FINAL DRAFT TECHNICAL REPORT

Illinois River Instream Flow Assessment

Prepared for

Oklahoma Water Resources Board

U.S. Army Corps of Engineers
Tulsa District

June 2016

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Acronyms and Abbreviations

1D	one-dimensional
ADCP	Acoustic Doppler Current Profiler
AF	acre-feet
AFY	acre-feet per year
AWS	area weighted suitability
CFDO	Commercial Flotation Device Operators
cfs	cubic feet per second
CI	confidence intervals
CTM	critical thermal maximum
fps	feet per second
ft.	feet
ft/mi	feet per mile
ft^2/ft	square feet per foot
GPS	global positioning system
HSC	habitat suitability criteria
IFG	Instream Flow Group
IFG-4	Instream Flow Group-4 (hydraulic model)
LAWPR	Lower Arkansas River Watershed Planning Region
NWS	National Weather Service
OCC	Oklahoma Conservation Commission
OCWP	Oklahoma Comprehensive Water Plan
ODWC	Oklahoma Department of Wildlife Conservation
ORW	outstanding resource waters
OSRA	Oklahoma Scenic Rivers Act of 1970
OSRC	Oklahoma Scenic Rivers Commission
OWRB	Oklahoma Water Resources Board's
PHABSIM	Physical Habitat Simulation
SZF	stage-at-zero-flow
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAF	velocity adjustment factor
WUA	weighted usable area
WWTP	wastewater treatment plant

SECTION 1

Introduction

In 2012, the Oklahoma Water Resources Board (OWRB) published its updated *Oklahoma Comprehensive Water Plan* (OWRB 2012). This plan, as well as previous plans, recommended the evaluation of nonconsumptive uses of water, including instream flows, for environmental and recreational uses. Based on earlier recommendations, the OWRB had convened an Instream Flow Work Group in late 2009 to solicit input from stakeholders and establish a path forward to further evaluate the need and options for establishing an instream flow policy or program for Oklahoma. The Work Group developed a report titled Instream Flow Issues and Recommendations (OWRB, February 2011). One of the recommendations in the report was to perform an instream flow pilot study on a state-designated Scenic River. In 2013, following completion of the 2012 *Comprehensive Water Plan*, OWRB created the Oklahoma Instream Flow Advisory Group to continue the efforts of the previous Work Group. To further define whether and how an instream flow program might be implemented, an instream flow Pilot Study Approach was prepared and submitted to the OWRB, U.S. Army Corps of Engineers, and Instream Flow Advisory Group (CH2M HILL 2014). The state-designated scenic reaches of the Illinois River and its tributaries, Barren Fork and Flint Creeks, were identified as preferred study streams.

The Instream Flow Incremental Methodology (IFIM) (Bovee 1982; Stalnaker et al. 1995) was deemed most suitable for addressing the prevailing comments and concerns of the Instream Flow Advisory Group. The IFIM is a decision-support process that provides a comprehensive framework for addressing streamflow needs for fish and other aquatic resources while incorporating consideration of other environmental and nonenvironmental interests (i.e., recreation, wildlife, water quality, and consumptive water uses such as public water supply, crop irrigation, power generation, and industrial uses). The IFIM is the most commonly used and accepted methodology by state and federal agencies in the United States and internationally. The methodology typically is used to assess impacts of specific water development proposals (for example, a water diversion) where alternative stream flow regimes can be assessed. However, this is not the circumstance for the Illinois River, which is largely an unregulated stream with no foreseeable major water development projects being contemplated. Therefore, the development of alternatives and their analysis, including an economic evaluation, may not be as important in this case. Still, the basic steps of the methodology are broad enough that they can be applied to any situation where instream flow prescriptions are being considered.

This technical report is part of the larger effort of employing the IFIM to test how the process, perhaps with modifications, might be used in the future for other streams in Oklahoma. As such, the overall process (steps) applied to the Illinois River is considered a pilot study. This "pilot" aspect applies to not only the steps required to obtain technical information (the subject of this report) but also the administrative steps of the decision-making process itself. The ultimate purpose of the pilot study is to gain a better understanding of the implications of a process to deal with instream flow issues consistent with the overall goal of managing water resources in Oklahoma for multiple uses.

Before conducting this study, input was sought from various agencies, technical advisors, and the general public with interest in the Illinois River watershed. They assisted in identifying issues, provided useful information on stream-related resources, and helped formulate a technical study plan for obtaining additional information, especially for the fish habitat modeling effort. The results of these consultation and outreach efforts are summarized in various documents available from the OWRB.

This technical report is presented in four sections. The first section is this Introduction. Section 2, Watershed Resources, summarizes available information on the various resources that are associated with the study streams. These resources are hydrology (including water usage), water quality, fisheries, wildlife, recreation, and riparian corridor.

Section 3, Fish Habitat Modeling, presents the results of a fish habitat modeling effort that was used to identify relationships between indices of fish habitat and stream flow for the three study streams. This modeling focused only on fish-rearing needs primarily during the base flow months, not on spawning or migration needs.

Section 4, Discussion, provides insight on the information presented in Sections 2 and 3. It includes interpretation of the fish habitat modeling results and attempts to integrate those results with the flow considerations identified for the other nonfish resources. A brief discussion of the importance of ecological process flows (also known as environmental flows) is presented in this section. Finally, because this report is not intended to recommend specific instream flows, a number of factors related to the technical information are identified that should be considered in the final decision-making process.

The next administrative steps that are required to actually establish and implement instream flow management prescriptions for the Illinois River and tributaries are still being formulated by OWRB in consultation with the Instream Flow Advisory Group. Those steps will constitute the continuation and hopefully the finalization of the IFIM process for the Illinois River. At that time, the use of the IFIM process, as used in this pilot study, can be evaluated as to its applicability to other streams in Oklahoma being considered for instream flow prescriptions.

SECTION 2

Watershed Resources

This section summarizes available information on the various resources that are associated with the study streams. These resources are hydrology (including water usage), water quality, fisheries, wildlife, recreation, and riparian corridor.

2.1 Watershed Overview

The Illinois River watershed encompasses approximately 1,671 square miles in northwestern Arkansas and northeastern Oklahoma (Figure 2-1). The river originates near Hogeye, Arkansas, approximately 15 miles southwest of Fayetteville. The 145-mile river flows west, crossing the Ozarks of northwest Arkansas and into Oklahoma near Watts, Oklahoma. Major tributaries of the Illinois River include Osage Creek, Clear Creek, Muddy Fork Creek, and Cincinnati Creek in Arkansas, and Flint Creek, Ballard Creek, Caney Creek, and Barren Fork Creek in Oklahoma.

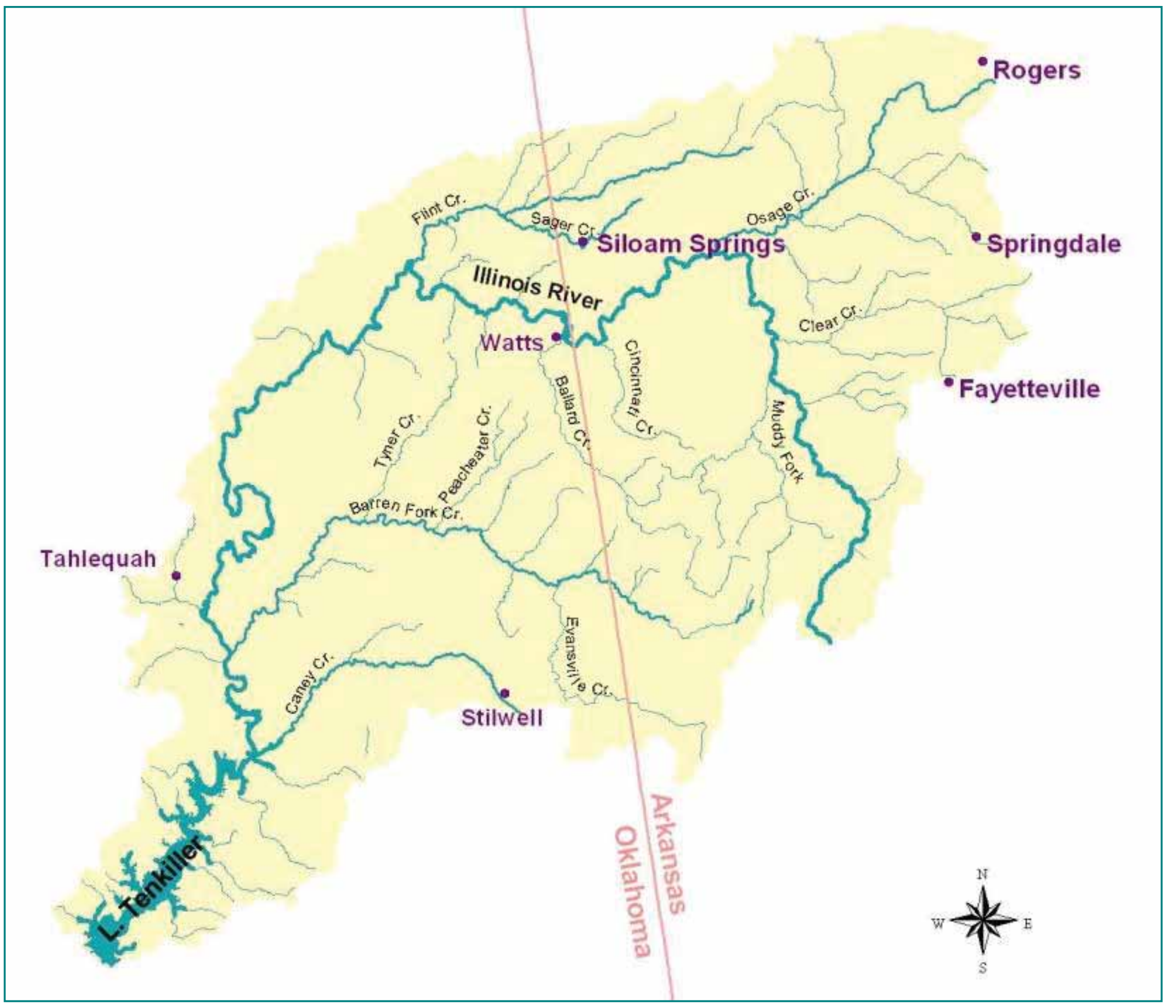


Figure 2-1. Major Tributaries and Towns in the Illinois River Watershed.

The Illinois River watershed lies mostly within the Ozark Highlands ecoregion. The Ozark Highland streams drain to the Arkansas River, which is a major tributary to the Mississippi River. The ecoregion is characterized by oak-hickory forests on well-drained soils of slopes, hills, and plains. Areas of exposed rock are common. Bottomland hardwood forests of oak, sycamore, cottonwood, and elm exist along the floodplains of the larger streams (Oklahoma Conservation Commission [OCC] 1998; Woods et al. 2005). The Illinois River and its major tributaries exhibit a range of conditions from areas with dense riparian forest buffers illustrating exceptional beauty and ecological value, to areas of exposed and eroding stream banks with no vegetated buffers. Presently, rugged areas are forested and nearly level sites are used for pastureland or hay production. Elevation in the Ozark Highlands ranges from 300 feet (ft.) to 1,800 ft.

Average annual precipitation in the Illinois River watershed is approximately 48 to 50 inches, with May, June, and September being the wettest months. Air temperatures average near 58 Fahrenheit degrees, with a range from an average daytime high of 91 degrees in July to an average low of 27 degrees in January.

Land use in the Oklahoma portion of the Illinois River watershed is diverse. Nearly half of the land coverage is forested, with most of the remaining land used for hay production or pasture (Table 2-1) (OCC 2010).

Table 2-1. Land Cover in the Oklahoma Portion of the Illinois River Basin from 2001 LandSat.

Land Cover	Fraction of Basin
Forest	45.90%
Hay	15.42%
Well Managed Pasture	24.34%
Poorly Managed Pasture	7.98%
Rangeland	0.60%
Roads	0.16%
Urban	2.91%
Water	2.04%
Row Crop/Small Grains	0.64%

Source: Storm et al. 2006.

The major agricultural industry in the Oklahoma portion of the watershed is poultry, and a significant number of cattle are also raised. Row crops and small grains comprise a small percentage of the land use (Table 2-1). Wheat, sorghum, soybeans, and various vegetables are grown in small quantities. Nursery plant production, though relatively small, has also remained constant in the region.

The designated beneficial uses for streams in the watershed include some or all of the following: public and private water supply, fish and wildlife propagation (both cool and warm water communities), agriculture, primary body contact recreation, aesthetics, industrial and municipal process and cooling water, and fish consumption (OWRB 2014). Additionally, numerous streams and rivers in the Illinois River Watershed are classified in the Oklahoma Water Quality Standards as outstanding resource waters (ORW), while the Illinois River, Barren Fork Creek, and Flint Creek are also classified as Scenic Rivers. These special classifications identify those waterbodies as having exceptional ecological or recreational significance deserving of extra protection to maintain their extraordinary existing water quality.

The Illinois River is designated as a state Scenic River from the Lake Frances Dam near the Arkansas border down to its confluence with Barren Fork Creek, a distance of approximately 60 miles. A 35-mile segment of Barren Fork Creek and a 12-mile segment of Flint Creek also are designated as Scenic Rivers upstream from their confluences with the Illinois River. The scenic portions of these streams are administered by the Oklahoma Scenic Rivers Commission (OSRC). The Illinois River Management Plan prepared by OSRC (1999) lists 10 management goals for the river and its corridor. Of these, three relate directly to instream flows: 1) conserve and enhance instream biological and physical resources such as native fish and their habitats as well as water quality, 2) maintain long-term protection of important instream and shoreline resources, including free-flowing character, water quality and quantity, and fish habitat, and 3) provide a diversity of high quality recreational opportunities that are compatible with each other and with river resources.

Approximately 243,000 people live in the Illinois River watershed (2010 US Census). About 170,000 (70%) live in urban areas, with the majority residing in the eastern portion of the watershed in Arkansas. The population of Oklahoma towns in the Illinois River basin is about 22,000. The largest city in the Oklahoma portion of the watershed is Tahlequah, which lies near the southern downstream portion of the Illinois River study area. The population of Tahlequah is 15,573 according to the 2010 US Census. Although there are rapidly growing urban centers in the eastern headwater areas from south Fayetteville to Rogers and Bentonville, Arkansas, the western portion of the watershed in Oklahoma remains largely rural.

Early occupants of the Illinois River valley included the Caddo Indians who were later succeeded by the Osage Indians (OSRC 1999). They were followed by the Western Cherokee Indians who moved from Arkansas Territory to the Illinois River valley following the Treaty of 1828. The Cherokees favored the area around the Illinois River because of the productive hunting and fishing. In 1839 the city of Tahlequah became the Cherokee Nation capital. Tahlequah is a historically significant town as it was the end of the “Trail of Tears” for the Cherokee Nation. Members of the Cherokee Nation today continue to value the Illinois River and valley for its historical and cultural significance.

There has been no cultural resources inventory conducted for the Illinois River corridor in Oklahoma, thus any significant cultural resources such as archaeological sites are not known within the study area. Typically, however, the value of these resources does not appear to be dependent on streamflow. Therefore, streamflow relationships would not need to be developed for cultural resource sites. However, some Native American resource values and nonconsumptive water uses associated with the management of the river ecosystem may depend on streamflow quantity. Many tribes traditionally have used water for a range of nonconsumptive purposes, including ceremonial and fishing practices. Many native peoples harvest plants for subsistence, medicinal, or cultural use from wetland and riparian areas. However, there is no publicly available information on any specific practices or sites used by the local Native American tribes in the Illinois River.

The streams of the Ozark Highlands are typically clear, moderate gradient, riffle-and-pool type with coarse gravel, cobble, boulder, and bedrock substrates of limestone, dolomite, and chert. Base flows usually are maintained during the dry season by springs and seeps. Both habitat diversity and fish species richness are high, and sensitive fish species are common (see Fisheries description). The most important game species is the smallmouth bass (see Recreation section). The Illinois River corridor contains an extensive network of remnant and intermittently-watered side channels and oxbow channels that support important habitat for fish, wildlife, and riparian vegetation. In general, phosphorus, bacteria, and sediment are the primary causes of water quality concerns in the watershed (see Water Quality section).

2.2 Hydrology

It is important to understand a steam’s flow regime, both natural and altered, in order to assess how those flows or proposed alternative flows might affect stream-related resources. Base flows, especially in the summer, are important components of the flow regime in providing suitable living conditions for fish and other aquatic organisms. Because summer is often the highest demand period for out-of-stream water uses (e.g. domestic and irrigation), most instream flow issues occur in the summer, and the competing demands for instream and out-of-stream water at this time of year are often the focus of instream flow studies. However, the higher flows that function to create and maintain the stream’s ecological processes are also important to consider when recommending instream flows (Annear et al. 2004). Flows that approximate bank-full conditions are particularly important as these help to create and maintain the channel shape, flush and transport streambed material, provide water and nutrients to riparian vegetation, disperse seeds, and recruit woody debris to the steam channel where it provides preferred habitat structure for many fish and other stream-dependent species. Overbank flows that occasionally inundate the low floodplain areas adjacent to the stream also provide important ecological functions including maintenance of wetlands, recharge of alluvial aquifers, and the exchange of nutrients, organic materials, sediments, and water between the stream and floodplain.

Hydrologic indices that depict the recurrence probability of various high flow events are well suited to describe these ecological process flows in an unregulated stream such as the Illinois River and its tributaries. For this reason, the annual peak flows are described at each gage site, as well as the frequency of recurrence for various high flow events measured at these gage stations. Review of these flow indices will be an important step in developing instream flow recommendations that consider the ecological health of the Illinois River and its tributaries consistent with the state's instream flow definition presented in the state's Comprehensive Water Plan (OWRB 2012a) and the goals stated in the Illinois River Management Plan (OSRC 1999). Average monthly flows are shown to describe general seasonal patterns, but these do not reveal the high year-to-year variability that is inherent in the Illinois River. Recurrence probability flows by month are useful in describing the variability in existing flows especially in the summer recreational period. For this purpose, monthly 25%, 50% (median), and 75% exceedance flows are depicted to represent wet, normal, and dry year conditions, respectively.

Hydrologic data are summarized for four U.S. Geological Survey (USGS) streamflow gages in the study area, two for the Illinois River and one each for Barren Fork Creek and Flint Creek (Table 2-2). Daily flow records are available for at least 60 years for these sites.

Table 2-2. USGS Stream Gage Information for the Illinois River Study Area.

Gage Name	USGS Gage Number	County	Drainage Area (square miles)	Elevation (ft)	Period of Record
Illinois River near Watts	07195500	Adair	630	893.8	1956 - 2014
Illinois River near Tahlequah	07196500	Cherokee	950	664.1	1936 - 2014
Barren Fork Creek near Eldon	07197000	Cherokee	312	701.1	1948 - 2014
Flint Creek near Kansas	07196000	Delaware	116	854.6	1956 - 2014

Monthly average flows for these four gage sites are shown in Figure 2-2. Flows are highest in the months of March, April, and May consistent with regional precipitation patterns. The lowest flows occur in September and October.

Monthly median (50 percentile), 25 percentile, and 75 percentile flows for the four gage sites are shown in Figure 2-2. The differences between the dry condition flows (75%) and the wet condition flows (25%) for each month are indicative of the large differences between these year types.

Annual peak flows at each gage site are shown in Figure 2-4. Analysis of these data were used to determine peak flow recurrence probabilities for the 1.5-year, 2-year, 5-year, 10-year, 50-year, and 100-year events (Table 2-3). For example, the 5-year peak flow event for the Illinois River at Tahlequah is 38,100 cubic feet per second (cfs). This compares to the estimated flood flow conditions as defined by the National Weather Service (NWS) (2015) for this site: minor flooding at 9,008 cfs, moderate flooding at 17,334 cfs, and major flooding at 33,652 cfs. The peak flow recurrence analysis indicates that at least moderate over-bank flooding occurs nearly every 2 years in the Illinois River.

Table 2-3. Peak Flow Recurrence Intervals Calculated using the Log -Pearson Type 3 Method.

Peak Flow Return Period (Year)	Probability (%)	Flow (cfs)			
		Illinois River near Tahlequah	Illinois River near Watts	Barren Fork at Eldon	Flint Creek near Kansas
1.5	67	14,112	13,912	11,099	2,520
2	50	19,535	18,868	16,250	3,917
5	20	38,289	33,947	29,836	10,234

Peak Flow Return Period (Year)	Probability (%)	Flow (cfs)			
		Illinois River near Tahlequah	Illinois River near Watts	Barren Fork at Eldon	Flint Creek near Kansas
10	10	53,919	45,185	37,328	16,450
25	4	77,173	60,390	44,675	26,772
50	2	96,925	72,233	48,789	36,274
100	1	118,643	84,362	51,962	47,307

Annual peak flow events that exceed the 1.5-year recurrence probability (14,112 cfs) in the Illinois River at Tahlequah can occur in any month (Table 2-4). However, most occur in the winter and spring months (December – June). The least likely months for these events to occur are August and September.

Table 2-4. Month of Occurrence for Annual Peak Flow Events Greater Than 14,112 cfs for the Illinois River at Tahlequah, Oklahoma.

Month	Number of annual peak flow events >14,112 cfs
January	4
February	6
March	5
April	9
May	10
June	4
July	3
August	1
September	1
October	3
November	4
December	6
Total Years	56

Notes:

USGS gage No. 07196500. Data for water years 1936 – 2015.

14,112 cfs corresponds to the 1.5-year recurrence flow at this gage site.

Trends in base flow, total flow, and base-flow index (ratio of base flow to total flow) were assessed for streams in Oklahoma, including the Illinois River and Barren Fork Creek, by the USGS (Esralew and Lewis 2010). No significant trends in annual or seasonal total-flow volume were detected for either stream (since 1936 for the Illinois River and since 1948 for the Barren Fork). However, there was a significant upward trend in base-flow volume at both stations. This observed increase in base flows was likely associated with the substantial wet period that occurred between 1985 and 2000 (Puls 2015). Several alluvial groundwater wells in the basin that were monitored from the late 1970s to 2008 also showed an increasing trend in water levels, possible reflecting the increase in precipitation and stream base flows during this period (Esralew and Lewis 2010).

Potential climate-change effects on stream flows in Oklahoma to year 2099 were recently evaluated by the Oklahoma Water Survey at the University of Oklahoma (Hong 2015). While air temperature increases are anticipated, no trends in precipitation are expected on a state-wide average basis. However, on a regional basis, precipitation is expected to increase in the northeast corner of the state (Ozark region) by as much as 24 mm/month. This increase in precipitation would be expected to increase the river basin water yields, but it is uncertain how it would manifest in terms of runoff behavior such as flood or drought frequency.

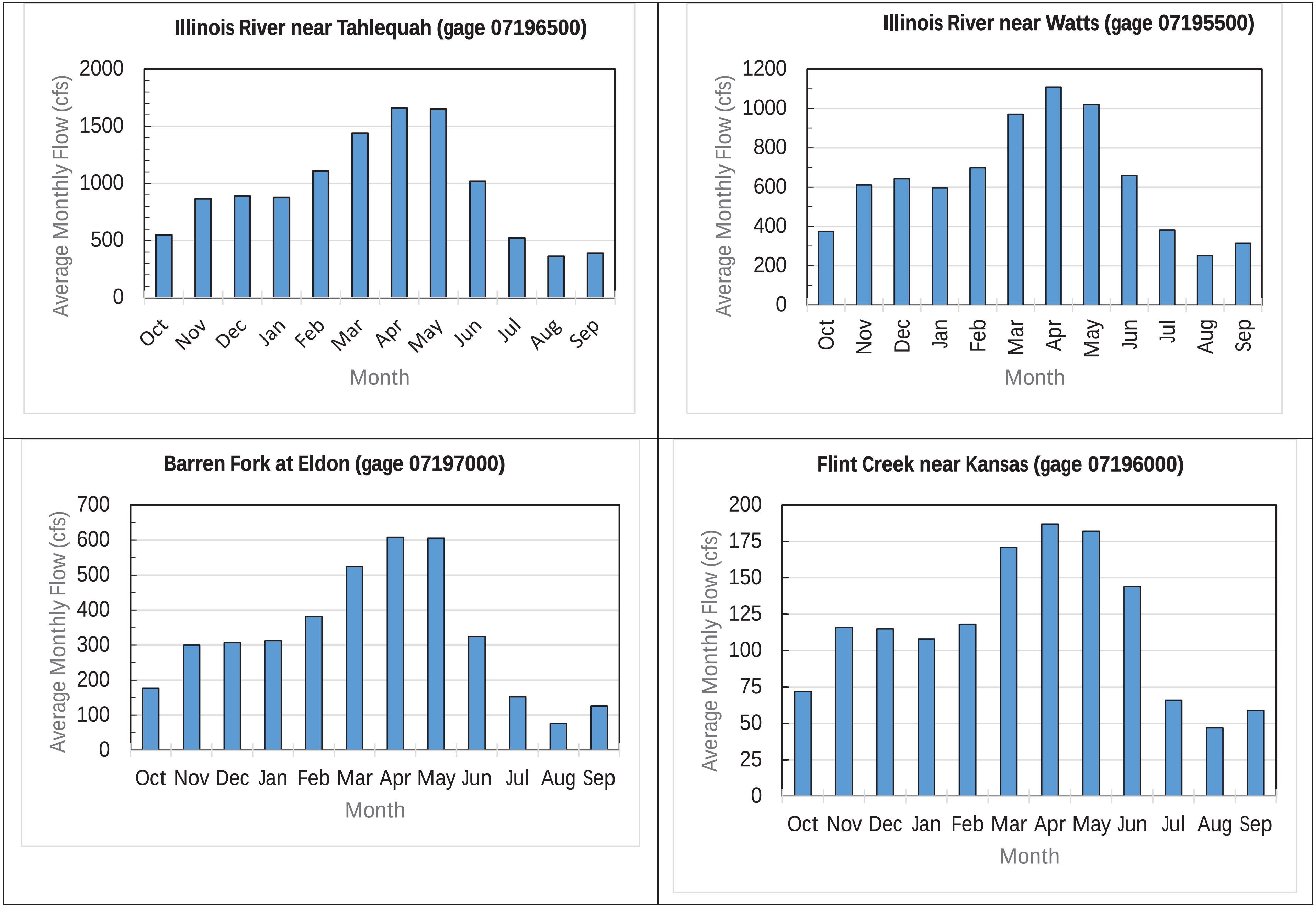


Figure 2-2. Monthly Average Flows (cfs) for the Illinois River (Two sites), Barren Fork Creek and Flint Creek, Oklahoma

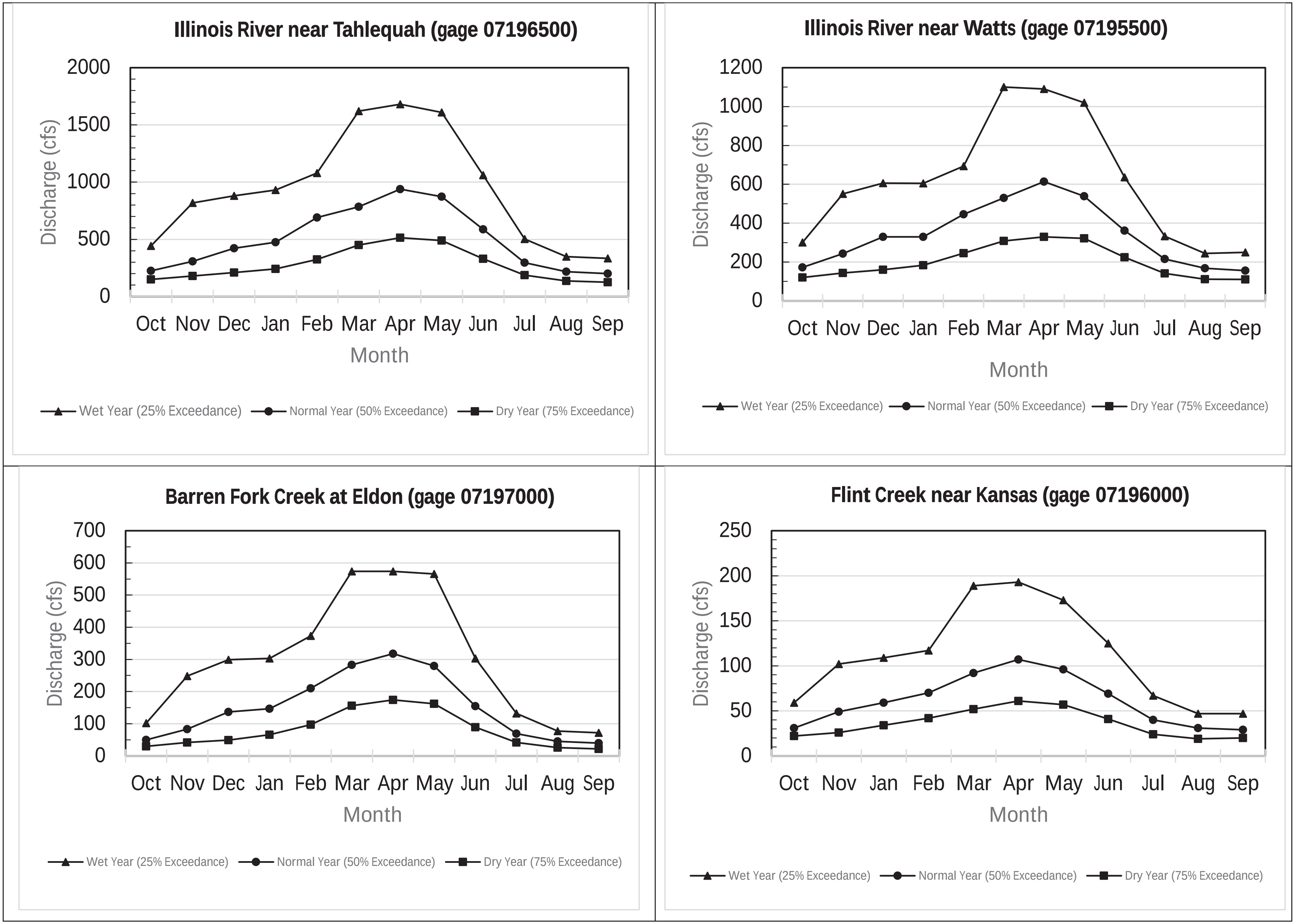


Figure 2-3. Monthly Exceedance Flows for Wet (25%), Normal (50%), and Dry (75%) Conditions.

