Major Components of Flow in the Republican River During Drought Conditions from Near Hardy, Nebraska, to Concordia, Kansas

Background

Streamflow in the Republican River from the Nebraska-Kansas stateline to Milford Lake, Kansas (fig. 1), was below normal from March 1988 through June 1992 because of drought conditions in the river's drainage basin and probably because of increased ground- and surface-water usage. The Republican River is the main source of inflow to Milford Lake; water released from Milford Lake may be used for industrial, municipal, and agricultural purposes and for maintenance of instream uses. Therefore, any loss of flow in the Republican River decreases the amount of water available to replenish storage in Milford Lake for downstream uses and may, if the losses are large enough, cause flow to fall below the minimum desirable streamflow (MDS) requirement at Concordia, Kansas, set by Kansas law K.S.A. 82a–703a.

Following the droughts and floods of the 1930's, the Bureau of Reclamation (BOR) and U.S. Army Corps of Engineers began construction of a series of dams and surface-water irrigation networks intended to reduce flooding and to provide water for agriculture. The Kansas Bostwick Irrigation District (KBID) (fig. 1), which was built by BOR and began operation in the study area in 1958, receives most of its water from requested releases from Harlan County Dam in Nebraska; Harlan County Dam, which was completed in 1952, generally does not release water unless it is requested by an irrigation district or precipitation is abundant. The releases for the KBID flow down the Republican River and are diverted at Guide Rock, Nebraska, by the Superior-Courtland Diversion Dam (completed in 1952) into the Courtland Canal, which transports the water to Lovewell Reservoir in Kansas. Lovewell Reservoir, which was completed in 1957, generally does not release water unless it is requested by the KBID or precipitation is abundant. Water released from Lovewell Reservoir for use by the KBID is distributed by a network of canals that begins just upstream of the gaging station on White Rock Creek at Lovewell. The lands irrigated by the KBID in the study area are the flat to gently rolling uplands west of the Republican River that are drained by Buffalo and White Rock Creeks and part of the valley east of the river (fig. 1).

This fact sheet briefly summarizes the preliminary results of a study by the U.S. Geological Survey (USGS) to quantify those components that have the most effect on streamflow in the Republican River during drought conditions from near Hardy, Nebraska, to Concordia, Kansas. A water budget describing the hydrologic system of flow in this section of the Republican River was developed using these major components of flow. Monthly estimates of the major components of flow are compared to monthly water-budget estimates, and monthly water-budget estimates are compared to measured streamflow in the Republican River at Concordia, which is at the downstream end of the study area. A companion study of flow from Concordia to Clay Center, Kansas, is being conducted by the Kansas Geological Survey.

The drought period from March 1988 through June 1992 was chosen for study to take advantage of the hydrologic and water-use data available for this period. Monthly major-component and water-budget estimates were quantified using data available from the BOR, the KBID, the Kansas Department of Agriculture, Division of Water Resources (DWR), and the USGS. The monthly interval was chosen as a compromise among the varying intervals (daily to annual) of the available data.

This study was done in cooperation with the Kansas Water Office and supported in part by the Kansas State Water Plan Fund.

