Arkansas River Corridor Projects
Fish Passage Data Review and Analysis

TO: Tulsa County

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FROM: CH2M HILL

DATE: July 2, 2009

PROJECT NUMBER: 386594

Introduction

Tulsa County, as part of a master plan for the Arkansas River Corridor, is undertaking an improvement project on the Arkansas River (Carter Burgess, 2004; Guernsey et al., 2005). The primary goals of the project are to increase connectivity between the river and surrounding communities, improve habitat for the federally endangered interior population of the least tern (*Sternula antillarum*)[1], improve the function of the river system itself, and improve recreational opportunities. Key components of the proposed project include:

- Design of a new Sand Springs low-head dam, pedestrian bridge, and amenities
- Design of modifications to the existing Zink Dam and lake with whitewater features
- Design of a new South Tulsa/Jenks low-head dam, pedestrian bridge, and amenities
- Design of bank stabilization and habitat improvements in selected areas

This Technical Memorandum (TM) investigates the upstream and downstream passage needs of migratory riverine fish species of potential interest to the Oklahoma Department of Wildlife Conservation (ODWC), the U.S. Fish and Wildlife Service (USFWS), and other stakeholders. The information gathered is used herein to identify potential fish passage implications and constraints for consideration in the project design effort and in preparation for agency consultation. This review identifies potential constraints but does not propose any design concepts or include any proposed alternatives. Specific design concepts and alternatives will be identified and evaluated in subsequent steps of project implementation.

Objectives

The success of the proposed Arkansas River Corridor Project will depend in part on incorporating appropriate design features for integrated operation of the low-head dams to balance multiple and diverse uses of the river (U.S. Army Corps of Engineers [USACE], 2009a; Proctor et al., 2008). The Arkansas River supports a prominent fishery providing

[1] Formerly referred to as *Sterna antillarum*.

valuable recreational opportunities to area residents. Key considerations for the design and operation of the low-head dams include passing migratory riverine species of fish at the correct time of year to allow upstream migration, spawning, and downstream egg transport.

The objectives of this evaluation are to:

- Describe the distribution, seasonal habitat needs, and occurrence of migratory fish species of interest in the project area
- Analyze potential project effects to migratory fish species as a result of project construction and operation
- Identify potential fish passage constraints and criteria that need to be considered in the project engineering design, construction, and operation

Migratory Fish Species of Interest

The primary migratory fish species of interest in the project area with respect to fish passage, as identified in the Arkansas River Corridor vision document prepared by the Tennessee Valley Authority (TVA) (Proctor et al., 2008), are:

- Shovelnose sturgeon (*Scaphirhynchus platorynchus*)
- Paddlefish (*Polyodon spathula*)
- Striped bass (*Morone saxatilis*)
- Sauger (*Sander canadensis*)

In addition, providing consistent habitat for and minimizing impacts to non-migratory and smaller native riverine fish species are of interest from the standpoint of maintaining aquatic biodiversity and supporting the food base of the federally endangered interior population of the least tern (Proctor et al., 2008). The least tern nests on emergent sandbar habitat in the project area from May to August and feeds mainly on minnows and other small fish (USFWS, 1990).

Description of the Arkansas River Basin

The proposed Arkansas River Corridor Project is located on the main-stem Arkansas River in the Tulsa metropolitan area in Tulsa County, Oklahoma (Figure 1). The Arkansas River is a major tributary of the Mississippi River, flowing east and southeast a distance of 1,450 river miles. The river drains an area of about 195,000 square miles. The Arkansas River forms on the east slope of the Rocky Mountains in southeastern Colorado, enters the Great Plains, and flows through Kansas, Oklahoma, and Arkansas to the Mississippi River.

In Oklahoma, two USACE reservoirs impound the Arkansas River upstream of the project study area: 17,000-acre Kaw Lake at river mile (RM) 654, completed in 1976; and 26,000-acre Keystone Lake at RM 539, completed in 1964. The power generated by the 70-megawatt hydroelectric facility at Keystone Dam (Figure 2), located just upstream of the proposed project, is marketed by the Southwestern Power Administration.

In the project study area, the Arkansas River flows about 84 river miles from Keystone Dam to the McClellan-Kerr Arkansas River Navigation System (MKARNS) near Muskogee in eastern Oklahoma. This reach includes: a 17-mile segment from Keystone Dam to the existing low-head Zink Dam at RM 522 in Tulsa (Figure 1); and a 64-mile segment from Zink Dam to Muskogee (RM 458). The river measures about 1,500 feet (ft) wide, is relatively shallow, and contains numerous braided channels and sandbars during base-flow periods. Figures 3 through 14 depict various segments of the Arkansas River in Tulsa County. All of these photographs except that in Figure 9 were taken at moderately high spring-time flows of about 17,500 cubic feet per second (cfs), which inundate and eliminate many sandbars from view. The photograph of Zink Dam in Figure 9 was taken at a flow of about 10,800 cfs.

The Arkansas River in the study area historically was a braided prairie river. The natural flow regime of the river has been modified by widespread water withdrawals, flow regulation by impoundments, hydropower production, channelization, and levee construction. In addition, agricultural, industrial, commercial, and urban land use activities have altered the riparian zone. The Tulsa County portion of the Arkansas River corridor has experienced significant degradation due to past alteration and encroachment from urban and industrial development (USACE, 2009a) (Figures 7, 8, 10, and 13) and agricultural activity (Figure 14).

The drainage area at the U.S. Geological Survey (USGS) gage on the Arkansas River at Tulsa (No. 07164500) is 74,615 square miles. The flow of the river varies widely on an annual and seasonal basis. Since the completion of Keystone Dam, annual mean flow at the Tulsa gage has ranged from 1,813 cfs in 1991 to 22,930 cfs in 1999. Based on the annual flow-duration curve for the period 1997-2007, daily mean flow exceeds 570 cfs about 90 percent of the time, 5,090 cfs about 50 percent of the time, and 38,000 cfs about 5 percent of the time. Daily mean flows have ranged from a low of 27 cfs on October 12, 1956 to a high of 261,000 cfs on October 5, 1986. The maximum instantaneous peak flow recorded by USGS at the Tulsa gage was 307,000 cfs on October 5, 1986. This wide range of flows in the same month demonstrates the high variability in flow in the Arkansas River near Tulsa.

Downstream of Muskogee, the Arkansas River is navigable by barges and large rivercraft downstream to the Mississippi River due to the series of numerous locks and dams comprising the MKARNS. The MKARNS is maintained and operated by the USACE.

Proposed Plans for Low-head Dams

The Ecosystem Restoration Plan prepared by USACE (2009a) includes the proposed development of two new low-head dams on the Arkansas River in the Sand Springs and South Tulsa/Jenks areas (Figure 1). These low-head dams would create a system of lakes, which, when operated in an integrated manner with the existing low-head Zink Dam, would reregulate releases from Keystone Dam to provide a wide range of benefits through the Tulsa County portion of the Arkansas River corridor (Proctor et al., 2008). In addition, although not included in the Ecosystem Restoration Plan, future development proposals may include rehabilitating and raising the height of Zink Dam to enhance safety and recreational boating opportunities (Proctor et al., 2008). The following sections describe preliminary design concepts for each of the three low-head dams.

