual mean discharge was indicated during the period of record.

5. For the Medicine Lodge and Chikaskia River Basins as well as the downstream part of the South Fork Ninnescah River Basin, a significant increase in mean base flow and 10th-percentile flow was indicated during the period of record. Also, for the latter two basins, a significant increase was indicated for minimum 7-day mean flow.

6. Because annual precipitation in the study area varied substantially from 1951 to 2013 with no pronounced long-term trend, a precipitation-related explanation for the decrease in annual mean discharge in the Cimarron River and Rattlesnake Creek Basins was not supported.

7. Given that the most pronounced decreases in annual mean discharge were located in the basin with the largest groundwater-level declines (that is, the Cimarron River Basin), both in terms of magnitude and areal extent, it is likely that groundwater withdrawals were a primary, if not dominant, causative factor.

8. For all basins, the occurrence of extremely low-flow (less than 1 cubic foot per second) and zero-flow days varied year-to-year and typically occurred in the summer and autumn.

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