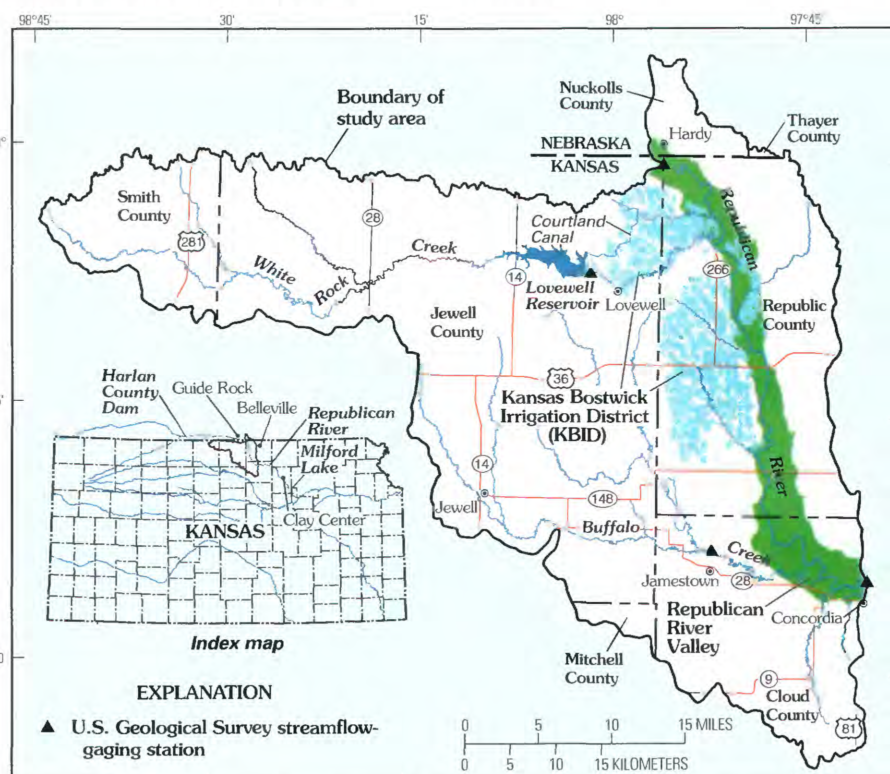

Figure 1. Location of Republican River and study area in Kansas.

Droughts

Climate is of great importance in the study area because most of the area's economy is dependent on raising crops and livestock. The climate of the study area is subhumid (Kansas Water Resources Board, 1961, p. 27), with average annual precipitation (1951–80) ranging from 25 to 29 inches per year from west to east (Hedman and Engel, 1989). Recorded annual precipitation at a long-term weather station at Belleville, Kansas, has varied from 11.79 inches in 1934 to 49.46 inches in 1993 (fig. 2). This unpredictability and lack of precipitation in some years has led to poor crop yields or crop failures in the study area.

Droughts occur when precipitation is less than average for several consecutive years (Clement, 1991, p. 288). The data in figure 2 and table 1 show the two regional droughts during 1929–41 and 1952–57 identified by Clement (1991) and the drought during 1988–92. Continuous precipitation and streamflow data before 1931 are not available for sites in or near the study area. Figure 2A and table 1 show that, although precipitation amounts at Belleville, Kansas, were similar during the three droughts, streamflow in the Republican River near Hardy, Nebraska, generally decreased after Harlan County Dam was completed in 1952.

Although precipitation was greater during the drought of 1988–92 than during the drought of 1952–57 (figs. 2*B* and 2*C*, table 1), streamflow was less near Hardy, Nebraska, and at Concordia, Kansas (table 1), during the 1988–92 drought. The decrease in streamflow may be due in part to diversion of water from the Republican River upstream of Hardy for use by the KBID and other irrigators. Streamflow gains between the gaging stations near Hardy, Nebraska, and at Concordia, Kansas, during the 1988–92 drought were almost double the gains during the 1952–57 drought (table 1). The larger streamflow gains during the 1988–92 drought probably were caused by canal return flows from the KBID, which did not begin full operation until 1958. At times during the 1952–57 and 1988–92 droughts, the streamflow at Concordia, Kansas, was less than the MDS. Streamflow at Concordia, Kansas, during September through November 1991 was much less than the MDS than at any time during the drought of 1952–57 (compare figs. 2B and 2C).

Components of Flow

Components that contribute or remove water from a hydrologic system can be estimated as part of a water budget, which can be used to describe the system. Components that contribute water to the hydrologic system of the study area from outside the area are the Republican River itself, the Courtland Canal, and the movement of ground water through the adjacent aquifer. Within the study area, precipitation is the main source of water to the hydrologic system. For example, precipitation may fall directly into water bodies; move by overland flow into tributaries, canals, or the Republican River; or infiltrate into the ground where it may be used by plants or continue down to the water table (fig. 3). Evaporation from water bodies and the land surface and evaporation and transpiration (evapotranspiration) by plants remove water from the hydrologic system within the study area, whereas the Republican River itself and ground-water movement through the adjacent aquifer remove

