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Historical Channel Change Along Soldier Creek, Northeast Kansas

By KYLE E. JURACEK

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Cover photograph: Rocky Ford on Soldier Creek, northeast Kansas, October 24, 2001.

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
foot per year (ft/yr)	0.3048	meter per year
inch (in.)	2.54	centimeter
inch per hour (in/hr)	2.54	centimeter per hour
mile (mi)	1.609	kilometer
mile per year (mi/yr)	1.609	kilometer per year
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	640	acre
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer

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By Kyle E. Juracek

Abstract

To assess historical channel change along Soldier Creek, northeast Kansas, available information from eight U.S. Geological Survey streamflow-gaging stations was analyzed. At each gaging station, channel change was assessed using channel-bed elevation as the primary indicator variable. Changes in channel-bed elevation were inferred from changes in the stage associated with the mean annual discharge at each station. The variables channel width, channel area, and streamflow velocity were used as additional indicators of change.

Results indicated that the most substantial channel changes occurred downstream from Rocky Ford at the Soldier Creek streamflow-gaging stations located near Topeka and Delia. The available evidence indicated that the channelization of Soldier Creek, completed in 1961, was likely the primary cause of the channel changes at these locations. The decreasing base level provided by the Kansas River also may have contributed to the channel changes at these locations. At the Soldier Creek gaging station near Topeka, immediate effects of the channelization included a decrease in channel-bed elevation of about 5 feet and an increase in channel width of about 35 feet. The instability introduced by the channelization caused channel-bed degradation that moved upstream at the rate of about 0.7 to 1.2 miles per year. At the Soldier Creek gaging station near Delia, located about 12 miles upstream from the upstream end of the channelized section, channel-bed degradation began during the 1970s and resulted in a net decrease in channel-bed elevation of about 5 feet by 1999.

The available evidence indicated that Soldier Creek at and upstream from Rocky Ford has not been substantially affected by the upstream-progressing channel-bed degradation as of 2001. In this part of the basin other causes of channel change, such as land use and floods, may be relatively more important.

INTRODUCTION

Soldier Creek is an important resource for the Prairie Band Potawatomi Nation as it flows directly through their reservation in Jackson County, Kansas (fig. 1). The habitat provided by the creek supports wildlife that helps meet the subsistence fishing and hunting needs of tribal members who supplement their income by using wildlife for food. Additionally, the creek is valued for its natural beauty and for providing a setting for cultural and recreational activities. One site that is particularly valued by tribal members is Rocky Ford (fig. 1, see photograph on report cover), where limestone bedrock in the channel creates a waterfall during low-flow periods.

Channel changes affecting Soldier Creek may threaten the benefits that have been traditionally enjoyed by tribal members. An understanding of the channel changes is needed to address several important issues being considered by the Prairie Band Potawatomi Nation, including the protection and restoration of aquatic and riparian habitat, the protection of property and structures from flooding and erosion hazards, the preservation of the natural beauty of the landscape, and the use of streams for cultural and recreational activities.

Figure 1. Location of Soldier Creek Basin, Soldier Creek, major tributaries, Prairie Band Potawatomi Nation Reservation, channelized section, weirs, and U.S. Geological Survey streamflow-gaging stations, northeast Kansas.

Channel changes may have both natural and human causes. Natural events such as floods may cause substantial channel change in a short period of time. Human disturbances such as channelization and land-use change introduce instability to which streams adjust over longer time periods by such processes as channel degradation [that is, erosion of the channel bed and (or) banks] and channel aggradation (that is, deposition of material). Channelization, which usually involves the straightening, deepening, and shortening of stream channels, the consequence of which is an increase in channel slope and streamflow velocity, can cause significant channel degradation that will move upstream from the original site of disturbance. Land-use changes, such as the conversion of forest and grassland to cropland, may result in increased runoff, increased sediment production, and streambank erosion. Additional causes of channel change include other channel modifications (for example, low-water crossings, weirs, bridge work, and bank stabilization), changes in base level (that is, the elevation below which erosion cannot occur), and climate change.

Previous studies have documented channel changes mostly caused by channelization of Soldier Creek in and upstream from the city of Topeka in Shawnee County, Kansas (fig. 1) (Booker, Engineers, Architects, Planners, [1986a?]; U.S. Army Corps of Engineers, 1988). In the vicinity of Topeka, Soldier Creek was channelized on at least two separate occasions. By 1933, the Northeast Drainage District of Topeka had channelized the downstream reaches of Soldier Creek in an effort to minimize flooding. As a result, the affected channel was reduced in length by about 27 percent (Booker, Engineers, Architects, Planners [1986a?]). Then, the U.S. Army Corps of Engineers (USCOE), as part of the Topeka, Kansas, flood protection project, constructed the Soldier Creek diversion unit between March 1957 and November 1961. This channelization project realigned several miles of Soldier Creek, reducing the affected channel an additional 20 percent in length (Booker, Engineers, Architects, Planners, [1986a?]). Also, the Soldier Creek confluence with the Kansas River was relocated 1.6 mi farther downstream (U.S. Army Corps of Engineers, 1988). The enlarged, straightened, and deepened section of Soldier Creek extends about 10 stream mi upstream from its confluence with the Kansas River.

Cross-sectional surveys completed by the USCOE indicated substantial channel changes in the years following the completion of the Soldier Creek diversion unit in November 1961. Cross-sectional surveys completed by the USCOE in 1969 and 1972 indicated as much as 4 to 10 ft of channel-bed degradation had occurred at locations in the upstream part of the channelized section of Soldier Creek. Downstream, the surveys indicated several feet of channel-bed aggradation had occurred. Also, in 1969 a widening of the channel bottom from 40 ft (original 1961 constructed width) to as much as 90 ft was determined near the upstream end of the channelized section. Photogrammetric analysis completed by the USCOE in 1984 indicated that additional channel-bed degradation and channel widening had occurred in the upstream end of the channelized section (U.S. Army Corps of Engineers, 1988).

To limit further degradation of the Soldier Creek channel bed and banks, the North Topeka Drainage District constructed a series of eight weirs during the 1980s and early 1990s. Built of concrete rubble, rock, and sometimes topped with concrete, the weirs are located between about 2.0 and 6.5 stream mi upstream from the near Topeka streamflow-gaging station (station 06889500, fig. 1). Also, at the same time, three weirs were constructed in the Little Soldier Creek channel within about 1.5 stream mi of its confluence with Soldier Creek (Dale Sundberg, North Topeka Drainage District, written commun., 2001).

To provide an assessment of channel change along Soldier Creek, a study was undertaken by the U.S. Geological Survey (USGS) in cooperation with the Prairie Band Potawatomi Nation. Specific objectives were to:

(1) Determine the type, magnitude, timing, and rate of channel change that has occurred at specific locations;

(2) Determine whether any trends in channel change exist throughout the basin; and

(3) Infer possible causes of past channel changes and the possibility of future channel changes throughout the basin.

The purpose of this report is to present the results of the USGS assessment of channel change along Soldier Creek. From a national perspective, the results presented enhance the understanding of the geomorphic (channel-changing) effects of human disturbances on small streams. Also, the methods used and results obtained will provide guidance and perspective for similar assessments conducted throughout the Nation.

DESCRIPTION OF SOLDIER CREEK BASIN

The Soldier Creek Basin is an area of about 334 mi^2 that drains parts of Shawnee, Jackson, and Nemaha Counties in northeast Kansas (fig. 1). Soldier Creek is a meandering stream with steep banks. The principal tributary to Soldier Creek is Little Soldier Creek. Lesser tributaries, in downstream-to-upstream order, include Indian Creek, Halfday Creek, Silver Lake Ditch, Messhoss Creek, Walnut Creek, Dutch Creek, James Creek, South Branch Soldier Creek, and Crow Creek (fig. 1).

The Soldier Creek Basin is located within the Dissected Till Plains Section of the Central Lowland Province (Fenneman, 1946). The Dissected Till Plains are characterized by dissected deposits of Pleistocene glacial till that consist of silt, clay, sand, gravel, and boulders overlying bedrock. Within the basin, the bedrock is mostly Pennsylvanian and Permian limestone and shale that dips gently northwestward (U.S. Army Corps of Engineers, 1974; Carswell, 1981). The flood plains of Soldier and Little Soldier Creeks consist of Pleistocene and Holocene alluvium (Walters, 1953; Carswell, 1981). The alluvium, which ranges in thickness up to 65 ft, generally consists of clay in the upper 30 to 40 ft underlain by as much as 30 ft of silty sand and gravel (U.S. Army Corps of Engineers, 1974). Soils within the basin are classified typically as either silt loam, clay loam, or silty clay loam. The land surface is rolling with gentle to moderate slopes generally less than 10 percent (U.S. Department of Agriculture, Soil Conservation Service, 1970, 1979). Slope, along with soil permeability and land use (discussed in a following paragraph), are important factors that affect storm runoff, which in turn affects streamflow and sediment loads and thus the size and shape of the channel.

Depth-weighted, mean soil permeability in the Soldier Creek Basin ranges from 0 to 2.2 in/hr with a mean of about 0.5 in/hr. In general, soil permeability is less in the uplands (typically less than 0.7 in/hr) and higher in the flood plains (typically between 1.0 and 1.3 in/hr) (Juracek, 2000).

Long-term mean annual precipitation in the Soldier Creek Basin is about 35 in. at Topeka (period of record 1948–2000) and about 36 in. at Circleville (period of record 1971–2000). Most of the annual precipitation is received during the growing season, April through September (High Plains Regional Climate Center, 2001).

Land use is predominantly agricultural with grassland, cropland, and woodland accounting for about 63, 30, and 6 percent of the basin, respectively. Much of the cropland is concentrated in the flood plains of Soldier and Little Soldier Creeks. Urban land use accounts for less than 1 percent of the basin (fig. 2) (Kansas Applied Remote Sensing Program, 1993).

METHODS

A stable stream channel naturally meanders across its valley over time while maintaining approximately the same cross-sectional shape (Leopold, 1994). Therefore, changes in channel shape may be used to infer channel instability (Thornes, 1977; Simons and Li, 1982). In this assessment, channel-bed elevation, channel width, channel area, and streamflow velocity were used as indicator variables of channel instability and historical channel change along Soldier Creek. Changes in channel-bed elevation were inferred from changes in the stage associated with the mean annual discharge at each streamflow-gaging station.

This assessment of temporal and spatial channel change used available information from seven USGS streamflow-gaging stations previously or presently located on Soldier Creek. Also, information from a gaging station on the Kansas River was analyzed to evaluate possible external basin controls of channel change on Soldier Creek (fig. 1, table 1). The gaging stations provide historical, site-specific channel and streamflow information that also may indicate conditions both upstream and downstream of the stations. On the basis of this site-specific information, inferences can be made about possible causes of past channel changes and the possibility of future channel changes throughout the basin.