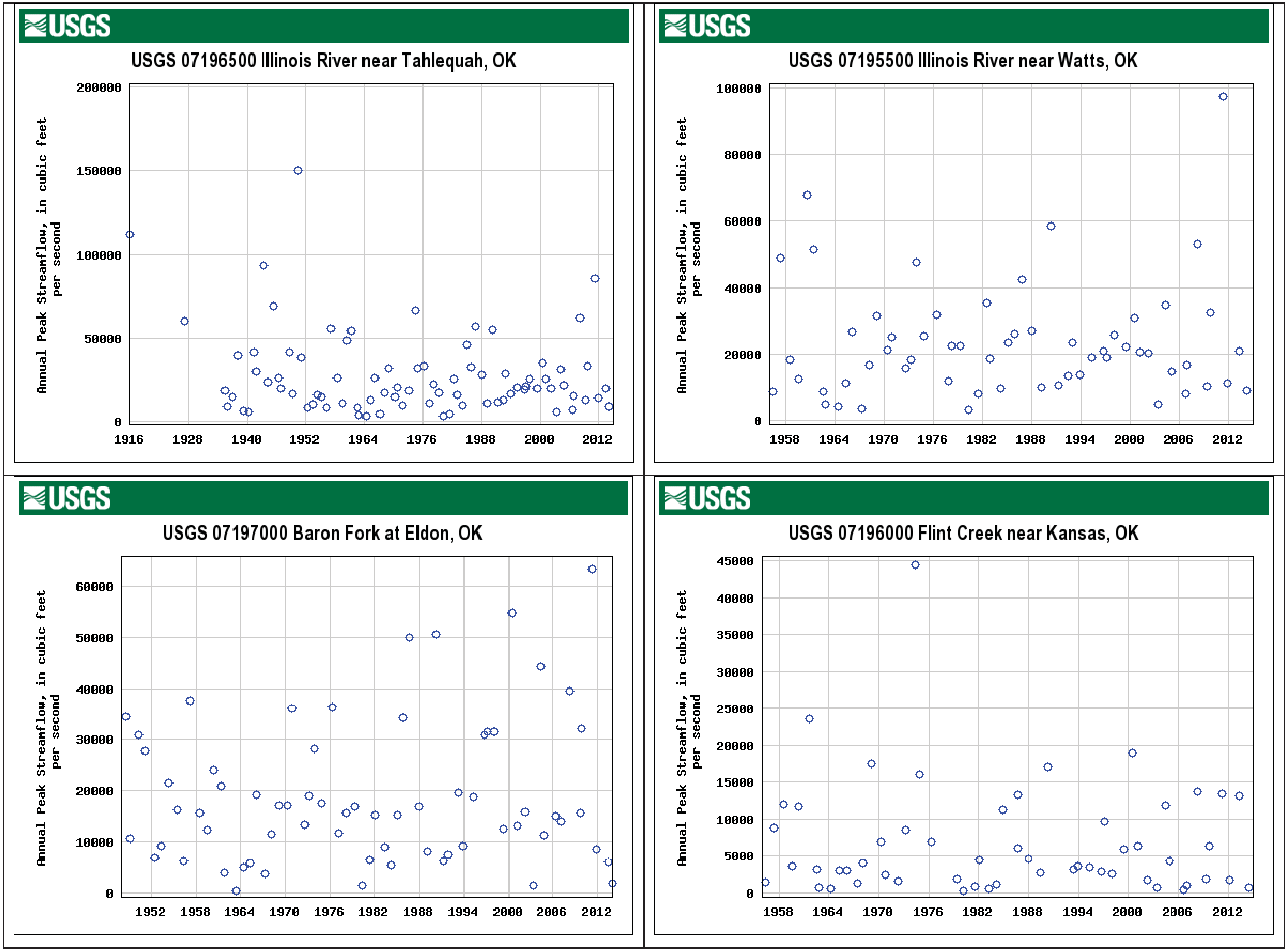


Figure 2-4. Annual Peak Flows for the Illinois River (2 sites), Barren Fork Creek and Flint Creek, Oklahoma.

2.3 Water Rights and Water Usage

2.3.1 Sources of Water

In Oklahoma, the upper Illinois River including its major tributaries, Flint and Barren Fork Creeks, are located in Basin 82, which is part of the Oklahoma Water Resources Board's (OWRB) Lower Arkansas River Watershed Planning Region (LAWPR) as defined in the 2012 Oklahoma Comprehensive Water Plan (OCWP) (OWRB 2012a). Basin 82 only includes the portion of the river basin (~40 percent) that lies in Oklahoma.

The Illinois River basin yields considerable quantities of surface and groundwater. The historical stream flows of the Illinois River near the basin outlet, measured below Tenkiller Dam from 1954 to present, indicate an annual average discharge of 1,548 cfs (1,121,000 acre feet per year, AFY). However, there are major year-to-year differences in water yield (Figure 2-5). The wettest year average is 3,199 cfs (2,317,000 AFY) and the driest year is only 208 cfs (150,725 AFY). Average monthly flows range from 2,682 cfs in April to 672 cfs in September (Figure 2-6). There is considerable variability in monthly flows between wet and dry years (see Hydrology section).

Mean annual discharges for Flint Creek at Kansas and Barren Fork Creek at Eldon are 116 cfs (83,900 AFY) and 324 cfs (234,700 AFY), respectively. The year-to-year variability and seasonal flow patterns for these tributary streams are similar to those of the Illinois River (see Hydrology section).

A majority of the Illinois River basin overlays two major groundwater aquifers, which are the Roubidoux major bedrock aquifer and the Boone minor bedrock aquifer (OWRB 2012a). Water storage in these two aquifer basins are estimated to be 8,994,000 AF and 9,044,000 AF, respectively. The alluvial aquifers along the stream corridors are estimated to store about 7,000 AF of water (OWRB 2012a), but their yield would be expected to be much greater given their connectivity to the streams.

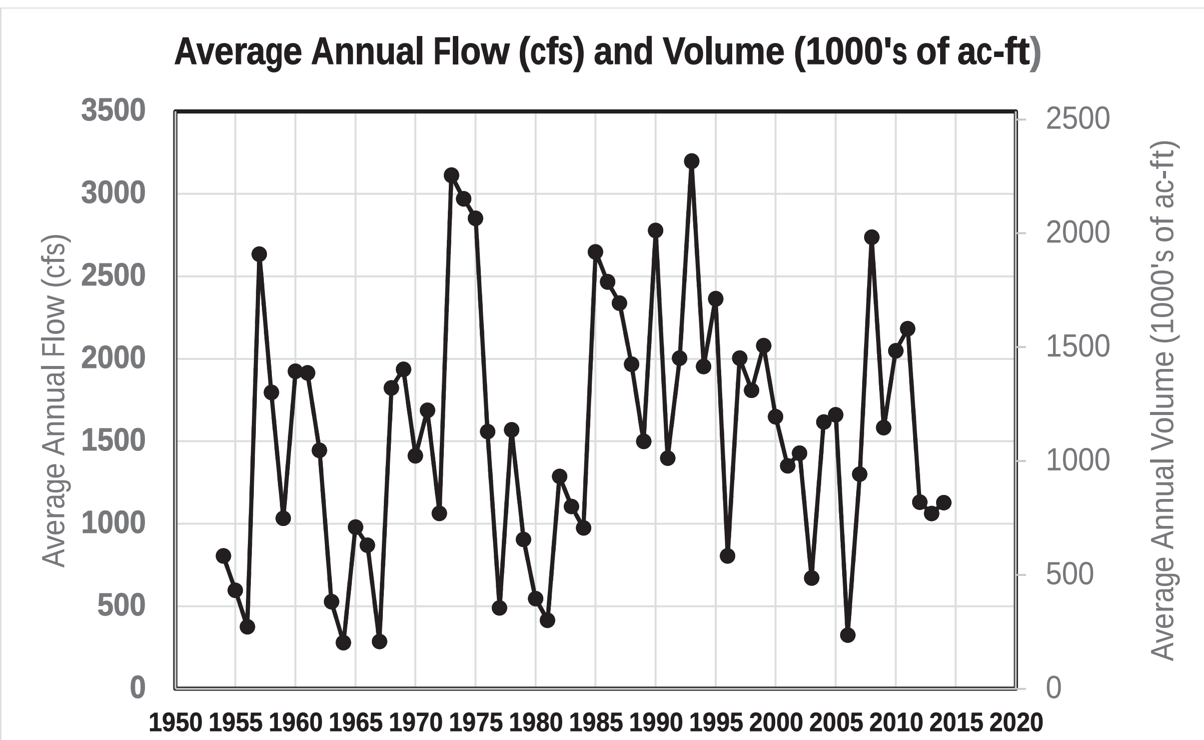


Figure 2-5. Average Annual Flows for the Illinois River near Gore, Oklahoma (USGS gage 0798000).

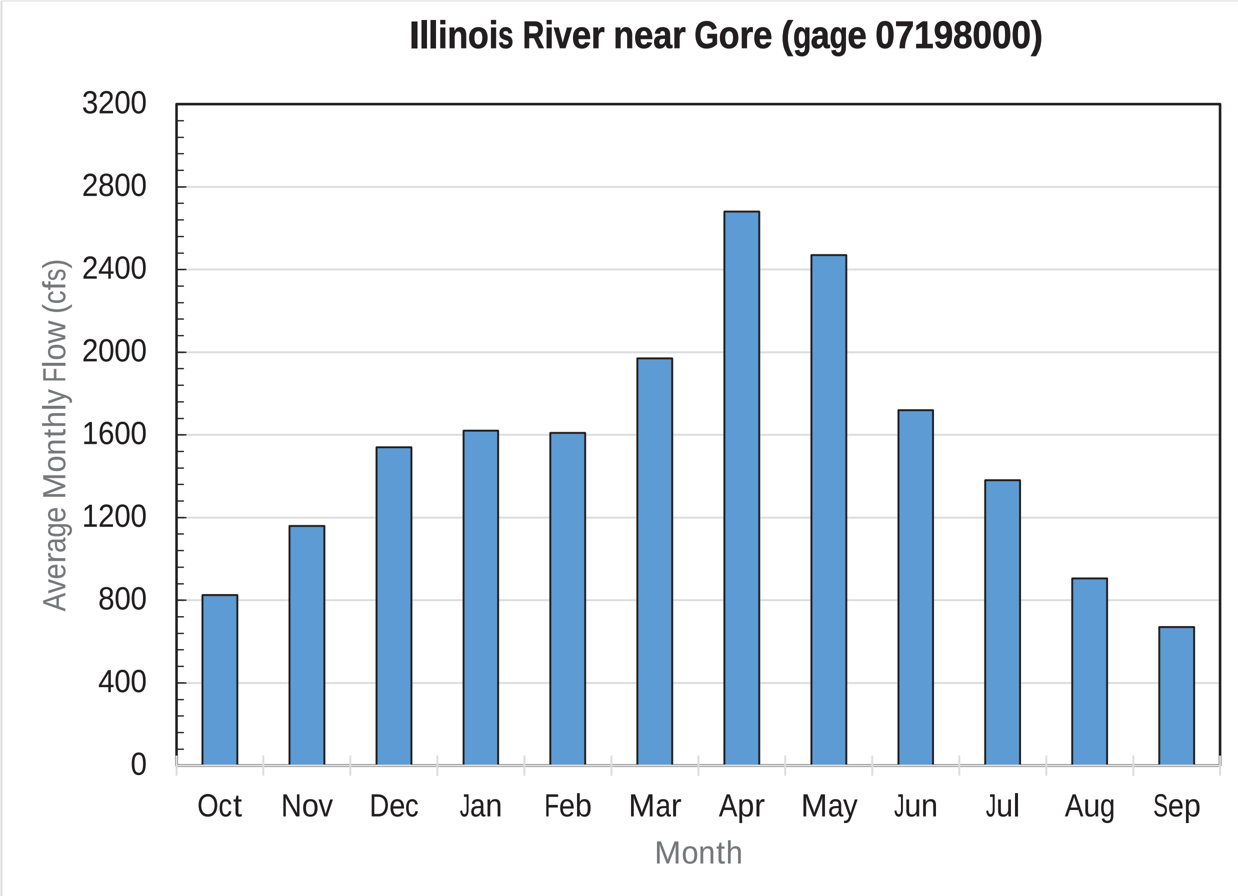


Figure 2-6. Average Monthly Flow (cfs) for the Illinois River near Gore, Oklahoma.

2.3.2 Water Rights

OWRB-appropriated surface water rights for the upper Illinois River above the Barren Fork confluence, including Flint and Barren Fork Creeks, total approximately 30,000 AF (Table 2-5). About 90 percent of the appropriations are for public water supply, with most of that for the City of Tahlequah and the nearby communities. Irrigation accounts for the second most appropriated surface water (2,160 AF) in the upper Illinois basin, but it equates to only about 7 percent of the total appropriation.

Table 2-5. Upper Illinois River Basin Surface Water Permits in Oklahoma.

Water-Use Sector	Flint Creek		Barren Fork Creek		Upper Illinois River	
	Permits	Acre-Feet	Permits	Acre-Feet	Permits	Acre-Feet
Irrigation	3	320	13	412	10	1,429
Agriculture	1	20	0	0	0	0
Public Supply	0	0	4	580	8	27,375
Rec, Fish, & Wildlife	0	0	1	22	0	0
Mining	0	0	1	320	0	0
Total	**4**	**340**	**19**	**1,334**	**18**	**28,804**

2.3.3 Water Usage

2.3.3.1 Oklahoma

The OWRB maintains records of surface water use for the upper Illinois River basin as reported by permitted water users. Average use by sector for the latest four years of available data (2010 through 2013) is shown in Table 2-6. Use of water for domestic purposes, generally defined as water for household purposes, for farm and domestic animals up to the normal grazing capacity of the land, and for the irrigation of land not exceeding a total of three acres in area (plus several other minor water uses not to exceed a total of five acre-feet annually), does not require a permit and is not included in the table. The total average use of 12,088 AFY (16.7 cfs equivalent) is approximately 40 percent of the appropriated amount (see Table 2-6). Similar to the appropriation, water is used primarily for public supply (89 %) and irrigation (11%). Most of the public supply use is by the City of Tahlequah, which diverts water from the Illinois River approximately 6 miles above the Barren Fork confluence. However, much of this water following treatment is discharged back to the river via Tahlequah Creek, which is located about 3 miles below the city's diversion.

The 2012 Oklahoma Comprehensive Water Plan (OWRB 2012) estimates that total water demand in the Illinois River basin is expected to increase about 50 percent by 2060.

Table 2-6. Average Annual Surface Water Usage (acre-feet) in the Upper Illinois River Basin above Barren Fork Creek Confluence in Oklahoma, 2010-2013.

Water Use	Flint Creek	Barren Fork Creek	Upper Illinois River	Total	Percent of Total
Irrigation	3.1	200.0	1,098.3	1,301.4	10.8
Agriculture	0	0	0	0	0.0
Public Supply	0	398.0	10,353.4	10,751.4	88.9
Rec, Fish, & Wildlife	0	0	0	0	0
Commercial	0	0	0	0	0
Industrial	0	0	0	0	0
Mining	0	0	0	0	0
Other	0	35.1	0	35.1	0.3
Total	**3.1**	**633.1**	**11,451.7**	**12,087.9**	**100.0**

Source: Oklahoma Water Resources Board

The total surface water demand in the Oklahoma portion of the watershed above (and including) Barren Fork Creek currently represents only about 1.3 percent of the available water in an average water year. However, most of this water use is for Tahlequah's public supply, which primarily effects only a three-mile reach of river. Water usage as a proportion of available surface water increases during the summer when demand is about twice the annual average (OWRB 2012) and stream flows are at their seasonal low.

For groundwater, the majority of the Oklahoma water rights (3,900 AFY) for the Illinois River basin are from the Boone minor bedrock aquifer. Water extracted from this deep bedrock aquifer has little if any effect on stream flows. For the alluvial aquifers along basin streams, OWRB has issued less than 50 AFY of groundwater rights (OWRB 2012). However, domestic wells using the alluvial groundwater do not require a water right. It is estimated that 8 percent of the total basin demand currently comes from alluvial groundwater (OWRB 2012). This equates to approximately 1,050 AFY (1.5 cfs daily average flow). Some of this water returns to streams via groundwater seepage. Use of groundwater in the Oklahoma portion of the basin has a very minimal effect on surface water flows.

2.3.3.2 Arkansas

The quantity of surface water used in the Arkansas portion of the Illinois River basin is similar to that used in Oklahoma (Andrews et al. 2010). Like in Oklahoma, the greatest proportion (86%) is used for public water supply especially in the upper Flint Creek and Osage Creek basins. A portion of this public supply water returns to the streams following treatment. Irrigation and livestock use constitute the second largest demand in Arkansas.

The Arkansas River Basin Compact, Arkansas-Oklahoma, gives the State of Arkansas the right to develop and use the waters of the Illinois River (only in Arkansas) sub-basin subject to the limitation that the annual yield shall not be depleted by more than 60 percent. However, municipal water needs for the major urban areas (Fayetteville, Springdale, Rogers) in the eastern portion of the Illinois River basin are provided by water imported from the White River basin to the east. In 2011 this imported amount averaged 37.1 cfs (26,870 AFY) (Arkansas River Compact Commission 2013). Most of this water, following use and treatment, is discharged into tributaries to the Illinois River. According to the Compact Commission 2012 Annual Report for water year 2011, the total of surface water depletions and increases from inter-basin transfers into the Illinois Basin resulted in an average net increase in flow of 32.2 cfs (23,312 AFY). The effect of this increase is most pronounced in the summer when natural stream flows are lowest.

Preliminary discussions have occurred in Arkansas to consider reuse of water from the Fayetteville area wastewater treatment plants as a means to reduce phosphorous loading into the Illinois River. If implemented, such reuse would reduce the amount of water currently augmenting flows in the river. However, the water reuse concept appears to be a low-priority alternative because it has a low benefit-to-cost ratio compared to other alternatives being considered to reduce phosphorous loading (Ammons, 2016, pers. comm.).

2.3.3.3 Summary

Current water use compared to the total available water in the Illinois River basin is minimal on average. Most of the water demand in Oklahoma is for public supply use, and most of that is located near the lower end of the designated Scenic River reach. In Arkansas, flow augmentation into the upper Illinois River system from water imported from the White River basin may more than compensate for the other surface withdrawals from the basin in both states, particularly in the summer when natural flows are lowest.

2.4 Water Quality

While much of the Illinois River and many of its tributaries are state-designated as “outstanding resource” waters, water quality problems in the basin have been recognized since at least the early 1980’s. These problems were initially perceived as decreased water clarity and frequent algal blooms in Lake Tenkiller. Substantial water quality research since then has been undertaken by both Arkansas and Oklahoma. An excellent chronology of the historical water quality problems in the basin and descriptions of the various measures to address these problems is presented in the “Watershed Based Plan for the Illinois River Watershed” prepared by the OCC, Water Quality Division (2010). Numerous studies concluded that the watershed was being most impacted by excess nutrient loading, primarily phosphorous. Sources have included both point sources such as wastewater treatment plant discharges, and nonpoint sources such as those associated with the substantial poultry operations in the basin. Streambank erosion due to degraded riparian zones and cattle access to streams also contribute to increased phosphorous loading and increased sedimentation. Most of the human population (approximately 90 percent) in the basin as well as most cattle grazing and poultry operations occur in the Arkansas portion of the watershed (OCC 2010).

Water quality at several locations on the Illinois River and its tributaries is listed as impaired under section 303d of the Clean Water Act (Oregon Department of Environmental Quality 2012)). Most of these impairments are for elevated total phosphorous or enterococcus bacteria (Table 2-7). Flint Creek and Lake Tenkiller are also listed for low dissolved oxygen levels, which are likely a consequence of occasional eutrophic conditions associated with the high phosphorous concentrations.

Table 2-7. Impaired Waters on the Oklahoma 303 (d) List for the Illinois River Basin.

OKWBID	Name	Listed on 303(d) for Impairments
121700020020	Tenkiller Ferry Lake	*Dissolved Oxygen, TP*
121700020110	Chicken Creek	*Fish Bioassessment*
121700020220	Tenkiller Ferry Lake, Illinois River Arm	*Chlorophyll-a, TP*
121700030010	Illinois River – Tahlequah	*TP, Enterococcus*
121700030040	Tahlequah Creek (Town Branch)	*Eschericia coli*
121700030080	Illinois River	*TP, Lead, Eschericia coli*
121700030280	Illinois River – Chewey Bridge	*TP, Escherichia coli. Turbidity Enterococcus*
121700030290	Flint Creek	*TP, Dissolved Oxygen*
121700030350	Illinois River – Watts	*TP, Turbidity, Enterococcus Escherichia coli*
121700030370	Ballard Creek	*Enterococcus*
121700040010	Caney Creek	*Enterococcus*
121700050010	Illinois River - Barren Fork	*TP, Enterococcus*
121700050090	Tyner Creek	*Enterococcus*
121700050120	Peacheater Creek	*Enterococcus*
121700050170	Illinois River - Barren Fork	*Enterococcus*
121700060010	Flint Creek	*TP, Enterococcus*
121700060040	Battle Creek (Battle Branch)	*Enterococcus*
121700060080	Sager Creek	*Enterococcus*

Considerable efforts have already been made to address water quality problems in the Illinois River basin. These efforts include reductions in point source loading, primarily from waste water treatment plants (WWTPs). The states of Arkansas and Oklahoma continue to work cooperatively to seek solutions to nonpoint-source pollution problems by funding programs including riparian protection, watershed education, streambank stabilization, and alternative uses and more effective uses of poultry waste. Perhaps reflecting some successes in these programs, estimated total phosphorous loading since 1999 (from samples excluding targeted high flows) have demonstrated a significant downward trend in the Illinois River at Watts and Tahlequah and in Barren Fork Creek (Arkansas-Oklahoma Arkansas River Compact Commission 2014). No significant trend in phosphorus loading has been observed for Flint Creek.

Streamflow has a substantial effect on surface water quality in the Illinois River basin. While greater volumes of water can act to dilute and assimilate wastes and contaminants, higher streamflows associated with storm events increase surface runoff and flushing of nutrients, bacteria, and sediments into the streams (Andrews et al. 2010). Large streamflows from storms may scour and resuspend streambed and riparian-source sediments containing phosphorous. Total phosphorous concentrations have been observed to generally increase with suspended sediment concentrations greater than 20 mg/l, which corresponds to streamflows of about 150 cfs in the Illinois River at both Watts and Tahlequah (Andrews et al. 2010).

The lower portion of the Illinois River watershed, especially the Illinois River and Flint and Barren Fork Creeks in Oklahoma, supports a local economy strongly reliant on tourism. This tourism is highly dependent on aesthetically pleasing water and water quality that is safe for body contact. To minimize eutrophication of its Scenic Rivers, Oklahoma established a total phosphorous criterion of 0.037 mg/l as a 30-day geometric mean. It has been implemented as a 3-month rolling geometric mean (OWRB 2014), with not more than 25 percent of the calculated means allowed to exceed the standard (OWRB 2012b). The standard was derived from an analysis of nutrient values in undeveloped stream basins (Clark et al. 2000), and compared favorably to median phosphorus concentrations seen in the Barren Fork and Mountain Fork Rivers (0.045 mg/L and 0.028 mg/L, respectively). Between 2009 and 2013, more than 90 percent of the water samples from the Illinois River and Flint Creek exceeded the state criterion of 0.037 mg/l phosphorous. For the Barren Fork only 32 percent of the samples exceeded the criterion, reflecting the better overall water quality in that basin.

Water temperature is an important water quality condition that has a major influence on fish communities. The water temperature regime shapes fish behavior, growth, condition, and distribution. Regulated streams that experience alterations in streamflow or are influenced by reservoirs always have altered temperature regimes, which in turn affects the fish community. As a result, potential temperature regime change is a common issue of concern associated with any proposal to modify streamflows or construct reservoirs.