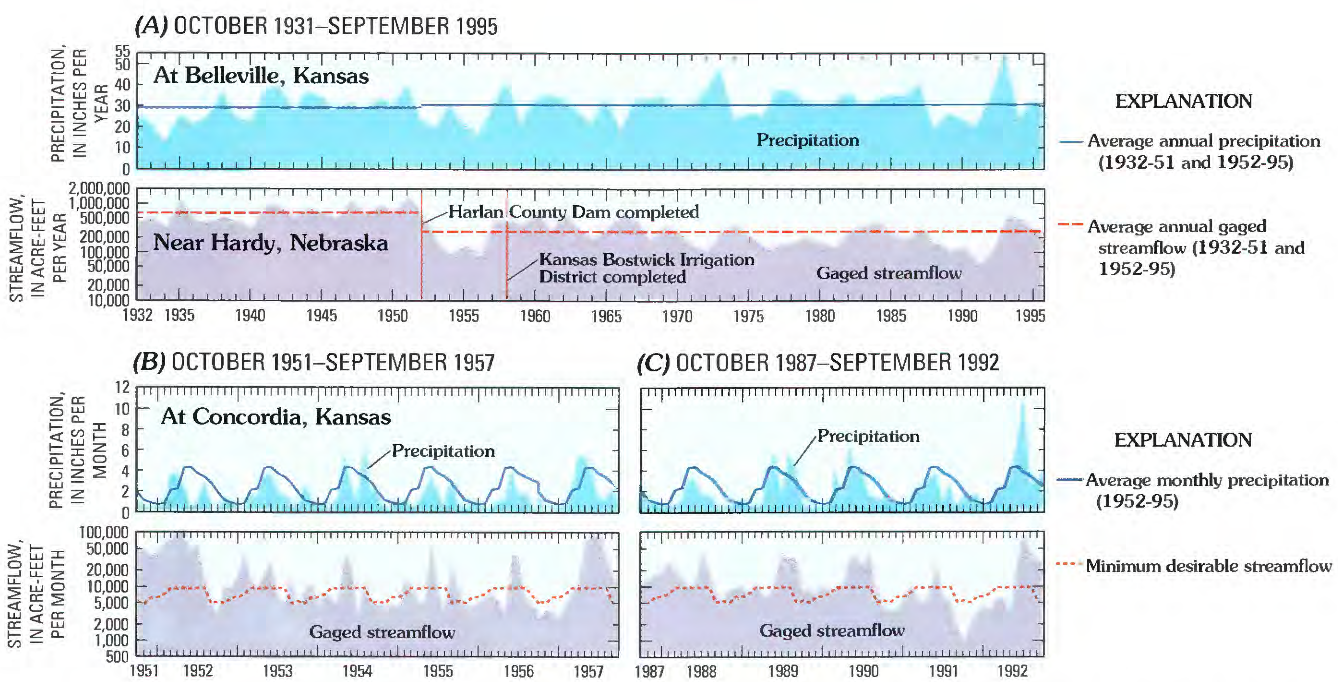

Figure 2. Precipitation and gaged streamflow in the study area: *A*, Average annual, October 1931–September 1995; *B*, Average monthly, October 1952–September 1956; *C*, Average monthly, October 1987–September 1992. (Sources: precipitation data from National Climatic Data Center, Asheville, North Carolina, 1996; streamflow data from U.S. Geological Survey, Lawrence, Kansas, 1996)

Table 1. Comparison of average annual precipitation and streamflow during three drought and three reference periods in the study area

[Precipitation is average annual precipitation in inches per year; streamflow is average annual streamflow in acre-feet per year; --, no data; purple shading indicates drought periods. Precipitation data from National Climatic Data Center, Asheville, North Carolina, 1996. Streamflow data from U.S. Geological Survey, Lawrence, Kansas, 1996]

Environmental factors and locations	Time periods					
	1932–1941	1942–1951	1952–1957	1958–1987	1988–1992	1993–1995
Precipitation						
Belleville, Kansas	24.97	32.74	23.12	31.87	24.15	36.97
Concordia, Kansas	--	--	18.89	29.42	24.25	32.76
Streamflow						
Near Hardy, Nebraska	517,784	763,296	238,863	273,253	100,662	407,018
Concordia, Kansas	--	--	285,488	450,245	184,036	790,029

water from the system to outside the study area. Water diverted within the study area by humans may be consumed and removed from the system, but some of the diverted water may be returned to the system by infiltration to the water table or through discharges into tributaries, canals, or the Republican River.