Sand Springs Low-head Dam

- The proposed Sand Springs Dam would be located just downstream of the Oklahoma Highway 97 bridge and upstream of Prattville Creek entering from the south (Figure 5).
- The dam would be 1,400 ft long and 11 ft high, creating a pool extending upstream at least 5 river miles to the 637-foot elevation contour. About 4 river miles or less would remain free-flowing between Keystone Dam and the Sand Springs pool.
- During Keystone Dam's non-generation periods, the upper 3 ft of the Sand Springs pool would be used to provide a continuous downstream minimum flow release of 400 to 1,000 cfs for aquatic habitat enhancement during low-flow periods, least tern nesting habitat protection, and recreational boating opportunities.
- TVA identified a variety of gated spillway methods to lower the dam for passing sediment loads or fish and proposed pneumatically operated Obermeyer gates as the preferred concept. At a dam height of 11 ft, the gated adjustable section would need to be 925 ft wide (Proctor et al., 2008).

Zink Low-head Dam

- The existing Zink Dam (Figures 9 and 10) would be modified to eliminate hydraulic rollers and enhance recreational boating opportunities on the lake and in the tailwater (Proctor et al., 2008).
- The height of the dam would be increased by up to 3 ft using Obermeyer gates, which would increase the length of the pool from just over 2 to about 5 river miles and provide additional depth for rowing skulls on Zink Lake. About 3 river miles would remain free-flowing between the proposed Sand Springs Dam and the expanded Zink Dam pool.
- Three existing bascule gates (50 ft wide by 5 ft tall) (Figures 9 and 10) would be rehabilitated or replaced and gates added if needed to ensure downstream passage of sand loads.
- The minimum flow release from Sand Springs and the increased elevation of Zink Lake would allow for future whitewater boating opportunities at Zink Dam.

South Tulsa/Jenks Low-head Dam

- The proposed South Tulsa/Jenks Dam would be located about 3,500 ft downstream of the Creek Turnpike and upstream of Polecat Creek entering from the west (Figure 12).
- The dam would be 1,400 ft long and 8 ft high, creating a pool extending upstream approximately 2.9 river miles. About 4.5 river miles would remain free-flowing between Zink Dam and the proposed South Tulsa/Jenks Dam pool.
- TVA has recommended a 700-ft-wide adjustable section in the middle of the dam with Obermeyer gates that could be lowered seasonally to allow the river to flow freely for fish passage and heavy sand load passage (Proctor et al., 2008).

Methodology

The current distribution, life cycles, habitat use, swimming capabilities, and other considerations for upstream and downstream passage of the migratory fish species of interest were investigated based on review of reasonably available literature and information sources. Key sources of information for this review included but were not limited to:

- A site reconnaissance conducted by CH2M HILL, which included ground surveys and a helicopter survey of the study area, from March 30 through April 1, 2009
- A site reconnaissance and 360-degree video documentation by multiple low-level helicopter flights conducted by Tulsa County and Program Management Group, LLC on March 24, 2009
- A meeting between CH2M HILL biologists and Kevin Stubbs of USFWS on March 31, 2009; and a teleconference with Brent Gordon of ODWC on April 2, 2009
- Fish community sampling and assessment conducted by ODWC biologists in the Tulsa County portion of the Arkansas River corridor as part of the Phase III study for the USACE Tulsa District (Cherokee CRC, LLC [Cherokee CRC], 2009)
- The striped bass radiotelemetry study conducted by ODWC (2009) on the Arkansas River and other readily available information on the distribution and population status of striped bass in the main-stem Arkansas River (Hendricks, 2006; Hawk, 2007)
- Life history, habitat use, and distribution information for the migratory species of interest provided by fisheries texts for Oklahoma (Miller and Robison, 2004), Missouri (Pflieger, 1997), and Tennessee (Etnier and Starnes, 1993), and other literature sources
- Oklahoma Natural Heritage Inventory (ONHI, 2003) occurrence information by county for federally and state listed species and state species of concern
- A variety of scientific and technical literature sources on the swimming capabilities of the migratory species of interest or similar species
- Information on the types and design features of fishways in use at dams, including design criteria for the upstream passage of adult migratory fishes (Clay, 1995) and research findings of the USACE St. Paul District and USGS on fish passage through dams on the upper Mississippi River (Wilcox, 1999)

The analysis of potential project effects also included impacts to forage species for the federally endangered least tern resulting from loss or alteration of riverine habitat.

The study area for this analysis was defined as the Arkansas River corridor in Oklahoma extending from Keystone Dam downstream through Tulsa, Wagoner, and Muskogee Counties approximately 84 river miles to the confluence of the Verdigris River at the MKARNS. Figure 1 shows the upstream portion of the study area from Keystone Dam to the Tulsa County-Wagoner County line. This study area was established, based upon professional judgment, to include the extent of possible effects on riverine habitat. As the understanding of the project evolves, the study area may be refined.

Current Distribution and Habitat of Species of Interest

A seasonal fisheries survey conducted by ODWC biologists from October 2006 through September 2007 (Cherokee CRC, 2009) reported the occurrence of 41 species of fish in 12 families from the Arkansas River in Tulsa County (Table 1). The families represented by the most species were sunfishes (9 species), carps and minnows (8 species), and suckers (7 species). The principal sport fishes collected included largemouth bass, spotted bass, striped bass, channel catfish, flathead catfish, white crappie, a variety of sunfishes, and sauger. The total number of species collected at each of five sampling sites ranged from 23 species at Zink Lake (Site 2) to 31 species at the most downstream station at the county line (Site 5).

ODWC collected 29 species from the reach between Keystone Dam and Zink Dam (Sites 1 and 2) and 37 species from the reach downstream of Zink Dam (Sites 3, 4, and 5) (Table 1). Eleven species were collected exclusively downstream of Zink Dam, potentially indicative of habitat differences, water quality conditions, or Zink Dam as an impediment to upstream dispersal (as currently operated). The 11 species included 4 native minnows, and the larger riverine species paddlefish, river redhorse, golden redhorse, sauger, and walleye.

Migratory Species of Interest

Three of the four migratory species of interest were collected during the ODWC seasonal survey (Cherokee CRC, 2009): paddlefish, striped bass, and sauger (Table 1). Shovelnose sturgeon was not collected. The following sections summarize the distinctive habitat characteristics, current distribution, and known population status of the four migratory species of interest relative to fish passage in the Arkansas River study area.

Shovelnose Sturgeon

- The shovelnose sturgeon inhabits open channels of large rivers, where it moves long distances. It lives and feeds on the bottom over sand or gravel, often in areas with swift current, and is highly tolerant of turbidity (Pflieger, 1997; Etnier and Starnes, 1993). Its food consists primarily of benthic insects.

