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# STREAMFLOW DEPLETION INVESTIGATIONS IN THE REPUBLICAN RIVER BASIN: COLORADO, NEBRASKA, AND KANSAS

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ABSTRACT

Water is a critical resource in the Great Plains. This study examines the changes in long-term mean annual streamflow in the Republican River basin. In the past decades this basin, shared by three states, Colorado, Nebraska, and Kansas, displayed decreased streamflow volumes as the river enters Kansas across the Nebraska-Kansas border compared to values preceding the 1950s. A recent lawsuit filed by Kansas challenges water appropriations in Nebraska. More than half of the source area for this water, however, lies outside of Nebraska. Today a higher percentage of the annual flow is generated within Nebraska (i.e., 75% of the observed mean annual streamflow at the NE-KS border) than before the 1950s (i.e., 66% of the observed mean annual streamflow) indicating annual streamflow has decreased more dramatically outside of Nebraska than within the state in the past fifty years.

## INTRODUCTION

The Republican River basin's 64,796 km$^2$ drainage area is shared by three states: Colorado, Nebraska, and Kansas (see Figure 1). Nebraska has the largest single share of the drainage area, 25,154 km$^2$ (39% of total); Colorado can claim about 20,000 km$^2$ (31%), while the rest, about 19,583 km$^2$ (30%), belongs to Kansas [1], from which about 12,800 km$^2$ (20%) lies upstream of Hardy, near the Nebraska-Kansas border. Exact figures for the contributing drainage areas (portions of the drainage areas that actually contribute water to the stream) are hard to obtain because these areas in the headwater sections of the basin have been shrinking constantly in the past fifty years. For example, Frenchman Creek once originated near the town of LeRoy in Logan County, Colorado, 50-km west of the Nebraska border [2]; today the river is entirely within Nebraska [3] (see Figure 2).

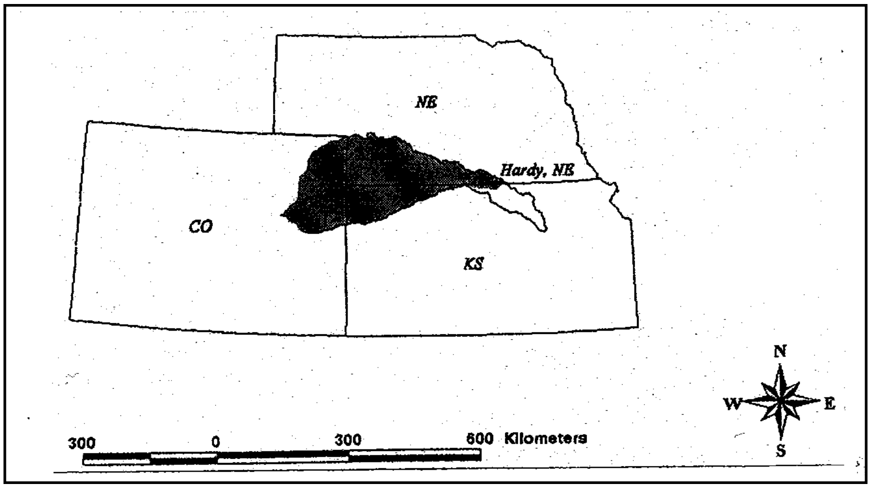



Figure 1. Location of the Republican River basin. The shaded area designates part of the watershed that contributes streamflow across the NE-KS border, near Hardy, NE.