The water budget used in this study describes flow in the Republican River only and not the hydrologic system of the entire study area. Therefore, not all components that contributed water to or removed water from the study area (fig. 3) were considered part of the water budget describing the flow in the Republican River. Water that enters or leaves the Republican River in the study area through tributaries or canals, through exchange of water between the aquifer and the river by streambed seepage, or through use by humans were considered to be major components of flow to the Republican River and were used in the water budget. Other components of flow were considered minor and were not used in the water budget because they are included within the major components or are small in comparison. For example, most of the precipitation that falls within the study area becomes part of other components (for example, flow in tributaries) before it reaches the Republican River and, therefore, is accounted for in the contributions made by the major components; the remaining precipitation that falls directly on the Republican River is small and was ignored. Other minor components were evaporation from water bodies and the land surface, evapotranspiration from plants, and infiltration to the water table from all sources other than seepage across the streambed of the Republican River (fig. 3).

Water-Budget Estimates

Each of the components of flow used in the water budget were quantified on a monthly basis for the drought period during March 1988 through June 1992. These quantified components then were combined to make monthly estimates of flow in the Republican River at Concordia, Kansas, during this drought period. The water budget and major components of flow used to describe flow in the Republican River in the study area are *upstream flow* near Hardy, Nebraska, plus *tributary flow* (including municipal and industrial discharges), plus *streambed seepage*, plus *canal return flow*, minus *surface-water diversions*.

Upstream flow data were collected and measured by the USGS at a streamflow gaging station near Hardy, Nebraska. These data provided a measurable inflow for purposes of the water budget. Because water in the Republican River takes about 1 day to travel from the gaging station near Hardy, Nebraska, to the gaging station at Concordia, Kansas, the upstream flow used was for the day previous to that measured at Concordia.

Tributary flow includes streamflow data collected and measured by the USGS at gaging stations on White Rock Creek at Lovewell, Kansas, and on Buffalo Creek near Jamestown, Kansas; estimates of ungaged flow, which were made on the basis of statistical methods; and discharge of water from municipal and industrial sources. Monthly discharge from municipal and industrial sources was estimated from annual discharge values and monthly diversion values reported by the municipality or industry to the DWR.

Streambed seepage is defined in this study as the increase or decrease of flow in the Republican River from seepage between the aquifer and the river. Streambed seepage was estimated using the com-

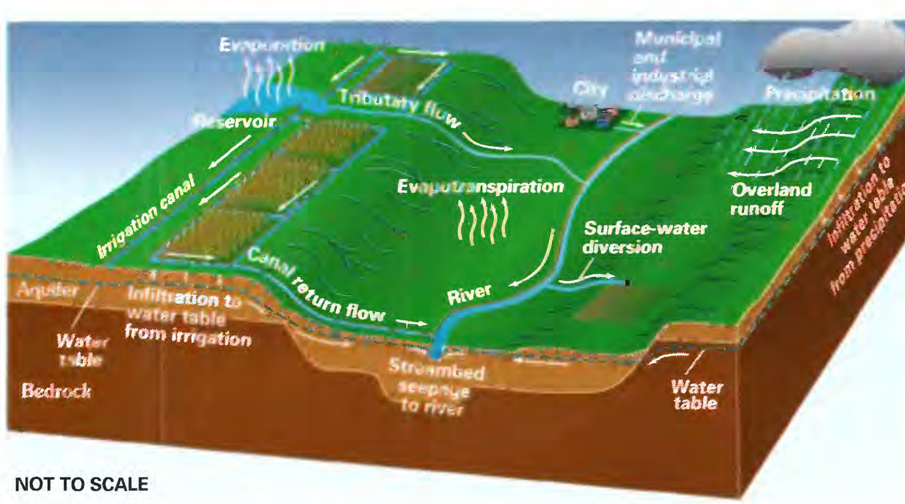

Figure 3. Components of flow in the study area.