- Little is known about the spawning behavior of shovelnose sturgeon. Spawning reportedly occurs from April to June in the open channels of large rivers in strong current over rocky or gravelly bottoms (Pflieger, 1997; Etnier and Starnes, 1993), or in tributary streams (Miller and Robison, 2004).

- The shovelnose sturgeon is native to the Arkansas River and is currently tracked as a state species of special concern. It currently is not known to occur in the Arkansas River in Tulsa County based on present and historic records in the ONHI (2003) database and may be extirpated from the area (Cherokee CRC, 2009). Its historic occurrence has been documented in Wagoner County downstream. Zink Dam likely would impede the upstream movement of any sturgeon approaching the Tulsa area. Few recent occurrences of the species are known for the Arkansas River or its tributaries in Oklahoma. Dams along the MKARNS may limit the species' westward distribution in Oklahoma (Miller and Robison, 2004).

TABLE 1
Seasonal Occurrence of Fish Species Collected in 2006-2007 from the Arkansas River, Tulsa County, Oklahoma[a]
(Source: Cherokee CRC, 2009)

FAMILY/Scientific Name	Common Name	Keystone Dam to Zink Dam		Downstream of Zink Dam		
		Site 1: Sand Springs near Shell Creek	Site 2: Zink Lake	Site 3: 61st and Riverside Drive	Site 4: 96th and Riverside Drive	Site 5: Tulsa-Wagoner County Line
PADDLEFISHES:						
Polyodon spathula	Paddlefish					Su
GARS:						
Lepisosteus oculatus	Spotted gar	Sp		Sp		Sp
Lepisosteus osseus	Longnose gar	Su	Su	Sp	Sp, Su	F, W, Sp, Su
Lepisosteus platostomus	Shortnose gar				Sp	Sp
HERRINGS AND SHADS:						
Dorosoma cepedianum	Gizzard shad	W, Sp, Su	W, Sp, Su	Sp	Sp, Su	Sp, Su
Dorosoma petenense	Threadfin shad					Su
CARPS AND MINNOWS:						
Campostoma anomalum	Central stoneroller			Su		
Ctenopharyngodon idella	Grass carp	Su	Su			
Cyprinella lutrensis	Red shiner			W, Sp	Sp	F, W, Sp, Su
Cyprinus carpio	Common carp	Sp, Su	W, Sp, Su	Sp	Sp, Su	Sp, Su
Macrhybopsis hyostoma	Shoal chub					W
Notropis blennius	River shiner			F, W, Sp, Su	F, Su	F, Su
Pimephales notatus	Bluntnose minnow			Sp		W
Pimephales tenellus	Slim minnow	F, Su	F		Su	F, W, Su
SUCKERS:						
Carpiodes carpio	River carpsucker	Sp, Su	W, Sp, Su	Sp, Su	Sp, Su	F, Sp, Su
Carpiodes velifer	Highfin carpsucker	Su		Sp	Sp, Su	Sp
Ictiobus bubalus	Smallmouth buffalo	Sp, Su	W, Sp, Su	F, Sp	Sp, Su	F, Sp, Su
Ictiobus cyprinellus	Bigmouth buffalo		Su		Su	Su

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		Site 1: Sand Springs near Shell Creek	**Site 2: Zink Lake**	**Site 3: 61st and Riverside Drive**	**Site 4: 96th and Riverside Drive**	**Site 5: Tulsa-Wagoner County Line**
Moxostoma carinatum	River redhorse			Sp	Sp, Su	Sp
Moxostoma duquesnei	Black redhorse			Sp		
Moxostoma erythrurum	Golden redhorse		Su		Su	
BULLHEAD CATFISHES:						
Ictalurus furcatus	Blue catfish	Sp				
Ictalurus punctatus	Channel catfish	Sp, Su	W, Sp, Su	Sp, Su	F, W, Sp, Su	F, Su
Pylodictis olivaris	Flathead catfish		Sp, Su	Sp, Su	Sp, Su	F, Su
SILVERSIDES:						
Labidesthes sicculus	Brook silverside	F, W, Sp, Su	F, W, Sp, Su	F, Sp, Su	F, Sp, Su	F, W, Sp, Su
LIVEBEARERS:						
Gambusia affinis	Western mosquitofish	F, W	F	F, W	F, W	F, W, Su
TEMPERATE BASSES:						
Morone americana	White perch	Sp	Sp			
Morone chrysops	White bass	Sp, Su	Sp, Su	Sp	Sp, Su	Su
Morone saxatilis	Striped bass	Sp	Sp	Sp	Sp, Su	F, Sp, Su
SUNFISHES:						
Lepomis cyanellus	Green sunfish	Su	W, Sp, Su	F, W, Sp, Su	F, Sp, Su	Su
Lepomis gulosus	Warmouth	Sp		Sp	Sp	
Lepomis humilis	Orangespotted sunfish	Sp				
Lepomis macrochirus	Bluegill	F, Sp, Su	F, W, Sp, Su	F, Su	F, Sp, Su	F, W, Sp, Su
Lepomis macrochirus x L. cyanellus	Hybrid bluegill-green sunfish		W			

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		Site 1: Sand Springs near Shell Creek	**Site 2: Zink Lake**	**Site 3: 61st and Riverside Drive**	**Site 4: 96th and Riverside Drive**	**Site 5: Tulsa-Wagoner County Line**
Lepomis megalotis	Longear sunfish	F, Su	F, W, Sp, Su	F, Sp, Su	Sp, Su	F, Sp, Su
Lepomis microlophus	Redear sunfish	Sp, Su	Su	F	Sp	
Micropterus punctulatus	Spotted bass	F, Sp, Su	F, W, Sp, Su	Sp, Su	F, Sp, Su	Sp, Su
Micropterus salmoides	Largemouth bass	Sp, Su	W, Su	Sp	Sp, Su	Sp, Su
Pomoxis annularis	White crappie	Sp, Su		Sp	Sp	Su
PERCHES:						
Sander canadensis	Sauger				Sp, Su	
Sander vitreus	Walleye				Sp	
DRUMS:						
Aplodinotus grunniens	Freshwater drum	Su	W, Sp, Su	Sp, Su	Sp, Su	Su
Total Number of Species		**26**	**23**	**28**	**30**	**31**

[a] Season of collection indicated by: F = fall; W = winter; Sp = spring; Su = summer.