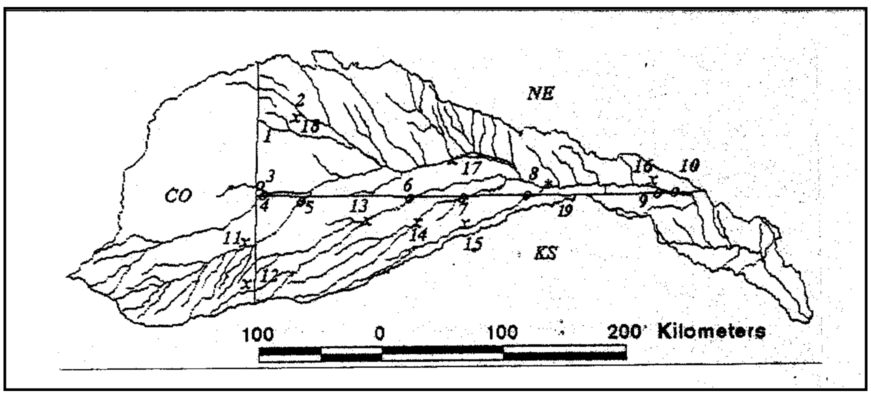



Figure 2. Republican River stream network with the locations of streamflow (circles) and precipitation (crosses) measurements.
Notation: 1. Frenchman Creek, 2. Stinking Water Creek, 3. North Fork Republican River, 4. Arikaree Creek, 5. South Fork Republican River, 6. Beaver Creek, 7. Lower Sappa Creek, 8. Prairie Dog Creek, 9. Courtland Canal, 10. Lower Republican River, 11. Bonny Dam (CO), 12. Burlington (CO), 13. Atwood (KS), 14. Oberlin (KS), 15. Norton Reservoir (KS), 16. Guide Rock (NE), 17. Cambridge (NE), 18. Imperial (NE).
The star (19) designates the location of the Harlan County reservoir.

With the advance of irrigation practices in the High plains, a tri-lateral agreement, called the Republican River Compact, was signed in 1942 by Colorado, Nebraska, and Kansas to manage the division of surface water resources among the states within the river basin. The compact allocates the volume of water each state may apply for consumptive use, mostly irrigation. However, the interpretation of the compact differs among the states, leading to a long-standing dispute between Nebraska and Kansas, which in 1998 evolved into a legal matter. The litigation centers on whether Nebraska uses more water than is approved by the compact. Consumptive water use in the basin is estimated by the Nebraska Department of Water Resources, Natural Resource Districts (NRDs), and state entities in Colorado and Kansas. Accurate figures are hard to obtain because the volume of water irrigated annually is not known for the entire basin since farmers in general are not required to document how much water they pump onto their fields. Consequently, consumptive water-use estimates in Nebraska, for example, are based on registered well distribution and well pumping capacity data, as well as on the farmers' water use and/or power consumption records (if available). Any consumptive water usage, however, must show up sooner or later in the flow regime of the river, since a considerable part of that water evaporates (including transpiration) back to the atmosphere, reducing the volume of water available to streamflow or baseflow (i.e., groundwater contribution to streamflow). On an annual basis more than 67 percent of the water a catchment receives as precipitation, irrigation water, and/or snow is returned to the atmosphere [4].

The focus of the present study is to define and compare the level of streamflow depletion of the past fifty years within the Republican basin in two geographically distinct regions: 1) on tributaries of the main channel before they reach Nebraska and; 2) on tributaries of the main channel plus the main channel itself within Nebraska. This formulation makes it possible to identify the relative contribution of these two regions to the past and current streamflow depletions observed at the Nebraska-Kansas border.

The present study does not aim to define the relative importance of the possible contributing factors, whether they involve increased irrigation, growing spread of phreatophytes, or improved water and soil conservation practices, to the observed streamflow depletions. Such a task is especially difficult if one considers the existing uncertainties in estimating the basin's water balance components, which, in turn, are the necessary building blocks for quantifying the relative contributions of the possible mechanisms that could lead to streamflow depletion. These uncertainties mainly stem from 1) inadequate data (e.g., missing basin-wide irrigation data); and 2) the yet unresolved problem of accurately estimating basin-scale evapotranspiration, the largest loss-term in the water balance equation [4]. Instead, the present study concentrates on the two most reliably measurable water balance components: precipitation and streamflow.

## DATA SELECTION

In order to identify the relative contribution of the two geographical regions to streamflow generation, altogether eight gaging stations were selected (Figure 2 and Table 1) from the USGS NWIS-W Internet data retrieval system [5]. For the eight stations annual flow volumes were calculated based on available daily mean-flow values with a typical measurement record starting in the 1930s and ending in 1996. There are only two streams where it was not possible to find a stream-gaging station at the corresponding state border: the Frenchman and Stinking Water Creeks (Figure 2). As mentioned earlier, Frenchman Creek emerged in Colorado originally, but heavy consumptive water usage in the past fifty to seventy years in its basin resulted in a shortening of the creek: the headwaters of Frenchman Creek no longer reach Colorado. In the case of the Stinking Water sub-basin, its drainage area within Colorado is very small (3%) when compared to the total drainage area of all the tributaries of the Republican River outside of Nebraska. Consequently, not including it in the ensuing analysis will probably have minimal effect on the results.