At any given time and location along a river or stream, a relation exists between river/stream stage (that is, the height of the water in the channel above a given datum) and discharge (that is, streamflow volume per unit time). These relations, quantified on rating curves, are updated as necessary to accommodate changes in channel shape, slope, and other factors that can affect the relation. Each rating curve represents a best-fit line through the measurement data (that is, paired measurements of river/stream stage and discharge). Discharge measurements at, and stage-discharge rating curves for, the streamflow-gaging stations were made using standard USGS techniques

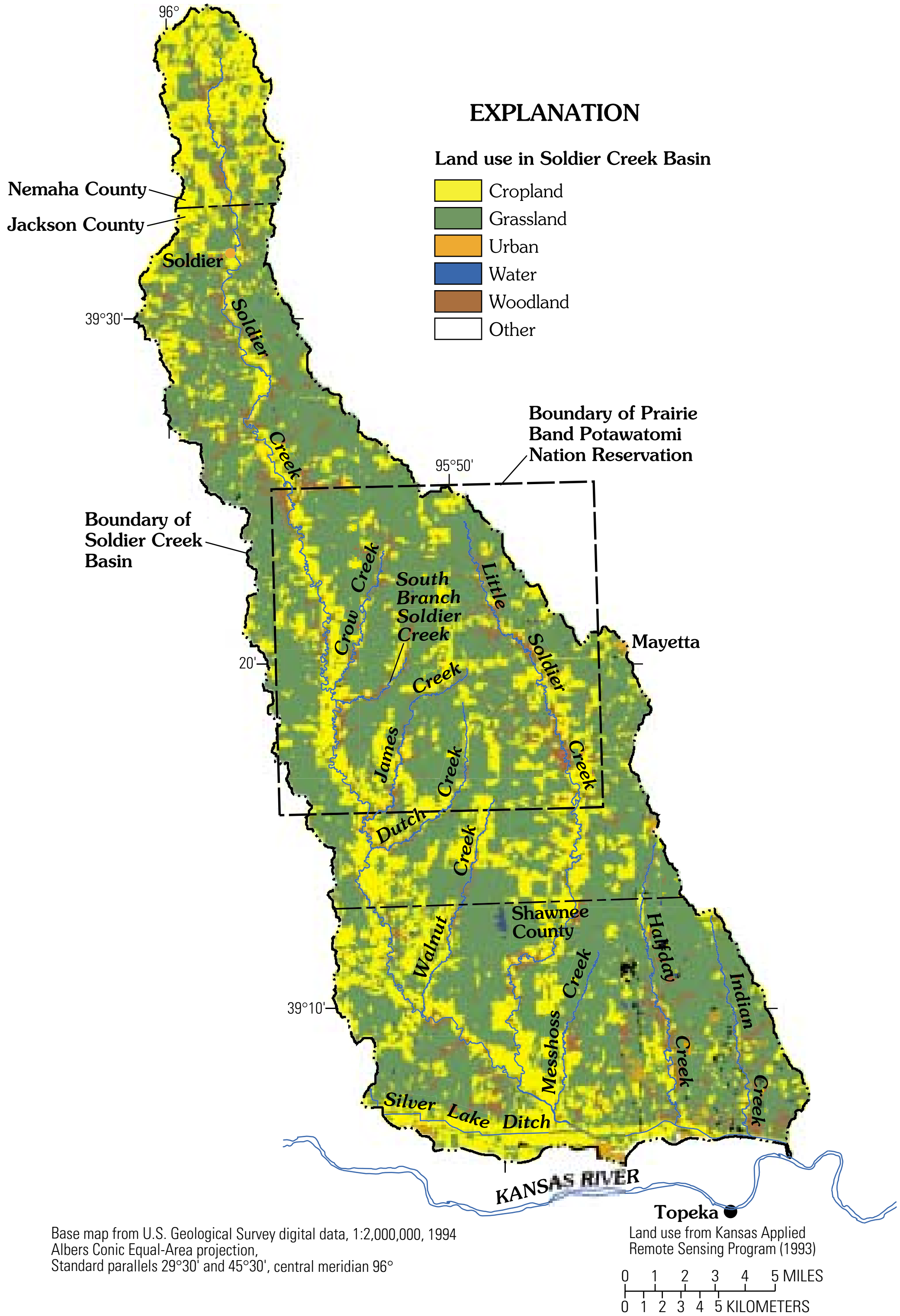

Figure 2. Land use in Soldier Creek Basin, circa 1992.

Table 1. U.S Geological Survey (USGS) streamflow-gaging stations on Soldier Creek and Kansas River, northeast Kansas

[--, not applicable]

USGS station number (fig. 1)	USGS station name	Approximate distance upstream from confluence with Kansas River (miles)	Approximate drainage area (square miles)	Period of record analyzed
06889100	Soldier Creek near Goff	72	2	1964–87
06889120	Soldier Creek near Bancroft	69	10	1964–88
06889140	Soldier Creek near Soldier	66	17	1964–98
06889160	Soldier Creek near Circleville	55	49	1964–2001
06889180	Soldier Creek near Saint Clere	45	80	1964–81
06889200	Soldier Creek near Delia	22	157	1958–2001
06889500	Soldier Creek near Topeka	6	290	1936–2001
06889000	Kansas River at Topeka	--	--	1961–2001

(Buchanan and Somers, 1969; Kennedy, 1984) with a typical accuracy of ±5 percent (Kennedy, 1983).

By computing the stage that relates to a reference discharge for each rating curve developed during the period of record of a gaging station (and correcting to a common datum, if necessary), trends in the elevation of the channel bed can be inferred by plotting the resulting time-series data. In this assessment, the river/stream stage for the mean annual discharge (rounded to the nearest 1 or 10 ft^3/s, as appropriate) for the period of record was used as the reference discharge (Chen and others, 1999). If the stage for the reference discharge has a downward trend, it may be inferred that the channel-bed elevation has declined over time due to erosion. Conversely, if the stage for the reference discharge has an upward trend, it may be inferred that the channel-bed elevation has risen over time due to aggradation. No trend indicates that the channel bed has been essentially stable.

In addition to the magnitude and trend of channel-bed elevation changes at each gaging station, information derived from the rating curves also was used to assess the rate of channel-bed elevation changes (rating-curve information is on file at the USGS office in Lawrence, Kansas). For a given trend, the rate of channel-bed elevation change was estimated as the net difference in stage (corresponding to the reference discharge) between the starting and ending dates that define the trend divided by the length of time between the two dates.

Changes in channel width, channel area, and streamflow velocity were assessed through an analysis of discharge-width, discharge-area, and discharge-velocity relations over a range of in-channel streamflow conditions for successive periods of time that cover the period of record for each gaging station (discharge, channel-width, channel-area, and streamflow-velocity information is on file at the USGS office in Lawrence, Kansas).

A statistical test was used to determine the significance of any observed trends in channel change. For this purpose, a nonparametric Spearman's rho correlation coefficient was computed. An advantage of Spearman's rho is that, because it is based on ranks, it is more resistant to the effects of extreme high and low values than the more commonly used Pearson's r correlation coefficient (Helsel and Hirsch, 1992). Trends were considered to be significant if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05.

HISTORICAL CHANNEL CHANGE

In the following sections, the results of the analyses to assess changes in channel conditions at each of the seven streamflow-gaging sites located on Soldier Creek, as well as one streamflow-gaging site located on the Kansas River at Topeka, are presented. The results presented include the type, magnitude, timing, rate, and trend of channel changes at each site.

Soldier Creek near Topeka

The Soldier Creek streamflow-gaging station near Topeka (station 06889500, fig. 1, table 1) is located within the channelized section of Soldier Creek. Consequently, the Soldier Creek channel at this site was directly affected by the channelization. A comparison of stream stages for the mean annual discharge (160 ft^3/s) (a substitute for measured channel-bed elevation) before and after USCOE channelization of

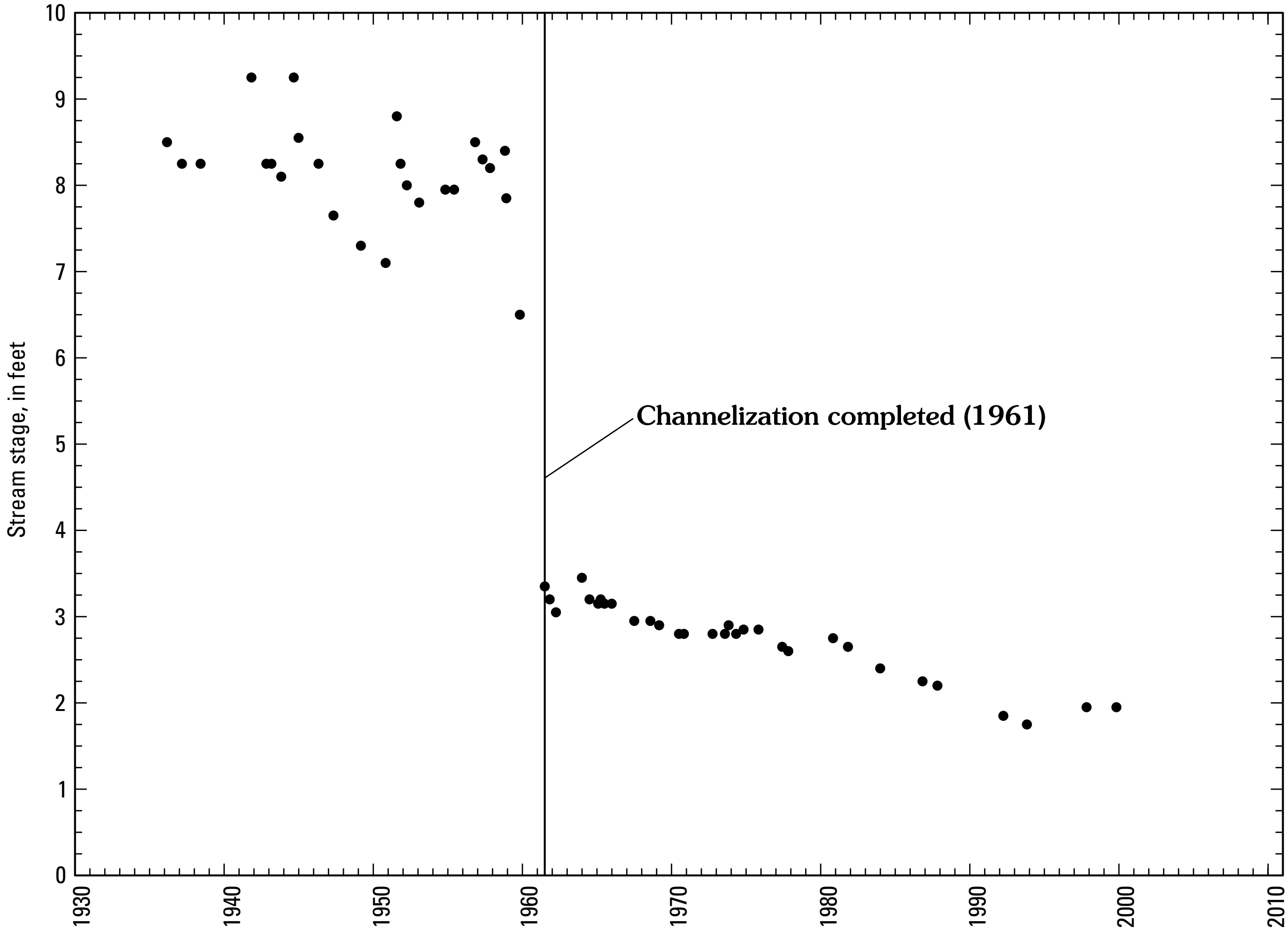

Figure 3. Variation in stream stage for mean annual discharge (160 ft^3/s) at Soldier Creek gaging station near Topeka (station 06889500, fig. 1), 1936–99.

Soldier Creek (1957–61) shows that there was about a 5-ft decline in channel-bed elevation at the time of the channelization (fig. 3). Prior to channelization between 1936 and 1956, the stream stage for the mean annual discharge generally varied within ± 1 ft of the mean value of 8.2 ft, with a standard deviation of about 0.5 ft. A statistically significant trend in stream stage was not indicated for this time period (Spearman's rho = -0.40, two-sided p-value = 0.08398). Instead, the channel bed at this location appeared to be fluctuating in response to scour (erosion) and fill (deposition) processes that may reflect short-term changes in response to individual flow events (fig. 3). In figure 3 and subsequent figures that show changes in the stage for the mean annual discharge over time, each data point represents the stage for the mean annual discharge on the date for which that specific rating curve became effective.

Following completion of the channelization project and the immediate lowering of the channel-bed elevation by about 5 ft, a steady decline in the stream stage for the mean annual discharge (from about 3.1 ft to about 2 ft) was evident from 1962 to 1999 (fig. 3). For this time period, a statistically significant negative trend (that is, decreasing stream stage with time) (Spearman's rho = -0.95, two-sided p-value = 0.00000) was indicated. Since the initial 5-ft decrease in elevation, the channel bed continued to degrade from 1962 to 1999 at an average rate of about 0.03 ft/yr.

Channel width at the Soldier Creek gaging station near Topeka also changed substantially as an immediate result of the channelization. As shown in figure 4, post-channelization (1962–99) widths were generally about 35 ft greater than pre-channelization (1936–56) widths.

