Hydrologic Droughts in Kansas—Are They Becoming Worse?

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Introduction

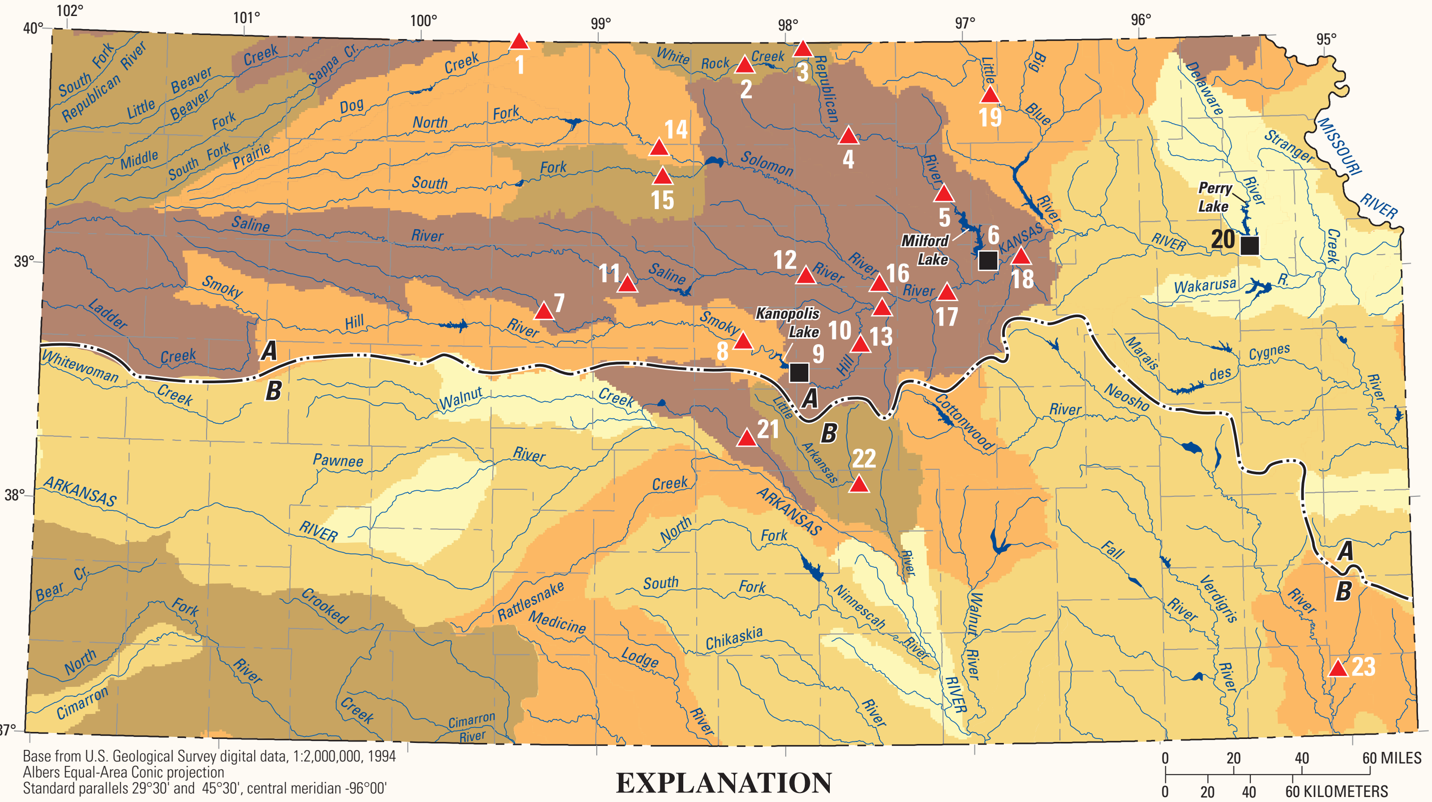
Multi-year droughts have been a recurrent feature of the climate and hydrology of Kansas since at least the 1930s. Streamflow records collected by the U.S. Geological Survey (USGS) indicate that water years 2000 to 2006 (October 1, 1999, through September 30, 2006) represent the sixth hydrologic drought during the past eight decades, and that corresponding streamflow levels in some parts of Kansas were lower than those during historic droughts of the 1930s and 1950s, even though the precipitation deficit was not as severe. Record-low streamflows in water year 2006 were recorded at USGS streamgages on the Republican, Smoky Hill, Solomon, Saline, upper Kansas, middle Arkansas, and Little Arkansas Rivers, as well as many tributary sites, and one tributary site of the Neosho River (fig. 1, table 1).

