2007

Homogenization of Fish Faunas and Concurrent Anthropogenic Impacts on Plains Streams in Western Kansas: 1854–2003

Mark E. Eberle
Fort Hays State University, meberle@fhsu.edu

Fort Hays Studies
Fourth Series Number 4 Fall 2007

Homogenization of Fish Faunas and Concurrent Anthropogenic Impacts on Plains Streams in Western Kansas: 1854-2003

by
Mark E. Eberle

Fort Hays Studies
Fourth Series Number 4 Fall 2007

Homogenization of Fish Faunas and Concurrent Anthropogenic Impacts on Plains Streams in Western Kansas: 1854–2003

by
Mark E. Eberle

Department of Biological Sciences
Fort Hays State University

Fort Hays Studies
Fourth Series, Number 4, Fall 2007

Series Editor: Bradley Will
Department of English
Fort Hays State University

Design, Layout, and Cover: Bradley Will

Support for this volume was provided by:

Steven Trout
Interim Dean of Graduate Studies and Research
Fort Hays State University

Larry Gould
Provost
Fort Hays State University

Fort Hays State University is a thriving liberal and applied arts, state-assisted institution with an enrollment of about 8,000 students. It offers bachelor's and master's degrees in many fields and provides a wide variety of cultural and intellectual resources, not only for its faculty, staff, and students but for the western Kansas region and beyond. Fort Hays State University occupies the southwest corner of Hays, Kansas, a city of about 20,000 people located halfway between Kansas City and Denver on Interstate 70. The city and its people make their livings from across a wide spectrum of industries—agriculture, education, light manufacturing, medical care, oil, retail, and technology.

Fort Hays Studies is an irregular series sponsored by the Graduate School at Fort Hays State University. The series has been published since 1939 and presents the scholarship of faculty, students, alumni, and other individuals associated with Fort Hays State University.

Acknowledgments

As with any study, many people, some of whom are unknown to me by name, assisted with this research. From Fort Hays State University, I thank Rob Channell and Cheryl Schmidt, who provided advice on statistical analyses; Gene Fleharty (retired), who directed me to the published historical agricultural data; Elmer Finck, Chair of the Department of Biological Sciences, who supported me with time and money needed for this research; students Rachel Copeland, Jason Green, Jennifer Oelschlager, Eric Starkey, and Curtis Wolf, who provided computer assistance and helpful discussions; and especially, Bill Stark, who offered advice and observations for this study, and who joined Joe Tomelleri, Guy Ernsting, and me on our earliest forays into research on stream fishes in western Kansas. I am also grateful to the Graduate School at Fort Hays State University (Tim Crowley, Dean), which provided funding for this publication. From Kansas State University, I thank Keith Gido, who provided a helpful review of the manuscript and suggestions for my research, and former student Jeff Falke for his assistance with data capture. I am grateful to Edie Marsh-Matthews at the University of Oklahoma and Tim Bonner at Texas State University, who took time from their busy schedules to read the manuscript and suggest improvements. From Oklahoma State University (more recently at the University of Kansas), I thank Geff Luttrell for providing data from his fish surveys conducted in the early 1990s. I thank all of the people who attended several oral presentations about this research and, perhaps unknowingly, contributed to improvements on the manuscript. I am also grateful to the numerous people who served on the field crews for the Kansas Department of Wildlife and Parks, especially Ryan Waters for his responses to my numerous requests for information, and to those who served on the field crews from Fort Hays State University, as well as all of the other collectors since 1885. Similarly, I am grateful for the important services provided by the museums, their staffs, and their students at the University of Kansas, University of Michigan, and Sternberg Museum of Natural History at Fort Hays State University. And lastly, but most especially, I am thankful for the valuable guidance and encouragement provided by the late Frank Cross (University of Kansas) and Tom Wenke (Fort Hays State University, retired) that ultimately led me to this research.

Abstract

The fish faunas of the Kansas and Arkansas river basins in western Kansas were significantly dissimilar at the time the Kansas Territory was established in 1854. The faunas were no longer dissimilar 150 years later. This homogenization of the faunas resulted primarily from extirpations, although additions of nonnative species, which now constitute 40% of extant faunas, also contributed. Two periods of changes in the faunas were associated with concurrent anthropogenic changes to the landscape that altered stream habitats. Early extirpations of native species (prior to 1920) occurred in clear, perennial creeks and were concurrent with rapid increases in human population and row-crop agriculture associated with increased demands on perennial water sources and increased sediment yields in streams. Late extirpations of native species and widespread additions of nonnative species (after 1960) occurred in formerly large, often turbid rivers with seasonally variable flows and were concurrent with increases in groundwater mining and construction of impoundments associated with dewatered stream segments, stabilized flows in other stream segments, reduced peak flows in all rivers during summer, increased lentic habitat, and reduced turbidity.

Contents

Introduction

Biotic homogenization is a process that increases similarity among ecosystems in space and time in their taxonomic, genetic, or ecological attributes (Olden et al., 2004; Olden and Rooney, 2006), typically through the replacement of unique elements of native communities by widespread, nonnative elements (McKinney and Lockwood, 1999). Although homogenization at regional scales can result primarily from introductions (Radomski and Goeman, 1995; Rahel, 2000; Marchetti et al., 2001; Carlson and Daniels, 2004), extinctions can play a dominant role in some ecosystems (Duncan and Lockwood, 2001). In North America, extinction rates of aquatic taxa are of particular concern and exceed those for terrestrial taxa (Ricciardi and Rasmussen, 1999). In addition to local impacts, the loss of unique taxa, alleles, or ecological attributes of ecosystems contributes to the impoverishment of global biodiversity. The loss of these elements from ecosystems can result from habitat changes, negative biological interactions with nonnative organisms, or both (e.g., Witte et al., 1992; Ricciardi et al., 1995; Rhymer and Simberloff, 1996; Lodge et al., 2000).

Rahel (2002) summarized information on the homogenization of aquatic faunas, primarily in North America, and discussed the interactive roles of habitat alterations, introductions, and extirpations in this process. In some instances, introductions or extirpations of key species can initiate homogenization. For example, the introduction of Nile perch (*Lates niloticus*) into Lake Victoria, Africa, led to a decline in cichlid diversity, which altered ecosystem processes (Witte et al., 1992). Conversely, the extirpation of beavers (*Castor canadensis*) likely altered patterns of species richness of stream fishes at the scale of drainage basins in North America (Snodgrass and Meffe, 1998). However, changes in taxonomic composition of communities often are preceded by anthropogenic habitat alterations to streams that are independent of species introductions or extirpations, and these anthropogenic changes can cause the extinction of some native taxa and facilitate introductions or range expansions of nonnative taxa (Rahel, 2000; Marchetti et al., 2001; Scott and Helfman, 2001).

Stream habitats and faunas on the plains of western Kansas have undergone substantial anthropogenic changes since the Kansas Territory was established in 1854 (Cross and Moss, 1987; Bergman et al., 2000). Although the types of stream habitats throughout western Kansas were similar (Cross, 1967), the region is drained by two major tributary systems of the Mississippi River: the Kansas (Missouri) River in northwestern Kansas and the Arkansas River in southwestern Kansas. Previous studies on distributional patterns of fishes in western Kansas include assessments of recent distributional patterns throughout the state (Smith and Fisher, 1970; Hawkes et al., 1986), comparison of Pleistocene and Recent faunas on the central plains (Cross, 1970), and a summary of the zoogeography of fishes in the western Mississippi River basin (Cross et al., 1986). However, no quantitative assessment has been made of the similarity of historical and recent fish faunas inhabiting similar stream habitats within the Kansas and Arkansas river basins on the western plains and the possibility of homogenization of these faunas.

The first objective of my study was to examine the level of distinctiveness between the native fish faunas of streams in the Kansas and Arkansas river basins of western Kansas and to ascertain whether any quantifiable changes in similarity had occurred since the late 1800s. The relatively well documented distributions of fishes in Kansas, the relatively depauperate fauna of native fishes in the study area, and the relatively brief time (compared to the eastern United States, for example) since substantial anthropogenic changes have occurred make it possible to classify species as native or nonnative with reasonable confidence.

The second objective of my study was to document any patterns in concurrent anthropogenic changes to the landscape that might be associated with changes in the fish faunas. Data that quantify anthropogenic activities, such as changes in human population, agricultural developments, and construction of dams—all of which potentially impact streams and their faunas—exist for all or nearly all of the study period since the late 1800s.

Cross and Moss (1987) previously discussed changes in the fish faunas of selected streams in northwestern Kansas and in the Arkansas River main stem in southwestern Kansas from the late 1800s through the 1980s. They assessed these faunal changes based on streamflow data and life-history attributes of the species related to general changes in their habitat. Thus, changes in the fish faunas are known to have occurred in the streams of western Kansas. My study builds on the study by Cross and Moss (1987) through its assessment of faunal similarity between the two basins and its documentation of the concurrent anthropogenic changes to the landscape that can alter streams and their faunas.

Study Area

The portion of the study area (Figure 1) within northwestern Kansas included streams in the Kansas River basin upstream from the confluence of the Republican and Smoky Hill rivers, which merge near Junction City to form the Kansas River, a tributary of the Missouri River. Headwaters of these streams are on the plains of Kansas, Colorado, and Nebraska. Lyon Creek, a tributary of the Smoky Hill River near its mouth, was excluded

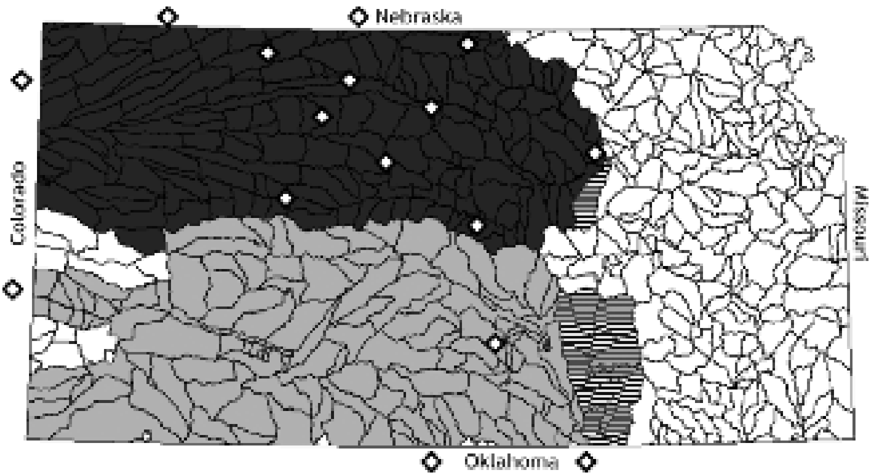

Figure 1. Map of the study area in western Kansas, encompassing the Kansas River basin (black hydrologic units) and Arkansas River basin (gray hydrologic units). Crosshatched hydrologic units represent Lyon Creek (Kansas River basin) and the Walnut River and Grouse Creek (Arkansas River basin), which were excluded from the study (see text for explanation). White hydrologic units in the upper Arkansas River basin (White Woman Creek and Bear Creek) are ephemeral drainages with no surface connection to the Arkansas River. Diamonds represent 16 federal impoundments located within or near the study area.

from this study because its aquatic fauna more closely resembled that of prairie streams in northeastern Kansas rather than the fauna of plains streams in northwestern Kansas (Cross, 1967; Hawkes et al., 1986). The portion of the study area within southwestern Kansas (Figure 1) included streams in the Arkansas River basin, including the Cimarron River, west of approximately 97° W longitude, the point at which the Arkansas River flows south from Kansas into Oklahoma. Streams in the Walnut River basin and Grouse Creek, two tributaries of the Arkansas River east of 97° W, were excluded from this study because their aquatic faunas more closely resembled those of prairie streams in southeastern Kansas (Cross, 1967; Hawkes et al., 1986).

Within the study area, mean annual precipitation increases from about 200 mm to about 700 mm as distance increases eastward from the Rocky Mountains (U.S. Geological Survey, 1970). Most precipitation occurs during the spring and summer, when moist air moves north from the Gulf of Mexico onto the plains, producing thunderstorms that can generate heavy, local downpours. Based on data from the mid-1900s, an annual mean of 60 to 80 thunder events occurred in the study area, and a monthly average of 10 or more thunder events occurred from May through August (Changnon, 1988).

Several extended droughts and wet periods have occurred in the study area since 1800 (Stockton and Meko, 1983; Figure 2). Within these extended periods of precipitation extremes, there can be substantial variation in precipitation. For example, 1934 and 1936 were ranked among the 20 driest years between 1640 and 1977 (Meko, 1982; Stockton and Meko, 1983). However, in May 1935, storms deluged much of northern Kansas and adjacent portions of northeastern Colorado and southern Nebraska, with reports of more than 380 mm (15 inches) of rain in a single day (Follansbee and Spiegel, 1937). Thus, precipitation in the study area was highly variable over the short-term and the long-term. In addition to temporal variation, precipitation in western Kansas varies spatially. For example, the total rainfall reported for Healy, Kansas, in June 1996 was 1.76 inches (45 mm), but the total rainfall reported during the same month for Gove, Kansas, about 40 km to the north, was 12.39 inches (315 mm), including a one-day total of 7.51 inches (191 mm) (National Climate Data Center, 2004a).

The principal landuse in the study area since 1880 has been agriculture: row crops and livestock. The Kansas State Board of Agriculture has published annual data on these commodities for each county since 1877 in their biennial and annual reports. From the late 1800s through the mid-1900s, crop irrigation in the study area was developed primarily through the diversion of surface flows through canals for flood irrigation, but these flows were often unreliable, especially during droughts, when irrigation demands were highest (Sherow, 1990). Thus, the extent of irrigated area was initially low. By 2002, the crop area irrigated with groundwater in western Kansas increased to about 9% (1.3 million ha) of the study area, primarily

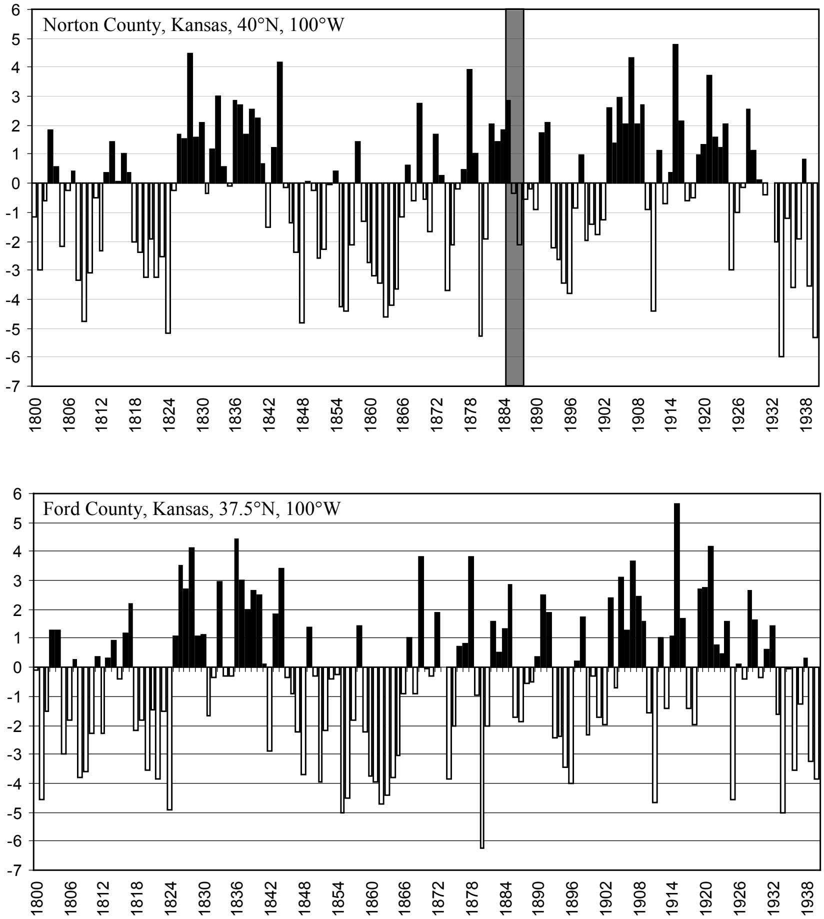

Figure 2. Reconstructed Palmer Drought Severity Indexes (PDSI) from 1800 through 1940 for northwestern Kansas (top graph) and southwestern Kansas (bottom graph). See map in Figure 3 for perspective on latitude and longitude in study area. PDSI values >2 are considered moist years, and PDSI values <-2 are considered drought years. The periods from 1801–1824 and 1847–1868 were the most prolonged reconstructed drought periods since 1800, and they were separated by the most prolonged reconstructed wet period from 1826–1844. The first scientific collections of fish were made in 1885 and 1887 (gray box in top graph). Data obtained from the National Climate Data Center (2004b).

in the western third of the state (Kansas Water Office, 2004), which overlies the High Plains Aquifer (Weeks et al., 1988; Miller and Appel, 1997).

Land not under cultivation in western Kansas has been devoted primarily to grazing. Domestic livestock have replaced the large herds of native grazing herbivores dominated by bison (*Bison bison*). Both native and domestic grazers probably impacted stream segments, either indirectly through vegetation removal that would allow more sediment to enter the streams with runoff, or directly, as suggested by Ki-ra-ru-tah, "filthy water," the Pawnee name for the lower Republican River in Kansas during the late 1700s—a reference to the waste deposited in the river by herds of bison (Rydjord, 1972). Cattle congregating in and around streams in locations throughout the study area have similar impacts on some stream segments.

The largest city in the study area was Wichita, with a population of 344,284 in 2000 (Policy Research Institute, 2003). Only four other cities had populations greater than 25,000 people (all less than 50,000) in 2000: one in the Kansas River basin (Salina, adjacent to the Smoky Hill River) and three in the Arkansas River basin (Dodge City, Garden City, and Hutchinson, all adjacent to the Arkansas River).