In addition to the streamflow measurements, precipitation was recorded at eight stations (National Climatic Data Center cooperative stations) within the Republican River basin (Figure 2 and Table 1). The data is distributed on CD-ROM by EarthInfo, Inc. [6].

Table 1. Precipitation and Stream-Gaging Stations Used in the Study

| Precipitation Station Locations | Gaging Station Locations |
|---|---|
| Bonny Dam, Yuma Co., CO | Beaver City, Furnas Co., NE, Lower Sappa |
| Burlington, Kit Carson Co., CO | Benkelman, Dundy Co., NE, South Fork Republication |
| Atwood, Rawlins Co., KS | Cedar Bluffs, Decatur Co., KS, Beaver |
| Norton Reservoir, Norton Co., KS | Haigler, Dundy Co., NE, Arikaree |
| Oberlin, Decatur Co., KS | Hardy, Nuckolls Co., NE, Republican |
| Cambridge, Furnas Co., NE | Harlan County Reservoir, Harlan Co., NE, Prairie Dog |
| Guide Rock, Webster, Co., NE | Sanborn, Dundy Co., NE, North Fork Republican |
| Imperial, Chase Co., NE | Superior, Nuckolls Co., NE, Courtland Canal |

## DATA ANALYSIS

Annual streamflow values of the Republican River at the Nebraska-Kansas border near Hardy, NE (Figures 1 and 2), exhibit a significant decreasing trend (Figure 3) starting in the 1950s following the opening of the Harlan County reservoir in Nebraska, constructed on the main channel of the Republican River (Figure 2). Table 2 displays the two sample *t*-test result to decide if the change in the multi-year mean values is significant or not. (Table 3 summarizes the best fit polynomial trend function coefficients applied throughout this study.)

The increased water surface (approx. 42 $km^2$) of the reservoir, without doubt, has an effect on the observed streamflow values of the Republican River at the Nebraska-Kansas border. However, this effect is small. The annual reservoir evaporation in 1990 was estimated [7] to be 4.59 $10^7$ $m^3$, which is a mere 5 percent of the observed mean annual streamflow volumes (approx. 8.2 $10^8$ $m^3$, see Figure 3) prior to reservoir operation.

The second factor that could directly contribute to the observed streamflow depletion in the basin is a possible reduction in the annual precipitation values; however, it is unlikely (Figure 4). The annual precipitation values measured throughout the watershed show no sign of a declining trend.

A third factor to affect streamflow at the NE-KS border is the Courtland Canal that delivers water across (from Nebraska to Kansas) the border 10-km west of

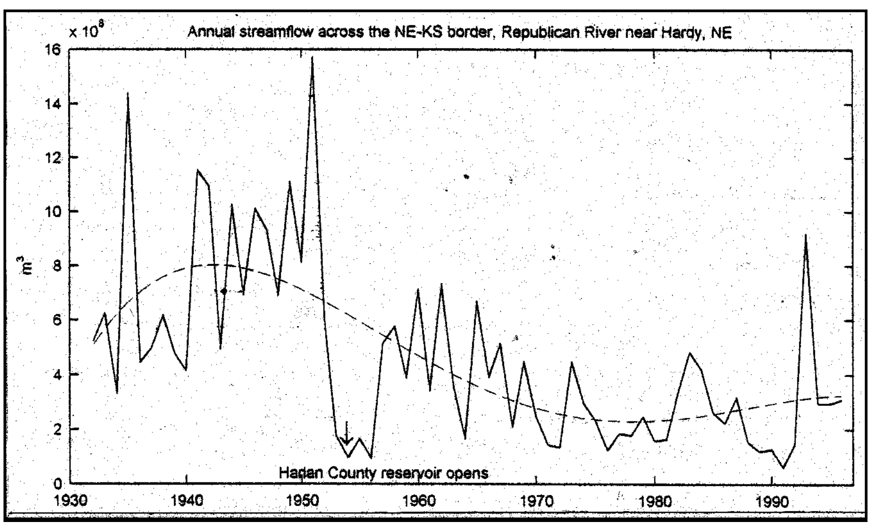



Figure 3. Annual streamflow volumes ($m^3$), and their 4th order polynomial trend function. Republican River, NE-KS border near Hardy, NE. See Table 2 for the coefficients of the polynomial.