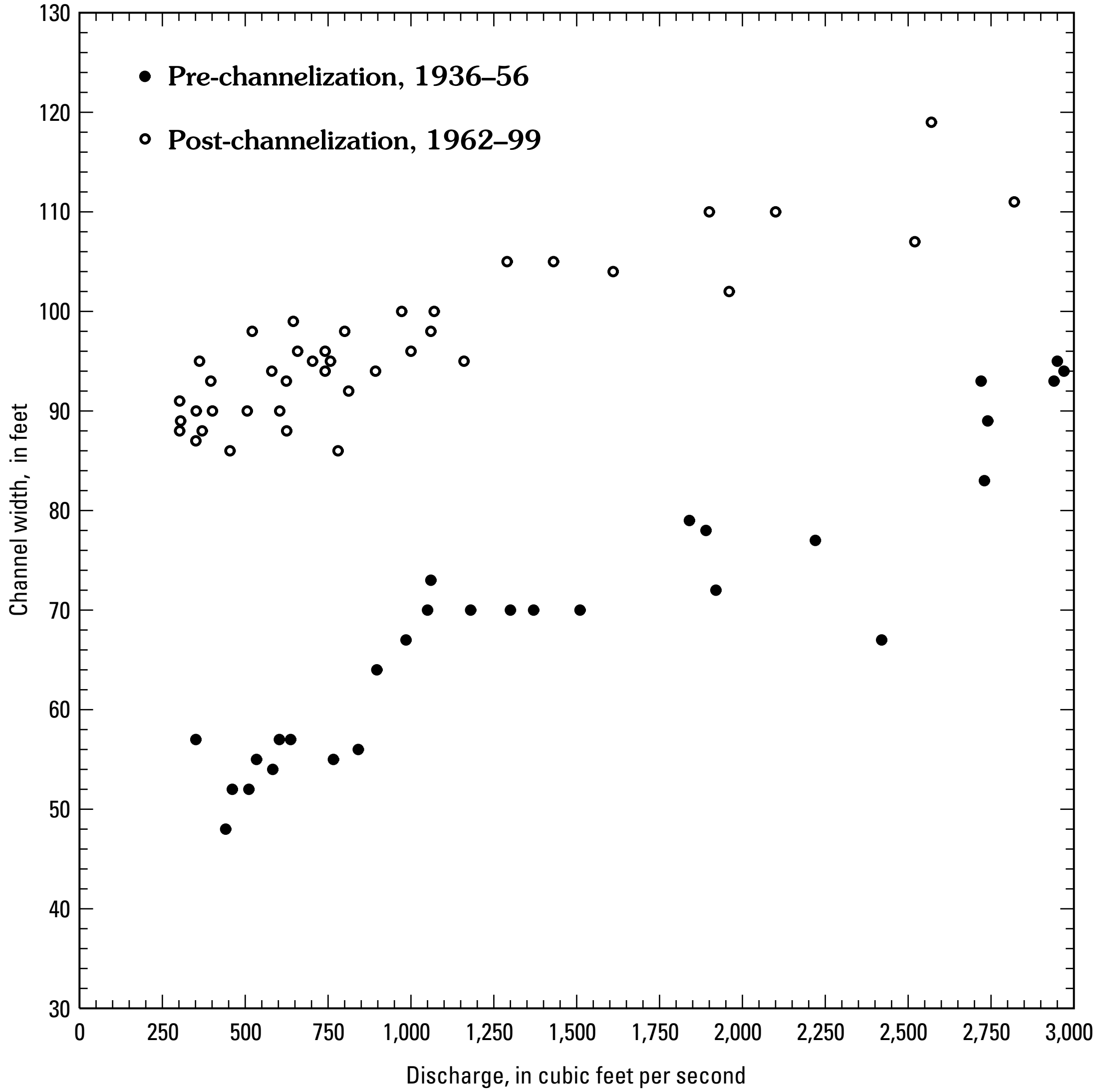

Figure 4. Relation between discharge and channel width at Soldier Creek gaging station near Topeka (station 06889500, fig. 1), pre- and post-channelization.

The analysis of relations between discharge and channel area and between discharge and streamflow velocity indicated that neither relation changed in response to the channelization. For a given discharge, the expected post-channelization response to shortened channel length and increased slope would be an increase in streamflow velocity and a decrease in channel area. However, because the channelization also included a widening of the channel bottom, the changes in velocity and area did not occur. This is because, with a wider channel, more of the streamflow is closer to the channel perimeter where the velocity is reduced by friction. Also, streamflow velocity at this location occasionally may be reduced due to the effects of backwater from the Kansas River.

Soldier Creek near Delia

The Soldier Creek streamflow-gaging station near Delia (station 06889200, fig. 1, table 1) is located about 12 stream mi upstream from the upstream end of the channelized section of Soldier Creek and about 16 stream mi upstream from the near Topeka gaging station (06889500, fig. 1). This gaging-station site is also located about 6.5 stream mi downstream from the southern boundary of the Prairie Band Potawatomi Nation Reservation (hereafter referred to as the reservation). Available information indicated that the channel at this location was straightened in conjunction with bridge construction in the mid-1950s (E.J. Kennedy, U.S. Geological Survey, written commun., 1958). A channel cutoff occurred about 0.25 mi downstream from the gaging station some time between 1967 and 1977 (U.S. Army Corps of Engineers, 1988), with a resultant shortening of the channel length by about 1,100 ft. On January 9, 1971, a low-water crossing for heavy equipment was constructed with large rock about 1,500 ft downstream from the gaging station (G.G. Quy, U.S. Geological Survey, written commun., 1972). The low-water crossing was partially washed out in 1978.

Three distinct periods of channel-bed activity were apparent for the period 1958 to 1999 (fig. 5). For 1958–70, the stream stage for the mean annual discharge (100 ft^3/s) varied about the mean value of 11.0 ft with a standard deviation of about 0.5 ft (fig. 5). A statistically significant trend in stream stage was not indicated for this time period (Spearman's rho = 0.28, two-sided p-value = 0.23406). Instead, the channel bed at this location appeared to be fluctuating in response to scour and fill processes in a manner similar to the pre-channelization channel-bed activity at the near Topeka gaging-station site (fig. 3). Of note during this period were large bank collapses that occurred following high flows on at least two occasions during 1965 (K.L. Lindskov, U.S. Geological Survey, written commun., 1966). The bank collapses may have been caused, in part, by the artificial straightening of the channel at the Soldier Creek near Delia gaging station site about a decade earlier.

For 1971–78, the stream stage for the mean annual discharge increased from 12.4 to 13.9 ft (fig. 5). This indicated an increase in the channel-bed elevation of 1.5 ft. For this time period, a statistically significant positive trend was indicated (Spearman's rho = 0.98, two-sided p-value = 0.00000). During this time period, the channel bed aggraded at an average rate of about 0.2 ft/yr.

For 1978–99, the stream stage for the mean annual discharge decreased from 13.9 to 7.3 ft (fig. 5). This indicated a decrease in the channel-bed elevation of

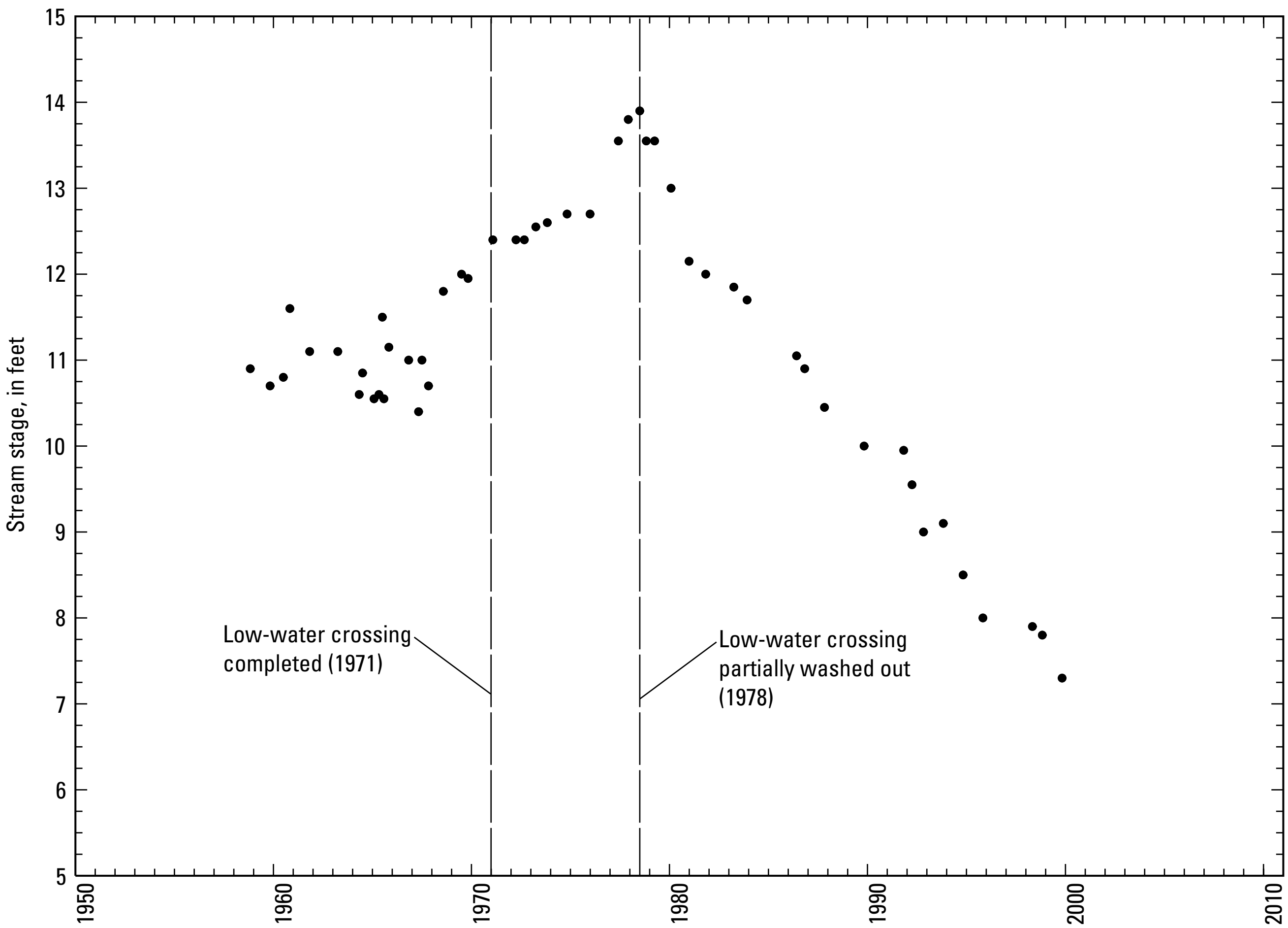

Figure 5. Variation in stream stage for mean annual discharge (100 ft^3/s) at Soldier Creek gaging station near Delia (station 06889200, fig. 1), 1958–99.

6.6 ft. For this time period, a statistically significant negative trend was indicated (Spearman's rho = -1.00, two-sided p-value = 0.00000). During this time period, the channel bed degraded at an average rate of about 0.3 ft/yr. The slope of the data points in figure 5 indicates that, as of 1999, the rate of channel-bed degradation had not yet begun to slow. Thus, unless bedrock is encountered or grade-control structures are built, additional channel-bed degradation at the Delia gaging-station site is likely.

Analysis of the relations between discharge and channel width, channel area, and streamflow velocity indicated a change in all three relations that appeared to correspond with the channel-bed degradation that began in the late 1970s. As shown in figure 6, the relation between discharge and channel width was similar for the period 1958–99 for discharges less than about 750 ft^3/s. However, for discharges larger than 750 ft^3/s, the associated channel widths were smaller for 1978–99 than for 1958–77. The difference was most pronounced for discharges larger than about 1,250 ft^3/s for which channel widths were generally about 70 ft less for 1978–99 (fig. 6). The decrease in channel widths for the larger discharges was indicative of a channel that has entrenched (that is, downcut).

The pattern of change for the relation between discharge and channel area was similar. As shown in figure 7, the relation between discharge and channel area was consistent for the period 1958–99 for discharges less than about 1,000 ft^3/s. For discharges larger than 1,000 ft^3/s, the associated channel areas were generally smaller for 1978–99 than for 1958–77.