Multipurpose federal reservoirs were constructed in or near the study area under the direction of the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation, primarily for irrigation, flood control, or both. In the Kansas River basin, there were 12 federal reservoirs within or near the study area, and in the Arkansas River basin, there were four federal impoundments within or near the study area (U.S. Army Corps of Engineers, 2004; Figure 1). Of the 16 dams, 15 were completed between 1943 and 1969; the dam at Kaw Reservoir on the Arkansas River immediately downstream from the study area in Oklahoma was completed in 1976 (U.S. Army Corps of Engineers, 2004). In addition to the federal reservoirs, more than 2,000 additional dams of various purposes (e.g., livestock ponds, irrigation diversions, municipal water supplies, and state fishing lakes) were listed within the study area in the national inventory of dams maintained by the U.S. Army Corps of Engineers (2004).

Methods

Assessment of Fish Faunas

Data on the historical (native) fish faunas of the Kansas and Arkansas river basins were derived primarily from an assessment of information summarized by Cross (1967), but also from summaries by Metcalf (1966), Cross et al. (1986), and Cross and Moss (1987). Data on recent (1991 through 2003) fish faunas were derived primarily from unpublished summaries of stream surveys conducted from 1994 through 2003 by personnel from the Kansas Department of Wildlife and Parks and Fort Hays State University. Voucher specimens from the recent surveys were deposited with the Sternberg Museum of Natural History at Fort Hays State University, Hays, Kansas, or the University of Kansas Museum of Natural History, Lawrence. Additional data from surveys of streams in the Arkansas River basin conducted by Luttrell et al. (1993) from 1991 through 1993 also were used. These specimens were housed at Oklahoma State University, Stillwater. To improve readability, only standard common names of fish are used in the text of this summary. Corresponding scientific names of all species are given in Table 1 and follow the summary by Nelson et al. (2004).

Given that this was an assessment of fish faunas in streams, I excluded nonnative species (e.g., striped bass, redear sunfish, and walleye) that typically were confined to impoundments in the region and have rarely or never been collected in the stream surveys within the study area. Thus, estimates of nonnative species in the region presented in this summary represent minimum values for the entire fish fauna of the region.

Presence or absence was assigned to each species for each of the two basins for the historical and recent periods (Table 1). The lists for the historical period included only those species likely extant in the basins in the mid 1800s (i.e., no nonnative species). The lists for the recent period (after 1990) included all species: extant native species, extirpated native species, and extant nonnative species.

Table 1. Species of fish in streams in the Kansas and Arkansas river basins in western Kansas during the period 1854-2003. Status as native extirpated, native extant, or nonnative extant was used in analyses.

	Kansas River Basin			Arkansas River Basin		
Species	Native extirpated	Native extant	Nonnative extant	Native extirpated	Native extant	Nonnative extant
Scaphirhynchus platorynchus, Shovelnose Sturgeon		●			●	
Polyodon spathula, Paddlefish		●			●	
Lepisosteus osseus, Longnose Gar		●			●	
Lepisosteus platostomus, Shortnose Gar			●			●
Hiodon alosoides, Goldeye		●			●	
Anguilla rostrata, American Eel		●		●		
Dorosoma cepedianum, Gizzard Shad			●			●
Campostoma anomalum, Central Stoneroller		●			●	
Carassius auratus, Goldfish			●			●
Cyprinella camura, Bluntface Shiner					●	
Cyprinella lutrensis, Red Shiner		●			●	
Cyprinus carpio, Common Carp			●			●
Hybognathus hankinsoni, Brassy Minnow		●				
Hybognathus placitus, Plains Minnow		●			●	
Luxilus cornutus, Common Shiner	●					
Lythrurus umbratilis, Redfin Shiner	●					
Macrhybopsis gelida, Sturgeon Chub		●				
Macrhybopsis hyostoma, Shoal Chub		●		●		
Macrhybopsis storeriana, Silver Chub		●			●	
Macrhybopsis tetranema, Peppered Chub					●	
Nocomis biguttatus, Hornyhead Chub	●					
Notemigonus crysoleucus, Golden Shiner		●			●	
Notropis atherinoides, Emerald Shiner		●			●	
Notropis bairdi, Red River Shiner						●
Notropis blennius, River Shiner	●			●		
Notropis buchanani, Ghost Shiner					●	
Notropis dorsalis, Bigmouth Shiner			●			
Notropis girardi, Arkansas River Shiner				●		
Notropis heterolepis, Blacknose Shiner	●					
Notropis stramineus, Sand Shiner		●			●	
Notropis topeka, Topeka Shiner		●		●		
Phenacobius mirabilis, Suckermouth Minnow		●			●	
Phoxinus erythrogaster, Southern Redbelly Dace	●					●
Pimephales notatus, Bluntnose Minnow		●			●	
Pimephales promelas, Fathead Minnow		●			●	
Pimephales tenellus, Slim Minnow					●	

Species	Kansas River Basin			Arkansas River Basin		
	Native extirpated	Native extant	Nonnative extant	Native extirpated	Native extant	Nonnative extant
Pimephales vigilax, Bullhead Minnow			●		●	
Platygobio gracilis, Flathead Chub	●				●	
Semotilus atromaculatus, Creek Chub		●				●
Carpiodes carpio, River Carpsucker		●			●	
Carpiodes cyprinus, Quillback			●			●
Catostomus commersoni, White Sucker		●			●	
Ictiobus bubalus, Smallmouth Buffalo		●				
Ictiobus cyprinellus, Bigmouth Buffalo			●			●
Ictiobus niger, Black Buffalo						●
Moxostoma erythrurum, Golden Redhorse					●	
Moxostoma macrolepidotum, Shorthead Redhorse	●				●	
Ameiurus melas, Black Bullhead		●			●	
Ameiurus natalis, Yellow Bullhead			●			●
Ictalurus punctatus, Channel Catfish		●			●	
Noturus flavus, Stonecat		●				
Noturus nocturnus, Freckled Madtom					●	
Pylodictis olivaris, Flathead Catfish			●			●
Fundulus notatus, Blackstripe Topminnow						●
Fundulus kansae, Northern Plains Killifish		●			●	
Gambusia affinis, Western Mosquitofish			●			●
Cyprinodon rubrofluviatilis, Red River Pupfish						●
Labidesthes sicculus Brook Silverside					●	
Menidia beryllina, Inland Silverside						●
Morone americana, White Perch			●			●
Morone chrysops, White Bass			●			●
Lepomis cyanellus, Green Sunfish		●			●	
Lepomis humilis, Orangespotted Sunfish		●			●	
Lepomis macrochirus, Bluegill			●			●
Lepomis megalotis, Longear Sunfish					●	
Micropterus salmoides, Largemouth Bass			●			●
Pomoxis annularis, White Crappie			●			●
Pomoxis nigromaculatus, Black Crappie			●			●
Etheostoma cragini, Arkansas Darter					●	
Etheostoma nigrum, Johnny Darter	●					
Etheostoma spectabile, Orangethroat Darter		●			●	
Percina caprodes, Logperch			●			●
Percina phoxocephala, Slenderhead Darter					●	
Aplodinotus grunniens, Freshwater Drum			●			●

For each period, the species composition of the two basins was compared by calculating a symmetrical similarity coefficient: Unnamed Coefficient Number 4 (UN4; Sokal and Sneath, 1963; sensu Rohlf, 1994). Although the asymmetrical Jaccard's coefficient (Jaccard, 1908) typically has been used in assessments of homogenization of fish faunas (Rahel, 2002), Eberle and Channell (2006) suggested that UN4 was more appropriate because it more accurately reflects the impact of both extinctions and introductions in the process of taxonomic homogenization.

After the similarity coefficients were calculated, a Monte Carlo simulation (50,000 iterations) of possible UN4 values was run for each period with Resampling Stats Add-in for Microsoft Excel (Resampling Stats, Inc., Arlington, Virginia) by holding the presence or absence of each species constant for the Kansas River basin and allowing the presence or absence of each species in the Arkansas River basin to be randomly assigned, with the species richness in the Arkansas River basin held constant. Similarly, a Monte Carlo simulation (10,000 permutations) was run to compare differences between the UN4 values for the historical period to the UN4 values for the recent period to assess whether the distance between them was greater than expected by chance, thereby indicating a trend toward greater similarity (i.e., taxonomic homogenization) or greater dissimilarity. The numbers of iterations were set at levels determined to be sufficient to eliminate variability inherent with fewer iterations.

Anthropogenic Changes

I obtained most historical agricultural data for each county in the study area from 1880 through 2000 from biennial and annual reports of the Kansas State Board of Agriculture through 1980 (published by the state of Kansas) and from the National Agricultural Statistics Service (2004b) after 1980. For clarity of graphic presentation, I only presented data on the area of harvested row crops and alfalfa from the final year of each decade (e.g., 1880, 1890, 1900, etc.), which coincided with census data. The harvested area of crops experienced anomalous one-year declines in 1890 and 1900, so I graphed data on harvested crops from the year prior to the census year (i.e., 1889 and 1899). Agricultural data were reported for each county, and three counties (Wichita, Scott, and McPherson counties) substantially overlapped both basins, so I included agricultural data from these counties in compilations for both basins. Data for Greeley, Lane, Ness, Rush, Barton, and Rice counties, which also overlapped the two basins, were included only in the compilation for the Arkansas River basin, which drained most of the surface area in those counties. Some plowed fields were not harvested because of crop losses due to factors such as drought, hail, or insect damage, and some fields occasionally were left idle (Miner, 2006). Thus, the harvested area typically would be lower than the area not vegetated with native and introduced pasture grasses, so the data provided in this account represent a conservative estimate of plowed cropland area.

I obtained irrigation data from summaries by the federal Census Bureau (1952, 1956, 1968, 1978), the National Agricultural Statistics Service (1999, 2004a), and the Kansas Water Office (2004). Some of these data were not summarized by county, but when they were, I apportioned the data as done for agricultural data in the counties overlapping the two basins. Numbers of dams constructed in each basin were obtained from the national inventory of dams maintained by the U.S. Army Corps of Engineers (2004) and were assigned to the specific basin in which they were built. Human population data came from federal Census Bureau records (Policy Research Institute, 2003) and were apportioned as done for agricultural data in the counties overlapping the two basins. Information on farm size and rural populations came from the Kansas Statistical Abstract 2002 (Policy Research Institute, 2003).

I obtained mean daily discharge data for streams from U.S. Geological Survey (2005) records from long-term gaging stations. Discharge data for each site were split into two periods: pre-1950 (pre-impact) and 1970 to 2003 (post-impact). The 20 years from 1950 through 1969 were omitted because they were the decades during which substantial increases initially occurred in irrigated area and numbers of dams constructed—two of the three principal impacts that were likely to alter streamflow. The third possible impact, precipitation, was assessed previously in the region and did not conform to the pattern of pre-impact and post-impact periods associated with irrigation and dam construction (Jordan, 1982; Ratzlaff, 1994; Rasmussen and Perry, 2001; Szilagyi, 2001). Mann-Whitney U-tests (SPSS Inc., Chicago, Illinois) were used to assess discharge data.

Results

Extirpated Species

My assessment included 74 native and nonnative species of fish (Table 1). Seven of the 50 native species (14%) have been extirpated from the entire study area: common shiner, redfin shiner, hornyhead chub, river shiner, Arkansas River shiner, blacknose shiner, and johnny darter. Due to reduced distributions or numbers of individuals in recent collections, five additional species were considered to be rare and at risk of extirpation: plains minnow, shoal chub, peppered chub, Topeka shiner, and flathead chub. All of the species considered to be rare and at risk of extirpation in the study area were listed in 2005 as protected species under the Kansas Nongame and Endangered Species Act of 1975 or were recently proposed for listing (Haslouer et al., 2005).

Within the Kansas River basin, nine of the 38 native species (24%) have been extirpated (Table 1). Of these nine species, six apparently were extirpated by the early 1900s: redfin shiner, hornyhead chub, blacknose shiner, southern redbelly dace, shorthead redhorse, and johnny darter. Three species were extirpated after 1960: common shiner, river shiner, and flathead chub. Four additional native species were rare and at risk of extirpation from the basin: plains minnow, shoal chub, silver chub, and Topeka shiner.

In the Arkansas River basin, five of 40 native species (12%) have been extirpated (Table 1). Of these five species, only one apparently was extirpated in the early 1900s: Topeka shiner. Four species were extirpated after 1960: American eel, shoal chub, river shiner, and Arkansas River shiner. Three additional native species were rare and at risk of extirpation from the basin: plains minnow, peppered chub, and flathead chub.

Nonnative Species

Throughout western Kansas, 27 of the 67 extant species (40%) were introduced or expanded their ranges into the region (Table 1). The relative components of nonnative species in recent collections were similar in the Kansas River basin (20 of 49 extant species = 40%) and the Arkansas River basin (25 of 60 extant species = 42%). Eighteen of the 27 species (67%) were added to the faunas in both basins, two species were added to only the Kansas River basin, and seven species were added to only the Arkansas River basin (Table 1). The data available suggested that the nonnative species were not widespread in streams in the study area until the late 1900s (Tables 2 and 3; Figure 3).

Faunal Similarity

The historical faunas in the two basins were significantly more dissimilar than expected by chance (UN4 = 0.36, P = 0.046). Conversely, the similarity coefficient for the extant faunas (UN4 = 0.58) was not significantly different from the randomly generated values (P = 0.133). The distance between the UN4 similarity coefficient for the historical faunas and the higher UN4 similarity coefficient for the extant faunas was greater than expected

Table 2. Summary of native and nonnative species of fish collected in the Smoky Hill River basin of northwestern Kansas. Data from Hay (1887), Gilbert (1889), and museum records at the University of Kansas and University of Michigan.

	Number of sites			Number of species	
Period of records	Total	With nonnative species	With species now extirpated	Native	Nonnative[1]
1885-1887	9	0	6	28	0
1910-1915, 1926, 1935-1942	10	3	0	14	4

[1] = Common carp, *Cyprinus carpio* (1 site). Common carp; flathead catfish, *Pylodictis olivaris*; and largemouth bass, *Micropterus salmoides* (1 site). Yellow bullhead, *Ameiurus natalis* (1 site).

Table 3. Summary of records of two nonnative species—common carp (*Cyprinus carpio*) and largemouth bass (*Micropterus salmoides*)—widely stocked in the Kansas River basin in northwestern Kansas.

Period of records	Data source	Common carp	Largemouth bass
July 1938	Breukelman (1940)	0% of 25 sites	8% of 25 sites
1974-1976	KDWP[1]	27% of 190 sites	11% of 190 sites
1994-1996	FHSU-KDWP[2]	27% of 116 sites	17% of 116 sites

[1] = Kansas Fish and Game Commission (now Kansas Department of Wildlife and Parks) stream surveys.

[2] = Fort Hays State University and Kansas Department of Wildlife and Parks stream surveys.

by chance (P = 0.009), indicating a significant trend toward taxonomic homogenization of the faunas in the two basins.

I also compared the historical faunas of the two basins as if they had been impacted only by the reported extirpations (i.e., no nonnative species had been added to the native faunas). The similarity coefficient for these extant, native faunas (UN4 = 0.58) was not significantly different from the randomly generated values (P = 0.226). Because the similarity coefficient for the historical faunas indicated that the faunas in the two basins had been significantly dissimilar, the higher similarity coefficient resulting from the extirpations alone suggested a trend toward taxonomic homogenization. This trend toward homogenization was confirmed by an analysis of the distance between these similarity coefficients (UN4 = 0.36 and 0.58), in which the distance between them was greater than expected by chance (P = 0.015).

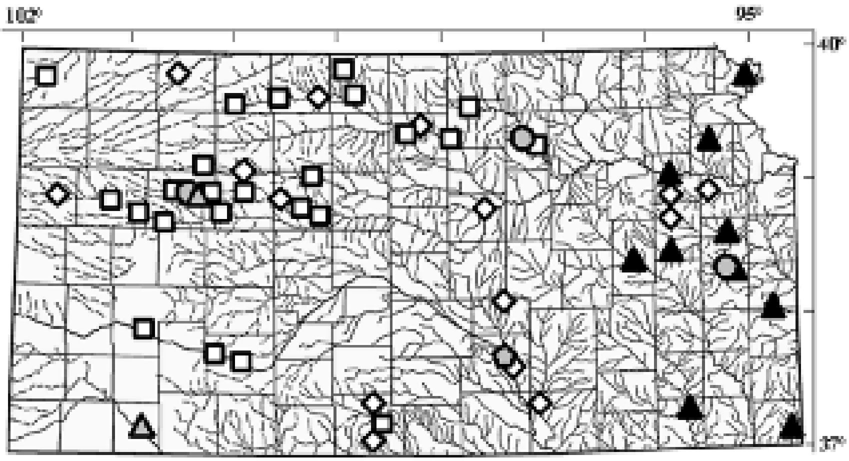

Figure 3. Distributional records of fishes in Kansas from 1885–1915 from maps by Cross (1967). Open diamonds (15) = native Topeka shiner (*Notropis topeka*), the most widely collected native species subsequently extirpated from clear, perennial creeks in western Kansas. Open squares (24) = collection sites for other native species in the study area of western Kansas (generally west of 97° W). Gray circles (3) = exotic common carp (*Cyprinus carpio*). Triangles = largemouth bass (*Micropterus salmoides*; gray triangles (2) = nonnative range; black triangles (10) = native range). Gray pentagon (1) = nonnative gizzard shad (*Dorosoma cepedianum*). The only two other records during this period of species classified as nonnative in western Kansas were for flathead catfish (*Pylodictis olivaris*), which was collected at the same site shown for common carp and largemouth bass in northwestern Kansas (Gove County), and for white crappie (*Pomoxis annularis*), which was reported at the same site for common carp in north-central Kansas (Clay County). These records suggest a limited occurrence of nonnative species of fish relative to collections of native species prior to 1915 within the study area.