Table 2. Summary of the Two Sample *t*-Test Results Applied in the Study

| | Period I. | Mean I. ($m_1$) | Period II. | Mean II. ($m_2$) | $H_0$: $m_1 \neq m_2$ (Significance level, %) | |
|---|---|---|---|---|---|---|
| Figure 3. | 1931-54 | $6.83 \cdot 10^8$ | 1955-96 | $3.26 \cdot 10^8$ | True | (95) |
| Figure 6a. | 1931-54 | $2.59 \cdot 10^7$ | 1955-96 | $1.33 \cdot 10^7$ | True | (95) |
| b. | 1934-54 | $4.32 \cdot 10^7$ | 1955-96 | $3.88 \cdot 10^7$ | True | (95) |
| c. | 1937-54 | $5.54 \cdot 10^7$ | 1955-96 | $2.99 \cdot 10^7$ | True | (95) |
| d. | 1945-60 | $5.39 \cdot 10^7$ | 1961-94 | $1.11 \cdot 10^7$ | True | (95) |
| e. | 1937-54 | $4.26 \cdot 10^7$ | 1955-94 | $1.32 \cdot 10^7$ | True | (95) |
| f. | 1947-60 | $2.58 \cdot 10^7$ | 1961-96 | $0.72 \cdot 10^7$ | True | (95) |
| Figure 7. | 1947-65 | $2.31 \cdot 10^8$ | 1966-94 | $0.88 \cdot 10^8$ | True | (95) |
| Figure 8a. | 1947-65 | $3.62 \cdot 10^8$ | 1966-94 | $2.63 \cdot 10^8$ | True | (93) |
| b. | 1947-65 | $2.86 \cdot 10^8$ | 1966-94 | $1.99 \cdot 10^8$ | True | (90) |
| Figure 9. | 1947-75 | 66.14 | 1976-94 | 72.37 | True | (95) |

Table 3. Best-Fit Polynomial Trend Function Coefficients Applied in the Study

| | Value of the Polynomial Exponent | | | | |
|---|---|---|---|---|---|
| | 4 | 3 | 2 | 1 | 0 |
| Figure 3. | −522 | $4.12 \cdot 10^6$ | $-1.22 \cdot 10^{10}$ | $1.62 \cdot 10^{13}$ | $-7.91 \cdot 10^{15}$ |
| Figure 6a. | 12.5 | $-9.83 \cdot 10^4$ | $2.89 \cdot 10^8$ | $-3.82 \cdot 10^{11}$ | $1.86 \cdot 10^{14}$ |
| b. | −5.35 | $4.24 \cdot 10^4$ | $-1.26 \cdot 10^8$ | $1.67 \cdot 10^{11}$ | $-8.25 \cdot 10^{13}$ |
| c. | −68.5 | $5.40 \cdot 10^5$ | $-1.59 \cdot 10^9$ | $2.14 \cdot 10^{12}$ | $-1.03 \cdot 10^{15}$ |
| d. | −69.9 | $5.52 \cdot 10^5$ | $-1.63 \cdot 10^9$ | $2.27 \cdot 10^{15}$ | $-1.06 \cdot 10^{15}$ |
| e. | −50.4 | $3.98 \cdot 10^5$ | $-1.18 \cdot 10^9$ | $1.55 \cdot 10^{12}$ | $-7.68 \cdot 10^{14}$ |
| f. | −17.6 | $1.41 \cdot 10^5$ | $-4.22 \cdot 10^8$ | $5.66 \cdot 10^{11}$ | $-2.79 \cdot 10^{14}$ |
| Figure 7. | 0 | 0 | $1.37 \cdot 10^5$ | $-5.52 \cdot 10^8$ | $5.46 \cdot 10^{11}$ |
| Figure 8a. | 0 | $-1.32 \cdot 10^4$ | $7.88 \cdot 10^7$ | $-1.61 \cdot 10^{11}$ | $1.03 \cdot 10^{14}$ |
| b. | 0 | $-1.09 \cdot 10^4$ | $6.47 \cdot 10^7$ | $-1.28 \cdot 10^{11}$ | $8.44 \cdot 10^{13}$ |
| Figure 9. | 0 | 0 | $3.15 \cdot 10^{-3}$ | −12.4 | $1.19 \cdot 10^4$ |

the main channel of the Lower Republican River. Again, its effect on the observed streamflow depletion is minor (Figure 5) when one compares the streamflow volumes after and before the 1950s.