Low streamflows during the hydrologic drought also resulted in record low levels at three Federal reservoirs in Kansas (fig. 1, table 2). An unprecedented number of administrative decisions were made by the Division of Water Resources, Kansas Department of Agriculture to curtail water diversions from rivers to maintain minimum desirable streamflows, and low flows on the lower Republican River in Kansas created concerns that Colorado and Nebraska were not complying with the terms of the 1943 Republican River Compact.

Statewide Runoff and Streamflow Conditions

Daily streamflow data for water years 1900–2007 are used to estimate average annual runoff (streamflow per unit area) for all streamgages in Kansas (U.S. Geological Survey, 2006a). The median runoff for each water year is then determined. Statewide median runoff for Kansas for water years 1920–2006 (fig. 2) indicates large departures from median runoff during five historic hydrologic droughts in Kansas that occurred during 1929–41, 1952–57, 1962–72, 1974–82, and 1988–92 (Paulson and others, 1991). The severity of streamflow conditions during water years 2000–06 is apparent when comparing the departures from median annual runoff for that period with those during the historic droughts. Annual runoff in Kansas was below the median all years during 2000–06 except water year 2004, which was near the median. Water year 2006, the driest year during the 2000–06 hydrologic drought, had the second lowest annual runoff during 1920–2006; the lowest annual runoff for Kansas occurred in water year 1956.

The streamflow effects of drought during water years 2000–06 were focused in northern Kansas on the Republican, Saline, Solomon, and Smoky Hill Rivers (fig. 1), whereas the 1950s drought effect was focused more in southeastern Kansas on the Verdigris, Fall, and Neosho Rivers (Paulson and others, 1991). Average annual flows at four long-term streamgages (fig. 3) indicate that average annual streamflow during 2000–06 at each of the streamgages was less than the average annual streamflow during other historic droughts in Kansas. Furthermore, the average annual flow for all streamgages was less than 25 percent of long-term median annual flow during 2000–06, indicating the severity of the drought. For example, annual average streamflow for the Republican River at Clay Center (site 5, fig. 1, fig. 3*A*, table 1), in continuous operation since 1919, was less than the long-term median streamflow each water year since 2000 and was the lowest on record in water year 2006. Moreover, five of the 10 lowest annual average flows for the Clay Center gage occurred during 2000–06 (U.S. Geological Survey, 2006b).



EXPLANATION

Drought condition by hydrologic unit
- Extreme
- Severe
- Moderate
- Below normal
- Normal

18 ▲ **Streamgage with record-low annual average streamflow—**Map index number shown in table 1

20 ■ **Reservoir with record-low elevation—**Map index number shown in table 2

Drainage basin
- *A* Missouri River Basin
- *B* Lower Mississippi River Basin
- —··— **Basin boundary**

Figure 1. Drought conditions by hydrologic unit in Kansas, comparison of water year 2006 streamflows with all other annual streamflows, water years 1930–2006, and location of streamgage with record-low annual streamflow in water year 2006, and reservoirs with record-low elevations, water years 2000–06 (hydrologic units from Seaber and others, 1987; data for drought conditions from WaterWatch, 2006 (U.S. Geological Survey, 2007a).

