Environmental Flow Requirements for the Kansas River: Background Literature Review and Summary

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US Army Corps of Engineers®
Kansas City District

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The shared purpose of the project was to convene key personnel and partners to provide strong scientific and stakeholder support for the Sustainable River Program's commitment to improving ecological flows and reservoir health in the Kansas River system. Stakeholders and partners listed in the Team Charter (Appendix B) provided the input, expertise, and hypotheses on current and historical conditions as well as issues and needs.

Debra Baker, Assistant Director and Informatics Specialist, Central Plains Center for BioAssessment. Kansas Biological Survey & Center for Ecological Research, prepared the bulk of the report. Ms. Baker was supported in this effort by Donald Huggins, Senior Scientist, Director, Central Plains Center for BioAssessment, Kansas Biological Survey & Center for Ecological Research. Their work was integral in the development of the literature review and summary. Debra Baker and Don Huggins were supported by a technical team represented by broad ecological expertise in the Kansas River (Dawn Buehler, Friends of the Kaw/Kansas Riverkeeper; Jessica Mounts, Kansas Alliance for Wetlands and Streams; Steve Cringan, Kansas Department of Health and Environment; Jeff Conley and Mark VanScoyoc, Kansas Department of Wildlife and Parks; Todd Gemeinhardt, Marvin Boyer, and Paul Simon, U.S. Army Corps of Engineers, Kansas City District; Bob Henthorne, Kansas Aggregate Producers Association; and Bob Angelo, U.S. Environmental Protection Agency) who ensured the data review was robust, accurate, and defensible. The mussel information was taken from a report prepared by Steve Cringan, Robert Angelo, and Debra Baker (Cringan et al. 2020).

A core team, represented by the project partners led the science and technical integration effort. This group spent extensive time developing a plan for coordination and communication of science-based planning across stakeholder groups and identifying and targeting technical assistance as needed. The Nature Conservancy, Kansas and the U.S. Army Corps of Engineers, Kansas City District, initiated the project as well as provided input, guidance, and feedback throughout this initial phase (literature review and summary).

We are grateful to everyone who has participated for their interest and contribution to improving the health of the Kansas River. The extensive contributions and collaboration efforts from the various agencies and individuals are integral to the effort now and for future coordination and implementation efforts.

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1.0 Introduction and Background

The Nature Conservancy (TNC) and U.S. Army Corps of Engineers (USACE) have partnered to form the Sustainable Rivers Program (SRP) to examine opportunities to optimize reservoir releases and river flows to benefit river ecology while maintaining the federal mandates of the reservoir system in the United States. Maintaining environmental flows (e-flows), or flows that benefit native species and ecological systems, would provide year-round river water levels suitable for the behavioral, reproductive, and habitat needs of river and floodplain flora and fauna. The flow regime of the river also impacts nutrient cycling, sediment transport, and bank erosion. Deriving more favorable e-flows (from more favorable reservoir releases within the range of authorized reservoir releases) requires compiling available data and literature of each river system.

In 2017, the Kansas River was added to the SRP. The first step of this program was to pull together a workgroup of people representing the various uses of the Kansas River stakeholders (reservoirs, businesses, drinking water, recreation, etc.) and those who study the ecological and hydrological systems of the river, to guide the process of determining e-flows. The next step was to assemble literature and data to identify flow-dependent fish, mussels, and other species in the Kansas River, examine changes in these species over time, and propose a hypothesis about likely causes of these changes. In turn, USACE will take into consideration impacts caused by reservoir operations and examine possibilities for reservoir management modifications within the range of authorized reservoir releases that would create flows beneficial to the Kansas River ecosystem and its biota.

In 2020, the geographic scope of the Kansas River SRP was expanded to include Kanopolis, Wilson, Harlan County, and Waconda Reservoirs and the extended reaches to these reservoirs. Reaches added include the Smoky Hill River downstream of Kanopolis Reservoir, the Saline River downstream of Wilson Reservoir, the Solomon River downstream of Waconda Reservoir, the Big Blue River downstream of Tuttle Creek Reservoir, and the Republican River downstream of Harlan County Reservoir and Milford Reservoir. The identification of literature and data was expanded to identify and quantify ecological resources, basin characteristics, river morphology and the information to establish period of record flows and constraints in extended reaches.

Section 7 reservoirs are owned and operated by the U.S. Bureau of Reclamation (USBR). The ability of the USACE to influence e-flows is limited with the exception of potential coordination during high flow releases as part of flood operations. Nonetheless, there may be opportunities to partner with the USBR to develop environmental strategies, using water management flexibility. Currently this effort includes the reach of the Solomon River below Glen Elder Dam where e-flows could be proposed that potentially provide better instream habitat for fish and wildlife and complement any environmental flow benefits of action proposed from USACE reservoirs.

This report presents the underlying literature and data review informing our understanding of the natural flow of the Kansas River, Smoky Hill River, Saline River, Solomon River, Big Blue River, and Republican River, and flow requirements of the native species and communities in these river reaches.

2.0 Goals and Objectives

This report identifies key aspects of flow regimes that are important in sustaining the ecological health of the river-floodplain systems on the Kansas River, Smoky Hill River, Saline River, Solomon River, Big Blue River, and Republican River. The information presented is the basis for exploring possible improved future flow alternatives. Ultimately, the goal is to identify and integrate understanding of flow needs into real-time decisions about how much and when water is released from the reservoirs to achieve more natural flow regimes, and to adjust operations as needed in response to monitoring and modeled responses.

The literature review has the following objectives:

- Compile existing data and literature on the flow requirement needs of Kansas River native species.
- Compile existing data and literature on the flow requirement needs of Smoky Hill River native species.
- Compile existing data and literature on the flow requirement needs of Saline River native species.
- Compile existing data and literature on the flow requirement needs of Solomon River native species.
- Compile existing data and literature on the flow requirement needs of Big Blue River native species.
- Compile existing data and literature on the flow requirement needs of Republican River native species.
- Identify key environmental flow components and summarize the current flow regime including periods of low discharge, high discharge, the duration and frequency of such discharges, and the rate of change from one condition to another.

Issues to be Explored

1) How have dam operations changed river hydrology and morphology?

  - Hydrogeomorphic processes – including channel formation, sediment dynamics, and gravel movement
  - Current and pre-dam channel morphology in the Kansas River and the tributaries from the upper limits of the Kansas River (i.e. at the confluence of the Republican and Smoky Hill Rivers near Junction City, Kansas), and tributary reaches to the Kansas River, to the confluence with the Missouri River
  - Current and pre-dam channel morphology in the Smoky Hill River and the tributaries from Kanopolis Dam to the confluence with the Republican River
  - Current and pre-dam channel morphology in the Saline River and the tributaries from Wilson Dam to the confluence with the Smoky Hill River
  - Current and pre-dam channel morphology in the Solomon River and the tributaries from Glen Elder Dam to the confluence with the Smoky Hill River
  - Current and pre-dam channel morphology in the Big Blue River and the tributaries from Tuttle Creek Dam to the confluence with the Kansas River
  - Current and pre-dam channel morphology in the Republican River and the tributaries from Harlan County Dam to Milford Reservoir

- Current and pre-dam channel morphology in the Republican River and the tributaries from Milford Dam to the confluence with the Kansas River
- Key indicator species – including a range of species with different life histories, with flow requirements identified for specific life-history stages
- Floodplain processes and functions – including functions such as vegetation establishment, seed dispersal, riparian community structure and function, seasonal access for fish, habitat for species such as amphibians and birds, etc.
- Water quality – including temperature, dissolved oxygen (DO), herbicides, and nutrients
- Implications for population dynamics of non-native species and their interactions with native species and communities

2) Summarize the current and historical hydrograph including:
   - Low flows (seasonal, annual, and extreme low flows)
   - High flow pulses (up to bank full discharge)
   - Small floods (overbank flows, approximately 2- to 10-year return period)
   - Large floods (floodplain maintenance flows, greater than approximately 10-year return period).
3) What opportunities exist in the Kansas, Smoky Hill, Saline, Solomon, and Republican Rivers to develop structure or off-channel habitat for aquatic and bird life (e.g. reconnection of old oxbows)?
4) When considering birds, amphibians and reptiles, mussels, and fish species of greatest conservation need, are there flow management strategies that would increase benefits to each group?
5) How has species usage of the river changed since the dams were initially put in service?

3.0 Basin Characteristics and Water Management

The Kansas River Basin drains almost the entire northern half of Kansas, as well as part of Nebraska and Colorado (60,500 square miles in all) (Figure 1) and is the longest prairie-based river in the world. The basin is approximately 490 miles long west to east, with a maximum width of approximately 200 miles north to south from Polk County, Nebraska, to McPherson County, Kansas. The Kansas River Basin includes 18 federal reservoirs (7 USACE and 11 USBR), 12 within Kansas, five in Nebraska, and one in Colorado (Table 1). USACE dams manage water flowing from most of the Kansas River Basin with a total of approximately 45,800 square miles upstream of USACE dams. Approximately 9,730 square miles of unregulated areas remain below major dams and the mouth of the Kansas River. Table 1 lists federal dam projects in the Kansas River Basin. Figure 1 shows the major impoundments in the Kansas River Basin. The Bowersock Dam also stores water within the Kansas River for release through its hydropower turbines.

Table 1. Water Management Projects

Water Management Project	Basin or Stream	Date of Closure	Operating Agency
Republican River Basin			
Bonny Dam	South Fork Republican River	1950	Bureau of Reclamation
Trenton Dam (Swanson Lake)	Republican River	1953	Bureau of Reclamation
Enders Dam	Frenchman Creek	1950	Bureau of Reclamation

Water Management Project	Basin or Stream	Date of Closure	Operating Agency
Red Willow Dam (Hugh Butler Lake)	Red Willow Creek	1961	Bureau of Reclamation
Medicine Creek Dam (Harry Strunk Lake)	Medicine Creek	1949	Bureau of Reclamation
Norton Dam (Keith Sebelius Lake)	Prairie Dog Creek	1964	Bureau of Reclamation
Harlan County Dam	Republican River	1951	USACE, Kansas City District
Lovewell Dam	White Rock Creek	1957	Bureau of Reclamation
Milford Dam	Republican River	1964	USACE, Kansas City District
Smoky Hill River Basin			
Kanopolis Dam	Smoky Hill River	1946	USACE, Kansas City District
Glen Elder Dam (Waconda Lake)	Solomon River	1967	Bureau of Reclamation
Wilson Dam	Saline River	1963	USACE, Kansas City District
Cedar Bluff Dam	Smoky Hill River	1950	Bureau of Reclamation
Webster Dam	South Fork Solomon River	1956	Bureau of Reclamation
Kirwin Dam	North Fork Solomon River	1955	Bureau of Reclamation
Lower Kansas River Basin			
Clinton Dam	Wakarusa River	1975	USACE, Kansas City District
Perry Dam	Delaware River	1966	USACE, Kansas City District
Tuttle Creek Dam	Big Blue River	1959	USACE, Kansas City District

- The Kansas River begins at the confluence of the Republican and Smoky Hill Rivers near Junction City, Kansas and flows 173 miles to the confluence with the Missouri River (Kansas City, Missouri).
- The Smoky Hill River begins approximately 40 miles west of the Colorado-Kansas state line. From its source the Smoky Hill flows in an easterly direction to Kanopolis Dam and then east-northeast for approximately 184 river miles to its confluence with the Republican, forming the Kansas River.
- The Saline River begins in western Kansas near Mingo, Kansas. From its source, the Saline River flows eastward 263 miles to Wilson Dam, then 154 miles east to its confluence with the Smoky Hill River.
- The Solomon River begins at the confluence of the South Fork and North Fork Solomon Rivers below Glen Elder Dam. Waconda Reservoir, at the confluence of the North Fork Solomon and South Fork Solomon rivers, was completed in 1967. From Glen Elder Dam, the Solomon River flows into the Smoky Hill River.

- The Republican River flows approximately 420 river miles generally easterly and southeasterly, joining with the Smoky Hill River immediately below Junction City, Kansas, to form the Kansas River.

There are approximately 640 freshwater stream miles below all major dams, and approximately 100,000 acres of federally owned freshwater impoundments, including USACE and USBR reservoirs, in the Kansas River Basin. A detailed map showing the predominant streams in the Kansas River Basin and the downstream reach of the Missouri River is shown in Figure 2.

3.1 Basin Climate and Physiography

The Kansas River Basin has a continental climate with cold winters and hot summers. The climate varies from humid in the eastern part of the basin to semi-arid in the west with average annual precipitation ranging from 39" over the eastern portion of the basin to 16" in western portions (Figure 3) (KSU 2020). Rainfall is concentrated in the summer months when convective storms often cause intense downpours. In the eastern part of the basin, May and June are typically the wettest months. In western Kansas the maxima shift to June and July. The climatic record of the basin includes intense and prolonged rainfall during some years and severe droughts in others without a fixed cyclic pattern. Much of the basin receives significant snowfall, but snow melts off before the summer months when rainfall is the primary source of hydrology in the basin. The average annual snowfall varies from 20 inches along the eastward and southern perimeter of the basin to 33 inches in north-central Kansas and in southeastern Nebraska.

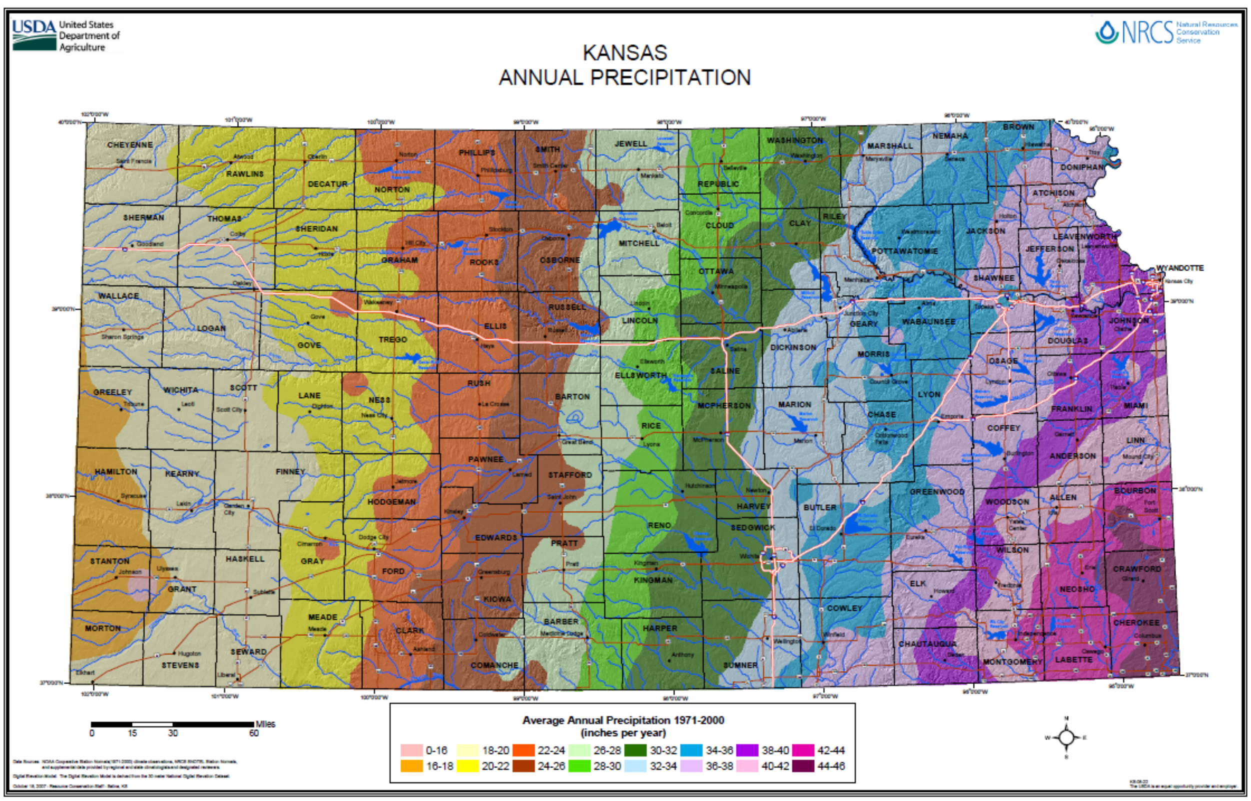

Figure 1. Kansas Annual Precipitation

Source: https://www.k-state.edu/ksclimate/

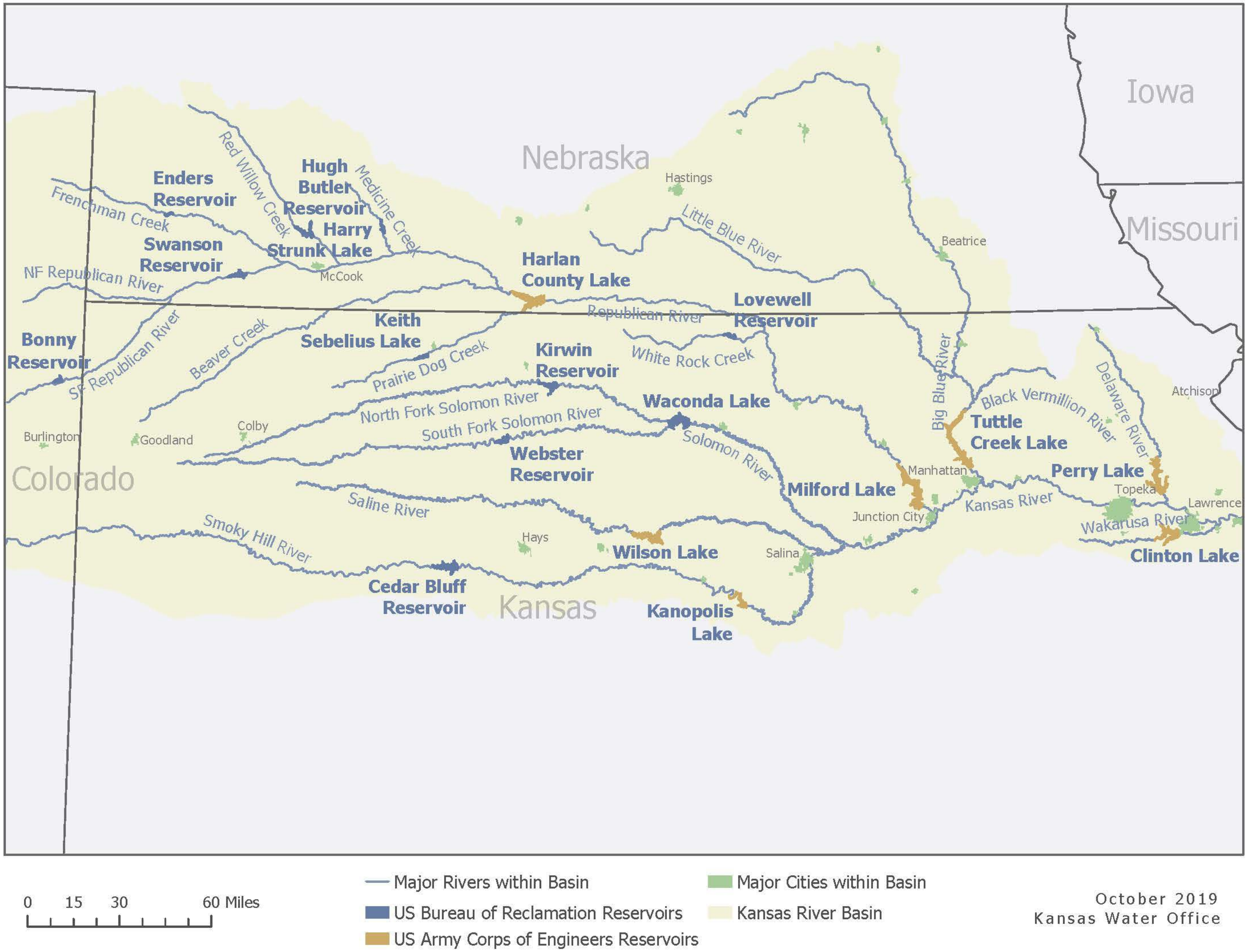

Figure 2. Kansas River Basin

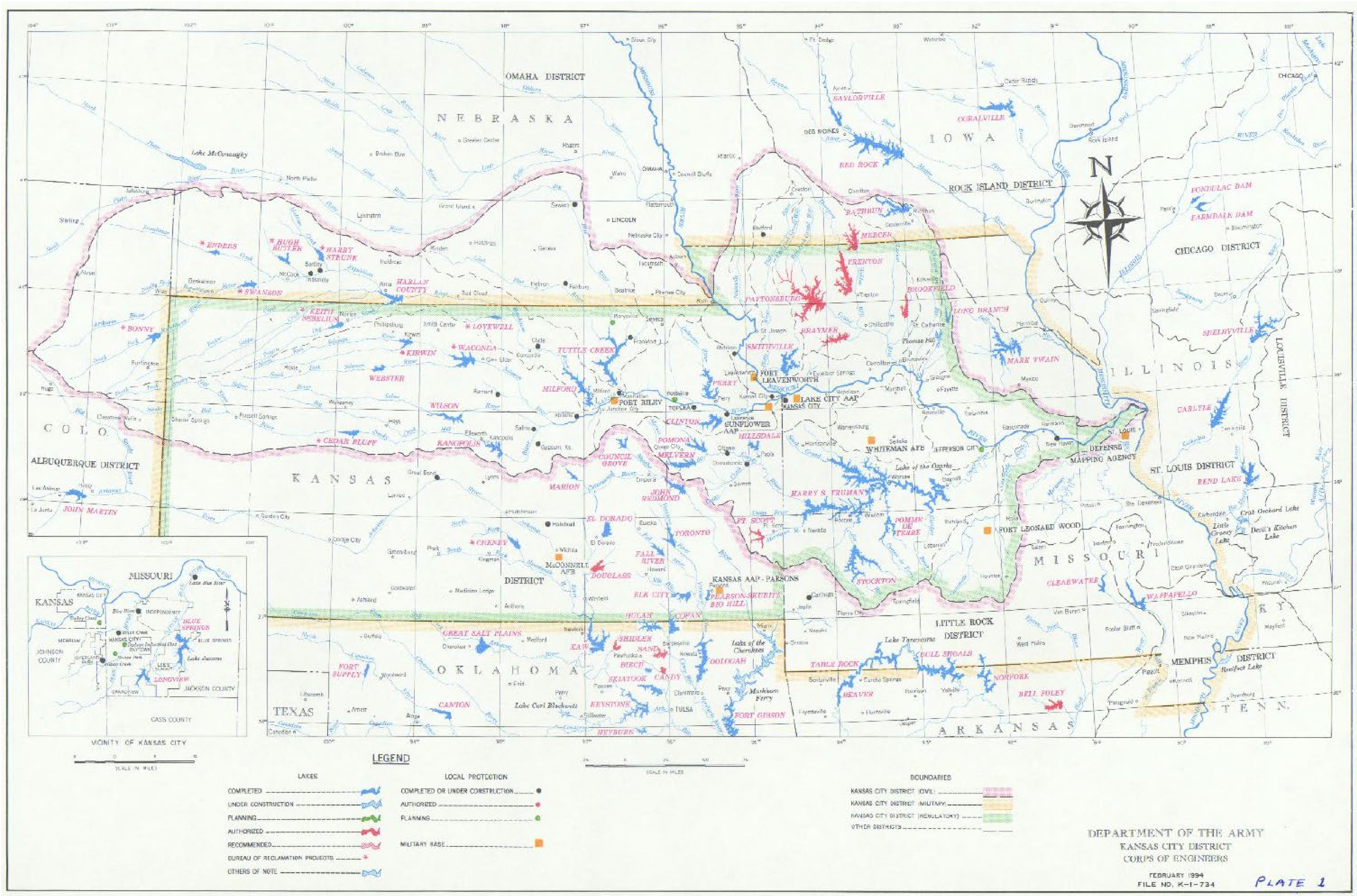

Figure 3. Kansas River Major Tributaries and Water Management Projects and Downstream Reach of the Missouri River

The upper portions of the Kansas River Basin lie in the High Plains region where topography is generally flat with minimal hills. The central portion of the basin is dominated by the Smoky Hills. East of the Smoky Hills, the Kansas River passes through the Flint Hills region and then follows the southern limits of the glaciated region east to the Missouri River at Kansas City (Figure 4). The elevations in the Kansas River Basin vary from nearly 6,000 feet near Cedar Point, Colorado to approximately 720 feet at Kansas City, Kansas.

Western regions of the Kansas River Basin in the High Plains region are characterized by high infiltration. Most water sources in the High Plains are groundwater. The Smoky Hill region is characterized by hills capped with sandstone or limestone. The Flint Hills region has shallow, rocky soils and is mostly used for grazing. Soils in the glaciated region in Northeast Kansas consist mainly of loess.

All suitable land in the Kansas River valley is devoted to agriculture, especially in the floodplain of the mainstem. The western portion of the basin is primarily in dryland or irrigated farming with sorghum and wheat the primary crops. The eastern two-thirds of the basin are in various agricultural uses with much of the floodplain area and many areas in the uplands in crops such as corn, wheat, and milo. Lands with steeper topography are mostly in pasture and hay.

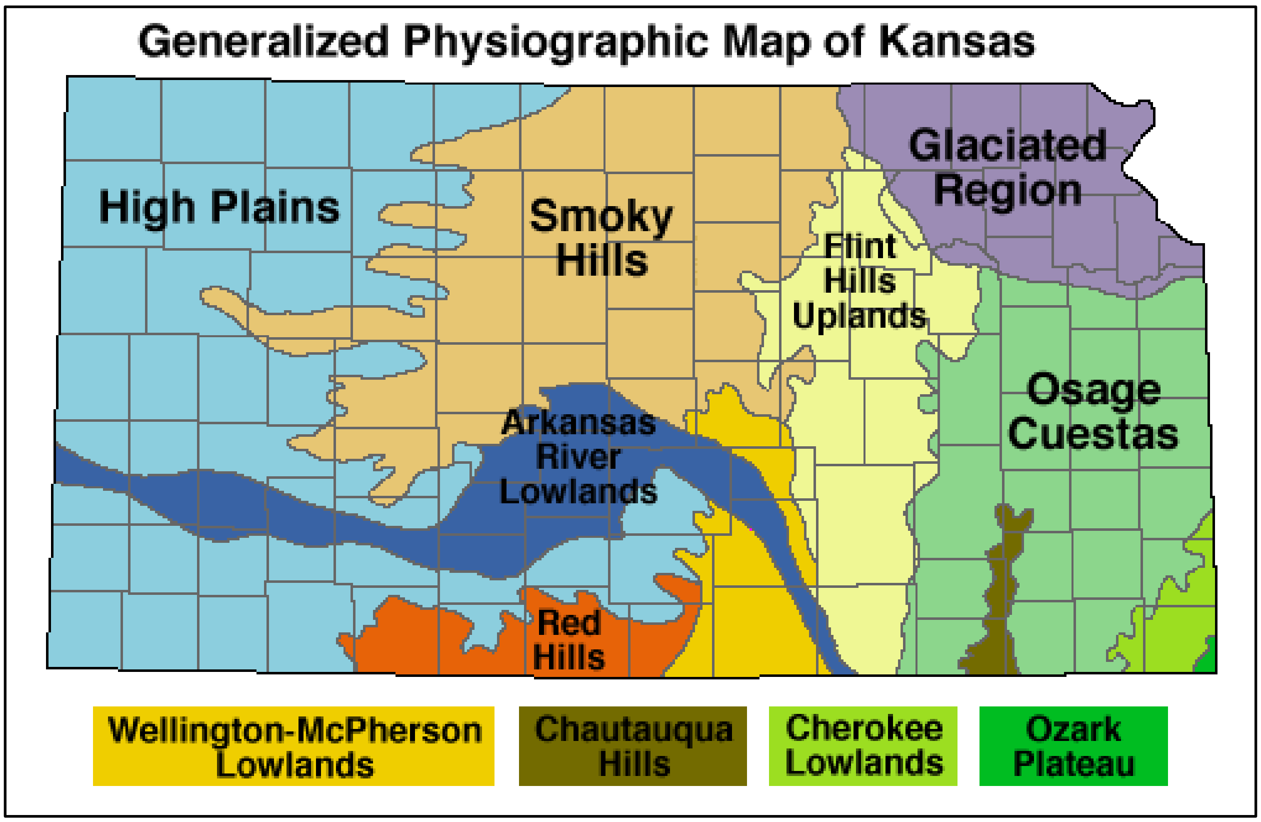

Figure 4. Physiographic Map of Kansas

Source: http://www.kgs.ku.edu/Physio/physio.html

3.2 History

Since the State of Kansas and other states comprising the Kansas River Basin were first settled, the conversion of the natural landscape to farmland, pasture, and urban area has occurred at varying rates and extents. For Kansas, Baker et al. (2009) obtained historic values for three broad-scale stressors from annual or biannual reports of the Kansas State Board of Agriculture (KSBA). To quantify the disturbance of the natural landscape in Kansas on an ecoregional scale, the densities of cultivated land and animal and human populations were calculated from the KSBA reports and used to plot the changes in stressor levels over time. Most of the Kansas River Basin discussed in this report occurs within the Central Great Plains ecoregion. This ecoregion was used to estimate timelines associated with major stressor growth within the basin. Using density values per year for cultivated land and animal populations expressed as animal units (Harner et al. 1995) within this ecoregion it was noted that these two stressor extents first peaked between 1900 -1920. Human population growth also peaked early in the 1900s and showed a slow but steady decline beginning in the 1920s. These data suggest that the major landscape changes within the Kansas River Basin had occurred well before the first major reservoirs were put in place. These legacy conditions may have contributed to early changes in fish populations separate from current reservoir impacts. We are not suggesting that other land use and management changes within this basin after the early 1900s have not potentially impacted fish populations but that major changes within the basin had already occurred 40 to 50 years before the Kansas River became a regulated stream system.

3.3 Hydrology

There are many tributaries contributing to the Kansas River mainstem. Table 2 summarizes the origin, length, and basin area of the various tributaries. A detailed map showing the predominant streams in the Kansas River Basin is shown in Figure 2.