A decline in all the incoming (i.e., into Nebraska) streamflows, similar to the one of the Lower Republican at the NE-KS border, is clearly detectable (Figure 6) in the six gaging stations' records of the past fifty to sixty years. See Table 2

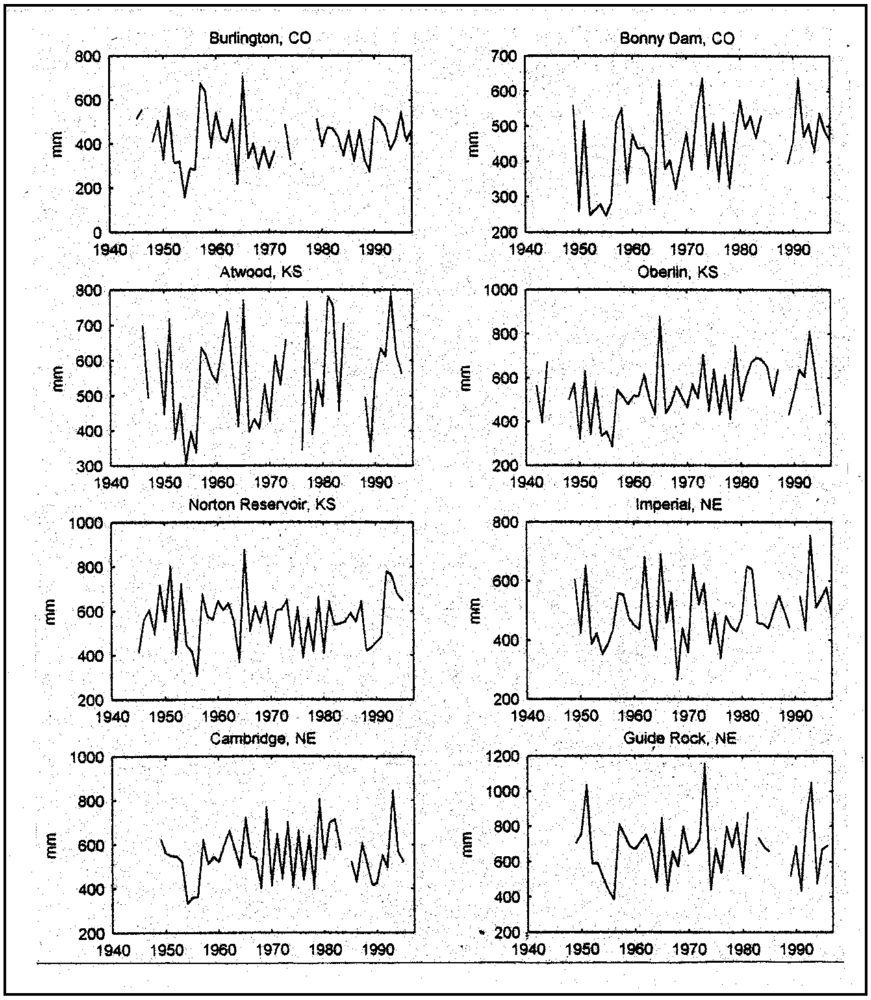



Figure 4. Annual precipitation (mm) at selected locations within the Republican River basin.

for the relevant *t*-test results. Note that the stream gaging station at Beaver City on the Lower Sappa Creek has measured values (solid line) only until 1972. In order to extend the record years of the gaging station over the study period, the streamflow record of an additional gaging station had to be used, the one near Beaver City, NE, on the Beaver Creek, where the streamflow record is up-to-date. The high correlation coefficient ($r$ = 0.91) between annual streamflow volumes at the two stations (i.e., Beaver City, Beaver