puter program BFI4 (Wahl and Wahl, 1995) that computes daily streambed seepage from average daily streamflow. The average daily streamflow data collected and measured by the USGS at gaging stations at Concordia, Kansas, and near Hardy, Nebraska, were used as input to the program. The BFI4 program uses streamflow hydrograph-separation techniques to estimate the part of the flow in an unregulated stream that is from streambed seepage. The Republican River is regulated by Harlan County Reservoir. Under low-flow conditions, releases from Harlan County Reservoir typically are fully diverted into the Courtland Canal at Guide Rock, Nebraska. Therefore, for the purposes of this study, the Republican River can be considered to begin immediately downstream of the Guide Rock diversion (Thomas Stiles, Kansas Water Office, oral commun., 1996). Under these conditions, the Republican River in the study area may be viewed as unregulated and suitable for application of the BFI4 program. The amount of streambed seepage to and from the Republican River was estimated as the BF14 results for the gaging station near Hardy, Nebraska, subtracted from the BF14 results for the gaging station at Concordia, Kansas, after compensating for a 1-day traveltime.

Canal return flow data were collected and measured by the KBID and BOR at discharge gates at the end of canals in the KBID. Canal return flow from the KBID to the Republican River generally occurs only during the months that irrigation is allowed in the district (June through September). Although irrigation does not occur in all 4 months during all years, canal return flow has occurred in July and August every year since 1958.

Surface-water diversions, the amount of surface water removed (diverted) by humans, were estimated from annual water-use data reported to DWR by the users. The only uses for which surface water was diverted in the study area were irrigation and recreation. Many of the diversions (including the large diversions to and from Lovewell Reservoir for the KBID) were upstream from the gaging stations on White Rock Creek at Lovewell or on Buffalo Creek at Jamestown; these diversions already are accounted for in the tributary or canal-return-flow components. Only diversions from tributaries and canals in the ungaged part of the study area or from the Republican River in the study area were considered to be part of this component. All water from these surface-water diversions was used for irrigation. The annual surface-water irrigation-use data for these diversions were divided into monthly data in the same ratios as the monthly irrigation data available from the KBID.

Table 2. Monthly water-budget estimates of flow in the Republican River from near Hardy, Nebraska, to Concordia, Kansas, compared to measured downstream flow and minimum desirable streamflow at Concordia, Kansas, during October 1990 through May 1992

[All values are in acre-feet. Minimum desirable streamflow from Kansas law K.S.A. 82a-703a. Blue shading indicates critical irrigation period; purple shading indicates peak of drought period]

Year	Month	Upstream flow +	Tributary flow +	Streambed seepage +	Canal return flow −	Surface-water diversions =	Water-budget estimate of downstream flow	Measured downstream flow at Concordia, Kansas	Minimum desirable streamflow at Concordia, Kansas
1990	October	2,150	203	1,715	0	0	4,068	3,955	5,227
	November	2,138	286	1,197	0	0	3,621	3,495	4,760
	December	2,172	293	1,197	0	0	3,662	3,420	6,149
1991	January	3,800	549	1,573	0	0	5,923	5,260	6,149
	February	8,255	1,985	637	0	0	10,877	11,151	6,942
	March	4,274	1,665	2,265	0	0	8,204	6,538	9,223
	April	2,313	3,320	1,567	0	0	7,200	4,514	8,926
	May	5,361	6,083	1,627	0	0	13,072	6,849	9,223
	June	14,236	6,458	2,687	1,096	1,360	23,117	26,918	8,926
	July	3,320	210	2,286	2,655	3,756	4,715	5,435	9,223
	August	3,600	156	1,522	1,264	1,360	5,183	5,282	9,223
	September	920	151	26	0	0	1,097	1,864	4,760
	October	1,033	129	-199	0	0	964	895	5,227
	November	1,333	88	494	0	0	1,914	2,021	4,760
	December	1,595	134	1,169	0	0	2,897	3,013	6,149
1992	January	2,075	231	2,120	0	0	4,427	4,267	6,149
	February	1,551	185	1,923	0	0	3,659	3,550	6,942
	March	4,417	580	1,933	0	0	6,930	5,794	9,223
	April	3,739	753	2,208	0	0	6,700	5,798	8,926
	May	1,835	271	1,296	0	0	3,402	3,148	9,223
Total		**70,117**	**23,730**	**29,243**	**5,015**	**6,476**	**121,632**	**113,167**	**145,330**
Monthly average		**3,506**	**1,186**	**1,462**	**251**	**324**	**6,082**	**5,658**	**7,266**