Table 2. Kansas River Tributaries

Tributary	Origin	Length	Basin Area
Kansas River	KS	148 mi (238 km)	60,114 mi2 (155,695 km2)
Republican River	NE	453 mi (729 km)	24,900 mi2 (64,491 km2)
White Rock Creek	KS	74 mi (119 km)	358 mi2 (930 km2)
Smoky Hill River	CO	575 mi (925 km)	19,260 mi2 (49,883 km2)
Big Blue River	NE	575 mi (925 km)	2,330 mi2 (6,000 km2)
Delaware River	KS	359 mi (578 km)	9,600 mi2 (25,000 km²)
Wakarusa River	KS	94 mi (151 km)	1,117 mi2 (2,890 km2)
Solomon River	KS	80.5 mi (130 km)	367 mi2 (950 km2)
North Fork Solomon	KS	184 mi (296 km)	6,835 mi2 (17,703 km2)
South Fork Solomon	KS	287 mi (462 km)	1,367 mi2 (3,540 km2)
Saline River	KS	292 mi (470 km)	1,150 mi2 (3,000 km2)
Prairie Dog Creek	KS	397 mi (639 km)	3,419 mi2 (8,855 km2)

The Kansas River Basin exhibits great variation in natural stream flows. Annual and daily discharges for any given location vary through a wide range, and considerably different discharges result from similar conditions at different locations. Severe drought periods frequently follow a flood. The entire Kansas River Basin is subject to severe flooding at infrequent intervals, erratically interspersed by less severe floods of varying magnitudes.

Channel capacities vary from 4,000 cubic feet per second (cfs) immediately below Wilson Lake Dam to 16,700 cfs at Enterprise, Kansas on the Smoky Hill River. Channel capacities of the Kansas River mainstem become progressively larger from Junction City, Kansas to the mouth, varying from 40,000 cfs to 119,000 cfs. Relatively large areas exist in the western portion of the basin that contribute little to no surface runoff to the Kansas River mainstem flows, while most of the runoff in the eastern portion of the basin contribute surface runoff to the Kansas River mainstem flows (USACE 1966).

3.4 Operations and Authorized Purposes for the Kansas River

3.4.1 Operations Overview

The USACE Kansas City District includes the Missouri River watershed from Rulo, Nebraska, (river mile 498.1 above the mouth) to the junction of the Missouri and Mississippi Rivers near St. Louis, Missouri. The Kansas City District fully operates 18 storage projects and manages flood control releases from 11 Section 7 USBR reservoirs. In the Kansas River Basin, there are 7 USACE reservoirs and 11 USBR lakes. The location of each lake and reservoir in the Kansas City District is shown on Figure 1.

Kansas River mainstem flows serve as a critical drinking water supply for more than 600,000 people in addition to being used for irrigation, municipal wastewater and industrial discharges, power generation, and as a source of commercial sand and gravel. Additionally, recreation use in the Kansas River Basin (boating, kayaking, camping, picnicking, fishing, swimming, hunting, wildlife viewing, etc.) provides substantial benefits to the local, regional, and national economy.

Each USACE and USBR reservoir operates for specific congressionally authorized purposes and has a Water Control Manual which details the rules and regulations specific to each reservoir. The following sections summarize the main rules used to regulate releases in both flood control and multipurpose pools. Within the Kansas River Basin, the congressionally authorized purposes include flood control, water supply, water quality, fish and wildlife, recreation, navigation support, and irrigation. The following table summarizes the authorized purposes for each USACE reservoir and for Waconda Reservoir that is owned and operated by the USBR. The USBR is responsible for irrigation operations, operation and maintenance, safety of the structure, and reservoir operations not specifically associated with regulation of the flood control storage at their reservoirs. Regulation of the flood control storage is the responsibility of the USACE at USBR reservoirs.

Table 3. Kansas River Basin Reservoirs Authorized Purposes

Reservoir	Flood Control	Water Supply	Water Quality	Fish and Wildlife	Recreation	Navigation	Hydropower	Irrigation
Kanopolis	X	X	X	X	X	*	*	*
Wilson	X		X	X	X	*		*
Harlan County	X			X	X			X
Milford	X	X	X	X	X	X		
Tuttle Creek	X	X	X	X	X	X		
Perry	X	X	X	X	X	X		
Clinton	X	X	X	X	X			
Waconda[1]	X			X	X			X

* Authorized purpose, not operating purpose based on PR-19 Authorized and Operating Purposes of Corps of Engineers Reservoirs July 1992, revised 1994

[1] USBR Reservoir

Operations can be broken into two major categories, flood control and multipurpose, each being governed by separate rules. Releases made from USACE and USBR reservoirs serve to fulfill one or more of the authorized purposes. Flood control and the various multipurpose operations are explained in the following sections.

3.4.2 Kansas River Basin Reservoir Operations

Typically, the flood control pools are designed to store runoff from major floods up to about the 1% annual chance inflow event. Stored flood flows are then evacuated as rapidly as the downstream channel capacities allow.

When flooding is not occurring, USACE works to seasonally fluctuate reservoir elevations near the multipurpose pool level in order to principally benefit on-reservoir fish and wildlife purposes. Minor releases at some projects are managed to benefit downstream fish and wildlife and special requests from river users. Minimum releases are maintained at all projects for the purpose of sustaining water quality control in the first reach downstream. Large portions of the multipurpose pools at Milford, Tuttle Creek, Perry, and Clinton have been purchased or reserved by the State of Kansas for downstream water supply (both municipal and industrial) in cooperation with the Kansas River Water Assurance District No. 1. Releases from this contracted storage are tracked and accounted for by the Kansas Water Office consistent with USACE monthly reservoir accounting for each project. Storage in the multipurpose pools at USACE projects that support irrigation have been contracted to irrigation districts. Generally, a portion of each multipurpose pool is reserved for sediment storage. On an interim basis, a portion of the multipurpose pools at Milford, Tuttle Creek, and Perry are available for supplementation of navigation flows on the Missouri River with Tuttle Creek having provision for some permanent support to Missouri River navigation.

Flood Control

The lower Kansas River Basin reservoirs, augmented with the upstream reservoir system and the local protection works, are intended to provide flood protection for the urban population centers along the Kansas River, including the Kansas City population, when operated as a system. The severity of floods over rural areas is also greatly reduced, but without agricultural levees this type of impact will continue to be substantial during major floods. The lower basin reservoirs have a combined capacity of 5.16 million-acre-feet (MAF) specifically allocated to flood control which is supplemented by an additional 1.73 MAF of upstream flood storage capacity. The flood control benefits of the Kansas River system of reservoirs extends downstream along the Missouri River. During major floods, releases from the Kansas River system flood storage capacity is coordinated with the Missouri River mainstem reservoirs upstream of Omaha, Nebraska to provide flood control benefits along the lower Missouri River.

General flood control storage and release criteria are as follows:

1. Flood control storage space is reserved for the reduction of damages caused by floods;
2. Releases are made to evacuate accumulated flood control waters only when the channel downstream can accommodate the releases without resulting in further flooding, accounting for local inflows and travel time;
3. In determining priority of releases from individual projects, consideration is given to the unoccupied flood control storage space in each reservoir and the potential that future basin runoff upstream of a dam will fill the flood control pool behind that dam. The process also accounts for travel times to downstream flood damage centers in such a manner that flood control benefits are maximized, and;
4. The seasonal hydrologic characteristics of each inflow basin are recognized in developing the plan for evacuating accumulated flood storage. When the top of the flood control pool has been exceeded, water begins accumulating in the surcharge pool and mandatory releases become necessary irrespective of downstream channel space. Surcharge storage is used only in

conjunction with the respective spillways to control floods in excess of project capacity and to preserve the safety of the dam and embankment from overtopping.

The flood control pool at each reservoir is divided into three zones for each season in diagrammatic form termed the Seasonal Guidelines (Figure 5, Figure 6, and Figure 7). The zones are designated in order from lowest to highest as Phase I, II, and III. Phase I storage occupies the lowest portion of the flood pool and occurs most frequently. Releases made to evacuate stored water from this zone should not exceed about 60% of channel capacity downstream. This provides a margin of safety if an unexpected storm arrives, increasing local inflows below the dam. As the reservoir fills, the chance that a future storm will fill the remaining flood control pool storage space increases, as does the chance of danger to the dam and downstream damage centers. Therefore, it becomes more urgent to evacuate the accumulated flood storage. As the reservoir rises into the Phase II zone, releases are made to essentially fill the downstream channel capacity up to the flood stage. This means that an unexpected storm will likely result in out-of-bank flows at the damage center. The Phase III zone is usually the last, upper, 10% of the flood pool. Phase III releases are intended to fill the downstream channels to a level that will not exceed what the Weather Service refers to as moderate flooding. This can result in impacts to agriculture and outbuildings. Above Phase III, flood control operations transition to surcharge operation and the preservation of the dam and embankment is prioritized over downstream flood control. The portions of the flood pool assigned to each zone varies seasonally to reflect the higher probability of major rainstorms in the spring.

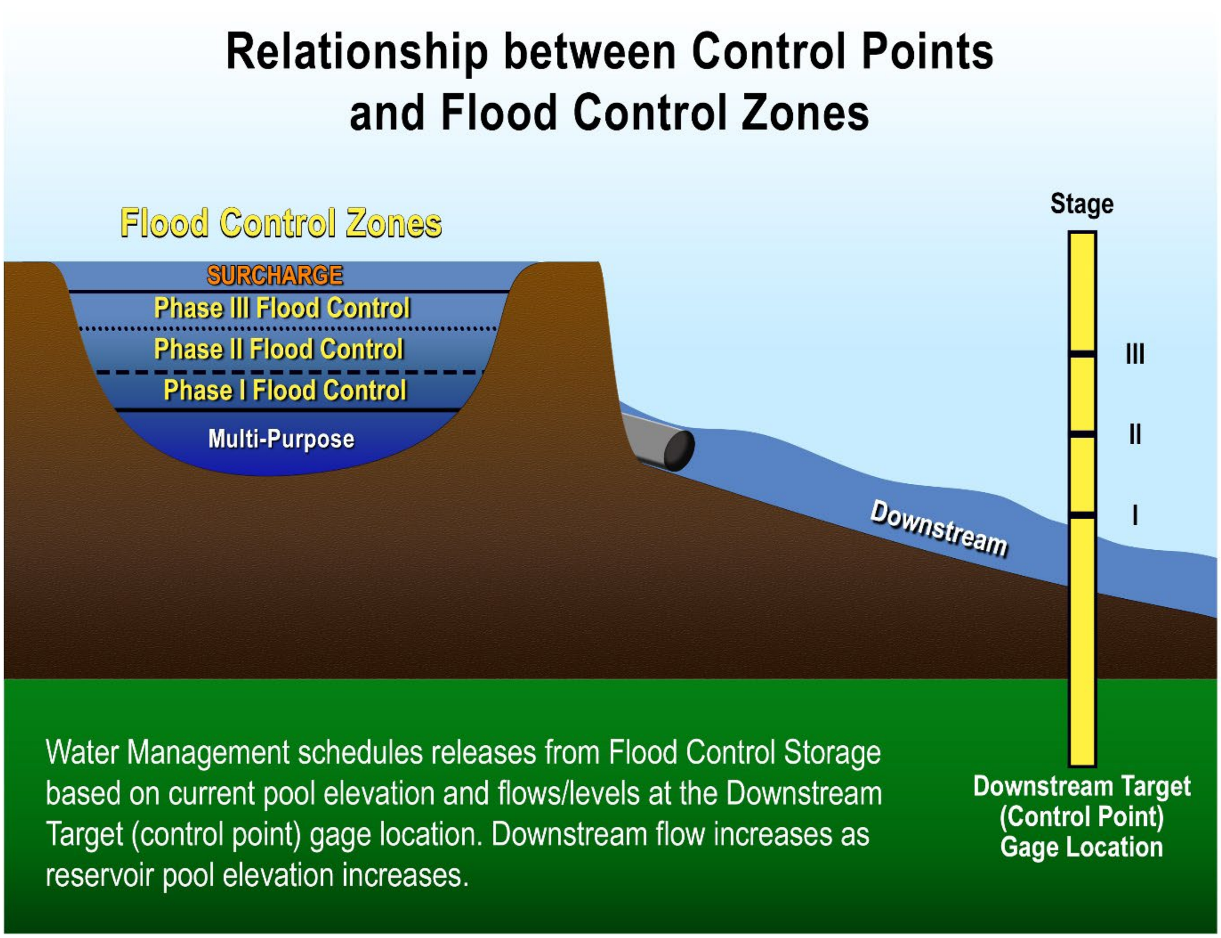

Figure 5. Flood Control Pool Seasonal Guidelines

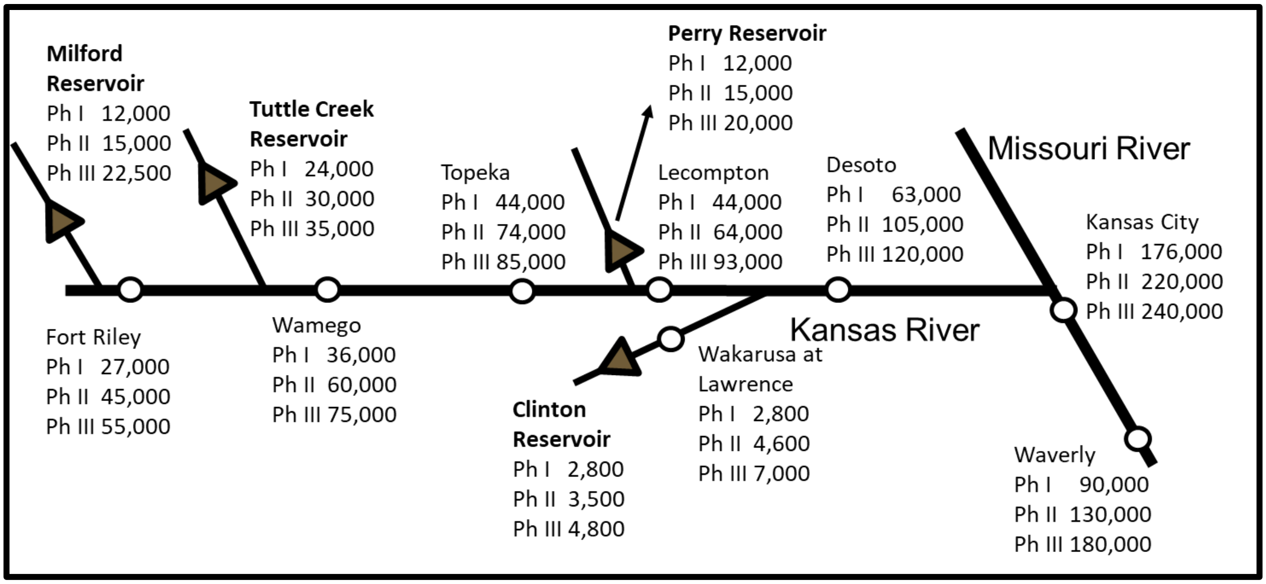

Figure 6. Kansas River Basin Reservoir Flood Control Releases and Control Point Gages, flows in cfs

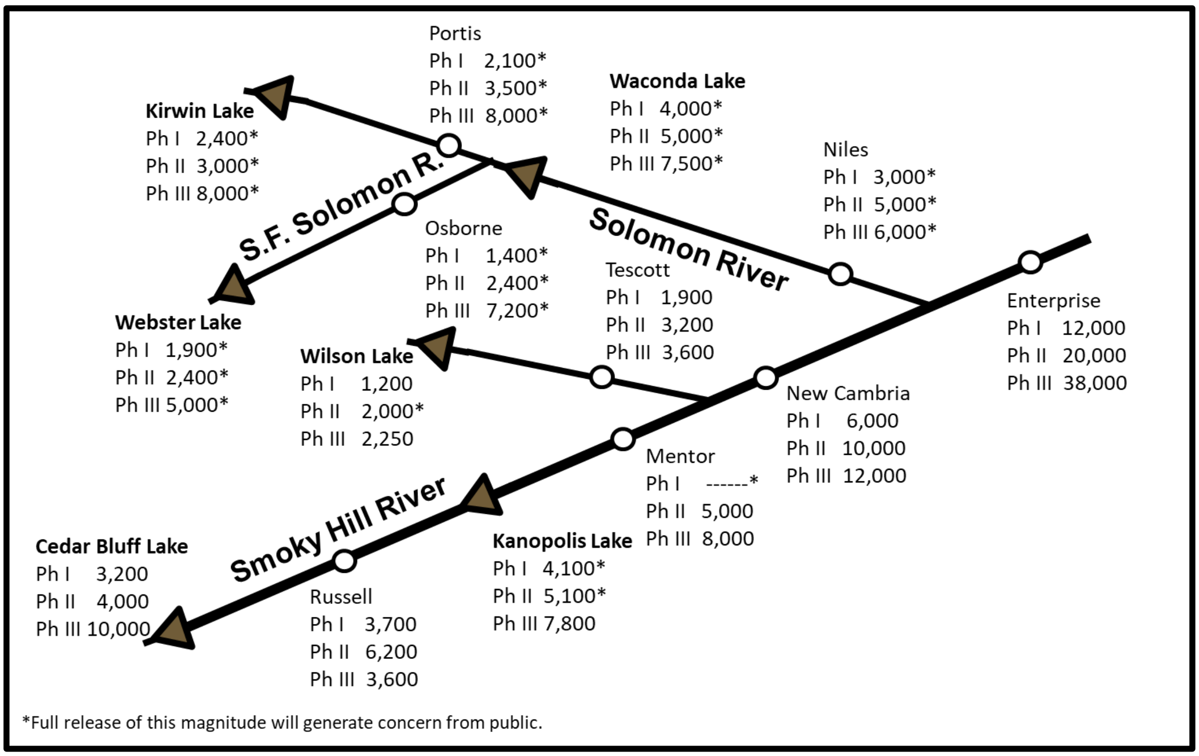

Figure 7. Upper Kansas River Basin Reservoir Flood Control Releases and Control Point Gages, flows in cfs

Municipal, Industrial, and Rural Water Supply and Water Quality

Minimum releases from each of the USACE reservoirs in the Kansas River Basin were established during the original design and authorization process using U.S. Public Health Service guidelines for downstream water quality needs along the tributary before it reaches the Kansas River. Minimum releases range from 7 cfs to 100 cfs (Figure 8 and Figure 9; Table 4). Clinton is also authorized to provide supplemental low flow releases for downstream fisheries during April through September.

Authorizations were also included at Milford, Tuttle Creek, and Perry reservoirs for low flow supplementation for water quality on the lower Kansas River and the Missouri River at Kansas City. The seepage through the USBR dams is considered enough for water quality purposes in the upper Kansas River Basin.

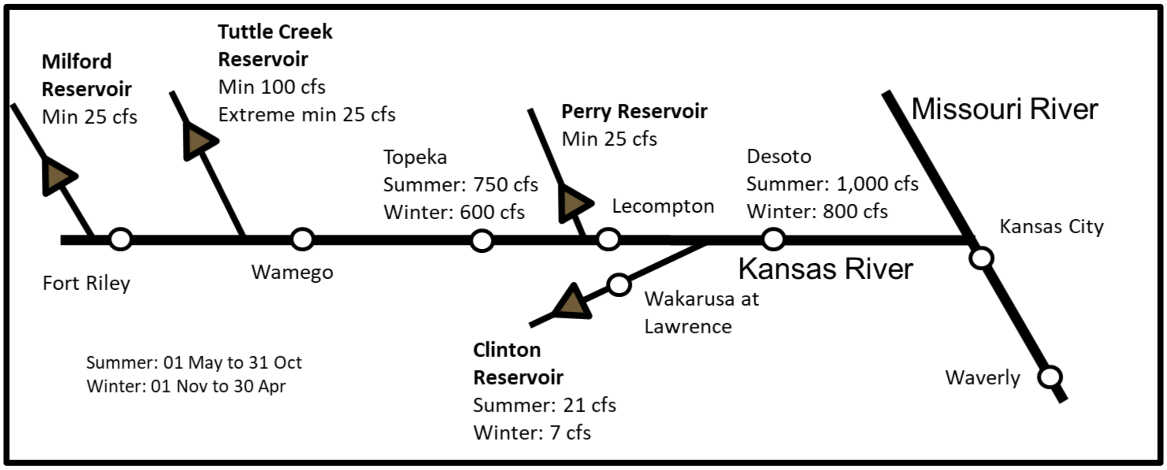

Figure 8. Kansas River Basin Low Flow Releases and Flow Targets

Table 4. Kansas River Flow Objectives

Tuttle Creek Elevation	Topeka	Desoto
1,075 – 1,070	750 cfs	1,000 cfs
1,070 – 1,065	Summer: 750 cfs Winter: 600cfs	Summer: 1,000cfs Winter: 800cfs
1,065 – 1,048	600 cfs	Summer: 750cfs Winter: 700cfs

Summer: 1 May to 31 Oct; Winter: 1 Nov to 30 Apr

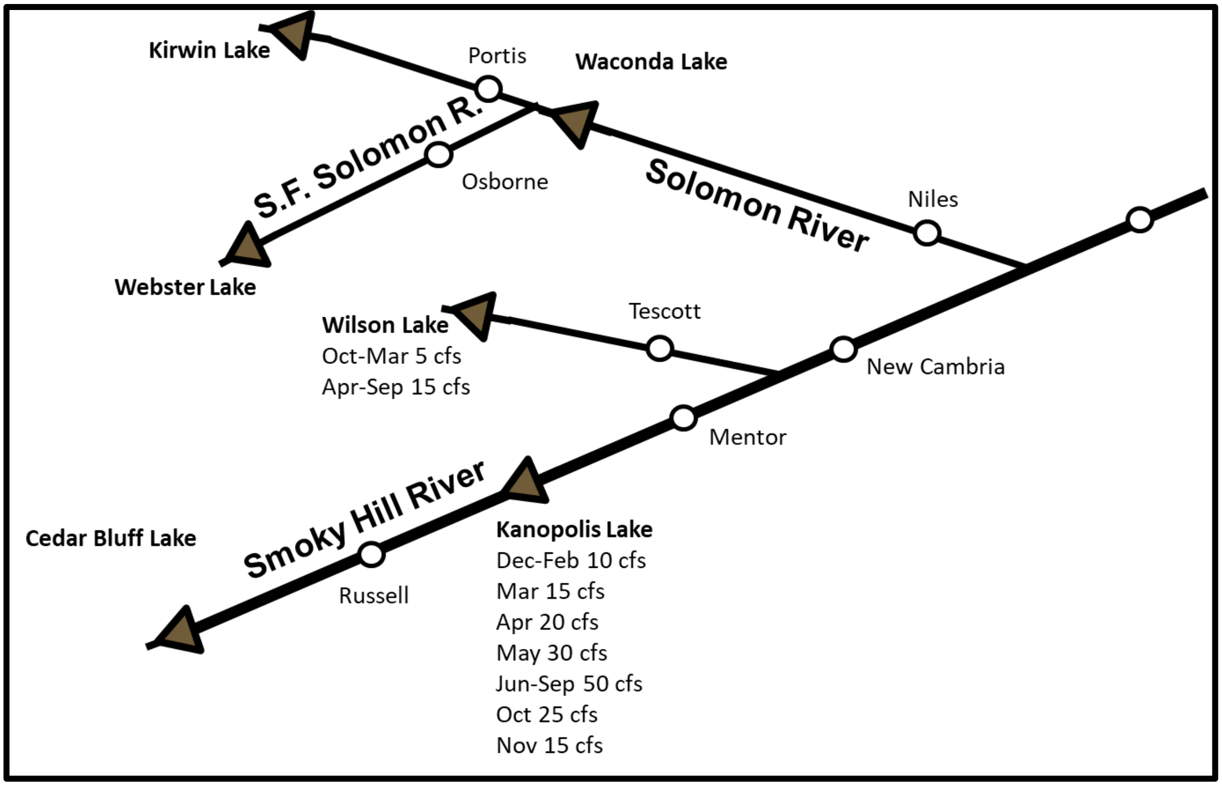

Figure 9. Upper Kansas River Basin Low Flow Reservoir Releases

Under the Water Supply Act of 1958 and amended by the Federal Water Pollution Control Act amendments of 1961, state and local interests were authorized to purchase storage rights in the multipurpose pools of most Federal reservoirs. The Act also set the policy of recognizing the primary responsibility of states and local interests to develop water supplies for domestic, municipal, industrial, and other purposes. Since then, the State of Kansas has reserved or purchased most of the multipurpose storage in Milford, Tuttle Creek, Perry, and Clinton allocated for water supply purposes.

The State of Kansas initially reserved storage in Milford and Perry Reservoirs under the terms of the Federal Water Supply Act of 1958 and the State Water Plan Act passed by the 1963 Kansas Legislature. The State Water Plan was supplemented and enacted in 1965. In 1986 the Kansas legislature enacted the Water Assurance Program Act which assigned the Kansas Water Office the authority to negotiate with the Federal government to contract for multipurpose storage in each reservoir for water supply and quality, which in turn would be contracted to local users. Water right holders are thereby provided with water during times of low flow.

The Kansas Water Office assisted in the formation of the Kansas River Water Assurance District No. 1 (Assurance District) and entered into a Memorandum of Understanding with the Department of the Army to give the state the first purchase option for multipurpose storage in Tuttle Creek and a number of other reservoirs in Kansas. The Assurance District includes municipal and industrial water rights holders along the Kansas River from Junction City in the west to the Kansas-Missouri border in the east. Reserve capacity in Milford and Perry previously purchased under the State Water Plan Act was then transferred to the Assurance program. Separate contracts for municipal water supplies from Clinton Reservoir are not affected by the Assurance program. The State of Kansas has now contracted for use of 300,000 acre-feet (AF) of the total 390,000 AF of multipurpose storage at Milford, 50,000 AF of the total 300,000 AF at Tuttle Creek, 150,000 AF of the total 210,000 AF at Perry, and 89,200 AF of the total 125,000 AF available at Clinton. Portions of the remaining storage in each reservoir are reserved for sediment. Releases for low flow supplementation on the Kansas River beyond the specified minimum reservoir releases are coordinated with the Kansas Water Office and through them with the Assurance District and other state offices.

Irrigation

Of all the USACE reservoirs in the Kansas River Basin, irrigation is an authorized use only of the Harlan County multipurpose pool. All authorized irrigation storage space in Federal reservoirs in the Kansas City District has been contracted out to irrigation districts. The USBR regulates the release of water from the contracted storage at the Harlan County multipurpose pool. Irrigation releases are not a factor in controlling flows at Wamego.

Navigation

Authorizations for Milford, Tuttle Creek, and Perry Reservoirs on Kansas River tributaries include supplemental flows for maintenance of navigation on the mainstem of the Missouri River (PL 83-780). Water from lower Kansas River Basin reservoirs of Milford, Tuttle Creek and Perry may be used effectively to replace releases from the mainstem reservoirs when natural gains in flow between Nebraska City and Kansas City are less than the increase in requirements for navigation, up to a maximum of 4 kilo cfs (kcfs).

USACE has established guidelines in the Water Control Manuals for the release of water from the joint use storage space available in each of these three reservoirs. The guidelines are intended to balance the needs of the multiple purposes authorized at each reservoir. The joint use space is used for navigation and water quality supplemental flows, recreation, fish and wildlife, and sediment storage.

Supplemental releases for navigation from Tuttle Creek, Milford, and Perry are limited each year prior to October 1 to the volume available through the first 3 ft (0.9 m) below multipurpose. After October 1 the allowable volume increases to the first 6 ft (1.8 m) below multipurpose. Releases for navigation supplementation originate with a requirement for water from Missouri River Basin Water Management Office and are coordinated by Kansas City District Water Management Office with the state of Kansas Water Office.

Hydropower

There are no hydropower facilities associated with USACE projects within the Kansas River Basin and tributaries. However, the Bowersock Mill run of river hydropower facility at Lawrence, under private ownership, is kept informed of changes in Kansas City District Reservoir Project releases and forecasts of flows above and below the plant.

Recreation

A comprehensive master plan for recreational purposes and land management for each project in the basin has been prepared in coordination with the National Park Service, U.S. Fish and Wildlife Service (USFWS), U.S. Public Health Service, Kansas Department of Forestry, Kansas Department of Wildlife, Parks, and Tourism (KDWPT), Kansas Park and Resources Authority, and Kansas Board of Health. Provisions have been made at each project for interior roads, parking areas, boat launching ramps, group shelters, comfort stations, drinking water supplies, and other facilities for picnicking or camping.

Optimum recreational use of the projects depends on maintaining the reservoir elevations near the multipurpose pool level, particularly for the boat ramps, marina facilities, and swim beaches. Moderate rises in the pools do not have a large impact on recreation. Some boat ramps and beaches become unusable when more than 25% of multipurpose pools are lost. Most of the recreational use occurs in the summer, but fishing and hunting access is important throughout the year

Fish and Wildlife

A wide variety of fish and game species occur within the Kansas River Basin, but aquatic resources can be limited in the western parts of the basin due to long periods of little or no stream flow. In the more humid eastern parts of the basin, natural stream flows are enough to support significant populations of fish and other aquatic organisms. Some mammals, birds, and fish species provide significant recreational opportunities for anglers, hunters, and non-consumptive recreationists.

Close cooperation between the USACE Kansas City District office, project operating personnel, and KDWPT has resulted in operation plans recognizing reservoir fish and wildlife management objectives. One significant feature of this cooperation is the annual development of water level management plans for each reservoir. These plans modify the effective multipurpose pool elevation for water release guidance to principally benefit fish and wildlife on the reservoir. Those plans are reviewed and modified annually in cooperation with the state with the restriction not to exceed the lowest 5% of the respective flood control storage.

The typical water level management plan for Kansas River reservoirs calls for a low winter level for ice control and to provide additional buffer storage for large winter and spring flows. In the spring, a slow pool rise is preferred to enhance fish spawning. For the same reason, large releases are minimized to prevent fish entrainment through dams. Later in the spring and in the summer, the pool is usually maintained close to the multipurpose level to enhance recreation and maximize flood control benefits during the wet season. In the late summer or early fall, the pool may be lowered to enhance shoreline vegetation growth. Then later in the fall the pool is allowed to rise when water is available to inundate the vegetation growth and maximize waterfowl habitat and hunting access. In late December the pool is lowered to its winter level.

3.4.3 System Limitations

Generally long travel times from the controlling dams and the opportunities for large uncontrolled local inflows are limited in the Kansas River Basin. In general, the water travel time with bank full flows is approximately 40 to 50 miles (64.4 to 80.5 km) per day. The travel time from Kanopolis, Wilson, and Waconda reservoirs to Junction City is about 4 days, and therefore those projects are typically not operated for points below Enterprise, KS. Wamego tends to be the index gauge in that reach and only Milford and Tuttle Creek can reduce flood flows at Wamego. During moderate and high flood flows, the controlling damage point for reservoir regulation often becomes Waverly, because of the restricted channel capacity on the Missouri River at that point.