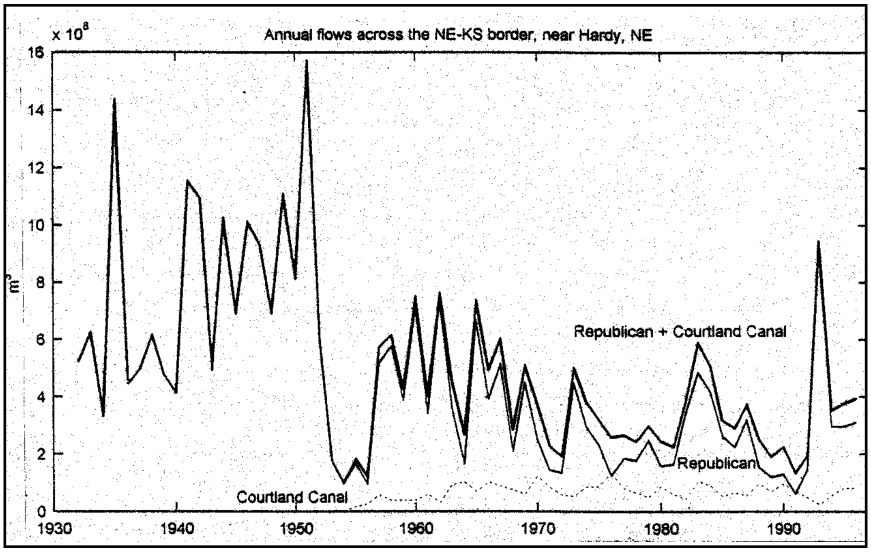



Figure 5. Annual flow volumes across the NE-KS border near Hardy, NE.

Creek, and Beaver City, Lower Sappa Creek) made the temporal extension possible by estimating annual streamflow volumes at Beaver City, Lower Sappa after 1972 (dotted line) by using a linear regression equation between the annual values of the two stations.

Total annual inflow to Nebraska declined from a trend value of 3.1 $10^8$ $m^3$ in 1947 to a value of 7 $10^7$ $m^3$ by the 1990s (Figure 7 and Table 2). This means that today inflow to Nebraska is only 23 percent of its 1940s level. By subtracting the annual incoming (i.e., to Nebraska) streamflow volumes from the outgoing flow values (Lower Republican plus Courtland Canal), measured near Hardy, NE, at the NE-KS border, one obtains the portion of the total streamflow of the Republican River upstream of Hardy, NE, that came from within Nebraska (Figure 8 and Table 2). Using the two trend-function-values, 6 and 2.5 $10^8$ $m^3$, respectively, it can be stated that today 42 percent of the mean streamflow value characteristic of the late 1940s is still maintained. The picture does not change if one is concerned with growing season (April-October) values only (i.e., the percent change is the same, 42%), when consumptive water use is larger. Based on the evidence, it is obvious that streamflow depletion has been far more advanced and serious outside of Nebraska than within. As a consequence, it can also be stated that today more streamflow is generated within Nebraska than forty to fifty years ago, in terms of relative contribution to total flows across the