Water temperatures in the Illinois River basin generally follow the seasonal pattern with the highest temperatures observed in July or August. Temperatures measured by OWRB staff since 1998 concurrent with water quality sampling indicate the flowing daily maximums:

- Illinois River at Watts - 31.5 °C (88.7°F)
- Illinois River at Tahlequah – 31.7°C (89.1°F)
- Barren Fork at Eldon – 28.6°C (83.5°F)
- Flint Creek at Flint – 28.7°C (83.7°F)

Maximum temperatures are higher in the Illinois River compared to the tributaries, as expected based on stream length, as well as decreased canopy cover in the larger Illinois River. Water temperatures only slightly warmer than those noted above have been documented during conditions of extreme air temperature and drought (Musselman 2014).

Temperature modeling has been done for the Illinois River (near Chewey), Barren Fork Creek, and Flint Creek to compare water temperatures under different flow conditions and then to compare these predicted temperatures to known “critical thermal maximum” (CTM) for fish species found in the Illinois River watershed (Musselman 2014). The comparative baseline temperatures and flows were those observed during the 2012 summer drought. Several arbitrary flow deviations (e.g. 50% and 200%) from these baseline conditions were modeled. For the Illinois River a reduction in the drought-condition base flow of 50% predicted an increase in maximum daily water temperature of 0.32°C, which in turn slightly increased the probability for some fish species being exposed to their associated CTM. Modeling results for Flint Creek followed a similar pattern as the Illinois River except maximum water temperatures were much cooler and the influence of flow changes was less. The probability of fish being exposed to their CTM in Flint Creek was minimal under all flow scenarios because of the lower baseline temperatures. Water temperature predictions for Barren Fork Creek differed from those for the Illinois River and Flint Creek in that reductions in base flow actually reduced maximum water temperatures, albeit slightly. It should be noted that these temperature modeling studies were done at the stream-reach scale and thus did not reflect possible temperature changes at the smaller patch-scale, where fish often seek temperature refuge during periods of warm weather. The fact that Flint Creek is noticeably cooler than the Illinois River during the summer suggests that it could be an important thermal refuge area in the future.

2.5 Fisheries

The Illinois River watershed supports a highly diverse fish community. Based on fish collections by OWRB staff over the previous decade, more than seventy-five species of fish have been enumerated throughout the watershed. These species represent nearly half of the fish families found in Oklahoma. The banded sculpin, northern hog sucker, cardinal shiner, bigeye chub, rock bass, and stippled darter are found in Oklahoma only in Ozark streams in the northeastern part of the state. Throughout the watershed, the most commonly occurring fish (i.e., species occurring in the most collections), include both orangethroat and stippled darters, cardinal shiner, central stoneroller, longear and green sunfish, slender madtom, smallmouth bass, and banded sculpin.

Of particular note is the fact that nearly all of the observed fish species in the Illinois River basin (except common carp) are native to the region.

Fish collection data for the Illinois River, Barren Fork Creek, and Flint Creek for the 10-year period from 2003 through 2012 are shown in Table 2-8. These collections were all made during low flow conditions using electrofishing gear per OWRB's standardized protocol (OWRB 2013). Each sampling event covered a pre-established stream length based on the wetted stream width. Therefore, the surface area covered by the sampling differed among sites. Most fish were netted by field crew wading in or below the effective electrical field. Fish were collected from the deeper pools of the Illinois River via a boat mounted electrofisher. The fish collections summarized in Table 2-8 represent 14 single-day sampling events in the Illinois River, 7 in Flint Creek, and 15 in Barren Fork Creek.

For the overall sampling of the three streams, 68 species of fish were collected (Table 2-8). When comparing the 10 most common species in each stream (in bold in Table 2-8), six occurred in all three streams. These included cardinal shiner, central stoneroller, longear sunfish, Ozark minnow, orangethroat darter, and slender madtom. Fish that were collected only in the larger Illinois River include several suckers, such as bigmouth buffalo, river and shorthead redhorse, river carpsucker, as well as spotted gar, black crappie, channel catfish, freshwater drum, steelcolor and wedgespot shiners, and threadfin shad. Species collected only in Barren Fork Creek include the pallid chub, emerald shiner, shortnose gar, and spotted sucker. Finally, those observed only in Flint Creek included the Ozark, redfin, and mimic shiners, the northern studfish, southern redbelly dace, and the white sucker.

Fish sampling using a combination of boat electrofishing, seining, gill nets, and hoop nets was conducted over several days in the Illinois River near No Head Hollow in 2014 by Oklahoma State University students and staff (unpublished data provided by Shannon Brewer, Oklahoma State University). While not presented here, the fish community data comprised of 27 species are consistent with those seen in the OWRB data with the exception that more redhorse species and northern hogsuckers were observed. These species prefer deep water and may have been more prone to being captured by the gear combination used at the sampling sites.

Table 2-8. Mean Abundance (numbers per sampling event) of Fish Species Collected in the Illinois River, Barren Fork Creek, and Flint Creek during 2003-2012

Common Species Name (alphabetic order)	Scientific Species Name	Illinois River	Flint Creek	Barren Fork Creek
Banded darter	*Etheostoma zonale*	14	2	9
Banded sculpin	*Cottus carolinae*	4	**34**	**26**
Bigeye chub	*Hybopsis amblops*	**17**	ND	8
Bigeye shiner	*Notropis boops*	6	1	11
Bigmouth Buffalo	*Ictiobus cyprinellus*	1	ND	ND
Black crappie	*Pomoxis nigromaculatus*	2	ND	ND
Black redhorse	*Moxostoma duquesnei*	9	1	**22**
Blackspotted topminnow	*Fundulus olivaceus*	2	3	2
Blackstripe topminnow	*Fundulus notatus*	1	3	2
Bluegill sunfish	*Lepomis macrochirus*	14	15	16
Bluntnose minnow	*Pimephales notatus*	13	ND	1
Brook silverside	*Labidesthes sicculus*	12	1	1
Cardinal shiner	*Luxilus cardinalis*	**127**	**142**	**104**
Central stoneroller	*Campostoma anomalum*	**82**	**136**	**130**
Channel catfish	*Ictalurus punctatus*	6	ND	ND
Chestnut lamprey	*Ichthyomyzon castaneus*	1	ND	2

Table 2-8. Mean Abundance (numbers per sampling event) of Fish Species Collected in the Illinois River, Barren Fork Creek, and Flint Creek during 2003-2012

Common Species Name (alphabetic order)	Scientific Species Name	Illinois River	Flint Creek	Barren Fork Creek
Common carp	*Cyprinus carpio*	1	ND	1
Creek chub	*Semotilus atromaculatus*	2	12	2
Emerald shiner	*Notropis atherinoides*	ND	ND	1
Fantail darter	*Etheostoma flabellare*	1	1	ND
Flathead catfish	*Pylodictis olivaris*	2	ND	3
Freshwater drum	*Aplodinotus grunniens*	4	ND	ND
Gizzard shad	*Dorosoma cepedianum*	**37**	ND	2
Golden redhorse	*Moxostoma erythrurum*	4	9	5
Gravel chub	*Erimystax punctatus*	**16**	ND	ND
Green sunfish	*Lepomis cyanellus*	8	8	**23**
Greenside darter	*Etheostoma blennioides*	5	2	14
hybrid sunfish	*Lepomis*	3	ND	ND
Largemouth bass	*Micropterus salmoides*	6	9	2
Logperch	*Percina caprodes*	13	1	4
Longear sunfish	*Lepomis megalotis*	**67**	**49**	**58**
Longnose gar	*Lepisosteus osseus*	3	ND	2
Mimic shiner	*Notropis volucellus*	ND	4	ND
Mosquitofish	*Gambusia affinis*	9	2	2
Northern hog sucker	*Hypentelium nigricans*	7	12	11
Northern studfish	*Fundulus catenatus*	ND	3	ND
Orangebelly darter	*Etheostoma radiosum*	2	**136**	ND
Orangespotted sunfish	*Lepomis humilis*	2	ND	ND
Orangethroat darter	*Etheostoma spectabile*	**22**	**39**	**35**
Ozark minnow	*Notropis nubilus*	**38**	**20**	**77**
Ozark shiner	*Notropis ozarcanus*	ND	**59**	ND
Pallid chub/shiner	*Hybopsis amnis*	ND	ND	3
Redear sunfish	*Lepomis microlophus*	4	ND	2
Redfin shiner	*Lythrurus umbratilis*	ND	1	ND
Redspot chub	*Nocomis asper*	3	17	9
River carpsucker	*Carpiodes carpio*	1	ND	ND
River redhorse	*Moxostoma carinatum*	8	ND	ND
Rock bass	*Ambloplites rupestris*	8	16	7
Rosyface shiner	*Notropis rubellus*	13	4	1
Shadow bass	*Ambloplites ariommus*	1	**21**	6
Shorthead redhorse	*Moxostoma macrolepidotum*	1	ND	ND
Shortnose gar	*Lepisosteus platostomus*	ND	ND	1
Slender madtom	*Noturus exilis*	**35**	**19**	**31**
Smallmouth bass	*Micropterus dolomieui*	**17**	10	**17**
Smallmouth buffalo	*Ictiobus bubalus*	9	ND	1

Table 2-8. Mean Abundance (numbers per sampling event) of Fish Species Collected in the Illinois River, Barren Fork Creek, and Flint Creek during 2003-2012

Common Species Name (alphabetic order)	Scientific Species Name	Illinois River	Flint Creek	Barren Fork Creek
Southern brook lamprey	*Ichthyomyzon gagei*	1	ND	2
Southern redbelly dace	*Phoxinus erythrogaster*	ND	4	ND
Spotted bass	*Micropterus punctulatus*	9	ND	2
Spotted gar	*Lepisosteus oculatus*	1	ND	ND
Spotted sucker	*Minytrema melanops*	ND	ND	1
Steelcolor shiner	*Cyprinella whipplei*	4	ND	ND
Stippled darter	*Etheostoma punctulatum*	4	13	8
Threadfin shad	*Dorosoma petenense*	6	ND	ND
Warmouth sunfish	*Lepomis gulosus*	7	2	3
Wedgespot shiner	*Notropis greenei*	7	ND	ND
White crappie	*Pomoxis annularis*	2	6	ND
White sucker	*Catostomus commersoni*	ND	2	ND
Yellow bullhead	*Ameiurus natalis*	1	5	3
Number of Sampling Events		14	7	15
Average Number of Fish/Event		644	587	584
Total Number of Species		58	39	45
Average Species Richness		34	22	21

Notes:

Numbers in **bold** are the 10 most commonly observed species in each stream.

D = species not collected on the waterbody.

Total species richness (number of species) appeared to increase with watershed size. The number of species collected in the Illinois River, Barren Fork Creek, and Flint Creek were 58, 45, and 39, respectively (Table 2-8). The lower number of species observed in Flint Creek may be an artifact of fewer sampling events. When the average number of species captured per sampling event was compared, Flint Creek and Barren Fork were nearly the same (21 Barren Fork, 22 Flint). Average species richness for the Illinois River was 34. These differences in species richness are consistent with stream ecosystem concepts whereby nutrient cycling, physical conditions, habitat diversity, and associated biotic responses tend to change progressively as the steam flows from its headwaters to its mouth (Vannote et al. 1980).

Smallmouth bass is the most sought after game fish in the upper Illinois River and tributaries (see Recreation section) and is a valuable recreational and ecological asset to streams throughout the southeast United States, including Oklahoma. Catch and harvest rates in Barren Fork Creek, Oklahoma are some of the highest reported in the literature (Martin and Fisher, 2008). Ecologically, smallmouth bass is noted for its role as a top predator within Ozark streams (Pflieger 1997; Brewer and Orth 2015). Two subspecies and an Ouachita lineage of smallmouth bass are recognized, including the Neosho subspecies (see Brewer and Orth 2015 for distributions; and Stark and Echellee 1998 for genetic descriptions) that, within Oklahoma, is restricted to the northeast part of the state (Brewer and Long 2015). The high conservation value of this unique species within Oklahoma is recognized by management agencies within Oklahoma (Ahlert et al. 1995; Malloy et al. 2000; Boxrucker et al. 2004).

2.6 Wildlife

The wildlife within the Illinois River corridor is quite diverse. Typical of the Ozark region, the animals in this area are associated with the eastern deciduous forest. Climate, terrain, and the abundance of water combine to support the diversity of animal species.

Common mammals in the Illinois River corridor include the white tailed deer, bobcat, raccoon, opossum, striped skunk, muskrat, eastern cotton tail, fox squirrel, gray squirrel, southern flying squirrel, red and gray fox, and coyotes (OSRC 1999). A large number of bats of several species are found in the basin because of the abundant habitat provided by nearby limestone caves and sinks. The most common bat species include the big brown bat, red bat, tri-colored bat, and the evening bat. Federally-listed bats that have been observed in the Illinois River basin are the endangered gray bat, the Ozark big-eared bat, and the threatened northern long-eared bat. The gray bat feeds on small insects over forested areas and wetlands and their decline in numbers has been attributed to the clearing of forests along streams and lakes as well as human disturbance of their breeding and hibernating caves (Oklahoma Department of Wildlife Conservation [ODWC] 2016a). The Ozark big-eared bat forages above the forest canopy and in forest clearings. They are associated with the oak-hickory forest types (ODWC 2016b). Human disturbance of caves is believed to be the primary reason for their decline. The northern long-eared bat feeds on insects caught in the forest understory or picked from the surface of waterbodies. It is threatened primarily by the continued spread of a disease known as white-nose syndrome (U.S. Fish and Wildlife Service [USFWS] 2015a).

A great number and variety of birds are found within the Illinois River corridor. Those most commonly seen on or near the river include the great and little blue heron, bald eagle, osprey, killdeer, belted kingfisher, and many common species of waterfowl. Other bird species commonly seen in the corridor include turkey vulture, red-tailed hawk, American kestrel, red-bellied and red-headed woodpecker, and cliff swallow. Songbirds include the Carolina chickadee, tufted titmouse, white breasted nuthatch, Bewick’s wren, mockingbird, robin, wood thrush, red-winged blackbird, and northern oriole. The primary game birds found in the Illinois River and tributary corridors are the turkey, bobwhite quail, and mourning dove.

The numerous limestone caves and sinks as well as wetlands in the Illinois River watershed provide good habitat for many species of amphibians. Salamander species include small mouth, tiger, slimy, cave, ringed, Oklahoma dwarf, and Ozark blind salamander. Other amphibians include the Louisiana waterdog, central newt, bull frog, green frog, gray tree frog, southern leopard frog, and Blanchard’s cricket frog. Toad species include the American, Hunter’s spadefoot, and the eastern narrow-mouthed toads.

Aquatic species found in the streams of the Illinois River watershed include as many as 72 species of fish. These are discussed in the Fisheries section of this report. None of these fish is listed as federally or state endangered or threatened species. The watershed also provides habitat for certain nonfish aquatic species that are both dependent on high water quality and are of special conservation status. One notable group consists of pearly freshwater mussels, also known as unionid mussels or simply “mussels.” This group is of special interest, in part because of significant ecosystem services they provide, but also because their sensitivity to environmental changes makes them good indicators of ecological health (Strayer et al. 2004). Environmental factors that are important in determining mussel occurrence include various components of stream flow. Studies of mussels of the Illinois River and its tributaries have found a moderately rich assortment of species (approximately 25; Isely 1924, Vaughn 1998, Mather 2005). One freshwater mussel, the Neosho mucket, is both state-listed and federally-listed as an “endangered” species. The Illinois River population (upstream of Tenkiller Ferry Reservoir) supports 1 of only 9 surviving populations of the Neosho mucket (ODWC, 2016c; USFWS 2015b). The USFWS recently included only the Illinois River upstream of the Barren Fork Creek confluence within its critical habitat designation area (USFWS 2015b). Reasons for its decline throughout its historic range are believed to include past pesticide use, water pollution, and construction of reservoirs. The rabbitsfoot mussel is also a federally-listed “threatened’ species that has been observed in the Illinois River. The Illinois River upstream of Tenkiller Ferry Reservoir supports 1 of only 28 surviving populations of the rabbitsfoot. However, its recent critical habitat listing did not include the Illinois River or its tributaries (USFWS 2015b). Reasons for the decline of the rabbitsfoot include construction of reservoirs and navigation projects, landscape modifications, and water pollution.

2.7 Recreation

The Illinois River and its two major tributaries, Barren Fork and Flint Creeks, are popular destinations for canoeists, kayakers, and fishermen. The nearby towns, including the city of Tahlequah, rely strongly on tourism to support the local economy. The amount of tourism and economic effect of tourism in the basin is highly dependent on aesthetically pleasing water and water quality that is safe for primary body contact recreation. Each year more than 150,000 persons float the Illinois River by canoe, raft, or kayak. Monthly visitor counts of floaters in the Illinois River watershed between 2003 and 2008, as reported by commercial and private float operators, are summarized in Table 2-9*.* In addition, a total estimated 350,000 visitors enjoy equestrian tours, mountain biking, road biking, swimming, fishing, camping, hiking, nature-watching, and hunting opportunities. Annual visitation is approximately 400,000 primarily from Oklahoma, Arkansas, Kansas, Missouri and Texas. Recreational boaters spend an average of about $60 per float trip per person on gas, food, lodging, and other amenities.

The OSRC estimates that recreation and tourism has an economic impact of approximately $12 million in the region around the upper Illinois River in Cherokee County (2009 dollars as reported in Andrews et al. 2010). An additional $30 million is spent each year by about 2 million visitors to Tenkiller Ferry Reservoir (Andrews et al. 2010).

The Illinois River, Barren Fork Creek, and Flint Creek are considered free-flowing streams (refer to Hydrology-section for additional information). Both the Illinois River Management Plan (1999) and the Oklahoma Scenic Rivers Act of 1970 (OSRA) aim to preserve the free-flowing nature of the River to protect the unique natural scenic beauty, water conservation, fish, wildlife and outdoor recreational values. The Illinois River Management Plan set a specific recreational goal to "Provide the opportunity for a high-quality recreation experience while protecting the river's outstanding resources and recognizing the needs of river outfitters and individual users."

The Illinois River offers swift to gentle currents for recreational boaters that support Class I and Class II waters throughout most of the year. The Illinois River has a sufficient volume of water to support floating year- round except under drought conditions. According to the OSRC (Ed Fite, personal communication), Commercial Flotation Device Operators (CFDO) will float canoe and kayak customers at flows as low as 150 cfs (Tahlequah gage) but with the expectation that boats will need to be dragged through some of the shallow riffle areas (Table 2-10). Rafts require higher flows of at least 250 cfs. Flows greater than about 1,200 cfs can pose safety risks to inexperienced boaters, although knowledgeable rafters sometimes float the river at flows up to about 4,000 cfs. Overall, a flow range from about 400 cfs to 1,200 cfs offers scenic and easy boating and seems to be the optimal range enjoyed. When flows start exceeding 1,600 - 1,800 cfs the river becomes turbid, which poses safety concerns (unable to see submerged snags) and is aesthetically less enjoyable. The peak floating season is summer (June through August). Barren Fork and Flint Creeks are floatable from the early spring to early summer.

The Illinois River is navigable for about 65 miles from Twin Falls at the Watts, Oklahoma Public Access Area where US Highway 59 crosses the river down to Carter's Landing at the headwaters of Tenkiller Ferry Reservoir. Floating trips of various lengths are available, ranging from six- to 60-mile-long stretches. The upper river in Oklahoma includes fifteen commercial rental operations. Most of them are located along SH-10. In recent years, the use of canoes has declined in popularity while the use of rafts and kayaks has increased exponentially (Ed Fite, OSRC, personal communication). Rafting is currently the most popular means of floating the river. No airboats, hovercrafts or jet-driven watercraft are allowed on the river except for purposes of search and rescue, navigational hazard removal, and law enforcement.

Table 2-9. Illinois River Monthly Float Users, 2003-2008, as Reported by Commercial and Private Float Operators in Oklahoma.

	2003		2004		2005		2006		2007		2008	
	Commercial	**Private**	**Commercial**	**Private**	**Commercial**	**Private**	**Commercial**	**Private**	**Commercial**	**Private**	**Commercial**	**Private**
January	0	162	0	0	2	0	0	0	0	46	0	0
February	0	0	0	200	8	0	2	5	0	0	0	0
March	1	10	184	60	167	17	268	9	37	20	0	0
April	161	22	338	65	611	86	644	193	334	121	0	0
May	4,109	224	14,549	690	16,021	568	10,653	481	14,294	505	0	0
June	9,194	462	23,235	550	28,613	795	28,617	871	23,283	824	23,461	585
July	27,760	1,028	33,174	668	48,945	1,614	41,260	1,128	35,265	1,181	38,240	942
August	19,539	1,185	26,149	749	23,846	929	18,531	729	27,963	603	31,214	626
September	7,493	233	11,875	408	9,646	312	7,037	414	11,249	753	4,641	277
October	2,814	45	402	43	379	23	477	164	620	49	576	232
November	425	10	6	23	0	2	18	90	0	0	8	18
December	38	2	0	3	0	4	0	65	0	182	0	31
TOTAL	**71,534**	**3,383**	**109,912**	**3,459**	**128,238**	**4,350**	**107,507**	**4,149**	**113,045**	**4,284**	**98,140**	**2,711**

Source: Oklahoma Scenic Rivers Commission

Table 2-10. Streamflow Considerations for Recreational Boating/Floating Activity on the Illinois River Based at the USGS Tahlequah Gage (Source: Ed Fite, Oklahoma Scenic Rivers Commission).

Activity	Flow (cfs)
Minimum Flow for Canoe and Kayak Passage	150
Minimum Flow for Raft Passage	250
Optimal Flow Range for All Flotation Devise Use	400 – 1,200
Maximum Safe Flow for General Public	1,200
Maximum Safe Flow for Experienced Users	4,000

Each time a rented flotation device is launched on the Illinois River a user fee is collected. People using private flotation devices such as canoes, kayaks, rafts and inner tubes, must also purchase a user fee wristband for each separate trip.

The OSRC maintains eight public access areas with convenient river access for swimming, fishing, boating and primitive camping. Public access areas are available to campers and recreationists, according to the designating signage. A $7.00 to $12.00 daily camping fee is collected by OSRC Park Rangers (OSRC Floaters Guide).

Outstanding fishing opportunities are available in the upper Illinois River including its major tributaries, Barren Fork and Flint Creeks. Over 60 species of fish occur in these waters but most are nongame species. Major game fish include a variety of bass species as well as sunfish and catfish. Smallmouth bass is the most sought after sport fish in the upper Illinois River and tributaries. Guides and anglers fish year round, but the majority of the fishing pressure is from mid-March through October depending on water and weather conditions. Gig fishermen target sucker species in the upper reaches of the Illinois River from December 1 through March 1, the legal season.

State regulations for bass species in the Illinois river system allow a catch possession of six combined per day, of which only one may be a smallmouth bass, and all must be 14-inches or longer. These restrictive regulations help maintain healthy bass populations and a quality fishing experience. Adding to this experience is the scenic nature of the stream and its natural unregulated stream flow regime in the designated Scenic reach. Angler access to the Illinois River is good with multiple public access areas established along the stream. Fishing from canoes and rafts is popular throughout the Illinois River. Most fishing access to Barren Fork and Flint Creeks is via private land and clubs.

Angler survey data (creel checks) are available only for the Barren Fork Creek (Martin and Fisher 2008). The smallmouth bass fishery in Barren Fork was characterized by relatively high catch and harvest rates, and the yield was among the highest reported in the literature for smallmouth bass stream fisheries in the country. Approximately 80 percent of the bass caught by anglers in the Barren Fork were released. These high angler catch rates are consistent with the biological studies of the stream that found that smallmouth bass were abundant and exhibited good year-class success and low annual mortality (Balkenbush and Fisher 1999). The authors attributed the health of Barren Fork smallmouth bass population to the relatively stable base flow regime and nutrient enrichment from agricultural activities in the basin.

2.8 Riparian Corridor

During the first stakeholder meeting held in Tahlequah on January 22, 2015, the topic of side channels and other off-channel waters (secondary channels) along the Illinois River was raised regarding their importance for fish and wildlife resources and associated ecological values. The existence of extensive side channels is not obvious to those viewing the river from the road or from the main river channel. However, review of the aerial photographs available on Google Earth reveal numerous secondary stream channels and other associated water features along the river's riparian corridor.

As a means to quantify these secondary channels, the aerial photographs highlight those channels that appeared to be active at the time the photographs were made, which seemed to correspond to a typical summer base flow. Many of these channels had only intermittent flows or backwaters at their downstream end at the time photographed. Results of this mapping effort are appended to this report. An example map for a 4-mile reach of the river near Tahlequah is shown in Figure 2-7. The maps in the appendix are sequenced from downstream to upstream starting at Tahlequah, and there is some overlap in coverage between maps.

For the 53-mile reach of the Illinois River from the Highway 10 bridge in Tahlequah upstream to the Arkansas border, a total of 31.4 miles of secondary channels was identified (Table 2-11). The ratio of secondary-to-main channel length is nearly 60 percent. The ratio tends to decrease somewhat moving upstream. While comparable data were not readily available for other streams, it is clear that the extent of secondary channels and ponds along the Illinois River is impressive, especially when considering the importance of these features in supporting fish, wildlife, water quality, and other ecological processes.

Table 2-11. Ratio of Secondary Channel Length to the Main Channel Length in the Illinois River between Watts and Tahlequah, Oklahoma.

River Reach	Watts to Flint Creek	Flint Creek to Peavine	Peavine to Tahlequah	Total
River Reach Length (mi)	13.3	16.3	22.9	53.0
Secondary Channel Length (mi)	7.1	7.0	17.3	31.4
Ratio of 2ndary channel to main channel length	**53.1 %**	**42.9%**	**75.6%**	**59.2%**

Although not delineated, it is apparent on the aerial photographs that these secondary channels consist of a wide variety of habitat types including flowing water, intermittent pools, backwaters connected to the river, backwaters disconnected from the river, and old oxbow ponds. These different channel types represent the evolution over time of their formation during the stream's natural meander process.

These secondary channels all have different levels of main river flows at which water begins to flow into them. However, most of the secondary channels on the Illinois River appear to contain water (standing or flowing) even during the summer base flow conditions. In some cases, water appears only in the in the lower portions of the channels via emergence of interstitial flow from the main river. While some secondary channels are fully flowing even when river is at base flow (active side channels), others are disconnected except during flood events and even then may only experience inundation (rather than significant channel flow). However, based on principals of fluvial geomorphology and natural stream processes, it is reasonable to assume that most of these secondary channels contain flowing water when the main river achieves bank-full conditions (Dunne and Leopold 1978).