The longer the travel time for flows from a reservoir to a downstream target flow point, the less chance the reservoir will be able to provide effective stage control because of the incidence of local inflows and lengthy reaction/travel time. From Milford Reservoir to Wamego travel time is about 2 days, and from Tuttle Creek to Wamego it is about 1 day. For points within one day travel time downstream, the reservoir releases could be reduced soon enough to have a large impact on potential flood flows, although sometimes the flood flows could not be entirely eliminated. Peak local flows generally occur in the intervening local reach within one day after a storm, and the effectiveness of the reservoir decreases rapidly after one day and with the magnitude of the storm.

3.4.4 System Flexibility

Much of the flood control flexibility of the reservoir project system is derived from the ability to regulate each reservoir within broad bands defined by the seasonal phase diagrams (see Figure 8 and Figure 9). Flexibility increases when normal basin runoff occurs. The flexibility of the system becomes much more restricted as the flood control pools fill and the urgency to evacuate accumulated flood control storage increases. Because the Kansas River Basin is subject to prolonged droughts it is desired to maintain the reservoirs at multipurpose pool. This also enhances recreation opportunities and fish and wildlife habitat. While a routine operational pattern is followed, detailed plans for specific floods are not a part of the normal operating plans.

3.5 Changes in Physical Processes and Flows Resulting from Impoundments

Compared to natural conditions reservoir regulation has resulted in a widely differing flow regime. The two principal differences comparing pre- to post-impoundment conditions include flow duration and sediment load changes. Flow duration for floods on the Kansas River mainstem have changed from a natural hydrograph with a high peak and a few days duration to a modified hydrograph with a lower peak and a longer duration. Likewise, sediment loads are mostly detained within the reservoirs while downstream post-impoundment sediment transport is of lower volume and altered particle-size distribution.

Sanders et al. (1993) discussed many of the flow scenarios an SRP for the Kansas River mainstem needs to consider, including shape, patterns, and timing of flows as well as magnitude. They summarize impacts of reservoirs on river flows, as described by Simons et al. (1984):

- Reservoirs modified lateral migration and trapped 95-98% of all suspended sediment and 100% of sand-sized particles
- Sediment yield in the Kansas River declined from 23.48x109 kg in 1958-1961 to 7.71x109 kg in 1978-1980
- Within 12 years of dam operation, clear water releases degraded (up to 3 miles) the areas immediately below dams
- There remains no more permanent riverine lentic habitat other than some oxbows
- The Simons et al. (1984) model of lower Kansas River pre-and post-impoundment flows shows higher high-water peaks without reservoirs (Fig. 10).

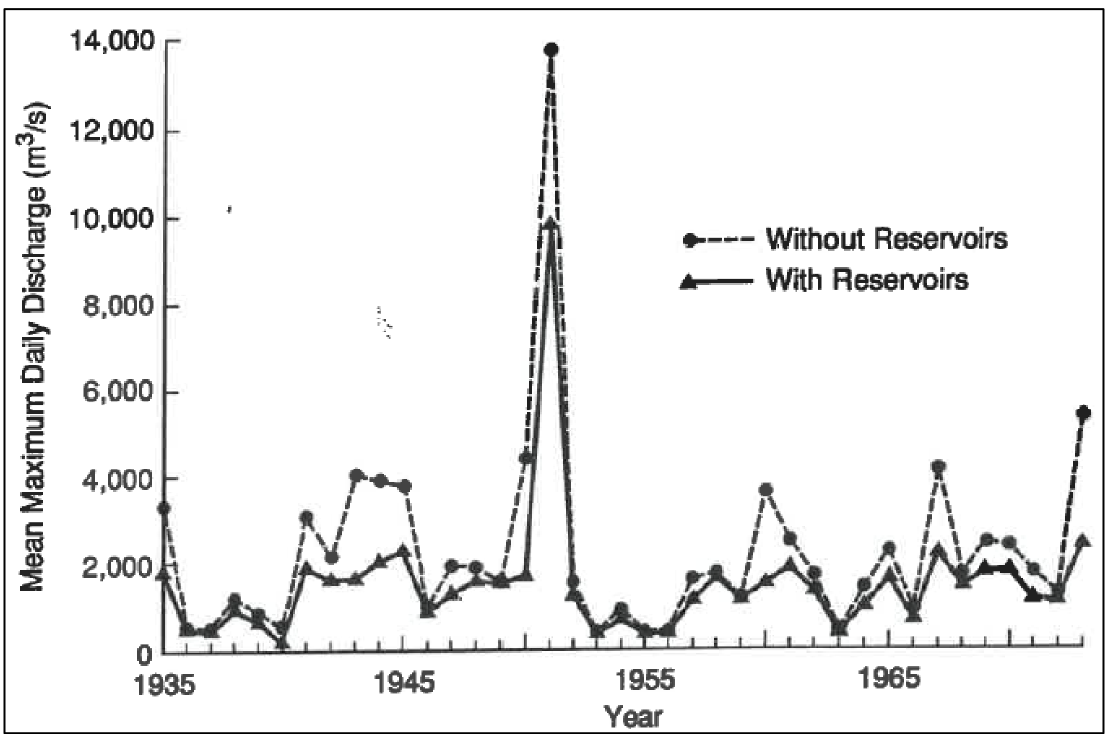

Figure 10. Modeled Lower Kansas River Flows - Pre- and Post-Impoundment (Simons et al. 1984)

Similarly, Figure 11 shows the average annual hydrographs for the Kansas River mainstem at Lecompton, Kansas based on discharge data collected before and after construction of the primary federal reservoirs (not including Clinton Reservoir) on the main tributaries of the Kansas River mainstem (Huggins and Liechti unpublished work using USGS data 2019).

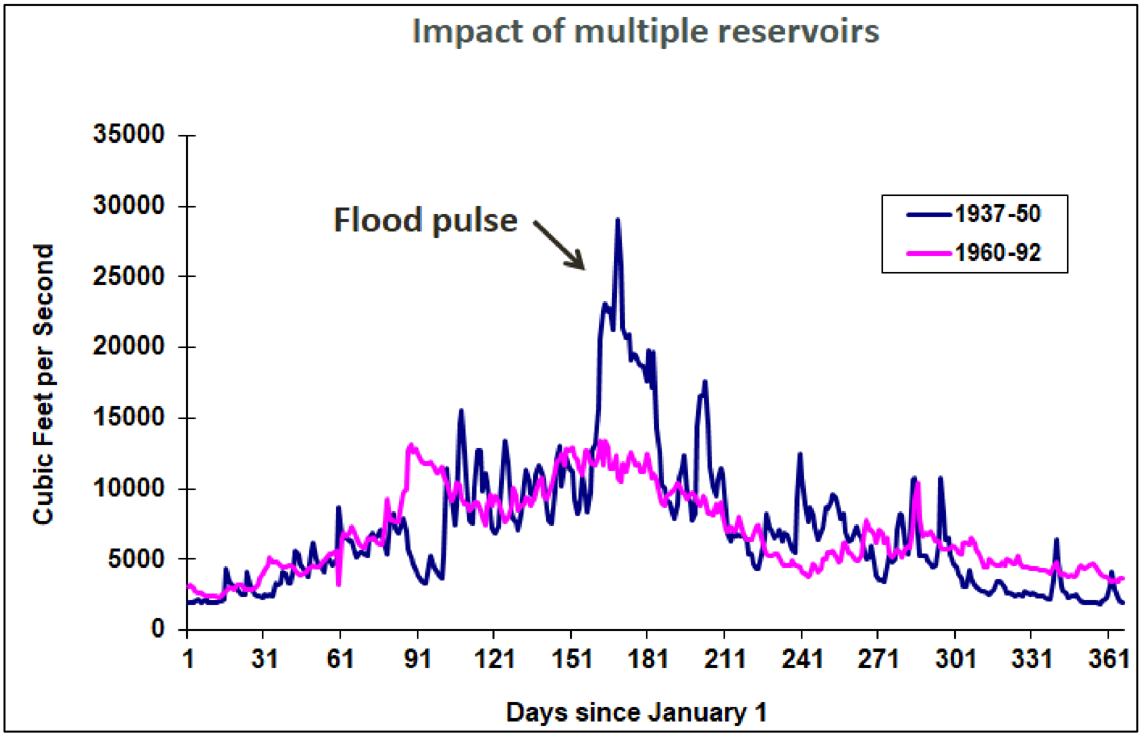

Figure 11. Kansas River Hydrographs at Lecompton, KS - Pre- and Post-Impoundment (Huggins and Liechti unpublished using USGS 2019)

More recently, O'Neil (2010) examined how the hydrology of the Kansas River mainstem affects habitat complexity and concluded that impoundments on the river have eliminated much of the complexity, which in turn reduces the diversity of the organisms found in this more homogenous habitat. There is less refugia for organisms to shelter in during flows which are now more abruptly high or low due to reservoir operation, as well as less variation needed for reproduction and feeding.

Quist et al. (2005), Perkin and Gido (2012), Hubert and Gordon (2006), and Perkin et al. (2015) found impoundments on Great Plains streams alter aquatic community structure both upstream and downstream with some species being extirpated. Stocked impoundments provide a source and opportunity for non-native fish species to proliferate and outcompete native species in altered habitats. Impoundments were also responsible for modifying the hydrograph and water clarity downstream to the detriment of native fish species (as cited in USBR 2016).

The Republican River system consists of nine operational storage projects. Milford and Harlan County Reservoirs, both located on the Republican River main stem, were constructed by the USACE. Swanson Lake, located on the main stem above Harlan County Reservoir, and Lovewell Reservoir, Harry Strunk Lake, Hugh Butler Lake, Norton Reservoir, Enders Reservoir, and Bonny Reservoir, are all located on major tributaries of the Republican River, and were constructed by the USBR. Irrigation is by far the dominant water demand within the Republican River Basin, with other water uses for municipal and domestic uses, industry, recreation, and wildlife. All of the federal reservoirs in the Republican River Basin provide water for irrigated agriculture in the alluvial valleys that border the Republican River and its primary tributaries. Declines in groundwater levels and stream flows have and continue to be widespread throughout the Republican River Basin, creating intense competition for limited water supplies. Republican River Basin impoundments have altered stream flow discharge and flow patterns.

The pre-settlement hydrograph (see Figure 14) has changed from flood flows in late winter and spring with lower flows or ponding in summer and fall to a new pattern where flood flows are impounded and released during the growing season to accommodate irrigation demands (USBR 2016).

Reductions in the volume of water conveyed through Republican River Basin streams along with habitat fragmentation caused by impoundment and diversion structures have become significant threats to native aquatic resources and biodiversity. In-stream diversions, groundwater pumping, on-farm soil and water conservation practices, upstream irrigation development, and extended drought in the Republican River Basin have significantly decreased stream flows and inflows in most reservoirs. These activities and conditions have transformed pre-settlement riverine habitats to highly-variable, inhospitable habitats in which long-term persistence of native fish is questionable. Reservoirs levels are lower than planned, and less water is available to release during the non-irrigation season. Only in those reaches of Republican River Basin streams where irrigation return flows, groundwater discharge, and canal or dam seepage occur have flows been somewhat sustainable (USBR 2016).

Perkins and Gido (2011) reported that groundwater withdrawals in western Kansas have contributed to dry streams during 70-99% of pelagic-spawning cyprinid reproductive seasons (May-August), providing limited opportunity for spawning and successful recruitment. Stream discharge in the Smoky Hill River Basin has generally decreased in quantity and variability (see Figure 12 and Figure 13) relative to eastern Kansas streams from groundwater withdrawals and increased fragmentation by impoundments (Gido et al. 2010). Both agricultural development and the construction of reservoirs and smaller impoundments have impacted streams in the Solomon River Basin in north-central Kansas (see Figure 17 and Figure 18). Diversions of reservoir releases for irrigation has dewatered stream segments below diversion structures threatening aquatic communities. The reduced peak discharges and generally stable flows produced by regulated releases following construction of large reservoirs has caused some river channels downstream from the reservoirs to become narrower and deeper with firmer substrates.

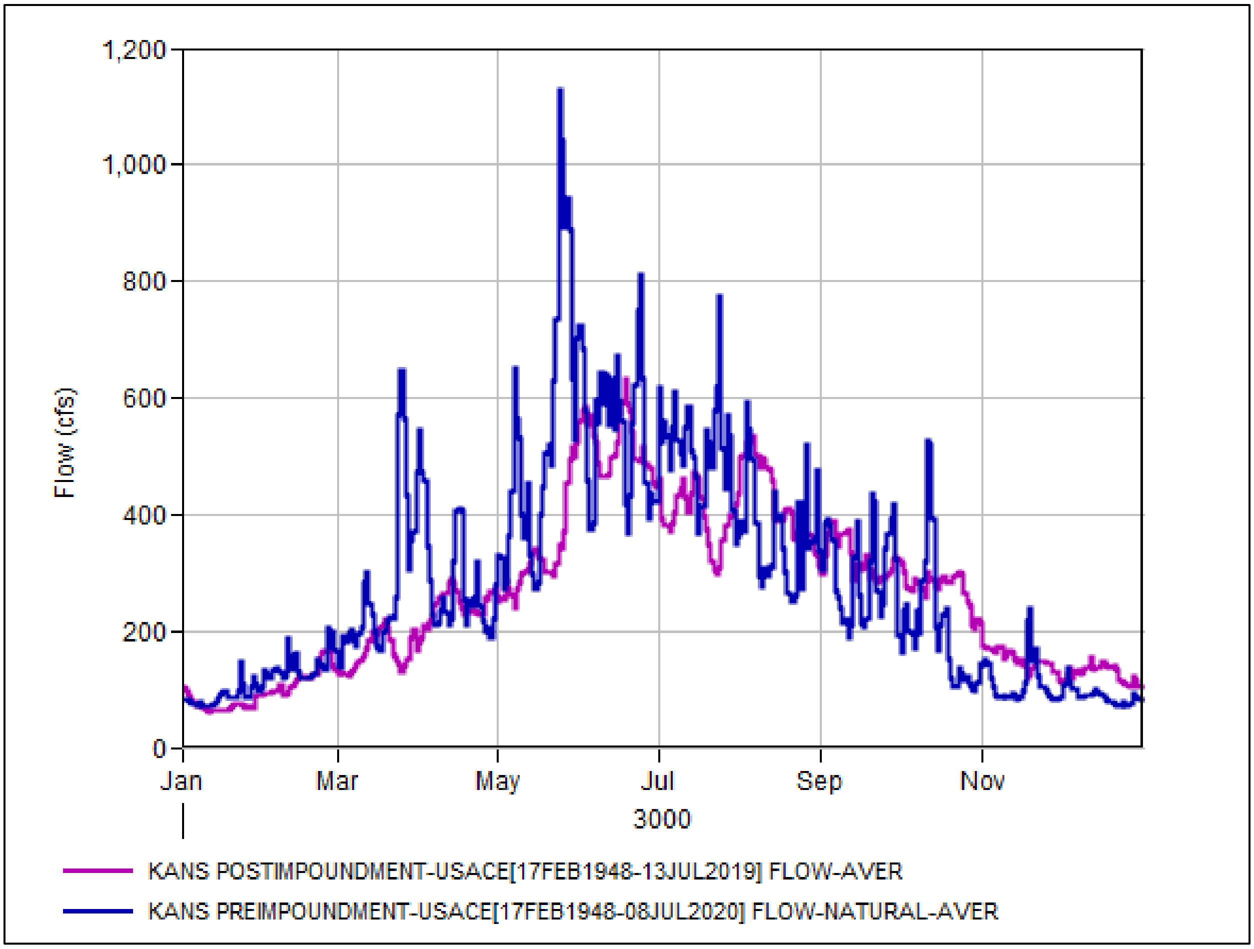

Figure 12. Smoky Hill River Hydrographs at Kanopolis Reservoir, KS - Pre- and Post-Impoundment

Figure 12 shows the flows from Kanopolis Reservoir pre- and post-impoundment. Pre-impoundment the Smoky Hill River was more prone to higher flows over shorter durations, with the higher flows occurring during spring. Post-impoundment the river flows have been significantly lower and over longer durations occurring during summer and early fall. The early spring flood flows are stored in impoundments and used during the growing season for irrigation of crops. The impoundment has also led to the ability to hold flood flows and slowly release throughout the summer to prevent flooding of downstream areas. Post-impoundment flows have increased during the winter months, which allows for the evacuation of excess water in the impoundment in anticipation of spring inflows.

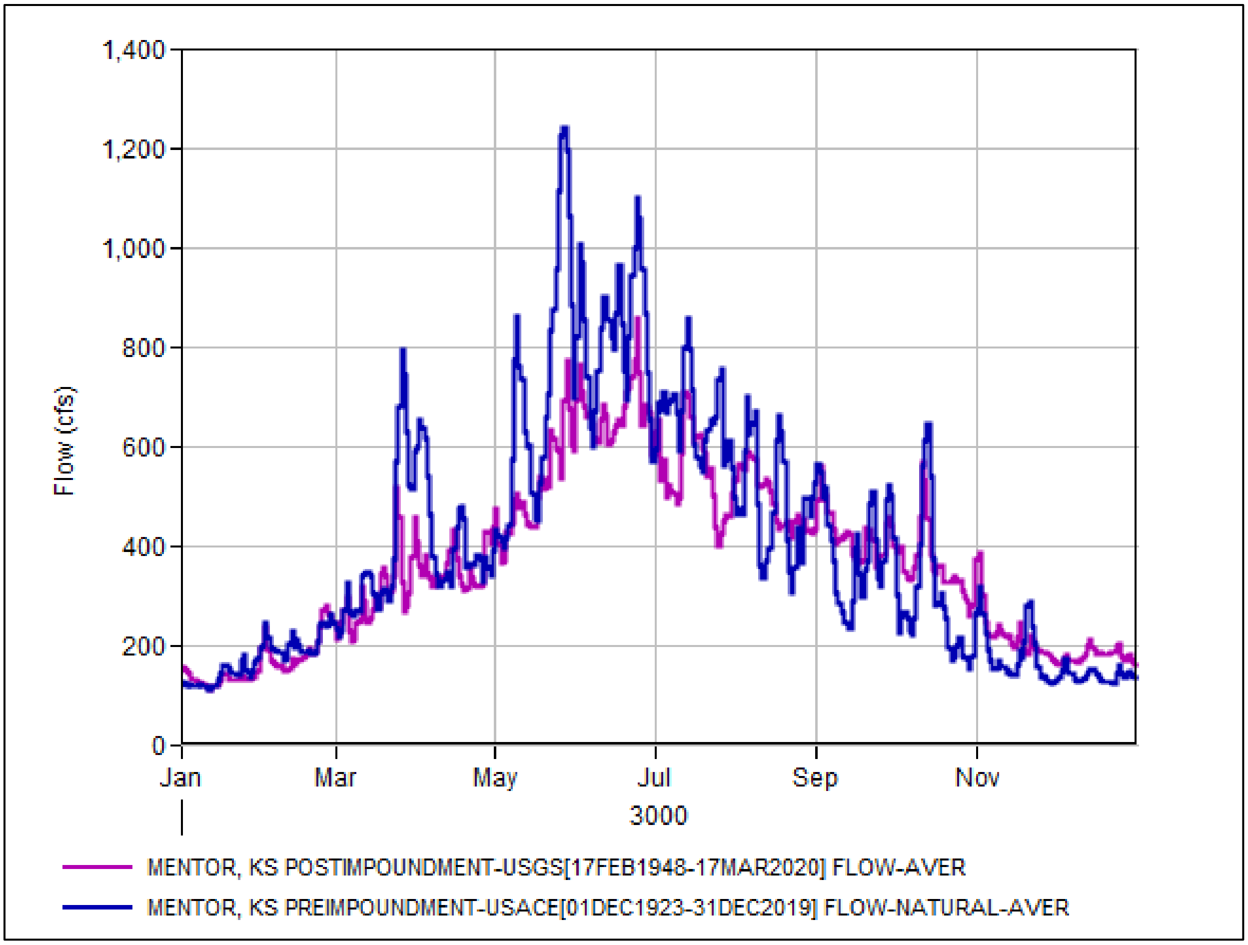

Figure 13. Smoky Hill River Hydrographs at Mentor, KS - Pre- and Post-Impoundment

Figure 13 shows the flows on the Smoky Hill River pre- and post-impoundment from the gauge located near Mentor, Kansas. Pre-impoundment the river was prone to higher flow rates during the spring caused by spring rains that would spike and last for a short duration before dropping back down. Post-impoundment the river flood flows are much lower due to the ability of the reservoir to hold flood flows. Flows are released at a lower rate for a longer duration and are controlled by the impoundment to protect downstream areas. However, due to the need to control flows and release them at a lower rate, higher flows are seen during the winter months, when historically the flows were lower.

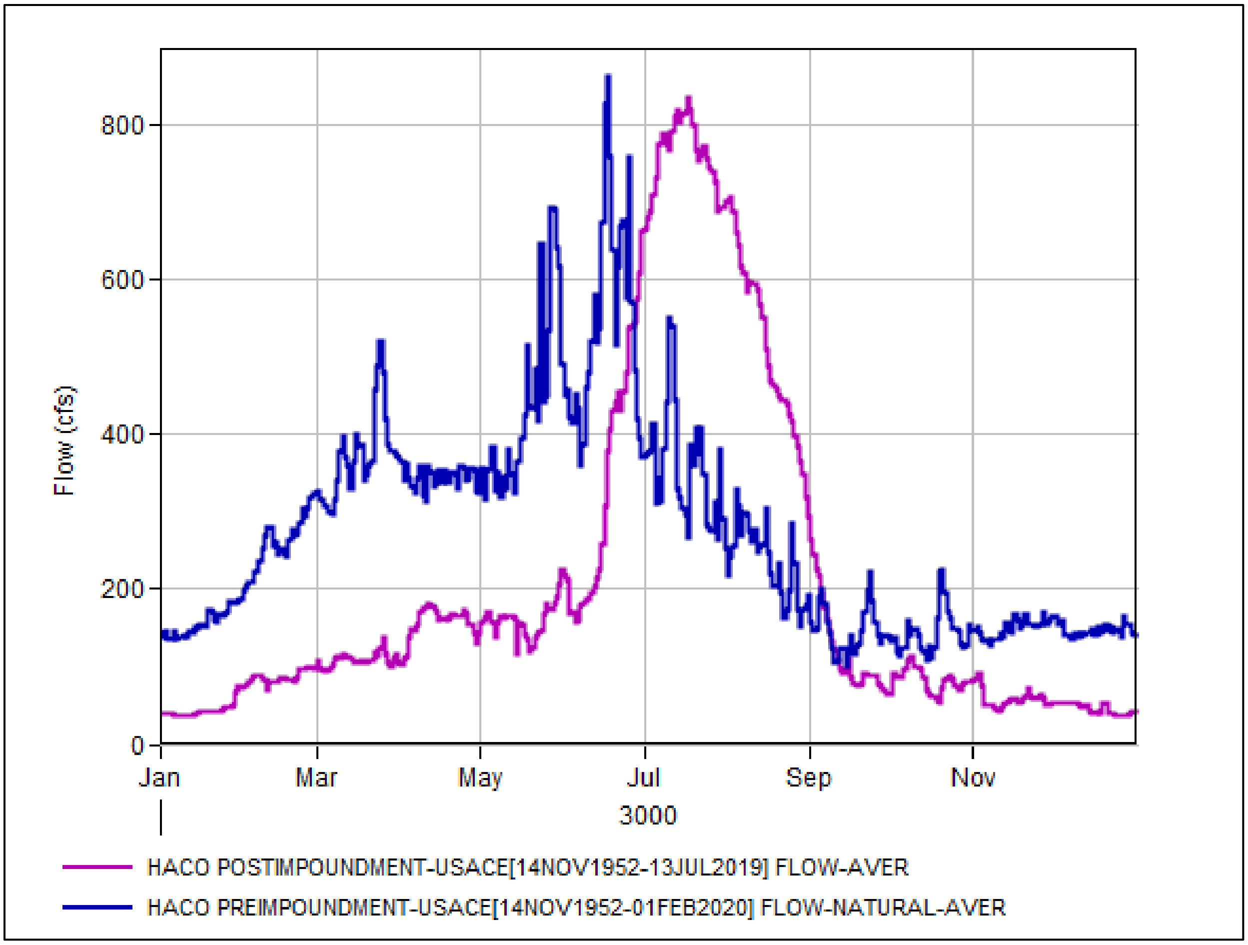

Figure 14. Republican River Hydrographs at Harlan County Reservoir, NE - Pre- and Post-Impoundment

Figure 14 shows the flows from Harlan County Reservoir pre- and post-impoundment. Pre-impoundment the Republican River was more prone to higher flows over shorter durations, with the higher flows occurring during the spring. Post-impoundment the river flows have been significantly lower during the spring and occur over longer durations, occurring during summer and early fall. The early spring flood flows are impounded and used during the growing season for irrigation of crops. Due to the possibility of ice, the reservoir is lowered before winter, resulting in higher flows of increased duration during late summer and fall.

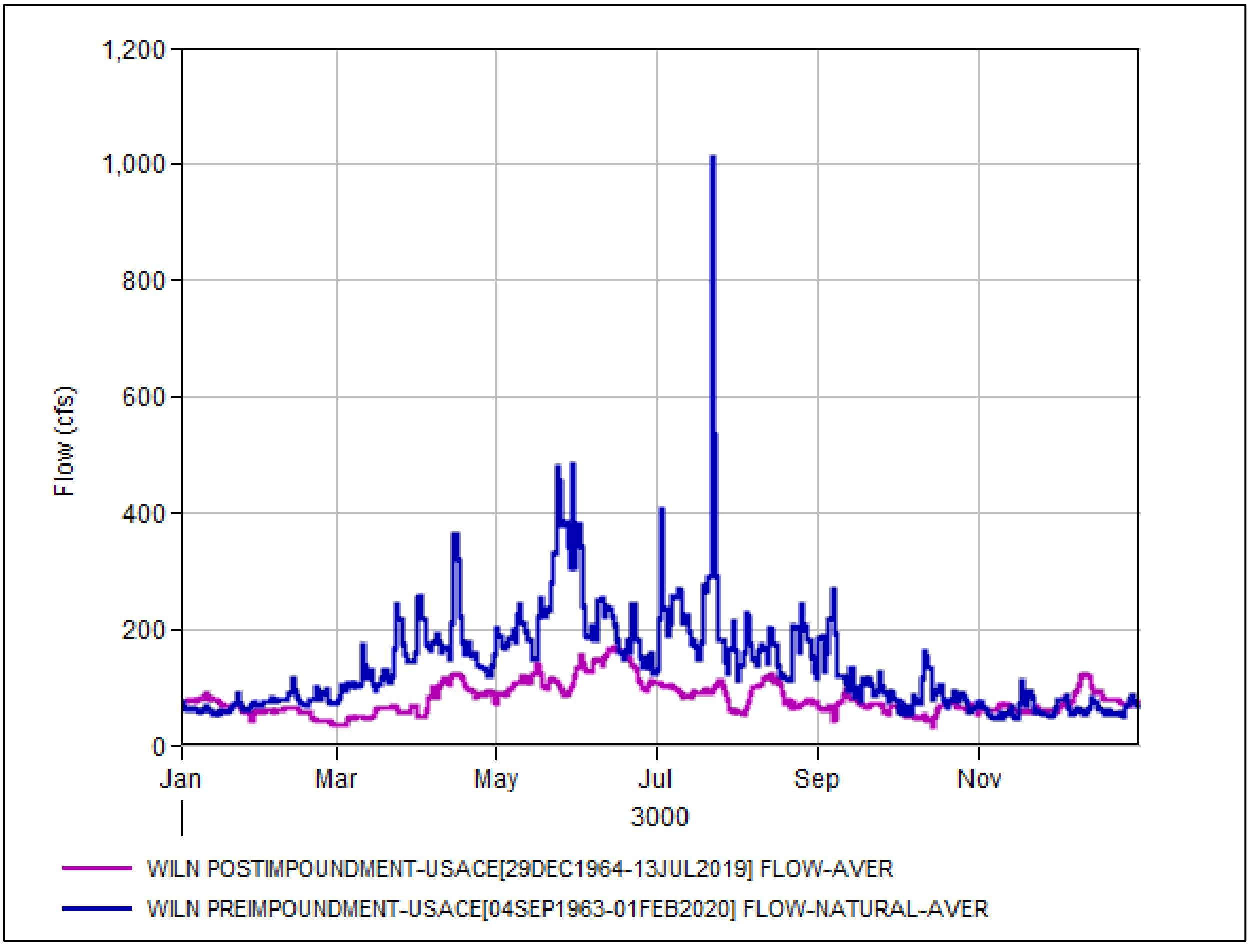

Figure 15. Saline River Hydrographs at Wilson Reservoir, KS - Pre- and Post-Impoundment

Figure 15 shows the flows from Wilson Reservoir pre- and post-impoundment. Pre-impoundment the Saline River was more prone to higher flows over shorter durations, with the higher flows occurring during spring and summer. Post-impoundment the river flows have been significantly lowered and over longer durations occurring during summer and early fall. The early spring flood flows are impounded to reduce flooding and allow slow release throughout the summer. Post-impoundment flows have increased during the winter months, which allows for the evacuation of excess water in the impoundment in anticipation of spring inflows.