Paddlefish

- The paddlefish inhabits open water of slow-flowing big rivers, backwaters, and reservoirs rich in zooplankton, on which it feeds (Pflieger, 1997; Etnier and Starnes, 1993). It swims near the surface or in shallow areas. Paddlefish are very mobile and frequently leap clear of the water.
- Spawning occurs in April and May in large free-flowing rivers in swift water over gravel bars and riprap areas (Pflieger, 1997). A rapid increase in river discharge is a spawning stimulus (Hubert et al., 1984). Eggs sink to the bottom, adhere to the substrate, and hatch in 9 days at 57ºF (Pflieger, 1997). Spawning success depends on sustained inundation of gravel bars until eggs hatch and larvae are swept into deeper water.
- One paddlefish was collected during summer 2007 downstream of Zink Dam at the county line (Table 1), indicating that the species presently occurs in the Arkansas River near Tulsa but it may be uncommon due to a lack of preferred habitats. Zink Dam likely would impede the upstream migration of any paddlefish approaching the Tulsa area.
- Native to the Arkansas River, the paddlefish is now uncommon in the free-flowing river in Oklahoma because of the limited availability of quiet backwaters, oxbows, and sloughs, which are its preferred habitats for feeding. Much of this habitat has been eliminated from rivers by channelization, levee construction, and drainage of bottomland hardwoods (Hubert et al., 1984; Pflieger, 1997). Now the largest populations are in reservoirs with favorable feeding habitat, such as in the Neosho and Grand Rivers of northeastern Oklahoma (Miller and Robison, 2004).

Striped Bass

- The striped bass is a schooling, predatory species native to rivers along the Atlantic and Gulf coasts. It is adapted for life-long residence in freshwater, and this has allowed the development of highly popular fisheries in inland waters. Many inland reservoirs, including Keystone Lake and other impoundments in the Arkansas River system, have been stocked with striped bass. The Arkansas River supports a stable, naturally reproducing population downstream of Zink Dam. Striped bass feed heavily on fish, including gizzard shad, which occur throughout the study area (Table 1) in relatively high abundance (Table 2).
- Striped bass spawning migrations occur when water temperature exceeds 58ºF (Pflieger, 1997), typically from April to early June. Eggs are broadcast midwater in rapids and strong currents and drift downstream in currents; they hatch in 36 to 75 hours (Pflieger, 1997; Robison and Buchanan, 1988). Continuous suspension and movement of the eggs in current are essential to survival and successful hatching, lest they settle to the bottom and die due to siltation, insufficient dissolved oxygen, or predation (Crance, 1984).
- The spawning success of striped bass depends on their access to free-flowing rivers of considerable length and with sufficient current to maintain the semi-buoyant eggs in suspension until hatching. Spawning occurs from 30 to 93 miles upstream of inland reservoirs and has been documented to occur 43 to 93 miles upstream of Keystone Lake (Crance, 1984, and sources cited therein). A minimum current velocity of about 30.5 centimeters per second (cm/s) (1 ft per second [ft/s]) is required to hold eggs in

suspension in freshwater, although the absolute minimum velocity may be site- and time-specific, depending on the density of the water and the eggs (Crance, 1984). Velocities as low as 15 cm/s (0.5 ft/s) may keep eggs suspended once they become water hardened (Crance, 1984). Surface water velocities in areas where striped bass eggs have been collected in the Arkansas River, Oklahoma (upstream of Keystone Lake), ranged from 50.0 to 83.5 cm/s (1.6 to 2.7 ft/s) (Combs, 1979, as cited by Crance, 1984).

- The Arkansas River below Tulsa supports good numbers of striped bass but the size and longevity of the fish appear to be limited by water temperature and dissolved oxygen conditions (Hendricks, 2006; Cherokee CRC, 2009). ODWC collected 22 striped bass downstream of Zink Dam in spring, summer, and fall (Table 1). Zink Dam currently impedes upstream migration, but some fish probably pass upstream of the low-head dam during high sustained spring-time flows (Hendricks, 2006). Large numbers of striped bass concentrate below Zink Dam during spring migration (Hawk, 2007).

- Striped bass also occur in the reach between Keystone Dam and Zink Dam. ODWC collected six striped bass in this reach in spring (Table 1). Evidence suggests that some fish arrive in this reach via spillway or turbine releases from Keystone Lake, where striped bass historically have been stocked. A two-year radio-tagging study of 16 adult striped bass conducted by ODWC (2009) found no evidence of movement across Zink Dam between groups of fish tagged in the Keystone Dam tailwater and the Zink Dam tailwater.

- Little is known about where striped bass spawn in the river downstream of Keystone Dam. The area below Zink Dam, which includes a remnant rock dam (Figure 10), may provide favorable velocity and turbulence for spawning, and the stretch of free-flowing river downstream (64 miles) is sufficiently long to suspend eggs until hatching. Spawning also may occur below Keystone Dam (Figure 2), where turbulence and depth appear favorable, but the short distance of free-flowing river to the backwaters of Zink Dam (15 miles) may preclude or severely limit egg hatching success.

Sauger

- The sauger occurs mainly in larger free-flowing rivers, where it uses strong currents and tolerates high turbidity (Pflieger, 1997; Etnier and Starnes, 1993). It has been successful in many reservoirs. Adults feed mainly on fish.

- Sauger begin congregating near spawning areas in late winter (Etnier and Starnes, 1993). Spawning occurs in the Arkansas River, Arkansas, in late February or early March, and into April and early May farther north (Pflieger, 1997). Adhesive eggs are scattered over rubble shoals or other firm substrates and abandoned, typically at night (Pflieger, 1997; Robison and Buchanan, 1988). Eggs become non-adhesive shortly after spawning and may be widely dispersed by currents (Etnier and Starnes, 1993). Eggs hatch in about 2 weeks, and young-of-year are pelagic during the early part of their first summer.

- ODWC collected a total of 9 sauger downstream of Zink Dam at Site 4 in the South Tulsa/Jenks area in spring and summer (Table 1). None were collected above Zink Dam, which appears to block upstream migrations (Cherokee CRC, 2009).

- The sauger is native to much of the Mississippi River basin but is considered a likely transplant to most of the Arkansas River system (Robison and Buchanan, 1988). It is currently limited in distribution in the study area to the reach below Zink Dam.

Forage Species for Interior Least Tern

Populations of suitable forage species for interior least terns are relatively abundant throughout the study area. Least terns breed in the Arkansas River corridor from mid-May to late August and feed principally on small fish. Table 2 lists the three most abundant fish species collected at each station sampled by ODWC in 2006-2007 (Cherokee CRC, 2009). The most abundant species included gizzard shad (genus *Dorosoma*), three species of minnows (genera *Cyprinella, Notropis, and Pimephales*), river carpsucker (*Carpiodes*), brook silverside (*Labidesthes*), and western mosquitofish (*Gambusia*). Five of these species are small, and the two larger ones (gizzard shad and river carpsucker) have juvenile life stages present during at least the latter portion of the tern breeding season. Sources cited in the interior least tern recovery plan (USFWS, 1990) identify *Notropis*, *Pimephales*, *Gambusia*, *Dorosoma*, and *Carpiodes* among important fish genera in the diet of least tern. Species of *Cyprinella* and *Labidesthes* also are small fish that are potentially suitable as prey.