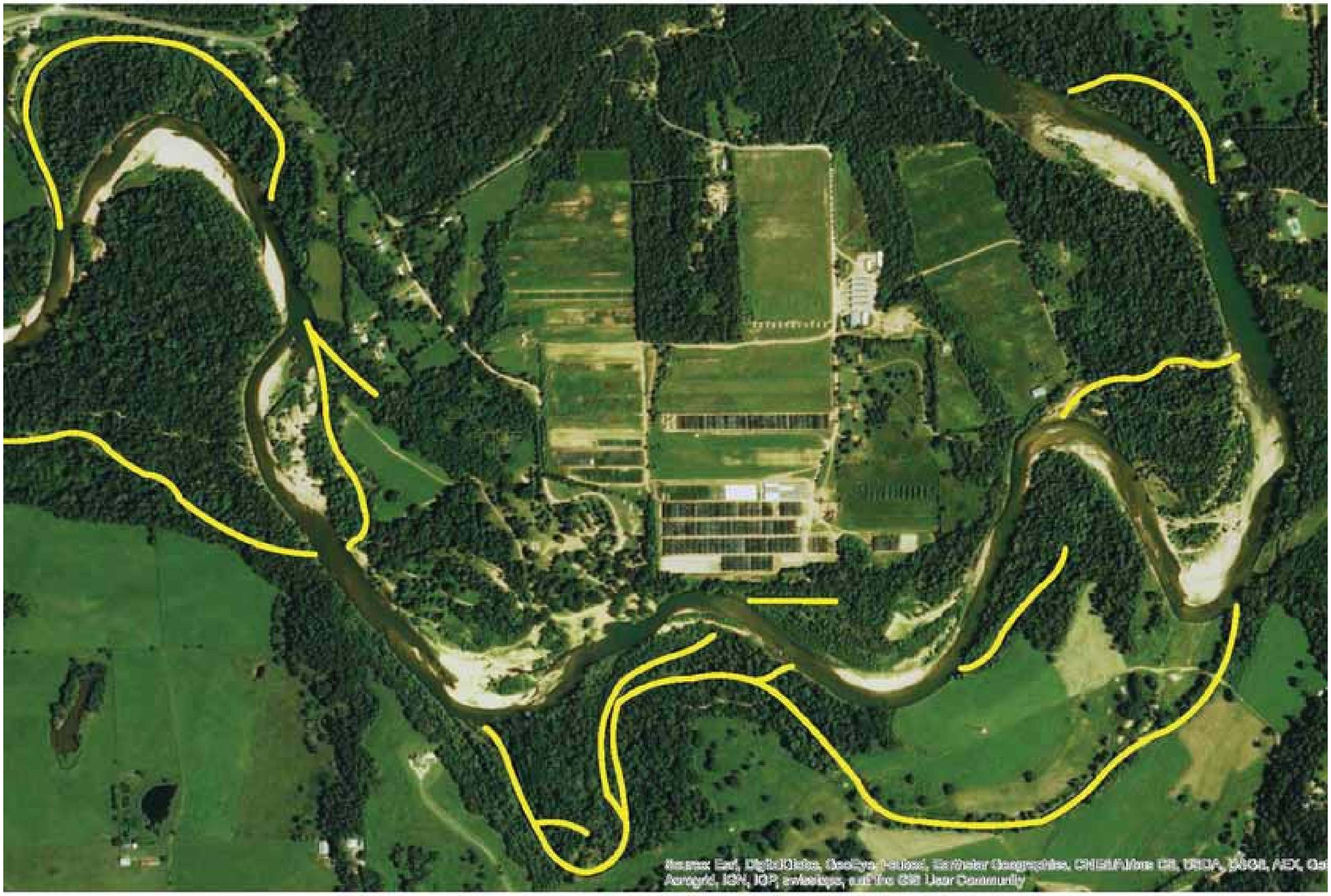


Figure 2-7. Highlighted Secondary Channels along a 4-mile Reach of the Illinois River near Tahlequah, Oklahoma

Stream flows that create and maintain these secondary channels are critically important for maintaining the ecological processes associated with them. Terms commonly used to describe these flows include channel formation, channel maintenance, habitat maintenance, dominant discharge, effective discharge, flushing flow, bank-full flow, and riparian maintenance. If the frequency of these bank-full flow events is diminished, the entrances to these secondary channels will tend to close up over time via encroachment of perennial vegetation, thus diminishing or eliminating the ecological values associated with these channels.

These riparian areas and associated water features provide numerous ecological values (Annear et al. 2004). Biologically, they support refuge habitat for fish during floods and drought, preferred habitat for some fish and macroinvertebrates, and important habitat for frogs, salamanders, water-dependent birds, some bat species, otter, mink, muskrat, beaver, and many other wetland-dependent species.

In addition to numerous biological benefits, these channels provide hydrological benefits during flood events. If these channels were allowed to close up, they would not be able to convey some of the flood water from the main channel. The greater energy from increased flow in the main channel would alter the dynamics of sediment movement and deposition, typically leading to greater bank erosion and increased lateral migration. Maintaining the healthy riparian areas associated with these secondary channels can further reduce flood water velocities by providing increased resistance or roughness. Riparian areas also collect debris and thus help prevent flood debris from being deposited on crop fields in the floodplain.

These secondary channels and ponds also provide water quality benefits. As water enters these areas it tends to infiltrate into the gravel and then emerge downstream in the lower portions of these side channels, backwaters, and main river channel. This process produces areas of clear water with attenuated temperature fluctuations. This in turn provides preferred or important refuge habitat for many fish and wildlife species.

SECTION 3

Fish Habitat Modeling

3.1 PHABSIM Study Objectives

The Physical Habitat Simulation (PHABSIM) modeling system was used to determine the incremental relationship between stream flow and an index of habitat suitability, referred to as weighted usable area (WUA) or area weighted suitability (AWS), for life stages of selected fish species and groupings (guilds) in the study area.

PHABSIM relies on collection of empirical hydraulic data, which are used in the calibration and computer simulation models, plus incorporation of fish species/life stage suitability criteria (also referred to as habitat suitability criteria [HSC]) for the major habitat component variables of velocity, depth, and substrate/cover. The AWS index can be interpreted in the context of stream hydrology and species life history to evaluate impacts, and serves as a partial basis for determining alternatives and mitigation. Since AWS does not represent actual physical area, it is more accurately described as an index that can be used comparatively to assess flow relationships with physical habitat.

The PHABSIM study objectives follow:

- Verify and/or develop habitat index-flow relationships (AWS) for selected life stages of target fish species or groupings of fish species (guilds)
- Provide a calibrated hydraulic data file for potential application to habitat suitability indices for subsequently identified fish species, habitat guilds, or fish passage needs
- Provide additional physical habitat information for application to other studies (such as riparian vegetation, water quality, recreational boating, or substrate particle incipient motion analyses) that may be part of the instream flow assessment

3.2 Study Area and Reach Boundaries

The geographic scope of the study area includes the state-designated "Scenic" section of the Illinois River, including Barren Fork and Flint Creeks, which are also designated as Scenic (Figure 3-1). The Illinois River study area extends from the Arkansas state boundary downstream to the confluence with Barren Fork Creek. The 2-mile section of the Illinois River from Barren Fork Creek to Tenkiller Ferry Reservoir, and the 9-mile section below Tenkiller Dam to the Arkansas River confluence are not part the study area. Flint Creek is included upstream to the Arkansas state line. The Barren Fork Creek study area (Scenic reach) extends from its confluence with the Illinois River upstream to the Highway 59 Bridge, which is approximately 7 miles from the Arkansas border. The upper Illinois River and these sections of the two tributaries were designated as Scenic Rivers per the OSRA of 1970 (82.0 Sections 1451-1471).

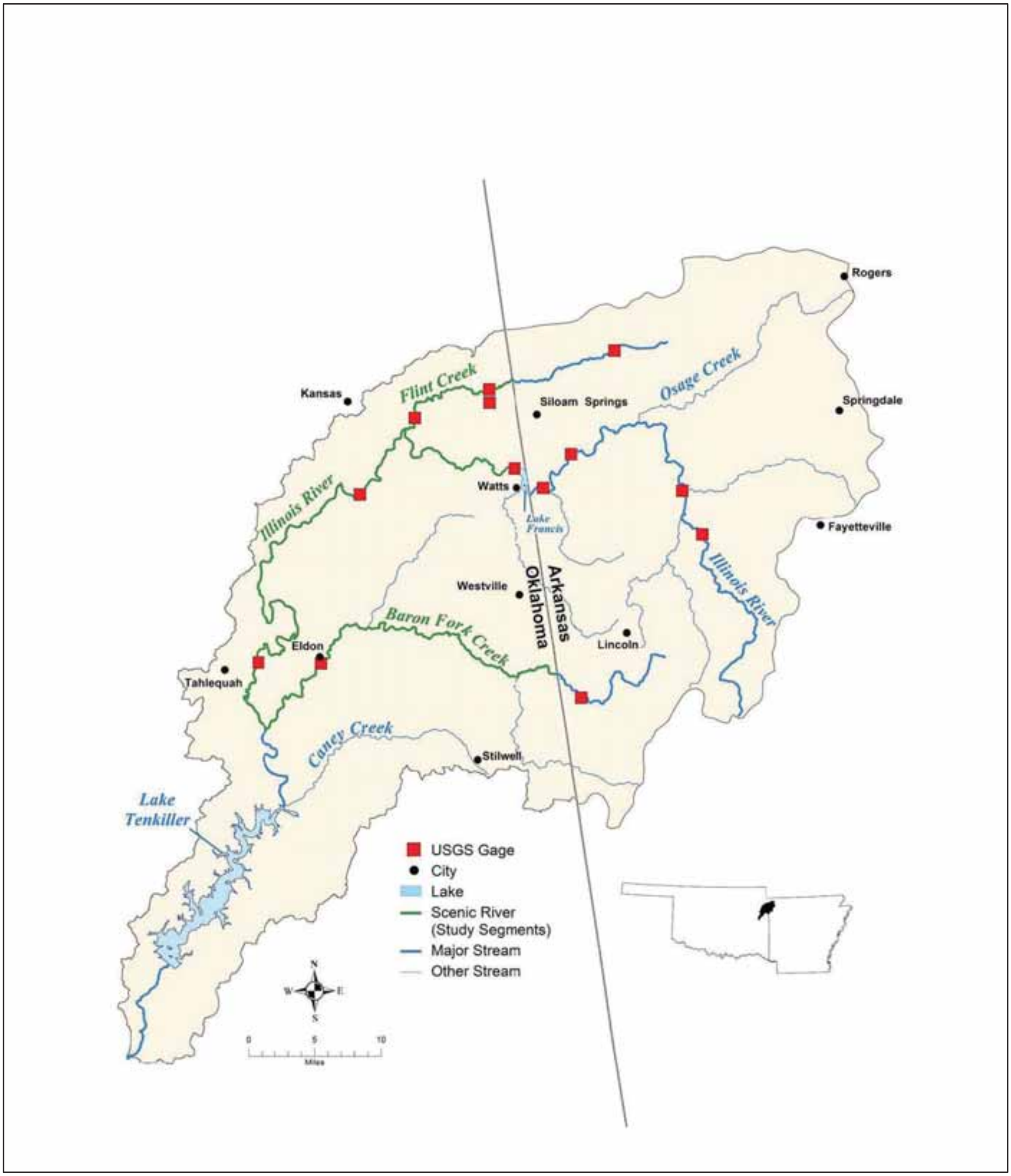


Figure 3-1. Illinois River Study Area

The gradient of the 63-mile study area along the Illinois River is consistent at 4.5 feet/mile (ft/mi). Barren Fork Creek has a gradient of approximately 8 ft/mi. The gradient in the lower 10 miles of Flint Creek is constant at about 10 ft/mi but increases to 16 ft/mi in the upper 4 miles of stream nearest the Arkansas border.

Manmade features and structures that significantly affect flows, such as diversion dams, storage dams, and return flows points, can also constitute reach boundaries, and operation of these facilities is frequently the focus of an instream flow study. No major flow-modification structures occur in the Illinois River study area. The reservoir behind Frances Dam, which spans the Illinois River near Watts, Oklahoma by the Arkansas border, provides no active water storage, although the town of Siloam Springs in northwestern Arkansas withdraws some water from the reservoir for municipal supply.

The Illinois River study area was divided into two reaches based on these considerations:

1. Lower reach from the confluence with Barren Fork Creek upstream to the confluence with Flint Creek
2. Upper reach from the Flint Creek confluence upstream to the Oklahoma-Arkansas state boundary near Watts

The lower reach of the Illinois River is 48 miles long, which is longer than a typical single reach for a PHABSIM application. Prior to field data collection, it was decided to focus the study on a 21-mile section in the lower reach because this area best represents the entire reach, and includes the Illinois River section most used for recreational boating.

The study area for Flint Creek was limited to the lower 2 miles of the stream. The intent of this study is to recommend flows that could potentially be used as guidelines in protecting the stream resources; therefore, it makes sense that those flows be quantified toward the lower end of the reaches assuming that is where flow compliance would be measured.

3.3 Methods

3.3.1 Habitat Mapping

Habitat mapping provides an overall instream mesohabitat (such as pools, runs, glides, and riffles) representation of each stream reach in the study area. Results of habitat mapping aids in transect selection were used for habitat weighting in reaches where fish habitat modeling was completed. The following habitat types and definitions were used for mapping in the study area:

- **Pool** - Scour areas within the stream channel with column velocities usually less than 1 foot per second (fps). Pools also generally lack surface agitation and commonly contain eddies or other slow water areas along one or both banks.
- **Run** - Swift flow areas with little surface agitation and no major flow obstructions. Runs may occur at heads or tails of pools. Between hydraulic controls, they may appear as flooded riffles and might contain some waves. Mean column velocities generally exceed 1 fps.
- **Glide** – Generally wide uniform channels with no flow obstructions, no surface agitation, and low velocities. Glides may occur at tails of pools. Substrate usually consists of cobble, gravel, and sand. Glides and runs are often combined as their differences are largely a function of stream flow.
- **Riffle** – Shallow areas with swiftly flowing, turbulent water often with some partially exposed substrate with a gradient less than 4 percent. Riffles are usually dominated by cobble or gravel substrate.

Mapping was conducted by canoe in the Illinois River and on foot in Flint Creek. Individual mesohabitat types were identified and habitat boundaries were delineated by breaks in stream channel slope, depth, or hydraulic controls. Boundaries were marked using handheld global positioning system (GPS) units. In long habitat units, additional GPS coordinates were taken to account for bends in the river. The minimum demarcated length of a habitat unit was generally limited to the width of the wetted stream channel unless they were of significance or rare, such as riffles. Habitat units with characteristics of more than one habitat type were identified with a sub-type (such as run/glide and run/riffle); however, only the primary type was used in calculating habitat type totals and percentages. Split channels and secondary flow channels were identified, although high flow channels were often not recognizable from the main channel because debris or vegetation obstructed the view.

Final habitat unit lengths were calculated and recorded in a spreadsheet, with a formula applied to the lengths that determines the distance between two GPS coordinates.

3.3.2 Study Site and Transect Selection/Placement

The primary goal of the study site and transect selection was to locate habitats units (pool, riffle, run) that are representative of those occurring throughout the study reach. The number of one-dimensional (1D) transects needed to adequately model hydraulics and produce a habitat index is dependent on habitat complexity, number of habitat types present, and general preferences of the aquatic species and life stages under study. Payne et al. (2004) determined that 18 to 20 transects will produce a robust habitat index function that differs little from results based on 40 to 70 transects, assuming all strata (habitat types) are sampled in relative proportion to the total, and the extent of hydraulic characteristics are included. Habitat index functions for this study were developed using generic criteria for a range of velocities and depths (shallow/fast, shallow/slow, deep/fast, and deep/slow) to include all potential aquatic microhabitat uses. As few as 10 transects can provide suitable results in less complex and uniform stream channels, though at a minimum two transects should represent each mesohabitat type, particularly those occurring infrequently. With these guidelines, each study reach was represented by 15 to 20 transects.

For this study, the lowest available habitat type by percentage was used to locate study sites. Access and logistical needs associated with collecting data at the sites were also considered. The number of transects established at a single site was dependent on the distribution of types in the immediate vicinity upstream and downstream of the selector habitat unit. Identifying and establishing a single site per study reach is not necessary and, in fact, not commonly done. Each study site consisted of all mesohabitat types where the transects were clustered. At least two of each major mesohabitat type were included in a reach. In some cases, particularly for pools, two or three transects were placed within a single habitat unit.

3.3.3 Data Collection

3.3.3.1 Calibration Flows

The flows at which field data were collected were based on predetermined target flows for calibrating the PHABSIM hydraulic models and identified considering water availability, physical safety, and preferred flow range for habitat analysis. The target high flows indicated in Table 3-1 correspond to the approximate mean annual flow for the lower section of each stream reach. This range should provide ample coverage of the flows that might be considered for fish habitat protection. The results of the PHABSIM model for the Barren Fork Creek (Fisher and Remshardt 2000) showed that maximum habitat occurred at flows (50 to 100 cubic feet per second [cfs]) considerably less than mean annual flow (330 cfs). These results suggest that the velocity calibration flows can be considerably less than those indicated in Table 3-1. This finding provided some flexibility in scheduling field work in the uncontrolled Illinois River.

Table 3-1. Target Calibration Flows by Reach for the Illinois River Instream Flow Study

River Reach	Target Calibration Flow (cfs)		
Lower Illinois	220	450	**900**
Upper Illinois	150	300	**600**
Flint Creek	25	50	**100**

Bold numbers indicate velocity data acquisition flow.

3.3.3.2 Field Techniques

Field data collection and recording followed the guidelines established in the Instream Flow Group (IFG) field techniques manuals (Trihey and Wegner 1981; Milhous et al. 1984; Bovee 1997). The following additional quality control checks were included:

- Rebar or spikes were place on each bank of each transect to serve as reference elevation points and working pins for measuring distances across transects.
- An independent benchmark was established for each transect or set of transects. This benchmark was an immovable tree, boulder, or other naturally occurring object that would not be subject to tampering, vandalism, or movement. Upon establishment of pin elevations, a level loop was shot to check the auto-level for measurement accuracy and verify measured elevations. Allowable error tolerances on level loops were set at 0.02 foot. This tolerance is also applicable unless extenuating circumstances (such as pins under sloped banks or shots through dense foliage) explain discrepancies and the accompanying pin elevation is free of excessive error.
- Temporary staff gages were established and continually monitored throughout the course of collecting data on each transect. If significant changes occur, water surface elevations were remeasured following collection of transect water velocity measurements.
- A minimum of two water surface elevations, one on each bank, were measured across each transect at each flow. The more complex and uneven the water surface transect is, the greater the number of measurements required. For example, a riffle transect may require more frequent water surface measurements, while pool and glide transects may require only two.
- All pin elevations and water surface elevations were calculated during field measurement and compared to previous measurements, if any. Stage change patterns were compared between transects and determined, if reasonable. If discrepancies were discovered, potential sources of error were explored and noted.
- Photographs were taken of all transects from downstream, across, and upstream at the measured flows. Photographs were taken from the same location at each flow level when possible. These photographs provided a record of the streamflow conditions (including velocity and depth), water surface levels, and channel configurations that may require confirmation during hydraulic model calibration.

3.3.3.3 Velocity Measurements

Most velocity measurements in the Illinois River were collected using a Teledyne RD Instruments Rio Grande Acoustic Doppler Current Profiler (ADCP). The ADCP gathers both depth and velocity information at very small steps, laterally and vertically, across each transect. The ADCP unit was operated by boat with the unit encased in an Ocean Sciences Trimaran Riverboat, and attached to the side of the vessel. When operated from shore, the trimaran was hauled back and forth across the channel with ropes and kept on line with tension. The operator views real-time data through a wired or radio modem connection between the ADCP and a computer. Because the ADCP can only accurately measure to a depth of approximately 1 foot, edge cell measurements were obtained by wading to complete the velocity patterns in shallow areas for each transect.

For those stations or transects requiring a handheld meter, the standard method for determining mean column velocity will be a single measurement at 0.6 of the water depth in depths less than 2.5 feet, and a 0.2 and 0.8 measurement for depths between 2.5 feet and 4.0 feet. Electromagnetic Marsh-McBirney flowmeters attached to 4-foot wading rods were used for locations not suited for the ADCP.

3.3.3.4 Transect Substrate and Cover Coding

During field data collection, the low flow, bottom substrate, and cover (if present) were identified and recorded across each transect. Stations (offset) were noted where substrate composition changed. In areas too deep for wading, a GPS unit was used to delineate changes in substrate composition. Distances between the coordinates were later calculated to locate the correct stationing. Substrate composition was noted by percentage of substrate categories at each location. These descriptive substrate/cover categories were converted to numerical codes for modeling purposes as was used by Fisher and Remshardt (2000) on the Barren Fork Creek study (Table 3-2).

Table 3-2. Categories of Substrate and Cover and their Codes used in the Barren Fork Creek Instream Flow Simulation

Category	Code
Substrate	
Detritus	1
Vegetation flocculation	2
Clay (0.0005-0.004 mm)	3
Silt (0.004-0.0625 mm)	4
Sand (0.0625-2 mm)	5
Small gravel (2-8 mm)	6
Medium gravel (8-16 mm)	7
Large gravel (16-64 mm)	8
Small cobble (64-128 mm)	9
Large cobble (128-256 mm)	10
Boulder (>256 mm)	11
Bedrock (slab)	12
Bedrock (fractured)	13
Cover	
None	0
Undercut bank	1
Bedrock (fractured)	2
Log	3
Tree root wad	4
Aquatic vegetation	5
Boulder	6

Source: Fisher and Remshardt 2000.
mm = millimeters

3.3.4 Hydraulic Simulation

3.3.4.1 Software

PHABSIM was originally developed and maintained by the U.S. Fish and Wildlife Service Instream Flow Group (now USGS, Aquatic Systems and Technology Application Group, Fort Collins Science Center). PHABSIM calculates a habitat index in part based on simulation of river depths and velocities from 1D hydraulic models that represent the river by cross-sections.

For 1D applications in this study, the hydraulic models and habitat index simulations were derived from the System for Environmental Flow Assessment (SEFA) computer program. SEFA was developed jointly by originators of the primary models used in instream flow studies, Bob Milhous (PHABSIM), Tom Payne (RHABSIM), and Ian Jowett (RHYHABSIM), and merges and expands the capabilities of these software programs. Primary upgrades include the addition of a second velocity calibration algorithm, sediment transport, and reach temperature and dissolved oxygen models.

The ADCP uses its proprietary software (WinRiver by RD Instruments) for data acquisition and playback. Because the ADCP collects water velocities throughout the water column at relatively short intervals, the output was synthesized and condensed into a form usable by PHABSIM software. For this task, an ADCP conversion program allowed the user to interactively view bottom profiles and velocity patterns and establish stationing, which can then be directly entered into the hydraulic programs.

3.3.4.2 Stage-Discharge Calibration

Unforeseen circumstances (extreme flooding) allowed collection of only two stage-discharge pairs on transects in the lower Illinois River and Flint Creek. One set of points included velocity data acquisition so that modeling could be performed. In most PHABSIM models stage-discharge relationships for each transect are developed using empirical log/log formula (IFG-4), or a hydraulic channel conveyance method. Under both methods each transect is treated independently to develop rating curves. The IFG-4 method generally requires a minimum of three sets of stage-discharge measurements and an estimate of stage-at-zero-flow (SZF) for each transect. The stage-discharge relationship quality is evaluated by examining the mean error and slope output from the model; however, with only two data points mean error could not be calculated.

Channel conveyance only requires a single stage-discharge pair and uses channel shape, depth, and the Manning's equation to determine a stage-discharge relationship (Bovee and Milhous 1978); however, it is generally validated by additional stage-discharge measurements. In situations where irregular channel features occur on a cross section, such as bars or terraces, hydraulic channel conveyance is often better at predicting higher stages than IFG-4. Conveyance is most often used on riffle or run transects, and is generally not applicable for transects with backwater effects from downstream controls, such as pools. The method can also be used as a test and verification of IFG-4 relationships.

3.3.4.3 Velocity Calibration

A 1D model represents a stream by means of vertical slices (transects) across the channel. Depths are simulated with the rise and fall of a single, level (in most cases) water surface. For simulating water velocities, the "one-flow" option was used. This technique uses a single set of measured velocities to predict individual cell velocities over a range of flows. Simulated velocities are based on measured data and a relationship between a fixed roughness coefficient (Manning's n) and depth. In some cases, roughness was modified for individual cells if substantial velocity errors were noted at simulation flows. Velocity adjustment factors (VAFs) were examined to detect significant deviations and determine if velocities remained consistent with stage and total discharge.

3.3.5 Target Species and Habitat Suitability Criteria

An important component of an instream flow study is the selection of target species and their corresponding HSC that typically describes the relative suitability of water depth, water velocity, stream substrate, and cover types for the fish species and life stages of interest in the study area.

Historically, PHABSIM has been used to describe fish habitat-flow relationships for specific target species, often those considered as important game species or designated species of concern. Including these species in an instream flow study also helps with the public acceptance of the study. In the Illinois River system, the smallmouth bass is the most sought after and harvested game fish, has been the focus of numerous PHABSIM studies throughout the country, and was included in the Barren Fork Creek instream flow study (Fisher and Remshardt 2000). Review of the HSC developed for smallmouth bass in Barren Fork Creek indicates that those criteria would be well suited for application to the Illinois River and Flint Creek PHABSIM. The streams are in the same river basin, share similar geomorphic characteristics (gradient, substrate) and hydrologic patterns, and support a similar fish community.

The Illinois River system supports over 60 species of fish, and each species and its life stage has a wide range of habitat needs. Defined habitat criteria (depth, velocity, and substrate) suitable for PHABSIM analysis are not available for most of these species. Therefore, to facilitate this many species in a habitat analysis, the species are categorized into habitat-use guilds, or assemblages (groups of fish that occupy similar habitats) (Leonard and

Orth 1988). This approach was also used in the Barren Fork Creek instream flow study where HSC were developed from fish-use data collected in that stream (Fisher and Remshardt 2000). Data analysis identified three habitat-use assemblages defined as shallow-fast (riffles), intermediate, and deep-slow (pools). These categories and their associated attributes (depth, velocity) are comparable to those developed in other stream systems (Leonard and Orth 1988; Bain and Knight 1996).

Assignment of most of the Illinois basin fish species to the three habitat assemblages is presented in Table 3-3. These assignments are based on those provided in Fisher and Remshardt (2000) for fish species identified in Barren Fork Creek. The deep-slow (pool) assemblage represents about half of the species, and include most of the sunfish and sucker species. The two most commonly observed species in the basin, cardinal shiner and central stoneroller (see Table 2-8), were placed in the intermediate assemblage. The shallow-fast (riffle) assemblage includes most of the darter species, which are also commonly observed throughout the basin.

Table 3-3. Common Names of Fish Species Found in the Illinois River Basin Associated with Key Habitat-Use Assemblages.

Habitat-Use-Assemblage		
Shallow - Fast	**Intermediate**	**Deep - Slow**
Stippled darter Orangethroat darter Redfin darter Banded darter Blackstripe topminnow Blackspotted topminnow Mosquitofish Banded sculpin Slender madtom	Stoneroller Northern hogsucker Bigeye chub Redspot chub Creek chub Rosyface shiner Cardinal shiner Ozark minnow Greenside darter	Black redhorse Golden redhorse Shorthead redhorse White sucker Spotted sucker Black bullhead Yellow bullhead Channel catfish Brook silversides Green sunfish Warmouth sunfish Redear sunfish Largemouth bass Smallmouth bass Rock bass Bluegill sunfish Longear sunfish White crappie Logperch Gizzard shad Common carp

Source: Fisher and Remshardt 2000.