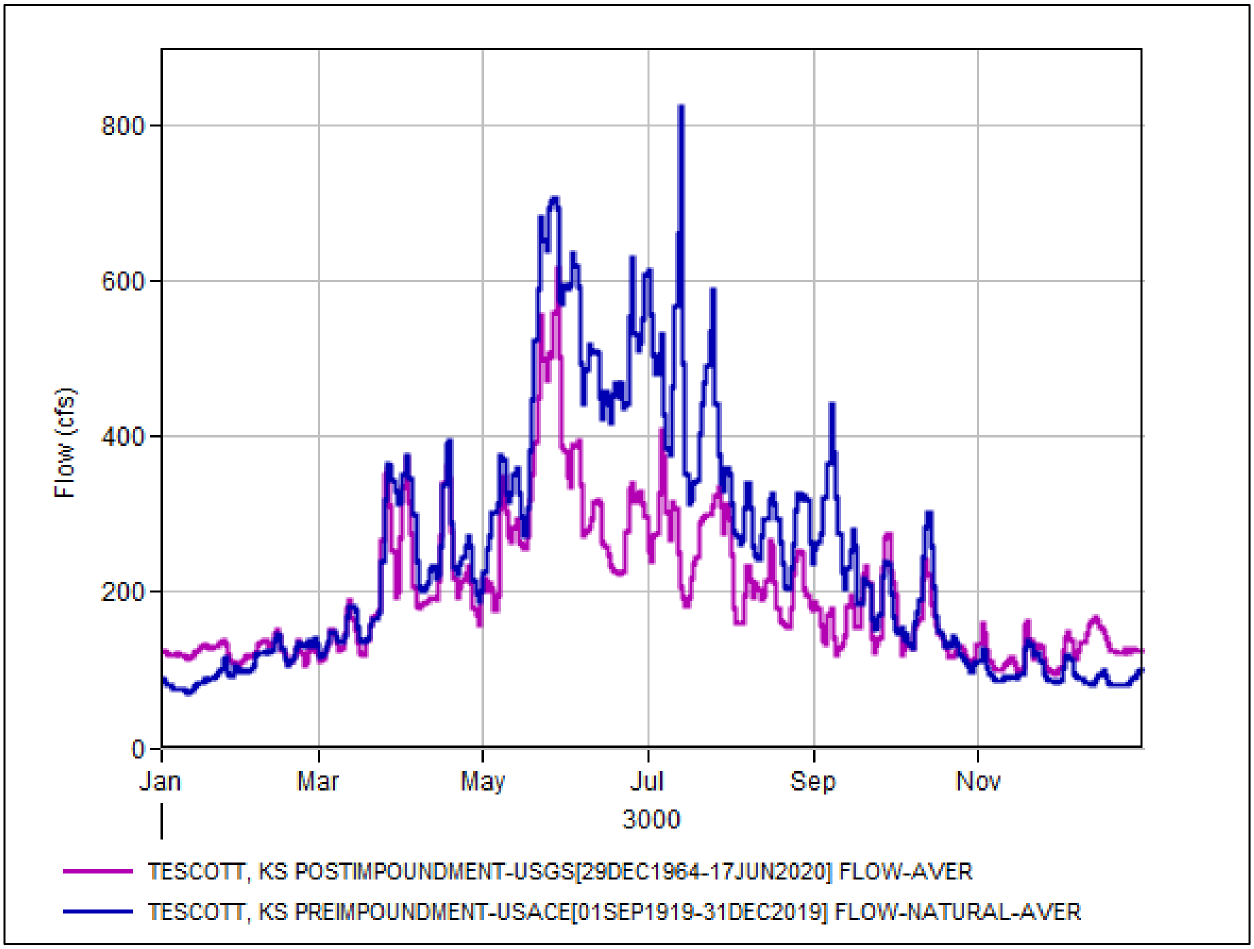

Figure 16. Saline River Hydrographs at Tescott, KS - Pre- and Post-Impoundment

Figure 16 shows the flows on the Saline River pre- and post-impoundment from the gauge located near Tescott, Kansas. Pre-impoundment the river was prone to higher flow rates during the spring and summer caused by spring rains that would spike and last for a short duration before dropping back down. Post-impoundment the river flood flows are much lower due to the ability of the reservoir to hold flood flows. Flows are released at a lower rate for a longer duration as they are controlled by the impoundment to protect downstream areas. However, as a result of reduced flows after spring flood capture, higher flows are seen during the winter months as reservoirs are lowered for winter when historically the flows were lower.

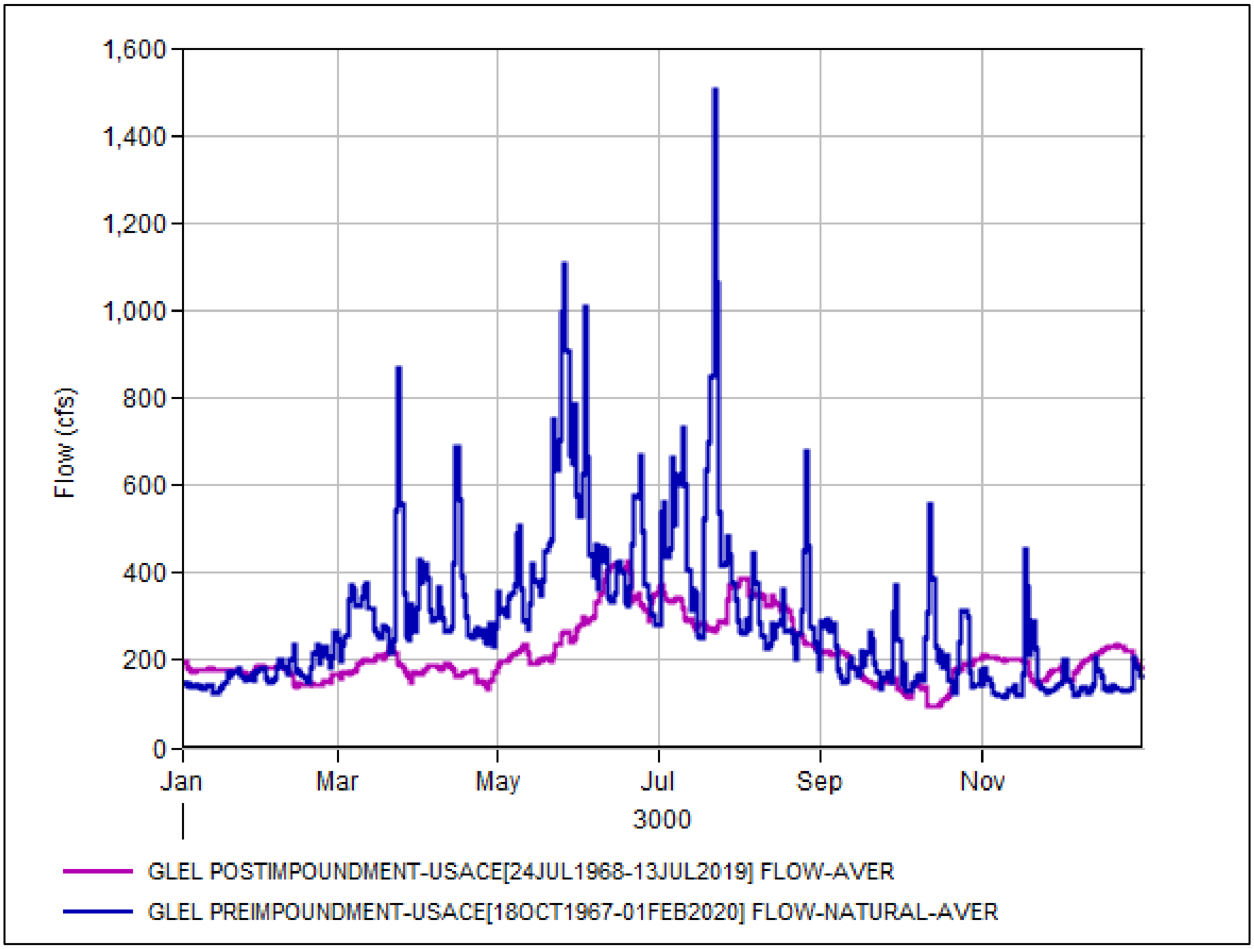

Figure 17. Solomon River Hydrographs at Waconda Reservoir, KS - Pre- and Post-Impoundment

Figure 17 shows the flows from Waconda Reservoir pre- and post-impoundment. Pre-impoundment the Solomon River was more prone to higher flows over shorter durations, with the higher flows occurring during spring and summer. Post-impoundment the river flows have been significantly lowered and over longer durations occurring during summer and early fall. The early spring flood flows are able to be impounded and used during the growing season for irrigation of crops. The impoundment has also led to the ability to hold flood flows and slowly release throughout the summer to prevent flooding of downstream areas. Post-impoundment flows have increased during the winter months, which allows for the evacuation of excess water in the impoundment in anticipation of spring inflows.

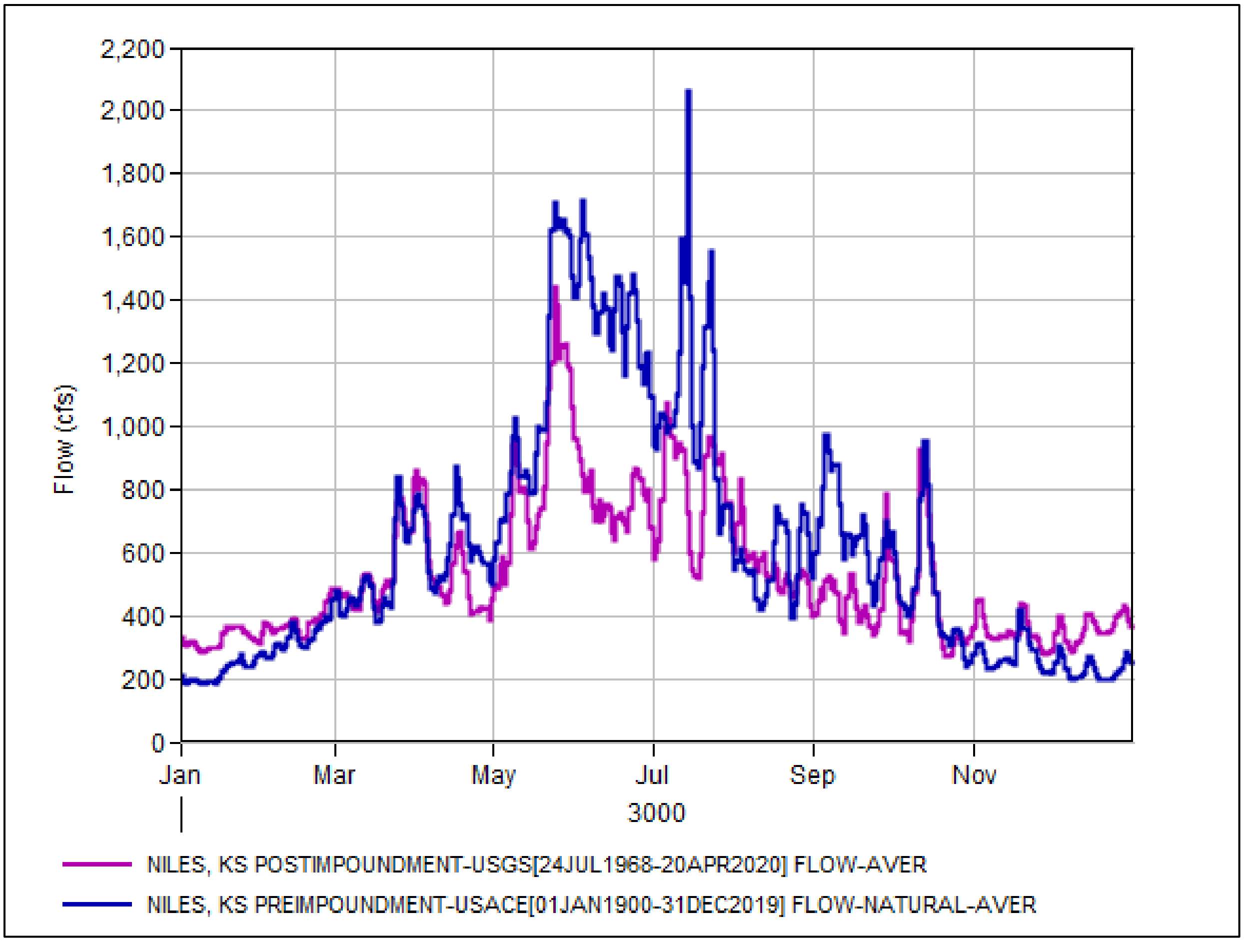

Figure 18. Solomon River Hydrographs at Niles, KS - Pre- and Post-Impoundment

Figure 18 shows the flows on the Solomon River pre- and post-impoundment from the gauge located near Niles, Kansas. Pre-impoundment the river was prone to higher flow rates during the spring and summer caused by spring rains that would spike and last for a short duration before dropping back down. Post-impoundment the river flood flows are much lower due to the ability of the reservoir to hold flood flows. Then are released at a lower flow rate for a longer duration as they are controlled by the impoundment to protect downstream areas. However, due to the need to control flows and having them at a lower rate, higher flows are seen during the winter months when historically the flows were lower.

3.5.1 Floodplain and Channel Modifications: Geomorphology

The lower average rainfall in the western portion of the basin results in the upper watershed contributing a smaller portion of runoff than the lower watershed. Wide river valleys with relatively small sinuous channels are predominant, and these characteristics are more exaggerated in some areas such as on the main stems of the Solomon, Smoky Hill, and Saline Rivers. Sand and gravel bed materials also predominate, but bedrock is exposed in a few places. Stage/discharge relationships vary because of sand bottoms, unstable banks, river cutoffs, and man-made modifications.

Several natural and man-made modifications (e.g., weirs, dams, river training structures, bank protection structures) to the rivers continue to change the river channel and flow characteristics. These man-made features affect aggradation/degradation and lateral erosion along the channels. Many of these structures are not operated by the USACE and are referenced only for context. Changes to these structures would not be considered in development of environmental flows.

The Kansas River mainstem upstream of Bowersock Dam has a relatively stable morphology, except for the Topeka area. A 2011 survey indicates that one to two feet of riverbed degradation has occurred within the Topeka area since 1992. The river channel in the Topeka area has been hardened and narrowed with flood-control works. Based on long-term gaging station data and survey data collected in 1992, the river channel downstream of Bowersock Dam appears to be less stable than the areas monitored upstream of the dam.

3.5.2 Streambank Erosion and Sedimentation

Soils of the Kansas River mainstem floodplain are sandy, readily eroded unless protected, and in many places underlain by sand. Generally, where the outside of bends are not protected by vegetation or bank stabilization structures, erosion occurs during moderate to high stages. At many places, bank stabilization projects have been constructed by local interests and are working satisfactorily, except where they do not extend far enough upstream or downstream.

The Kansas River and all principal tributaries (e.g., Republican, Smoky Hill, Saline River, Solomon River) are sediment bearing streams and usually meander through a relatively wide floodplain. Streambeds of the Kansas and Republican Rivers are generally composed of sand. Long sections of the Big Blue, Solomon, and Saline Rivers appear to have silt or a mixture of silt and sand beds. Sediment carried in the streamflow and deposited in the beds is a factor in determining channel behavior (USACE 1966).

Sediment loads of the Kansas River mainstem, Republican River, Smoky Hill, Saline, and Solomon Rivers are affected by existing reservoirs. Reservoirs trap the bedload material and between 95 to 100% of the suspended sediment load (USACE 1966). According to the National Research Council (2011), reservoirs within the Kansas River basin have decreased the annual suspended sediment load from approximately 22,000 acre-feet/year to approximately 6,500 acre-feet/year, effectively reducing ambient turbidity downstream of the impoundments and Kansas River mainstem. The combination of six Federal reservoirs (Table 5) upstream of Wamego, KS alone are estimated to trap 8,070 acre-feet annually that would otherwise flow into the Kansas River (Shelly et al. 2016). The annual rates given in Table 5 are based on repeat bathymetric surveys and represent long-term averages.

Table 5. Sediment Trapping in Federal Reservoirs on Kansas River Tributaries Upstream of Wamego, Kansas.

Reservoir	Agency	Sediment Trapping (acre-feet/year)
Tuttle Creek	USACE	4,741
Milford	USACE	984
Kanopolis	USACE	566
Wilson	USACE	279
Harlan County	USACE	814
Waconda	USBR	686

Shelly et al. (2016) suggests sufficient monitoring data exists for Tuttle Creek (the largest of the Kansas River reservoirs) to define the typical timing as well as the quantity of sediment delivery. Whereas many of the other reservoirs within the Kanas River basin do not have sufficient monitoring data to be specifically represented. Furthermore, Tuttle Creek Reservoir would contribute to approximately 60% of the sediment load at Wamego, KS on an annual basis if sediment was not trapped within the impoundment. Figure 19 shows the average monthly suspended sediment loads for Tuttle Creek flowing into, passing through, and being trapped in the reservoir from 1984 to 2014. Values calculated from incoming sediment loads approximate the sedimentation rate calculated using repeat bathymetric surveys, as listed in Table 5. Shelly et al. (2016) applied data from Table 5 with monthly sediment delivery methodologies from Tuttle Creek to estimate sediment deficits in the Kansas River attributed to six of the Federal reservoirs (Figure 20).

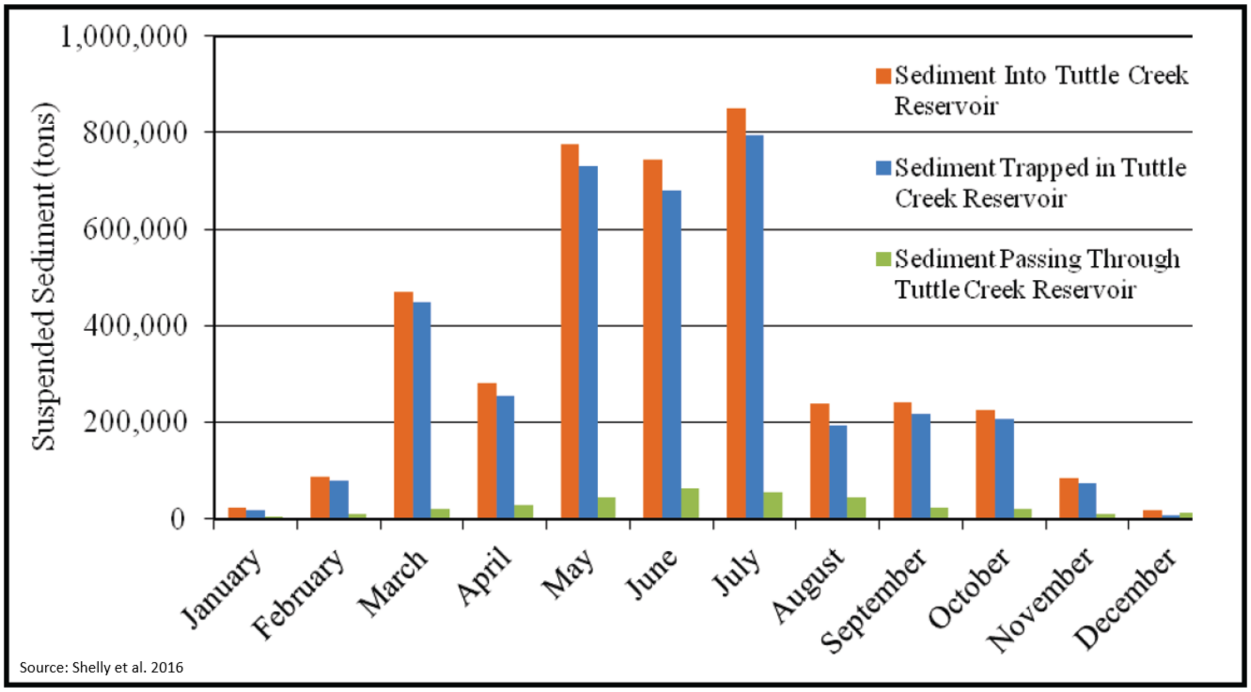

Figure 19. Sediment Into, Trapped, and Passing Through Tuttle Creek Reservoir from 1984 to 2014 (Shelly et al. 2016)

Sediment trapping by the dams has induced bed degradation and bank erosion in the channels downstream of every reservoir in the Kansas River Basin except for Wilson Reservoir. During the past several decades, various reaches of the Kansas River mainstem have experienced riverbed degradation. The most pronounced adverse effects have occurred in the lower river. These effects have been attributed to several causes, including commercial sand and gravel dredging, the federal reservoir system, lowering of the Missouri River water surface elevation(s), and other man-made influences such as Bowersock Dam and a rock weir in Johnson County. Riverbed degradation can create an unstable river channel which results in secondary impacts such as bank erosion, channel widening, lowering of water surface elevations in the river channel, lowering of water table elevations adjacent to the river, and alteration of aquatic and terrestrial habitat.

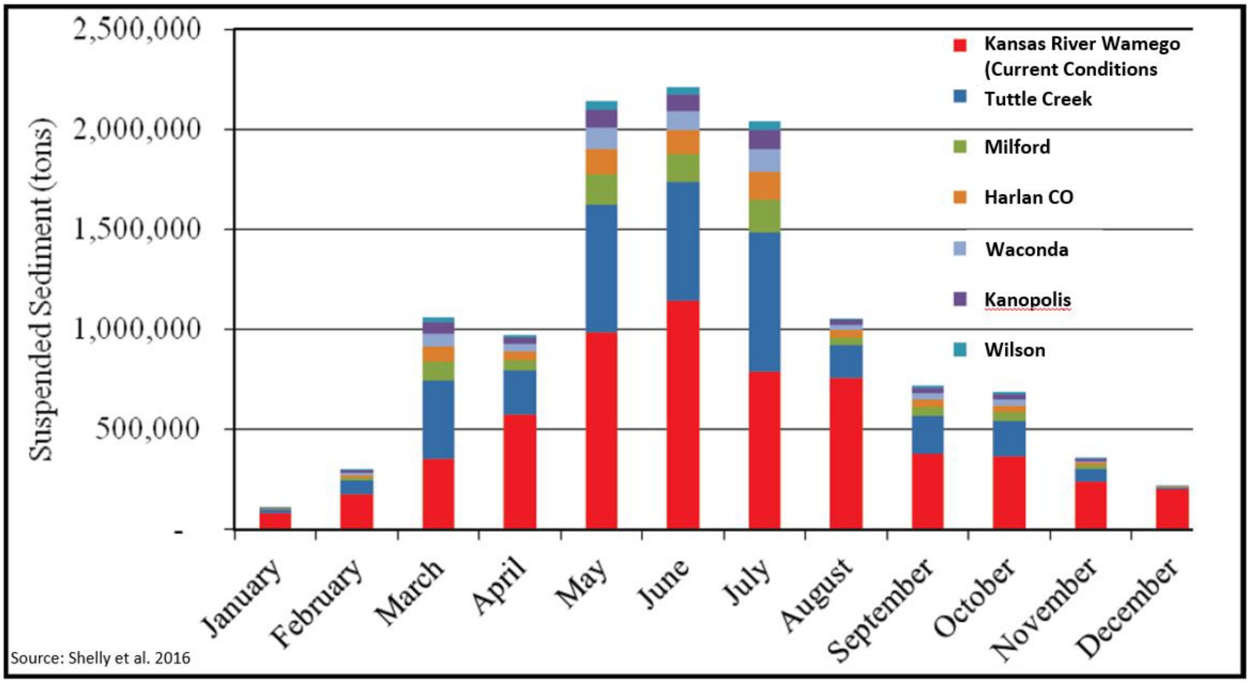

Figure 20. Approximate Average Monthly Sediment Load Deficit in the Kansas River Attributed to Six Federal Reservoirs (Shelly et al. 2016)

3.5.3 Water Quality

Water quality issues in the Kansas River Basin are dominated by non-point sources for contamination from agricultural land. Water quality issues include: 1) large sediment discharges into streams and sediment deposition in reservoirs caused by intensive cultivation of row crops and subsequent erosion; 2) pesticides washed into streams and reservoirs that could affect aquatic life and impair raw public water supplies, including both surface and groundwater sources; 3) bacterial contamination to surface water and groundwater caused by runoff from pastureland and feedlot operations, and municipal wastewater discharges; and 4) nutrient enrichment in reservoirs and in the river channel (USACE 2017; USGS 1987). Water quality issues in the lower Kansas River Basin are primarily related to land-use practices with agricultural being the dominant factor; however, industrial and residential land uses also impact water quality in the Kansas River and the adjacent alluvial aquifer.

Runoff from agricultural land contributes sediment, pesticides, and other organic compounds and nutrients to river systems, reservoirs, and groundwater sources. Reservoir management can affect channel geometry and, therefore, erosion and sediment transport, which in turn influence the transport of contaminants that are attached to sediment. Sediment further serves as a vehicle for the transport of phosphorus, ammonia, organic nitrogen, organic carbon, and sparingly soluble pesticides. The transport of these constituents associated with sediment discharge is viewed by state and federal agencies as an important water-quality issue in the basin (USACE 2017; USGS, 1987). Nutrient enrichment has been identified as one of the leading causes of impairment for rivers and streams in Kansas (USACE 2017; KDHE 2002).

A study conducted by the USGS and KDHE (1999–2003) to describe water quality in the lower Kansas River Basin found that, of the total flow for the Kansas River at DeSoto during the 5-year period the largest contribution to stream flow (29%) came from the Big Blue River as discharge from Tuttle Creek Reservoir. The next largest flow contribution (18%) came from the Smoky Hill River. The Delaware River downstream from Perry Reservoir contributed 10%, the Republican River downstream from

Milford Reservoir contributed 8%, and the Wakarusa River downstream from Clinton Reservoir contributed 4% of the stream flow at DeSoto. The remaining 31% came from combined miscellaneous sources including Vermillion, Mill, Soldier, and Stranger Creeks; direct rainfall and runoff; and groundwater contributions (USACE 2017; Putnam and Schneider 2004).

The transport of constituents (nutrients, bacteria or sediments) through reservoir-controlled river systems is affected by the interaction between the inflowing water and the chemical and biological processes occurring in the reservoir (Thorton, Kimmel, & Payne 1990). Reservoirs serve as repositories, or sinks, for contaminants such as nutrients, pesticides, and sediment-associated contaminants (USEPA 1984; Humenick, Smolen, and Dressing 1987). Although most of the sediment entering reservoirs is permanently trapped and deposited on the bottom, chemicals such as soluble herbicides remain in the water column and are stored temporarily until flushed from the reservoir, which results in smaller peak concentrations that can persist for much longer periods (Stamer, Battaglin, and Goolsby 1998). Consequently, with few exceptions (i.e. ammonia), nutrient and pesticide concentrations are lower below the Kansas reservoirs than what is observed entering the reservoirs (Figures 21 and 22) (USACE unpublished data 2021).

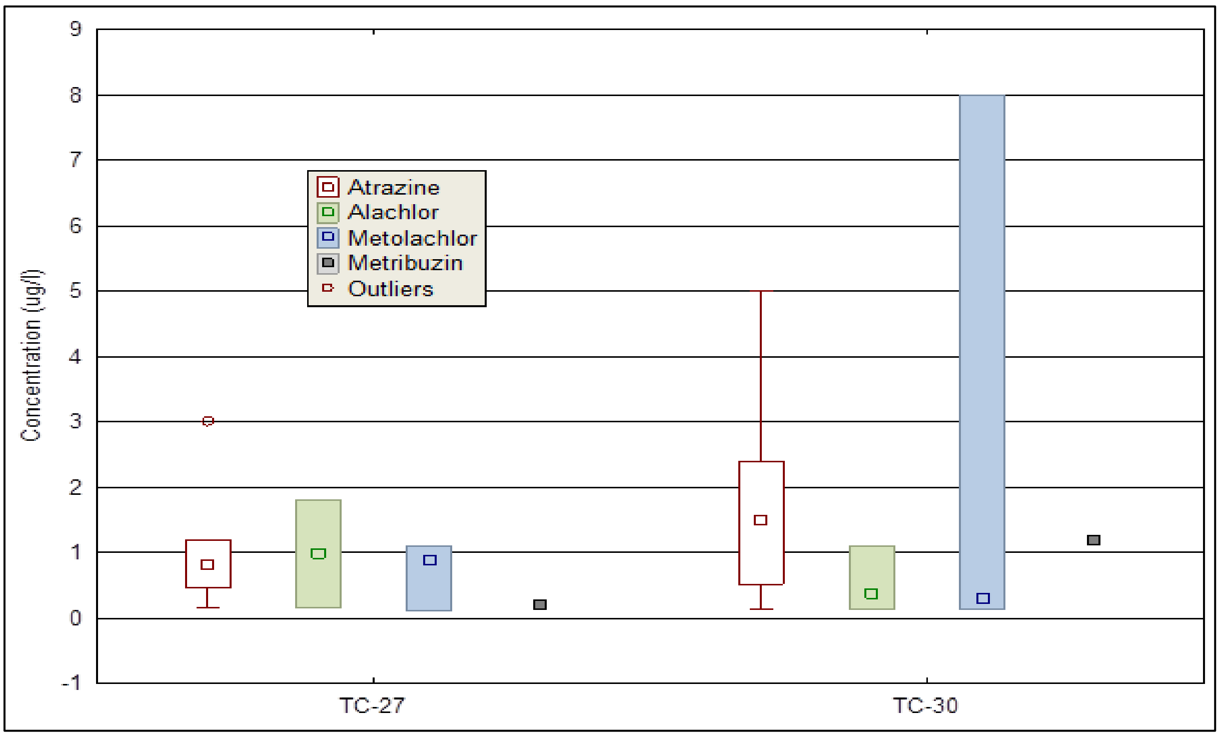

Figure 21. Herbicide concentration (ug/L) measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) sites from 2010-2019 (USACE unpublished data)

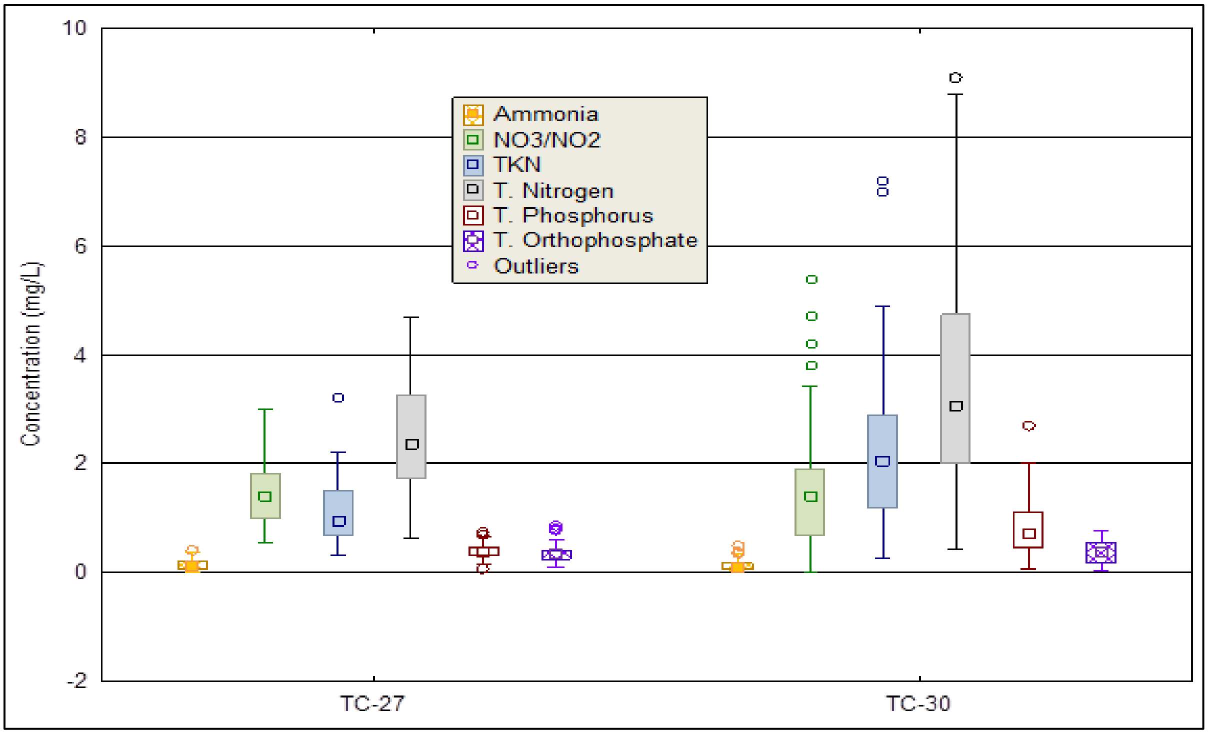

Figure 22. Nutrient concentration (ug/L) measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) USACE water quality sample sites from 2010-2019 (USACE unpublished data)

3.6 Biological and Ecological Conditions

Bank erosion, sediment, and channel widening have a high potential to impact the biological community. Bank erosion impacts aquatic organisms by increasing suspended solids concentrations in the river which reduce light transmission and increase siltation and embeddedness of the channel bottom material. Erosion adversely impacts wildlife populations by destroying riparian habitat. Some reaches of the Kansas River mainstem have only a narrow band of uncleared land along their banks and, when erosion destroys these fringe areas, many birds, mammals, and other terrestrial animals lose critical habitat. Channel widening increases the river's cross-sectional area and therefore, may reduce flow velocities and increase siltation.