Comparison of Water-Budget Estimates

Three important periods within the March 1988 through June 1992 drought were identified. The first period was when measured streamflow at the gaging station at Concordia, Kansas (downstream flow), commonly was less than the MDS (October 1990 through May 1992). The second period was at the peak of the drought when downstream flow was extremely low (September and October 1991). The third period was the critical irrigation period (July and August 1991) when upstream and downstream flow was low and irrigation demand was high. Annual precipitation at Concordia, Kansas, was 70, 37, and 49 percent of average (1952–95), respectively, during these three periods. Table 2 shows the monthly estimates of the major components of flow and the water-budget estimates for October 1990 through May 1992 (which includes peak of the drought and critical irrigation periods). Measured downstream flow and MDS are included in table 2 for comparison purposes. Each month's water-budget estimate of downstream flow can be compared with the monthly measured downstream flow (table 2). Table 3 shows comparison of estimates of each of the major components of flow and of mea-

Table 3. Comparison of major components of flow and downstream flow to water-budget estimates of downstream flow during important periods in 1988–92 drought

[MDS, minimum desirable streamflow at Concordia, Kansas (Kansas law K.S.A. 82a–703a). Components of flow may not add up to 100 percent due to errors in estimation]

Major component	Component as a percentage of water-budget estimate of downstream flow			
	Period with downstream flow generally less than MDS (October 1990–May 1992)		Peak of drought period (September–October 1991)	Critical irrigation period (July–August 1991)
	Monthly range	Monthly average	Monthly average	Monthly average
Upstream flow	32 to 107	58	95	70
Tributary flow	3 to 46	20	14	4
Streambed seepage	-21 to 52	24	-8	38
Canal return flow	0 to 56	4	0	40
Surface-water diversions [1]	0 to 80	5	0	52
Measured downstream flow	52 to 170	93	134	108

[1]Diversions are removals of water from the system and are substracted when combining the major components of flow to make the water-budget estimates.

sured downstream flow to the water-budget estimates of downstream flow during each of the three periods identified within the March 1988 through June 1992 drought.

Upstream flow is generally the largest contributor to the water-budget estimates. Even during the period from October 1990 through May 1992 when upstream flow was only about 16 percent of average (1952–95) and downstream flow commonly was less than the MDS, upstream flow typically contributed more than one-half and averaged about 58 percent of the water-budget estimates (tables 2 and 3). During the peak of the drought (September and October 1991), upstream flow was only about 4 percent of average (September and October 1952–95), but its contribution to the water-budget estimates increased to about 95 percent. During the critical irrigation period (July and August 1991), upstream flow was about 13 percent of average (July and August 1952–95) and contributed about 70 percent of the water-budget estimates.

Tributary flow can be a major contributor to the water budget, especially when evapotranspiration is low (winter and early spring) or when precipitation is consistently about 2 or more inches per month (for example, April through June 1991). However, during October 1990 through May 1992, tributary flow commonly was less than 10 percent of the water budget but averaged about 20 percent due to large contributions in some months (tables 2 and 3). Tributary flow averaged a little less, about 14 percent of the water-budget estimates, during the peak of the drought. However, during the critical irrigation period, the contribution of tributary flow was very small, averaging only about 4 percent of the water-budget estimates. Although tributary flow can contribute substantial amounts of water to the water-budget estimates, it cannot be considered a reliable source of water during the critical irrigation months of July and August or during periods when precipitation is consistently less than about 2 inches per month.

Streambed seepage generally is positive, indicating that the Republican River is a gaining stream—that is, the ground water flows into the river from the adjacent aquifer because the water table is higher than the water level in the river (fig. 3; tables 2 and 3). A negative streambed-seepage value may indicate that this situation is reversed and that the water table in the adjacent aquifer is lower than the water level in the river causing the river to lose water to the aquifer (for example, October 1991, table 2). Streambed seepage averaged about 24 percent of the water-budget estimates during October 1990 through May 1992. However, during the peak of the drought when streamflow was very low in the Republican River, streambed seepage averaged -8 percent, indicating a loss to the adjacent aquifer. During the critical irrigation period, streambed seepage contributed about 38 percent of the water-budget estimates. Although streambed seepage can contribute substantially to the water-budget estimates during most of a drought, it cannot be considered a reliable source of water during periods of very low flow.