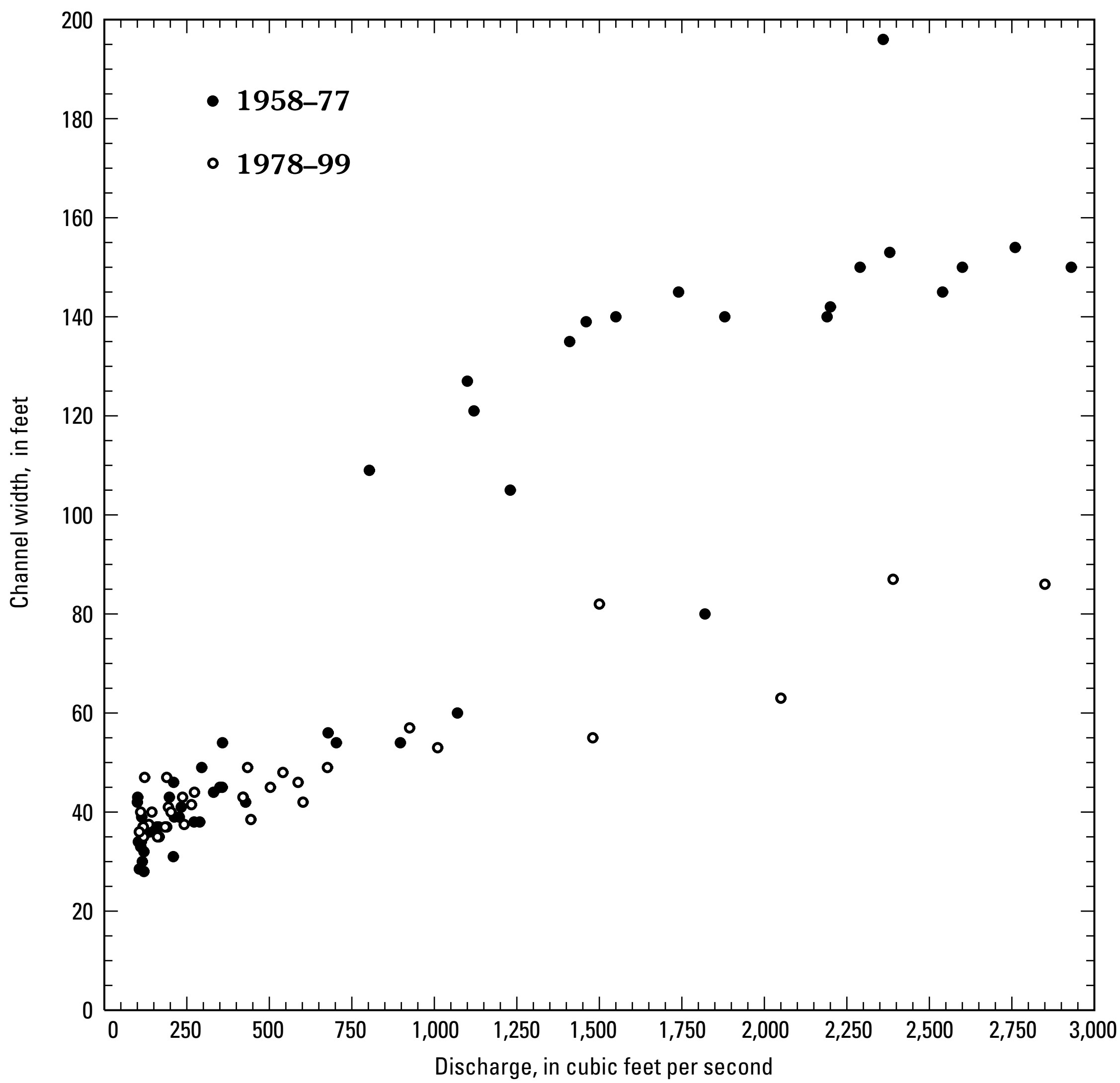

Figure 6. Relation between discharge and channel width at Soldier Creek gaging station near Delia (station 06889200, fig. 1).

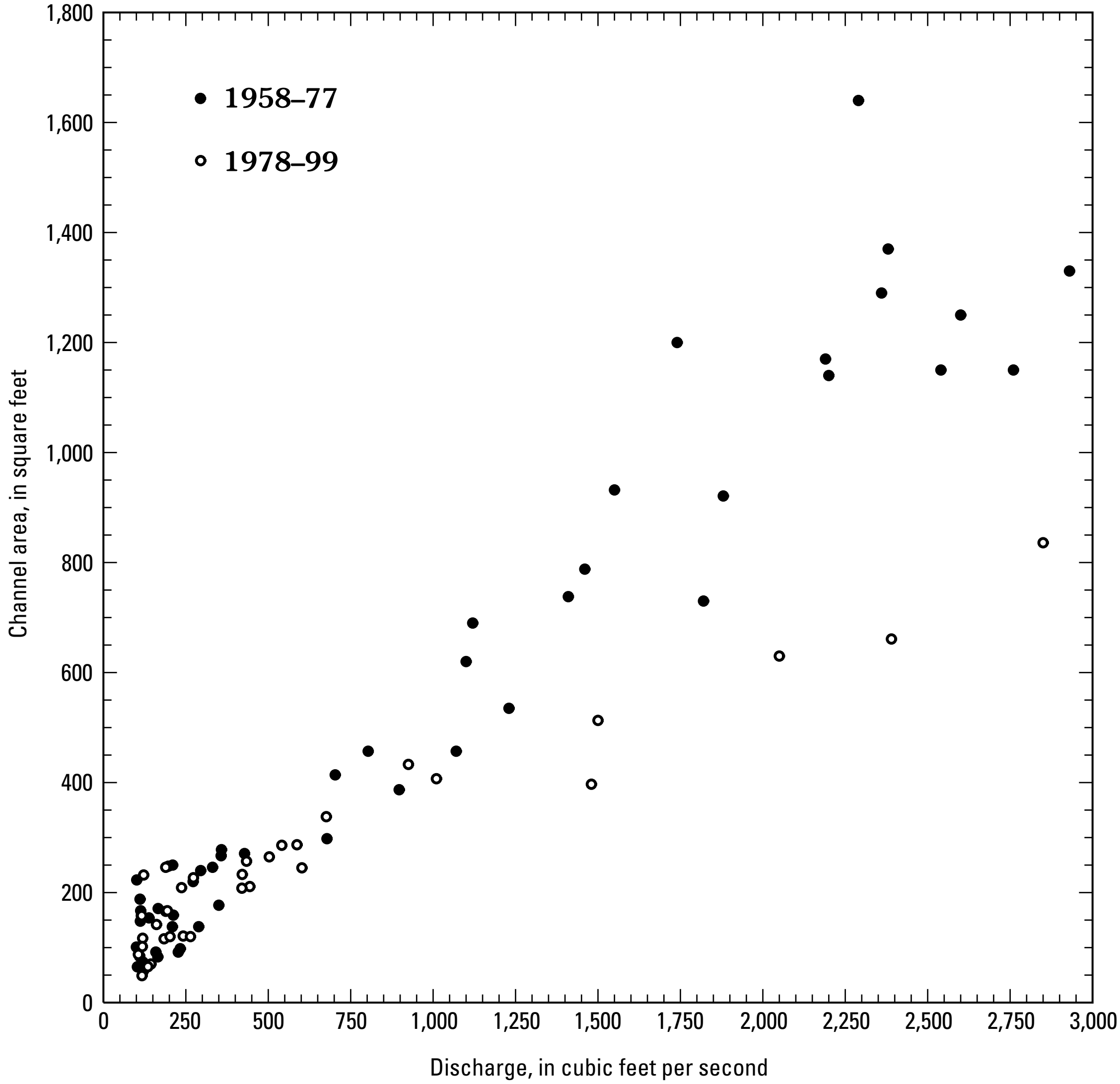

Figure 7. Relation between discharge and channel area at Soldier Creek gaging station near Delia (station 06889200, fig. 1).

The difference was more pronounced for the larger discharges (fig. 7).

The relation between discharge and streamflow velocity exhibited considerable scatter, which in part may be attributed to problems associated with debris and beaver dams in the vicinity of the gaging-station site near Delia. For 1958–67 (data not shown), there was no discernible relation between discharge and velocity. For 1968–99, shown in figure 8, the expected pattern of increasing velocity with increasing discharge was apparent. Despite the scatter, a pattern of increased velocity over time was indicated. Possible explanations for the increased velocity, and associated decreased channel areas, are an increase in channel slope and (or) a decrease in channel roughness.

Soldier Creek near Saint Clere

The streamflow-gaging station for Soldier Creek near Saint Clere (station 06889180, fig. 1, table 1) is located within the reservation about 23 stream mi upstream from the Delia gaging station (station number 06889200, fig. 1) and about 16 stream mi upstream from Rocky Ford (which is just upstream from the southern reservation boundary). Unfortunately, this gaging station was only active from 1964 to 1981. In 1981, the bridge at this site was removed and replaced with a low-water crossing. Thus, the gaging station was discontinued. In 1985, the present (2001) bridge was constructed.

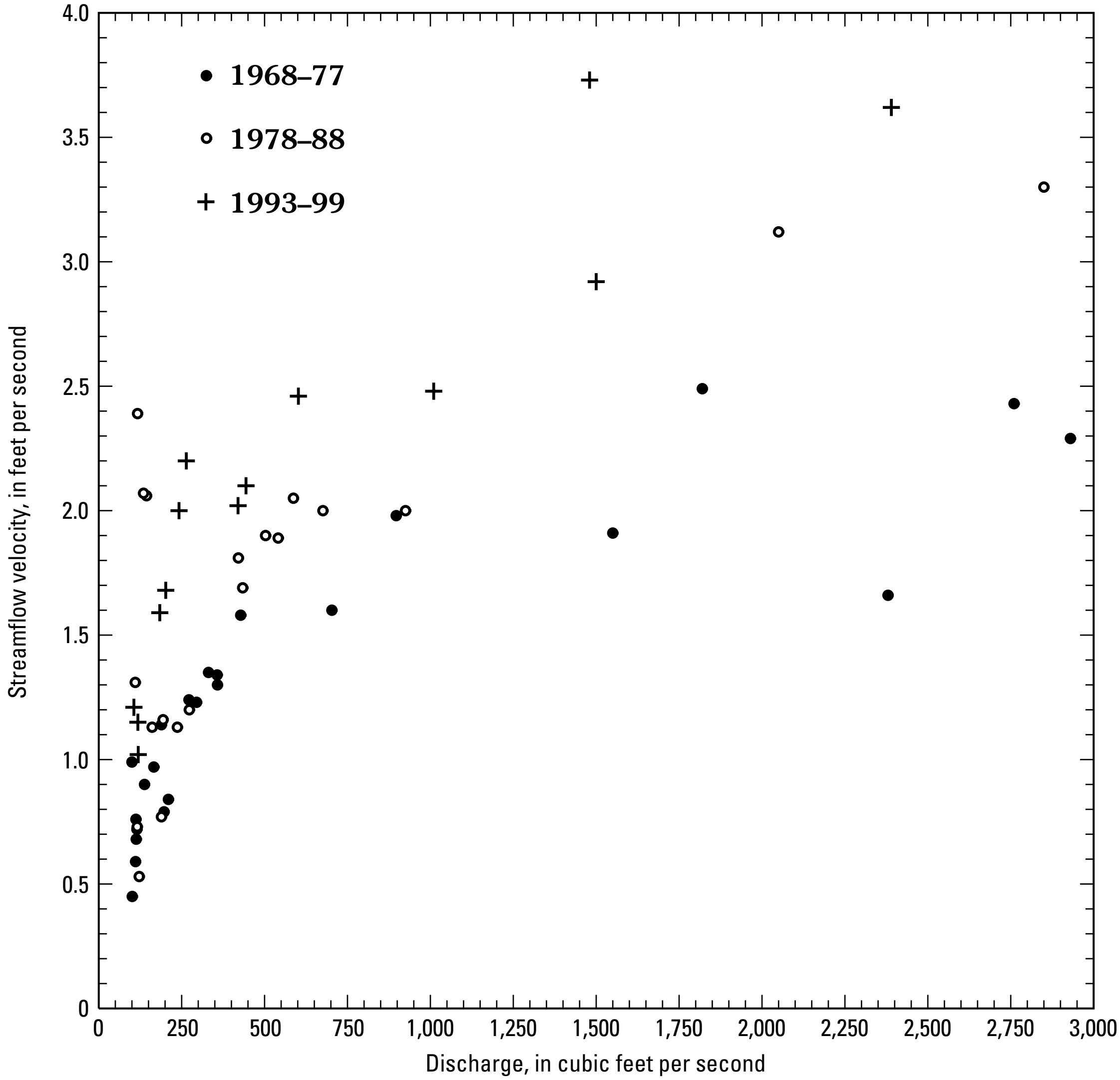

Figure 8. Relation between discharge and streamflow velocity at Soldier Creek gaging station near Delia (station 06889200, fig. 1).