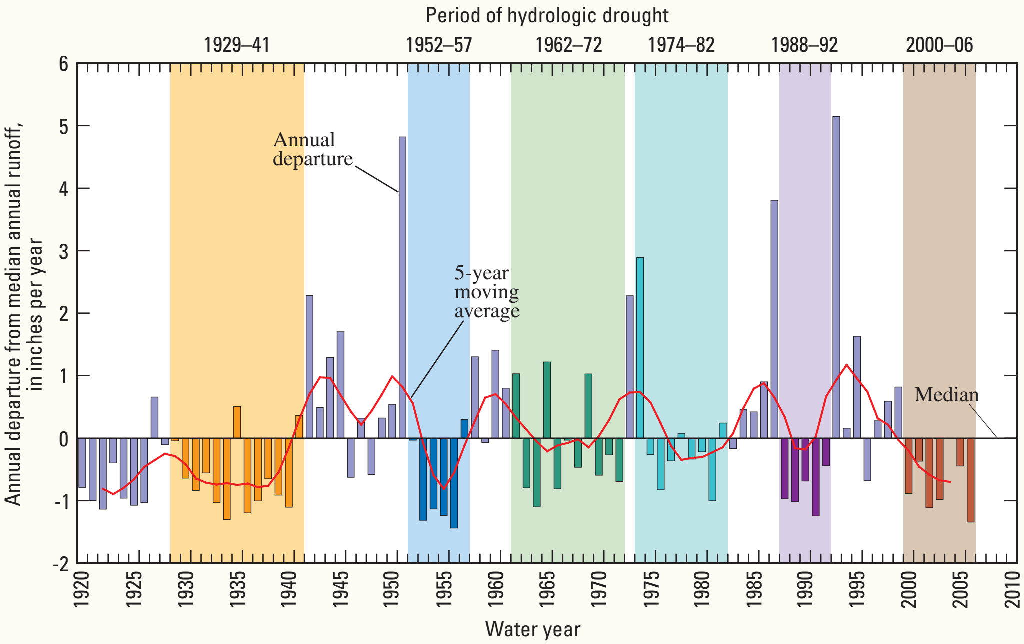


Figure 2. Statewide runoff showing annual departure of runoff from the statewide median of 1.63 inches per year and a 5-year moving average line for water years 1920–2006. Wetter years plot above the median line and drier years plot below the median line, (data from U.S. Geological Survey, 2006a).

Current and Historic Precipitation

Meteorological conditions during the 2000–06 drought were different than those during previous severe droughts in the 1930s and 1950s. Statewide average annual precipitation for Kansas during water years 2000–06 (fig. 4) was greater than that during all previous droughts except for the 1974–82 drought (National Oceanic and Atmospheric Administration, 2007a). Furthermore, statewide average annual precipitation for water years 2000–06 was less than 1 inch below normal, whereas the average annual precipitation during one of the worst Kansas droughts, 1952–57, was nearly 6 inches below normal. The average statewide Palmer

Table 1. U.S. Geological Survey streamgages with record-low average annual streamflows during water year 2006.

[Data from U.S. Geological Survey, 2006b; mi², square miles; ft³/s, cubic feet per second]

Map index number (fig. 1)	Station name	Drainage area (mi²)	Long-term median annual average streamflow (ft³/s)	Water year 2006 annual average streamflow (ft³/s)	Years of record
1	Prairie Dog Creek near Woodruff, KS	1,007	0.11	0.03	61
2	White Rock Creek near Burr Oak, KS	227	22.5	2.52	49
3	Republican River near Hardy, NE	22,401	380	19.2	74
4	Republican River at Concordia, KS	23,560	492	44.9	60
5	Republican River at Clay Center, KS	24,542	827	82.7	88
7	Big Creek near Hays, KS	549	18.4	.71	60
8	Smoky Hill River at Ellsworth, KS	7,580	151	24.2	94
10	Smoky Hill River near Mentor, KS	8,358	274	26.8	65
11	Saline River near Russell, KS	1,502	47.7	3.59	55
12	Saline River at Tescott, KS	2,820	120	14.1	86
13	Smoky Hill River at New Cambria, KS	11,730	398	60.3	44
14	North Fork Solomon River at Portis, KS	2,315	77.8	11.8	54
15	South Fork Solomon River at Osborne, KS	2,012	42.0	4.10	61
16	Solomon River at Niles, KS	6,770	328	72.0	95
17	Smoky Hill River at Enterprise, KS	19,260	1,139	191	72
18	Kansas River at Fort Riley, KS	44,870	2,019	418	42
19	Little Blue River near Barnes, KS	3,351	629	213	48
21	Cow Creek near Lyons, KS	728	53.4	7.42	58
22	Little Arkansas River at Alta Mills, KS	736	168	11.8	33
23	Lightning Creek near McCune, KS	197	131	10.7	55

Drought Severity Index (PDSI), one of the indices used to classify and assess long-term meteorological droughts (Hayes, 2002), for water years 2000–06 was -0.03 (normal), whereas the average PDSI for the 1952–57 drought was -3.22, indicating a severe drought (National Oceanic and Atmospheric Administration, 2007b). Statewide average precipitation during the five consecutive driest years of the 2000–06 drought also was greater than the statewide average precipitation during the five driest years of the 1930s and 1950s droughts (fig. 5); however, the annual statewide median runoff during the 2000–2006 drought was near the low runoff levels that occurred in the 1930s and the 1950s. Precipitation in the area of Kansas where most of the record-low streamflows occurred during water year 2006 was generally about 75–90 percent of normal, not an indication of a significant lack of precipitation (National Oceanic and Atmospheric Administration, 2007a).