Alternatively, if only the additions of nonnative species had occurred as reported, but no extirpations had occurred, the resulting faunas of the two basins would not be significantly dissimilar (UN4 = 0.40, P = 0.097). Because the similarity coefficient for the historical faunas indicated that the faunas in the two basins had been significantly dissimilar, the resulting nonsignificant similarity coefficient from only additions of nonnative species suggested a trend toward homogenization. However, this trend toward homogenization was not supported by an analysis of the distance between these similarity coefficients (UN4 = 0.36 and 0.40; P = 0.292), indicating that the additions of nonnative species alone did not make a significant contribution to a trend toward taxonomic homogenization of the faunas in the two basins.

Anthropogenic Changes

Human population density increased rapidly from 1870 through 1910, especially in the Kansas River basin (Figure 4). Rapid, early increases in the area of harvested row crops and alfalfa mirrored the early increases in population density, with the larger area initially in the Kansas River basin (Figure 5). After 1930, the population density in the Kansas River basin declined slightly and the population density in the Arkansas River basin (excluding Wichita and its suburbs in Sedgwick County) increased slightly, but none of the later changes in overall population density within either basin were as dramatic as the initial increases. However, the rural population in the study area in western Kansas progressively declined from 77% of the population in 1930 to 46% in 2000, while the total population changed little (Table 4), indicating a consolidation of the formerly more

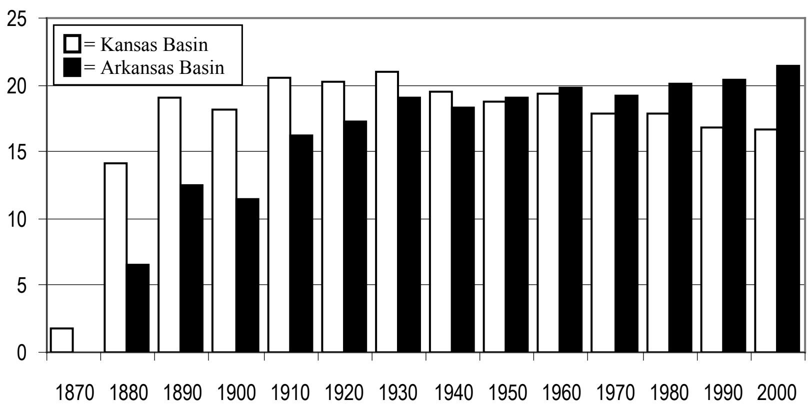

Figure 4. Population densities (people per 1,000 acres) in decennial federal censuses in the Kansas and Arkansas river basins in western Kansas, excluding Sedgwick County (city of Wichita and environs) in the lower Arkansas River basin. Data from the federal Census Bureau as summarized in the Kansas Statistical Abstract (Policy Research Institute, 2003).

Table 4. Data on the sizes of farms* throughout Kansas and percentage of population classified as rural in western Kansas, excluding Sedgwick County (Wichita and environs) (Policy Research Institute, 2003). For 2002, the categories western, central, and eastern represent approximate thirds of Kansas; the western and central regions encompass the study area.

Year	Number of farms	Land in farms (acres)	Mean farm size (acres)	Population Total	Population % rural
1920	167,000	45,400,000	272		
1930	166,000	47,000,000	283	704,937	77%
1940	159,000	48,200,000	303	661,040	73%
1950	135,000	50,500,000	374	663,727	64%
1960	110,000	50,200,000	456	686,823	56%
1970	87,000	49,900,000	574	648,898	53%
1980	75,000	48,300,000	644	663,041	51%
1990	69,000	47,900,000	694	648,496	50%
2000	64,000	47,500,000	742	664,905	46%
2002	63,000	47,400,000	752		
Western	11,700	16,600,000	1,419		
Central	22,900	17,500,000	764		
Eastern	28,400	13,300,000	468		

* = Definition of farms changed through the period. Prior to 1959, a farm was 3 or more acres with agricultural products worth at least $150 annually or less than 3 acres with agricultural products of $250 or more. Between 1959 and 1975, a farm was 10 acres or more with agricultural products worth at least $50 annually or less than 10 acres with agricultural products of $250 or more. Beginning in 1975, a farm was any size place that had agricultural products worth at least $1,000 annually.

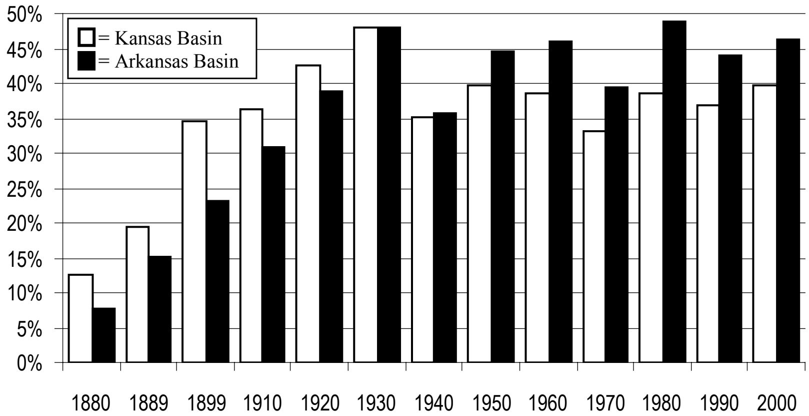

Figure 5. Percentage of area in harvested row crops and alfalfa reported in the Kansas and Arkansas river basins in western Kansas for the years indicated. Data obtained through 1970 from Kansas State Board of Agriculture biennial and annual reports and after 1980 from the National Agricultural Statistics Service (2004b).

widely dispersed human population. This was also reflected in the number of farms throughout Kansas, which declined substantially from 1920 to 2000, although the number of acres in farms changed little; thus, the average farm size increased, especially in western Kansas (Table 4).

The area of irrigated crops and the number of dams constructed both increased substantially from 1950 through 1980 (Figures 6 and 7), but the increases differed within the study area. In 2002, 76% of the irrigated area in western Kansas occurred in the Arkansas River basin (Table 5), and most of this area was in the western half of the study area (Figure 8), which overlies the High Plains Aquifer. About 13% of the total area in the Arkansas River basin was irrigated in 2002, while only about 4% of the total area in the Kansas River basin was irrigated (Table 5). Conversely, twice as many dams were constructed in the Kansas River basin as in the Arkansas River basin, and most of these dams were constructed in the eastern half of the study area (Figure 8). The most heavily irrigated and impounded counties illustrated in Figure 8 are listed in Tables 5 and 6.

Given the potential impacts on streams and aquatic organisms of the concurrent development of crop irrigation and impoundments, I compared discharge data prior to 1950 (pre-impact) and after 1969 (post-impact). At

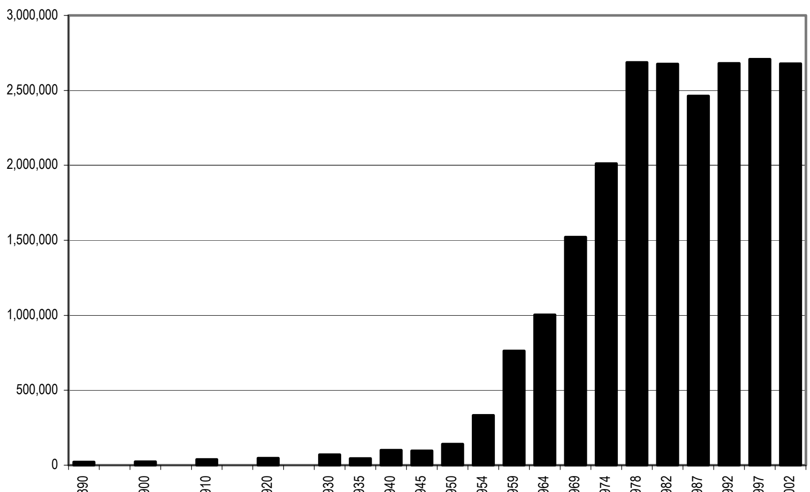

Figure 6. Number of irrigated acres reported in Kansas for the years given. After 1930, data were compiled every four or five years, so spacing of bars reflects this time interval. Statewide data were used because data were not available for counties in the early summaries; however, most irrigated acres occurred within the study area (e.g., 98% of all irrigated acres in Kansas in 2002 were within the study area; Kansas Water Office, 2004). Data are from the federal Census of Agriculture conducted from 1890 through 1992 by the federal Census Bureau (1952, 1956, 1968, 1978) and after 1997 by the National Agricultural Statistics Service (1999, 2004a).

Table 5. Most heavily irrigated counties during 2002 of 66 counties in western Kansas. Total area of the 19 counties listed is 28% of the study area. Total area irrigated in the 19 counties is 74% of the irrigated area in the study area. See Figure 8 for spatial relationship of the counties. In the entire study area, 76% of the irrigated acres were in the Arkansas River basin in 2002. Data for irrigated area are from the Kansas Water Office (2004).

Rank	County	Irrigated acres	Total acres	Percentage of area irrigated
1	Haskell	213,174	369,280	57.7%
2	Stevens	171,987	465,920	36.9%
3	Gray	184,703	556,160	33.2%
4	Grant	120,684	368,000	32.8%
5	Stanton	141,430	435,200	32.5%
6	Seward	130,649	409,600	31.9%
7	Finney	244,296	833,280	29.3%
8	Edwards	101,252	398,080	25.4%
9	Meade	125,677	625,920	20.1%
10	Kearny	107,255	557,440	19.2%
11	Pratt	83,494	470,400	17.8%
12	Wichita	81,438	460,160	17.7%
13	Sherman	115,501	675,840	17.1%
14	Pawnee	79,472	482,560	16.5%
15	Stafford	82,454	506,880	16.3%
16	Thomas	101,332	688,000	14.7%
17	Scott	61,338	459,520	13.4%
18	Sheridan	76,432	573,440	13.3%
19	Ford	93,396	702,720	13.3%
Totals		2,315,964	10,038,400	23.1%
	Kansas Basin	798,533	17,989,120	4.4%
	Arkansas Basin	2,492,217	19,398,400	12.8%

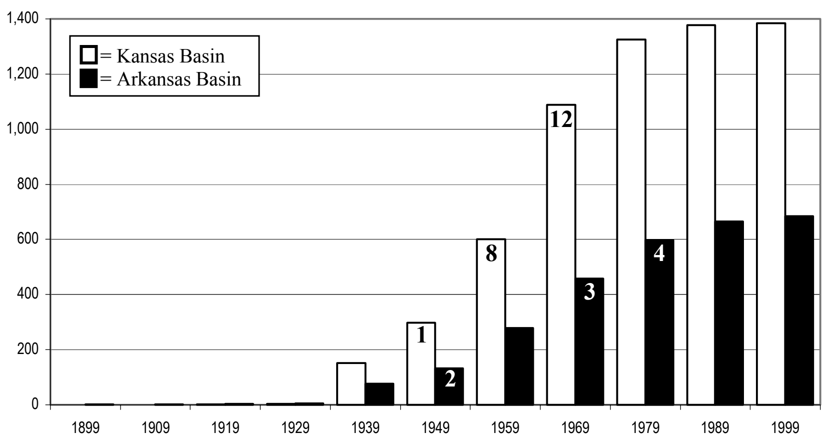

Figure 7. Cumulative numbers of dams constructed in the Kansas and Arkansas river basins in western Kansas through each of the years given. Numbers at the tops of the bars are cumulative numbers of reservoirs in or adjacent to the study area through the year given that were operated by the U.S. Army Corps of Engineers or U.S. Bureau of Reclamation; all federal reservoirs were still present after 1999. Data obtained from the U.S. Army Corps of Engineers (2004).

Table 6. Counties with the greatest densities of impoundments of 66 counties in western Kansas. Total area of the 14 counties is 21% of the study area. Total number of dams in the 14 counties is 51% of the dams in the study area. Numbers of dams are from the U.S. Army Corps of Engineers (2004). See Figure 8 for spatial relationship of counties.

Rank	County	Number of dams	Number of federal reservoirs	Acres	Density of dams (per 100,000 acres)
1	Ottawa	112		461,440	24.3
2	Saline	103		460,800	22.4
3	Lincoln	90		460,160	19.6
4	Osborne	103		570,880	18.0
5	Smith	82		572,800	14.3
6	Dickinson	75		542,720	13.8
7	Ellsworth	63	1	458,240	13.8
8	Barber	94		725,760	13.0
9	Phillips	68	1	567,040	12.0
10	Norton	61	1	561,920	10.9
11	Rooks	61	1	568,320	10.7
12	Mitchell	46	1	448,000	10.3
13	Sedgwick	65		639,360	10.2
14	Clay	41		412,160	10.0
Totals		1,064	5	7,449,600	14.3

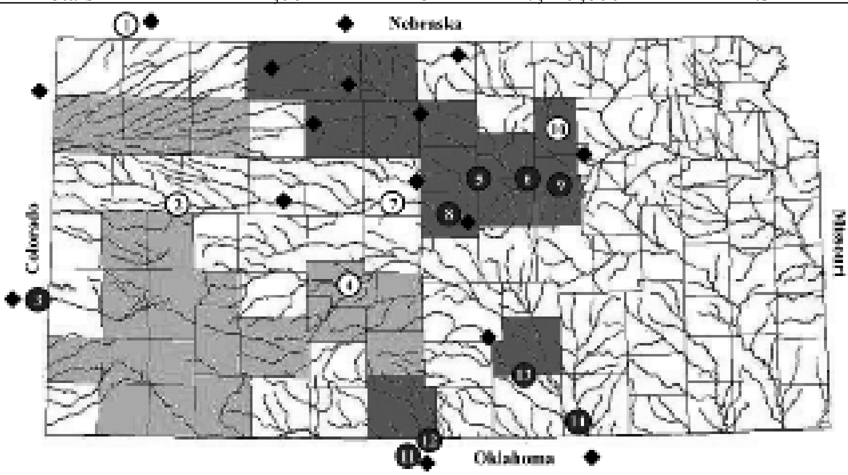

Figure 8. Regional impacts of impoundments and irrigation in the 66-county study area in western Kansas. The 14 most heavily impounded counties (dark shading; 10 to 24 dams per 100,000 acres in each county; data in Table 6) represent 21% of the study area and 51% of the dams. The 19 most heavily irrigated counties (light shading; 13 to 58% of the total area was irrigated in each county in 2002; data in Table 5) represent 28% of the study area and 74% of the irrigated area. Data are from the U.S. Army Corps of Engineers (2004) for dams and the Kansas Water Office (2004) for irrigated area. Dark circles represent U.S. Geological Survey gaging stations that had streamflows that were more stable or essentially unchanged after 1969 compared to streamflows prior to 1950 (see Figure 9). White circles represent gaging stations that had reduced flows after 1969 compared to flows prior to 1950 (see Figure 9). Numbers in circles correspond to gaging stations used in other figures and in the appendices. Black diamonds represent federal impoundments.

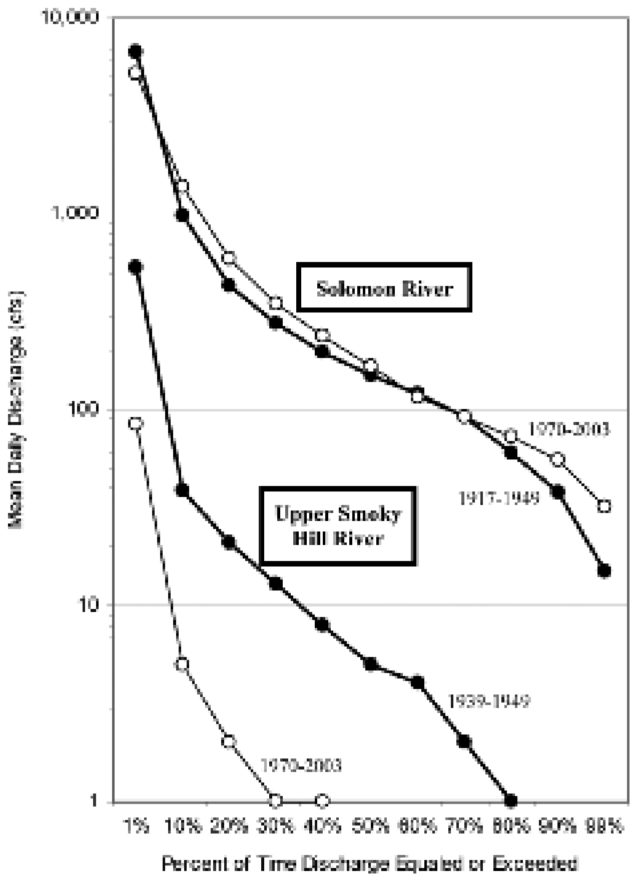

Figure 9. Flow duration curves illustrating two patterns of altered discharge in rivers flowing through the study area in western Kansas, represented by the Solomon River at Niles (upper two lines; location illustrated in Figure 8, circle 6) and the Smoky Hill River at Elkader (lower two lines; location illustrated in Figure 8, circle 2). Two periods of discharge are graphed for each site: discharge prior to 1950 (thick lines with solid circles) and discharge after 1969 (thin lines with open circles). Discharge data omitted from 1950 to 1969 represent the impact period, when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred. The graph for the Solomon River illustrates streamflows that became generally higher or remained essentially the same after 1969, all with higher minimum flows and reduced summer peak flows (Figure 10; Appendix B). Sites with similar discharge patterns are marked as dark circles in Figure 8 and are graphed in Appendix A. The graph for the upper Smoky Hill River illustrates streamflows that exhibited an overall decline after 1969 compared to streamflows prior to 1950. Sites with similar discharge patterns are marked as white circles in Figure 8 and are graphed in Appendix A. Discharge data from the U.S. Geological Survey (2005).

most sites in the eastern part of the study area, where more of the dams were built and the smaller area of cropland was irrigated (Figure 8), the flow duration curves suggested that post-impact flows were similar to or higher than pre-impact flows, as illustrated for the site on the Solomon River (Figure 9; other sites in Appendix A). I used Mann-Whitney U-tests to compare pre-impact and post-impact mean daily discharge data at four U.S. Geological Survey gaging stations in north-central Kansas. I selected these gaging stations because they included discharge data beginning in 1917 or 1919, which allowed up to 33 years of pre-impact data to be compared with 34 years of post-impact data; most other gaging stations in western Kansas provided data only back to the 1930s. Results of the Mann-Whitney U-tests (Table 7) indicated that post-impact flows were higher than pre-impact flows in the Smoky Hill and Solomon rivers, and were statistically similar to pre-impact flows in the Saline River. However, the lowest 20% of mean daily discharges for all three rivers were higher in the post-impact period and were significantly different than those of the pre-impact period (Table 7). In addition, all of the rivers exhibited a substantial decline in the peak discharges (mean daily discharges met or exceeded 10% of the time each month) during May or June in the post-impact period compared to the pre-impact period, as illustrated for the Solomon River (Figure 10; other

Table 7. Results of Mann-Whitney *U*-tests comparing two periods of mean daily discharge data at four U.S. Geological Survey gaging stations in north-central Kansas. The discharge data from 1950 through 1969 not included in the analyses represent the impact period, when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred. Analyses of "all flows" were based on all available discharge data for the years given. Analyses of "low flows" were based on only the lowest 20% of ranked discharge data for the years given.