The Barren Fork Creek HSC used in this study are presented in Tables 3-4 and 3-5 and on Figures 3-2 through 3-6. Habitat quality is classified as optimal, usable, and suitable. The optimal range contained the central 50 percent of the observations and is given a normalized suitability index of 1.0 in following the formula:

$$NSI=2(1-P)$$

where:

NSI = the normalized suitability index
P = the proportion of the population under the curve (50, 75, and 95 percent ranges)

Optimal habitat encompasses the central 50 percent (NSI=1.0), usable habitat encompasses the broader central 75 percent (NSI=0.5) of the observations, and the broadest range of habitat suitability contains the observations within the 95 percent (NSI=0.1) range (Bovee 1986).

Table 3-4. Habitat Suitability Criteria for Juvenile and Adult Smallmouth Bass

Habitat Quality Category	Habitat variable	
	Juvenile	Adult
Depth (cm)		
Optimal	35-115	55-155
Usable	15-135	25-180
Suitable	5-150	5-200
Velocity (cm/s)		
Optimal	25-80	10-30
Usable	10-95	5-35
Suitable	0-105	0-40
Substrate (code)		
Optimal	7	8
Usable	7,8	6,8,11
Suitable	4,6-9	4,6-12
Cover (code)		
Optimal	1	4
Usable	1,4,5	1,4,6
Suitable	0,1,3-6	0,1,3,4,6

Source: Fisher and Remshardt 2000.

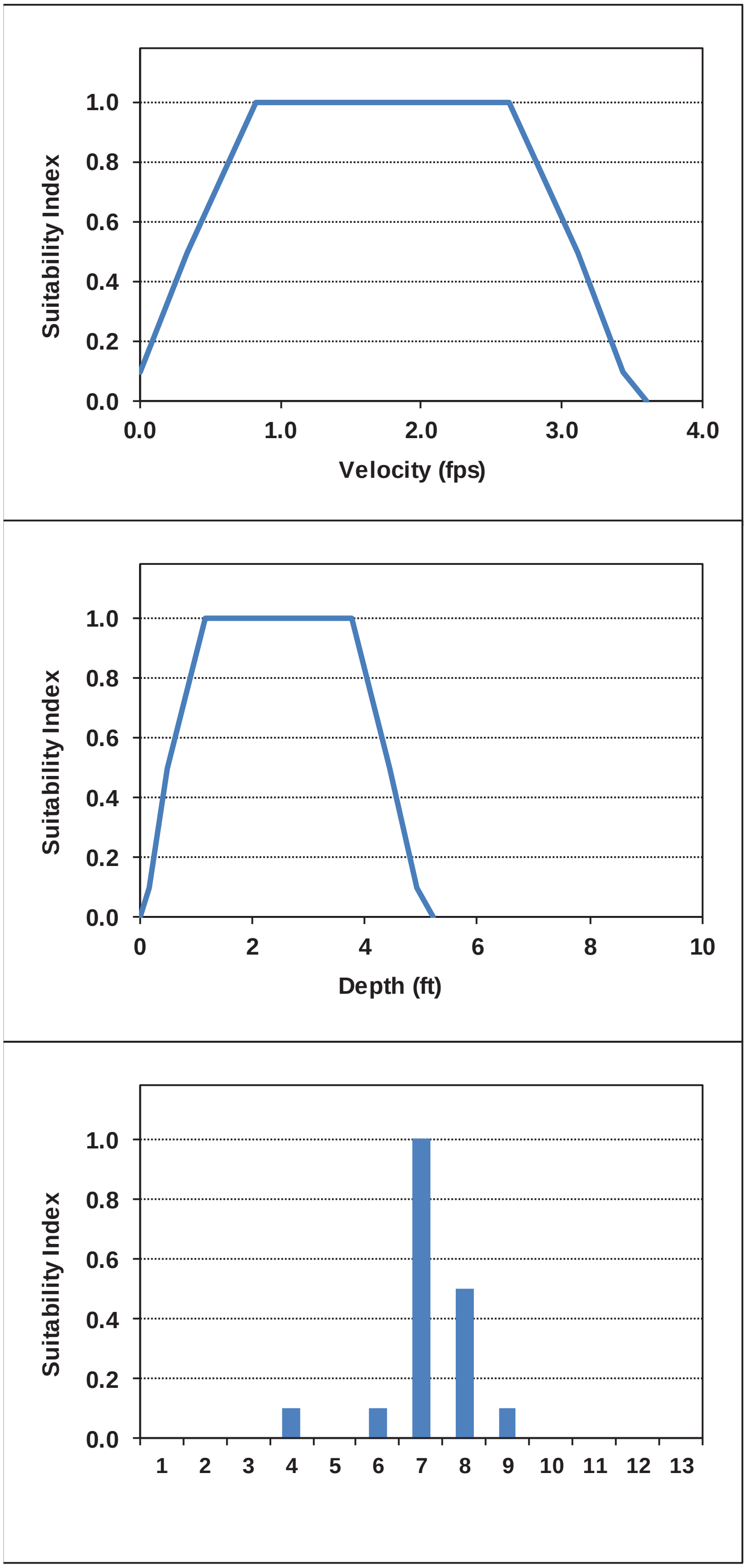
cm = centimeters
cm/s = centimeters per second

Table 3-5. Habitat Suitability Criteria for Shallow-fast, Intermediate, and Deep-slow Habitat-use Assemblages

Habitat Quality Category	Habitat variable		
	Shallow-fast	Intermediate	Deep-slow
Depth (cm)			
Optimal	10-25	25-60	55-110
Usable	10-45	15-80	40-145
Suitable	5-60	5-115	25-200
Velocity (cm/s)			
Optimal	10-45	5-25	0-5
Usable	5-55	5-40	0-10
Suitable	0-85	0-80	0-25
Substrate (code)			
Optimal	1, 2, 5, 10, 13-15	1, 2, 5, 10, 13-15	1, 2, 5, 10, 13-15
Usable	1, 2, 4-15	1, 2, 4-15	1, 2, 4-15
Suitable	1, 2, 4-15	1, 2, 4-15	1, 2, 4-15
Cover (code)			
Optimal	0-3	0-3	0-4
Usable	0-3	0-4	0-6
Suitable	0-5	0-6	0-6

Source: Fisher and Remshardt 2000.

Smallmouth Bass Juvenile



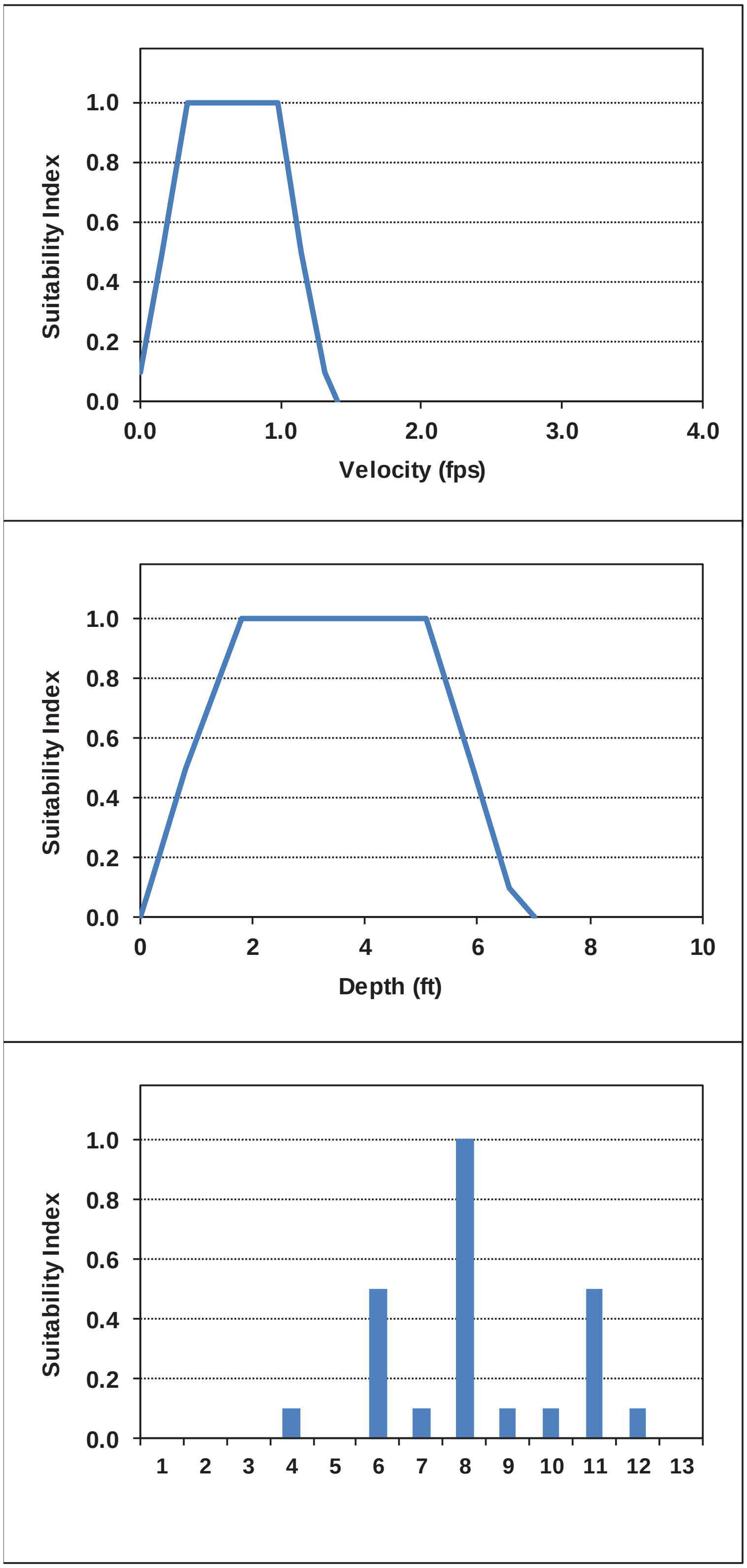
Velocity (ft/s)	SI
0.00	0.10
0.33	0.50
0.82	1.00
2.62	1.00
3.12	0.50
3.44	0.10
3.60	0.00

Depth (ft)	SI
0.00	0.00
0.16	0.10
0.49	0.50
1.15	1.00
3.77	1.00
4.43	0.50
4.92	0.10
5.20	0.00

Substrate Code	SI
1	0.00
2	0.00
3	0.00
4	0.10
5	0.00
6	0.10
7	1.00
8	0.50
9	0.10
10	0.00
11	0.00
12	0.00
13	0.00

Figure 3-2. Smallmouth Bass Juvenile HSC for Velocity, Depth, and Substrate

Smallmouth Bass Adult



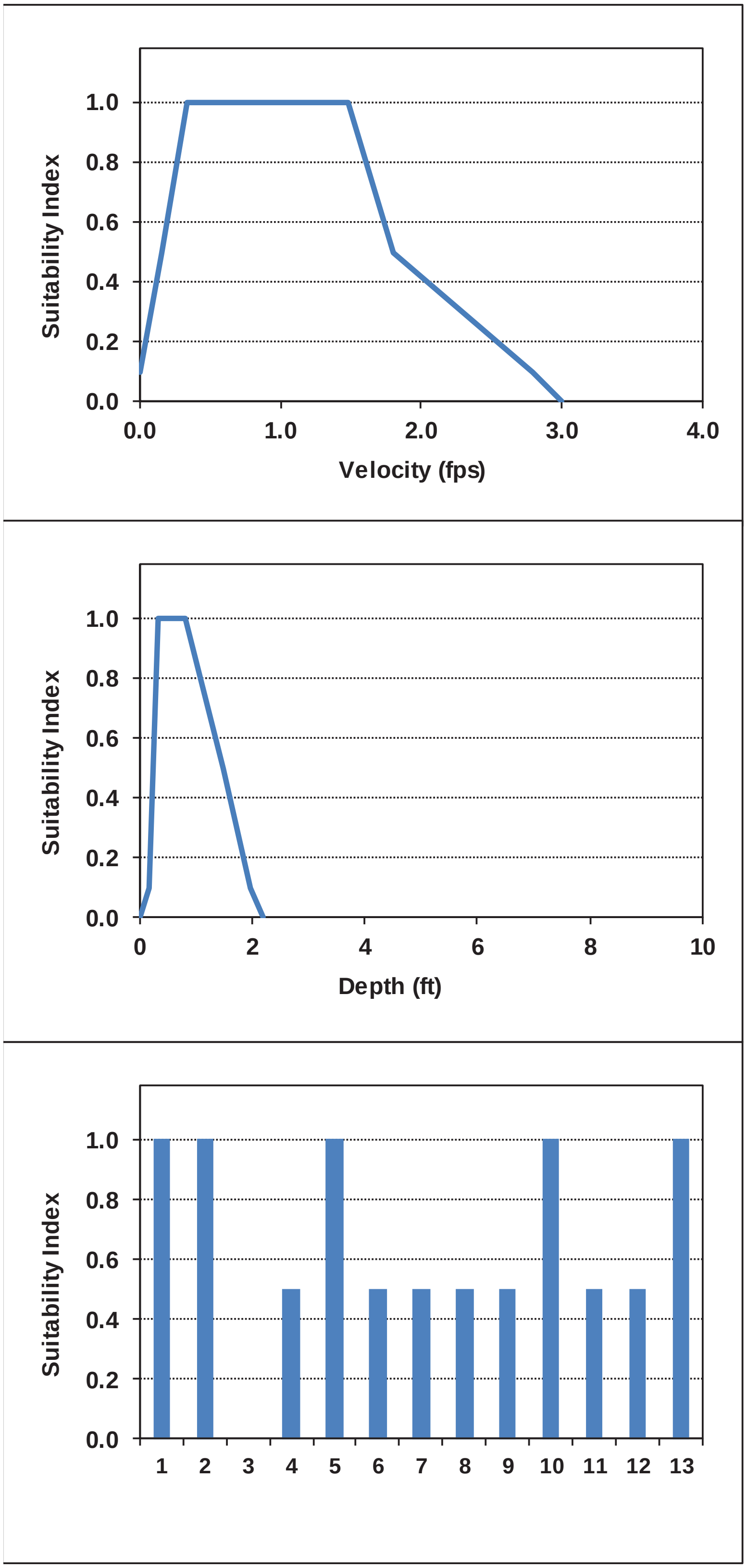
Velocity (ft/s)	SI
0.00	0.10
0.16	0.50
0.33	1.00
0.98	1.00
1.15	0.50
1.31	0.10
1.40	0.00

Depth (ft)	SI
0.00	0.00
0.16	0.10
0.82	0.50
1.80	1.00
5.09	1.00
5.91	0.50
6.56	0.10
7.00	0.00

Substrate Code	SI
1	0.00
2	0.00
3	0.00
4	0.10
5	0.00
6	0.50
7	0.10
8	1.00
9	0.10
10	0.10
11	0.50
12	0.10
13	0.00

Figure 3-3. Smallmouth Bass Adult HSC for Velocity, Depth, and Substrate

Shallow-Fast



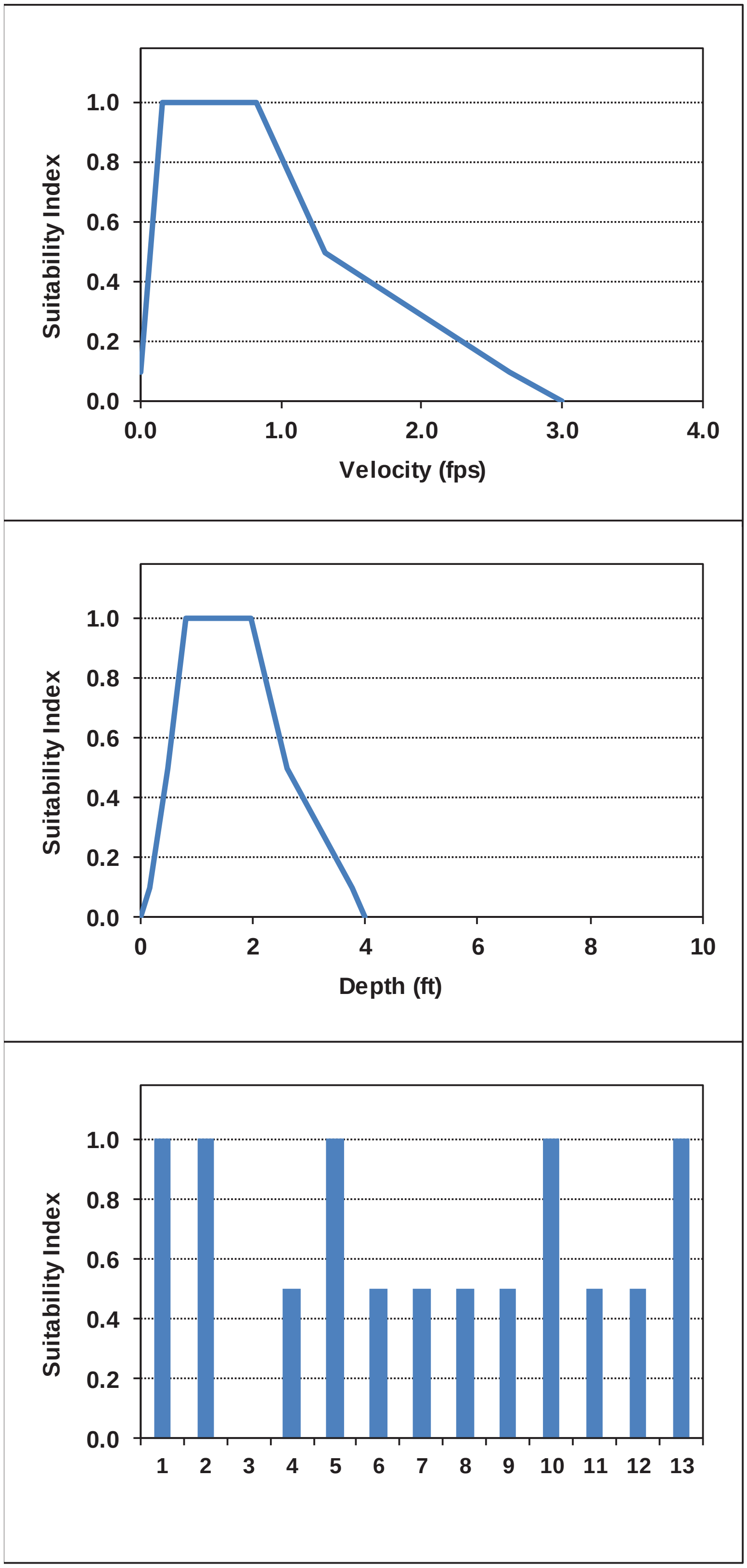
Velocity (ft/s)	SI
0.00	0.10
0.16	0.50
0.33	1.00
1.48	1.00
1.80	0.50
2.79	0.10
3.00	0.00

Depth (ft)	SI
0.00	0.00
0.16	0.10
0.33	1.00
0.82	1.00
1.48	0.50
1.97	0.10
2.20	0.00

Substrate Code	SI
1	1.00
2	1.00
3	0.00
4	0.50
5	1.00
6	0.50
7	0.50
8	0.50
9	0.50
10	1.00
11	0.50
12	0.50
13	1.00

Figure 3-4. Shallow-fast Fish Assemblage HSC for Velocity, Depth, and Substrate

Intermediate



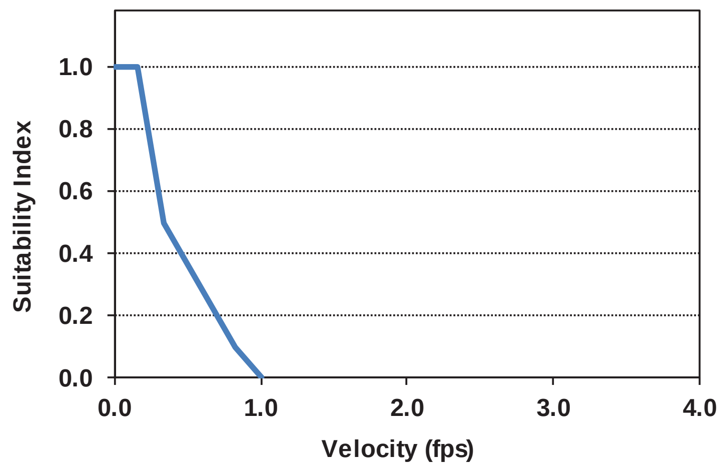
Velocity (ft/s)	SI
0.00	0.10
0.16	1.00
0.82	1.00
1.31	0.50
2.62	0.10
3.00	0.00

Depth (ft)	SI
0.00	0.00
0.16	0.10
0.49	0.50
0.82	1.00
1.97	1.00
2.62	0.50
3.77	0.10
4.00	0.00

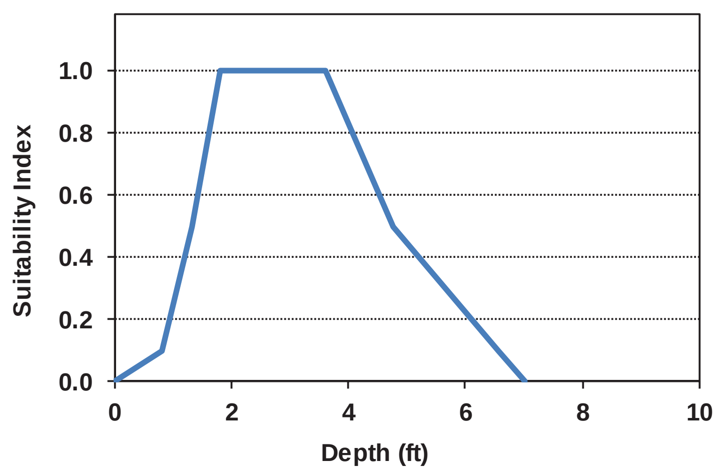
Substrate Code	SI
1	1.00
2	1.00
3	0.00
4	0.50
5	1.00
6	0.50
7	0.50
8	0.50
9	0.50
10	1.00
11	0.50
12	0.50
13	1.00

Figure 3-5. Intermediate Fish Assemblage HSC for Velocity, Depth, and Substrate

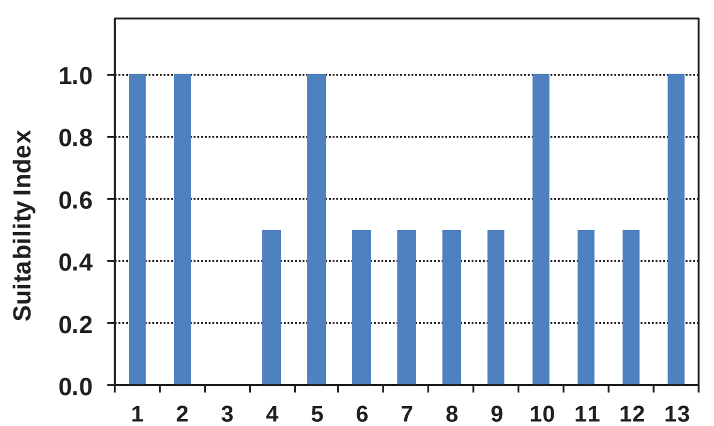
Deep-Slow



Velocity (ft/s)	SI
0.00	1.00
0.16	1.00
0.33	0.50
0.82	0.10
1.00	0.00



Depth (ft)	SI
0.00	0.00
0.82	0.10
1.31	0.50
1.80	1.00
3.61	1.00
4.76	0.50
6.56	0.10
7.00	0.00



Substrate Code	SI
1	1.00
2	1.00
3	0.00
4	0.50
5	1.00
6	0.50
7	0.50
8	0.50
9	0.50
10	1.00
11	0.50
12	0.50
13	1.00

Figure 3-6. Deep-slow Fish Assemblage HSC for Velocity, Depth, and Substrate

3.3.6 Physical Habitat Simulation

Once the hydraulic data are calibrated through standard methods, AWS by discharge is generated. The range of flows included in the habitat simulations was determined by the calibration flows obtained in the field and by the suitability of the hydraulic data for extrapolation. The hydraulic and HSC data were used to generate AWS relationships for Smallmouth Bass juvenile and adult and species guilds in the lower Illinois River and Flint Creek. A cell's suitability is calculated by multiplying the individual variable suitabilities (depth, velocity, and substrate/cover) at the center of each cell. The suitability of all the cells within each transect are added together to calculate the habitat for each transect. Reach habitat is computed by applying weighting factors to each transect and summing the result.

Confidence limits can be calculated for AWS predictions using bootstrapping with random selection within each habitat type. Confidence limits indicate the range that can be placed on an AWS value at a particular flow, assuming that cross sections have been randomly selected within each stratum. The cross-section weights (as determined by habitat mapping) are used to determine the cross-section combinations that are randomly selected. For example, if there are run, riffle, and pool cross sections, AWS will be calculated for randomly selected cross sections of each habitat type. It is assumed that the cross-section weights for each habitat type are different. If they are the same, it will be assumed that they represent the same habitat type.

These statistical confidence limits reflect the variability in cross-section properties and do not address all uncertainties in instream habitat modeling. Results are presented by displaying error bars on AWS values graphically.

3.4 Results

3.4.1 Habitat Mapping

Habitat mapping was conducted under flow conditions that allowed visual habitat type distinction (Table 3-6). Habitat mapping summaries are presented for the lower Illinois River (Table 3-7), upper Illinois River (Table 3-8), and Flint Creek (Table 3-9).

Table 3-6. Habitat Mapping Date and River Flow in Three River Reaches used for the Illinois River Instream Flow Study

River Reach	Date	Flow (cfs)
Lower Illinois River	September 29-30, 2015	280-289
Upper Illinois River	October 5, 2015	193
Flint Creek	September 28, 2015	44

Pool was the overall dominant habitat type in the lower Illinois River accounting for over 50 percent, followed by run (23 percent), glide (12 percent) and riffle (8 percent). A similar mesohabitat distribution was found in the upper Illinois River, though pool accounted for a larger percentage and run slightly less. Mapping on Flint Creek was conducted in the lower 1.6 miles, upstream of the confluence with the Illinois River. Pool was again the dominant habitat type (35 percent) followed by riffle (25 percent) with relatively equal amounts for run and glide. The lower 0.3 mile, composed of heavily braided channels through large gravel bars, accounted for 40 percent of all riffle habitat in Flint Creek.

Table 3-7. Habitat Mapping Summary for the Lower Illinois River

Habitat Type	Count	Length (feet)	% Length
Pool	79	62,016	56
Glide	31	13,907	12
Run	59	26,089	23
Riffle	38	9,464	8
Total	**207**	**111,477**	**100**

Table 3-8. Habitat Mapping Summary for the Upper Illinois River

Habitat Type	Count	Length (feet)	% Length
Pool	33	24,609	62
Glide	10	3,793	10
Run	24	7,063	18
Riffle	16	4,004	10
Total	**83**	**39,470**	**100**

Table 3-9. Habitat Mapping Summary for Flint Creek

Habitat Type	Count	Length (feet)	% Length
Pool	14	2,994	35
Glide	7	1,709	20
Run	11	1,736	20
Riffle	15	2,108	25
Total	**47**	**8,548**	**100**

3.4.2 Study Site and Transect Selection/Placement

Prior to study site selection, the lower Illinois River was split into two segments, each of which was proposed to include 10 transects, to allow for study site separation and incorporate any potential habitat variability. Riffle habitat was used as a selector for locating study sites in the lower Illinois River for the following reasons:

1. Riffle habitat was the least available habitat type by percentage.
2. Of the 38 riffles identified, only 11 were considered suitable for modeling using transects. Those not judged suitable for modeling were either in braided channels, along cut banks, or transverse to the channel.