Runoff-Precipitation Relation

The Statewide relation between runoff and precipitation (fig. 5) does not indicate that there has been a significant change in runoff between past droughts and the 2000–06 drought when comparing the lowest five consecutive years of runoff in each drought. This statewide analysis, however, includes many areas of Kansas that were not even in drought conditions during much of 2000–06. The relation indicates that, generally, runoff increases as precipitation increases, an intuitive conclusion. However, if the same analysis is completed using median annual runoff for the four long-term sites in Kansas (fig. 3) that represent the worst drought-affected areas during the 2000s drought, the results appear different (fig. 6) because the regional affects of the 2000s drought are not smoothed by statewide averaging

Table 2. Location of Federal reservoirs in Kansas with record low elevations during water years 2000–06.

[Data from Putnam and Schneider, 2003 and U.S. Geological Survey, 2006c; mi², square miles; ft, feet]

Map index number (fig. 1)	Station name	Drainage area (mi²)	Top of conservation pool elevation (ft)	Lowest elevation and date		Percent conservation pool
				Elevation (ft)	Water Year	
6	Milford Lake near Junction City	24,880	1,144.4	1,136.90	2003	68
9	Kanopolis Lake near Kanopolis	7,857	1,463	1,456.22	2006	55
20	Perry Lake near Perry	1,117	891.5	884.90	2003	64

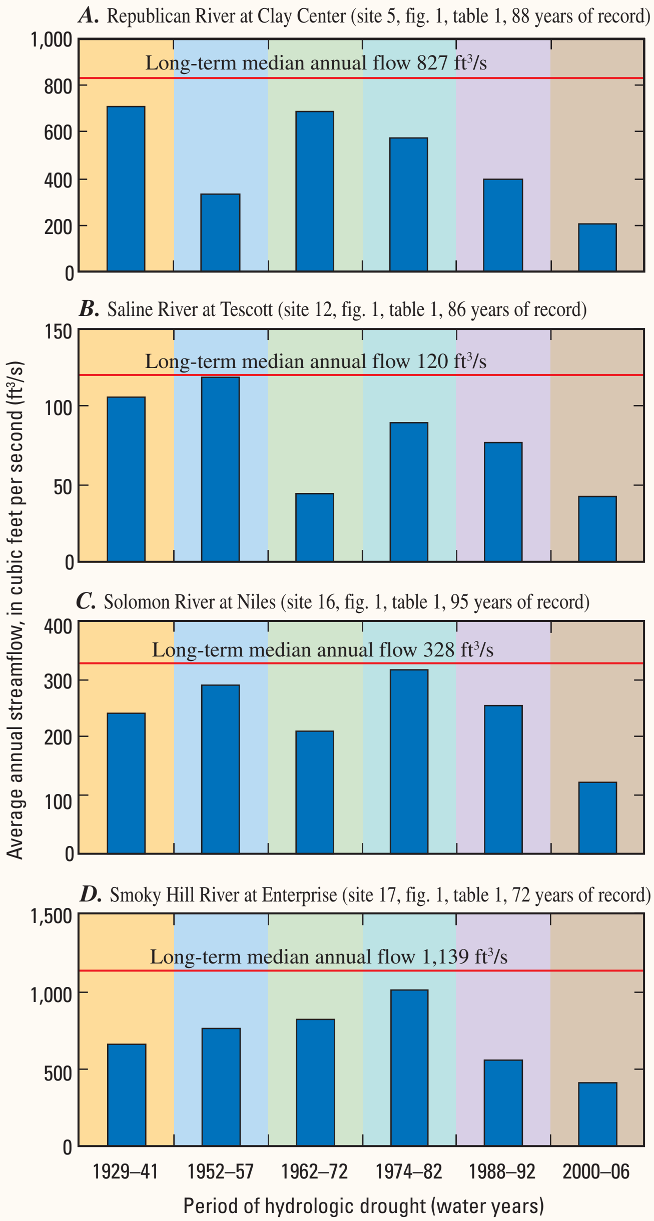


Figure 3. Average annual streamflow at four selected streamgages in Kansas during five historic droughts and for water years 2000–06 (data from U.S. Geological Survey, 2006b).