Site	*n*	Mean rank	*U*	*P*
Saline River (Tescott)				
All flows, 1919-1949	11,035	11,612.36	67,251,228	0.141
All flows, 1970-2003	12,326	11,742.45		
Low flows, 1919-1949	2,192	1,657.34	1,229,353	<0.0001
Low flows, 1970-2003	2,465	2,926.28		
Smoky Hill River (Ellsworth)				
All flows, 1919-1949	9,835	10,825.64	58,101,654	<0.0001
All flows, 1970-2003	12,326	11,284.75		
Low flows, 1919-1949	1,967	1,933.95	1,868,548	<0.0001
Low flows, 1970-2003	2,465	2,441.97		
Solomon River (Niles)				
All flows, 1917-1949	11,780	11,598.12	67,235,792	<0.0001
All flows, 1970-2003	12,326	12,488.71		
Low flows, 1917-1949	2,342	1,622.90	1,057,168	<0.0001
Low flows, 1970-2003	2,451	3,136.68		
Republican River (Clay Center)				
All flows, 1917-1949	11,902	13,716.37	54,286,592	<0.0001
All flows, 1970-2003	12,326	10,567.73		
Low flows, 1917-1949	2,380	3,102.43	1,316,296	<0.0001
Low flows, 1970-2003	2,465	1,766.99		

sites in Appendix B). The Saline River (downstream from Wilson Reservoir; Appendix Figure B11) also had a lower, post-impact peak discharge in June, but differed from the other sites in having substantially higher peak discharges in April, May, July, and August after 1969. The combination of increased minimum discharges and the general absence of scouring peak discharges suggested a more stable flow pattern in the rivers after 1969. The exception to this pattern in the eastern part of the study area was the overall lower discharge in the lower Republican River (Table 7; Appendix Figure A5), which was associated with overuse of water allocations and inadequate regulation of groundwater pumping upstream in Nebraska (U.S. Supreme Court, Kansas v. Nebraska and Colorado, No. 126 Original; Final Settlement Stipulation, 19 May 2003).

The overall decline in discharge in the Republican River in the eastern part of the study area was similar to the change in most rivers in the western part of the study area, as illustrated by the flow duration curve for the upper Smoky Hill River in northwestern Kansas (Figure 9; other sites in

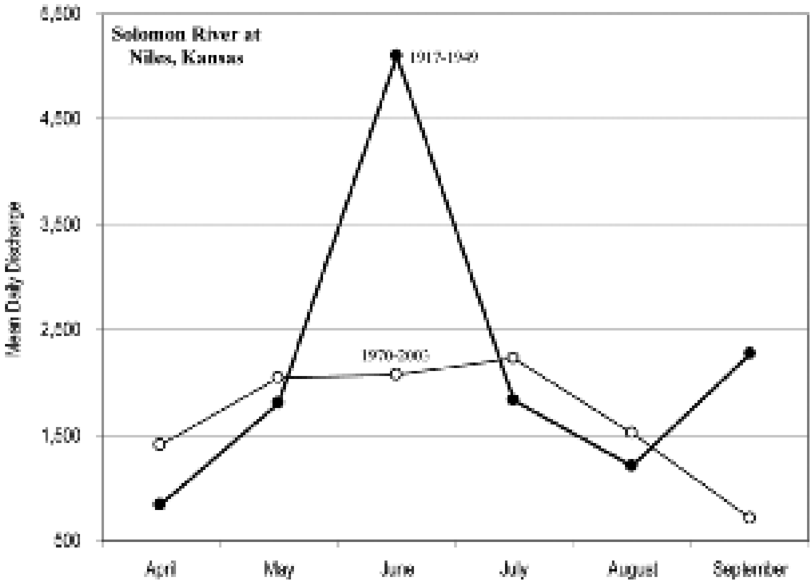

Figure 10. Discharge met or exceeded 10% of the time each month from April through September for years prior to 1950 (thick line with solid circles) and for years after 1969 (thin line with open circles) in the Solomon River in north-central Kansas (location illustrated in Figure 8, circle 6). All sites marked with dark or white circles in Figure 8 had similarly reduced peak discharges after 1969 during June or during May in the Salt Fork Arkansas River basin (see graphs in Appendix B). Data omitted from 1950 to 1969 represent the impact period, when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred. Discharge data from U.S. Geological Survey (2005).

Appendix A). The western part of the study area was where most of the groundwater withdrawals for irrigation occurred and fewer dams were constructed (Figure 8). The exception to this pattern was the upper Arkansas River at Lamar, Colorado, near the Kansas border (Appendix Figure A1); this site had generally higher streamflows similar to rivers in the eastern part of the study area. The Arkansas River was the only stream in the study area to receive substantial runoff from snowmelt in the Rocky Mountains, which was held and periodically released for irrigation by two main-stem impoundments in Colorado (Pueblo and John Martin reservoirs), altering the streamflow pattern near the Kansas-Colorado border. As with monthly peak discharges in the eastern portion of the study area (Figure 10), all rivers in the western part of the study area showed a substantial decline in monthly peak discharges during May or June after 1969 compared to peak discharges prior to 1950 (Appendix B).

Discussion

The fish faunas of streams in the Kansas and Arkansas river basins in western Kansas when the territory was established in 1854 were significantly dissimilar. However, the ensuing 150 years of changes in the two faunas made them significantly more similar. Additionally, my analyses primarily considered the presence or absence of species, rather than their abundance. Some extant, native species have been greatly reduced in both abundance and distribution, and they might be extirpated in the near future. It also is possible that additional species will be added to one or both faunas. For example, the Red River shiner, Red River pupfish, and inland silverside introduced into the Arkansas River basin could be transported from that basin to the Kansas River basin, as occurred with the western mosquitofish and bullhead minnow. Thus, additional extirpations and introductions could cause the two faunas to become even more similar.

The initial differences (and the similarities) between the faunas of the Kansas and Arkansas river basins resulted from events during the Pleistocene that created dispersal opportunities or subsequently caused extirpations of fish species in western Kansas streams (Metcalf, 1966; Cross, 1970; Cross et al., 1986). Exchanges of faunal elements in river systems throughout the western Great Plains probably occurred during the Kansan glacial maximum. The advance of the continental glacier as far southwest as present-day northeastern Kansas led to connections among plains streams through the Ancestral Plains Stream that likely flowed south along the western margin of the glacier from southwestern North Dakota through the McPherson Channel in central Kansas toward the Gulf of Mexico (Metcalf, 1966; Cross et al., 1986). The McPherson Channel was located in the area where the present-day Smoky Hill River turns southeast toward the headwaters of the Little Arkansas River basin in central Kansas (McPherson County). The Smoky Hill River probably was a tributary of the Arkansas River until the mid Pleistocene, when it was pirated by the Kansas River as its headwaters eroded westward (Metcalf, 1966; Cross et al., 1986).

The new stream connection for the Smoky Hill River through the Kansas, Missouri, and Mississippi rivers might have allowed some species, such as the common shiner, to enter the upper Kansas River basin, and this could explain their absence from the Arkansas River basin (Metcalf, 1966). However, other species with northern affinities, such as the brassy minnow, that were similarly absent from the historical fauna of the Arkansas River basin have been reported from fossil deposits in southwestern Kansas (Meade County) (Smith, 1963). Their absence from the historical fauna probably resulted from extirpations during the Pleistocene that likely were associated with a warmer, drier climate (Cross, 1970). These climate changes and their impacts on streams apparently reduced the ranges of several species of fish, including the southern redbelly dace and blacknose shiner, as indicated by the distributions of their disjunct populations in the historical faunas (Cross, 1970; Cross et al., 1986). As a consequence, the historical distributions of fishes seem to be more strongly related to climate variables than to drainage basins (Cross, 1970; Cross et al., 1986). Nonetheless, these variations in dispersal opportunities and extinctions on a geological timescale resulted in the dissimilarity between the historical fish faunas of the Kansas and Arkansas river basins noted in this study. However, the relatively rapid increase in similarity between the faunas in the two basins during the past 150 years was associated with anthropogenic changes to the streams and their faunas.

There were two general periods of historical extirpations in the streams of western Kansas. Most of the species of fish extirpated by the early 1900s were generally restricted to small, clear, perennial streams in the Kansas River basin, as was the single species extirpated from the Arkansas River basin (Cross, 1967). During this same period, the common shiner and Topeka shiner were nearly extirpated in the Kansas River basin, and the common shiner was extirpated after 1960 (Cross and Moss, 1987). Contrasted with this, most extirpations that occurred after 1960 were species that characteristically inhabit larger, often turbid rivers, as were nearly all of the species considered most at risk of extirpation (Cross, 1967; data from recent surveys). This pattern of regional extirpations conforms to the pattern of general changes summarized by Cross and Moss (1987) for portions of the study area considered here and is supported by the additional data compiled in this study.

Early Changes in the Faunas and Concurrent Landscape Changes

The increase in human population through 1890, especially in the Kansas River basin, was represented primarily by people who developed small farms. Homesteads were initially set at 160 acres (65 ha) based on experiences with sustainable farm sizes in the more humid eastern United States (Miner, 1986). However, these small allotments were not sustainable during dry years on the semiarid plains of western Kansas, and early settlers often abandoned their homesteads (Miner, 1986), which resulted in variation in annual estimates of population and harvested crops during the late 1800s. Despite this, the population in the Kansas River basin in 1890 was primarily rural and exceeded that of any census since 1960. In 1899, these people harvested row crops and alfalfa from nearly 35% of the study area. The area of plowed grassland on the Great Plains increased to a maximum, sustainable level for dryland crops through about 1920, continued to increase into marginal areas through the 1930s, and returned to near 1920 levels after 1940 (Cunfer, 2005); however, cropland subsequently increased in southwestern Kansas concurrent with the development of groundwater irrigation. The increasing amount of harvested row crops and relatively high rural population probably both played a role in the concurrent extirpations of fishes.

Data from 1956 through 1970 indicated that the sediment yield in streams draining areas of row crops in north-central Kansas, where most of the early extirpations of fishes had occurred, was at least twice the sediment yield of streams draining areas of intact grassland (Holland, 1971). In general, variable precipitation regimes typical of the study area correspond to high rates of erosion by streams, and precipitation variability is more important in this regard than total annual precipitation (Harlin, 1980). Although specific limnological data are unavailable, high sediment yields from erosional runoff following intense thunderstorms probably were typical of conditions in much of the study area in the late 1800s and early 1900s, as the area of row crops rapidly increased. The increase in sediment in streams probably had a role in the concurrent extirpations of southern redbelly dace, hornyhead chub, common shiner, and johnny darter in western Kansas and elsewhere (Cross, 1967; Pflieger, 1997). Their continued presence in small, clear streams within intact grasslands in the lower Kansas River basin (Cross and Collins, 1995; data from recent surveys) supports this view. Similarly, the Arkansas darter, a species associated with clear, vegetated, spring-fed habitats, persists in the largely grassland area of south-central Kansas known as the Red (Gypsum) Hills (Eberle and Stark, 2000).

The negative impacts of the increased silt loads that contributed to the extirpations of these species probably were both direct and indirect. The hornyhead chub, common shiner, southern redbelly dace, and Topeka shiner spawn over nests that they (or some other species) have cleared of silt or over naturally unsilted areas of gravel (Pflieger, 1997); thus, substantially increased siltation would eliminate suitable nesting sites. Indirect negative effects of increased sedimentation on the fishes could result from the loss of photosynthetic aquatic organisms (algae and aquatic plants) and silt-sensitive invertebrate animals that constituted the food or vegetative cover used by the fishes.

The potential impacts of herds of domestic livestock on the early extirpation of fishes in the perennial streams in the Kansas River basin were not specifically considered in this study, because it was not possible to accurately assess their impacts. These impacts would vary with local stocking rates, which cannot be discerned from the available data on cattle numbers. This problem is compounded by the combined reports of the numbers of cattle grazing on grassland and those confined to feedlots, and the latter increased substantially during the second half of the 1900s (Cunfer, 2005). Also, the native grasslands were adapted to extensive herds of large, native grazers, primarily bison. However, overgrazing by cattle did occur and resulted in substantial loss of basal cover of vegetation, as documented in central Kansas during the droughts of the 1930s and 1950s (Tomanek and Hulett, 1970). Loss of vegetative cover due to overgrazing would substantially increase the sediment yield in streams, as occurs in areas of row crops (Holland, 1971). Although the lack of precipitation during a severe drought would produce little or no runoff into streams, heavy precipitation can occur during droughts, as occurred in the Republican River basin during May and June 1935 (Follansbee and Spiegel, 1937), and damage to the vegetation would persist into the early period of precipitation during recovery from the drought. Thus, overgrazed grasslands in the Kansas River basin around the time of the drought in the 1890s could have expanded the impact on streams of high sediment yields derived from cropland that would be detrimental to the species extirpated by the early 1900s from the clear, perennial creeks.

In addition to increased sediment yields, dewatering of streams during droughts also might have contributed to the extirpation of species characteristic of small perennial streams in the Kansas River basin during the late 1800s and early 1900s. Although data currently are limited for an assessment of the impacts of droughts on the fishes characteristic of perennial streams (Matthews and Marsh-Matthews, 2003), these species in the Kansas River basin apparently persisted through several droughts that occurred during the 1800s, including a series of drought years beginning in 1847 that culminated in a prolonged drought during the 1860s that probably equaled or exceeded the severity of the drought in the 1930s (Stockton and Meko, 1983; Woodhouse and Overpeck, 1998). As streamflow was restored, these species of fish characteristic of small, perennial streams probably recolonized channels from local refugia maintained by groundwater, as suggested by their widespread presence in samples collected in 1885 and 1887 (Hay, 1887; Gilbert, 1889) at the close of a brief moist period following the severe drought of the mid 1800s (temporal perspective illustrated in Figure 2).

During droughts, it is possible that increased reliance by diffuse populations of people and livestock on the water associated with these stream refugia could have exacerbated the impacts of the drought on native fishes, impacts that they might otherwise have survived. Although no quantifiable data on streamflows in the small streams are available for this period, the rapid increase in a rural population spread among many small farms in the late 1800s suggests that consumption of water by people (directly and for their gardens) and by domestic livestock also would have increased and been widespread across the region at this time. Efforts were underway in the late 1800s to develop this consumption of water by drilling water wells and constructing dams across streams and below springs (Hay, 1895; Newell, 1895). In addition to water quantity, water quality in the stream refugia also could have declined. In contrast to the extensive migrations of the native bison, domestic livestock restricted to using reduced perennial stream segments harboring native fishes during a drought could degrade water quality through increased nutrient concentrations derived from their wastes and through the disruptive action of their hooves on the stream substrate.

Thus, the combined impacts of degradation of stream habitat from increased sediment yield or stream use by livestock and the consumption of water from perennial stream sources, especially during a drought, could have contributed to these early extirpations, and it is likely that multiple causes contributed to the extirpations at the regional scale considered in this study. The fact that these changes in the fish faunas and the probable underlying causes occurred early in the history of the state illustrates the value of truly long-term studies of changes to communities of native species where possible.

In addition to their contributions to extirpations, high population densities of people have been associated with high numbers of nonnative species of fish across Kansas and Oklahoma (Gido et al., 2004) and across larger areas of North America (McKinney, 2001). Efforts by the Fish Commissioner of the Kansas State Board of Agriculture to establish nonnative species of fish began in 1877 (Long, 1878), and introductions by governmental agencies and private individuals have continued to the present. Although apparently self-sustaining populations of nonnative species were documented from western Kansas early in the study period (prior to 1915; Cross, 1967), a compilation of presence-absence data for species captured at sites in northwestern Kansas during a sequence of time periods (summarized in Tables 2 and 3 and in Figure 3) suggested, when viewed on a regional scale, that the early extirpation of the native species in small streams was not concurrent with the widespread establishment of nonnative species, such as common carp and largemouth bass, two of the most widely promoted species during this time.

The low incidence of common carp in the early stream samples occurred despite the report in 1885 that common carp were "…now raised for food in artificial ponds in all parts of the State" (Cragin, 1885:109). The low incidence of largemouth bass in the early stream samples concurs with the results of a survey conducted in northwestern Kansas during July 1938, in which largemouth bass were collected from only two sites, where they had been stocked, of the 25 sites sampled (Breukelman, 1940). Their limited distribution in the early 1900s is further supported by the continued increase in the relative numbers of sites where they were present in samples collected in the 1970s and 1990s (Table 3), during the period when most impoundments were being constructed and some streamflows were becoming more stable—habitat alterations that would benefit lentic species such as largemouth bass. Falke and Gido (2006) suggested that populations of lentic species, such as largemouth bass and bluegill, that existed in small (first to third order) streams in Kansas originated in the thousands of small impoundments in each basin.