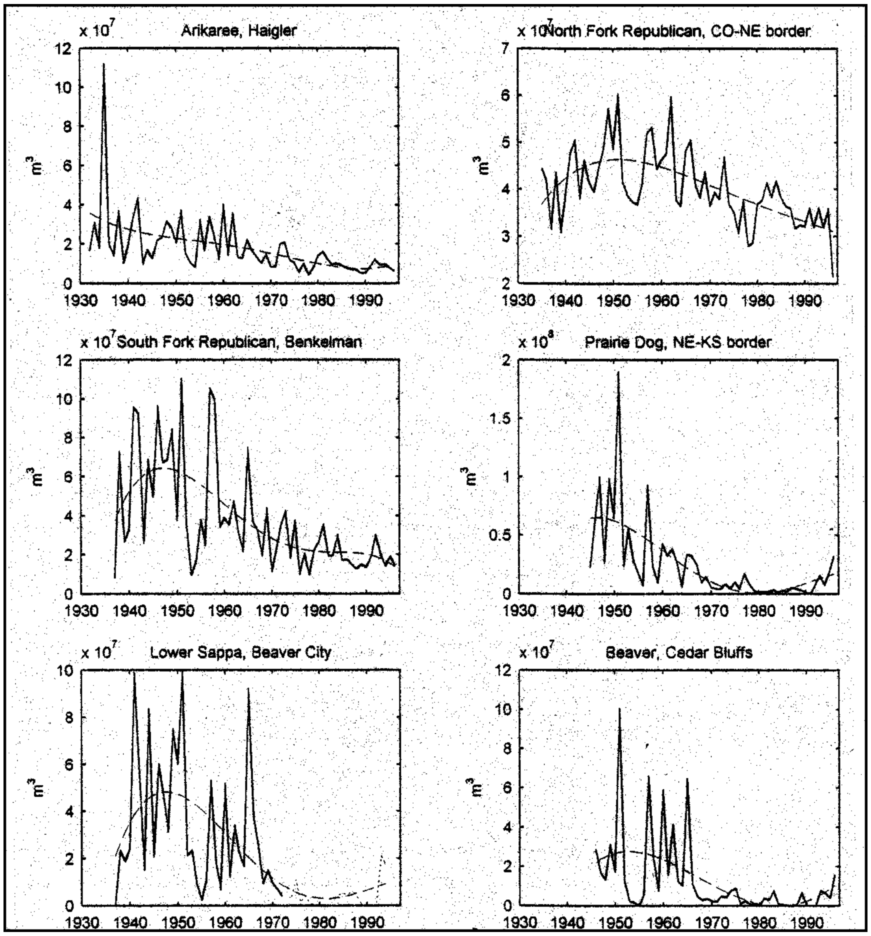
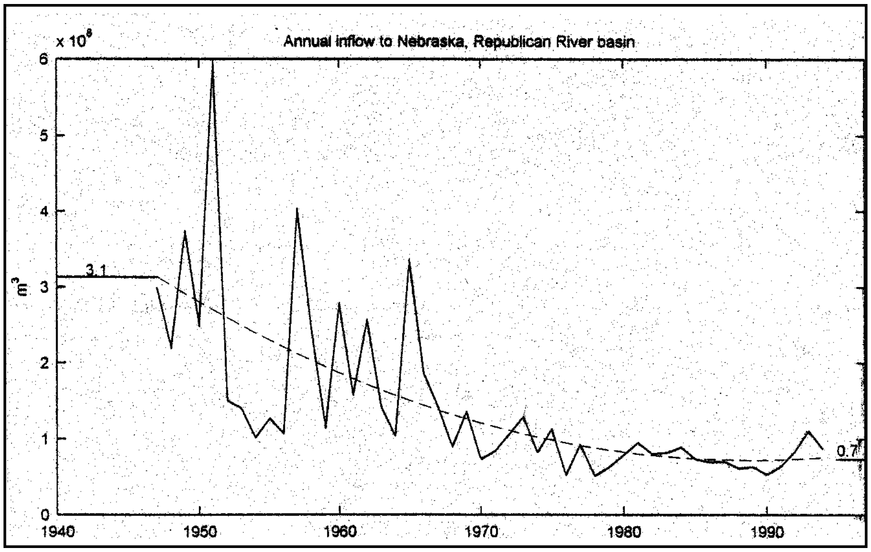



Figure 6. Annual flow volumes (m$^3$) across the NE-CO and NE-KS borders, respectively, upstream of Hardy, NE. The intermittent lines are the 4th order polynomial trend functions. The dotted line in the Lower Sappa Creek values are estimates. See Table 2 for the coefficients of the polynomial.

NE-KS border, near Hardy, NE, from 66 percent in the 1940s to 75 percent in the 1990s, an increase of 9 percent (Figure 9 and Table 2). Note that the lowest values (i.e., corresponding to 1953-1957) around the opening of the Harlan County reservoir in 1954 were excluded from the polynomial trend function calculation, which would have otherwise resulted in incorrectly low values for the 1940s.




## RESULTS AND DISCUSSION

Based on findings presented in this article, the following can be concluded: 1) streamflow has displayed a significant overall decreasing trend at all locations studied in the Republican River basin during the past forty to fifty years; 2) this general decline cannot be explained by long-term precipitation trends or the opening of the Harlan County reservoir, which is, by far, the largest open water body in the basin; and 3) the decline in streamflow volumes differs among geographic areas, defined by state boundaries, with the most advanced streamflow depletions occurring outside of Nebraska.

The Republican River is a typical example of conflicting watershed management objectives among states sharing the same basin. Similar conflict situations can be expected in the near future in other parts of the country where the management of existing water resources may affect neighboring states through shared water basins and/or aquifers. Quick solutions to these problems, in many cases, will be unlikely to achieve due to 1) the complexity of the hydrology involved; 2) common inadequacy of available data and; 3) inaccurate water balance component estimates (e.g., basin-scale evapotranspiration), just to mention a few. While all of the above apply to the Republican River basin, the present study aimed to illustrate only the complexity of the hydrologic