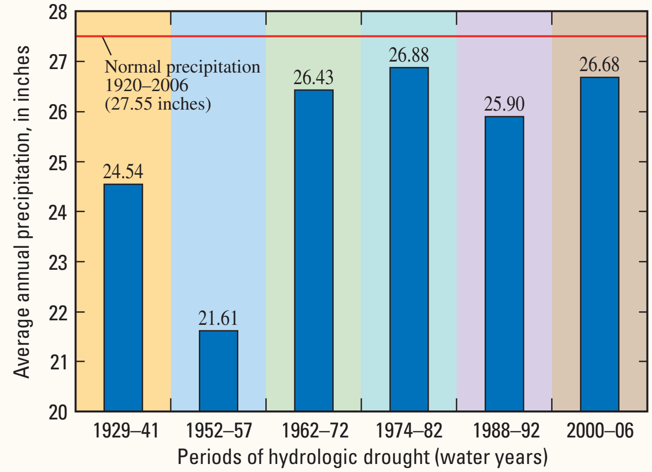


Figure 4. Statewide average annual precipitation during water years 2000–06 compared with average annual precipitation during five historic droughts in Kansas (precipitation data from National Oceanic and Atmospheric Administration, 2007a).

as in figure 5. Streamflow records have been collected since the 1930s at Republican River at Clay Center (site 5, fig. 1, table 1), Saline River at Tescott (site 12, fig. 1, table 1), Solomon River at Niles (site 16, fig. 1, table 1), and Smoky Hill River at Enterprise (site 17, fig. 1, table 1). Moreover, these sites are located at the downstream most location in the primary river basins that experienced record-low streamflows in water year 2006. Precipitation data for this analysis is from the PRISM group (PRISM, 2007), which provides precipitation data that are distributed over a delineated river basin. National Oceanic and Atmospheric Administration divisional precipitation data (used in analysis in figure 5) is collected at nine nearly equal areas in Kansas, and does not provide data for a specific basin. In fact, these precipitation data may include data for parts of several river basins; therefore, it was not used.

The relation between annual precipitation for the river basin, and averaged annual runoff for the four sites during the five driest consecutive years for each drought (same water years as those used in previous analysis) was much lower during the 2000s drought than during the 1930s and 1950s drought, even though average precipitation was greater (fig. 6). This analysis indicates a change in the runoff-precipitation relation between earlier droughts and the current drought.

The runoff ratio, the amount of precipitation that becomes streamflow, can be computed annually for each of the sites listed above by dividing the annual runoff by annual precipitation and multiplying by 100. A 5-year moving average was used to smooth the computed annual runoff ratios. For each site, the mid year of the five consecutive driest years during each drought was determined for each drought. For each site, the runoff ratio has decreased for each drought, and the more recent droughts have a lower runoff ratio, as shown in figure 7. The runoff ratio for the 2000s drought was the lowest of all droughts.

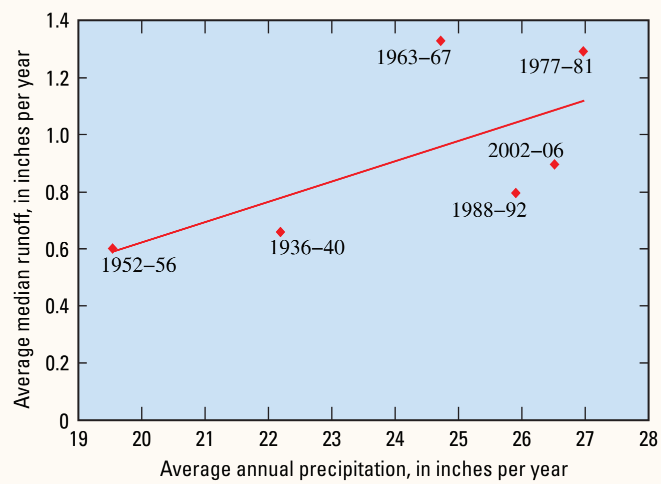


Figure 5. Statewide relation between median annual runoff and average annual precipitation for 5 consecutive driest years during six hydrologic droughts in Kansas (precipitation data from National Oceanic and Atmospheric Administration, 2007a; runoff data from U.S. Geological Survey, 2006a).