3.6.1 Land Use and Major Habitat Types

Today, all suitable land in the Kansas River valley is devoted to agriculture (USACE 1966). The western portion of the Kansas River Basin is primarily in dryland farming with sorghum and wheat the primary crops with areas of irrigated cropland (Rohweder 2015). The eastern two-thirds of the Basin are in various agricultural uses with much of the floodplain area and many areas in the uplands in crops such as corn, wheat, soybeans, and milo. Lands with steeper topography are mostly in pasture and hay.

Current land use is a mixture of agricultural uses (cropland and pasture/hay), urban developed areas (high, medium, and low density) (including Junction City, Manhattan, Topeka, Lawrence, and Kansas City, Kansas), grasslands, forested lands, transportation corridors and extensive water bodies (lakes, rivers, ponds, and wetlands).

Land use adjacent to the Kansas River mainstem floodplain is predominantly agricultural with 28% in cropland and 45% in grassland. These are the two most widespread land cover types in the floodplain as well with cropland approximately 60% of the area and grassland 14%. Cultivated land located outside of the Kansas River floodplain extends up the valleys of many of the larger tributaries such as the Wakarusa River south of Lawrence, Vermillion Creek north of Wamego, and the Big Blue River at Manhattan. Westward from Shawnee County, the uplands become increasingly covered by grassland. Table 6 shows the areal extent and percent coverage for 10 different land-cover categories in the Kansas River mainstem floodplain.

Table 6. General Land Use Classifications - Kansas River Floodplain

General Class	Percent	Square Miles
Commercial / Industrial	4	14.1
Cropland	60	201.4
Grassland	14	48.6
Other	4	15.0
Residential	3	10.4
Urban-Grassland	1	4.8
Urban-Water	0	0.2
Urban-Woodland	0	0.5
Water	6	19.1
Woodland	7	24.1

The vegetative community within the urban grassland and woodland consists of a mix of grasses and trees. These urban areas attract a variety of small mammals, such as mice, shrews, voles, rabbits, and squirrels; and various songbirds (e.g., blue jays, robins, sparrows) and occasionally hawks and owls. Vegetative communities in the woodland category consists of riparian corridors consisting of bur oaks, elms, sycamore, box-elder, silver maple, cottonwood, willows, green ash, and hackberry trees with an herbaceous understory typically consisting of several species of grass, buckbrush, redbud, elderberry, Virginia creeper, and Virginia wild-rye. Terrestrial, riparian, and aquatic areas provide habitat for a variety of wildlife species, for example, deer, foxes, bobcats, opossums, rabbits, raccoons, bats, turkey, beaver, and a variety of bird species. Several species of migratory birds and their habitats can be found along the Kansas River mainstem floodplain using habitats such as wetlands, prairies, and forested areas. Invasive plant species within riparian areas include brome, fescue, Japanese honeysuckle, and garlic mustard.

Terrestrial and Riparian Communities and Habitat Types

Historically vegetation across the Kansas River Basin was mostly comprised of prairie in the west transitioning to a combination of tallgrass prairie and oak hickory woodland in the east. Upland forests were dominated by shagbark hickory, bitternut hickory, red oak, white oak, and black oak with Ohio buckeye, American bladdernut, and pawpaw found as common understory trees.

The Kansas River floodplain and the floodplains of its tributaries are important resources that convey large stormwater events and provide high-quality wildlife habitat. The floodplain of the Kansas River is defined as a riverine floodplain, which is comprised of the floodway and the flood fringe. The floodway encompasses the channel and a portion of the adjacent floodplain area necessary to convey floodwaters. The flood fringe is land located outside the floodway that is at or below the base flood elevation and stores but does not effectively convey floodwaters.

Most of the floodplain (74%) is covered by agricultural lands and grassland and water covers 6% of the floodplain. Woodlands comprise 7% of the Kansas River floodplain. Some of the larger tracts are in the east half of the floodplain in the bluffs bordering the Kansas River and along some of the river's small tributaries. Woodlands generally have less coverage west of Topeka and are confined to many small drainages and creek valleys branching off the Kansas River and its larger tributaries. In the Fort Riley area northeast of Junction City and north of the Kansas River, the larger tributary valleys are filled with woodlands; however, on privately owned land south of the river, tributary valleys are mostly cropland. Although few large woodland tracts can be found, a discontinuous riparian forest grows along the entire length of the Kansas River.

Aquatic and Wetland Communities

The Kansas River is relatively wide and shallow with a meandering course and a sandy bed. Channel widths vary from 300 to 1,000 feet from the confluence of the Smoky Hill and Republican Rivers at Junction City, Kansas and the mouth of the Big Blue River at Manhattan, Kansas. Below Manhattan the channel alternates between a minimum width of 600 feet at many locations to a maximum width of approximately 1,500 feet. The river is typically braided in the wider sections with considerable willow growth along the banks and on low islands. Old oxbows are present in various stages of reclamation along the Kansas River and provide potential opportunities to create wetland and aquatic habitat that is currently lacking. Turbidity readings for the Kansas River at Desoto from 1970-2002 ranged between 11-3,900 Nephelometric Turbidity Units (NTU) (Putnam et al. 2003).

The Republican River is a meandering sand bed stream with a typically wide and shallow channel. The floodplain varies from one to three miles in width and is generally composed of level to gently sloping benches suitable for crops. Aquatic resources in the Republican River Basin consist of plants and animals that require open water to complete some portion of their life cycle. This includes organisms like fish and submerged aquatic plants, but also includes invertebrates, reptiles, amphibians, birds, and mammals that feed or reproduce in the water or periodically inhabit aquatic or riparian habitats. The most important aquatic resource in the basin, the Republican River and its tributaries, have been substantially altered since 19th century settlement with long-lasting effects on aquatic resources. Native fish in Great Plains' streams are currently vulnerable to mortality by being stranded in streambed pools with highly-elevated water temperatures for extended periods or being entrained into reservoirs of canals. Dam construction, diversions, and groundwater pumping in the basin have moderated historic extreme conditions that supported resilient native species and created environments favorable for less-resilient organisms to inhabit and sometimes dominate basin streams (USBR 2016).

The Smoky Hill River below Kanopolis Lake Dam is a meandering channel through a wide valley of moderately deep soils. The river ranges from 120 to 250 feet wide near Salina, Kansas. Old oxbows are in various stages of reclamation, but active bank erosion is evident on nearly every bend of the river. Turbidity readings from 1970-2002 ranged between 14-1,600 NTU at Enterprise, Kansas (Putnam et al. 2003).

The Solomon River below Glen Elder Dam varies in width from 100 to 200 feet. The river flows 184 miles from Glen Elder Dam before joining the Smoky Hill River immediately south of Solomon, Kansas. The Solomon River is a meandering channel with an abundance of sand bars, formed by the confluence of the North Fork Solomon River and the South Fork Solomon River at Waconda Lake (Glen Elder Reservoir), which was impounded in January 1969. Turbidity readings from 1970-2002 ranged between 5-1,500 NTU at Enterprise, Kansas (Putnam et al. 2003).

The Saline River below Wilson Reservoir Dam is a meandering channel that varies in width from 75 to 200 feet. The Saline River is sluggish and unnavigable with no major tributaries and has a riverbed of sand and mud. The Saline River joins the Smoky Hill River just east of Salina, KS.

The Big Blue River downstream from Tuttle Creek Lake Dam varies in width from 200 to 300 feet. The channel is generally well armored with sand, gravel, and stones for several miles below the Rocky Ford Dam, an abandoned privately-owned run-of-the-river hydroelectric plant. The channel has a long history of caving banks due to the erosion of sand strata which are found near the bottom at numerous locations.

The Delaware River below Perry Lake Dam ranges from 50-100 feet in width, except in the Kansas River floodplain where it has widened to approximately 300 feet. Channel depths vary greatly. Channelization of the Delaware River above Highway 24 occurred in 1960. Turbidity readings from 1970-2002 ranged between 5-1,500 NTU at Muscotah, Kansas (Putnam et al. 2003).

Seven smaller tributaries enter the Kansas River downstream of Junction City. These tributary channels are generally steeper and proportionately smaller, but otherwise have many of the characteristics of the Kansas River channel.

The Kansas River floodplain is generally a flat topographic feature where conditions are favorable for development of woody plants during prolonged drought periods. The reaches of the Republican, Saline, and Big Blue Rivers below the reservoirs and the lower Smoky Hill River are much like the Kansas River. The Solomon and Delaware Rivers have comparatively narrow, deep, and well-defined channels in the lower reaches where willow growth is less likely to develop but where degradation is likely. The Smoky Hill River just below Kanopolis Reservoir is much like these latter mentioned streams. Here, degradation has amounted to about four feet for about a mile and then progressively less until, at ten miles downstream, no trend is discernable (USACE 1966).

Wetlands remaining along the Kansas River occur both in the floodplain and the river. Floodplain wetlands include farmed wetlands, scrub-shrub wetlands, palustrine emergent wetlands, and forested wetlands. Floodplain wetlands are supported by overland runoff, overbank flooding and occasionally by high water tables. In-stream wetlands primarily occur on islands within the Kansas River.

3.6.2 Fish

Routine, comprehensive surveys of the fish community from the Kansas River mainstem have not occurred, however there have been several surveys conducted in various portions of the watershed that can provide insight into the historical and current fish community. Included below is a list of the fish surveys that were reviewed in this report.

- In "The Fishes of Northwestern Kansas" Breukelman (1940) reports on the very early scientific collections and publications about Kansas fish. Only three papers had been published from 1889 until his 1940 paper. Eight collections were made between 1910 and 1938, including his own surveys. While his compilation of species focuses on northwestern Kansas, this report is a good reference for those early studies.
- The Cross (1967) Handbook of Fishes in Kansas was the first Kansas-wide compilation of fish species.
- The Kansas River System and Its Biota (Sanders et al. 1993) provides a history of the Kansas River and describes impacts of impoundments on sediment yields and other river conditions. It also discusses pre-and post-impoundment flows, compiling literature and graphs of the main stem and tributaries.
- Gido et al. 2010 compiled lower Kansas River Basin fish data into four collecting periods: 1947-1962, 1963-1977, 1978-1990, and 1991-2003. Using these surveys, Gido et al. (2010) examined changes in the abundance of various fish species from the Kansas River during these three periods. The statistical analyses determined which species significantly declined or increased over these periods. The examination of this data focuses on species that increased or decreased between 1947-1962 (pre-impoundment) and 1991-2003 (post-impoundment).
- The Kansas Fishes book (KS Fish Comm. 2014) updated the Cross fish guides of 1967 and 1995. Range maps are created from a comprehensive dataset compiled by Gido and Paukert and grouped into three time periods: 1884-1950, 1951-1990, and 1991-2012. It contains the most recent species names and information about habitat and behavior.

Data was compiled from various studies done by universities and state and federal agencies to examine trends in fish populations over time (i.e. pre- and post-impoundment). Pre-impoundment data on fish species is sparse. All data was converted to species presence/absence by site and sampling event for comparison across datasets. The following datasets were included (Table 7):

Table 7. Fish Databases Compiled

Source	# Records	# Sites	# Events	Time Period
Kansas Aquatic Gap Project	47	39	39	1886-2003
KDWPT	22	2	2	2004-2008
USEPA (2016)	27	2	2	2009
USEPA (unpublished)	11	1	1	2013
CPCB	26	3	3	2009
MRRP	10,841	2,865	2,865	2006-2018
Paukert	5,392	164	968	2004-2011

- Presence/absence data from 1886-2012 for the Kansas River from the Kansas Aquatic Gap project (Gido and Dodds 2013), 47 records, with one record from 1886 and the remainder from 1947-2003. Data from 2004-2012 was removed to avoid duplication of data when merged with post-2003 datasets.
- Data collected from 1994-2008 (KDWPT 2008) by the Kansas Department of Wildlife, Parks and Tourism (KDWPT) Stream Survey and Monitoring Program. However, some samples that were included in the Kansas Aquatic Gap project data for the 1994-2003 time period was removed to avoid overlap between datasets.
- Data collected from the 2008-2009 and 2013 U.S. Environmental Protection Agency (USEPA) National Aquatic Resource Surveys provided fish count data for two sites (USEPA 2016, USEPA unpublished).
- Data from 2009 from the Central Plains Center for BioAssessment (CPCB) of the Kansas Biological Survey (KBS) (Everhart and Huggins 2011) provided fish count data for three sites on the Kansas River.
- Data from 2006-2018 from the USACE Missouri River Recovery Program (MRRP) Pallid Sturgeon Population Assessment Program (PSPAP) provided the most recent data of fish in the Kansas River. Gill and mini-fyke nets, otter and push trawls, and trotlines were used to collect fish from a variety of habitats from Bowersock Dam (RM 52.1) to the confluence with the Missouri River (Wellemeyer 2018).
- Paukert compiled fish data from various studies.

The resultant presence/absence database was mapped to show the distribution of sites and historic data. The river was divided into segments to determine if the data would show a relationship between the presence of fish assemblages and the upstream reservoirs.

- Segment 1 - Below Milford Reservoir (Junction City) to Manhattan, 485 records
- Segment 2 - Below Tuttle Reservoir (Manhattan) to Lecompton, 1,730 records
- Segment 3 - Below Perry Lake (Lecompton) to Eudora, 3,258 records
- Segment 4 - Below Clinton/Wakarusa (Eudora) to mouth, 10,844 records

Pre-impoundment data was lacking in all but Segment 3, which were collected along the Douglas County, Kansas border, likely due to the presence of the University of Kansas and the KBS. Locations of fish samples in each segment are shown in Figure 23 and samples by date of collection are shown in Figure 24.

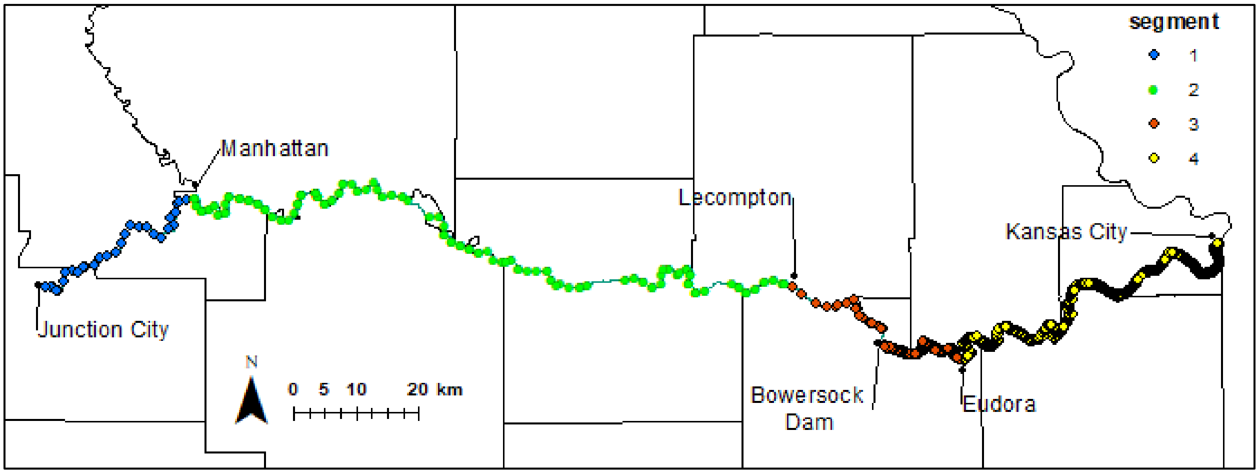

Figure 23. Fish Sampling Site Locations by Segment

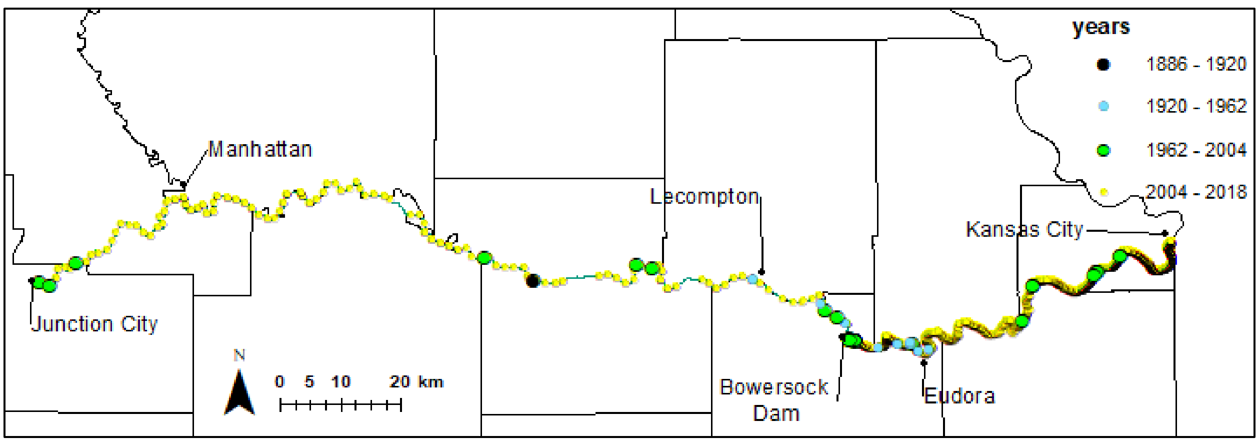

Figure 24. Fish Sampling Site Locations by Date of Collection

Further analysis of the Gido et. al. (2010) study showed that Lower Kansas River Basin fish species statistically increased or decreased in occurrence in collection events between 1947-1962 and 1991-2003 (Table 8). An analysis of Segment 3 by itself was also performed since pre-1964 data was sparse in all but Segment 3 (Table 8).

Table 8. Number of Fish Collection Records - All Segments and Segment 3

Time Period	All Segments	Time Period	Segment 3
1886-1962	18	1941-1962	14
1963-1977	8	1963-1975	6
1980-1990	17	1981-1990	8
1994-2003	4	1994	1
2004-2018	3,235	2004-2016	482

A list of species exhibiting 10% change or greater between time periods was developed (Table 9). Data for these species was further examined comparing feeding and reproductive fish guilds to flow and substrate needs, two of the factors influenced by reservoirs.

Table 9. Fish Species with More Than 10% Change - Pre-1964 Compared to Post 2003

Species and Common Name	% Change		Channel	Spawning Habitat	Current / Depth	Turbidity	Substrate / Depth	Other	Ref*
	All	3							
Hybognathus placitus - plains minnow	-49	-64	backwater, sandbar pools	pelagic, shallow backwater	low flow or wide flux, shallow	turbid preferred, clear ok	sand/ shifting	Decreased with impoundments & modified flows	W95, KS14
Notropis percobromus - carmine shiner	-61	-64		clean gravel, slow velocity	swift pools & riffles	clear	limestone, rocky, gravel	Impoundments improve habitat, sight feeder	KS14
Notropis stramineus - sand shiner	-62	-61	along sandbars	mud, sand, gravel	moderate flow, pool, run	clear to turbid	sand, gravel	In Ohio siltation decreased numbers	KS14
Macrhybopsis storeriana - silver chub	-47	-56	backwater, pools	pelagic	shallow, but in summer deep		silty riffles, sand, gravel	Seasonally migratory, taste & sight feeder	KS14
Pimephales promelas - fathead minnow	-59	-55	pools			turbid	mud, firm	Hardy, tolerate high temp & low O2	F07, KS14
Lepomis cyanellus - green sunfish	-45	-51				tolerant	pools near veg.	Tolerate high temp & low O2	KS14
Carpiodes carpio - river carpsucker	-33	-47	secondary, backwater, pools	migrates, margins in vegetation, adhesive	faster		looser material		G15, KS14
Cyprinella lutrensis - red shiner	-44	-43	main, backwater & pools	shallow, gravel, vegetation	shallow, slow	tolerate high turbidity & silt	riffles	Tolerate high temp & low O2	G15, KS14
Ameiurus melas - black bullhead	-33	-42	pools	under log, cover	shallow, little flow	turbid	soft bottom		KS14
Cyprinus carpio - common carp	-40	-42	pools, backwater	shallow, eggs adhere to vegetation	not high gradient	tolerate high	all	Tolerate high temp & low O2	KS14
Lepomis humilis - orange-spotted sunfish	-35	-40	pools, backwater	nest sand, fine gravel			sand, gravel, mud	Tolerate. high temp & low O2	KS14
Luxilus cornutus - common shiner	-33	-29		adhesive eggs stick to gravel		tolerate turbidity if flow & no siltation	riffles, pools, coarse, no veg.		KS14
Macrhybopsis gelida - sturgeon chub	-22	-28	main, edge not thalweg	pelagic	fast/strong, shallow, low discharge	turbid	fine gravel, coarse sand, silt	Islands, braided, tactile feeding	L03, W03, KS14
Pomoxis annularis - white crappie	-31	-25	open, deep	nests near deep structure		tolerates		Expand due to stocking	KS14
Micropertus salmoides - largemouth bass	-30	-25	backwater	submerged or overhanging structure		clear	submerged logs, rocks, plants	Site predator	KS14

Species and Common Name	% Change		Channel	Spawning Habitat	Current / Depth	Turbidity	Substrate / Depth	Other	Ref*
	All	3							
Phenacobius mirabilis - suckermouth minnow	-30	-23		on gravel riffles	riffles, runs >10cm deep	moderate	gravel, sand		KS14
Macrhybopsis meeki - sicklefin chub	-16	-21	main, edge not thalweg	pelagic	strong, deep	turbid	sand, gravel/ smooth, silt	Edge not thalweg, sensory buds for feeding	L03, W03, KS14
Semotilus atromaculatus - creek chub	-33	-20		spring, gravel nests above riffles	low flow/shallow	clear, turbid ok if clean spawning gravel	gravel	Riffles, pools, cool water, intermittent streams	H82, KS14
Pimephales notatus - bluntnose minnow	-12	-17	pools, backwater	nest under rock			gravel	Moderate aquatic veg., tolerate high temp, low oxygen	KS14
Hybognathus hankinsoni - brassy minnow	-17	-14	backwater	shallow backwater, in vegetation, temp triggered (16-27C)	low velocity	clear	silt, sand	Pools, tolerate high temp & low O2	W95, F07, KS14
Notropis dorsalis - bigmouth shiner	-11	-14	main		shallow, slow		shifting sand		KS14
Campostoma anomalum - central stoneroller	-27	-13		gravel riffle near pools, protracted in variable temperature, condition, turbidity, discharge	tolerate short-term intermittent	semi-tolerant	unsilted gravel riffles	Eat algae	KS14
Ictiobus niger - black buffalo	-17	-7		slower flow	deep, fast		riffles		KS14
Dorosoma cepedianum - gizzard shad	-21	-4	secondary	surface of shallow, open water		tolerates		Sensitive to low oxygen and temp	G15, KS14
Catostomus commersonii - white sucker	-11	2		swift current, gravel		tolerates, but prefer clear	pools, riffles	Stable pop., tolerate degraded habitat	G15, KS14
Cycleptus elongatus - blue sucker	10	11	main	migrate, deep swift riffles	swift, turbulent riffles, deep chutes	intolerant silt	bedrock with gravel, sand, hard clay	Juveniles less turbulent waters	KS14
Pylodictis olivaris - flathead catfish	9	14			high flow recruit				G15
Aplodinotus grunniens - freshwater drum	14	16	secondary, floodplain	deep pools		clear to turbid	clean sand, gravel		G15, KS14
Ictiobus bubalus - smallmouth buffalo	17	17	main, pool, oxbow, mouth	no current	low current	clear	firm	Secure population	G15, KS14

Species and Common Name	% Change		Channel	Spawning Habitat	Current / Depth	Turbidity	Substrate / Depth	Other	Ref*
	All	3							
Ictalurus furcatus - blue catfish	26	18	main		swift, deep		sand, coarse	Migrates in response to water temp	KS14
Ictalurus punctatus - channel catfish	8	20		migrates		tolerant	woody debris, riffles, some pools, runs	Secure population, tolerate high temp, low DO	KS14
Pimephales vigilax - bullhead minnow	23	25	pools, backwater			tolerant	sand, silt	Tolerate high temp & low DO	KS14
Scaphirhynchus platorynchus - shovelnose sturgeon	25	28	main, edge not thalweg		high flow recruit				W03, G15
Extirpated:									
Platygobio gracilis - flathead chub			margins	unknown	slow/swift, deep pools or swallow	turbid	gravel, fine sand	Taste and site feeder	W95
Others that also decreased according to Gido's study:									
Hiodon tergisus - goldeye			main, pools	migrates, cooler temp	strong	tolerant		Migrates upstream from Missouri River or reservoirs	KS14
Notropis blennius - river shiner			summer		shallow	clear, tolerant turbid in day	sand, gravel	Decrease in KS, increase in Missouri River after impoundment	KS14
Macrhybopsis hyostoma - shoal chub			shifting main	unknown	swift, deep		pea-sized gravel, clean sand		KS14
Hybognathus argyritis - western silvery minnow			pools and backwaters	unknown	low		silt, sand		KS14

Notes:
1. Those that also showed decrease by Gido et al. (2010) between 1947-1962 and 1991-2003 are bold and shaded.
2. Those that showed increase are in italics.
3. * F07 = Falke et al. 2007, G15 = Gerken 2015, H82 = HIS 1982, L03 = Layher 2003, W03 = Wildhaber et al. 2003, W95 = Wenke 1995, KS14 = various authors KS Fishes Com. 2014

Changes in stocked fish species was also considered for Cedar Bluff, Waconda, Kanopolis, Kirwin, Wilson, Milford, Tuttle, Perry, and Clinton reservoirs. The changes noted include:

- Decreased pre-1964 to post-2003 – White crappie (*Pomoxis annularis*), Largemouth bass (*Micropertus salmoides)*
- No noted change – Gizzard shad (*Dorosoma cepedianum)*, hybrid striped bass (*Morone saxatilisX chrysops)*, emerald shiner (*Notropis atherinoides*)
- Increased pre-1964 to post-2003 – Blue catfish (*Ictalurus furcatus*), Channel catfish (*Ictalurus punctatus*)
- Species present after 1993 (but not previously) – redear sunfish (*Lepomis microlophus),* goldfish (*Carassius auratus),* walleye (*Sander vitreus),* smallmouth bass (*Micropterus dolomieu*), striped bass (*Morone saxatilis*), paddlefish (*Polyodon spathula)*

Sediment and Turbidity

While the focus of this SRP effort is to identify opportunities to implement e-flows, it is important to distinguish the effects of reduced sediment loads and subsequent changes to turbidity (see Section 3.5.2) Hernandez-Abrams et al. (2021 draft) showed that dams interrupt a natural sediment regime resulting in downstream changes to habitat (e.g., channel incision and coarsening of bed material), decreased water turbidity, and changed concentrations of nutrients and other constituents. These abiotic changes from sediment starved water may in turn affect primary producers (e.g., decrease biodiversity), invertebrates (e.g., decline in burrowing taxa) and fish species (e.g., increased predation). In contrast, excess sediment may contain high concentrations of heavy metals affecting fish physiology, bury fish embryos, or induce loss of invertebrate habitat due to excess deposition which may lead to trophic cascading. Furthermore, increased turbidity from suspended sediment can influence primary producers within the food web leading to ecological effects such as reducing phytoplankton (food) and aquatic plants (habitat). Increased turbidity in combination with depth reduction can also influence heat distribution and increase temperature, which can cause dissolved oxygen stressors (Shelly 2016).

Sediment sensitive or sediment tolerant aquatic species respond differently to sediment and turbidity changes and physical habitat influences of dams depending on habitat preference, feeding, typical movement patterns, life history, and reproduction and predator-prey relationships (Hernandez-Abrams et al. 2021 draft). For example, the Johnny darter (*Etheostoma nigrum*), a species in need of conservation (SINC) in Kansas (KDWPT 2019), thrives in clear water streams and deposits eggs in the interstitial spaces between stones in the stream bed (Cross and Collins 1995). Whereas the flathead chub (*Platygobio gracilis*), a threatened species in Kansas (KDWPT 2019), is a sediment tolerant species. The flathead chub favors turbid, fast-flowing and warm water with sand and gravel substrate, using chemosensory barbels and buds to enhance their feeding ability (Rahel et al. 2004)(Eberle 2014).

Spawning substrate is also important and can vary within species depending on other habitat conditions. For example, the creek chub (*Semotilus atromaculatus)* habitat suitability index (HSI 1982) indicates the species needs clear water but can tolerate turbidity if clean spawning gravel is present. Another example is brassy minnow (*Hybognathus hankinsoni)* eggs adhering to vegetation above silt (Falke 2014).