TABLE 2
Percent Relative Abundance of the Top Three Most Abundant Species per Site Collected in 2006-2007 from the Arkansas River, Tulsa County, Oklahoma
(Source: Cherokee CRC, 2009)

	Percent Relative Abundance (All Seasons Combined)				
Species	Site 1 Sand Springs	Site 2 Zink Lake	Site 3 61st Street	Site 4 96th Street	Site 5 County Line
Gizzard shad	38.8	12.5	13.4	26.0	2.0
Red shiner	--	--	--	--	91.8
River shiner	--	--	49.3	--	--
Slim minnow	--	--	--	29.2	1.8
River carpsucker	--	6.1	13.9	--	--
Brook silverside	11.4	75.1	--	--	--
Western mosquitofish	38.4	--	--	17.8	--
Total Percent	88.6	93.7	76.6	73.0	95.6
Sample Size, All Species	4,177	6,816	2,199	4,240	13,880

Potential Project Effects

The construction and operation of the key components of the Arkansas River Corridor Project have the potential to affect upstream and downstream passage of highly migratory riverine fishes in the Arkansas River in the Tulsa area. The potential effects listed below have not been assessed yet for their significance or duration and will need to be evaluated further as alternatives are refined.

The environmental baseline against which impacts will be assessed includes Zink Dam as an existing barrier or impediment to the passage of the upstream migrant fishes of interest.

Two of the species (paddlefish and sauger) appear to be restricted in their current distribution to the reach downstream of Zink Dam. The dam may block their upstream migration. If the shovelnose sturgeon still occurs in the area, Zink Dam also would likely impede upstream migration. Only the striped bass presently occurs both upstream and downstream of Zink Dam, and ODWC (2009) research indicates that the species may gain access to the upstream reach via releases from Keystone Lake more than from upstream passage at Zink Dam.

Potential project effects to migratory fish species will depend in part on the fish passage design technologies and operational measures, if any, proposed at each low-head dam. These effects may include the following:

- Potential loss or disruption of existing spawning and rearing habitats for migratory fishes in a 7.4-mile reach below Zink Dam resulting from the construction and operation of the proposed South Tulsa/Jenks Dam, unless seasonal upstream and downstream fish passage is provided at the South Tulsa/Jenks Dam
- Potential disruption of existing striped bass habitat in the reach between Keystone Dam and Zink Dam resulting from the construction and operation of the proposed Sand Springs Dam; potential effects would be minor to the extent that: (1) existing spawning success may be precluded or severely limited by the short distance of free-flowing river downstream to the Zink Dam pool; (2) striped bass passing downstream from Keystone Lake tend to remain in the vicinity of Keystone Dam; and (3) few striped bass currently negotiate upstream passage at Zink Dam
- Potential beneficial effects to the existing striped bass fishery in the Keystone Dam tailwater as a result of the construction and operation of the Sand Springs Dam, which would provide deeper pool habitats, possibly including cool-water refuge during summer and increased habitat area for forage fish such as gizzard shad
- Potential beneficial effects of increased access to potentially suitable spawning and rearing habitats for migratory fishes as a result of the installation and operation of fish passage facilities at one or more of the low-head dams (if proposed)
- Potentially negative effects to striped bass due to the short distance of free-flowing river downstream of each dam, which could preclude or severely limit egg hatching success; downstream passage through open gates or over the crests of spillways would not be expected to adversely affect juvenile or adult striped bass or any life stages of the other migratory fishes of interest. The eggs of the other species tend to remain in upstream habitats until hatching and are less sensitive in their incubation requirements than striped bass eggs
- Temporary effects on migratory fish passage during dam construction
- Indirect long-term effects on the availability of spawning and rearing habitats for migratory fishes as a result of future river corridor development

Regarding potential project effects to forage fish populations for interior least tern, the proposed Sand Springs and South Tulsa/Jenks low-head dams would inundate about 8 miles of riverine habitat. The two new low-head dams would fragment riverine habitat into a 4-mile or shorter segment below Keystone Dam, a 3-mile segment below Sand Springs

Dam, and a 4.5-mile segment below Zink Dam. As a result, the species composition and relative abundance in the inundated segments would be expected to shift toward those more characteristic of reservoir fish communities, with fewer riverine-specialist species and increased relative abundance of habitat generalist species. Nevertheless, operation of the Sand Springs Dam to provide a continuous downstream minimum flow release of 400 to 1,000 cfs would enhance aquatic habitat for riverine-specialist species in the remaining free-flowing segments by increasing habitat area and providing greater stability of flow for shallow-water species. Populations of potentially suitable forage species for least terns would be expected to remain relatively abundant throughout the study area.

Fish Passage Considerations for Project Design and Operation

This section identifies potential fish passage constraints that need to be considered in the project engineering design, construction, and operation of the proposed system of low-head dams. Potential biological constraints to providing successful upstream passage include the availability of suitable habitat upstream of the dams, the status of affected populations, the seasonal timing of spawning migrations, and the differing spawning behaviors, habitat use, and swimming abilities of the migratory species of interest. Table 3 summarizes a variety of factors that may be important to the preliminary design of the proposed project.

TVA identified a variety of gated spillway methods to lower the proposed Sand Springs and South Tulsa/Jenks Dams for passing heavy sand loads or fish (Proctor et al., 2008). These included inflatable rubber dams, Obermeyer gates, conventional mechanical gates, and fusegates. The focus on gates as the preferred method of fish passage was based in part on concern for the downstream passage of striped bass eggs. Obermeyer gates were identified as the preferred concept (Proctor et al., 2008). Although a variety of conventional fishway designs (ladders) are in use throughout North America (Clay, 1995), and these also may warrant consideration during the preliminary design as fish passage priorities become more firmly established, the migratory species of interest in the Arkansas River tend not to pass readily through fish ladders even though velocity criteria may be considered favorable.

The following sections identify several key considerations for designing the proposed low-head dams to provide for efficient upstream and downstream passage.

Providing for Fish Passage at the South Tulsa/Jenks Dam would Maintain Continued Access to Existing Important Habitat and Angling Opportunities in the Zink Dam Tailwater

- Striped bass, sauger, and paddlefish currently use the reach below Zink Dam, and shovelnose sturgeon, although rare, also may occur there. The proposed South Tulsa/Jenks Dam would block upstream migrant fishes and their potential use of the reach for spawning and rearing habitat, unless seasonal passage were provided for upstream migration, spawning, and downstream transport of eggs and young.
- The reach below Zink Dam sustains popular fisheries for striped bass and sauger, which are the main source of brood stock for the Oklahoma hatchery system.
- To the extent that striped bass may currently spawn in the Zink Dam tailwater, providing downstream transport of striped bass eggs would be crucial to reproductive

success. Sauger, paddlefish, and shovelnose sturgeon eggs would be less vulnerable because their egg incubation requirements are less exacting relative to current velocity.