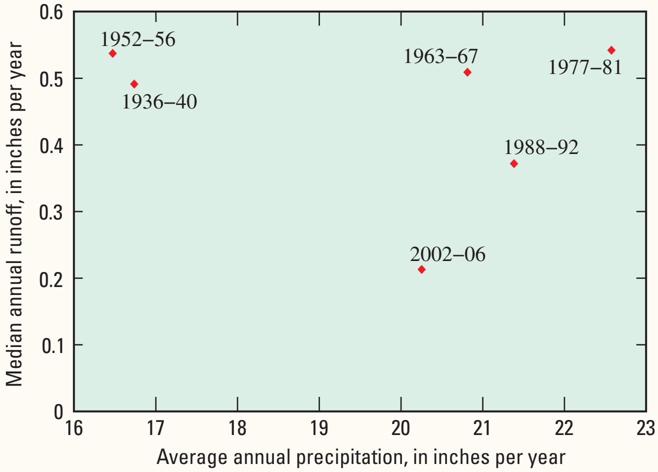


Figure 6. Relation between annual runoff and annual precipitation for five consecutive driest years during six hydrologic droughts at Republican River at Clay Center, Saline River at Tescott, Solomon River at Niles, and Smoky Hill River at Enterprise (precipitation data from PRISM Group, 2007; runoff data from U.S. Geological Survey, 2006b).

The decreases in runoff-precipitation ratio for the four sites in figure 7 indicate that less precipitation was contributed to streamflow during the 2000s drought then in the previous droughts, and that this change has occurred progressively with time. What may contribute to this change? One of the most significant water- and land-management changes in Kansas has been the construction of a large number of small lakes used for water supply and flood control. The number of small lakes in Kansas has increased from 12 in 1920 to 5,240 in 1995 (USACE, 2007). For example, nearly 78 percent of the basin upstream from Solomon River at Niles (site 16, fig. 1, fig. 7*C*, table 1) is affected by impoundments (Putnam, 2003). These impoundments trap runoff that may be slowly released, or the water is lost by infiltration or evaporation, and never reaches a stream channel. Other conservation and farming practices, such as contour farming and terraces, also may contribute in part to the change in runoff ratio because these land-management practices trap runoff, allowing it to infiltrate slowly into the ground instead of flowing into streams. Other changes in land management, such as conversion of crop land to grassland (Conservation Reserve Program), also may affect the runoff-precipitation ratio.

Demand for water has increased in Kansas and is expected to continue to increase. Changes in water use also may be a factor in the runoff ratio decrease. Increases in water demand become a management issue during periods of drought (Nace and Pluhowski, 1965). Water use in Kansas increased 200 percent between 1955 and 1980 (Joan Kenny, USGS, written comm., 2007), largely because of the development of groundwater wells for irrigation in western Kansas. Water use in the State decreased from 6,600 million gallons per day in 1980 to 3,670 million gallons per day in 2005 (Joan Kenny, USGS, written comm., 2007). In 2006, communities that receive their municipal water supply from alluvial wells connected to the Smoky Hill River experienced water shortages because of low streamflows.

Many other factors in addition to those discussed in the preceding paragraphs, or a combination of factors, could be affecting the historical relation between runoff and precipitation, the change in runoff ratio, and the low streamflows documented during the 2000s hydrologic drought. A better understanding of the runoff ratio change and the contribution of each of the factors needs more study and is beyond the scope of this paper, but is critical to improved drought management.