Nonetheless, largemouth bass (and relatively high numbers of small impoundments) have been associated with local extirpations of Topeka shiners in eastern Kansas (Schrank et al., 2001), and concurrent reductions in populations of central stoneroller, fathead minnow, Topeka shiner, and orangethroat darter have been noted following the introduction of largemouth bass in Willow Creek in northwestern Kansas (Stark et al., 2002; W. J. Stark, Fort Hays State University, personal communication). Thus, nonnative species likely contributed little to the early regional extirpations of native fishes in western Kansas compared with the negative impacts of habitat modifications, but it is possible that negative interactions with nonnative fishes contributed to the extirpation of some native species, such as the Topeka shiner, on a local scale, especially when native species were already being negatively impacted by the habitat modifications.

Late Changes in the Faunas and Concurrent Landscape Changes

The major landscape modifications in western Kansas during the latter half of the 1900s were made in response to the natural variation in precipitation and streamflow. Droughts often encourage the development of irrigation projects, and floods often encourage the construction of dams. A substantial flood in 1951 (U.S. Geological Survey, 1952) and a drought during 1952–1956 (National Climate Data Center, 2003) helped win support for the construction of dams and the development of associated irrigation programs. Although more than 75% of the irrigated land was in the Arkansas River basin and 67% of the dams were in the Kansas River basin, the alterations to streamflows exhibited similar patterns within the study area that were spatially associated with which impact, either dewatering or flow regulation, was dominant in a particular section of each basin. Over 75% of the irrigated land in the study area was in the Arkansas River basin, which would suggest that dewatering of streams would be more prevalent in this basin. Similarly, 67% of the dams were constructed in the Kansas River basin, which suggests that flow regulation would be more prevalent in this basin. However, both irrigated land and construction of dams occurred in portions of each basin at a level sufficient to alter streamflows accordingly. In most western stream segments of both basins, which were formerly fed by baseflow from the High Plains Aquifer that now supports most of the irrigation in the region, streamflows declined dramatically as water tables declined. In most streams in north-central Kansas and along the Kansas-Oklahoma border in south-central Kansas, where the numbers of dams were highest, decreased flow variability occurred in the rivers.

Other than the obviously negative impacts on fishes of dry stream channels, the most serious consequence for the native species of fish associated with both types of impacted streams—those with decreased streamflows and those with stabilized streamflows—probably was the reduction in peak discharges that formerly occurred during the late spring or summer. Annual peak discharge for the period of record (>38 years) was assessed at 54 U.S. Geological Survey gaging stations in Kansas by Rasmussen and Perry (2001). At 34 sites within my study area of western Kansas, they noted a significant decreasing trend in discharge at 15 sites, no trend at 18 sites, and a significant increasing trend at only two sites near Wichita. In contrast, at 20 sites in eastern Kansas, only one site had a significant decreasing trend, 14 sites had no trend, and five sites had a significant increasing trend (Rasmussen and Perry, 2001). Although annual precipitation is lower in western Kansas, the reduced flows in this region apparently were not the result of below-normal annual precipitation (Jordan, 1982; Ratzlaff, 1994; Rasmussen and Perry, 2001), but rather the lowering of the water table that once supported baseflow in streams (Sophocleous, 1981, 2003; Rasmussen and Perry, 2001) and the greater retention of runoff by dams, terraces, and other water-retention features placed on agricultural land (Jordan, 1982). Similar conclusions were reached in a study of declines in runoff in the Republican River basin of Colorado, Kansas, and Nebraska between two 20-year periods: 1949–1968 and 1977–1996 (Szilagyi, 2001). The result of these impacts has been a widespread decline in discharge in the western portion of the study area and a generally eastward retreat of headwater segments of the rivers (Cross and Moss, 1987; Eberle et al., 2002), all of which generally flow from west to east across the study area.

The absence of these peak flows in plains rivers during the late spring or summer would be detrimental to several species, including the Arkansas River shiner and peppered chub, because their reproductive behavior was associated with these conditions. A sufficiently high discharge (Moore, 1944; Bottrell et al., 1964; Lehtinen and Layzer, 1988; Taylor and Miller, 1990) maintained over a sufficient stream length (Platania and Altenbach, 1998; Bonner and Wilde, 2000) is essential for the successful reproduction of these riverine species, because their eggs must float within the water, held there by the current, to develop properly.

These high discharges also scoured rooted vegetation from the channel and maintained its braided morphology, resulting in high turbidities in the main channel. Several native minnows, such as peppered chub and flathead chub, that are characteristic of turbid plains rivers feed effectively at high turbidities in flowing water, unlike the species that have replaced them (Wilde et al., 2001; Bonner and Wilde, 2002). The braided nature of the streamflow also provided sunlit side channels and backwater areas of little or no flow and warm temperatures, where communities of algae and invertebrates could grow and support the rapid growth of larval fish (Platania and Altenbach, 1998), as well as the adults of some species, such as the plains minnow (Cross, 1967) and Arkansas River shiner (Wilde et al., 2001). The reduction in peak flows has resulted in narrower active channels in rivers throughout the western plains and the encroachment of terrestrial vegetation onto the extensive, dry channel beds (Nadler and Schumm, 1981; Tomelleri, 1984; Friedman et al., 1998; VanLooy and Martin, 2005). Thus, the impact of reduced peak flows on the native fishes and their habitat is complex, but decidedly negative.

Although the operation of federal reservoirs has altered attributes of stream ecosystems, including the reduction of peak discharges during late spring or early summer in rivers (Cross and Moss, 1987), data compiled for my study suggested that the cumulative effect of large numbers of smaller impoundments also contributed to decreased peak discharges in western Kansas. The same reduction in peak discharges observed in this study on the rivers with federal reservoirs also occurred in the Medicine Lodge River in south-central Kansas, which is upstream from all major impoundments within the Arkansas River basin. Although federal reservoirs were absent from the Medicine Lodge River basin, this river system drains Barber County, which was the eighth most heavily impounded county of 66 comparably sized counties in the study area (listed in Table 6). Dewatering due to groundwater withdrawals or surface-water diversions within a basin also could contribute to the reduced peak discharges in early summer, but this apparently was not the case with the Medicine Lodge River. Less than 1% of the land in Barber County was irrigated in 2002 (Kansas Water Office, 2004), and only about 18% of the area in the county was in harvested row crops in 2000 (compared with 46% throughout southwestern Kansas). The absence of federal reservoirs, the small areas of total cropland and irrigated cropland, and the absence of any decreasing trend in annual regional precipitation between 1958 and 1997 (Rasmussen and Perry, 2001) suggested that the relatively large number of smaller impoundments contributed substantially to the decreased peak discharges in the Medicine Lodge River.

In addition to the alterations in discharge in Great Plains rivers caused by impoundments, fragmentation of streams by dams also has been cited as the cause of extirpations of some species of native minnows, such as peppered chub and plains minnow, because dams block spawning runs or recolonization of upstream segments following drought (Winston et al., 1991; Luttrell et al., 1999; Wilde and Ostrand, 1999). However, concurrent changes in other habitat features, such as current velocities and substrate attributes, could preclude successful reintroduction upstream from impoundments (Luttrell et al., 2002). In addition to dams, dry stream sections also have fragmented the main stems of some rivers in the study area, such as sections of the Arkansas River in southwestern Kansas (Cross and Moss, 1987; Eberle et al., 1993, 1994). The fragmentation of stream segments, dewatering, and reduction in peak discharges during the late spring or early summer probably all contributed to the extirpation of native species of fish, especially as occurred in the rivers during the late 1900s, through their consequent changes on the stream habitats and ecosystem processes.

In addition to their likely contribution to the extirpation of native species, impoundments have enhanced the potential for introductions and range expansions of nonnative species of fish through increased lentic habitat, stabilized streamflows, and reduced turbidities downstream from the dams (Cross and Moss, 1987). At the scale of stream segments, impoundments on Kansas and Oklahoma streams apparently have only a local impact on the presence of nonnative species (Gido et al., 2004). In rivers upstream from federal reservoirs in Kansas, the presence of larger, lentic species (e.g., bigmouth buffalo) decreased with distance from the reservoir and was limited to suitable habitat in mid-sized streams (fourth and fifth order). However, smaller lentic species (e.g., largemouth bass and bluegill) occurred throughout small streams (first to third order), probably dispersing from the thousands of small impoundments throughout the basins where the federal reservoirs were located, rather than from the reservoirs themselves (Falke and Gido, 2006). At the scale of drainage basins across temperate North America, high numbers of reservoirs, in combination with large drainage areas and low diversities of native species, were associated with high numbers of nonnative species (Gido and Brown, 1999). These conditions occurred within the two drainage basins in western Kansas, where approximately 40% of the extant fish fauna in streams was composed of nonnative species.

Conclusions

Although changes in the fish faunas and concurrent anthropogenic changes in landuse can be documented in the Kansas and Arkansas river basins in western Kansas, the causal relationship of the landscape changes on the faunal changes is not directly testable and can only be based on intuitive correlation. However, significant extirpations of fishes in streams in western Kansas occurred during two general periods, prior to 1920 and after 1960, and the preponderance of evidence supports a conclusion that multiple, anthropogenic landscape changes during these two periods likely contributed to the extirpations, and to the additions of nonnative species.

The addition of nonnative species has substantially impacted the species composition of streams in western Kansas, but it has contributed less to the homogenization of the faunas in the Kansas and Arkansas river basins through 2003 than the extirpations of native species. Despite the smaller number of native species extirpated relative to the number of nonnative species added to the basins, my analysis suggested that these extirpations alone, many of which involved species that occurred in only one basin or the other, were enough to drive the process of homogenization in fish faunas of streams at the scale of basins in western Kansas. However, the roles of extirpations of native species and additions of nonnative species in taxonomic homogenization under various conditions are complex (Olden and Poff, 2003, 2004). Situations will vary in different spatial and temporal contexts, and attributes of streams in other parts of the Great Plains respond differently to landscape changes (Friedman et al., 1998), all of which invite additional studies on the Great Plains and elsewhere.

In addition to the taxonomic homogenization of fish faunas described here, the associated habitat changes have altered other ecosystem components and processes. For example, the construction of impoundments has converted stream segments from benthic photosynthetic communities to planktonic communities (Cross and Moss, 1987), and dewatering has reduced the capillary fringe habitat of wet sand adjacent to the once broad rivers that had braided flows (Ferrington, 1992). Additionally, introductions of nonnative species of fish can impact several attributes of ecosystem functions in plains streams other than the species composition of fishes. For example, Matthews et al. (1987) documented that the presence of piscivorous largemouth bass in a small Oklahoma stream indirectly influenced the amount of algal growth through their impact on the behavior of central stonerollers, which grazed substantially more algae in the absence of largemouth bass. Similarly, reduced populations of native minnows and orangethroat darters and the increased growth of aquatic vegetation have been noted following the introduction of largemouth bass in Willow Creek in northwestern Kansas (Stark et al., 2002; W. J. Stark, Fort Hays State University, personal communication). Unfortunately, little documentation exists for these other impacts on processes in stream ecosystems of the Great Plains, and more study is needed.

Genetic homogenization (i.e., reduction in genetic variability within a species) resulting from extirpations is also a concern. The extent of genetic homogenization that has resulted (or is likely to result) from the extirpation of populations of species on the western Great Plains that also occur across larger portions of the Mississippi River basin is unknown. Peripheral populations often have been considered genetically depauperate and unimportant in the conservation of species, but this assumption is not valid in the absence of supporting data for the species under consideration (Channell, 2005). Preliminary information on the last surviving population of Topeka shiners from western Kansas suggested that they possessed unique alleles compared with populations in eastern Kansas and elsewhere (Michels, 2000). It is unknown whether unique alleles absent in populations east of the Great Plains are present in western populations of other species, such as the hornyhead chub, common shiner, and johnny darter, which have been extirpated from the upper Kansas River basin but still occur in the upper Platte River basin. This would be an excellent subject for additional study. Protection of genetically unique peripheral populations, in addition to general protection of native species and their habitats, should be a priority of conservation.

Despite the analytical limitations of most long-term historical data, thorough documentation of these data associated with changes in landscape features and attributes of stream communities can illustrate patterns of ecological relationships supported by studies encompassing shorter periods of time. This combination of approaches can provide a reasonable foundation on which to base additional studies and to develop and assess conservation programs for streams of the Great Plains and elsewhere.

Literature Cited

Bergman, S. M., M. E. Eberle, and B. K. Obermeyer. 2000. Freshwater mussels (Bivalvia: Unionoidea) in streams of northwestern Kansas. Prairie Naturalist 32:1-15.

Breukelman, J. 1940. The fishes of northwestern Kansas. Transactions of the Kansas Academy of Science 43:367-375.

Bonner, T. H., and G. R. Wilde. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology 15:189-198.

Bonner, T. H., and G. R. Wilde. 2002. Effects of turbidity on prey consumption by prairie stream fishes. Transactions of the American Fisheries Society 131:1203-1208.

Bottrell, C. E., R. H. Ingersol, and R. W. Jones. 1964. Notes on the embryology, early development, and behavior of *Hybopsis aestivalis tetranemus* (Gilbert). Transactions of the American Microscopical Society 83:391-399.

Carlson, D. M., and R. A. Daniels. 2004. Status of fishes in New York: increases, declines and homogenization of watersheds. American Midland Naturalist 152:104-139.

Census Bureau, U.S. Department of Commerce. 1952. U.S. Census of Agriculture, 1950. Volume III: irrigation of agricultural lands. Part 7: Kansas [data for census years 1890-1950]. U.S. Government Printing Office, Washington, D.C. Accessed at http://www2.census.gov/prod2/decennial/documents/38921062v3_TOC.pdf.

Census Bureau, U.S. Department of Commerce. 1956. U.S. Census of Agriculture, 1954. Volume II: general report, statistics by subjects, chapter 1 – farms and land in farms [data for census years 1945-1954]. U.S. Government Printing Office, Washington, D.C.

Census Bureau, U.S. Department of Commerce. 1968. U.S. Census of Agriculture, 1964. Volume II: statistics by subjects, chapter 9 – irrigation, land improvement practices, and use of agricultural chemicals [data for census years 1959-1964]. U.S. Government Printing Office, Washington, D.C.

Census Bureau, U.S. Department of Commerce. 1978. U.S. Census of Agriculture, 1974. Volume II: statistics by subject, part 9 – irrigation and drainage on farms [data for census years 1969-1974]. U.S. Government Printing Office, Washington, D.C.

Changnon, S. A., Jr. 1988. Climatography of thunder events in the conterminous United States, part II: spatial aspects. Journal of Climate 1:399-405.

Channell, R. 2005. The conservation value of peripheral populations: the supporting science. Proceedings of the Species at Risk 2004: Pathways to Recovery Conference, 2-6 March 2004, Victoria, British Columbia, Canada. Accessed at http://www.speciesatrisk2004.ca/pdf/channell_edited_final_feb_8.pdf.

Cragin, F. W. 1885. Preliminary list of Kansas fishes. Bulletin of the Washburn College Laboratory of Natural History 1:105-111.

Cross, F. B. 1967. Handbook of fishes of Kansas. University of Kansas Museum of Natural History, Miscellaneous Publication Number 45:1-357.

Cross, F. B. 1970. Fishes as indicators of Pleistocene and Recent environments in the central plains. Pages 241-257 in: Pleistocene and Recent environments of the central Great Plains. W. Dort, Jr. and J. K. Jones, Jr., editors. University Press of Kansas, Lawrence.

Cross, F. B., and J. T. Collins. 1995. Fishes in Kansas, second edition. University of Kansas Natural History Museum, Public Education Series Number 14:1-315.

Cross, F. B., R. L. Mayden, and J. D. Stewart. 1986. Fishes in the western Mississippi Basin (Missouri, Arkansas, and Red rivers). Pages 363-412 in: Zoogeography of North American freshwater fishes. C. H. Hocutt and E. O. Wiley, editors. John Wiley & Sons, New York.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in: Community and evolutionary ecology of North American stream fishes. W. J. Matthews and D. C. Heins, editors. University of Oklahoma Press, Norman.

Cunfer, G. 2005. On the Great Plains: agriculture and environment. Texas A&M University Press, College Station.

Duncan, J. R., and J. L. Lockwood. 2001. Spatial homogenization of the aquatic fauna of Tennessee: extinction and invasion following land use change and habitat alteration. Pages 245-257 in: Biotic homogenization. J. L. Lockwood and M. L. McKinney, editors. Kluwer Academic/ Plenum Publishers, New York.

Eberle, M. E., and R. B. Channell. 2006. Homogenization of fish faunas in two categories of streams in a single basin in Kansas and the choice of similarity coefficients. Transactions of the Kansas Academy of Science 109:41-46.

Eberle, M. E., G. W. Ernsting, J. R. Tomelleri, and S. L. Wells. 1993. Assessment of restored streamflow on fish communities in the Arkansas River of southwestern Kansas. Transactions of the Kansas Academy of Science 96:114-130.

Eberle, M. E., G. W. Ernsting, J. R. Tomelleri, and S. L. Wells. 1994. Corrections to "Assessment of restored streamflow on fish communities in the Arkansas River of southwestern Kansas". Transactions of the Kansas Academy of Science 97:68.

Eberle, M. E., E. G. Hargett, T. L. Wenke, and N. E. Mandrak. 2002. Changes in fish assemblages, Solomon River basin, Kansas: habitat alterations, extirpations, and introductions. Transactions of the Kansas Academy of Science 105:178-192.

Eberle, M. E., and W. J. Stark. 2000. Status of the Arkansas darter in south-central Kansas and adjacent Oklahoma. Prairie Naturalist 32:103-113.

Falke, J. A., and K. B. Gido. 2006. Spatial effects of reservoirs on fish assemblages in Great Plains streams in Kansas, USA. River Research and Applications 22:55-68.

Ferrington, L. C., and D. S. Goldhammer. 1992. The biological significance of capillary fringe habitat in large rivers of the central High Plains of the United States. Pages 203-225 in: Aquatic ecosystems in semi-arid regions: implications for resource management. R. D. Robarts and M. L. Bothwell, editors. NHRI Symposium Series 7, Environment Canada, Saskatoon.

Follansbee, R., and J. B. Spiegel. 1937. Flood on Republican and Kansas rivers, May and June 1935. U.S. Geological Survey, Water-Supply Paper 796-B:21-52.