When the first suitable riffle was located, a study site was established. A transect was placed across that riffle and other transects were established in the immediate vicinity to represent other habitat types. This process continued until the predetermined number of transects were established (Table 3-10). Because only three riffles were needed, the fourth study site (Transects 15-20) was selected based on a combination of access and availability of the remaining habitat types. Four study sites with 4 to 6 transects each were established (Figures

3-7 and 3-8). The same process was used on the upper Illinois River where 16 transects were placed to represent that reach (Table 3-11).

Glide habitat was used as a selector for Flint Creek because glide and run were the least available habitat type, and there were only seven habitat units identified during mapping. A total of 15 transects were established in Flint Creek (Table 3-12 and Figure 3-9).

Table 3-10. Number of Transects by Habitat Type and Percent Representation Based on Habitat Mapping Results for the Lower Illinois River

Habitat Type	No. of Transects	Percent/Transect
Pool	9	6.2%
Glide	3	4.2%
Run	5	4.7%
Riffle	3	2.8%
Total	**20**	

Table 3-11. Number of Transects by Habitat Type and Percent Representation Based on Habitat Mapping Results for the Upper Illinois River

Habitat Type	No. of Transects	Percent/Transect
Pool	8	7.8%
Glide	2	4.8%
Run	4	4.5%
Riffle	2	5.1%
Total	**16**	

Table 3-12. Number of Transects by Habitat Type and Percent Representation Based on Habitat Mapping Results for Flint Creek

Habitat Type	No. of Transects	Percent/Transect
Pool	4	8.8%
Glide	3	6.7%
Run	4	5.1%
Riffle	4	6.2%
Total	**15**	

Figure 3-7. Location of Transects 1-10 in the Lower Illinois River between No Head Hollow and Echota

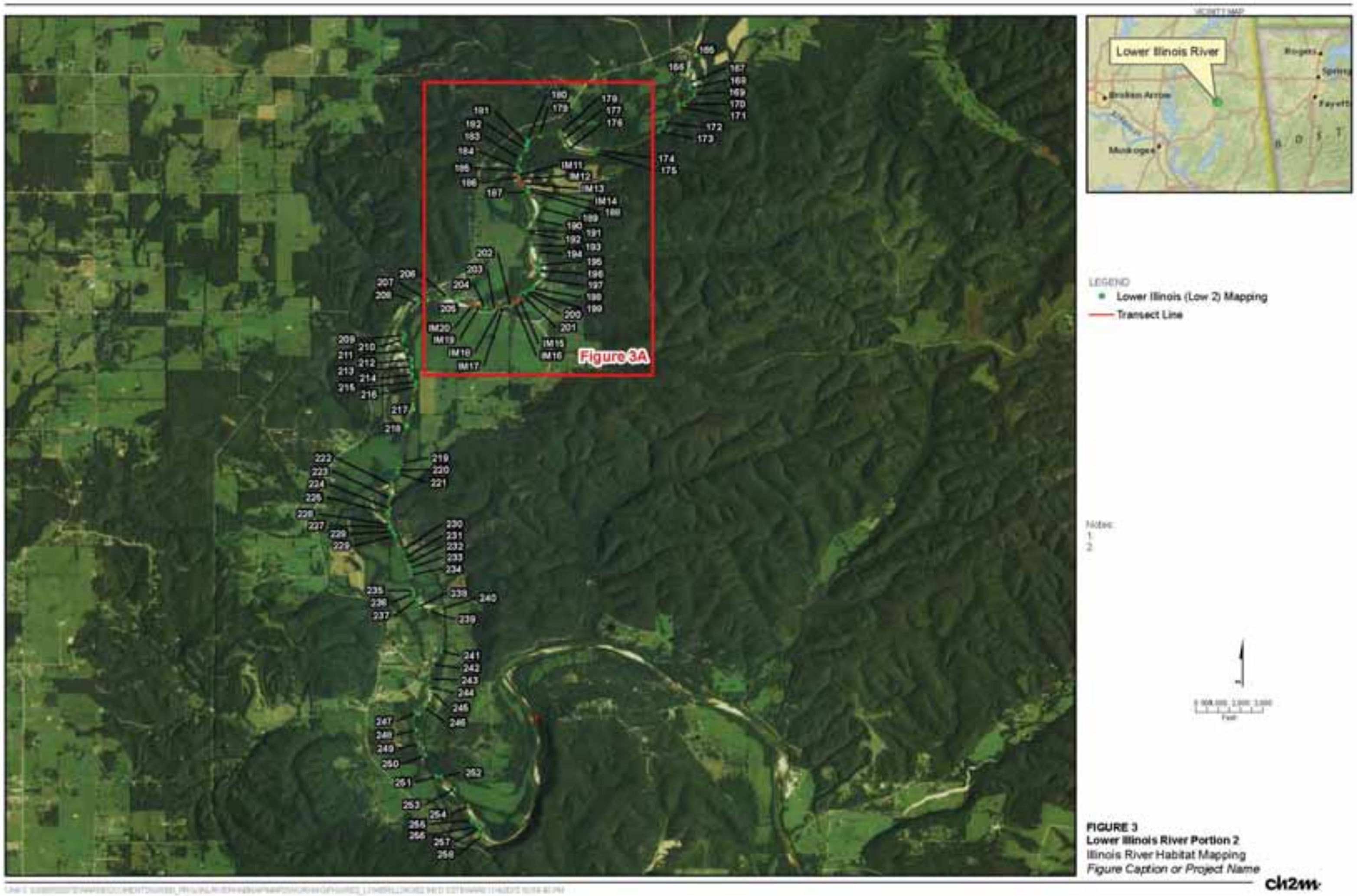


Figure 3-8. Location of Transects 11-20 in the Lower Illinois River between Peavine and No Head Hollow

Figure 3-9. Location of Transects 1-15 in Flint Creek

3.4.3 Data Collection

3.4.3.1 Measured Flows

Measured high calibration flows in the lower Illinois River and Flint Creek were within 5 percent of target flows (Table 3-13). Normally two additional measurements of water surface elevation for each transect and a single discharge measurement (per transect cluster) would be made at the remaining flow levels. Both low and high flows were measured on the lower Illinois River transects and Flint Creek. However, unforeseen and unprecedented flooding occurred in the basin in late December 2015, precluding any additional data collection.

Table 3-13. Measured Calibration Flows by Reach for the Illinois River Instream Flow Study

River Reach	Measured Flow (cfs) [a]		
	Low	Middle	High
Lower Illinois	272-282	NM	906-941
Upper Illinois	197	NM	NM
Flint Creek	NM	43	106

[a] High velocity acquisition flow
NM = not measured

Substrate coding was completed at low flow in the lower and upper Illinois River and at middle flow in Flint Creek. Bottom profiling (measuring elevations of out-of-water stations) was accomplished on all but four transects in Flint Creek. Time did not permit out-of-water elevation profiling beyond the high flow water line on the lower or upper Illinois River.

Complete sets of high flow velocities and depths were obtained on 18 of 20 transects in the lower Illinois River (Table 3-14) and 14 of 15 transects in Flint Creek (Table 3-15), using a combination of ADCP and wading measurements. In the lower Illinois River, equipment issues prevented measurement of two transects. In Flint Creek, one pool transect measurement was not completed because of channel changes caused by woody debris and bank collapse between middle and high flow.

Table 3-14. Measured High Flow and Wetted Width of Transects in the Lower Illinois River

Transect	Measured Flow (cfs)	Width (feet)
T1 - Pool	906.1	194.3
T2 - Pool	921.6	142.7
T3 - Riffle	961.6	198.0
T4 - Run	894.8	187.2
T5 - Pool	912.8	136.7
T6 - Pool	853.1	203.0
T7 - Pool	894.8	222.8
T8 - Glide	907.1	230.5
T9 - Riffle	NM	NM
T10 - Run	NM	NM
T11 - Glide	960.6	163.5

Table 3-14. Measured High Flow and Wetted Width of Transects in the Lower Illinois River

Transect	Measured Flow (cfs)	Width (feet)
T12 - Pool	967.8	134.2
T13 - Pool	955.7	158.7
T14 - Riffle	935.7	204.9
T15 - Run	937.8	106.3
T16 - Run	924.3	103.3
T17 - Run	941.6	141.4
T18 - Glide	910.2	154.4
T19 - Pool	939.8	135.2
T20 - Pool	902.2	164.2

NM = not measured

Table 3-15. Measured High Flow and Wetted Width of Transects in Flint Creek

Transect	Measured Flow (cfs)	Width (feet)
F1 –Run	104.6	54.6
F2 - Run	104.1	42.0
F3 - Riffle	107.1	40.1
F4 - Riffle	114.0	62.5
F5 - Pool	NM	NM
F6 - Pool	105.2	70.7
F7 - Glide	99.9	58.9
F8 - Riffle	110.3	32.0
F9 - Glide	103.1	66.0
F10 - Pool	108.9	45.6
F11 - Run	105.9	47.7
F12 - Pool	113.1	41.8
F13 - Glide	103.6	60.0
F14 - Run	101.0	44.9
F15 - Riffle	101.8	52.1

NM = not measured

3.4.4 Hydraulic Model Simulation

3.4.4.1 Stage-Discharge Calibration

Rating curves were developed for the lower Illinois River and Flint Creek using the two measured calibration flows. When using a 2-point rating curve with a SZF estimate, interpolation between the points and extrapolation down from the lowest measured flow is considered acceptable; however, extrapolation above the highest flow can be uncertain. Because both the log/log and channel conveyance methods produced very similar results, the final rating curves are considered suitable for modeling. As shown in the habitat modeling portion of the report, the highest habitat index values also tend to occur within the interpolation and low end extrapolation range of the curves.

One riffle transect in the lower Illinois River was calibrated using the channel conveyance method with a single stage-discharge pair because an adequate relationship could not be obtained using the lowest measured calibration flow. The resulting hydraulic rating curve was considered adequate, based on the comparison of rating curve slope to other transects.

3.4.4.2 Velocity Calibration

Velocity calibration involves examination of velocity simulation profiles and VAFs to detect significant deviations and determine if velocities remain consistent with stage and total discharge. Edge cells near the banks of a transect, even in riffles and runs, often have very low measured velocities (sometimes negative) caused by shallow depths and flow obstruction by substrate. Velocity adjustments were made to some of these points if simulation of higher flows showed unusual patterns. An example of this is shown on Figure 3-10, which shows an unadjusted velocity pattern with low negative velocities predicted across a shallow bar at high simulation flows. The adjusted pattern is more realistic and allows velocities to increase across the same bar as flows increase (Figure 3-11).

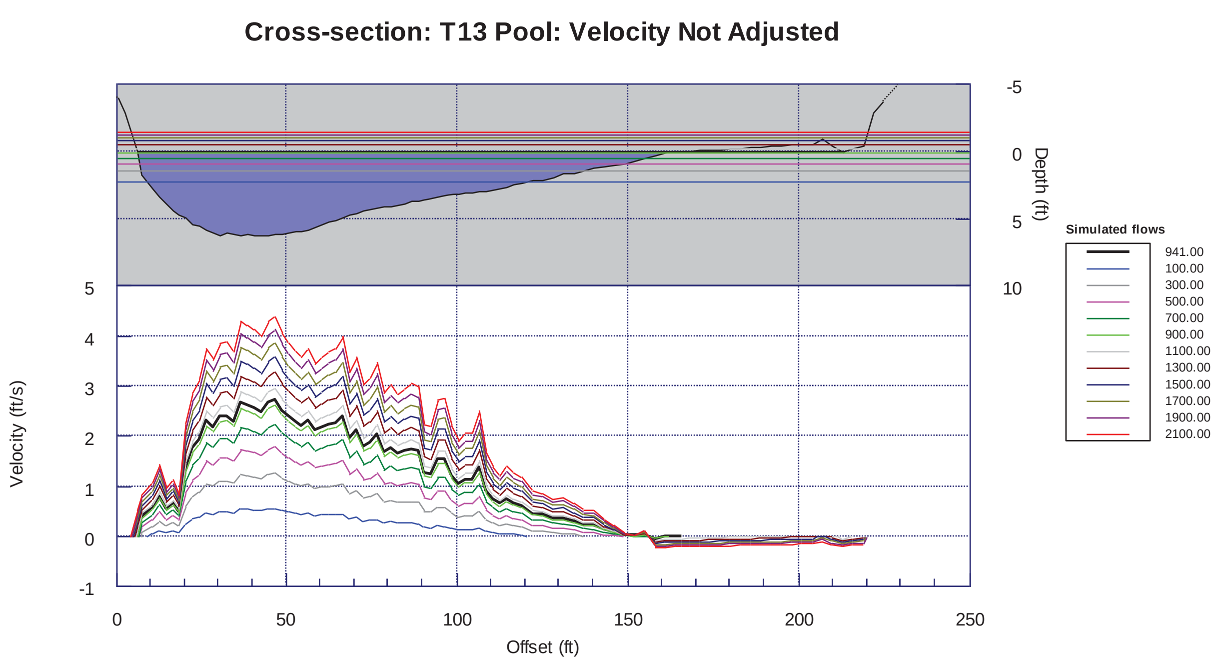


Figure 3-10. Velocity Simulation over a Range of Flows without Adjustment

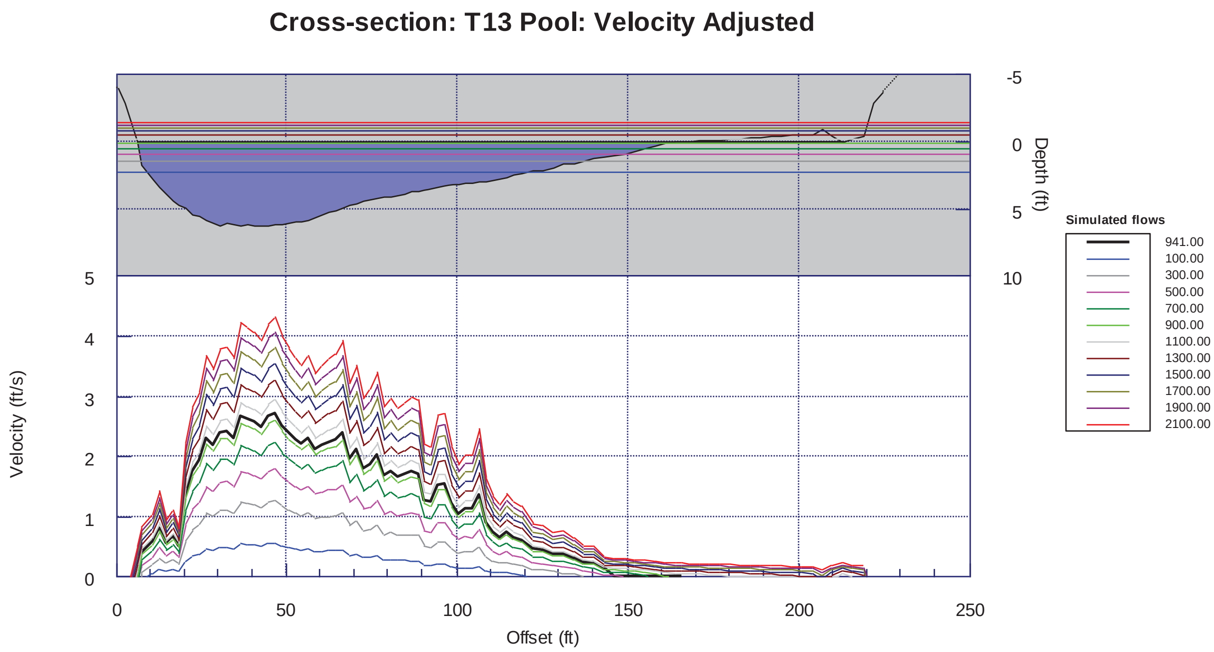


Figure 3-11. Velocity Simulation over a Range of Flows with Adjustment

3.4.5 Physical Habitat Simulation

3.4.5.1 Lower Illinois River

All the satisfactorily calibrated hydraulic transects were weighted according to the percentage of each major habitat type modeled in the study reach (Table 3-16).

Table 3-16. Final Number of Transects and Weight per Transect Used in Habitat Calculations in the Lower Illinois River

Habitat Type	No. of Transects	Weight/Transect
Pool	9	6.2%
Glide	3	4.2%
Run	4	5.8%
Riffle	2	4.3%
Total	**18**	

Habitat simulation for smallmouth bass juvenile and adult in the lower Illinois River was run based on AWS calculated, using a combination of velocity x depth and velocity x depth x substrate (Figure 3-12). As shown, the addition of substrate does not change the shape or peak of the AWS curves but only reduces the values. Even more reduction would occur if cover were added to the calculation (not shown in Figure 3-12) because the vast majority of points on transects had no cover, and a suitability of 0.1 would be applied to the AWS calculation. This is a common result when additional criteria are included in the calculations and most suitability values are less than 1.0. All subsequent analyses include the substrate component in calculating AWS habitat.

Normalized AWS provides an alternative perspective and allows for examination of habitat retention over a range of flows (Figure 3-13). With respect to smallmouth bass juvenile, 90 percent of the habitat is retained between flows of 250 to 900 cfs. Smallmouth bass adults maintain 90 percent of habitat at flows between 100 and 350 cfs. The intersection of these two normalized curves at 300 cfs represents the flow that optimizes habitat between the two life stages (Leonard and Orth 1988).

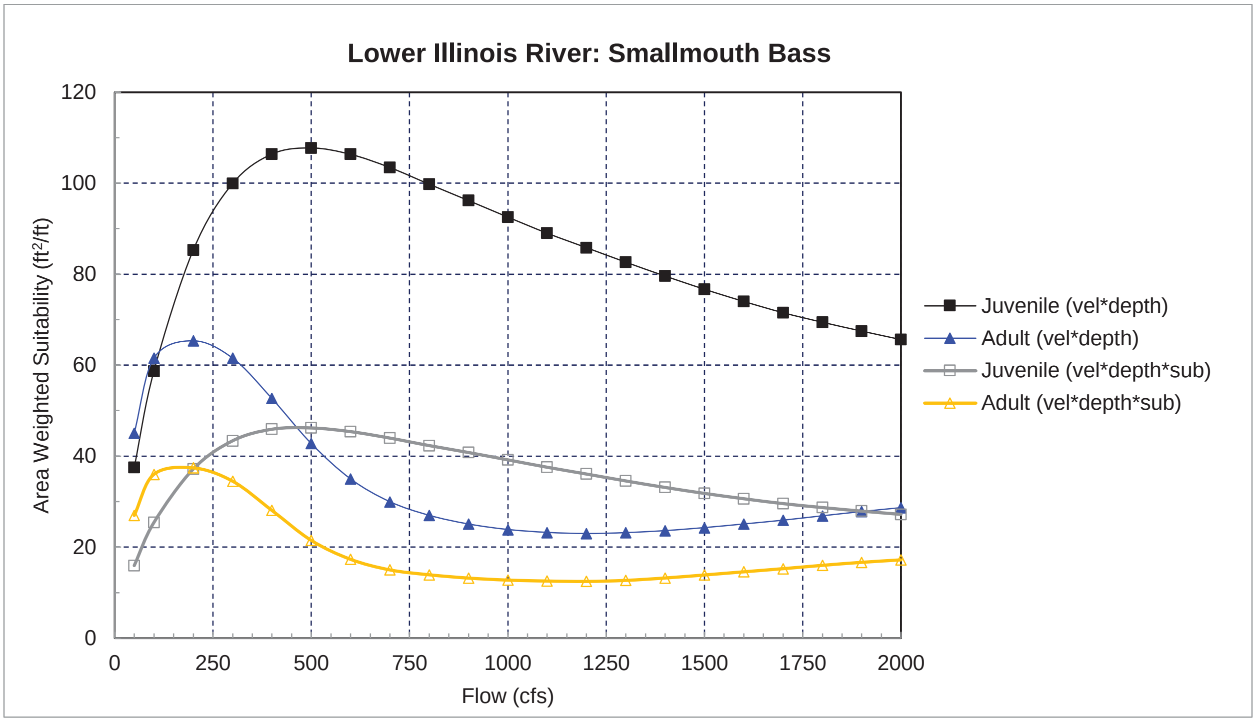


Figure 3-12. Smallmouth Bass Juvenile and Adult AWS versus Flow in the Lower Illinois River Using Velocity and Depth Suitability only with Addition of Substrate

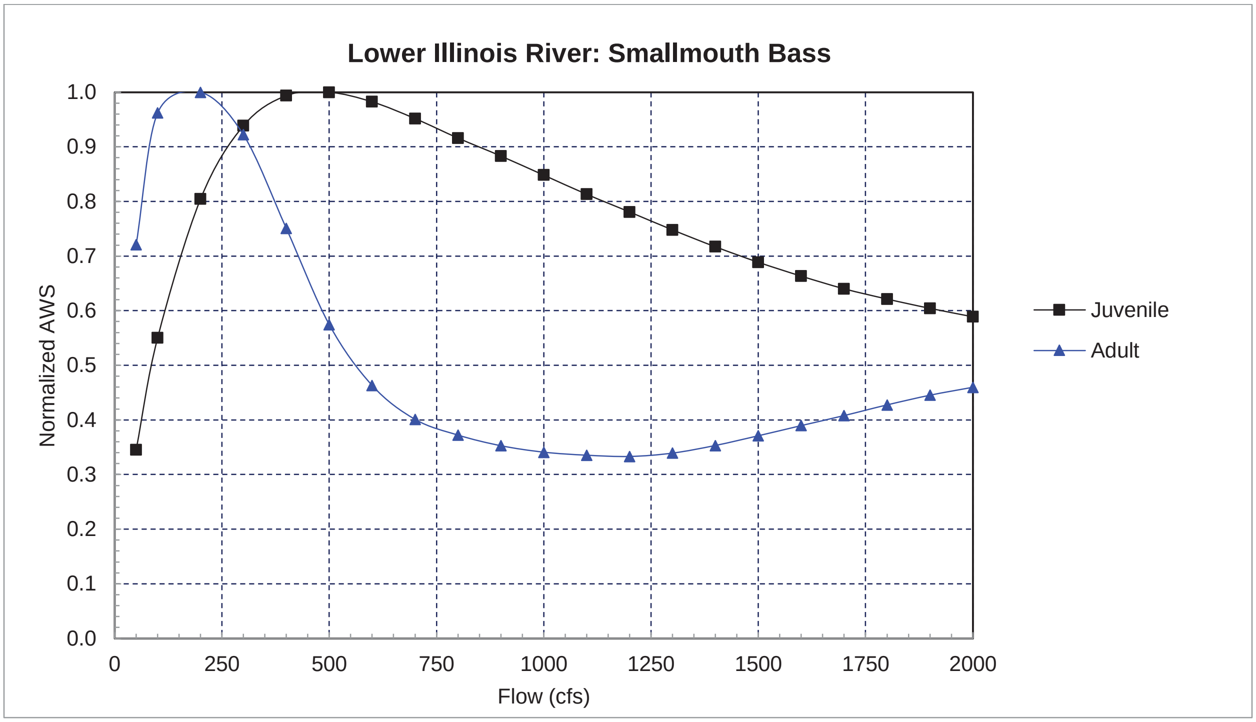


Figure 3-13. Normalized AWS versus Flow for Smallmouth Bass in the Lower Illinois River

3.4.5.2 Mesohabitat Consideration

The three habitat assembly categories (guilds) used in this study represent those species that, as a group, prefer either shallow-fast, intermediate, or deep-slow depth and velocity condition. The microhabitat (AWS) results depicted on Figure 3-14 represent how these habitat conditions respond to flow regardless of where in the stream they occur.

Some species within these categories may show strong fidelity to the specific mesohabitat (pool, riffle, run) where they reside; therefore, even when suitable depth and velocity conditions temporarily occur at certain flows at a location outside of their mesohabitat, they may not seek out and use these locations. To analyze this potential habitat (AWS) versus flow curves for mesohabitats were developed by applying the specific assemblage criteria to the transect types that correspond to these mesohabitats.

Specifically, shallow-fast criteria were applied only to riffles, deep-slow criteria only to pools, and intermediate criteria only to glides and runs. The results shown in Figures 3-15 to 3-17 are similar to those obtained using all habitat types with respect to curved shape. Though this may seem unusual, it is not necessarily an unexpected result. For example, because shallow-fast habitat is found primarily in riffles, the shallow-fast criteria show the most response in riffles. The addition of pools does little to change the curve since a very small component of pools is shallow-fast habitat. For pools, deep-slow habitat is available at lower flows but declines rapidly as flows increase, the result of increasing velocities overriding suitable depth.