Kansas River native fishes are well adapted to turbid conditions. Therefore, unnaturally clear water downstream of reservoirs enables predators to improve efficiency of sight-feeding species potentially outcompeting and/or preying on species evolved in naturally turbid environments (Rahel et al. 2004). For example, sturgeon chub (*Macrhybopsis gelida)* and sicklefin chub (*Macrhybopsis meeki*) are sensory feeders, using barbels or other organs to feel their environment (KS Fish Com. 2014). Albers (2014) cites many studies relating sturgeon chub abundance to dams, and notes that numbers are reduced downstream of dams (Albers 2014).

Hernandez-Abrams et al. (2021 draft), have proposed conceptual models (Figures 25 and 26) for sediment sensitive and tolerant fish species. These models are intended to be applied concerning potential sediment conveyance (hydro-suction and dredging) at Tuttle Creek Reservoir and the Big Blue River. Restoring natural flows and sediment regimes downstream may aid in the recovery of sediment tolerant species populations. Conversely, existing sediment sensitive populations are expected to decline from increases in turbidity. Conceptual models developed by Hernandez-Abrams et al. (2021 draft) have the potential to be applied for sediment management for other reservoirs across Kansas.

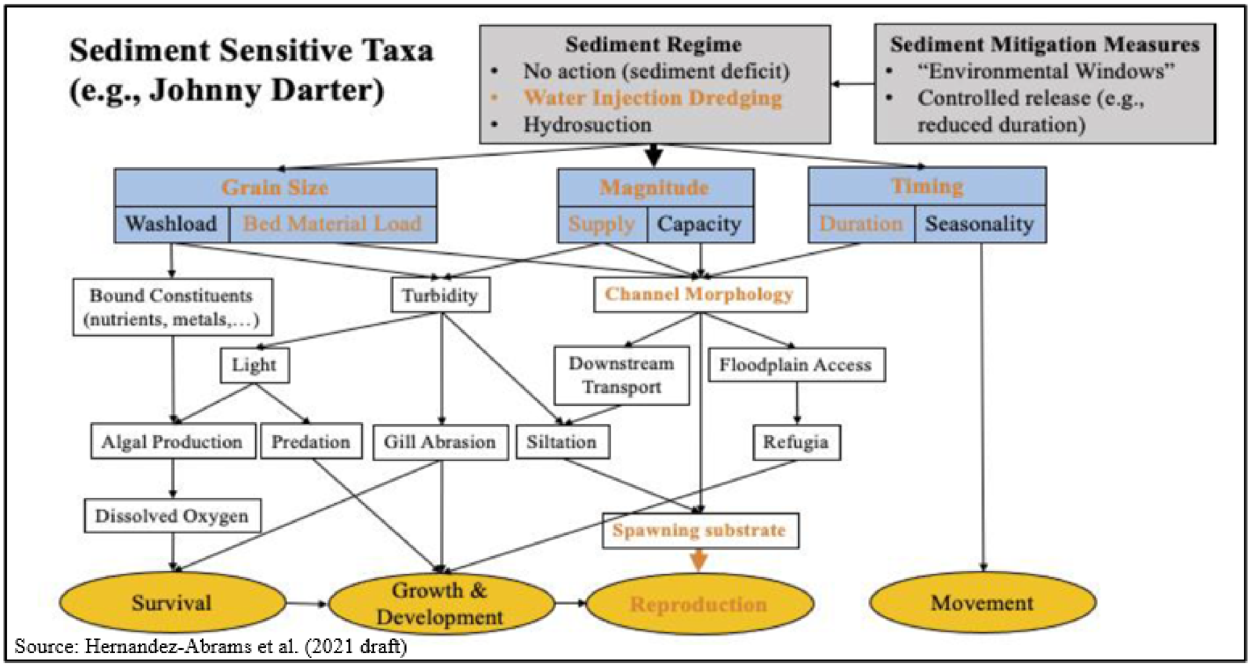

Figure 25. Conceptual Model for Potential Ecological Effects of Sediment Release from Tuttle Creek in Sediment Sensitive Taxon (Hernandez-Abrams et al. 2021 draft)

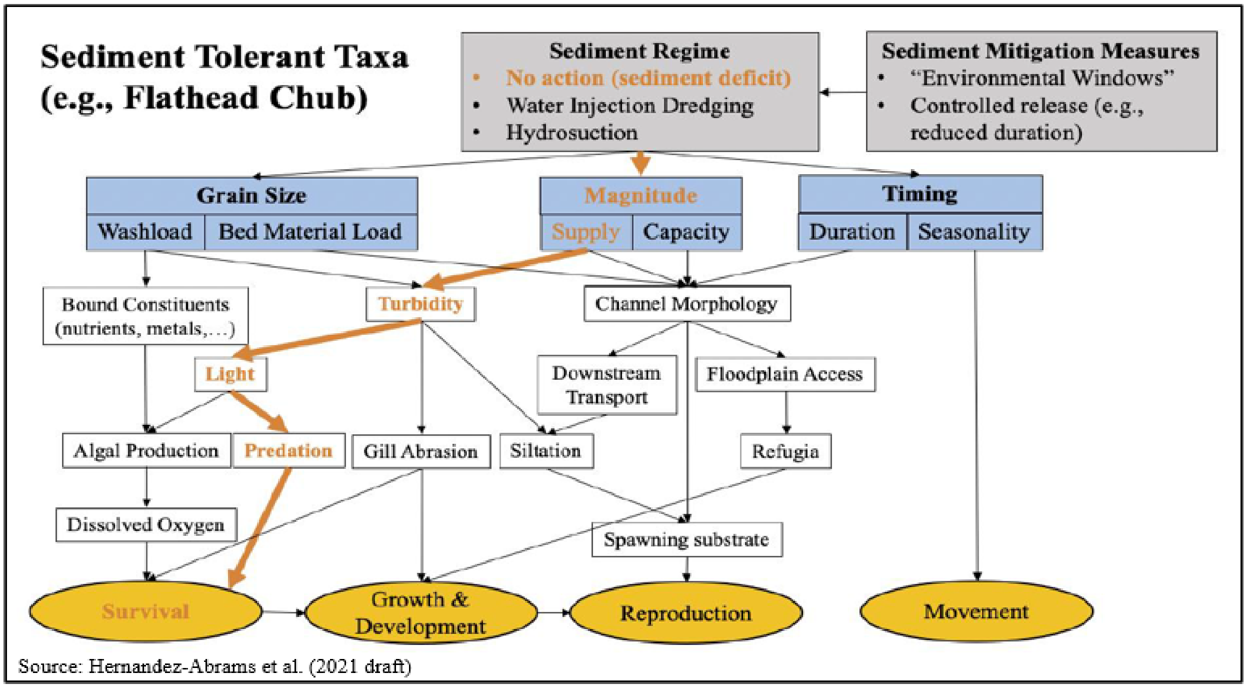

Figure 26. Conceptual Model for Potential Ecological Effects of Sediment Release from Tuttle Creek in Sediment Tolerant Taxon (Hernandez-Abrams et al. 2021 draft)

Reservoir sedimentation is not unique to Kansas and has received increased attention in recent years (Bhattacharyya and Singh 2019). A number of sediment management options for reservoirs can be considered, including dredging, reallocation, new reservoirs or dam raises, and allowing sediment to pass through the impoundment (e.g., sediment bypass, sluicing, drawdown flushing, hydro-suction, density current venting, water injection dredging, etc.). However, sediment management can be an expensive process. For example, John Redmond Reservoir in Kansas was mechanically dredged 3-million cubic yards of sediment in 2016 at cost of approximately $20 million (Kansas Water Office 2015). The State of Kansas (Kansas Water Office), along with other stakeholders, are looking into economical means to manage sediment conveyance within reservoirs. Specifically, Tuttle Creek Reservoir is a major focus point because it traps approximately 60% of sediment that would otherwise integrate into the lower Kansas River (Shelly et al. 2016). As result of sediment trapping, Tuttle Creek alone is predicted to lose 80% of its multipurpose pool and 21% of its flood storage capability within 50 years.

Flow Needs

Ecological requirements of fish species found in the Kansas River were derived from autecology classifications for trophic and reproductive guilds. Several documents and databases containing this information were compiled into a database. Also included were whether the species is native or introduced, and the current conservation status of each species. See Appendix A for the complete autecology table and an explanation of fields. Key literature that provided fish autecology and related data include:

- Liechti (2007) created an index of biological integrity (IBI) for the lower Kansas River based on feeding and reproductive guilds of fish, as well as tolerance and other metrics. The IBI was applied in the initial analyses of pre- and post-impoundment fish communities.
- Perkins and Gido (2011) examined effects of river fragmentation on Great Plains pelagic spawning populations, including five species that were found in the Kansas River prior to 1962, of which only one was found 1991-2003.

- An Ecological Monitoring and Assessment Program (EMAP) table of fish found in USEPA Region 7 provides autecology categories (trophic and reproductive guilds, Peck 2004).
- Kansas Natural Heritage Inventory (KNHI) conservation status of fish in Kansas (KNHI 2018).

Looking at the presence and absence of fish species across all segments pre-1964 and post-2003 was used as a basis to examine trends that could support a decrease or increase in certain fish guilds and to examine the habitat needs of each species to determine if any are impacted by changes in flows. The following changes were noted when comparing all fish species collected in all segments pre-1964 with those species collected post-2003.

- 39 fish species were present in both time periods
- 5 fish species were absent from both time periods, yet collected at least once in between: southern redbelly dace (*Phoxinus erythrogaster*), chestnut lamprey (*Ichthyomyzon castaneus*), shoal chub (*Macrhybopsis hyostoma*), flathead chub (*Platygobio gracilis*), and spotfin shiner (*Cyprinella spiloptera)*
- 3 fish species present in the pre-1964 data were absent in the post-2003 data: hornyhead chub (*Nocomis biguttatus*), common shiner (*Luxilus cornutus*), and bigmouth shiner (*Notropis dorsalis)*
- 46 fish species were collected post-2003 not collected in pre-1964: six stocked in reservoirs (redear sunfish, goldfish, walleye, smallmouth bass, striped bass, paddlefish; four carp species (bighead (*Hypophthalmichthys nobilis*), black (*Mylopharyngodon piceus),* grass (*Ctenopharyngodon idella),* and silver (*Hypophthalmichthys molitrix)*); nonnative western mosquitofish (*Gambusia affinis)* and slenderhead darter (*Percina phoxocephala***)**; and pallid-shovelnose hybrid, lake sturgeon (*Acipenser fulvescens*), and American eel (*Anguilla rostrata*)

Most of those species that decreased between the pre-1964 and post-2003 time periods prefer, or can tolerate, turbid conditions (plains minnow (*Hybognathus placitus*), red shiner (*Cyprinella lutrensis)*, black bullhead (*Ameiurus melas*), and sturgeon chub) and many prefer pools and backwater, and silt, sand, or gravel. Also, species that decreased are pelagic and others spawn in backwaters or need sand or gravel. Species that increased tend to be sediment sensitive and prefer clear waters (white sucker *(Catostomus commersonii*), blue sucker (*Cycleptus elongatus*), and smallmouth buffalo (*Ictiobus bubalus*) and bedrock or firm substrate (smallmouth buffalo and blue sucker). A clear trend among the spawning habitats of fish species that increased was not observed.

Though comparisons show several species that increased, studies specific to those species give more detail about abundance and distribution, and perhaps these species showed increase due to these targeted studies. Blue sucker, a SINC species in Kansas (KDWPT 2019), showed 11% increase in presence in sample events after impoundment. However, the catch per unit effort was lower in 2017 than the previous seven years in the USACE pallid sturgeon (*Scaphirhynchus albus*) monitoring program on the Kansas River from Bowersock dam downstream to the mouth (USACE 2018). Eitzmann et al. (2005) performed a targeted study on blue suckers throughout the Kansas River from May - August 2005 and concluded that at times their relative abundance was high, though they found only two young fish.

Literature detailing the life histories of fish species guides the determination of what flows are ideal for successful reproduction. Overlaying flow needs on historic and current hydrographs helps to pinpoint the time of year critical to specific critical flows. The literature shows that turbid heterogeneous habitat supports many of the fish species that declined, while clearer homogenous habitat supports those fish species that increased.

Habitat heterogeneity is a common element among the fish species that decreased. The Kansas Recovery Plan for sicklefin chub, sturgeon chub, and western silvery minnow (*Hybognathus argyritis*) (Layher 2003) indicates:

- Sicklefin chub prefer smooth sand or gravel bottom, deep water with strong currents, and turbid conditions
- Sturgeon chub prefer shallow strong current, fine gravel or course sand, islands or braided channels

Wildhaber et al. 2003 indicates:

- Sicklefin chub, sturgeon chub, and shovelnose sturgeon (*Scaphirhynchus platorynchus*) are associated with river borders rather than the thalweg
- The body forms of shovelnose sturgeon and sturgeon chub facilitate use of higher flows; thus, they may have less need for bed-form relief as refugia from flow
- Bedform troughs as refugia are also of limited importance for sicklefin chub which are more streamlined and not as directly associated with the river bottom

Quist et al. (1999) found that 80% of the locations of shovelnose sturgeon in the Kansas River were in water depths of 1.0–2.0 m, with current velocities 0.01–1.11 m/s at the surface and 0.02–0.79 m/s at the bottom, indicating that this species needs shallow water habitats that are less frequent with higher post reservoir releases after removing the flood peak.

Fischer (2012) discusses other fish that need uninterrupted reaches, and studies that show that blue sucker, shovelnose sturgeon, plains minnow, and shoal chub may move 100 km within a year (Dudley and Platania 2007; Neely et al. 2009; Wildhaber et al. 2011).

Spawning and fry growth and development deserves greater examination as we look at the impact of reservoirs on reproductive success. Spawning and larval growth is affected by many dimensions of stream flow, not just velocity and discharge, but also duration and timing of flows, and how flow shapes the channel and alters substrate. Many studies have been devoted to pelagic spawners which broadcast drifting eggs or have a drifting larval stage. Flow timing and temperature has a great impact on these species which include the chub species, all of which have decreased in the Kansas River. Flow is necessary to maintain egg buoyancy of these pelagic spawners, including the plains minnow, which showed the greatest decrease from pre- to post-impoundment (Taylor 2014). Perkin and Gido (2011) note the effects of reservoirs on this guild, including: hypolimnion release of cool water delays egg development several km downstream, sustained high flow homogenizes habitat, and river fragmentation disrupts development. These species need long river fragments, over 100 km, for full development of eggs. Perkin and Gido (2011) cite the greatest challenge associated with conservation of pelagic-spawning cyprinids is the need to allow their ichthyoplankton (larval form) through reservoirs that fragment rivers. They are not aware of initiatives that allow these larval fish to bypass reservoirs.

The interaction of flow and temperature on spawning must be considered. Brassy minnow spawning is temperature triggered, and they will not spawn if the temperature drops (Falke, J.A. in. KS14). This plays into the timing and duration of flows, whether the ideal flow occurs at the ideal water temperature. Many native species of the Kansas River not only tolerate water level fluctuations but are adapted to and thus need these fluctuations. For example, the common shiner, which decreased in northwest Kansas due to intermittency deteriorating (Cathcart 2014), also shows a decrease in the Kansas River. Moss et al. (1983) reported blue sucker spawning in the Neosho River in 1976 and 1977 (approximately 35 km below impoundments) in late May at 20°C water temperature, and found tuberculated (reproductive) males in a spawning riffle April-June in water 20-23°C, suggesting this as the spawning season, and that spawning could occur at temperatures as low as 17°C. The right amount of flow in the right place affects fish success, as shown in plains and brassy minnows which need backwater (Wenke 1995).

High Flows

Gerken (2015) studied fish community response to flow magnitude in the Kansas River and concluded that a natural and variable flow regime may be important for maintaining fish community structure in the Kansas River, and made these observations and points about the overall importance of floodplain inundation on riverine ecosystems:

- Species found in main channel habitats: shovelnose sturgeon, blue sucker, red shiner, shortnose gar (*Lepisosteus platostomus),* goldeye (*Hiodon alosoides*), and smallmouth buffalo
- Species found in the inundated secondary channel: longnose gar (*Lepisosteus osseus*), river carpsucker (*Carpiodes carpio*), freshwater drum (*Aplodinotus grunniens)*, gizzard shad*,* white bass (*Morone chrysops),* and sauger *(Sander canadensis)*
- "Floods result in a pulse of higher macroinvertebrate densities that may be used as prey for fishes in secondary channel and main channel habitats."
- "Increased discharges during flooding can increase shear stress near the benthos and cause "catastrophic drift" where most benthic invertebrates enter the drift thereby lowering the density of benthic invertebrates and subsequently increasing the density of invertebrates in the drift."
- "Although the energy input provided by one inundated habitat may be negligible, the total influx of energy provided by all inundated terrestrial habitats is likely to provide benefits to the riverine ecosystem. Maintaining lateral connectivity in large rivers may benefit many native fishes found in these systems and management and restoration efforts focused on large river fishes may benefit by increasing or maintaining lateral connectivity between main channel and inundated terrestrial habitats."

In summary, the variety of spawning and habitat needs of the native fish of the Kansas River and its tributaries point to a need for a heterogeneous flow regime. However, changes in fish assemblages and increase in non-native species point to a homogenization of habitat and flow, corresponding with modification of the river by reservoirs. This can be seen on hydrographs comparing pre- and post-impoundment flows. Studies on watersheds nested within the entire Kansas River Basin also support this. Eberle et al. (2002) found in 1996-1997 in the Solomon River Basin that 32% of native fish species were extirpated, while 51% of the current assemblage was nonnative. They attribute this to impoundments and agricultural development shifting the habitat towards homogenous conditions. Moore and Thorp (2008) suggest that fish have adapted to the dynamic and variable flows in prairie rivers through a more generalist lifestyle and by (i) temporarily using higher flow habitats (except possibly the thalweg) to cope with intermittent loss of prime habitat; or (ii) extending spawning through favorable and demanding conditions.

The observations by Sanders et al. (1993) in a comprehensive paper about how impoundments have impacted the Kansas River and its biota provide a summary presented in this literature and data review:

- The Kansas River is becoming less turbid.
- Regulated flows have caused spatial and temporal changes in stream flow and the nature of the stream bed.
- Indigenous fish were tolerant of great fluctuations in discharge, shifting sand substrate, high turbidity. Shovelnose sturgeon, chub species (*Platygobio* and *Macrhybopsis*), plains minnow, western silvery minnow, and river carpsucker are especially adapted to these conditions due to their tactile and chemical sensory systems.
- Large, sight-feeding piscivores were rare or absent, and gars and catfish were the main predators.

- Turbid river species were more prevalent until mid-20th century, and then were replaced by planktivores and visual predators.
- With reservoirs, the river substrate stabilized and enhanced benthos production, which increased plankton abundance, therefore Centrarchids (except green and orange-spotted sunfish (*Lepomis humilis*)) increased and buffalo, drum, flathead catfish, walleye extended their ranges.

Sanders et al. (1993) also give suggestions for enhancing the Kansas River including a fish monitoring system (which is currently being implemented by KDWPT); altering water rights to allow permanent flows in the western part of the basin; bank stabilization; and controlling nonpoint pollution. However, it was not suggested to modify flows to allow for more natural conditions. When published (1993), the authors assumed that altering dam releases was not a management possibility (Huggins pers. com. 2019).

Spawning and Variation in Hydrography

Fish native to the Kansas River have adapted to the interaction and timing of the variable flows typical of prairie rivers. However, reservoirs have disrupted the natural timing and magnitude of flows, moderating and homogenizing conditions, making the river more ideal for nonnative species and less ideal for native species.

Interposing spawning timing on hydrographs of historic, pre-impoundment flows, and comparing that to modern post-impoundment flows helps to see the natural flow pulses and durations during spawning season, and how the river has strayed from that. Spawning periods were obtained from the Kansas Fishes Book (KS Fish Comm. 2014) and compiled in a table, with peaks noted if given. Additional sources were used for river redhorse (*Moxostoma carinatum*) (Becker 1983). This table includes all fish in Table 10 that showed change pre- to post-impoundment, plus those that decreased according to Gido et al. 2010, and the state listed species in Table 11.

Spawning ranges are compiled for 46 species. Critical periods are those that contain the most overlap among species, plus ranges that contain the state listed species. May 1 – June 30 has the highest overlap of spawning ranges, with 33 - 35 of 46 species spawning during this time. Within that window, are 3 peaks including 34 or more species. Within those three peaks are two peaks that capture 7 – 8 of the 11 Threatened and Endangered or SINC species, May 20 – 21 (when chestnut lamprey and shoal chub overlap) and June 15 (when shoal chub and silvery minnow overlap). These peaks were plotted on the hydrograph of pre- and post-impoundment flows, and a graph highlighting the key spawning times of Table 10 was produced (Figure 27).

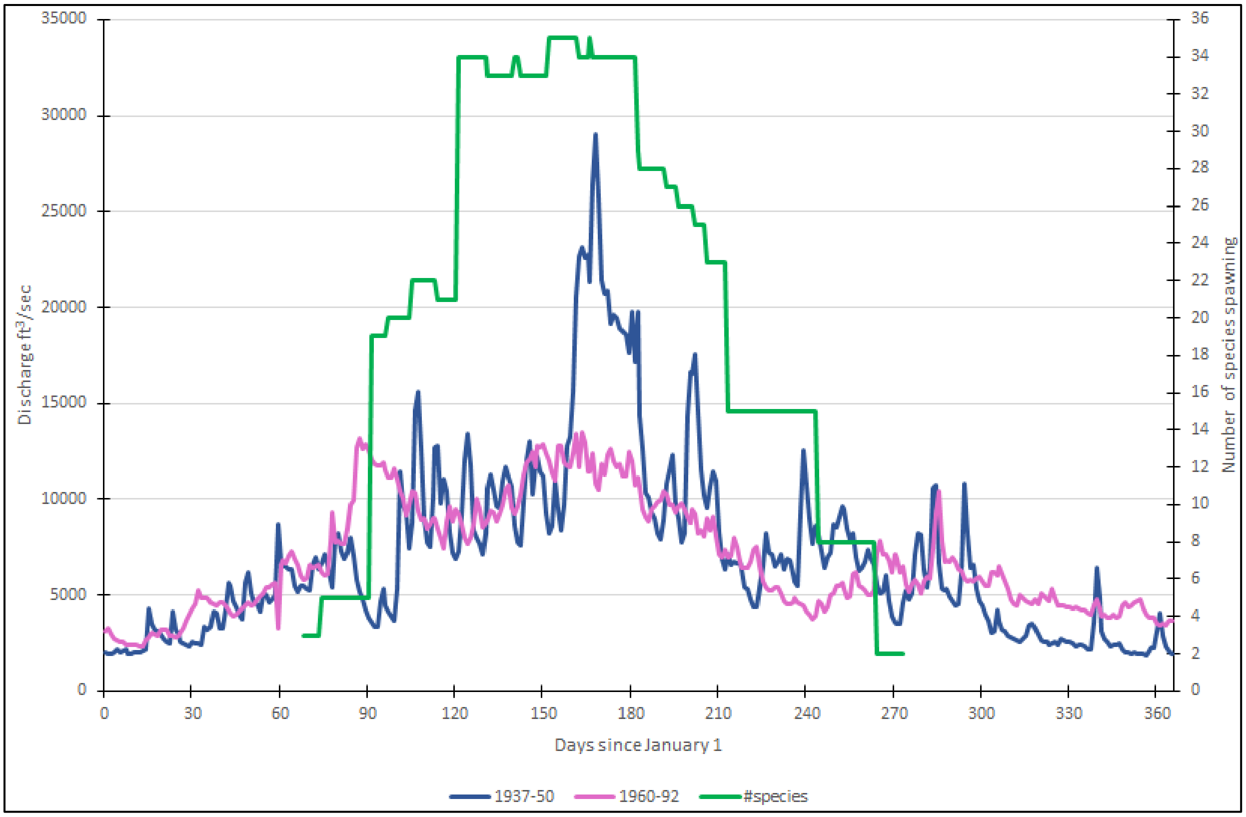

Figure 27. Number of Fish Species Spawning on the Kansas River

Notes:
1. Lecompton, Kansas
2. Based on discharge data collected before and after construction of the primary federal reservoirs on the main tributaries of the river.
3. The period of record form 1951 through 1959 was not included because of recorded flooding and construction of the reservoirs occurred during this period.

Table 10. Critical Spawning Periods May 1 - June 30

Dates	Day of Year	# of Species Spawning	
		All	State-listed
May 1-10	121 - 130	34	7
May 11-19	131 - 139	33	7
May 20-21	140-141	34	8
May 22-31	142-151	33	8
June 1-10	152-161	35	8
June 11-14	162 -165	34	8
June 15	166	35	9
June 16-30	167-181	34	8

Notes: May 1 – June 30 is the period with the highest occurrence of fish species spawning (33-35 of 46 species)

Most fish species found on the Kansas River spawn between May through June and two critical time periods occur in late May and during June for state-listed species (Figure 28).

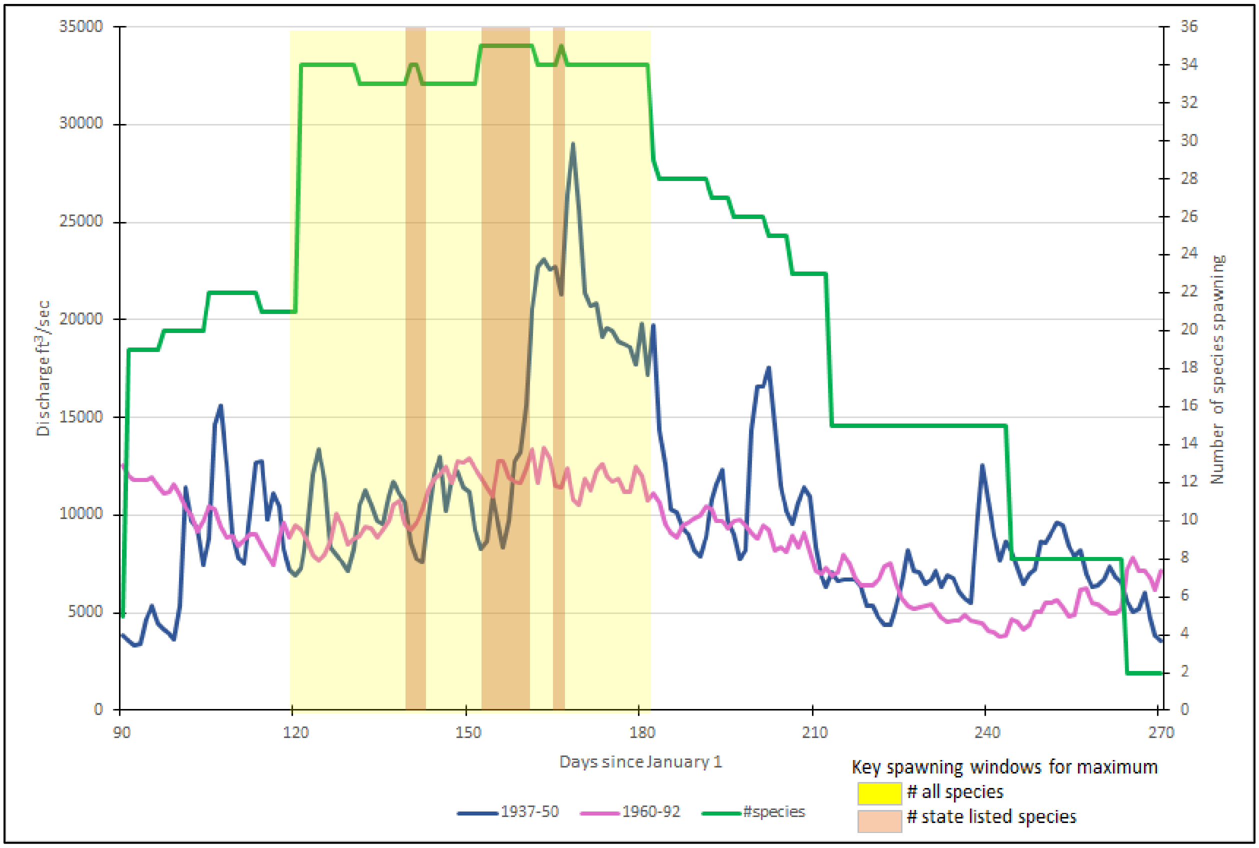

Figure 28. Kansas River Fishes Key Spawning Periods

Notes: Yellow = Maximum number of spawning species; Orange = Maximum number of state-listed species spawning

The minimum, maximum, the range, and the standard deviation of natural flows were compared to that of modified flows during each spawning period for state-listed fish species (Table 11). The variance between natural compared to modified flows (4,035 to 4,280 cfs) was greatest during the spawning periods of shoal chub, river redhorse, and Johnny darter. The flows from May 1 – June 30, when the majority of fish species spawn, was similar at 4,228 cfs (Table 11). These data show that variation in flows may enhance spawning success.