Friedman, J. M., W.R. Osterkamp, M.L. Scott, and G. T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: regional patterns in the Great Plains. Wetlands 18:619-633.

Gido, K. B., and J. H. Brown. 1999. Invasion of North American drainages by alien fish species. Freshwater Biology 42:387-399.

Gido, K. B., J. F. Schaefer, and J. Pigg. 2004. Patterns of fish invasions in the Great Plains of North America. Biological Conservation 118:121-131.

Gilbert, C. H. 1889. Fourth series of notes on the fishes of Kansas. Bulletin of the Washburn College Laboratory of Natural History 2:38-43.

Harlin, J. M. 1980. The effect of precipitation variability on drainage basin morphometry. American Journal of Science 280:812-825.

Haslouer, S. G., M. E. Eberle, D. R. Edds, K. B. Gido, C. S. Mammoliti, J. R. Triplett, J. T. Collins, D. A. Distler, D. G. Huggins, and W. J. Stark. 2005. Current status of native fish species in Kansas. Transactions of the Kansas Academy of Science 108:32-46.

Hawkes, C. L., D. L. Miller, and W. G. Layher. 1986. Fish ecoregions of Kansas: stream fish assemblage patterns and associated environmental correlates. Environmental Biology of Fishes 17:267-279.

Hay, O. P. 1887. A contribution to the knowledge of the fishes of Kansas. Proceedings of the U.S. National Museum 10:242-253.

Hay, R. 1895. Water resources of a portion of the Great Plains. Sixteenth Annual Report of the United States Geological Survey to the Secretary of the Interior, 1894-1895: Part II—Papers of an Economic Character. Pages 535-588.

Holland, D. D. 1971. Sediment yields from small drainage areas in Kansas. State of Kansas Water Resources Board, Bulletin Number 16:1-26.

Jaccard, P. 1908. Nouvelle recherches sur la distribution florale. Bulletin de la Société Vaudoise des Sciences Naturelles 44:223-270.

Jordan, P. R. 1982. Rainfall-runoff relations and expected streamflow in western Kansas. Kansas Water Office, Topeka, Bulletin 25:1-42.

Kansas Water Office. 2004. 2002 Kansas water use tables. Kansas Water Office, Topeka. Accessed at http://www.kwo.org/Reports%20&%20Publications/irrigation_water_use.htm.

Lehtinen, S. F., and J. B. Layzer. 1988. Reproductive cycle of the plains minnow, *Hybognathus placitus* (Cyprinidae), in the Cimarron River, Oklahoma. Southwestern Naturalist 33:27-33.

Lodge, D. M., C. A. Taylor, D. M. Holdrich, and J. Skurdal. 2000. Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fisheries 25(8):7-20.

Long, D. B. 1878. First biennial report of the Commissioner of Fisheries of the state of Kansas for the years 1877-8. Kansas State Board of Agriculture, Topeka.

Luttrell, G. R., A. A. Echelle, and W. L. Fisher. 2002. Habitat correlates of the distribution of *Macrhybopsis hyostoma* (Teleostei: Cyprinidae) in western reaches of the Arkansas River basin. Transactions of the Kansas Academy of Science 105:153-161.

Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the *Macrhybopsis aestivalis* complex (Teleostei: Cyprinidae) in the Arkansas River basin and related effects of reservoirs as barriers to dispersal. Copeia 1999:981-989.

Luttrell, G. R., A. A. Echelle, and A. V. Zale. 1993. Status of the speckled chub in the Arkansas River basin. Federal Aid Project E-8, Objective Number 3, Job Number 3, Oklahoma Department of Wildlife Conservation, Oklahoma City.

Marchetti, M. P., T. Light, J. Feliciano, T. Armstrong, Z. Hogan, J. Viers, and P. B. Moyle. 2001. Homogenization of California's fish fauna through abiotic change. Pages 259-278 in: Biotic homogenization. J. L. Lockwood and M. L. McKinney, editors. Kluwer Academic/Plenum Publishers, New York.

Matthews, W. J., and E. Marsh-Matthews. 2003. Effects of drought on fish across axes of space, time and ecological complexity. Freshwater Biology 48:1232-1253.

Matthews, W. J., A. J. Stewart, and M. E. Power. 1987. Grazing fishes as components of North American stream ecosystems: effects of *Campostoma anomalum*. Pages 128-135 in: Community and evolutionary ecology of North American stream fishes. W. J. Matthews and D. C. Heins, editors. University of Oklahoma Press, Norman.

McKinney, M. L. 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States. Biological Conservation 100:243-252.

McKinney, M. L., and J. L. Lockwood. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology and Evolution 14:450-453.

Meko, D. M. 1982. Drought history in the western Great Plains from tree rings. Pages 321-326 in: Proceedings of the International Symposium on Hydrometeorology, American Water Resources Association, Bethesda, Maryland. Technical Publication Series TPS-82-1.

Metcalf, A. L. 1966. Fishes of the Kansas River system in relation to zoogeography of the Great Plains. University of Kansas Publications, Museum of Natural History 17(3):23-189.

Michels, A. M. 2000. Population genetic structure and phylogeography of the endangered Topeka shiner (*Notropis topeka*) and the abundant sand shiner (*Notropis ludibundus*) using mitochondrial DNA sequence. Unpublished Ph.D. dissertation, University of Kansas, Lawrence.

Miller, J. A., and C. L. Appel. 1997. Ground water atlas of the United States: Kansas, Missouri, and Nebraska. HA 730-D. U.S. Geological Survey, Reston, Virginia.

Miner, C. 1986. West of Wichita: settling the High Plains of Kansas, 1865-1890. University Press of Kansas, Lawrence.

Miner, C. 2006. Next year country: dust to dust in western Kansas, 1890-1940. University Press of Kansas, Lawrence.

Moore, G. A. 1944. Notes on the early life of *Notropis girardi*. Copeia 1944:209-214.

Nadler, C. T., and S. A. Schumm. 1981. Metamorphosis of South Platte and Arkansas rivers, eastern Colorado. Physical Geography 2:95-115.

National Agricultural Statistics Service, U.S. Department of Agriculture. 1999. 1997 Census of Agriculture: 1998 Farm and Ranch Irrigation Survey [data for census years 1974-1997]. Accessed at http://www.nass.usda.gov/Census_of_Agriculture/1997/index.asp.

National Agricultural Statistics Service, U.S. Department of Agriculture. 2004a. 2002 Census of Agriculture: 2003 Farm and Ranch Irrigation Survey [data for census years 1982-2002]. Accessed at http://www.nass.usda.gov/Census_of_Agriculture/index.asp.

National Agricultural Statistics Service, U.S. Department of Agriculture. 2004b. State and county data. Accessed at http://www.nass.usda.gov/.

National Climate Data Center, U.S. Department of Commerce. 2003. North American drought: a paleo perspective. National Climate Data Center, Asheville, North Carolina. Accessed at http://www.ncdc.noaa.gov/paleo/drought/drght_history.html.

National Climate Data Center, U.S. Department of Commerce. 2004a. Locate weather station observation record. National Climate Data Center, Asheville, North Carolina. Accessed at http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.html.

National Climate Data Center, U.S. Department of Commerce. 2004b. Drought atlas PDSI reconstructions: time series plots. National Climate Data Center, Asheville, North Carolina. Accessed at http://www.ncdc.noaa.gov/paleo/newpdsi.html.

Nelson, J. S., H. Espinosa-Pérez, L. T. Findley, C. R. Gilbert, R. N. Lea, N. E. Mandrak, and J. D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico, sixth edition. American Fisheries Society, Bethesda, Maryland.

Newell, F. H. 1895. Report of progress of the Division of Hydrography for the calendar years 1893 and 1894. Well records in Nebraska, Colorado, and Kansas. Bulletin of the United States Geological Survey Number 131:92-126.

Olden, J. D., and N. L. Poff. 2003. Toward a mechanistic understanding and prediction of biotic homogenization. American Naturalist 162:442-460.

Olden, J. D., and N. L. Poff. 2004. Ecological processes driving biotic homogenization: testing a mechanistic model using fish faunas. Ecology 85:1867-1875.

Olden, J. D., N. L. Poff, M. R. Douglas, M. E. Douglas, and K. D. Fausch. 2004. Ecological and evolutionary consequences of biotic homogenization. Trends in Ecology and Evolution 191:18-24.

Olden, J. D., and T. P. Rooney. 2006. On defining and quantifying biotic homogenization. Global Ecology and Biogeography 15:113-120.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.

Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande basin cyprinids. Copeia 1998:559-569.

Policy Research Institute. 2003. Kansas Statistical Abstract 2002. University of Kansas, Lawrence. Accessed at http://www.ku.edu/pri/ksdata/ksah/KSA37.pdf.

Radomski, P. J., and T. J. Goeman. 1995. The homogenizing of Minnesota lake fish assemblages. Fisheries 20(7):20-23.

Rahel, F. J. 2000. Homogenization of fish faunas across the United States. Science 288:854-856.

Rahel, F. J. 2002. Homogenization of freshwater faunas. Annual Review of Ecology and Systematics 33:291-315.

Rasmussen, T. J., and C. A. Perry. 2001. Trends in peak flows of selected streams in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 01-4203, Lawrence, Kansas.

Ratzlaff, J. R. 1994. Timing and magnitude of changes in runoff for Kansas watersheds, 1940-1990. Transactions of the Kansas Academy of Science 97:26-35.

Rhymer, J. M., and D. Simberloff. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics 27:83-109.

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13:1220-1222

Ricciardi, A., F. G. Whoriskey, and J. B. Rasmussen. 1995. Predicting the intensity and impact of *Dreissena* infestation on native unionid bivalves from *Dreissena* field densities. Canadian Journal of Fisheries and Aquatic Sciences 52:1449-1461.

Rohlf, F. J. 1994. NTSYS-pc: numerical taxonomy and multivariate analysis system, version 1.80. Exeter Software, Setauket, New York.

Rydjord, J. 1972. Kansas place-names. University of Oklahoma Press, Norman.

Schrank, S. J., C. S. Guy, M. R. Whiles, and B. L. Brock. 2001. Influence of instream and landscape-level factors on the distribution of Topeka shiners *Notropis topeka* in Kansas streams. Copeia 2001:413-421.

Scott, M. C., and G. S. Helfman. 2001. Native invasions, homogenization, and the mismeasure of integrity of fish assemblages. Fisheries 26(11):6-15.

Sherow, J. E. 1990. Watering the valley: development along the High Plains Arkansas River, 1870-1950. University Press of Kansas, Lawrence.

Smith, G. R. 1963. A Late Illinoian fish fauna from southwestern Kansas and its climatic significance. Copeia 1963:278-285.

Smith, G. R., and D. R. Fisher. 1970. Factor analysis of distribution patterns of Kansas fishes. Pages 259-277 in: Pleistocene and Recent environments of the central Great Plains. W. Dort, Jr. and J. K. Jones, Jr., editors. University Press of Kansas, Lawrence.

Snodgrass, J. W., and G. K. Meffe. 1998. Influence of beavers on stream fish assemblages: effects of pond age and watershed position. Ecology 79:928-942.

Sokal, R. R., and P. H. A. Sneath. 1963. Principles of numerical taxonomy. W. H. Freeman and Company, San Francisco, California.

Sophocleous, M. 1981. The declining ground-water resources of alluvial valleys: a case study. Ground Water 19:214-226.

Sophocleous, M. 2003. Chapter 4, Environmental implications of intensive groundwater use with special regard to streams and wetlands. Pages 93-112 in: Intensive use of groundwater: challenges and opportunities. R. Llamas and E. Custodio, editors. A. A. Balkema, Lisse, The Netherlands.

Stark, W. J., J. S. Lugenbill, and M. E. Eberle. 2002. Natural history of a relict population of Topeka shiner (*Notropis topeka*) in northwestern Kansas. Transactions of the Kansas Academy of Science 105:143-152.

Stockton, C. W., and D. M. Meko. 1983. Drought recurrence in the Great Plains as reconstructed from long-term tree-ring records. Journal of Climate and Applied Meteorology 22:17-29.

Szilagyi, J. 2001. Identifying cause of declining flows in the Republican River. Journal of Water Resources Planning and Management 127:244-253.

Taylor, C. M., and R. J. Miller. 1990. Reproductive ecology and population structure of the plains minnow, *Hybognathus placitus* (Pisces: Cyprinidae), in central Oklahoma. American Midland Naturalist 123:32-39.

Tomanek, G. W., and G. K. Hulett. 1970. Effects of historical droughts on grassland vegetation in the central Great Plains. Pages 203-210 in: Pleistocene and Recent environments of the central Great Plains. W. Dort, Jr. and J. K. Jones, Jr., editors. University Press of Kansas, Lawrence.

Tomelleri, J. R. 1984. Dynamics of the woody vegetation along the Arkansas River in western Kansas, 1870-1983. Unpublished M.S. thesis, Fort Hays State University, Hays, Kansas.

U.S. Army Corps of Engineers. 2004. National Inventory of Dams. Accessed at http://crunch.tec.army.mil/nid/webpages/nid.cfm.

U.S. Geological Survey. 1952. Kansas-Missouri floods of July 1951. U.S. Geological Survey Water-Supply Paper 1139.

U.S. Geological Survey. 1970. The national atlas of the United States of America. U.S. Geological Survey, Washington, D.C.

U.S. Geological Survey. 2005. Water Watch – current water resource conditions. Accessed at http://water.usgs.gov/waterwatch/.

VanLooy, J. A., and C. W. Martin. 2005. Channel and vegetation change on the Cimarron River, southwestern Kansas, 1953-2001. Annals of the Association of American Geographers 95:727-739.

Weeks, J. B., E. D. Gutentag, F. J. Heimes, and R. R. Luckey. 1988. Summary of the High Plains regional aquifer-system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Professional Paper 1400-A.

Wilde, G. R., and T. H. Bonner. 2001. Diets of the Arkansas River shiner and peppered chub in the Canadian River, New Mexico and Texas. Journal of Freshwater Ecology 16:403-410.

Wilde, G. R., and K. G. Ostrand. 1999. Changes in the fish assemblage of an intermittent prairie steam upstream from a Texas impoundment. Texas Journal of Science 51:203-210.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120:98-105.

Witte, F., T. Goldschmidt, P. C. Goudswaard, W. Ligtvoet, M. J. P. van Oijen, and J. H. Wanink. 1992. Species extinction and concomitant ecological changes in Lake Victoria. Netherlands Journal of Zoology 42:214-232.

Woodhouse, C. A., and J. T. Overpeck. 1998. 2000 years of drought variability in the central United States. Bulletin of the American Meteorological Society 79:2693-2714.

Appendix A

Flow duration curves for sites on rivers within or adjacent to the study area in western Kansas (Figure 8). Two periods of discharge are graphed for each site: discharge prior to 1950 and discharge after 1969. Discharge data omitted from 1950 to 1969 represent the impact period, when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred. Discharge data from the U.S. Geological Survey (2005).

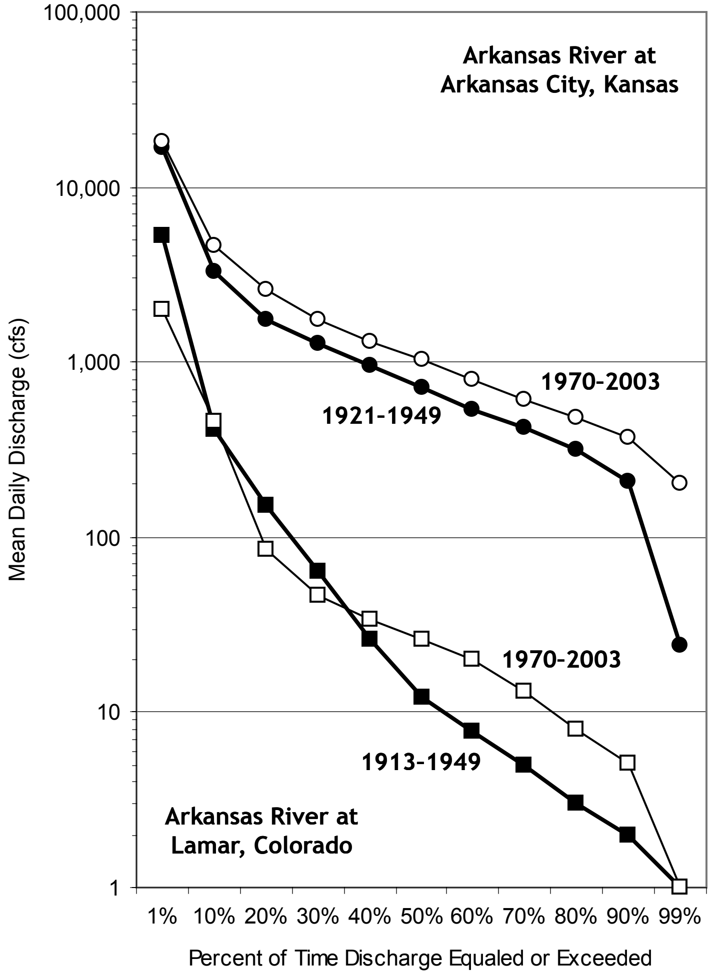

Figure A1. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Arkansas River at Arkansas City, Kansas (location illustrated in Figure 8, circle 14), and flow duration curves for discharge prior to 1950 (thick line with solid squares) and after 1969 (thin line with open squares) in the Arkansas River at Lamar, Colorado (location illustrated in Figure 8, circle 3). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