Providing for Fish Passage at the Other Low-head Dams would Increase Access to Upstream Riverine Habitats for Migratory Species but could Adversely Affect Striped Bass Reproductive Success

- The Arkansas River downstream of Zink Dam supports a stable, naturally reproducing population of striped bass descended from fish stocked in Keystone Lake years ago. ODWC does not currently stock striped bass in the region. Hence, sufficient spawning habitat already is available downstream of Zink Dam to sustain a healthy population.
- Passing upstream migrant striped bass into short riverine segments that would remain above Zink Dam and Sand Springs Dam (3 and 4 miles, respectively) would increase access to riverine habitat, but would risk potentially adverse impacts to existing spawning success by passing spawning adults into riverine segments that are too short to maintain eggs in suspension until hatching.
- Providing downstream transport of striped bass eggs at the low-head dams would require providing for a current velocity of 30.5 cm/s (1 ft/s) or greater to keep the eggs in suspension (Crance, 1984).
- Lowering gates at Sand Springs Dam, and potentially the other low-head dams, for downstream transport of striped bass eggs would reduce the flow re-regulation capacity of the dams, which may be important to sustaining inundation of gravel bars and firm substrates used by sauger, paddlefish, and shovelnose sturgeon as egg deposition sites below all three low-head dams.

Providing for Fish Passage during a March through May Window would Cover Peak Spawning Periods of All of the Migratory Species of Interest

- The greatest overlap in spawning period occurs among striped bass, paddlefish, and shovelnose sturgeon, which spawn over the period April to June (Table 3). However, April and May likely include peak spawning periods of all three species.
- Sauger spawn earlier than the other three species. They congregate near spawning areas in late winter and begin spawning in late February or March. Including March in the fish passage window would likely capture peak spawning activity of the sauger as well.

Studies at Upper Mississippi River Locks and Dams Indicate that Migratory Fishes with Stronger Swimming Capabilities Pass Upstream through Gated Spillway Sections when Gates are Raised Out of the Water

- USGS and the St. Paul District of USACE examined the effects of existing locks and dams on the longitudinal movement of migratory fishes in the upper Mississippi River and concluded that the opportunity for upstream passage is greatest when upriver migrations coincide with higher levels of river discharge and uncontrolled, open-channel conditions, when the gates are raised out of the water and velocity and head differential through the gated sections are lowest (Wilcox, 1999).

- Analysis of numerous mark-recapture and telemetry studies involving 15 fish species in the upper Mississippi River found that 12.4 percent of recaptured fish moved upriver beyond one or more dams (Wlosinski and Marecek, 1996; Marecek and Wlosinski, 1996). The majority of fish passing upstream were walleye. Sauger and paddlefish were among the species passing upstream.
- Shovelnose sturgeon was included in the studies but was not recaptured upstream of dams, presumably because of its more bottom orientation in the water column. Striped bass were not included in the studies.
- Of the fish moving upstream through existing dams, 88 percent passed at a head differential conservatively estimated at less than 2 ft, and only 3.9 percent passed when the head differential was at least 4 ft (Marecek and Wlosinski, 1996).
- Thus, lowering gates at the proposed low-head dams to eliminate the head differential could be a primary means for allowing upstream passage of the species of interest.

The Velocity of Water through the Fishway must be Less than the Burst Speeds and the Velocity in the Pools must be less than the Cruising Speeds of the Migratory Species of Interest

- Available swimming performance information and data indicate the following likely descending order of swimming capabilities among the migratory species of interest: striped bass; walleye; paddlefish; shovelnose sturgeon. In general, studies show that swimming performance of upstream migrant fishes is positively correlated with water temperature and the size of the fish (Clay, 1995).
- Available swimming speed data for families of freshwater fish indicate substantially higher expected burst performance and critical performance for Percidae (includes sauger) compared to Acipenseridae (includes shovelnose sturgeon) (Clay, 1995; Wolter and Arlinghaus, 2003).
- A study of the sprint performance of upstream migrant fishes in open-channel flow found stronger overall performance of striped bass compared to walleye in the maximum distance traversed in test flumes at velocities ranging from 1.5 to 3.5 m/s (4.9 to 11.5 ft/s) (Haro et al., 2004). Length of the test fish was positively correlated with swimming performance, with the effect being much stronger among striped bass.
- Attempt rates at migrating past velocity barriers also vary between species and are influenced by hydraulic variables, including velocity of flow and discharge. Castro-Santos (2004) found that distance of ascent for walleye in test flumes was primarily influenced by flow velocity. Over short distances, models predicted greater passage success against higher velocities, due to the associated increased attempt rate.
- Paddlefish are highly mobile, swimming high in the water column against strong currents, but adult performance data are lacking. Juveniles exhibited higher sustained swimming speed than juvenile sturgeon, but modeled ranges of prolonged swimming speeds and burst speeds ranged higher in sturgeon (Hoover et al., 2005).

Natural Channel Designs Test Well with Sturgeon and Provide a Wide Range of Velocities that could Benefit Other Migrating Species

- Tests of shovelnose sturgeon behavior and swimming performance in multiple fishway designs, including a standard vertical slot, dual vertical slot, and a rock fishway with a boulder pattern, found passage to be most successful in the rock fishway (White and Mefford, 2002). Adult shovelnose sturgeon appeared to search for the best hydraulic conditions available for passage. Flow orientation and attraction to the fishway became strong at 2 ft/s and remained strong at higher velocities tested. Sturgeon successfully negotiated velocities of up to 6 ft/s over all substrates (smooth, fine sand; and coarse sand, gravel, and cobble) but poorest passage success occurred with cobble.
- For shovelnose sturgeon passage in the Yellowstone River, White and Mefford (2002) recommended a natural channel or rock channel fishway design using the design criteria specified in Table 4. In addition to positive test results with sturgeon, this type of fishway would provide a diversity of velocities that could accommodate a variety of other migrating fish species.
- Thus, a roughened spillway channel could enhance the ability of sturgeon and other upstream migrant fishes to pass through lowered gates at the proposed low-head dams.

Operating Gates to Provide for Upstream and Downstream Passage would Require Close Coordination with the Tulsa District's Operation of its Multipurpose Projects for Protection of Breeding Interior Least Terns

- The USACE Tulsa District implements comprehensive guidelines for managing and protecting interior least terns nesting downstream of USACE water resource projects on the Arkansas, Canadian, and Red Rivers. The guidelines (USACE, 2009b) set forth long-term and short-term management strategies to achieve compliance with the Endangered Species Act in accordance with the Biological Opinion issued by USFWS (2005) for the operation of USACE's multipurpose projects.
- USACE coordinates its operations and activities with representatives of USFWS, ODWC, Southwestern Power Administration, and Oklahoma Municipal Power Authority to protect the least terns while preserving authorized project purposes. Short-term strategies include such practices as managing high-flow releases during non-nesting periods to periodically inundate and scour islands for maintenance of favorable sandbar habitat, and limiting maximum water releases during the nesting season (typically May 15 to August 22) to prevent flooding of active least tern nests.