For 1964–78, the stream stage for the mean annual discharge (50 ft^3/s) showed minimal change (fig. 9). Stream stage varied closely about the mean of 4.0 ft with a standard deviation of about 0.2 ft. A statistically significant positive trend (that is, increasing stage with time) (Spearman's rho = 0.50, two-sided p-value = 0.00904) was indicated. However, inspection of figure 9 shows that the aggradation that occurred was minor. From 1978 to 1981, the channel bed was apparently stable (as evidenced by the fact that no new rating curves were developed during this time period). No obvious changes in the relations between discharge and channel width, channel area, and streamflow velocity were indicated for this site.

Soldier Creek near Circleville

The streamflow-gaging station for Soldier Creek near Circleville (station 06889160, fig. 1, table 1) is located about 10 stream mi upstream from the Saint Clere gaging-station site (station 06889180, fig. 1) and about 5 stream mi upstream from the northern boundary of the reservation. The Circleville gaging station was discontinued in 2001 due to the planned replacement of the bridge. In its place, a new "Soldier Creek near Holton" station (06889170) was established about 3 stream mi downstream (fig. 1). The new gaging station is located about 2 stream mi upstream from the northern boundary of the reservation.

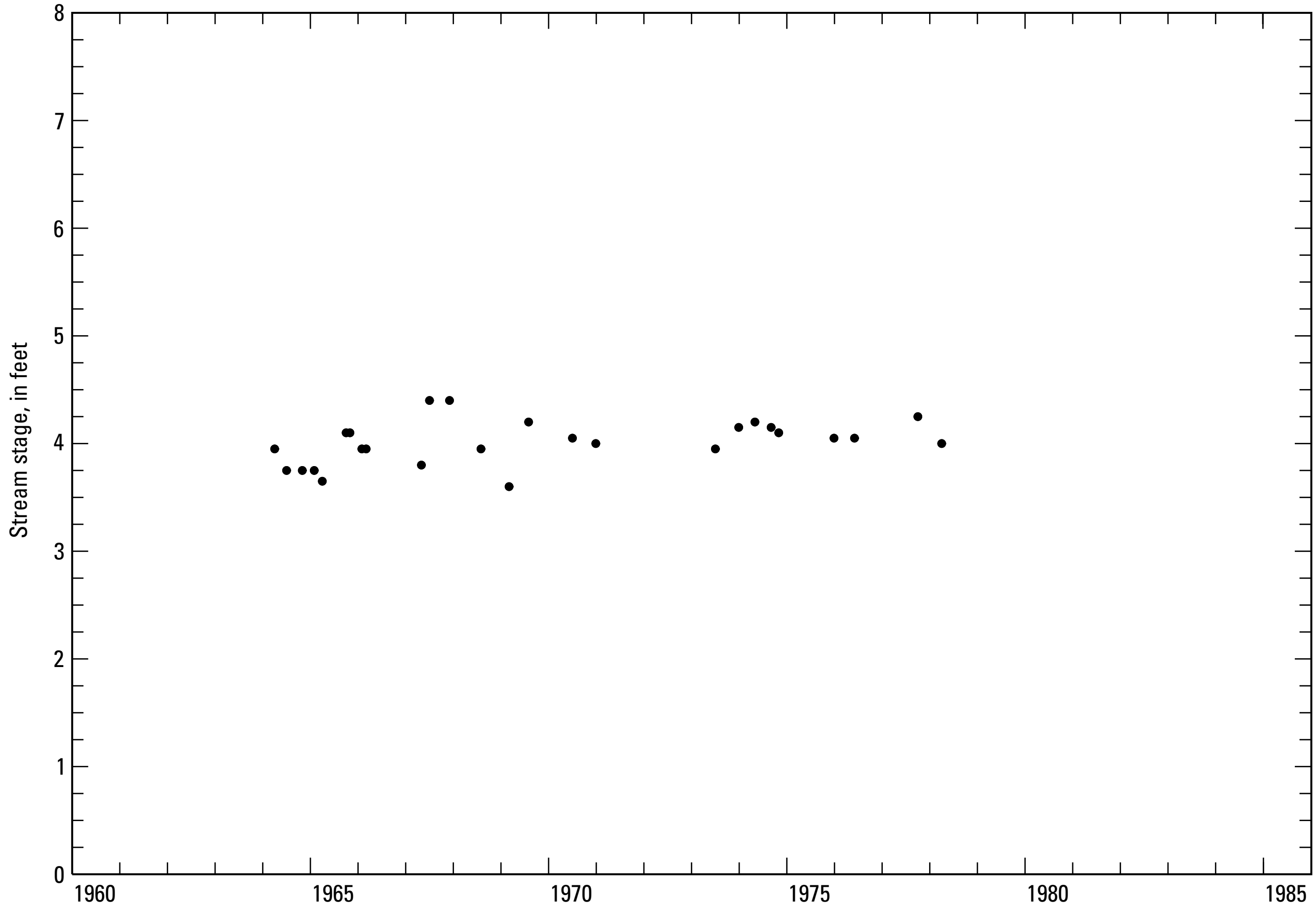

Figure 9. Variation in stream stage for mean annual discharge (50 ft^3/s) at Soldier Creek gaging station near Saint Clere (station 06889180, fig. 1), 1964–78.

Three distinct periods of channel-bed activity were apparent for the period 1964 to 1997 (fig. 10). For 1964–72, the stream stage for the mean annual discharge (30 ft^3/s) varied about the mean value of 3.7 ft with a standard deviation of about 0.2 ft. A statistically significant trend in stream stage was not indicated for this time period (Spearman's rho = 0.37, two-sided p-value = 0.12831). Instead, the channel bed at this location appeared to be fluctuating in response to scour and fill processes (fig. 10).

For 1972–92, the stream stage for the mean annual discharge decreased from 3.9 to 2.45 ft (fig. 10). This indicated a decrease in the channel-bed elevation of 1.45 ft. For this time period, a statistically significant negative trend was indicated (Spearman's rho = -0.95, two-sided p-value = 0.00000). During this time period, the channel bed degraded at an average rate of about 0.07 ft/yr. For 1992–97, the channel bed was relatively stable. Likewise, the channel bed was apparently stable from 1997 to 2000 (as indicated by the fact that no new rating curves were developed during this time period).

The analysis of the relations between discharge and channel width and between discharge and channel area indicated that neither relation changed appreciably during the period of record. The relation between discharge and streamflow velocity was not discernible and was characterized by considerable scatter. The lack of a relation between discharge and streamflow velocity was due, in part, to problems associated with debris and beaver dams in the vicinity of the gaging station.

Soldier Creek near Soldier

The streamflow-gaging station for Soldier Creek near Soldier (station 06889140, fig. 1, table 1) is located about 11 stream mi upstream from the Circle-

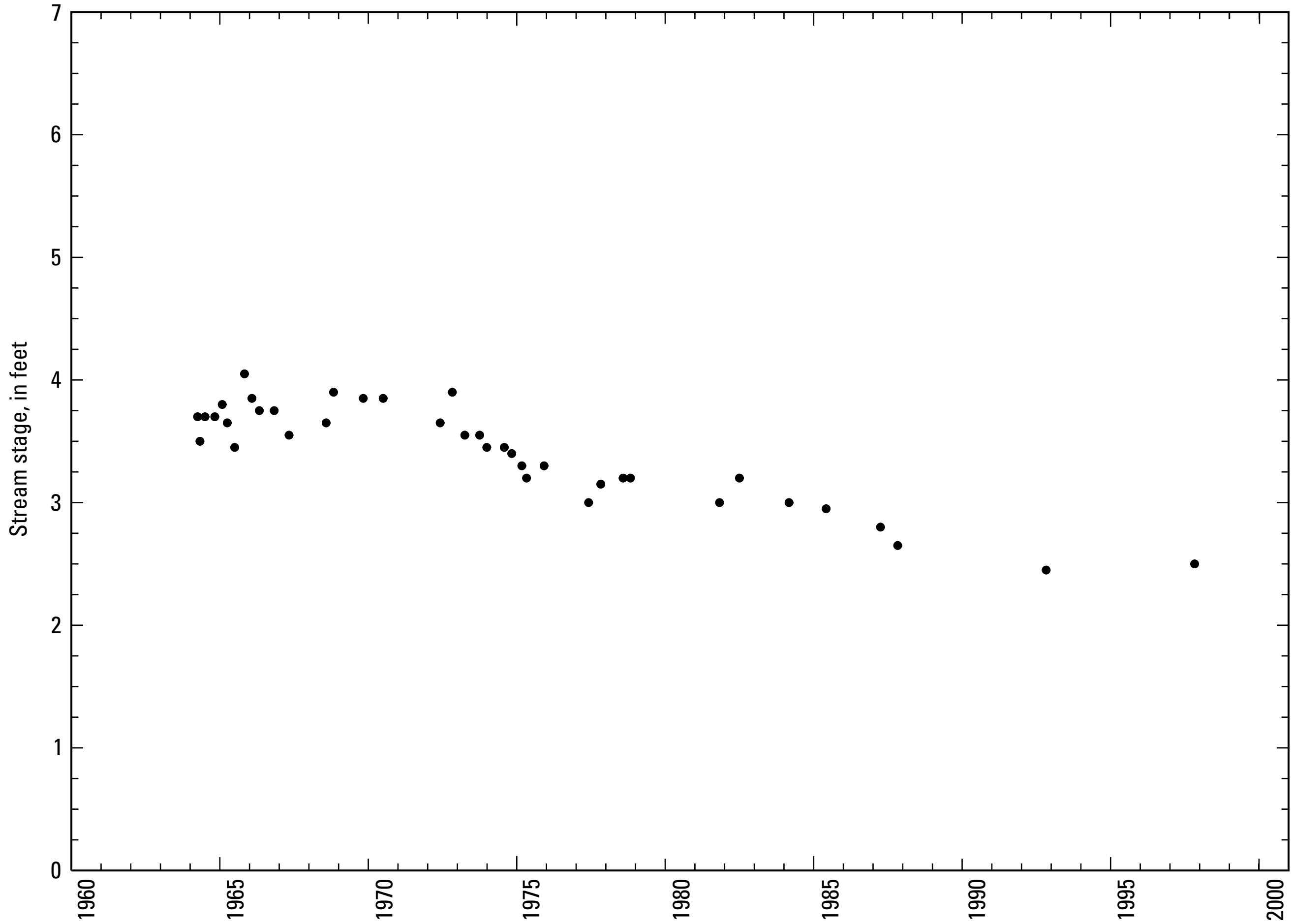

Figure 10. Variation in stream stage for mean annual discharge (30 ft^3/s) at Soldier Creek gaging station near Circleville (station 06889160, fig. 1), 1964–97.

ville gaging-station site (station 06889160, fig. 1). For 1964–95, a statistically significant negative trend (Spearman's rho = -0.87, two-sided p-value = 0.00000) in stream stage for the mean annual discharge (10 ft^3/s) was indicated (fig. 11). During this time period, the stream stage for the mean annual discharge decreased from 2.95 to 1.10 ft, which indicated a decrease in channel-bed elevation of 1.85 ft. The average rate of channel-bed decline during this period was about 0.06 ft/yr. However, the degradation was not uniform over time. The most pronounced degradation at this gaging-station site occurred in the 1960s. From 1964 to 1969, the stream stage for the mean annual discharge decreased 1.2 ft at an average rate of about 0.2 ft/yr. Then, following the deposition and subsequent erosion of 1.2 ft of sediment, the degradation continued during the period 1973–86 at an average rate of about 0.05 ft/yr. For 1986–95, the channel bed was relatively stable (fig. 11). Likewise, the channel bed was apparently stable from 1995 to 1998 (as indicated by the fact that no new rating curves were developed during this time period).

No discernible changes in the relations between discharge and channel width, channel area, and streamflow velocity were indicated for this gaging-station site. The relation between discharge and streamflow velocity exhibited some scatter, which was caused, in part, by problems with debris and beaver dams in the vicinity of the gaging station.