Table 11. Discharge During Spawning Periods

Majority of Species (Days 121-181)		
n = 61	natural	modified
min discharge ft^3/s	**7,163**	**7,680**
Max	29,009	13,450
Difference	**21,846**	**5,770**
std dev	5,756	1,528
std dev difference		**4,228**

Plains Minnow (Days 74-263)		
n = 190	natural	modified
min discharge ft^3/s	3,356	3,764
max	29,009	13,450
difference	**25,653**	**9,686**
std dev	4,926	2,614
std dev difference		**2,311**

River Redhorse (Days 91-171)		
n = 81	natural	modified
min discharge ft^3/s	3,356	7,416
Max	29,009	13,450
Difference	**25,653**	**6,034**

River Redhorse (Peak Days 91-120)		
n = 30	natural	modified
min discharge ft^3/s	3,356	7,416
max	15,599	12,055
difference	**12,243**	**4,639**

std dev	5,594	1,559
std dev difference		**4,035**

std dev	3,527	1,340
std dev difference		**2,186**

Johnny Darter (Days 91-181)		
n = 91	**natural**	**modified**
min discharge ft^3/s	3,356	7,416
Max	29,009	13,450
Difference	**25,653**	**6,034**
std dev	5,817	1,537
std dev difference		**4,280**

Blue Sucker (Days 91-201)		
n = 111	**natural**	**modified**
min discharge ft^3/s	3,356	7,416
max	29,009	13,450
difference	**25,653**	**6,034**
std dev	5,453	1,458
std dev difference		**3,995**

Common Shiner (Days 105-195)		
n = 91	**natural**	**modified**
min discharge ft^3/s	6,891	7,416
Max	29,009	13,450
Difference	**22,118**	**6,034**
std dev	5,221	1,528
std dev difference		**3,692**

Common Shiner Peak (Days 131-142)		
n = 12	**natural**	**modified**
min discharge ft^3/s	7,607	8,863
max	11,698	10,739
difference	**4,091**	**1,876**
std dev	1,367	600
std dev difference		**767**

Shoal Chub (Days 140-167)		
n = 27	**natural**	**modified**
min discharge ft^3/s	**7,607**	**9,269**
Max	23,139	13,450
Difference	**15,532**	**4,181**
std dev	5,270	1,024
std dev difference		**4,246**

River Shiner (Days 152-343)		
n = 92	**natural**	**modified**
min discharge ft^3/s	4,344	3,764
max	29,009	13,450
difference	**24,665**	**9,686**
std dev	6,006	2,766
std dev difference		**3,240**

W. Silvery Minnow (Days 166-181)		
n = 16	**natural**	**modified**
min discharge ft^3/s	17,175	10,518
Max	29,009	12,598
Difference	**11,834**	**2,079**
std dev	3,324	646
std dev difference		**2,678**

Sturgeon Chub (Days 172-263)		
n = 92	**natural**	**modified**
min discharge ft^3/s	4,344	3,764
max	20,883	12,598
difference	**16,539**	**8,833**
std dev	4,321	2,505
std dev difference		**1,816**

Notes:

1. Data at Lecompton, KS gage 1937-1950 and 1960-1992
2. Flows in cubic feet per second
3. Natural = Pre-impoundment; Modified = Post-impoundment
4. Spawning range = days after January 1
5. n = number of spawning days; min = minimum; max = maximum; difference = difference between min and max; std dev = standard deviation of during spawning periods of the given species; std dev diff = difference between the standard deviation of the natural and modified flows

Juvenile Development and Hydrography

Newly hatched fry also have flow requirements that influence refugia and food sources. Fry find refuge in debris, under logs and undercuts, in backwater, and in other features that add heterogeneity to a river system. Food sources such as algae and macroinvertebrates also need these features that create a heterogeneous environment. To measure complexity of this system, O'Neill (2010) developed the river complexity ratio (RCR), a metric that measures all types of river structures, and demonstrated that discharge can be used to predict river complexity on the Kansas River (Figure 29). This can be used to find a time where a river has the most flow refuges created by features within the river, for example, mid-channel sandbars and slackwaters. Low and varied discharge results in higher river complexity. However, on the Kansas River hydrographs (Figure11) it clearly shows that during the time that fry need refugia (fall) we see reservoir discharges are maintaining flows at a higher level than naturally occurred, thus can hypothesize that river complexity, and therefore refugia for fry, is reduced. Thus, lower river discharge during the fall season following the critical spawning window would benefit fish species.

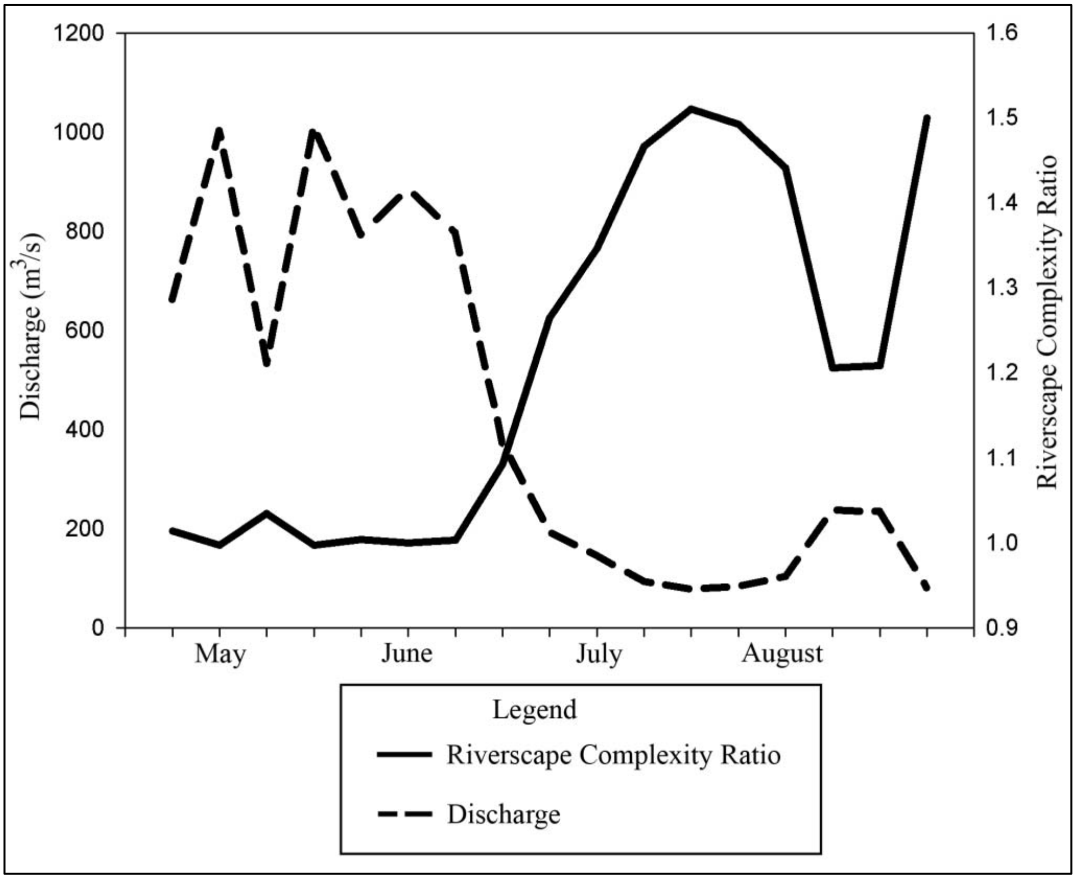

Figure 29. Kansas River - River Complexity Ratio

According to the RCR the greatest change on RCR values between the pre- and post-impoundment flows occurs during the winter months of November through mid-February. It is during these months that reservoir releases typically elevate flows by as much as 2,500 cfs above pre-impoundment levels (see Figure 11). While winter is a period of limited fish growth and activity, these months display the largest flow departures from pre-impoundment flows and represent the highest potential changes in habitat complexity according to the RCR. It remains unclear if the extent and duration of reduced winter flows are related to fish community alterations and loss or reductions in individual fish species. The idea that the maintenance of intermediate flows may be of greater importance is presented below.

In a study of young of the year fishes (YOY) of the lower Kansas River researchers found that intermediate flow regimes supported high diversity and evenness of YOY fishes (Moore and Thorp 2008). Most of these YOY fishes were members of the minnow family Cyprinidae. They hypothesized that higher flows tend to reduce habitat diversity and increase flow velocities while low flows tend to maximize habitat heterogeneity, but the diminished flows and harsher water quality of these somewhat disconnected habitats reduced their habitat value. They suggested that intermediate flows tend to provide good habitat diversity and optimum habitat quality for YOY.

Benefits to fish recruitment, species diversity and increased habitat heterogeneity can be attributed to restoration and/or reconnection of oxbows to main channel habitat. Penczak et al. (2003) described seasonal benefits to native fish species and higher species diversity associated with oxbow lakes over a 30-40 year period. The final conclusion from Penczak et al. (2003) was that oxbow lakes and connection to parent rivers was "indispensable for maintaining historically natural biodiversity in catchments".

King (2004) suggested that low flow periods concentrate prey resulting in increased foraging success and rapid growth of YOY fish. Moore and Thorp found that the Kansas River seems to exhibit characteristics of the low-flow model.

However, at least in the lower Kansas River it appears that the low-flow recruitment model best explains Moore and Thorp's work and it is the fall and winter flows (aside from flood peak reductions) that show the most departures from pre-impoundment flows. These flow reductions may have moved the system from intermediate to lower, less desirable flow conditions for YOY. One example of the importance of winter flow conditions is the use of 1-2-meter-deep habitats with low velocities by shovelnose sturgeon in the Kansas River (Quist et al. 1999). These authors observed that shovelnose sturgeon seems to prefer these moderately deep, slow velocity areas maintained, in part, by discharges ranging from 671 to 1,356 cfs (moderate to low flows).

River Fragmentation Due to Large Dams

Concurrent with the changes in flow regimes associated with all the reservoirs on the major tributaries of the Kansas River is the physical and genetic isolation of fish communities and species inhabiting this large river system. While there are no comprehensive studies of reservoir and impoundment impacts on the immigration, emigration, and life history of fishes of the Kansas River Basin, there are many scientific studies of the negative impacts of fragmentation of dendritic ecological networks (e.g. streams, cave and plant architecture). River networks are often impacted and especially venerable to breaks in network connectivity (see 2017 Freshwater Biology vol. 63). The effects of river discontinuity on fish as a result of dams are impacting fish diversity on a global scale (Liermann et al. 2012). Separating the impacts of altered flows from stream fragmentation is difficult where large dams can cause both conditions. Research on low-head dams suggest that fragmentation of flow regimes alone can impact fish species richness and functional composition (Tiemann et al. 2004, Santucci et al. 2005, Helms et al. 2011, Perkins et al. 2015).

Because large dams can negatively impact fish species and fish community through flow alterations and fragmentation, it can only assume that restoring some natural flow regime elements will improve fish community health. Restoring the pre-impoundment flows (or portions of the flow regime) of the Kansas River is an important step in improving the ecological condition of the river and thus its biota. However, fragmentation of this river system by 18 large federally operated dams may constrain ecological improvements suspected to respond to improved ecological flows (e-flows) from future reservoir management. This does not lessen the importance of trying to improve e-flows to the Kansas River but should be considered when measuring future biological responses.

Smoky Hill, Saline, Solomon, Republican, and Big Blue River Reaches

The Smoky Hill, Saline, Solomon, Republican, and Big Blue rivers are all tributaries of the Kansas River that have been impounded with large dams creating Kanopolis, Wilson, Waconda, Harlan County, Milford, and Tuttle Creek lakes respectfully. A study conducted in various parts of the United States suggest that dams on both river main-stems and tributary streams can adversely affect native species (Mammoliti 2002). A 1981 study by Moss and Bunson sought out to categorize Kansas Streams by their fisheries resources. The Big Blue, Republican, Solomon, and Smoky Hill river reaches below the impoundments were categorized as high priority fisheries. The Saline River below Wilson Lake was categorized as a moderate priority fishery (Moss and Brunson 1981). This classification was created to assist federal and state agencies and water users in assessing the impact of proposed water development projects on existing fishery resources.

A channel catfish age and growth study by Klaassen and Eisler in which a pectoral spine system was used for aging specimens revealed channel catfish in the Smoky Hill River system were growing at a much slower rate than specimens in other parts of the country, especially in Eastern Kansas streams. The study discussed a possible reason for this slow growth rate could be the absence of deep sheltered holes. When the river was impounded, flooding that would wash out large deep holes was limited and have allowed the deeper holes to fill in with sand (Klaassen and Eisler 1970). Farmers in the area often mentioned the deep holes were locations where large channel catfish were present before the dams were constructed, while samplers recorded very few shelter holes that were more than one meter deep. It is surmised that larger catfish may be more subject to natural predation or downstream migration to larger reaches of Smoky Hill River or into the Kansas River mainstem (Klaassen and Eisler 1970).

A 2005 update by Haslouer et al. to the evaluation of the status of native Kansas fish species, showed a decline in many large river species populations. The shovelnose sturgeon, a species that was once prevalent in the lower portions of the Republican, Big Blue and Smoky Hill rivers is believed to no longer occur in these habitats due to the changing of riverine habitat caused by dams, channel modifications, and increased water clarity (Haslouer et al. 2005). The sturgeon chub is another species that has seen a serious decline over the years, as it was once an abundant species in the lower Smoky Hill and Republican rivers, however none have been observed in these stretches in the last 25 years (Haslouer et al. 2005). The river shiner *(Notropis blennius*) once had a widespread distribution in Kansas including the Smoky Hill River, however it has now been listed as a "vulnerable" species in Kansas due to few recent samples (Haslouer et al. 2005). The flathead chub, Topeka Shiner (*Notropis topeka*), river shiner, and plains minnow seem to have been extirpated from the Republican River Basin due to a change in habitat from a lotic habitat to a lentic habitat (Eberle et al. 1989).

Channel blockage has important ramifications on species adapted to streams with variable or discontinuous flow patterns. A dam impedes movement of fish, especially species adapted to spawn in headwater pools (Mammoliti 2002). Typically, headwater species seek refuge in downstream areas during prolonged drought and recruit upstream when higher flow conditions resume. After dam construction, headwater species are forced to seek refuge downstream in the impoundment as upstream habitats dry, which places obligate stream fish into habitats for which they are poorly adapted and where they might be preyed upon by piscivores (Mammolitti 2002). Mammolitti (2002) suggests this has been a cause of the decline of Topeka Shiner population in the Republican River.

A 2002 study in the Big Blue River basin compared fish community's preconstruction and 40 years after construction of Tuttle Creek Lake. 14 sample sites were able to be sampled in the 1950s and in 2001. The most notable changes to the fish assemblages were the introduction and presumed establishment of four species: emerald shiner, bullhead minnow, mosquitofish, and golden shiner (Gido et al. 2002). These species were likely to have been introduced through bait-bucket introductions, as they are common to other Midwestern drainages. It has been hypothesized the introduced species are successful because of the lentic habitat and relaxed competition with other stream fish (Gido et al. 2002). There was the extirpation of one species, the shoal chub, believed to have been caused due to the semi buoyant eggs that require an unimpeded reach of river for the embryos to develop into free-swimming larvae. If eggs drift into slack water habitats, they presumably will settle to the bottom or possibly be consumed by predators (Gido et al. 2002).

A USBR study (USBR 2016) found that decreased flows and altered hydrographs are the primary limiting factors throughout the Republican River Basin. Due to these effects fish populations will continue to shift toward species that are benthic spawners rather than pelagic spawners due to the decrease in spawning and drift distance for larval fish. The basin would also continue to see an increased shift towards non-native species. Additionally, Perkins and Gido (2011) looked at the reach of the Republican River from Harlan County Reservoir Dam to Milford Reservoir and determined that 2 species of Great Plains fish species are declining in this reach, the flathead chub and the silver chub from stream fragmentation. Perkins and Gido (2011) suggest that mitigation of the effects of stream fragmentation could include management of flow regimes that target recruitment of native fishes, release of epilimnetic water to minimize thermal alterations, and management of instream habitat complexity to facilitate increased heterogeneity.

Eberle et al. (2002) sampled fishes at 12 sites above and below the reservoirs on the Solomon, North Fork Solomon, and South Fork Solomon rivers during 1996 and 1997 to assess the extent to which fish assemblages had changed because of extirpations and introductions in stream reaches impacted to various degrees by agricultural developments and impoundments on the main stem of the rivers. Three sites were sampled on the reach of the Solomon River below Waconda Reservoir. Of the 43 species of fishes reported from the Solomon River Basin, it was determined that 17 native species were extant, 8 native species were extirpated, and 18 species were introduced or had immigrated into the basin. Eberle et al. (2002) placed species into categories based on their predominance in low-discharge or hi-discharge streams and their status as native or nonnative species within the basin. Of the 43 species reported, 6 species that were extant are low-discharge species, 3 are high-discharge species, and 8 utilized both low- and high-discharge streams. Of the 8 native species that are extirpated, 5 are low-discharge species and 3 are high-discharge species. The 18 species that are considered nonnative, 1 is a low-discharge species, 13 are high-discharge species, and 4 utilized both low- and high-discharge streams. Most of the species that were extirpated were restricted to small, clear streams which were present historically in the head waters sections of the Solomon River Basin. While most of the species extirpated from the Solomon River Basin inhabited the river headwaters and tributary streams, two species, Goldeye and Plains Minnow, were likely limited to the broad flows of the larger Solomon River reaches. While the number of Goldeye in the Solomon River likely varied from year to year, the extirpation of the Plains Minnow has been more dramatic. The Plains Minnow historically occurred in all 3 of the Solomon River reaches. Throughout northwestern Kansas, reduction in streamflow and regulation of discharge by dams have eliminated much of this habitat (i.e., broad streams with shifting sand bottoms and braided flow). The extant species in the basin are among those with life history attributes that make them generally tolerant of a wide range of environmental conditions which served them well in an environment that varied seasonally from broad torrents to narrow flows or isolated pools.

Prior to settlement the Solomon River was a moderately sized plains river with often turbid water. Surveys performed from 1858 to 1861 recorded widths of 32 to 44 meters and the presence of springs and clear brooks near the river. The Solomon River was likely more incised than the upper reaches of the North and South Fork Solomon River with few natural gravel bars. Following construction of the reservoirs several aspects of riverine habitat changed, including narrower widths, firmer stream substrates, and few natural gravel bars. Most of the successful introductions or range extensions into the Solomon River Basin have involved species generally adapted to reservoirs and riverine pools, which provide large areas of lentic habitat with relatively low turbidity and increased availability of plankton. These conditions favor species of sport fishes, such as largemouth bass, white bass, and walleye, that rely of sight to find their prey (Eberle et al. 2002). Eberele et al. (2002) suggest that there are 2 identifiable fish assemblages within the main stems of the rivers in the Solomon River Basin. One was associated with river segments in the lower basin that had relative high discharges. They also suggest that changes in the fish assemblages in the Solomon River have mainly been the result of introductions and immigrations of fish that prefer lentic habitats. However, the primarily cause of changes in fish species in the Solomon River were attributed to changes in habitat rather than biological interactions among native and introduced species of fishes. Overall there has been a substantial reduction in the native fauna of the basin (32%) and a potential loss of generic diversity from populations on the fringe of the overall distributions of these species (Eberle et al. 2002).

Eberle et al. (2000) sampled the range extensions for the emerald shiner within the Solomon River Basin during 1996-1997. Emerald shiners were unknown from the Solomon River Basin (Cross, 1967) until they were documented in Phillips and Rooks counties (Cross and Collins, 1995). Kirwin and Webster reservoirs are located in these counties on the North Fork Solomon and South Fork Solomon rivers, respectively. Emerald shiners were reported first from the main stem of the Solomon River in Saline County near its mouth on 22 October 1995 (Eberle et al., 1995). On 19 October 1996 14 emerald shiners were collected in the Solomon River in Ottawa County downstream from the municipal dam near Minneapolis (sec. 1, T.11S., R.4W.). One additional individual was captured at this site on 6 September

1997. Single specimens were captured in May and October 1996 at a site in Saline County, where the species had been reported previously (Eberle et al., 1995). However, we collected no emerald shiners at any of our nine sites on the North Fork Solomon and South Fork Solomon rivers sampled during 1996 and 1997. Although emerald shiners might maintain populations near reservoirs, Cross and Collins (1995) suggested that the distribution and abundance of emerald shiners might be declining in the Kansas River Basin as a result of regulated streamflow's by federal reservoirs. Within the Republican and Smoky Hill river basins of northwestern Kansas, emerald shiners have been noted to be relatively abundant only in the Republican River, which has a loose, sandy substrate and broad channel, unlike rivers in the Smoky Hill River Basin that have streamflow's regulated by federal reservoirs.

Osterhaus and Martin (2019) sampled for the Plains Minnow, a once common specimen found throughout Kansas, one area that was focused on was the Smoky Hill-Saline River Basin. Their study found a drastic decline in the Plains Minnow population from 1974 to 1999. Within Kansas it is probable that a combination of three stressors have led to the decline of Plains Minnow within the state as a whole. First, and likely most detrimental, is fragmentation due to damming (either for flood control, water retention, or beautification) and dewatering. Fragmentation results in the gradual disappearance of pelagic broadcast-spawning cyprinids from the river reach that is affected (Perkin and Gido, 2011). Dewatering results in the elimination of all fish species from the affected reach. In a study by Perkin et al. (2015), the mechanism that is seemingly causing the decline of Plains Minnow in these fragmented and dewatered river reaches is described as an ''Ecological Ratchet". Regarding the loss of native species, the proposed ratchet works in the following steps: (1) desiccation of a stream reach eliminates a species from the reach, and (2) all attempts of upstream repatriation are blocked by dams, which stop upstream fish movement into the previously desiccated stream reach (Perkin et al., 2015). Second, the disruption of the natural flow regime (Poff et al., 1997) by flood water retention in large man-made reservoirs eliminates the variable flow in which the Plains Minnow evolved to survive and reproduce (Sliger, 1967; Lehtinen and Layzer, 1988). Multiple studies have illustrated that high flow events synchronize Plains Minnow spawning (Cross and Moss, 1985; Eberle, 2007; Patton and Hubert, 1993). The absence of these events may decrease the reproductive output of Plains Minnow populations, as conditions for reproduction are not ideal. In addition, flooding is vital for the creation of backwater habitats (Schmidt et al., 2001) in which Plains Minnow have been observed aggregating to spawn (Cross, 1967). Third, channelization alters flow and habitat within the impacted stream reach and leads to the loss of spawning habitat and the appropriate stream morphology for Plains Minnow to complete their reproductive cycle (Di Tomaso, 1988; Worthington et al., 2014; Pennock, 2017). As Plains Minnow are known to aggregate in areas of lower water velocity to spawn (Cross, 1967; Taylor and Miller, 1990), loss of these habitats is apt to negatively impact the viability of Plains Minnow populations within channelized stream reaches. Channelization is continuously occurring within the region as the result of human interaction with the stream environment (Pennock, 2017),

Many larger rivers in the region formerly had widely fluctuating, turbid flows over broad beds of shifting sand, but they have been altered by reduced streamflow's and the construction of impoundments (Cross and Moss, 1987; Sanders, Huggins, and Cross, 1993). Construction of small dams, usually associated with mills, began in the late 1800s. From the late 1940s through the 1960s, several federal reservoirs were constructed on all of the principal rivers in northwestern Kansas. The reduced peak discharges and generally stable flows produced by regulated releases of water from reservoirs have caused some river channels downstream from the reservoirs to become narrower and deeper with firmer substrates (Cross and Moss, 1987). Impoundments also reduce the sediment load of water released from the reservoir, and they block the upstream movements of aquatic organisms (Cross and Moss, 1987). Diversion of reservoir releases for irrigation can threaten aquatic communities by dewatering stream segments below the diversion structures. Runoff and seepage returning to streams from cropland irrigated by groundwater or surface diversions can carry chemicals harmful to aquatic ecosystems. For example, arsenic and selenium levels in reservoir sediments in the Solomon River basin in north-central Kansas increased significantly during the latter 1900s (Christensen, 1999). Although a number of species of fishes adapted to the original conditions in the large and small streams have been extirpated from northwestern Kansas, the impoundments have made possible the successful introduction of several species of fishes adapted to lentic habitats (Cross and Moss, 1987; Sanders, Huggins, and Cross, 1993).

Conclusions

Assembling a database of fish collected from the Kansas River (1886-2018), review of literature related to changes in the fish community from the Smoky Hill, Saline, Solomon, Republican, and Big Blue Rivers, determining which species decreased after impoundment, and examining the autecology and spawning periods of these species, along with pre-and post-impoundment flows during critical life history moments, have allowed us to incorporate multiple lines of evidence to estimate critical flow needs for Kansas River fish. To reintroduce heterogeneity to the Kansas River and its tributaries, modification of dam releases in consideration of these flow needs must incorporate:

- Frequency – How often flows increase and decrease (variability of flows). Frequency in flows increases water and terrestrial connectivity and shifts instream habitat availability.
- Duration – The temporal range of flow events. While large flood peaks must be attenuated, both high and low flow periods should follow normal patterns.
- Extent – The magnitude of flow increases and decreases. Again while flood peaks need to be attenuated, both extreme high and low flow periods should not be extended beyond normal time periods.
- Temporal shifts – Current flow regimes remain closely correlated with natural flow regimes. The historic changes in river flows were linked to climate and precipitation patterns within the basin and shifts in seasonal flow patterns should be minimized.

Native fish are adapted to the natural heterogeneity of the Kansas River and its tributaries and need not only the habitat that is shaped by variance in flows, but also physical dynamics of the water for egg and juvenile development. This review looks at historic and modern flows and fish data for the Kansas River, Smoky Hill River, Saline River, Solomon River, Republican River, and Big Blue River. The Powell Center Working Group Project "Synthesizing Multiple Long-Term Datasets to Test Flow Ecology Relationships for Fishes" met in April 2019 to look at long-term datasets to hypothesize effects of river flow on various fish guilds (Freeman 2018). The outcome from that work may provide more guidance in selecting optimal flows for the guilds present in the Kansas River and its tributaries (Smoky Hill, Saline, Solomon, Republican, and Big Blue Rivers).

Guidance should be developed for modifying dam releases to mimic the natural flows that occurred during the peak spawning period of late May and June, as well as the fall when fry are growing. Allowing variability and some high-water events in the summer, while reducing flows in the fall, will improve habitat and spawning and enhance habitat and flow conditions for fish.

3.6.3 Freshwater Mussels

The Kansas River historically supported a diverse assemblage of native freshwater mussels. During the urban, industrial, and agricultural development of the native freshwater mussel experienced a rapid decline in species richness. Today, freshwater mussels are perhaps the most threatened fauna on the Kansas River. Of the 48 species historically found in Kansas, six are extirpated, one lacks reproductively viable populations (i.e., faces imminent extirpation), 38 have suffered evident range reductions or a widespread thinning of former populations), and 23 are designated as threatened, endangered, or SINC (Angelo et al. 2009). Angelo et al. 2009 provides a list of these species along with a thorough literature review and examination of decline in Kansas.

Cringan et al. 2020 provides information on the occurrence and distribution of freshwater mussels in the Kansas River. The study examines major changes occurring in the mussel community over the past 150 years and identifies key natural and anthropogenic factors contributing to these changes. The study also discusses opportunities and challenges relating to the protection and restoration of mussel populations in the Kansas River and its watershed. Cringan et al. 2020 obtained data from available governmental databases, museum shell collections, and published and unpublished studies to determine the occurrences and distributions of individual mussel species in the Kansas River Basin. Based on the earliest records (1883-1906), the basin once supported at least 32 mussel species with 24 reported historically from the Kansas River.

This report also looked at occurrence of mussel species in the Kansas River by compiling two datasets obtained from Kansas Department of Health and Environment (KDHE): a dataset of 2009-2010 surveys, and a dataset of pre-1990 through 2007 surveys (with collection dates specified as pre- or post-1990). The resulting dataset was reviewed for only Kansas River specimens. The review resulted in 25 Kansas River sites containing 212 records of 25 species found pre-1990 to 2010 (Figure 30, Table 12).

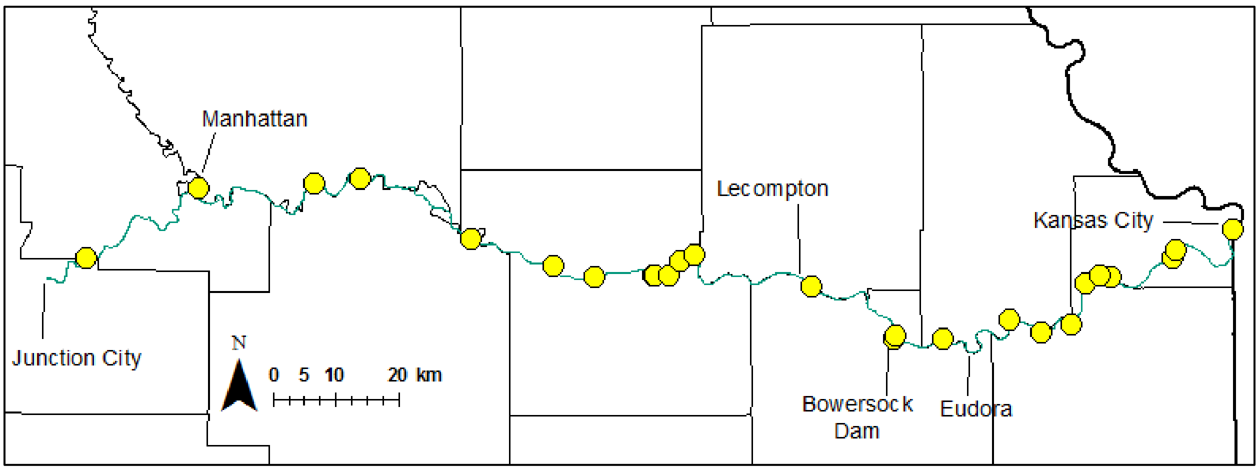

Figure 30. Mussel Data Sites on the Kansas River

Notes: Collected pre1990, 1990-2007, and 2009-2010

Table 12. Presence of Mussels in Kansas River Surveys

Scientific Name	Common Name	Status[2] (State Listing/ Watershed/ Kansas River)	Pre-1990	1990-2007	2009-2010
Actinonaias ligamentina	mucket	E/x/x	p	-	-
Amblema plicata	threeridge	NA/D/x	p	-	-
Anodontoides ferrusacianus	cylindrical papershell	E/x/x	p	-	-
Corbicula fluminea	Asian clam	I	p	p	p
Cyclonaias pustulosa	pimpleback	NA/D/D	p	p	
Dreissena polymorpha	zebra mussel	I	-	-	p
Fusconaia flava	Wabash pigtoe	NA/D/x	-	p	-
Lampsilis cardium	Plain pocketbook	NA/x/x	p	-	-
Lampsilis siliquoidea	fatmucket	S/D/x	p	p	-
Lampsilis teres	yellow sandshell	S/D/x	p	p	p
Lasmigona complanata	white heelsplitter	NA/D/st?	-	p	-
Leptodea fragilis	fragile papershell	NA/st/st	p	p	p
Ligumia recta	black sandshell	NA/x/x	P	-	-
Ligumia subrostrata	pondmussel	NA/D/x	-	p	p
Megalonaias nervosa	washboard	S/x/x	p	-	-
Obliquaria reflexa	threehorn wartyback	NA/x/x	-	p	-
Obovaria olivaria	hickorynut	NA/X/x/x	p	p	-
Potamilus alatus	pink heelsplitter	NA/D/D	-	p	p
Potamilus ohiensis	pink papershell	NA/st/st	-	p	p
Pyganodon grandis	giant floater	NA/D/st?	-	p	-
Quadrula quadrula	mapleleaf	NA/D/D	-	p	p
Strophitus undulatus	creeper	NA/D/x	p	-	-
Truncilla donaciformis	fawnsfoot	S/D/D	p	p	-
Truncilla truncata	deertoe	S/x/x	p	p	-
Uniomerus tetralasmus	pondhorn	NA/D/D	-	p	-

Notes:
1. p = presence
2. Status – D = declining, E = endangered, X = extirpated in Kansas, x = extirpated from watershed or the Kansas River, T = threatened, S = species in need of conservation concern, st = stable
3. Angelo et al. 1990; Cringan et al. 2020

Historical records suggest that 14 freshwater mussel species (see Table 12) were extirpated from the Kansas River between 30 to 140 years ago (Cringan et al. 2020). The hickorynut (*Obovaria olivaria)* is now extirpated in Kansas, while in the Kansas/Lower Republican River Basin the plain pocketbook (*Lampsilis cardium*) became eliminated and the fatmucket (*Lampsilis siliquoidea)* became sparsely scattered (Angelo et al. 2009). None were found on the Kansas River in 2009/2010. Today, the Kansas River Basin supports only 18 mussel species, showing a 44% decline in taxa richness. Declines range from 33 to 52% in some component watersheds, including the Big Blue, Republican, Smoky Hill, and Wakarusa river basins. Most extant species (pimpleback (*Cyclonaias pustulosa*), creeper (*Strophitus undulatus*), fawnsfoot (*Truncilla donaciformis*), and pondhorn (*Uniomerus tetralasmus*), have seen dramatic reductions in distribution and are now found only in a few isolated, widely scattered habitats. The Kansas River currently supports only nine species, representing a 56% decline in taxa richness. Most extant species include a few widely scattered, adult individuals, and populations exhibit little evidence of recent recruitment. Since the turn of the 20th century, dominant mussel species in the Kansas River have changed from three long-lived, slowing maturing species (hickorynut (*Obovaria olivaria*), fatmucket, yellow sandshell (*L. teres*)) to two short-lived, rapidly maturing species (fragile papershell (*Leptodea fragilis*), pink papershell (*Potamilus ohiensis*)). Cringan et al. 2020

The two introduced species listed in Table 12 do not require a host fish for larvae development. The Asian clam (*Corbicula fluminea*) does well in a variety of substrates, flows, and water quality. By 1983 it was well-established in Perry Reservoir and in the Kansas River was found in two locations downstream of Bowersock Dam (Mackie and Huggins, 1983). Zebra mussels (*Dreissena polymorpha*) were found in Perry Lake in 2007 and in the Kansas River by 2009 (KDHE 2010).