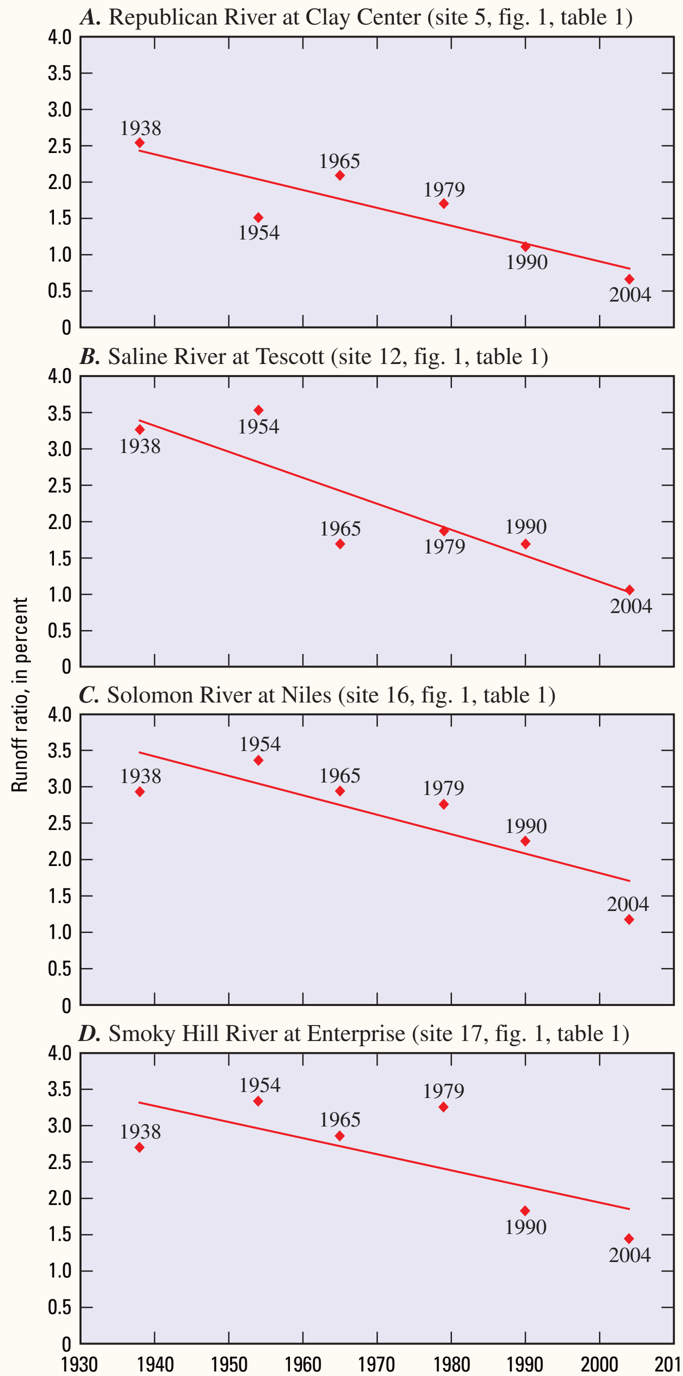


Figure 7. Runoff ratio at *(A)* Republican River at Clay Center, *(B)* Saline River at Tescott, *(C)* Solomon River at Niles, and *(D)* Smoky Hill River at Enterprise for the mid-year of five consecutive driest years at six hydrologic droughts in Kansas (precipitation data from PRISM group, 2007; runoff data from U.S. Geological Survey, 2006b).

Effects of Low Streamflows in Kansas, Water Years 2000–06

- Record-low water levels at Milford Lake near Junction City (site 6, fig. 1, table 2) and Perry Lake near Perry (site 20, fig. 1, table 2) in water year 2003. Water elevations at Kanopolis Lake near Kanopolis (site 9, fig. 1, table 2) were below conservation pool all of water year 2006.
- A water emergency in Salina because of extreme low streamflows in Smoky Hill River in July, 2006. Salina's principle water supply is from alluvial wells in connection to the Smoky Hill River.
- A record number of minimum desirable streamflow (MDS) violations (State administers MDS at Kansas streams to maintain adequate streamflow for habitat and water supply; Katie Tietsort, Kansas Department of Agriculture, Division of Water Resources, written comm., 2007). This reflects degradation of stream habitat as well as the curtailment of many water users.

What Does the Future Hold?

Streamflow conditions during future droughts in Kansas may look more like those that occurred during 2000–06 on the Republican, Saline, Solomon, and Smoky Hill Rivers than those during the 1950s largely because of the factors noted earlier in this paper. In fact, if a sustained period of below-normal precipitation occurs, comparable to the 1950s, future hydrological droughts in Kansas probably will be much more severe than any previous droughts on record, and streamflows will be adversely affected. If climate change occurs and results in even more severe precipitation deficits during droughts, streamflow probably will be even more severe; therefore, State programs initiated to manage water supplies for users during drought that are based on the 1950s drought may need to be modified, or new programs may need to be developed to better reflect the lower streamflows that may occur in future droughts with similar, or even less amounts, of precipitation that occurred in the 1950s drought. More study also is needed to understand the historic change in runoff ratio and the factors that contribute to this change.

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