Soldier Creek near Bancroft

The streamflow-gaging station for Soldier Creek near Bancroft (station 06889120, fig. 1, table 1) is located about 3 stream mi upstream from the Soldier gaging-station site (station 06889140, fig. 1). For 1964–81, a statistically significant negative

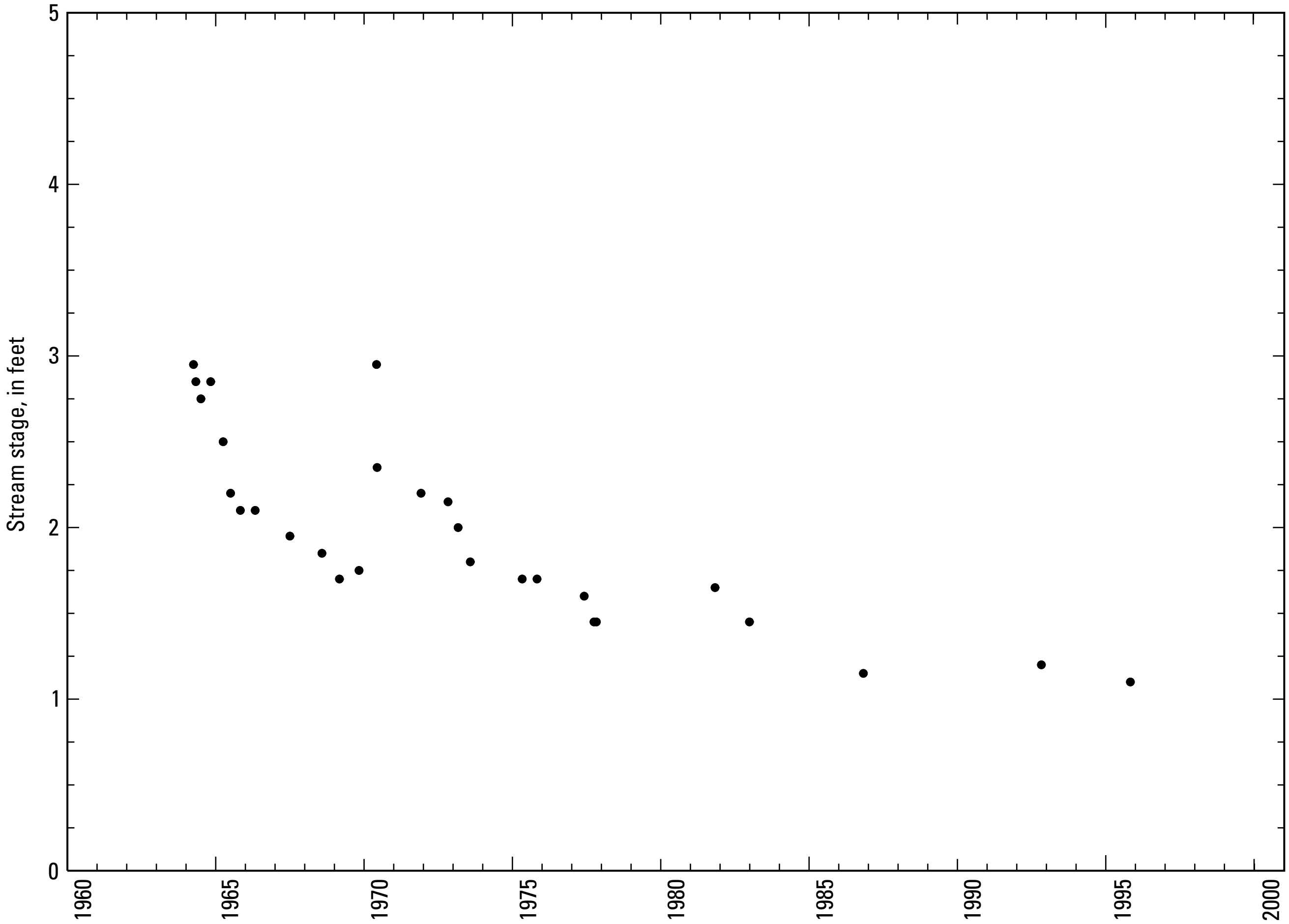

Figure 11. Variation in stream stage for mean annual discharge (10 ft^3/s) at Soldier Creek gaging station near Soldier (station 06889140, fig. 1), 1964–95.

trend (Spearman's rho = -0.82, two-sided p-value = 0.00000) was indicated for the change in stream stage for the mean annual discharge (7 ft^3/s) (fig. 12). From 1964 to 1977, the stream stage for the mean annual discharge decreased from 3.45 to 2.70 ft. This indicated a decrease in the channel-bed elevation of 0.75 ft at an average rate of about 0.06 ft/yr. The overall trend of degradation during this time period was characterized by several periods of scour and fill. From 1977 to 1981, the channel bed was apparently stable (fig. 12). The channel bed also was apparently stable from 1982 to 1988 (as indicated by the fact that no new rating curves were developed during this time period). Due to limited information and artificial control provided by concrete bridge abutments, an assessment of changes in the relations between discharge and channel width, channel area, and streamflow velocity for the period of record was not possible for this gaging-station site.

Soldier Creek near Goff

The streamflow-gaging station for Soldier Creek near Goff (station 06889100, fig. 1, table 1) is located about 3 stream mi upstream from the Bancroft gaging-station site (station 06889120, fig. 1) and is the most upstream station on Soldier Creek. With one exception, the channel bed at this location has been relatively stable. For 1964–69, the stream stage for the mean annual discharge (1 ft^3/s) varied about the mean value of 2.2 ft with a standard deviation of about 0.1 ft. A statistically significant trend in stream stage was not indicated for this time period (Spearman's rho = 0.21, two-sided p-value = 0.58252). Instead, the channel bed

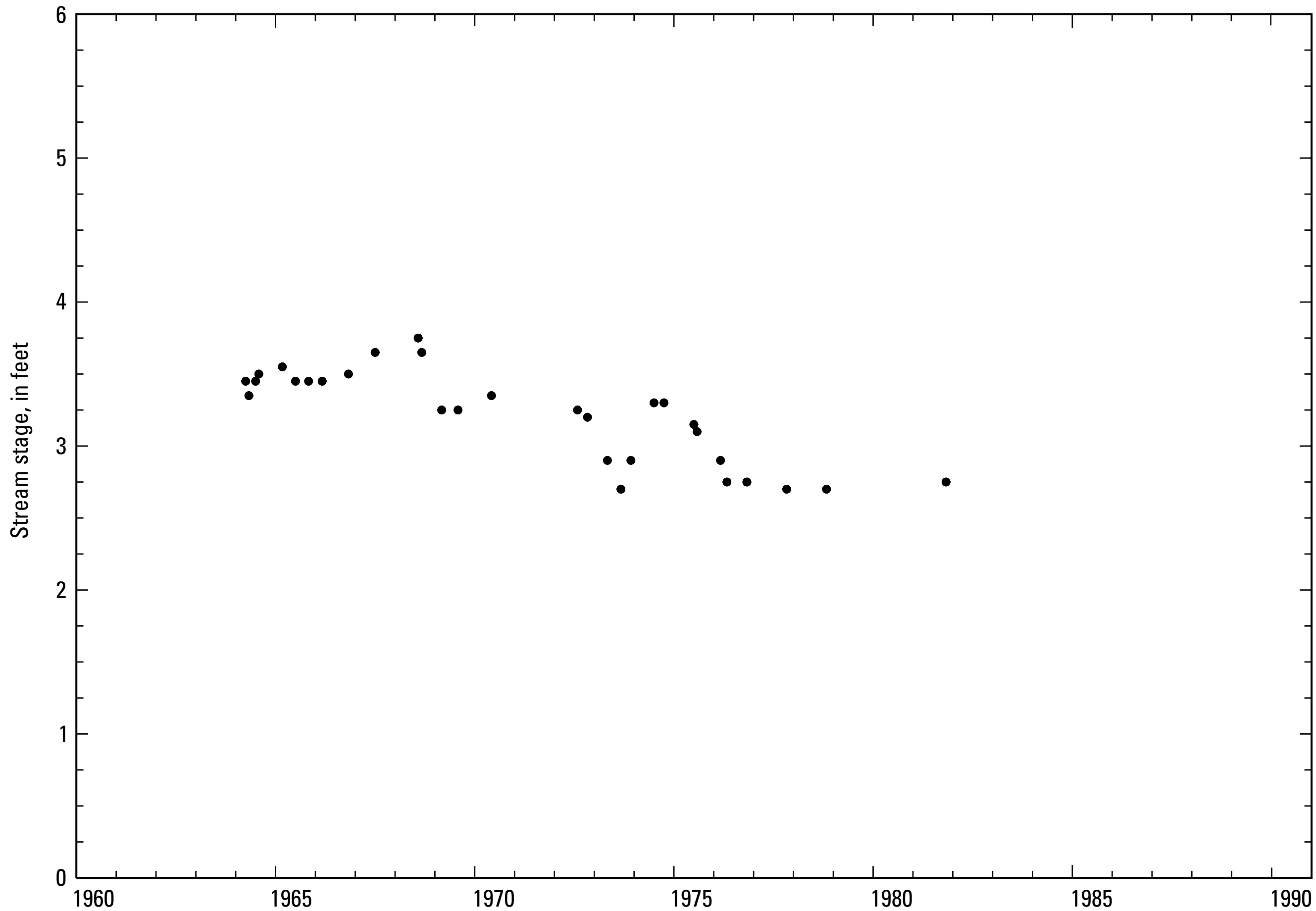

Figure 12. Variation in stream stage for mean annual discharge (7 ft^3/s) at Soldier Creek gaging station near Bancroft (station 06889120, fig. 1), 1964–81.

at this location appeared to be fluctuating in response to scour and fill processes (fig. 13).

The exception occurred from 1970 to 1973 when about 1 ft of sediment was deposited and then partially eroded. The channel bed appeared to stabilize during the period 1974–80 with the stream stage for the mean annual discharge averaging about 3 ft. The channel bed also was apparently stable from 1980 to 1987 (as indicated by the fact that no new rating curves were developed during this time period). Due to limited information, an assessment of changes in the relations between discharge and channel width, channel area, and streamflow velocity for the period of record was not possible for this site.

Kansas River at Topeka

The Kansas River streamflow-gaging station at Topeka (station 06889000, fig. 1, table 1) is located about 2.3 river mi upstream from the Soldier Creek confluence. For 1961–95, the river stage for the mean annual discharge (6,000 ft^3/s) decreased from 10.60 to 8.35 ft (fig. 14). This indicated a decrease in the channel-bed elevation of 2.25 ft at an average annual rate of about 0.07 ft/yr. For this time period, a statistically significant negative trend (Spearman's rho = -0.95, two-sided p-value = 0.00000) was indicated. The channel bed was apparently stable from 1995 to 2000 (as indicated by the fact that no new rating curves were developed during this time period). Changes in channel width, channel area, and streamflow velocity were not assessed for this site.