Canal return flow and *surface-water diversions* occur only during the irrigation season (commonly the months of June through September); therefore, they can seem to be insignificant components of the water-budget estimates if averaged over a period longer than the irrigation season. For example, canal return flow contributed about 4 percent to, and surface-water diversions removed about 5 percent from, the water-budget estimates if averaged over the period of October 1990 through May 1992; nothing was contributed to or removed from the water-budget estimates by these components during the peak of the drought (September and October 1991). However, during the critical irrigation period (July and August 1991), canal return flow contributed about 40 percent to and surface-water diversions removed about 52 percent from the water-budget estimates. The combination of these two components can be considered to show the effect of human use (irrigation) on the water-budget estimates in the ungaged part of the study area. In 10 out of the 15 months that irrigation is estimated to have occurred during the March 1988 through June 1992 drought, the combination of the canal return flow and surface-water diversions resulted in a small net contribution of about 1 percent to the water-budget estimates of downstream flow. However, during the 1991 irrigation season, the members of the KBID were restricted in their use of water, and surface-water diversions by other users were greater than in previous years. The combination of the canal return flow and surface-water diversions during July and August 1991 resulted in a net withdrawal of about 12 percent from the water-budget estimates.

Downstream flow data were collected and measured by the USGS at a streamflow-gaging station on the Republican River at Concordia, Kansas. These data provided a measurable outflow for comparison with the water-budget estimates. Downstream flow was about 16 percent of average (1952–95) during the drought period, and commonly was less than the MDS. Downstream flow decreased to about 4 percent of average (September and October 1952–95) during the peak of the drought period (table 2). Tables 2 and 3 show that although there was substantial disagreement between the water-budget estimates and downstream flow from month to month during October 1990 through May 1992, monthly water-budget estimates varied on average less than 10 percent from measured downstream flow during both the period when downstream flow commonly was less than the MDS and the critical irrigation period. However, during the peak of the drought period, measured downstream flow exceeded water-budget estimates of downstream flow by about one-third; this may be due to errors in estimating the tributary flow.

Conclusions

During the drought of March 1988 through June 1992, there were three important periods—the period when flow in the Republican River at Concordia, Kansas, commonly was less than the MDS (October 1990 through May 1992); the period at the peak of the drought when flow in the Republican River was very low (September and October 1991); and the critical irrigation period (July and August 1991).

During all three periods, the upstream flow was the most important and most reliable component of the monthly water-budget estimates. Upstream flow is considered the most important and reliable source of water to the Republican River, with its importance increasing as the drought worsens. Tributary flow was an important component of the water-budget estimates during the periods when downstream flow commonly was less than the MDS and when the drought peaked. However, it was not a significant component during the critical irrigation period and, therefore, is not considered a reliable source of water to the Republican River during drought periods. Streambed seepage was an important component of the water-budget estimates during the period when downstream flow commonly was less than the MDS and during the critical irrigation period. However, the value of this component can become negative, as it did during the peak of the drought period, resulting in removals from rather than contributions to the water-budget estimates. This indicates that streambed seepage is not always an available or reliable source of water to the Republican River because at times the river loses water to the adjacent aquifer. Canal return flow and surface-water diversions were small if averaged over the period when downstream flow was less than the MDS and were zero during the period at the peak of the drought; however, they accounted for large contributions to and removal from the water-budget estimates during the critical irrigation period. Although the combination of canal return flow and surface-water diversions commonly results in a net contribution to the water-budget estimates, when water usage by the KBID is restricted, as it was during the critical irrigation period, their combination may become negative and result in a net withdrawal. Therefore, canal return flows and surface-water diversions are each considered important components of the flow in the Republican River during irrigation seasons, but their combination may change from a net contribution to a net withdrawal of water from the river if water usage by the KBID is restricted.

Consideration of upstream flow, canal return flow, and surface-water diversions and how these components can be managed to minimize the effect of drought conditions may allow streamflow in the Republican River at Concordia, Kansas, to remain above the MDS and ensure an adequate supply of water to fulfill the needs of downstream users.

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