TABLE 3
Potential Biological Constraints to the Preliminary Design of Low-head Dams for Upstream and Downstream Passage of the Migratory Species of Interest

Species	Spawning Period	Spawning Behavior	Swimming Performance	Other Relevant Factors
Shovelnose sturgeon	April-June	Eggs deposited in strong current over coarse substrates	Adults actively swam for 10 minutes (min) or more at fishway velocities of 3 to 4 ft/s; average success rate negotiating fishway designs declined from 81-87 percent at 4 ft/s to 47 percent at 6 ft/s (White and Mefford, 2002)	Unique among the species of interest in its bottom habits, which could prove problematic in fish passage design Lack of firm spawning substrates could limit reproductive success
Paddlefish	April-May	Eggs adhere to silt-free gravel, hatch in about 9 days	Juveniles exhibited higher sustained swimming speed than juvenile sturgeon, but modeled ranges of prolonged swimming speeds and burst speeds ranged higher in sturgeon (Hoover et al., 2005).	Upstream migrants move high in water column and are capable of leaping clear of the water Consistent releases from the Sand Springs Dam could promote reproductive success if they were to result in sustained inundation of gravel bars through the egg incubation period
Striped bass	April-early June	Eggs broadcast in currents, drift downstream for 36-75 hours until hatching	Sprint performance in open-channel flow stronger than that of walleye at velocities ranging from 1.5 to 3.5 m/s (4.9 to 11.5 ft/s) (Haro et al., 2004); length of adults highly correlated with stronger swimming performance	Exacting spawning requirements could limit reproductive success; the free-flowing reaches between dams would be too short and the new pools unfavorable for egg survival Adults need a minimum depth of 1.5 ft to swim upstream to spawning areas (Crance, 1984) A minimum current velocity of about 1 ft/s is required to hold drifting eggs in suspension until hatching (Crance, 1984)
Sauger	February-April	Adhesive eggs deposited over firm rubble substrates, hatch in 2 weeks	Walleye as surrogate (Peake et al., 2000): • Maximum sustained speed for 60 min: 0.30-0.73 m/s (1.0-2.4 ft/s) • Maximum sustained speed for 10 min: 0.43-1.14 m/s (1.4-3.7 ft/s) • Burst speed: 1.60-2.60 m/s (5.2-8.5 ft/s)	Sauger numbers increased substantially in Arkansas after construction of the MKARNS (Robison and Buchanan, 1988), indicating a relatively high probability of success for upstream and downstream passage

TABLE 4
Fishway Design Recommendations for Shovelnose Sturgeon in Yellowstone River

Fishway Feature	Design Recommendation
Attraction flow	2 to 4 ft/s
Flow depth	0.7 to 4.5 ft (4 ft or more desirable)
Maximum passage velocity	3 to 4 ft/s
Fishway type	Natural channel or rock channel fishway design

Source: White and Mefford (2002)

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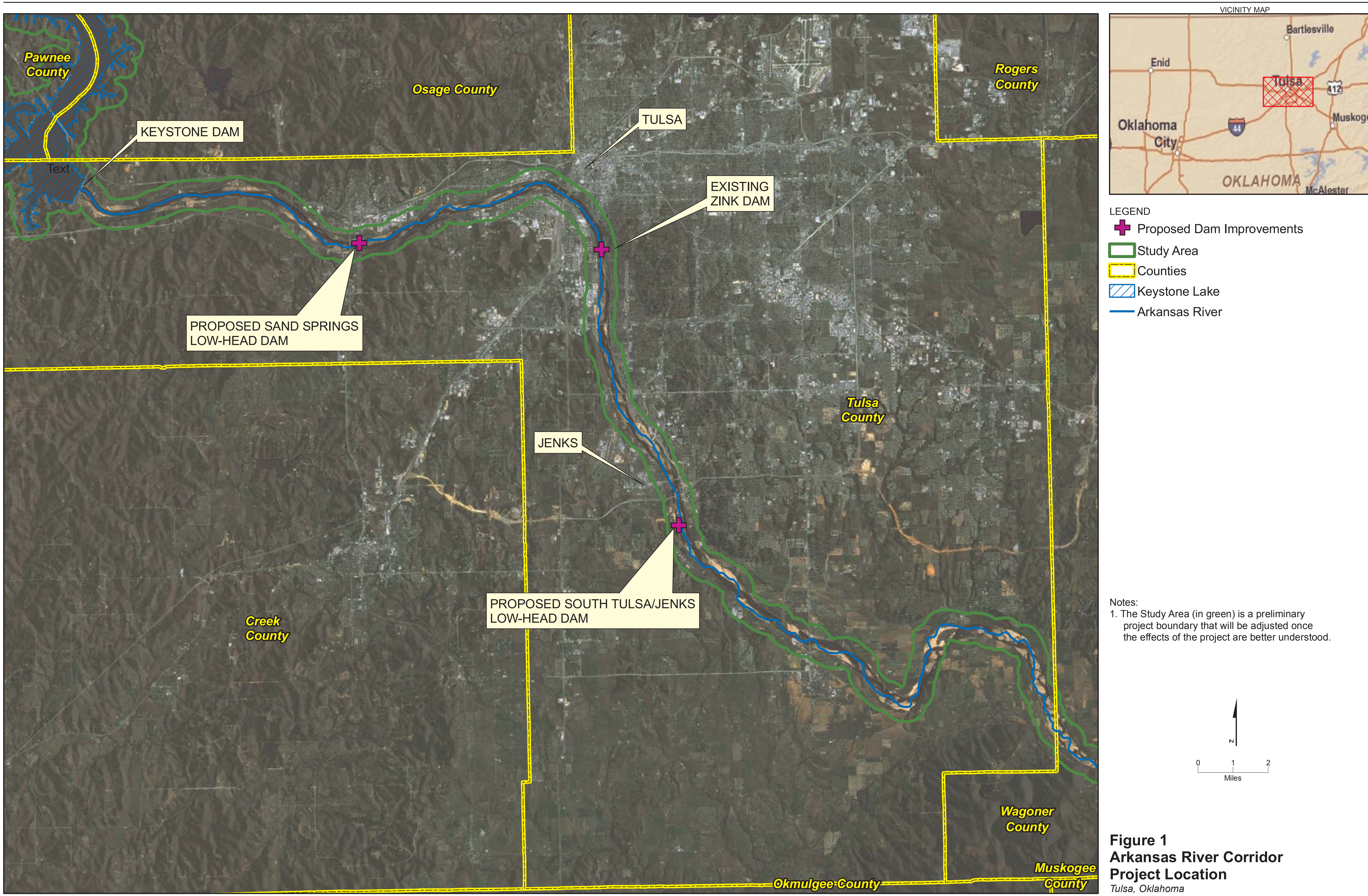

Figure 1
Arkansas River Corridor Project Location
Tulsa, Oklahoma

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Figure 2. Upstream View of Keystone Dam (17,500 cfs)

Figure 3. Downstream View between Keystone Dam and Sand Springs (17,500 cfs)

Figure 4. Downstream View approaching Highway 97 Bridge in Sand Springs (17,500 cfs)

Figure 5. Downstream View of Proposed Site of Sand Springs Low-head Dam (17,500 cfs)

Figure 6. Downstream View between Sand Springs and Tulsa (17,500 cfs)

Figure 7. Downstream View of Tulsa and Sunoco Refinery (17,500 cfs)

Figure 8. Downstream View of Zink Pool from I-244 Bridge in Tulsa (17,500 cfs)

Figure 9. Zink Dam and Pedestrian Bridge from West Shoreline (10,800 cfs)