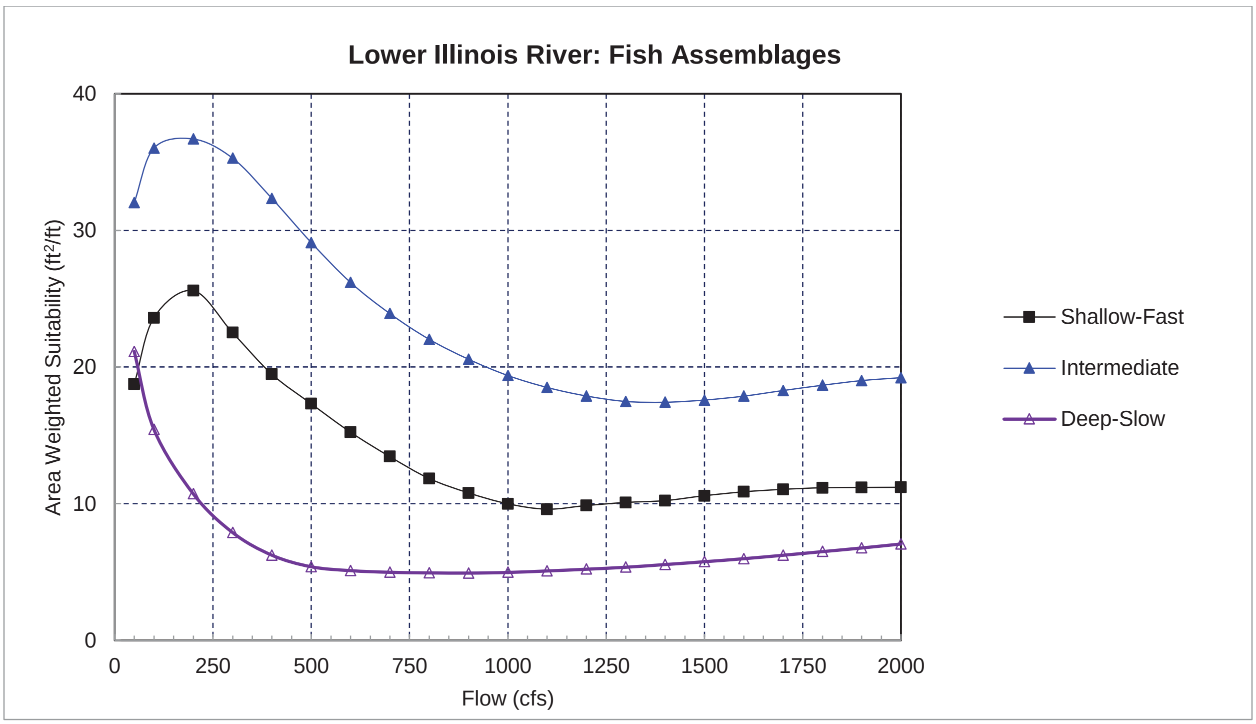


Figure 3-14. Fish Assemblage AWS versus Flow in the Lower Illinois River

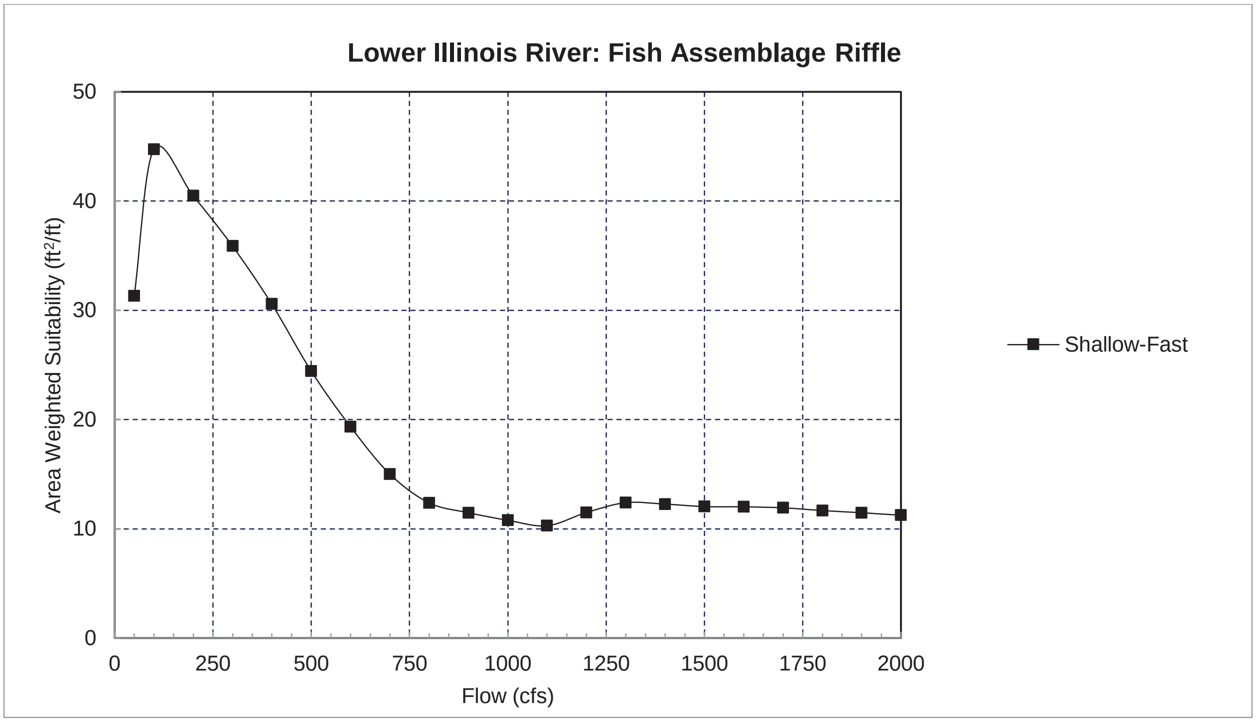


Figure 3-15. Shallow-fast Fish Assemblage Criteria Applied to Riffle Habitat in the Lower Illinois River

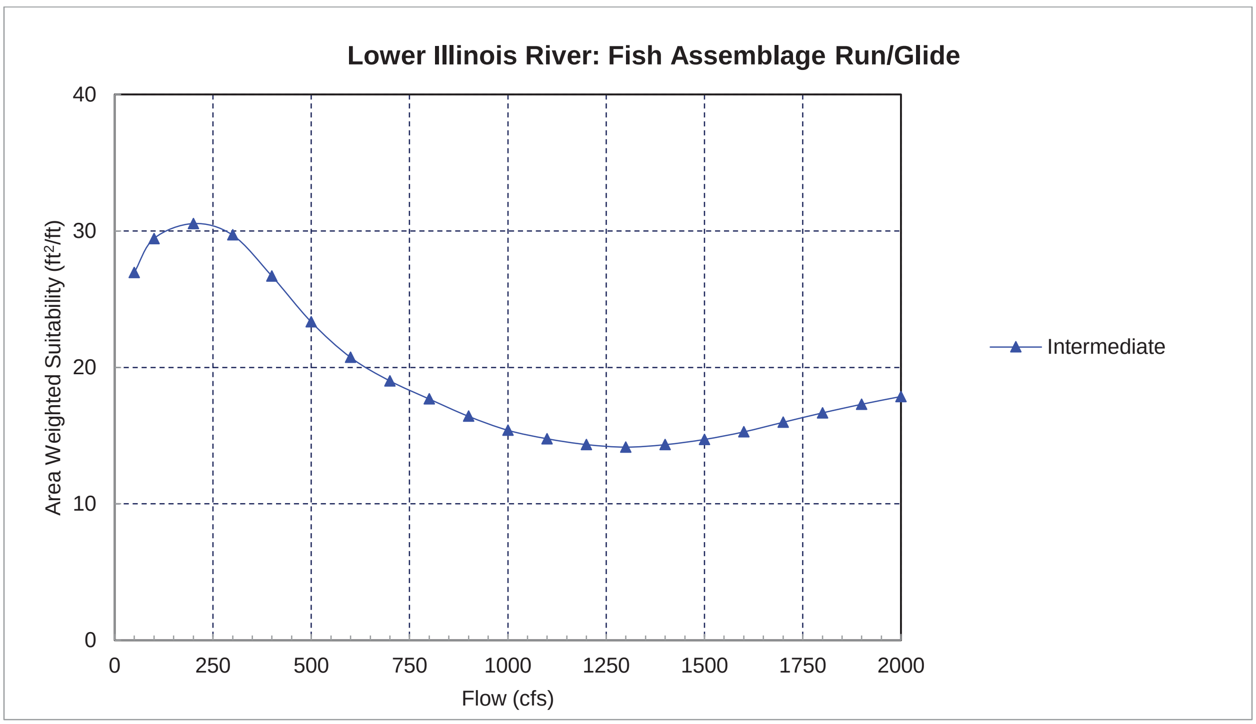


Figure 3-16. Intermediate Fish Assemblage Criteria applied to Riffle Habitat in the Lower Illinois River

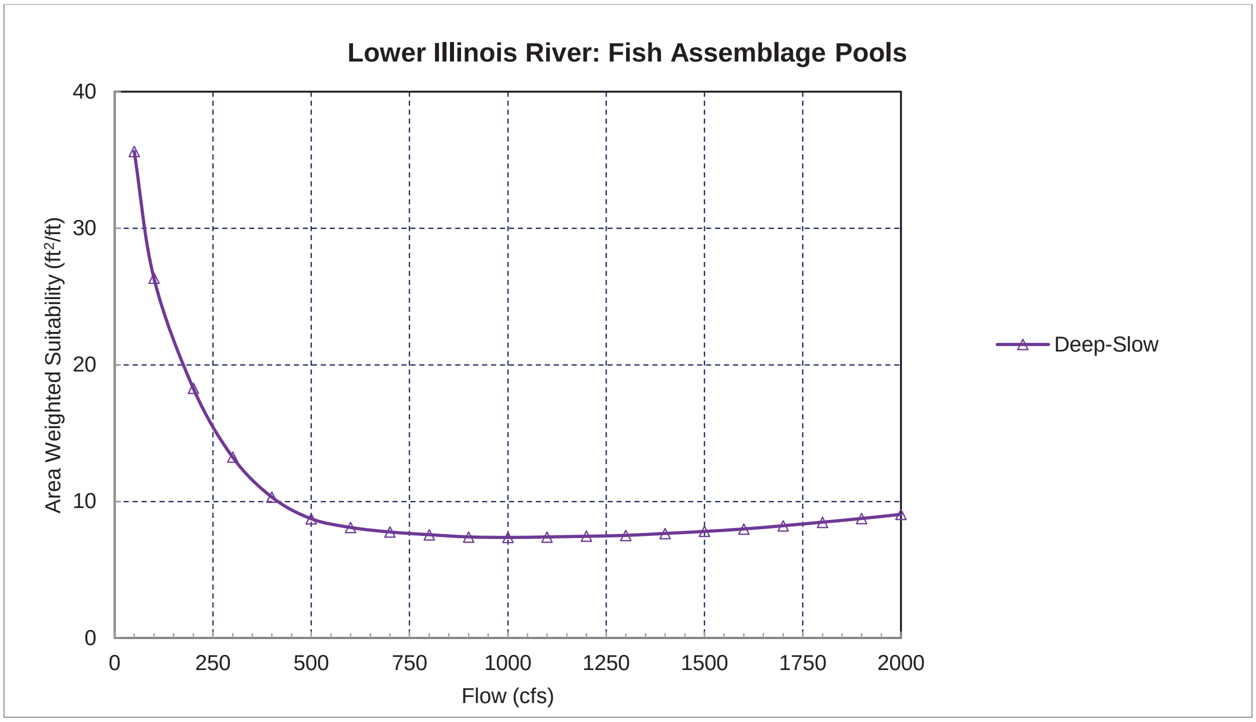


Figure 3-17. Deep-slow Fish Assemblage Criteria Applied to Riffle Habitat in the Lower Illinois River

3.4.5.3 Flint Creek

One pool transect was removed from the analysis in Flint Creek, resulting in pool habitat being weighted slightly higher than other habitat types (Table 3-17).

Table 3-17. Final Number of Transects and Weight per Transect Used in Habitat Calculations in Flint Creek

Habitat Type	No. of Transects	Weight/Transect
Pool	3	11.7%
Glide	3	6.7%
Run	4	5.1%
Riffle	4	6.2%
Total	**14**	

Similar to the lower Illinois River, smallmouth bass adults show a higher suitability at lower flows than juveniles (Figure 3-18). Smallmouth bass juvenile AWS at 60 cfs is nearly identical to that at 250 cfs. Adult smallmouth bass shows the highest suitable habitat range between 20 and 70 cfs. Fish assemblage AWS curves are also similar to those for the lower Illinois River with higher habitat values at lower flows (Figure 3-19).

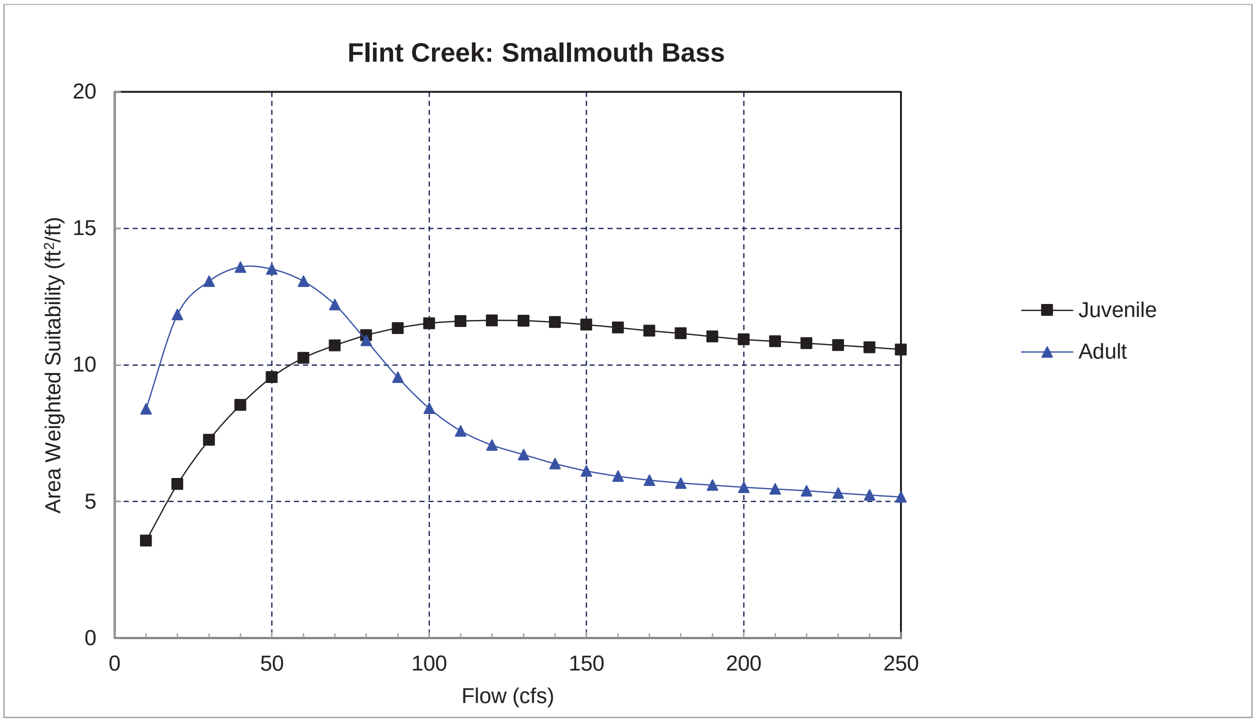


Figure 3-18. Smallmouth Bass Juvenile and Adult AWS versus Flow in Flint Creek

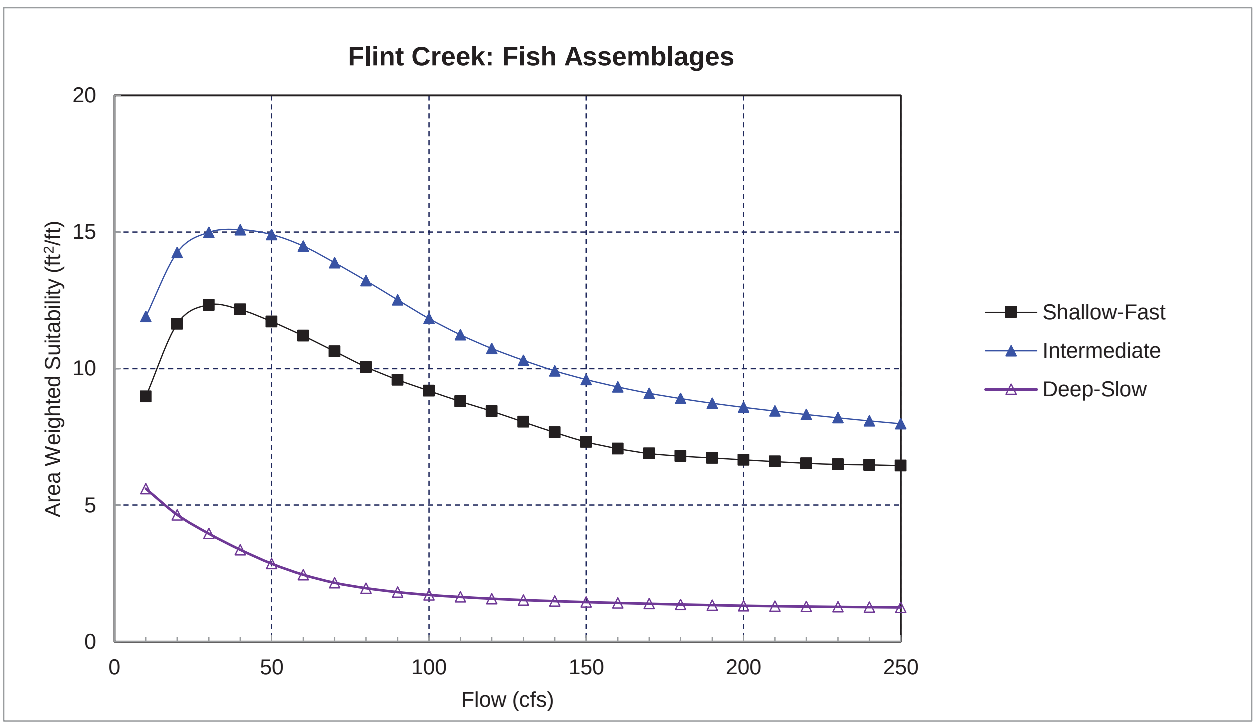


Figure 3-19. Fish Assemblage AWS versus Flow in Flint Creek

3.4.5.4 Barren Fork Creek

Habitat modeling results for Barren Fork Creek were obtained from Fisher and Remshardt (2000). The results are comparable to those for the Illinois River and Flint Creek because the same habitat criteria were used for all three streams. The habitat index (weighted usable area or WUA) shown for Barren Fork Creek represents the same values as the AWS used for the Illinois River and Flint Creek results. AWS is simply a more contemporarily used term for the same habitat index.

Similar to Flint Creek and the Illinois River, juvenile smallmouth bass show a higher habitat suitability at slightly higher flows compared to adults (Figure 3-20 (Fisher and Remshardt, 2000). Good habitat conditions for juvenile smallmouth bass range from 50 to 150 cfs, peaking at 75 cfs. For adult smallmouth bass good habitat conditions range from 40 to 100 cfs, peaking at 50 cfs.

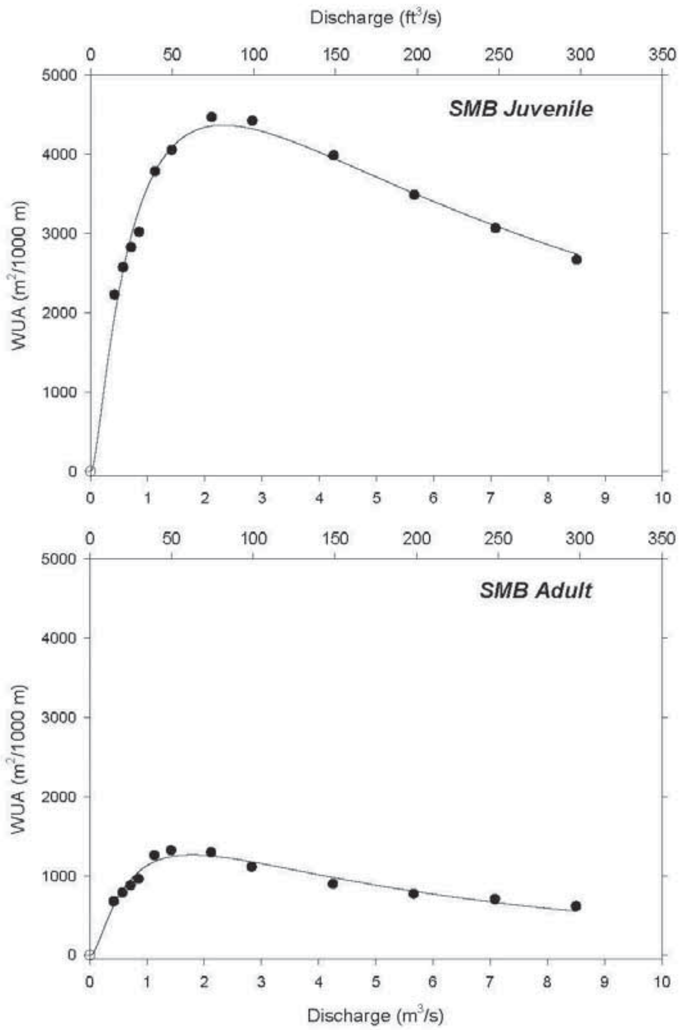


Figure 3-20. Relationship between Weighted Usable Area (WUA) and Discharge for Juvenile and Adult Smallmouth Bass in Barren Fork, Oklahoma

For the three fish assemblages in Barren Fork Creek, habitat peaks at 50 cfs for the shallow-fast and intermediate assemblages (Figure 3-21) (Fisher and Remshardt, 2000). For the deep-slow assemblage, habitat peaks at 20 cfs.

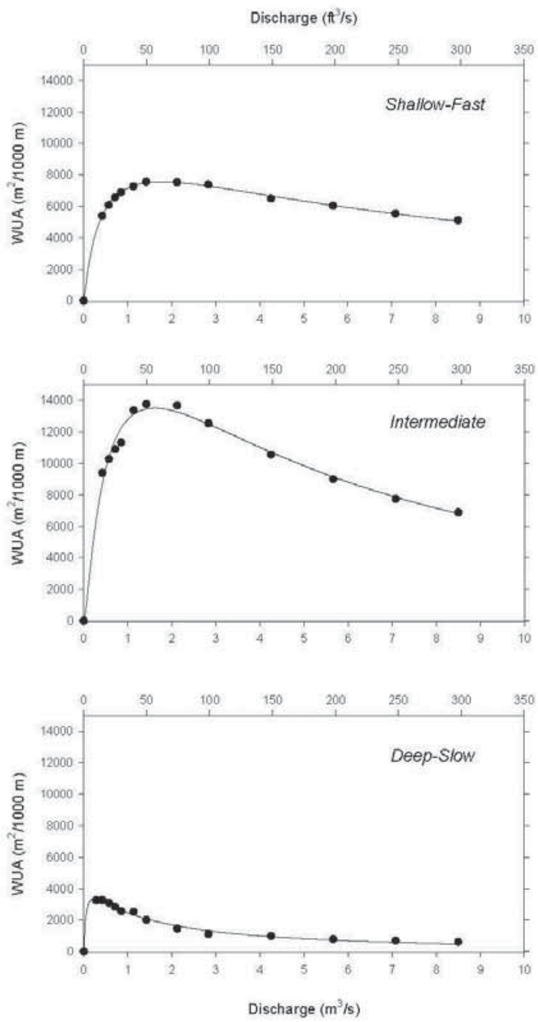


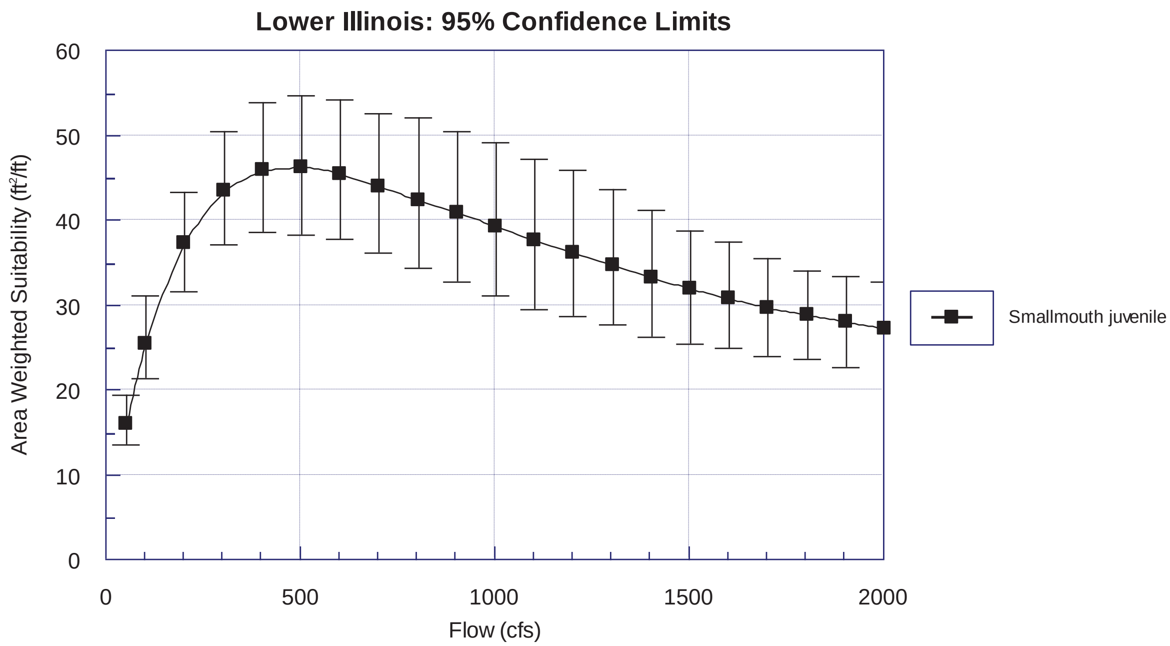
Figure 3-21. Relationship between Weighted Usable Area (WUA) and Discharge for Shallow-fast, Intermediate, and Deep-slow Habitat-Use Fish Assemblages in Barren Fork, Oklahoma

3.4.5.5 Sensitivity Analysis

There is always uncertainty in flow-habitat relationships because of sample size (transects) or the suitability criteria applied. Using a bootstrap method with replacement by habitat type, confidence intervals (CI) were applied to AWS values for juvenile and adult smallmouth bass in the lower Illinois River (Figure 3-22) and Flint Creek (Figure 3-23). In the Illinois River, CI tended to be greater at lower flows for adult smallmouth bass but relatively constant at all flows for juvenile smallmouth bass. Similarly, in Flint Creek CI were greater at lower flows, but the opposite trend was observed for juvenile smallmouth bass. The juvenile smallmouth bass showed narrower CI in AWS compared to adult smallmouth bass at a similar flow in both streams, which is probable because there is less overall defined habitat for adult smallmouth bass compared to juvenile smallmouth bass, based on the criteria used to define habitat.

A further analysis was conducted for the lower Illinois River to determine the effect that sampling different habitat units and types may have on results. There were a total of 9 pool, 4 run, 3 glide, and 2 riffle transects in the lower Illinois River. Three sets of 9 transects containing 5 pools, 2 runs, 1 glide, and 1 riffle were randomly selected. One stipulation established with regard to the sample was that each habitat unit must be used at least once. Results for smallmouth bass are similar for all groups of randomly selected transects (Figures 3-24 to 3-

26). Fish assemblage results show a small difference for the Group 1 transects (Figures 3-27 to 3-29); however, the highest habitat values still occur over the same range of flows as the other two groups. These results demonstrate the robustness of the modeling and emphasizes the importance of having an adequate sample size to reduce results uncertainty.