DISCUSSION

Channel change may result from a variety of human and natural causes. Human causes include channel modifications such as channelization, low-

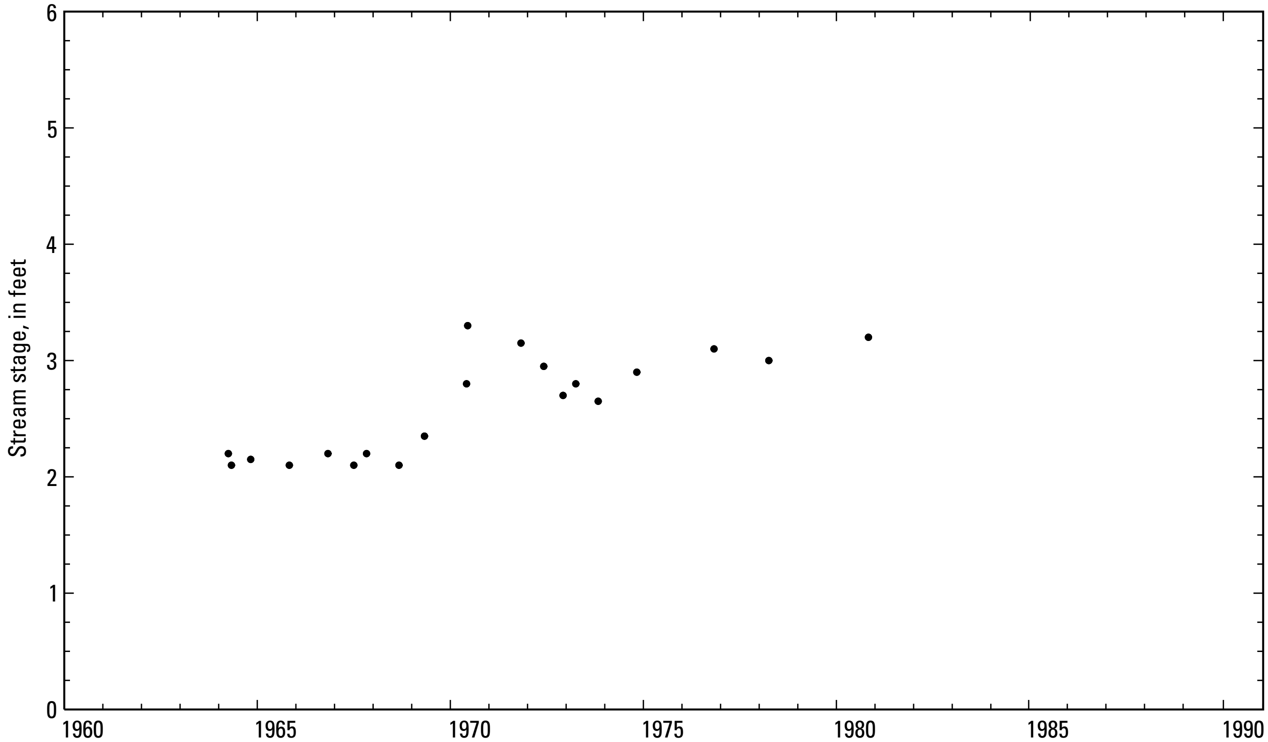

Figure 13. Variation in stream stage for mean annual discharge (1 ft^3/s) at Soldier Creek gaging station near Goff (station 06889100, fig. 1), 1964–80.

water crossings, weirs, bridge work, and bank stabilization, as well as land-use change. Natural causes, which also may be affected by human activity, include base-level change, floods, and climate change. As evidenced by the spatial and temporal variability of channel changes throughout the basin (fig. 15), many of these causes may have contributed to channel changes along Soldier Creek. In the following paragraphs, these potential causes of channel change are discussed within the context of the analysis of data from USGS streamflow-gaging stations located in or near the Soldier Creek Basin.

Channel degradation represents the expected response of Soldier Creek as it adjusts to the changes introduced by channelization in an attempt to establish a new equilibrium condition (Knighton, 1998). As the adjustment progresses, channel degradation will move upstream from the original site of channelization and affect additional reaches of Soldier Creek as well as its tributaries. The magnitude and extent of the upstream channel degradation has not been determined. However, it has been proposed that channel-bed degradation of 4 to 9 ft, with accompanying bank erosion, may be expected along Soldier Creek in Shawnee County (upstream from Topeka) during the next few decades (Booker, Engineers, Architects, Planners, [1986b?]).

The susceptibility of a channel to upstream-progressing degradation is controlled by a number of factors, including discharge, sediment load, bed and bank material composition, local bed-elevation control (for example, bedrock, armoring), and vegetation. Also, human-caused changes such as grade-control structures (for example, low-water crossings, weirs) and bank stabilization may affect the response of the stream channel. Considerable variation in the type, magnitude, and rate of channel degradation may occur even between sites located close together due to the variability of the controlling factors. If unchecked by natural and (or) human-caused factors, the upstream-progressing degradation potentially may affect the stream network throughout the entire basin.

Since completion of the USCOE channelization project in 1961, channel-bed degradation has migrated upstream to the streamflow-gaging station near Delia (station 06889200, fig. 15). The gaging station near Delia is located about 12 stream mi upstream from the upstream end of the channelized section of Soldier Creek.

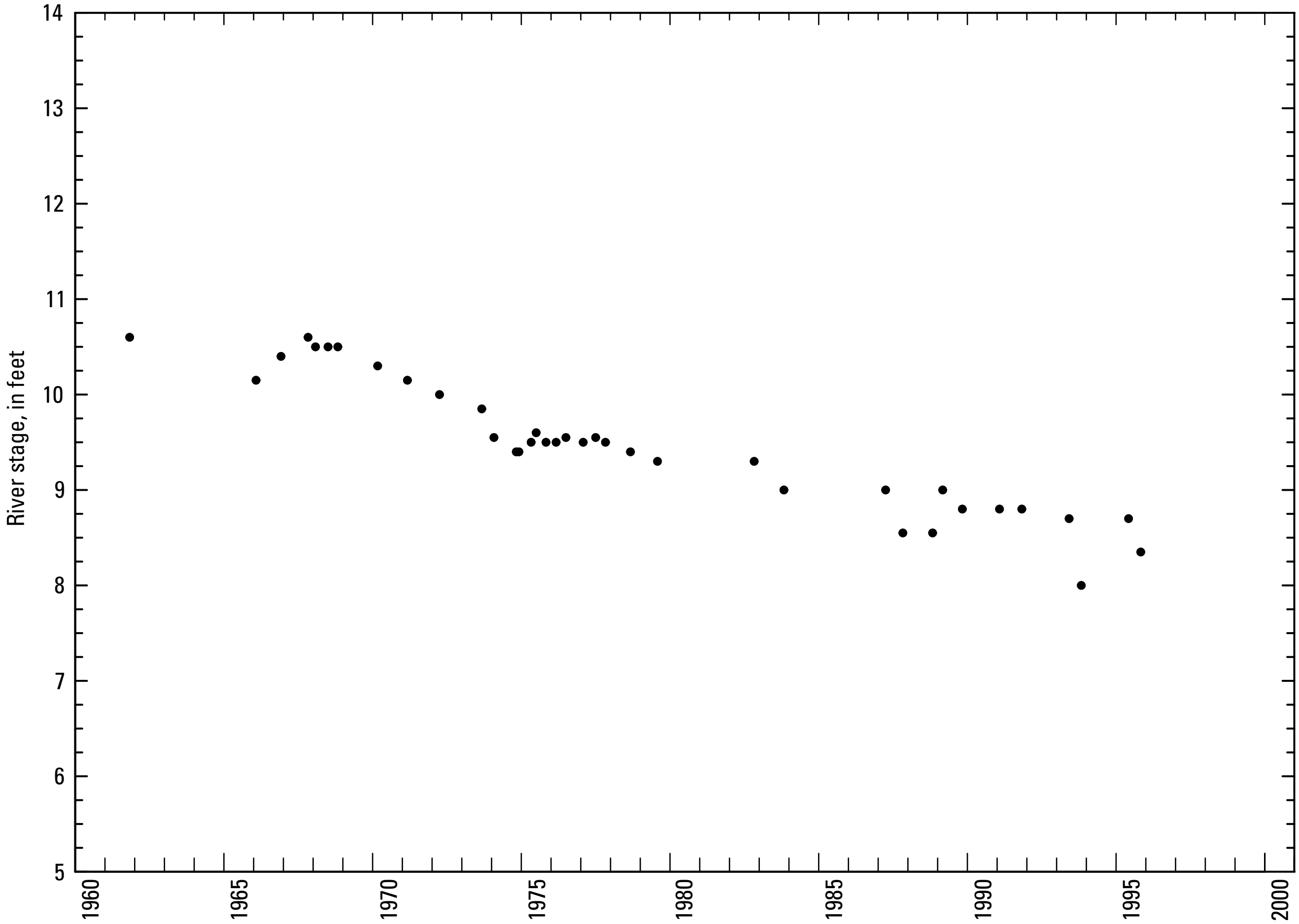

Figure 14. Variation in river stage for mean annual discharge (6,000 ft^3/s) at Kansas River gaging station at Topeka (station 06889000, fig. 1), 1961–95.

As of January 1971, when a low-water crossing was constructed about 1,500 ft downstream from the Delia gaging station, the upstream progression of channel-bed degradation had not yet reached the gaging station near Delia (figs. 5 and 15). Subsequently, when the low-water crossing partially washed out in 1978, channel-bed degradation began and continued at least through 1999. The correspondence of the beginning of channel-bed degradation with the partial washout of the low-water crossing indicated that the low-water crossing temporarily may have prevented the upstream progression of channel-bed degradation that would have reached the gaging station as early as 1971 or as late as 1978. This translates to a total traveltime of 10 to 17 years for the degradation to migrate from the upstream end of the channelized section of Soldier Creek to the gaging station near Delia (fig. 15). Using the upstream end of the channelized section as the point of reference, the average rate at which the channel-bed degradation progressed the 12 stream mi upstream to reach the Delia gaging-station site was 0.7 to 1.2 mi/yr.

An additional factor that may have contributed to channel-bed degradation at the Delia gaging station was a channel cutoff that occurred about 0.25 mi downstream some time between 1967 and 1977. The resultant shortening of the channel locally increased the channel slope and streamflow velocity and thus the erosive capability of the stream. With continued channel-bed degradation at the Delia gaging-station site, it is possible that a critical bank height eventually may be reached that causes the banks to become unstable. Such instability may initiate a period of bank collapse and channel widening (Simon, 1989).

If uninhibited by bedrock or human-built, grade-control structures, the post-1978 upstream progression of channel-bed degradation (at the estimated rate of 0.7 to 1.2 mi/yr) potentially reached the southern

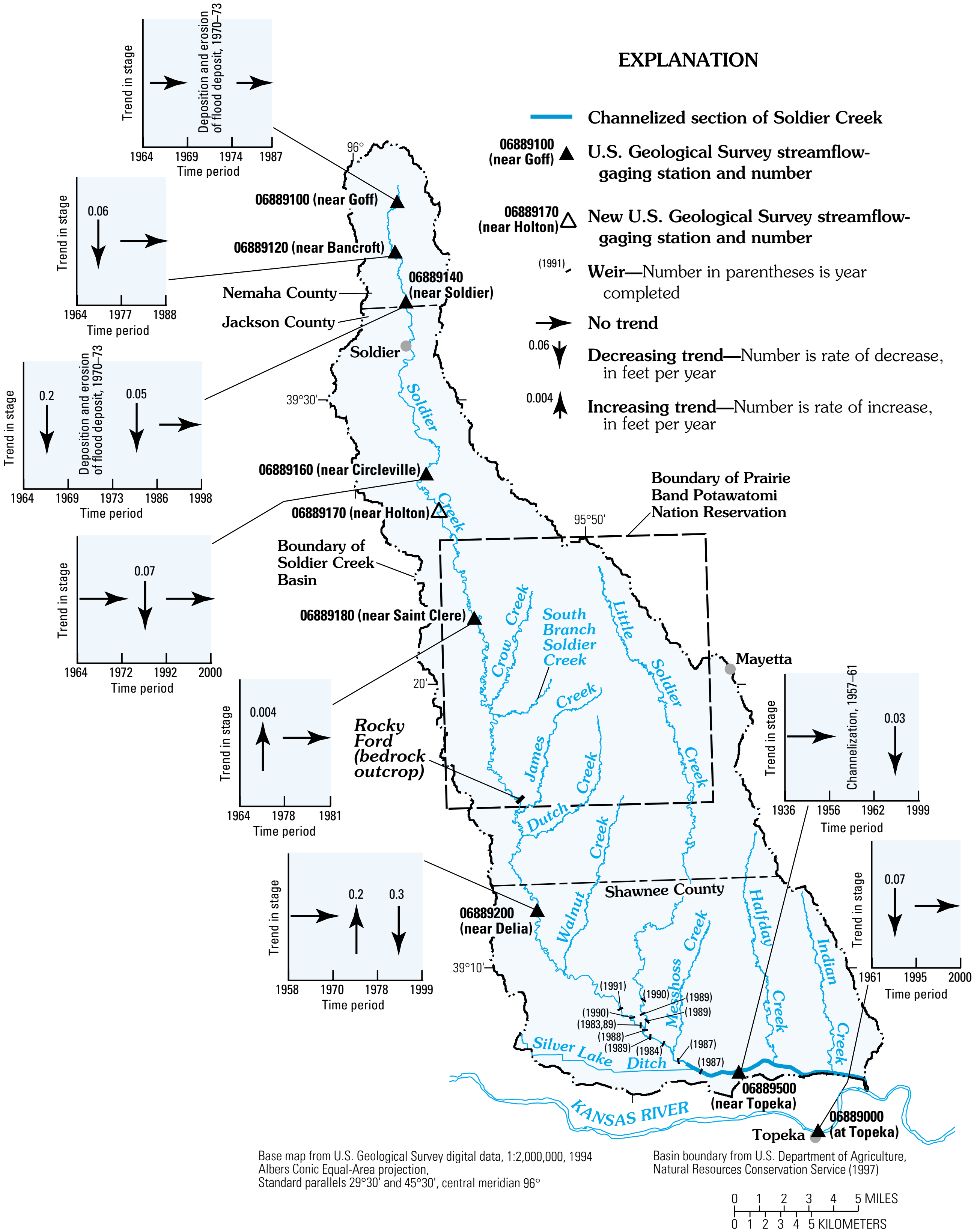

Figure 15. Historical trends and rates of channel-bed elevation change at U.S. Geological Survey streamflow-gaging stations located on Soldier Creek and Kansas River.

boundary of the reservation, located about 6.5 stream mi upstream from the Delia gaging station, in about 5 to 9 years. Thus, the Soldier Creek channel bed at this location potentially would have started to degrade some time between 1983 and 1987.