Freshwater mussels are largely sedentary, spending their entire juvenile and adult lives in the same general location, making them unusually sensitive to local changes in water and sediment quality and physical habitat conditions (Cringan et al. 2020). Angelo et al. (1990) cite alterations in stream flows due to impoundments as a contributor to the decline of mussels. Prolonged reservoir discharges into late summer and fall create higher flows than those to which the mussels are adapted and that are important for mussel reproduction. We can see this in the hydrograph of Figure 11 at day 270 (October) where post-impoundment flows become and remain higher than pre-impoundments flows. These prolonged discharges often destabilize the downstream benthic substrate, displacing juvenile mussels, hampering interactions between gravid mussels and host fishes, and in some cases eliminating entire mussel assemblages (Cringan et al. 2020). Rapid reductions in reservoir release rates can also strand large numbers of mussels on exposed shorelines and sand and gravel bars (Cringan et al. 2020).

Also, mussels rely on fish as hosts for the glochidia stage of their reproductive cycle (see Cringan et al. 2020 for a list of potential biological hosts for each mussel species), therefore modification of Kansas River flows to improve fish populations and removal of impediments to migration of fish will also benefit mussels. Cringan et al. 2020 cite several interacting factors that have contributed to observed declines in mussel species richness. The major factors are (1) stream siltation and other forms of water and sediment pollution, and (2) changes in physical habitat resulting from the construction of dams, channelization of streams, dredging of sand and gravel, removal of riparian vegetation, and draining of wetlands. Other contributing factors include stream dewatering, declines in host fish abundance, commercial mussel harvests, and the infiltration of nonindigenous aquatic species.

Some reservoirs in the Kansas River Basin (e.g. Tuttle Creek Lake) support mussel communities on at least a transient basis. These species are the most commonly occurring mussel species in the Kansas River and are likely habitat generalists. Mussel species in reservoirs have become stranded given the often-variable fluctuations in reservoir water levels and it is thought the reservoirs may be too unstable to sustain viable mussel populations (as cited in Cringan et al. 2020). The long-term viability of reservoir mussel populations has received limited investigation to date.

Cringan et al. cite the following measures that would benefit mussel recovery efforts in the Kansas River Basin that could be considered by the Kansas River SRP:

- **Changes in the seasonal operation of existing flood control dams – Gradual attenuation of high reservoir release rates.** Streamflow in the Kansas River is dominated at times by releases from reservoirs, and the rapid attenuation of these releases can strand mussels on exposed sand

and gravel bars. Stranding often results in lethal heat stress and heavy predation, and severe or repeated stranding events can jeopardize entire mussel communities (Freske 2001; Obermeyer 2001; Vaughn and Taylor 1999 as cited in Cringan et al. 2020). ***To minimize stranding-related mortality, reservoir releases should be attenuated over at least a one to two-week period, particularly during the summer and early fall when daytime air temperatures commonly exceed 90 °F (32°C).*** This precaution is especially important when streamflow falls below the level needed to inundate most sand and gravel bars. In the Kansas River, this level corresponds to about 5,000 cfs (Cringan et al. 2020).

Cringan et al. cite additional measures that are outside of the scope of SRP that would benefit mussel recovery in the basin including:

- Enactment of a moratorium on new dam construction
- Removal/circumvention of artificial barriers to fish migration
- Translocation of stranded mussels following reservoir drawdowns
- Transition to pit mine and quarry-based sources of sand and gravel
- Moratorium on stream channelization projects
- Performance of field and laboratory studies
- Adoption/implementation of protective water quality standards
- Transition to less polluting farming practices
- Restoration of riparian areas and riverine wetlands
- Prohibition on commercial mussel harvests
- Restrictions on the importation/release of nonindigenous species
- Development of mussel sanctuaries and mussel restocking programs
- Transition to dryland crop production
- Participation in global climate change initiative

3.6.4 Sandbar Nesting Birds

Many species of shore and wading birds use the Kansas River; however it is the sand-bar nesting species that have limited and tenuous habitat on the river. The two sandbar-nesting species in the Kansas River are piping plover (*Charadrius melodus*) and least tern (*Sternula antillarum*). Both prefer sandy beaches, open lake shores, and sparsely vegetated sandbars. Populations of both have declined in the central United States due to loss of habitat. Piping plover is federally and state threatened, while least tern is federally and state endangered. The entire length of the Kansas River is designated critical habitat (KDWPT 2019).

Busby et al. (1997) noted that little is known about historic use of the Kansas River by these two species. They surveyed the Kansas River in 1996-1997 for nesting colonies of piping plover and least tern on the Kansas River. In July 1996 they found two breeding pair of plovers (with eggs on a sandbar in a new channel created by the 1993 flood) and seven breeding pairs of terns (with juveniles and an egg) upstream of Wamego. In July 1997 they found one pair of plovers with downy young and five pairs of terns with eggs and a fledged juvenile downstream of Wamego. These were the first records of plover breeding in Kansas and terns breeding on the Kansas River. The authors conclude that the heavy flooding of 1993 created new sandbars where modified releases from impoundments had reduced suitable habitat for sandbar nesting birds.

The majority of studies on plovers and terns in this region focus on Missouri River populations (Buenau et al. 2014, USFWS 2016). However, since the 1996/1997 survey 11 additional nest sites have been found on the Kansas River, between Manhattan and Lawrence, including sites near Belvue in an April-June

2006 survey at RM 114 (Boyd and Olsen 2006). A query of Cornell Laboratory's eBird indicates more recent sightings of both species on or near the Kansas River:

- Piping plover near Topeka in May 2005 and least tern near Wamego in May 2013
- Around Clinton Lake: 1-5 adult and juvenile terns in August 2012, 2013, 2014, and 2015, and 1-3 plovers in April 2004, July – Sept. 2012, April and Aug. 2013, May 2014, and Aug. 2018
- Terns were also seen at Tuttle Creek Lake in Aug. 2005, and May 2015 and 2018
- Plovers were also seen at Perry Lake May 2005 and Sept. 2015 (eBird 2019).

These sightings indicate that these birds are present in the Kansas River area during breeding season, though there is no indication of whether the birds on their way to other areas to nest.

Anthropogenic changes in flows, such as diminished variance and duration, has decreased nesting habitat as well as food (invertebrate and fish) availability. While high episodic flows create the emerged sandbars that these birds need for nesting, high flows during the nesting period will destroy nests. Above 8,000 cfs there are no sandbars on the Kansas River (http://kansasriver.org/). However low flows allow encroachment of vegetation which provides cover for predators (Boyd and Olsen 2006). Examining nesting period on the pre-and post-dam hydrographs gives us an idea of how impoundments altered flows during nesting season. The 1996/1997 and 2006 reports of nest initiation and fledging correspond with the breeding chronology reported in the literature, with nesting beginning in mid to late April, incubation of 25-28 days, and hatching late May to early June, peaking in June and early July. Chicks are brooded up to 21 days but may be deserted at 5 – 10 days (USFWS 2016) (Figure 31). The USFWS (1990) least tern recovery plan describes similar breeding chronology, with arrival at breeding sites beginning late April, egg laying by late May 17-28-day incubation, brooding for 1 week, and fledged at 3 weeks.

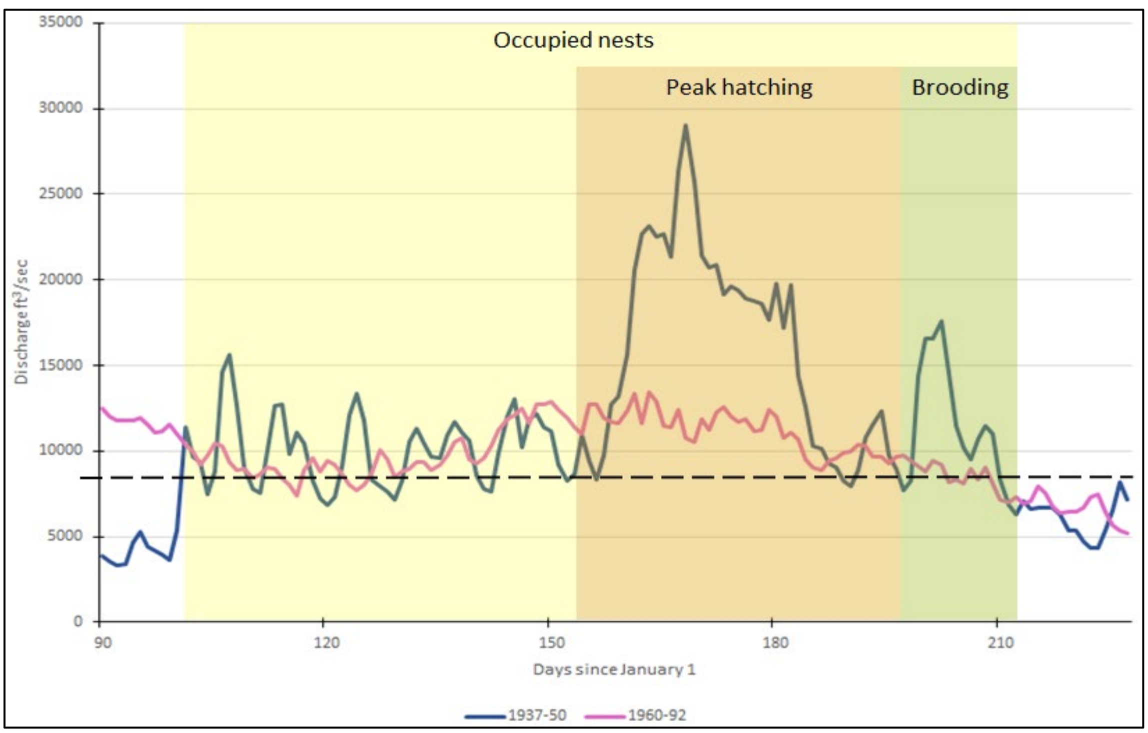

Figure 31. Piping Plover Nesting (yellow), Hatching (orange), and Brooding (green) Periods April-July, Interposed on Kansas River Flows at Lecompton

Note: Dashed line is 8000 CFS which is the discharge when sandbars are covered with water.

Human-constructed sandbars have been found to be inferior to naturally created sandbars as piping plover habitat on the Missouri River (Hunt et al. 2018). The natural sandbars had higher nest success, pre-fledging chick survival, and hatch-year survival. Modifying river flows to allow for sandbar creation and adequate exposure during nesting season will improve habitat for these threatened and endangered birds.

3.6.5 Reptiles and Amphibians

The only two Kansas River turtle species that require sandbars for nesting are smooth (*Apalone mutica*) and spiny (*Apalone spinifera*) softshells. Smooth softshell nesting peaks in late May and June, while spiny softshells nest in June and perhaps July (Collins et al 2010). The hydrograph shows that post-impoundment flows remain almost continuously above sandbar height, while pre-impoundment flows had more variance and episodes of sandbar exposure (Figure 34).

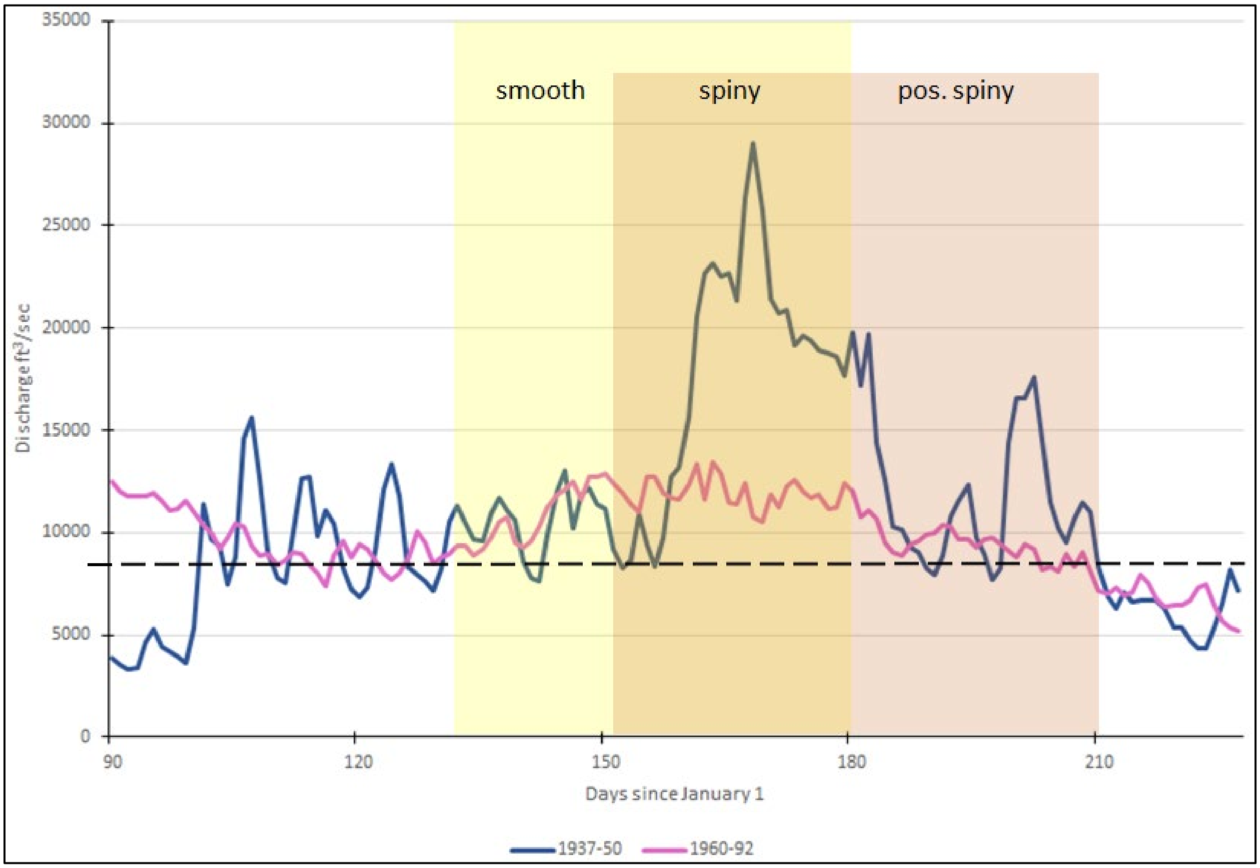

Figure 32. Nesting Period of Smooth and Spiny Softshell Turtles

Note: Dashed line is 8000 CFS which is the discharge when sandbars are covered with water.

4.0 Defining Ecosystem Flow Alterations and Restoration Needs

Flow-ecology hypotheses are designed to describe how specific taxa and ecological process are expected to respond to changes to the flow regime. Related hypotheses can be aggregated based on similar timing, flow-sensitive life stages and ecosystem function into a set of related flow needs that combine one or more responses of a group of taxa expected to respond similarly to a change in flow conditions.

4.1 High Flows

In Midwestern rivers, high flow events and floods provide cues for fish migration, maintain channel and floodplain habitats, inundate submerged and floodplain vegetation, transport organic matter and fine sediment, and help maintain temperature and dissolved oxygen (DO) concentrations. These events range from relatively small, flushing pulses of water (e.g., after a summer rain) to extremely large events that reshape floodplains but historically have occurred infrequently (e.g., large snowmelt or rain-or-snow events, major regional spring and summer storm events such as 2019). For the purposes of defining environmental flow components as per Matthews and Richter (2007), we distinguish between high flow pulses, small floods, and large floods. High flow pulses refer to low rises above seasonal flows that remain within the channel. "Small floods" are those that typically exceed bankfull flow, when flood waters allow fish and other organism's access to floodplains or flooded wetlands, secondary channels, backwaters, sloughs, and other off-channel habitats. In the Midwest, these typically occur on a 2-5-year recurrence interval. "Large" or "extreme" floods will often re-shape the physical structure of the channel and floodplain, scouring some areas and depositing sediment in others to form new channels, point bars, and off-channel habitats. We represent these floods as those with a 5% probability or lower (20-year recurrence interval or more).

Increased magnitude and/or frequency on any of these types of events can lead to channel instability, floodplain and riparian disturbance, and/or prolonged floodplain inundation. Reduced frequency of these events typically leads to channel aggradation, loss of floodplain inundation, and altered vegetation communities. Although the bankfull and overbank events that provide channel and floodplain maintenance commonly occur in May-July in the Kansas River system, these events can occur in any season.

4.2 Seasonal Flows

Seasonal flows provide habitat for spring, summer, and fall spawning fishes and mussels; ensure that eggs in nests, reds, and various substrates are wetted; provide overwinter habitat and prevent formation of anchor ice; maintain bank habitat for nesting and hibernating mammals/herpetofauna; and maintain a range of persistent habitat types. Naturally occurring variability within seasons helps maintain a variety of habitats and provide conditions suitable for multiple species and life stages.

Seasonal flows, often represented by median daily and monthly flows, are correlated with area and persistence of critical fish habitat, juvenile abundance and year-class strength, juvenile and adult growth, and overwinter survival. In summer, fall, and winter, studies in other rivers have shown that decreases in median monthly flow correspond to reduced macroinvertebrate density and richness, reduction of sensitive taxa, increase in tolerant taxa, and decrease in mussel density. Many studies cited tie ecological response to change in median monthly flows in a specific month or throughout a season. These flows represent a "typical" range of flows in each month and are useful for describing variation between seasons (e.g., summer and fall). Most of the time, in all but the wettest and driest portions of the flow record, flows are within this range.

4.3 Low Flows

Low flows provide habitat for aquatic organisms during dry periods, maintain floodplain soil moisture and connection to the hyporheic zone, and maintain water temperature and DO. Although low flow events naturally occur, decreases in flow magnitude and increases in frequency or duration of low flow events affect species abundance and diversity, habitat persistence and connectivity, water quality, increase competition for refugia and flood resources, and decrease individual species' fitness. When they do occur, extreme low flows enable recruitment of certain aquatic and floodplain plants; these periodic disturbances help maintain populations of a variety of species adapted to different conditions. Decreases in low flow magnitude have been correlated with changes to abundance and diversity of aquatic insects, mussels, and fish. Low flows also influence habitat persistence and connectivity, including riffle, pool, backwater and hyporheic habitats critical for fish, aquatic insect, crayfish, mussel, and reptile reproduction and juvenile and adult growth. Water quality, specifically DO concentration, is directly correlated to low flow magnitudes.

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Appendix A: Spawning Periods of Kansas River Fishes

date		day	season	chestnut lamprey	pallid sturgeon	shovelnose sturgeon	gizzard shad	central stoneroller	red shiner	common carp	western silvery minnow	brassy minnow	plains minnow	card shiner	common shiner	red shiner	sturgeon chub	shoal chub	sicklefin chub	silver chub	flathead chub	gold shiner	emerald shiner	river shiner	bigmouth shiner	carmine shiner	sand shiner	suckermouth minnow	bluntnose minnow	fathead minnow	bullhead minnow	flathead chub	creek chub	river carpsucker	white sucker	blue sucker	smallmouth buffalo	bigmouth buffalo	black bullhead	black buffalo	river redhorse	blue catfish	channel catfish	flathead catfish	green sunfish	orange-spotted sunfish	largemouth bass	white crappie	Johnny darter	freshwater drum	# spawners	# listed spawners
				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-	+		
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	31	212																																																	23	3
Aug	1	213																																																	15	4
	31	243																																																	15	4
Sep	1	244																																																	8	2
	20	263																																																	8	2
	21	264	fall																																																2	
	30	273																																																	2	

Notes:
1. Shading indicates spawning periods. Darker shading indicates peak spawning. Orange = S = SINC; T = threatened; E = endangered; x = extirpated from Kansas River. Blue = I = introduced. Contiguous spawning dates have been removed.
2. Day = day past January 1.
3. # of spawners are the number of spawners for that day and excludes introduced species.
4. # listed spawners are the number of state listed species spawning that day.
5. - = Decreased post impoundment; + = Increased post impoundment

Appendix B: Team Charter

Sustainable Rivers Program (SRP) – Kansas River Basin

Team Charter

Goals (Shared Purpose): To convene key personnel and partners to provide strong scientific and stakeholder support for The Sustainable River Program's commitment to improving ecological flows and reservoir health in the Kansas River system. To do this we will:

- Provide readily applicable and scientifically defensible products and services for the SRP program and e-flow workshops.
- Develop and maintain strong partnerships, regularly communicate progress to stakeholders, and leverage partner resources and stakeholder input to achieve success.
- Provide strong science communication to promote scientifically defensible modifications to the reservoir and river system and avoid negative impacts.

Core Team: The core team is represented by the project partners who are leading the science and technical integration. These members are providing the largest percentage of their time to this effort, are responsible for team deliverables (as necessary); developing a plan for coordination and communication of science-based planning across stakeholder groups; and identifying and targeting technical assistance as needed. This group will meet regularly via conference call/WebEx and in-person and is responsible for drafting the annual work plans and reports. Team members are:
*(**Bold** indicates primary point of contact)*

- USACE Kansas City District – **Christy Ostrander**, Todd Gemeinhardt, Paul Simon, Chris Purzer, David Hoover, Laura Totten
- The Nature Conservancy, Kansas – **Heidi Mehl**, Jim Hays, Kris Knight
- Friends of the Kaw/Kansas Riverkeeper – **Dawn Buehler**
- Kansas Alliance for Wetlands and Streams – **Jessica Mounts,** Brad Loveless, Deb Baker
- Kansas Biological Survey – **Debbie Baker**, Don Huggins, Scott Campbell**,** James Thorp, Amy Burgin
- Kansas Water Office – **Kirk Tjelmeland**, Earl Lewis, Nathan Westrup, Ginger Harper
- U.S. Geological Survey – **Brian Kelly**, Mandy Stone, Brian Klager

Steering Committee: This group consists of key external partners who are engaged in the Sustainable Rivers Program. Committee members will provide critical feedback to the core team via conference calls (as needed) and annual in-person meetings. All other communication will be via email. Activities include (1) reviewing team deliverable s, including annual work plans; (2) providing steering guidance on core team direction and efforts; (3) sharing information related to external science and conservation efforts; and (4) collaborating on funding proposals (when necessary) with the Core Team. This committee consists of:

- Kansas Department of Health and Environment – **Trevor Flynn**, Amanda Reed, Jamie Gaggero, Tom Stiles
- Kansas Department of Wildlife, Parks, and Tourism – **Aaron Deters,** John Reinke, Steve Adams
- Kansas Forest Service – **Bob Atchison**

- Kansas Geological Survey – **Susan Stover**
- Kansas Regional Advisory Committee – **Brad Bradley,** Sarah Hill Nelson, Katie Miller
- Kansas Water Assurance District – **Galen Biery,** Mike Lawless, Greg Wilson
- Kansas Water Authority – **Brad Loveless**, Mike Armstrong or Dennis Schwartz
- KDA Division of Conservation – **Rob Reschke**
- KDA Division of Water Resources – **Katie Tietsort,** Lane Letourneau
- K-State – **Keith Gido**
- Kansas Aggregate Producers Association – **Bob Henthorne (**Mid-States Materials), Jerry Younger
- U.S. Environmental Protection Agency – **Craig Thompson, Amy Shields**
- U.S. Fish and Wildlife Service – **Jason Luginbill**
- **John Hickey**, USACE Institute for Water Resources
- **Gretchen Benjamin,** TNC North American Water program

Advisors & Stakeholders: This group represents broad interests and stakeholders across the Kansas River basin. This group will provide critical feedback on planning and implementation via stakeholder meetings and the e-flow workshop. Other progress updates will be communicated to this group via email. This list will expand as partnerships are developed.

- **Environmental interests**
  - Kansas Wildlife Federation – Angela Anderson
  - KDWPT biologists and managers – Richard Sanders, Ely Sprenkle, Nick Kramer, Jeff Koch, Dough Nygren
  - Ducks Unlimited – Justin Williams, Matt Hough
- **Tribes and HINU**
  - Prairie Band Potawatomi Nation – Verna Potts
  - Kickapoo Nation in Kansas – Eric Sheets
  - Sac & Fox Nation – Lisa Montgomery
  - Iowa Tribe – Alan Kelley
  - Haskell – Bridgett Chapin
- **Recreational interests**
  - Heartland Visioning
  - Kayak businesses
    - *KC Kayak & Canoe*
    - *Kaw Valley Canoe*
    - *Pathfinder*
    - *360 Kayaking*
    - *Fort Riley Recreation*
    - *Sunflower Outdoor & Bike*
    - *Up A Creek*
    - *Kaw River Adventures*

        - *Dirty Girl Adventures*
        - *Konza Kayaks*
    - K-State Outdoor Recreation
    - KU Row Team
    - KU Recreation Services
    - Manhattan Parks & Recreation
    - Manhattan Convention & Visitors Bureau
    - Marinas, Boating interests and Yacht clubs
        - *Clinton Marina*
        - *Fort Riley Marina*
        - *Kansas Sailing Association*
        - *Lake Perry Yacht & Marina*
        - *Milford Lake Marina*
        - *Perry Yacht Club*
        - *Rock Creek Marina (Perry)*
        - *Thunderbird Marina*
        - *Wildcat Marina*
    - National Park Service – Brian Leaders
    - Topeka Riverfront Authority
    - TravelKS - KDWPT tourism division – Linda Craghead
- **Municipal and Business interests**
    - Aggregate Producers
        - *Kansas Aggregate Producers' Association – Jerry Younger*
        - *Builder's Choice*
        - *Holliday Sand and Gravel Company, LLC*
        - *Kaw Valley Companies, Inc.*
        - *Master's Dredging Company, Inc.*
        - *LBB, LLC*
    - Bowersock Mills & Hydropower – Sarah Hill Nelson
    - City of DeSoto – Mike Brungardt
    - City of Lawrence - Mike Lawless, Dale Nimz
    - City of Manhattan – Randy DeWitt
    - City of Olathe - John Gilroy, Joe Foster
    - City of Topeka - Braxton Copley
    - Fort Riley - Jeff Keating, Alan Hynek
    - Kansas River Water Assurance District (all members)
    - Kansas Rural Water Association
    - KC Board of Public Utilities (BPU) – Jim Epp
    - Wastewater Treatment Plants
        - *Manhattan*
        - *South Topeka WWTP (Oakland)*
        - *North Topeka*
        - *Lawrence*

        - *Johnson County*
    - WaterONE – Darci Meese, Paul Corkill, Michelle Wirth, Mike Armstrong
    - Westar Energy - Brad Loveless, Terry McCormick
        - *Green Team*
- **Operational interests (dam operators, public lands managers)**
    - Daniel Hays
    - William Whitworth
    - Stuart Cook
    - Clinton – USACE – Samantha Jones
    - Clinton – KDWPT – Justin Hamilton
    - Milford – USACE – William Whitworth
    - Milford – KWDPT – Kristin Kloft
    - Perry – USACE – RJ Harms
    - Perry – KDWPT – Andrew Page
    - Tuttle Creek – USACE – Brian McNulty
    - Tuttle Creek – KDWPT – Nathan Henry
- **Agricultural interests**
    - Kansas Farm Bureau - Kent Askren
    - Kansas Farmer's Union - Donn Teske, Mary Howell
    - Kansas River Irrigation Association – Howard Parr
    - Irrigation districts
    - Kansas Rural Center - Natalie Fullerton
    - Midwest Irrigation Systems – Gordon Michel
    - MWI Valley – Keith Grimm
    - NRCS - Troy Munsch, Bruce Wells

Technical Team: This team was convened to assist with synthesis of the ecological data. The ecological literature review and summary will provide key inputs for the Regime Prescription Tool (RPT), which in turn is used to evaluate the feasibility of different flow-plan proposals. The technical team represents broad ecological expertise in the Kansas River, and is tasked with ensuring the data review is robust, accurate, and defensible.

- Kansas Biological Survey – **Debbie Baker (team lead)**, Don Huggins
- Friends of the Kaw/Kansas Riverkeeper – Dawn Buehler
- Kansas Aggregate Producers Association – Bob Henthorne (Mid-States Materials)
- Kansas Alliance for Wetlands and Streams – Jessica Mounts, Deb Baker
- Kansas Department of Health and Environment - Steve Cringan (ret.)
- Kansas Department of Wildlife, Parks, Tourism – Jeff Conley, Mark VanScoyoc
- U.S. Army Corps of Engineers, Kansas City District - Todd Gemeinhardt (Science); Marvin Boyer (Water Quality); Paul Simon (Water Control)
- U.S. Environmental Protection Agency - Bob Angelo (ret.)