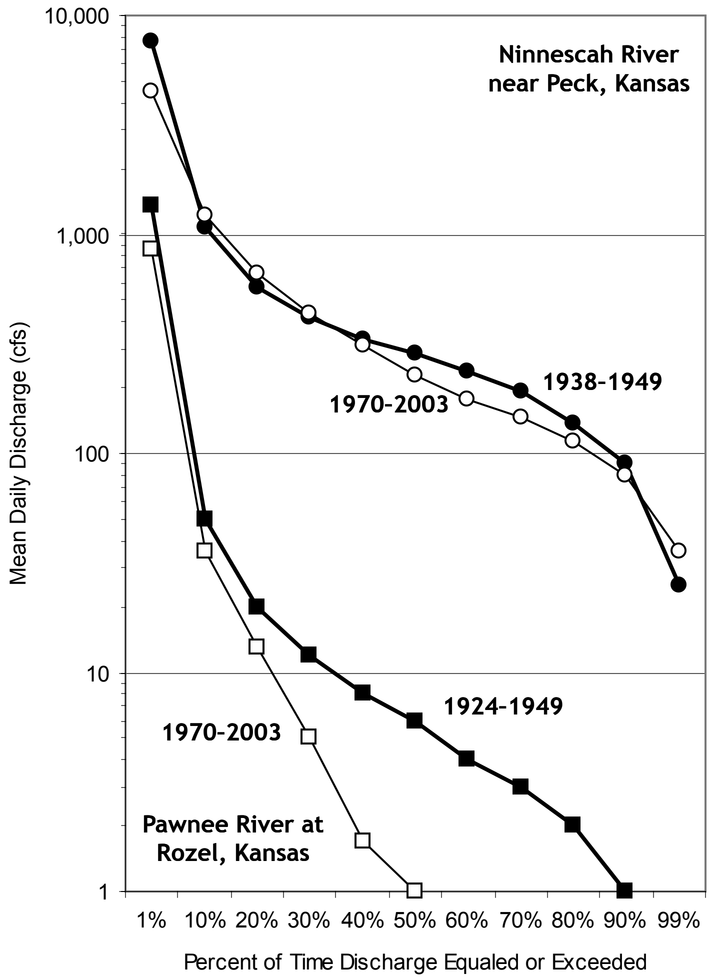

Figure A2. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Ninnescah River near Peck, Kansas (location illustrated in Figure 8, circle 13), and flow duration curves for discharge prior to 1950 (thick line with solid squares) and after 1969 (thin line with open squares) in the Pawnee River at Rozel, Kansas (location illustrated in Figure 8, circle 4). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

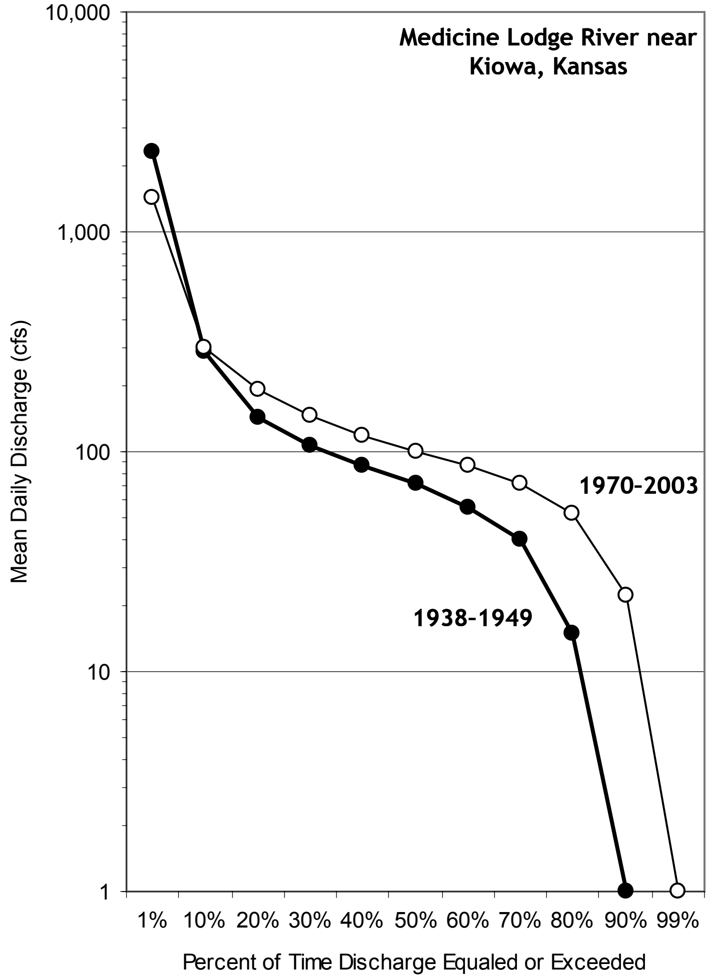

Figure A3. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Medicine Lodge River near Kiowa, Kansas (location illustrated in Figure 8, circle 12). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

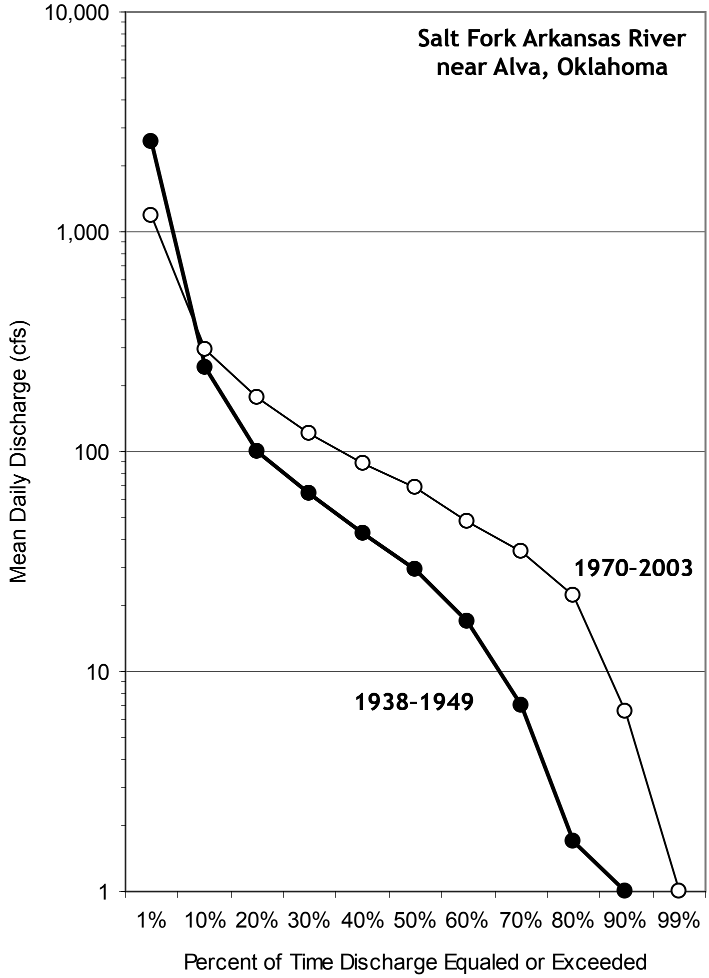

Figure A4. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Salt Fork Arkansas River near Alva, Oklahoma (location illustrated in Figure 8, circle 11). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

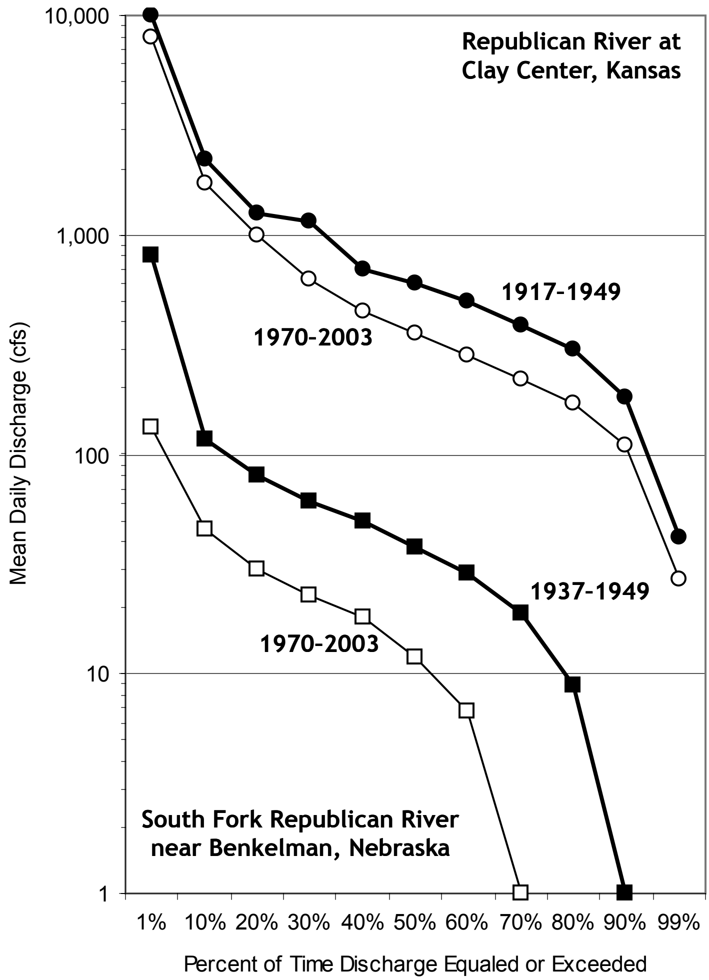

Figure A5. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Republican River at Clay Center in north-central Kansas (Figure 8, circle 10) and flow duration curves for discharge prior to 1950 (thick line with solid squares) and after 1969 (thin line with open squares) in the South Fork Republican River near Benkelman in southwestern Nebraska (location illustrated in Figure 8, circle 1). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

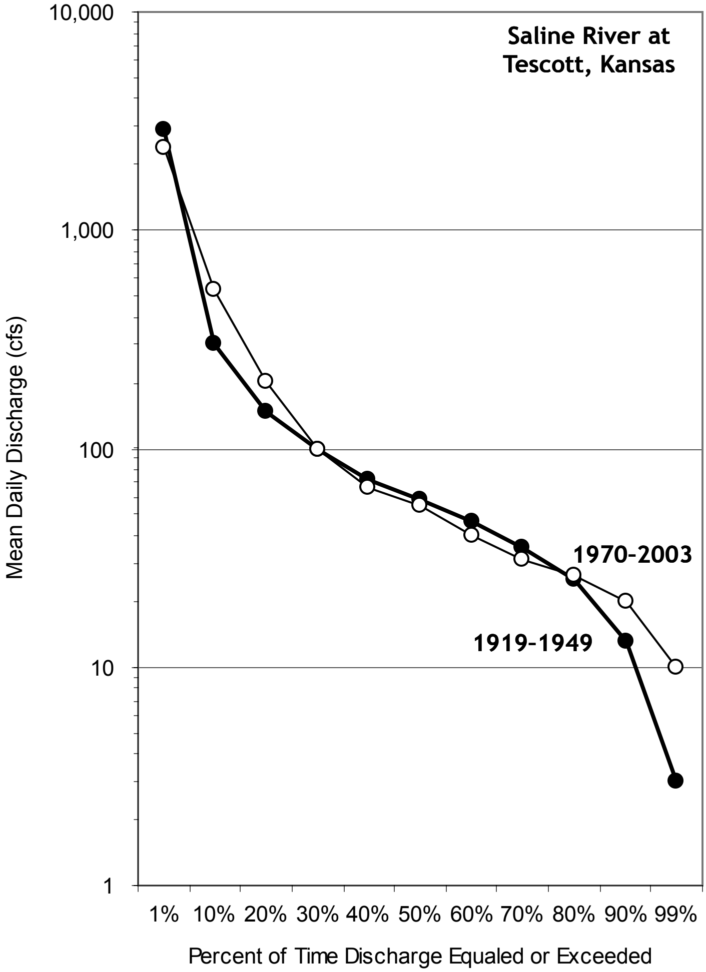

Figure A6. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Saline River at Tescott, Kansas (location illustrated in Figure 8, circle 5). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

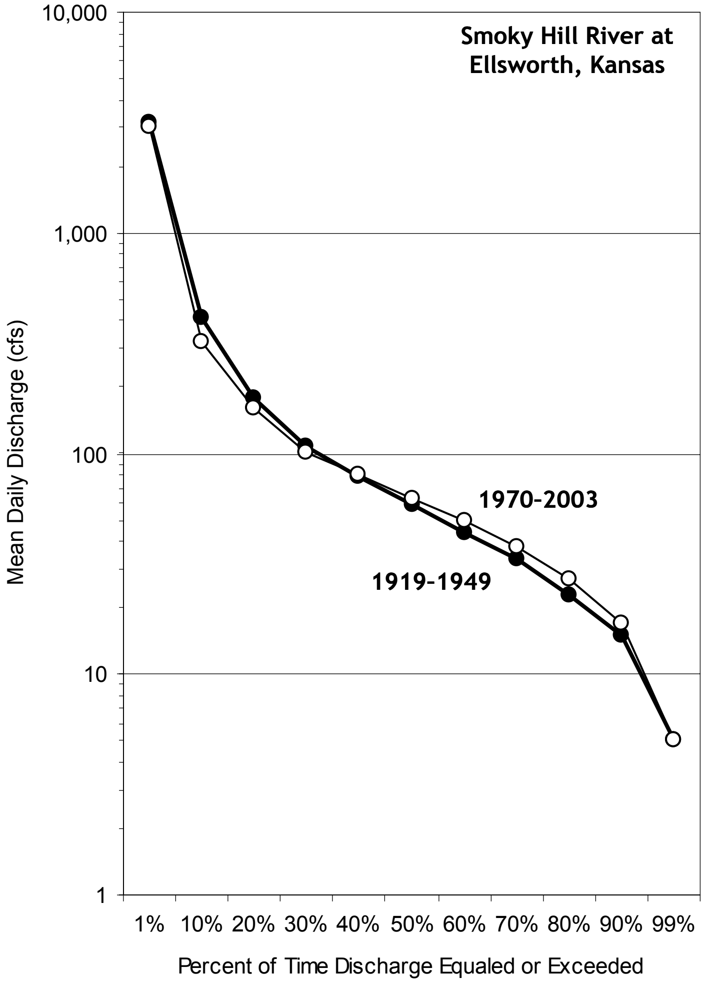

Figure A7. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Smoky Hill River at Ellsworth, Kansas (location illustrated in Figure 8, circle 8). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

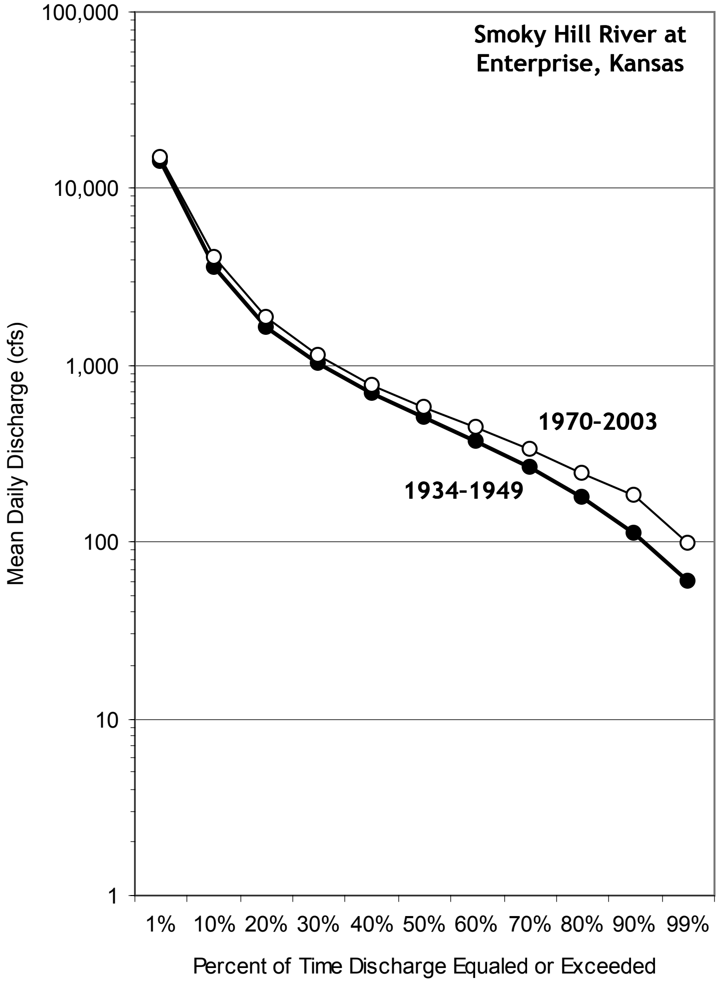

Figure A8. Flow duration curves for discharge prior to 1950 (thick line with solid circles) and after 1969 (thin line with open circles) in the Smoky Hill River at Enterprise, Kansas (location illustrated in Figure 8, circle 9). Discharge data omitted from 1950 to 1969 represent the impact period when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred in western Kansas. Discharge data from the U.S. Geological Survey (2005).

Appendix B

Graphs of mean daily discharge equaled or exceeded 10% of the time each month from April through September for years prior to 1950 and after 1969 at gaging stations on rivers within or adjacent to the study area in western Kansas (Figure 8). Data omitted from 1950 to 1969 represent the impact period, when substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) initially occurred. To facilitate comparisons among sites with similar discharges, scales on the y-axes are set at four maximum values: 350 cubic feet per second (cfs), 2,000 cfs, 4,000 cfs, and 12,000 cfs. Discharge data from U.S. Geological Survey (2005).

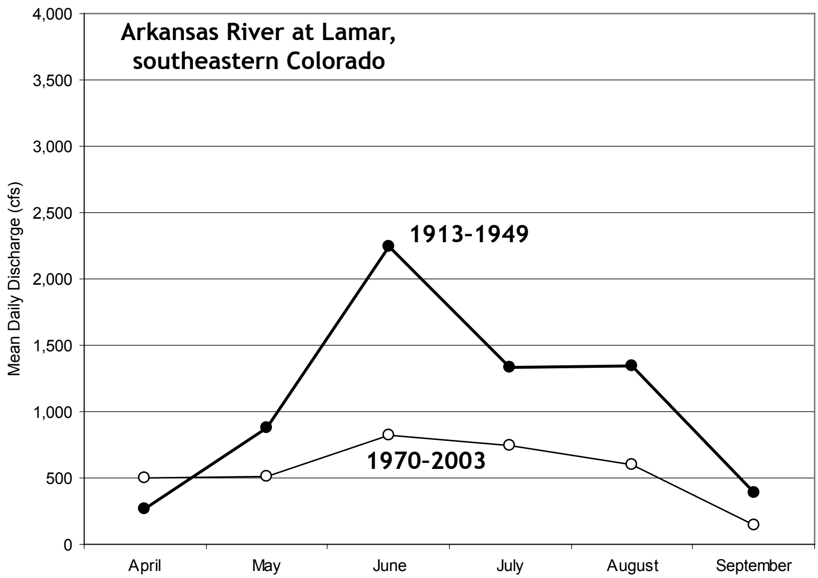

Figure B1. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Arkansas River at Lamar, Colorado, illustrated in Figure 8 (circle 3). Discharge data from U.S. Geological Survey (2005).