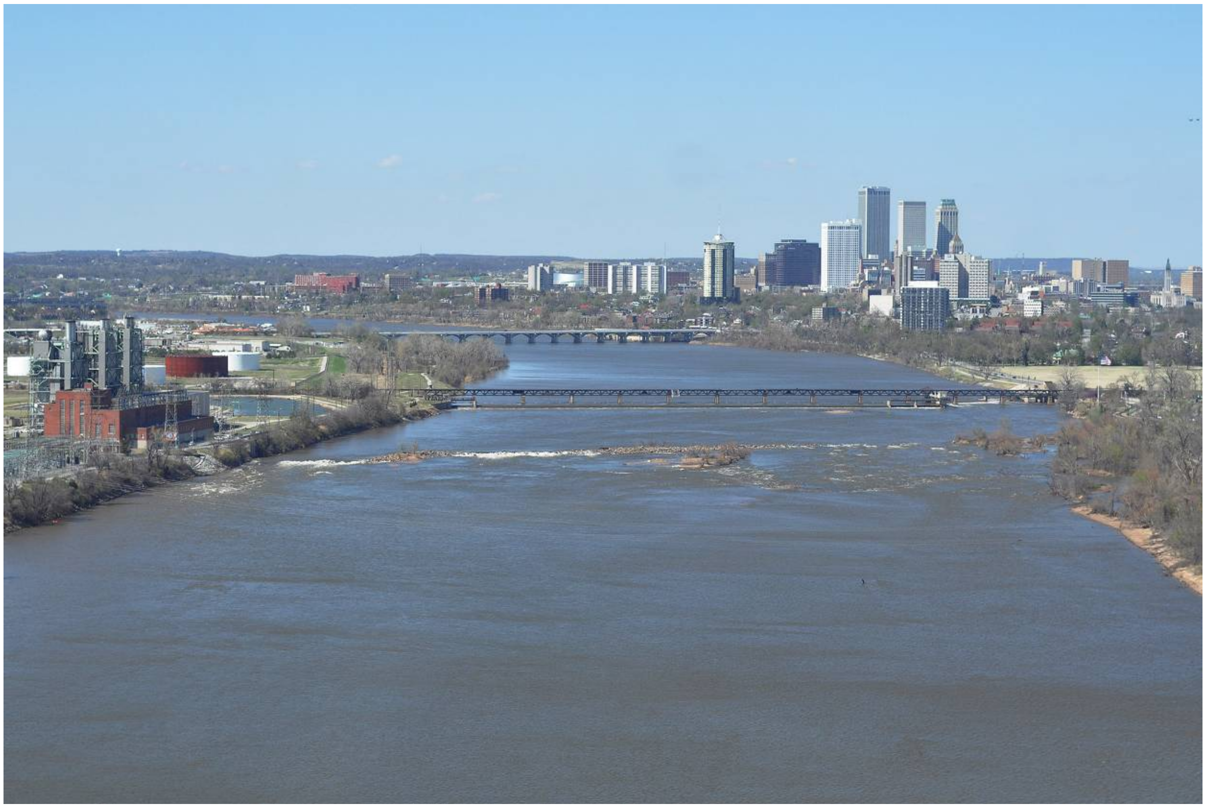

Figure 10. Upstream View of Zink Dam and Pedestrian Bridge, and Remnant Rock Dam (17,500 cfs)

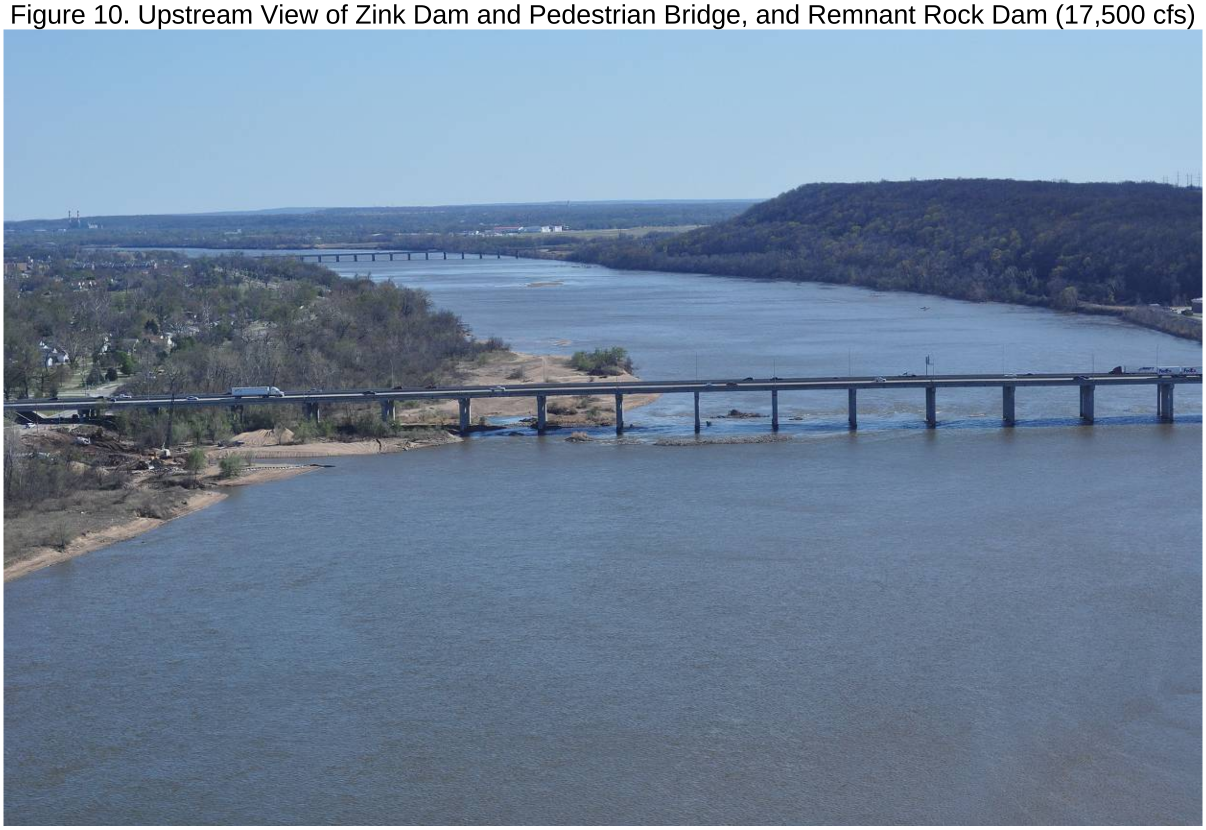

Figure 11. Downstream View of the I-44 Bridge between Zink Dam and Jenks (17,500 cfs)

Figure 12. Downstream View of Proposed Site of South Tulsa/Jenks Low-head Dam (17,500 cfs)

Figure 13. Downstream View from Vicinity of Polecat Creek Confluence (17,500 cfs)

Figure 14. Downstream View of Riparian Zone along East/North Shore at Bixby (17,500 cfs)