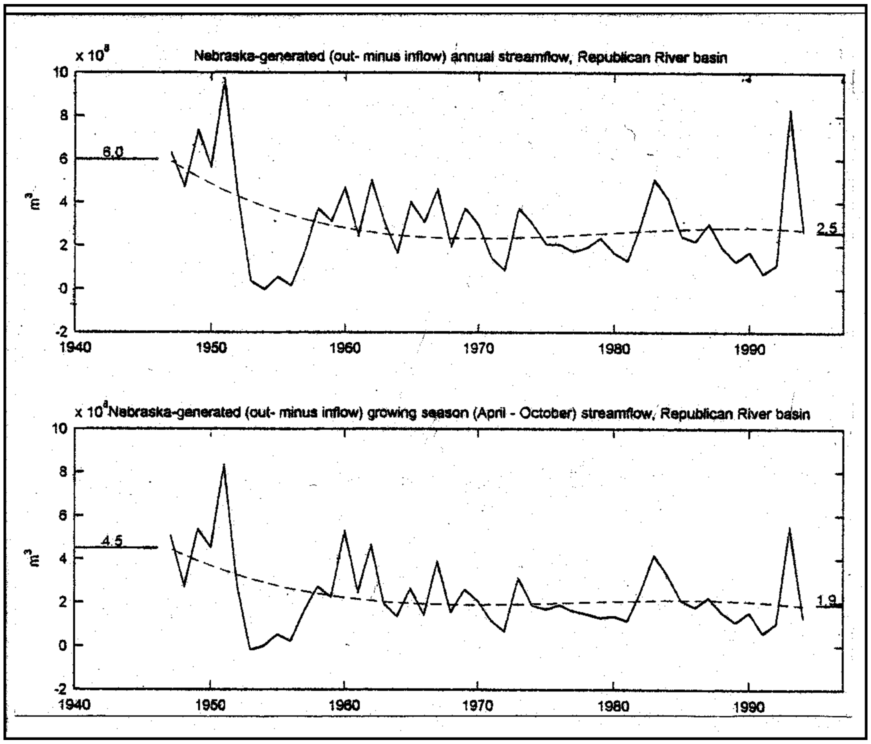



Figure 7. Annual inflows ($m^3$, and their 2nd order polynomial trend function) to Nebraska, Republican River basin. See Table 2 for the coefficients of the polynomial.

problem one may encounter, making it hard even to decide who can blame who in a typical interstate water management conflict situation.

## ACKNOWLEDGMENTS

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## DISCLAIMER

The views, conclusions, and/or opinions expressed in this article are solely those of the author and not the University of Nebraska, state of Nebraska, or any political subdivision thereof.

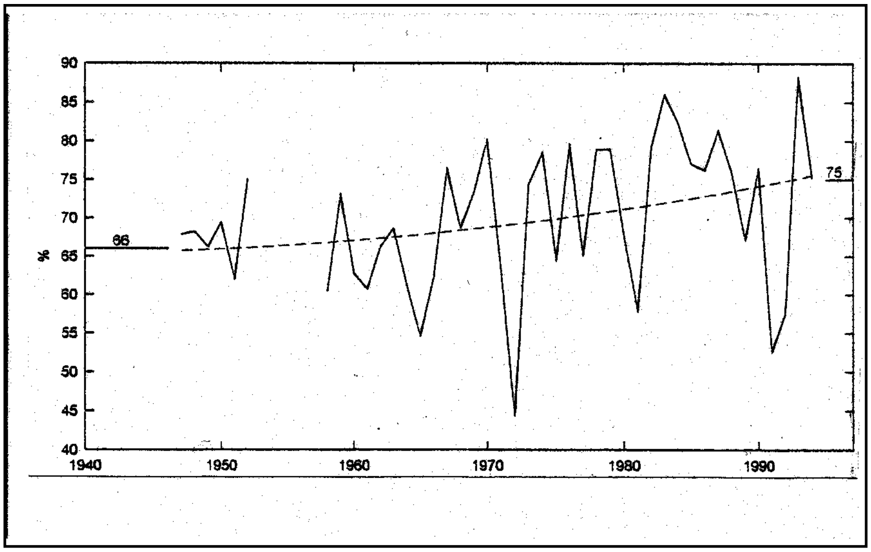


Figure 8. Nebraska-generated annual and growing season (April-October) streamflow volumes ($m^3$) and their 3rd order polynomial trend functions, Republican River basin. See Table 2 for the coefficients of the polynomial.

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