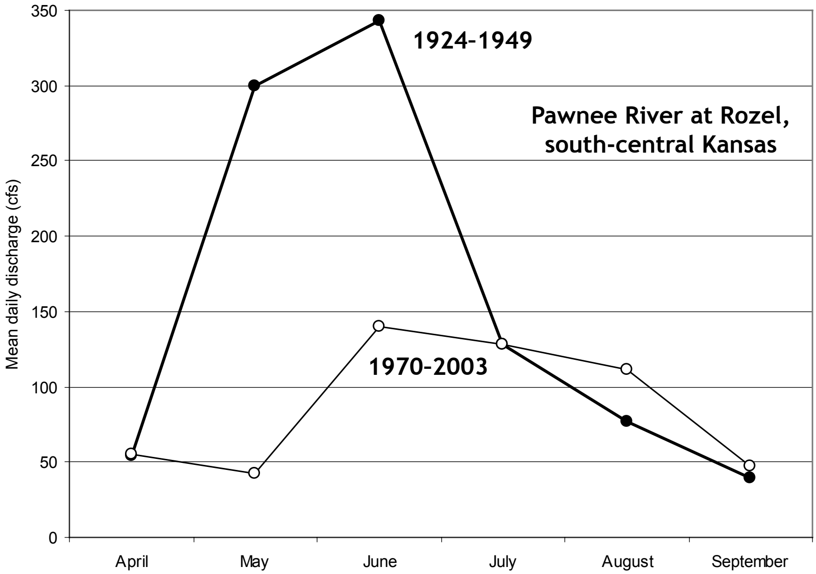

Figure B2. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Pawnee River at Rozel, Kansas, illustrated in Figure 8 (circle 4). Discharge data from U.S. Geological Survey (2005).

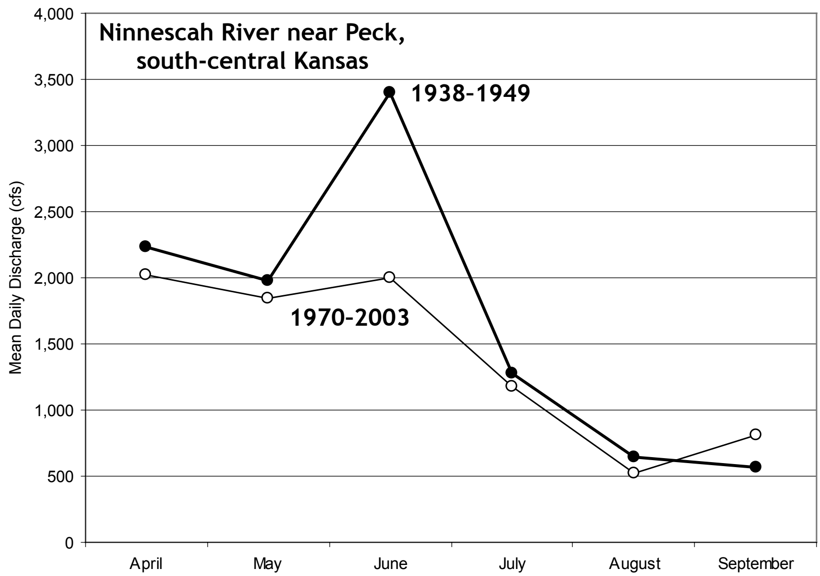

Figure B3. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Ninnescah River near Peck, Kansas, illustrated in Figure 8 (circle 13). Discharge data from U.S. Geological Survey (2005).

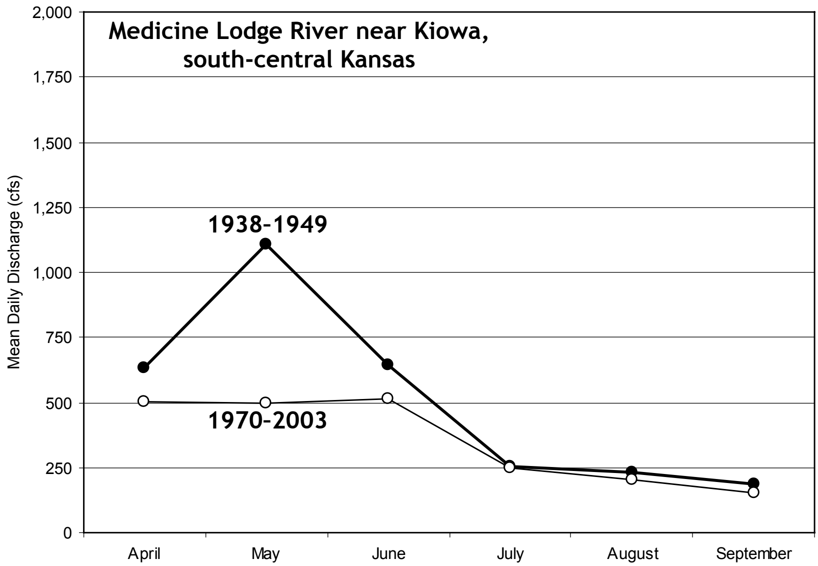

Figure B4. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Medicine Lodge River near Kiowa, Kansas, illustrated in Figure 8 (circle 12). Discharge data from U.S. Geological Survey (2005).

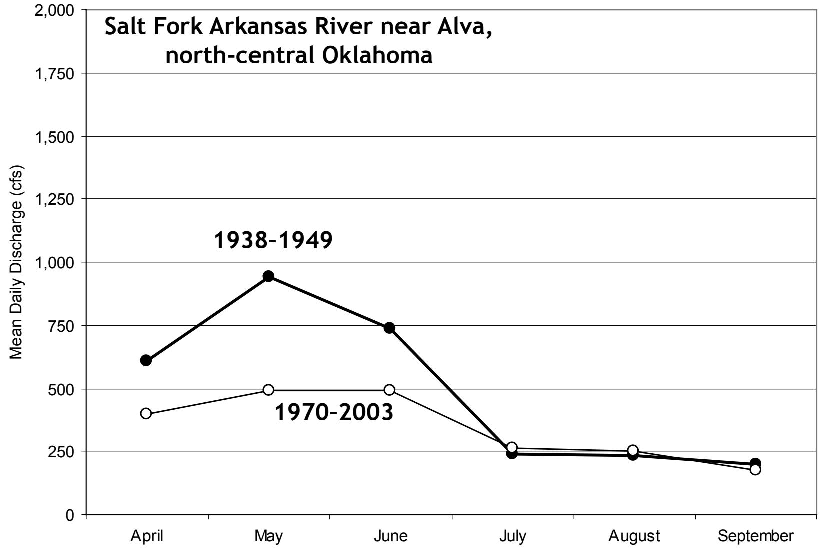

Figure B5. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Salt Fork Arkansas River near Alva, Oklahoma, illustrated in Figure 8 (circle 11). Discharge data from U.S. Geological Survey (2005).

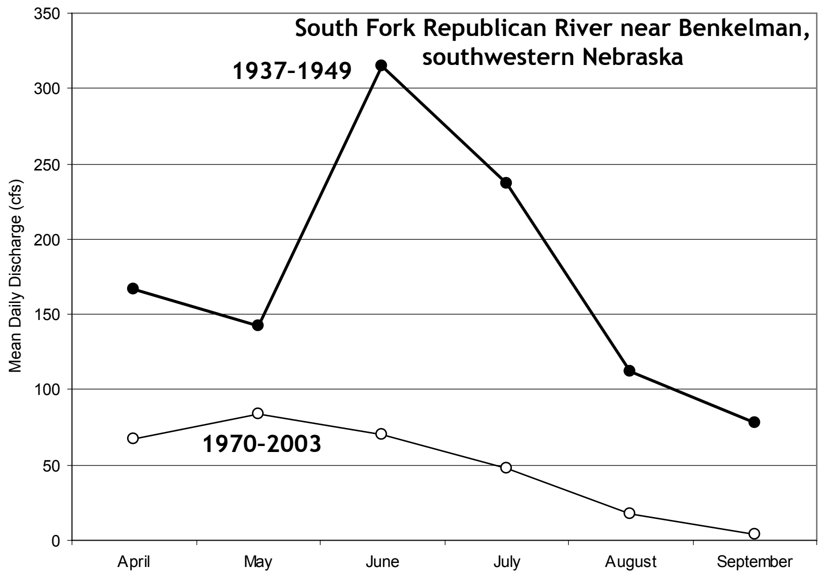

Figure B6. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the South Fork Republican River near Benkelman, Nebraska, illustrated in Figure 8 (circle 1). Discharge data from U.S. Geological Survey (2005).

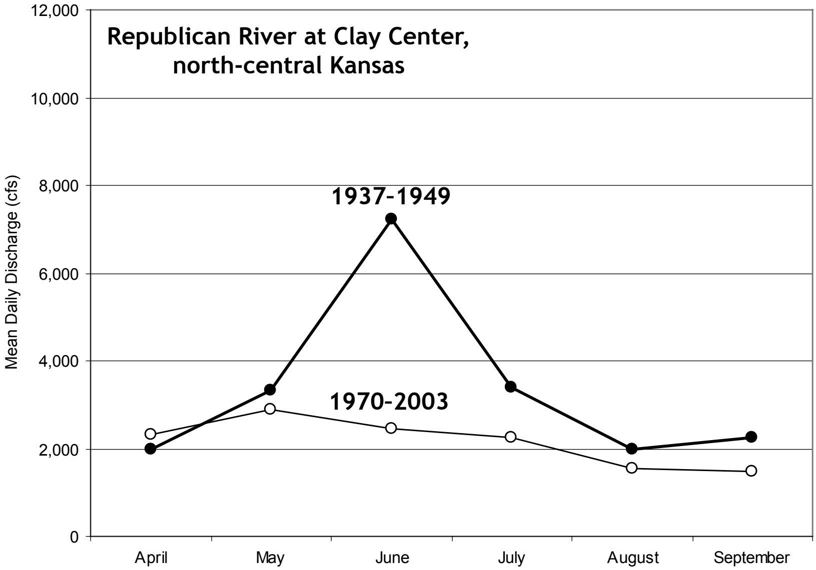

Figure B7. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Republican River at Clay Center, Kansas, illustrated in Figure 8 (circle 10). Discharge data from U.S. Geological Survey (2005).

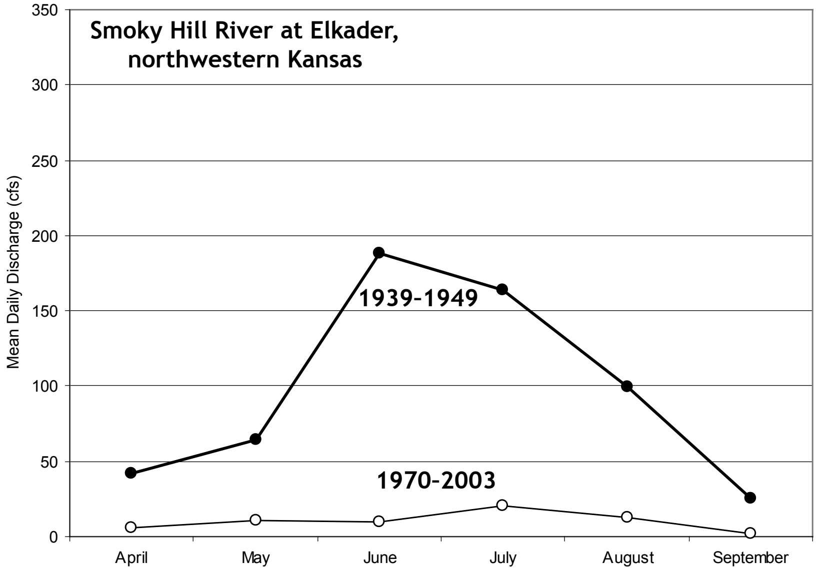

Figure B8. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Smoky Hill River at Elkader, Kansas, illustrated in Figure 8 (circle 2). Discharge data from U.S. Geological Survey (2005).

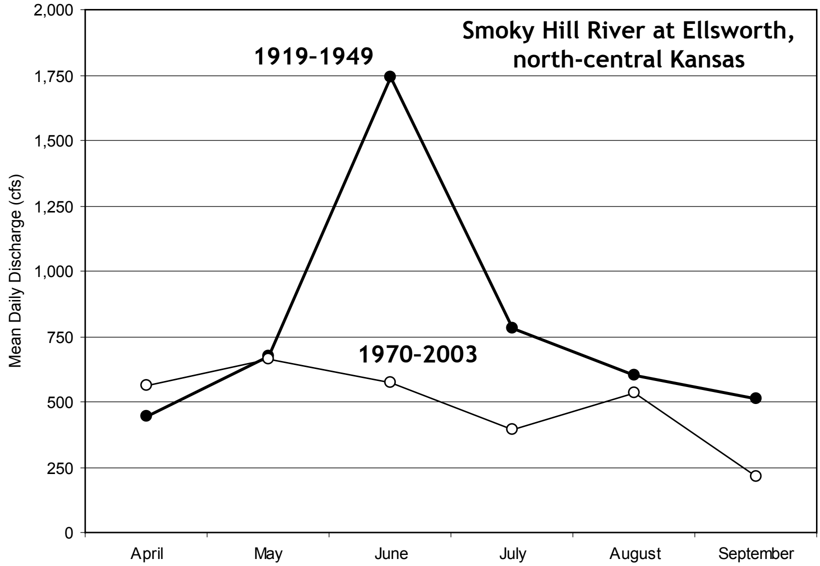

Figure B9. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Smoky Hill River at Ellsworth, Kansas, illustrated in Figure 8 (circle 8). Discharge data from U.S. Geological Survey (2005).

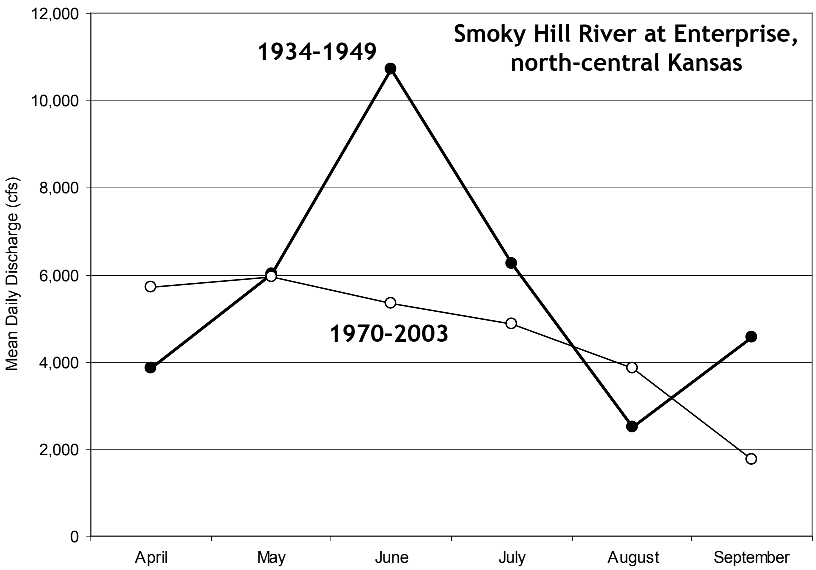

Figure B10. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Smoky Hill River at Enterprise, Kansas, illustrated in Figure 8 (circle 9). Discharge data from U.S. Geological Survey (2005).

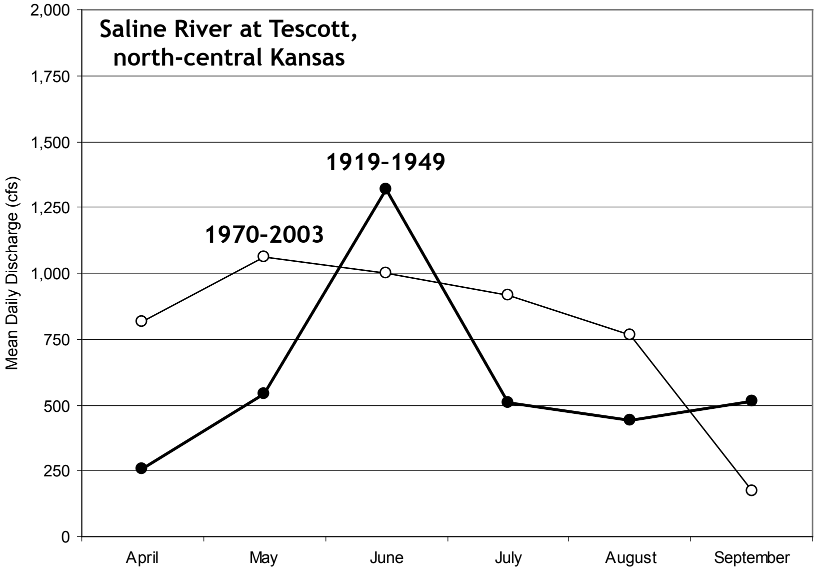

Figure B11. Mean daily discharge (cubic feet per second) equaled or exceeded 10% of the time each month during periods prior to and after initial impacts of substantial increases in irrigated area (Figure 6) and numbers of impoundments (Figure 7) in western Kansas. Gaging station location on the Saline River at Tescott, Kansas, illustrated in Figure 8 (circle 5). Discharge data from U.S. Geological Survey (2005).

FORT HAYS STATE UNIVERSITY

www.fhsu.edu