For 1978–99, the channel bed at the Delia gaging station decreased 6.6 ft at an average rate of about 0.3 ft/yr. However, if the 1.5 ft of aggradation apparently due to the presence of the low-water crossing is discounted, the channel bed at this location decreased 5.1 ft at an average rate of about 0.2 ft/yr. Using the average degradation rate determined for the Delia gaging station (that is, 0.2 or 0.3 ft/yr), the channel bed at the southern boundary of the reservation potentially degraded from 2.6 to 5.1 ft through 2000.

At Rocky Ford, located about 0.3 mi upstream from the southern boundary of the reservation (fig. 15), the upstream progression of channel-bed degradation potentially arrived shortly after it crossed the reservation boundary. Thus, potential channel-bed degradation immediately downstream from Rocky Ford is comparable to that which may have occurred at the southern reservation boundary. Such degradation, if it is occurring, may accelerate the undercutting and eventual collapse of the bedrock that creates the low-flow waterfall at Rocky Ford. Evidence of channel-bed degradation at Rocky Ford would include an increase in the height of the waterfall.

In April 2001, the height of the waterfall at Rocky Ford (measured from the top of the bedrock to the downstream water surface during low-flow conditions) was determined to be about 1.55 ft. Available evidence, which included an interview with a long-time local resident and old photographs, indicated that the height of the waterfall (during low-flow conditions) at Rocky Ford has been about the same at least since the 1960s. Thus, as of April 2001, the channel bed immediately downstream from Rocky Ford apparently has yet to be affected discernibly by the upstream progression of degradation.

Several possibilities may account for the apparent lack of channel-bed degradation immediately downstream from Rocky Ford. For example, the upstream progression of degradation may be inhibited by grade-control structures (for example, low-water crossings, weirs). Onsite inspection of the Soldier Creek channel between Rocky Ford and the Delia gaging-station site determined that no such structures presently (May 2001) exist. However, at one site, possible evidence of a washed-out structure (large rocks and concrete rubble in the channel) was found. Also, large rocks were observed in the channel at two other sites—near a bridge and at a site where an attempted bank stabilization had partially failed. Such artificially introduced rock may provide at least some temporary resistance to channel-bed degradation.

Another possibility is that natural channel conditions may have slowed or prevented the upstream progression of degradation. Onsite inspection of the Soldier Creek channel between Rocky Ford and the Delia gaging-station site revealed that, at one location where the channel is located next to an outcrop of limestone and shale bedrock on the valley wall, a deposit of loose bedrock debris had accumulated across the channel bed. The bedrock debris creates a rapid during low-flow conditions over which the water surface drops an estimated 1.5 ft. The loose bedrock debris at this site may provide at least some temporary resistance to channel-bed degradation. Also, exposed bedrock was observed across the channel bed at a site located about 0.3 mi upstream from the Delia gaging-station site. Available evidence, which included an interview with a long-time local resident and observation of exposed tree roots, indicated substantial channel-bed erosion upstream from the bedrock outcrop. Thus, the bedrock outcrop may have been exposed relatively recently. The bedrock may provide resistance to future upstream progression of channel-bed degradation.

Also, it is possible that the channel immediately downstream from Rocky Ford may be armored. An armored channel bed is one in which the fine material has been eroded and carried away leaving a layer of coarse material that inhibits further degradation of the channel bed. The armor on the channel bed at this location may include cobble-sized material as well as bedrock slabs.

A final possibility is that a combination of natural and human-caused conditions may have limited the upstream progression of channel-bed degradation. However, it is not known if the limitation is complete or partial, permanent or temporary. It is possible that with more time channel-bed degradation immediately downstream from Rocky Ford may become more evident. The bedrock outcrop in the channel at Rocky Ford should minimize the progression rate of channel-bed degradation upstream from that site.

The weirs constructed upstream from the Soldier Creek near Topeka gaging station (06889500, fig. 15) by the North Topeka Drainage District, in the 1980s and early 1990s, may prevent additional channel-bed degradation from progressing upstream from those structures. However, the substantial channel-bed degradation that occurred during the 1960s through the early 1980s had already progressed upstream before the weirs were built.

Bridge work may have contributed to channel change at the Soldier Creek near Soldier streamflow-gaging station (06889140, fig. 15). At this site, the relatively rapid channel-bed degradation from 1964 to 1969 (compared to subsequent years) (fig. 11) may have been caused, in part, by the disturbance of the channel when the bridge was constructed not too long before the gaging station was established (L.M. Pope, U.S. Geological Survey, written commun., 1975).

The effects of land-use and climate changes on the Soldier Creek channel cannot be determined solely on the basis of the gaging-station information used in this assessment. However, it is reasonable to expect that land use and climate may have contributed to the channel-bed changes that occurred along Soldier Creek. In particular, land-use and climate changes may be relatively more important as causes of channel change in the upstream part of the Soldier Creek Basin (upstream from Rocky Ford) (fig. 15), which does not appear to have been affected by the downstream channelization.

Base level is another factor that may contribute to, or prevent, changes in channel-bed elevation. For Soldier Creek, base level is provided by the Kansas River. For 1961–95, the channel-bed elevation for the Kansas River at Topeka streamflow-gaging station (06889000, figs. 14 and 15) decreased 2.25 ft at an average rate of 0.07 ft/yr. This decrease in base level may have contributed to channel-bed degradation along Soldier Creek downstream from Rocky Ford (fig. 15). At Rocky Ford, the limestone bedrock in the channel provides a local base-level control that will minimize the rate of channel-bed degradation. Likewise, upstream at the Soldier Creek near Soldier gaging station (06889140, fig. 15), base-level control is provided by exposed bedrock that forms the channel bed. Thus, unless disturbed by human activity, additional channel-bed degradation at this location also is expected to be minimal.

Floods can cause substantial channel change in a short period of time. Flood-related changes in channel-bed elevation were determined for two locations in the upstream part of the basin. At the Soldier Creek near Goff streamflow-gaging station (06889100, figs. 13 and 15), two successive increases in channel-bed elevation (totaling about 1 ft) during 1970 were apparently due to deposition of sediment caused by high flows on May 10 and May 23, 1970. The May 10 flood was the largest for the period of record (peak discharge of 7,080 ft^3/s). Downstream at the Soldier Creek near Soldier gaging station (06889140, figs. 11 and 15), a degradational trend was interrupted on May 10, 1970, when the largest flood for the period of record (peak discharge of 11,700 ft^3/s) deposited 1.2 ft of sediment in the channel. Unlike the Goff (upstream) and Soldier (downstream) gaging-station sites, the Soldier Creek near Bancroft gaging station (06889120, figs. 12 and 15) did not have a substantial deposition of sediment caused by the May 10, 1970 flood, which was the largest for the period of record at this site (peak discharge of 13,100 ft^3/s). In addition, the May 10, 1970 flood apparently had little effect on channel-bed elevation at other downstream gaging stations. By the time the flood reached the gaging station near Circleville, its peak discharge had diminished to 5,570 ft^3/s.

SUMMARY AND CONCLUSIONS

Available information from eight U.S. Geological Survey streamflow-gaging stations was used to assess historical channel change along Soldier Creek, northeast Kansas. For each gaging station, channel change was assessed using channel-bed elevation as the primary indicator variable. Changes in channel-bed elevation were inferred from changes in the stage associated with the mean annual discharge at each station. The variables channel width, channel area, and streamflow velocity were used as additional indicators of change.

Results indicated that the most substantial channel changes in the basin occurred downstream from Rocky Ford at the Soldier Creek streamflow-gaging stations located near Topeka and Delia. The available evidence indicated that channelization was likely the primary cause of the channel changes at these locations. The channel-bed degradation at these locations also may have been caused, in part, by the decreasing base level provided by the Kansas River. Throughout the basin several other causes contributed, or potentially contributed, to channel changes along Soldier Creek including additional channel modifications (for example, low-water crossings, weirs, bridge work), land-use change, floods, and climate change.

Upstream from Rocky Ford, the most recently available information indicated that the channel bed had become relatively stable at all gaging-station sites. As of 2001, the available evidence indicated that Soldier Creek at and upstream from Rocky Ford has not been substantially affected by the upstream-progressing channel-bed degradation.

The channelization of Soldier Creek, completed in 1961, caused substantial channel change at the Soldier Creek gaging station near Topeka, which is located within the channelized section. Immediate channel changes at this station included a decrease in channel-bed elevation of about 5 ft and an increase in channel width of about 35 ft. Subsequently, from 1962 to 1999, the channel bed continued to degrade at an average rate of about 0.03 ft/yr.

The instability introduced by the channelization of Soldier Creek caused channel-bed degradation that progressed upstream at the rate of about 0.7 to 1.2 mi/yr. At the Soldier Creek gaging station near Delia, which is located about 12 stream mi upstream from the upstream end of the channelized section, channel-bed degradation began following the partial washout of a downstream low-water crossing in 1978. As of 1999, the channel bed at the gaging station near Delia had degraded 5.1 or 6.6 ft (depending on whether the sediment deposited upstream from the low-water crossing is included or discounted in the calculated change) at an average rate of about 0.2 or 0.3 ft/yr, and channel-bed degradation as of 1999 had not yet begun to slow.

At Rocky Ford, a bedrock outcrop in the Soldier Creek channel that is located about 6.8 stream mi upstream from the Delia gaging station and within the Prairie Band Potawatomi Nation Reservation, the upstream progression of channel-bed degradation potentially began to affect the channel in the mid-1980s. However, a lack of increase in the height of the low-flow waterfall at Rocky Ford indicated that the channel bed immediately downstream has yet to be degraded substantially as of 2001. A combination of natural and human-caused conditions may have limited the upstream progression of channel-bed degradation. However, it is not known if the limitation is complete or partial, permanent or temporary. It is possible that with more time channel-bed degradation immediately downstream from Rocky Ford may become more evident. The bedrock outcrop in the channel at Rocky Ford should minimize the rate of channel-bed degradation upstream from the site.

This assessment determined that the channel-bed degradation caused primarily by the channelization of Soldier Creek had migrated upstream at least as far as the Delia gaging station and potentially may be affecting the channel within the reservation immediately downstream from Rocky Ford. Long-term monitoring of channel conditions at and immediately downstream from Rocky Ford may provide the information necessary to determine the magnitude and rate of channel-bed degradation should it occur in the future. The monitoring, at a minimum, should include the annual remeasurement of the height of the waterfall at Rocky Ford during low-flow conditions. Ideally, the monitoring also would include the establishment and annual resurvey of several monumented cross sections to more comprehensively assess channel changes.

Because degradation of Soldier Creek may have causes other than the channelization, especially upstream from Rocky Ford, additional investigation may be warranted. For example, a low-altitude aerial reconnaissance and acquisition of photographs during low-flow, leaf-off conditions, coupled with the use of historical aerial photographs, may provide some of the information needed to comprehensively determine locations of channel degradation along Soldier Creek. The aerial photographs potentially could be used to determine the timing and location of bank collapses, which then could be investigated in relation to various potential causes including human disturbances, streamflow, the composition of the channel bed and banks, channel geometry, and vegetation. A comprehensive analysis of streamflow characteristics, including the frequency and “flashiness” of high flows, also may provide important information for understanding the hydrology and stability of the Soldier Creek system. Related studies (perhaps involving a modeling approach), which may provide important information for understanding storm runoff within the basin, could include analyses of sediment loads, basin characteristics (for example, soils, land use, slope), and land-management practices (for example, terraced versus unterraced cropland). Together, such studies would provide information necessary for improved understanding and management of the Soldier Creek system.

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