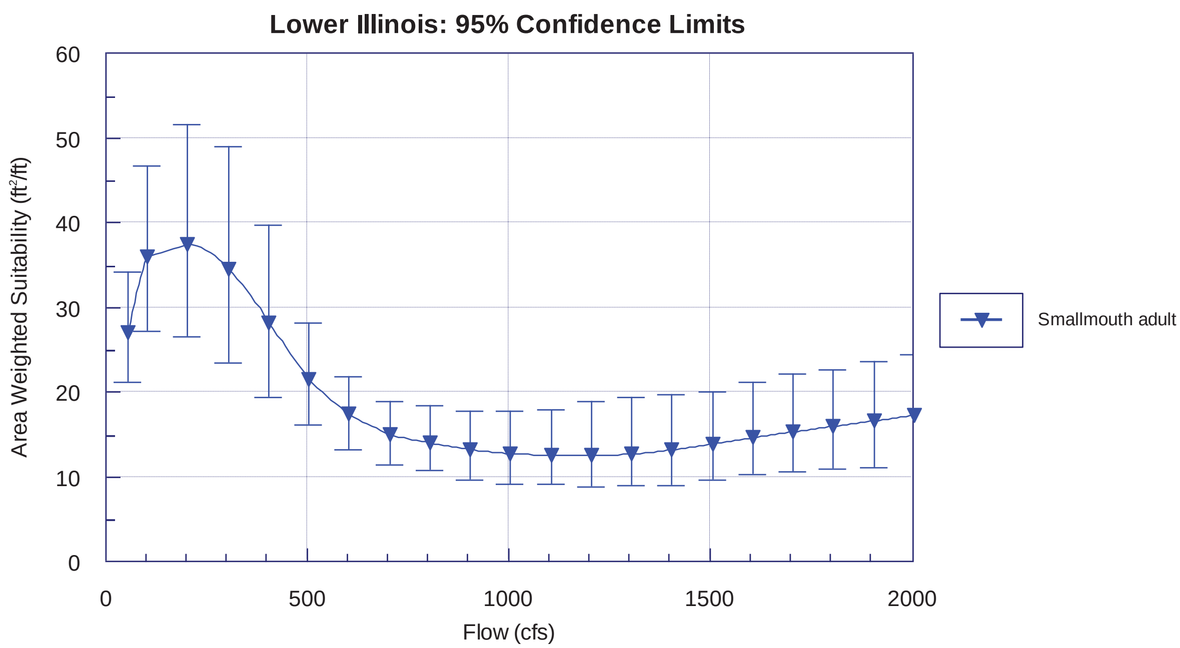


Figure 3-22. Confidence Limits around Smallmouth Bass Juvenile and Adult AWS Values versus Flow in the Lower Illinois River

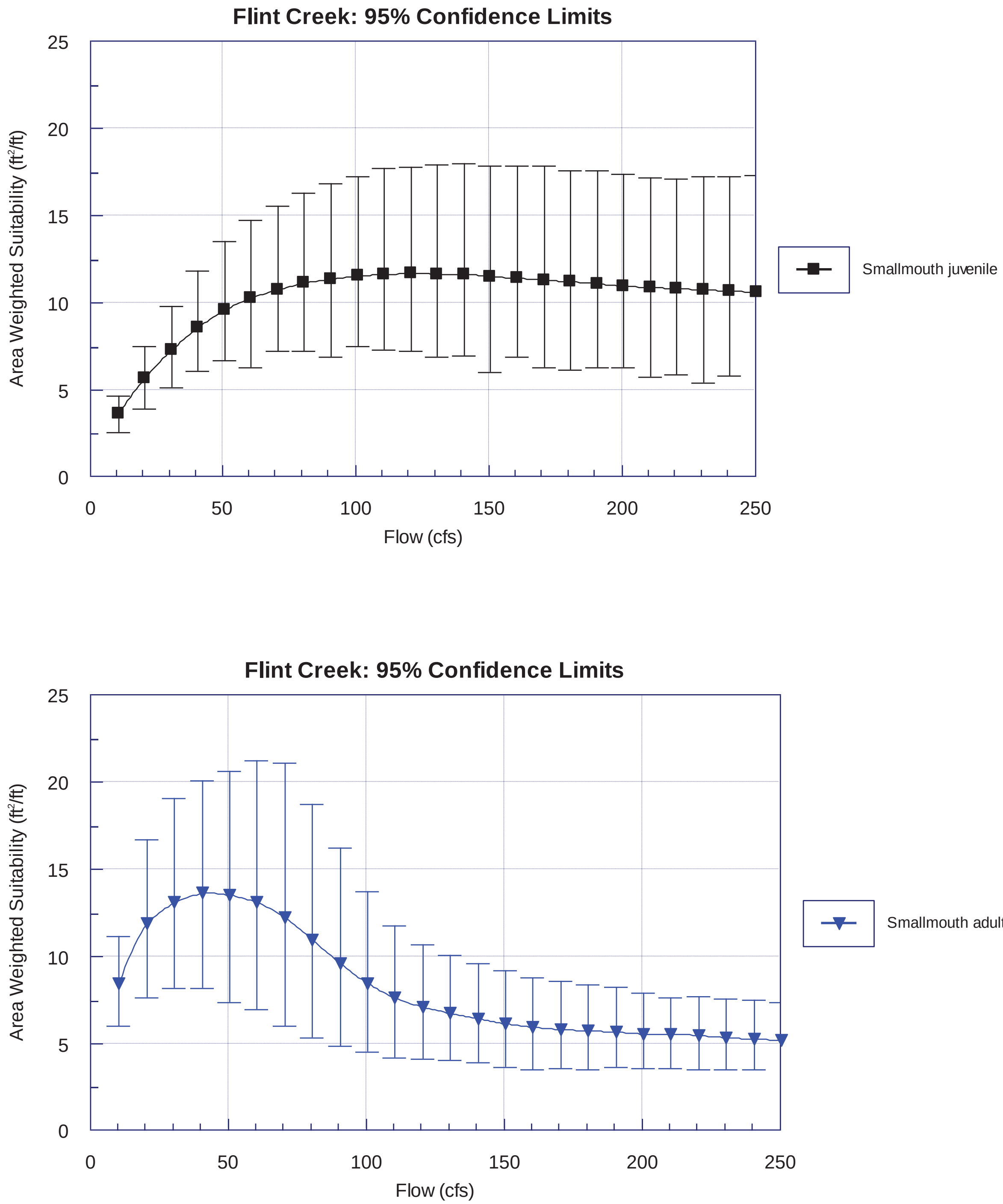


Figure 3-23. Confidence Limits around Smallmouth Bass Juvenile and Adult AWS Values versus Flow in Flint Creek

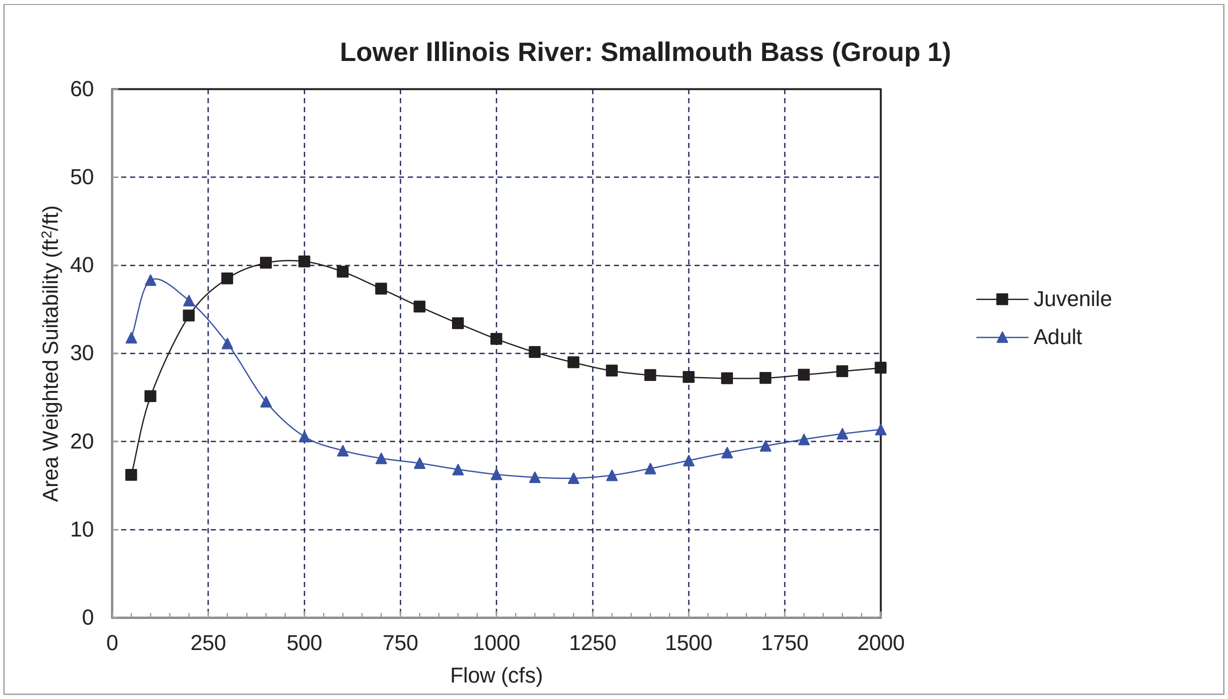


Figure 3-24. Smallmouth Bass Juvenile and Adult AWS versus Flow in the Lower Illinois River (Group 1) based on Nine Randomly Selected Transects

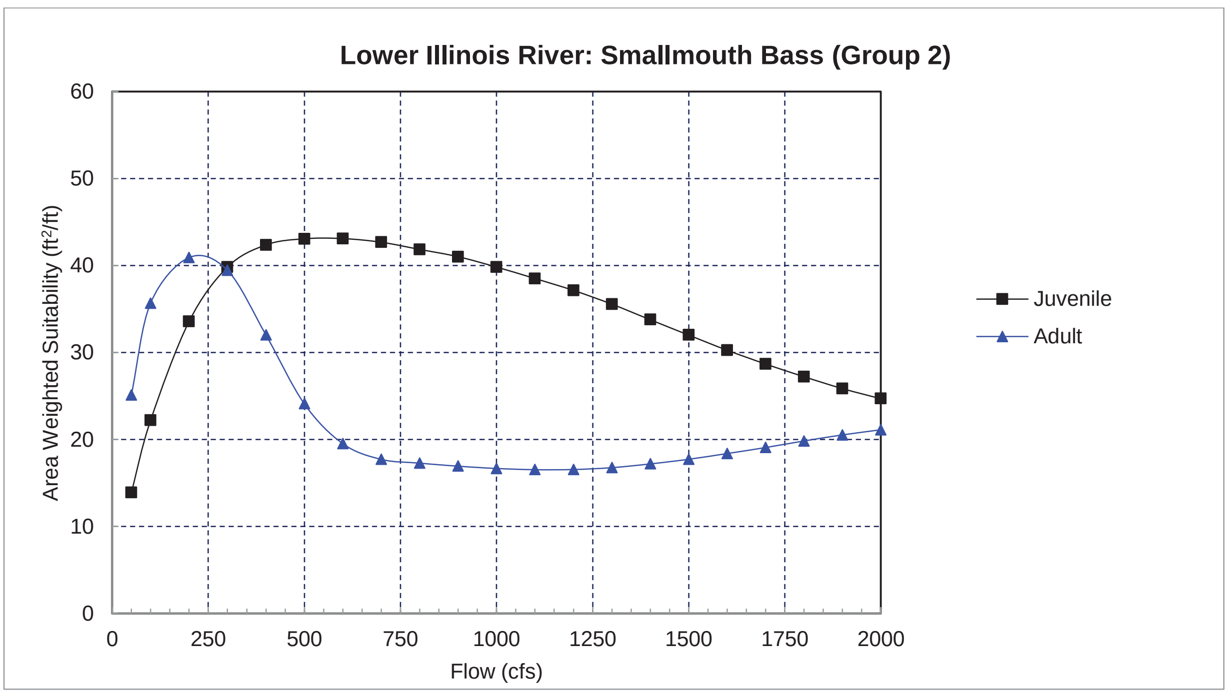


Figure 3-25. Smallmouth Bass Juvenile and Adult AWS versus Flow in the Lower Illinois River (Group 2) based on Nine Randomly Selected Transects

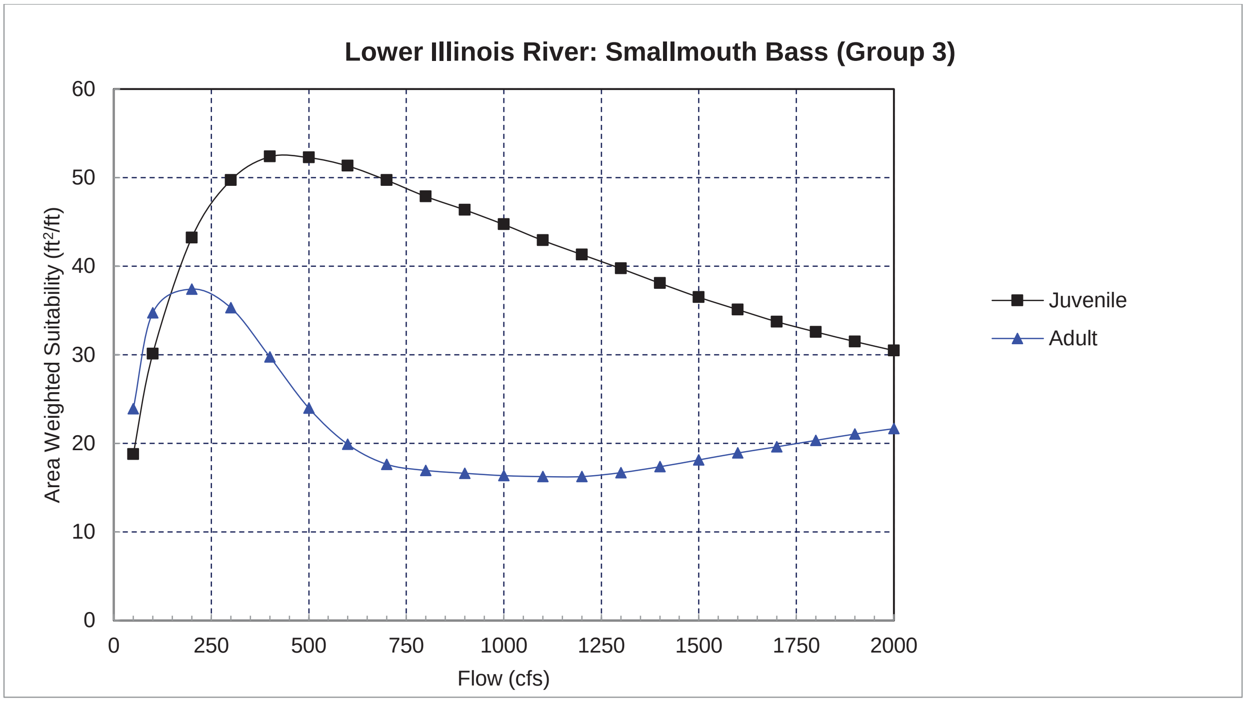


Figure 3-26. Smallmouth Bass Juvenile and Adult AWS versus Flow in the Lower Illinois River (Group 3) based on Nine Randomly Selected Transects

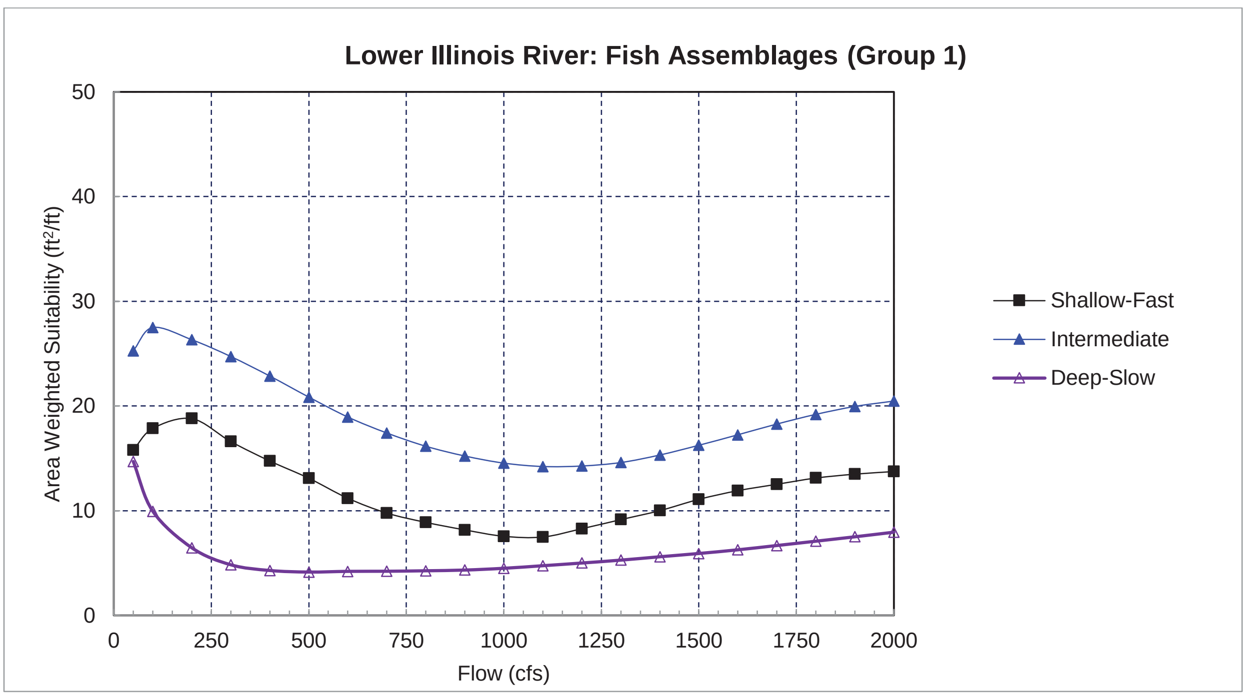


Figure 3-27. Fish Assemblages AWS versus flow in the Lower Illinois River (Group 1) based on Nine Randomly Selected Transects

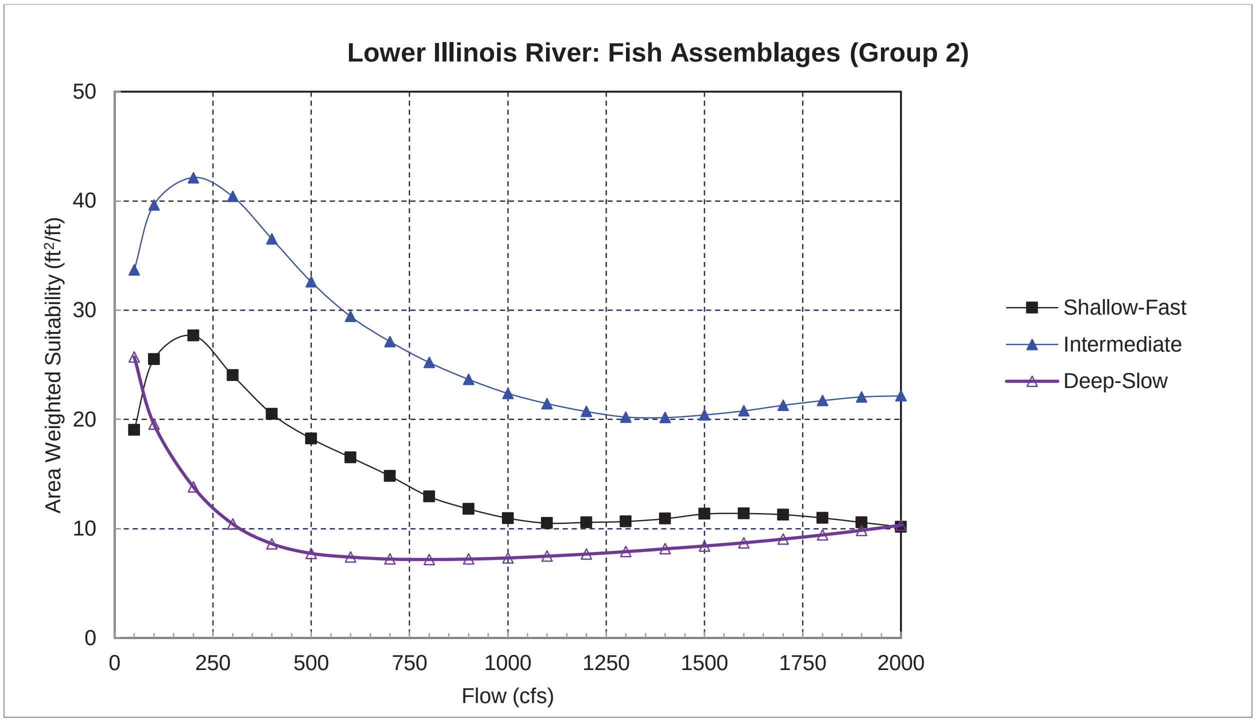


Figure 3-28. Fish Assemblages AWS versus Flow in the Lower Illinois River (Group 2) based on Nine Randomly Selected Transects

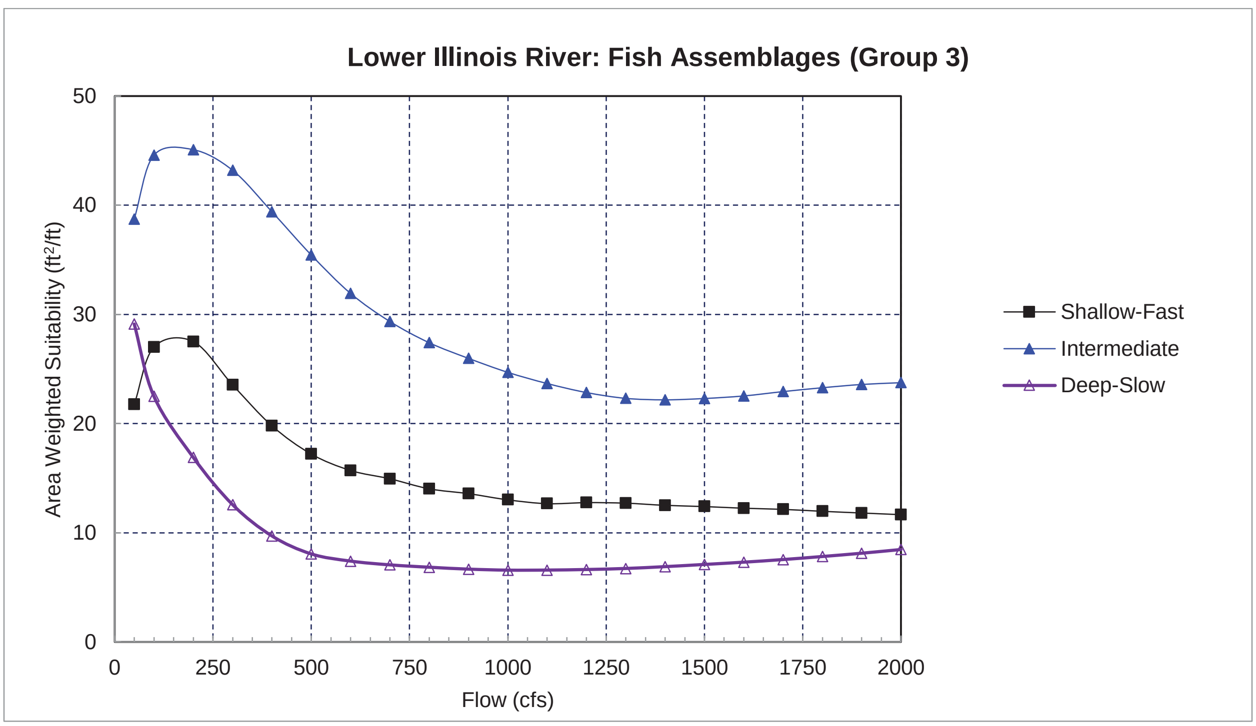


Figure 3-29. Fish Assemblages AWS versus Flow in the Lower Illinois River (Group 3) based on Nine Randomly Selected Transects

The results of the PHABSIM modeling also were compared to the results of a wetted perimeter analysis for riffles in the Illinois River and Flint Creek study sites as a way to validate the PHABSIM against a common simple instream flow method. The wetted perimeter method is a flow-based approach that considers aquatic productivity in shallow-fast waters (riffles) of a stream (Nelson 1983, Gipple and Stewardson 1998). The wetted perimeter is the distance across the bottom of the stream channel that is in contact with water. A graph of the wetted perimeter versus discharge generally identifies a turning or breakpoint of the curve. Incremental flows above the breakpoint produce smaller increases in wetted streambed compared to flows below the breakpoint. This breakpoint is often used to identify an instream flow value for protection of aquatic communities, especially fish. Results of that analysis for the Illinois River and Flint Creek are presented in Figures 3-30 and 3-31.

For the Illinois River, the wetted perimeter-discharge curve identifies a distinct breakpoint at 200 cfs. This is the same flow that also provides maximum habitat for the shallow-fast and intermediate fish assemblages as determined in the PHABSIM analysis. For Flint Creek, the wetted perimeter curve indicates a breakpoint at approximately 20 cfs, but it is not very distinct. This flow is within the range providing good habitat conditions for most species in Flint Creek but less than the flows (30-40 cfs) providing maximum habitat.

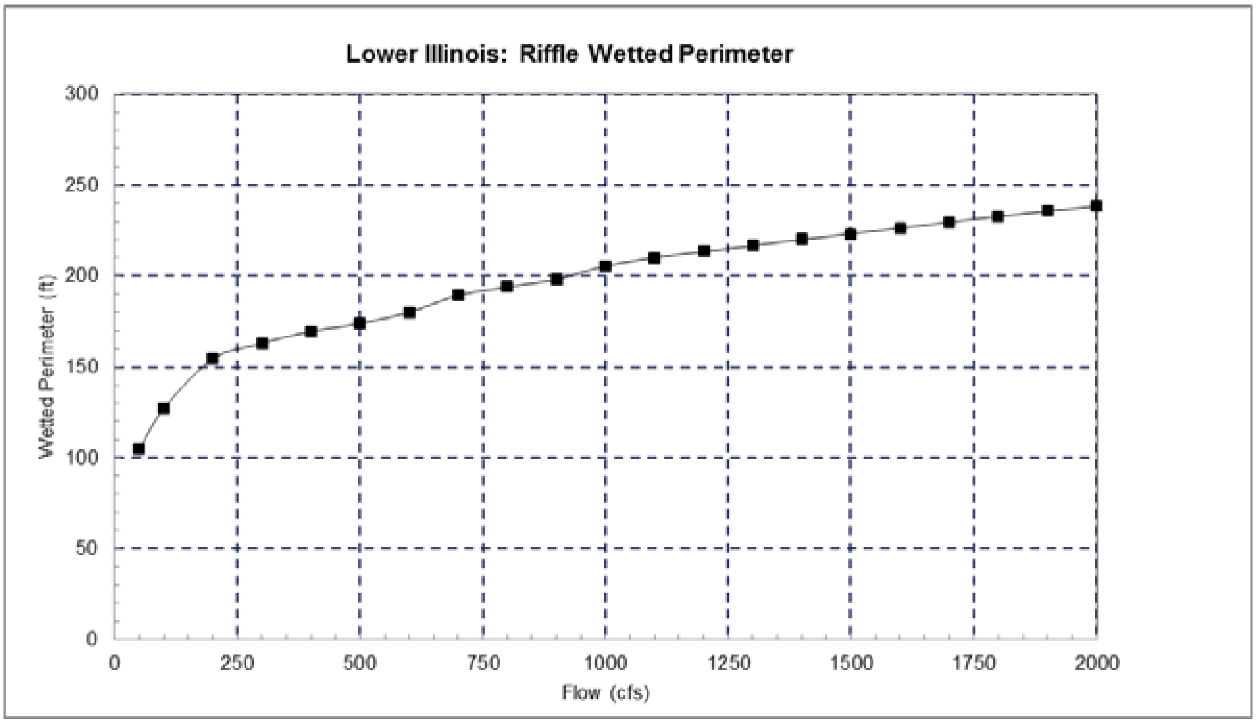


Figure 3-30. Wetted Perimeter versus Discharge Relationship for Riffle Transects in the Illinois River Study Site

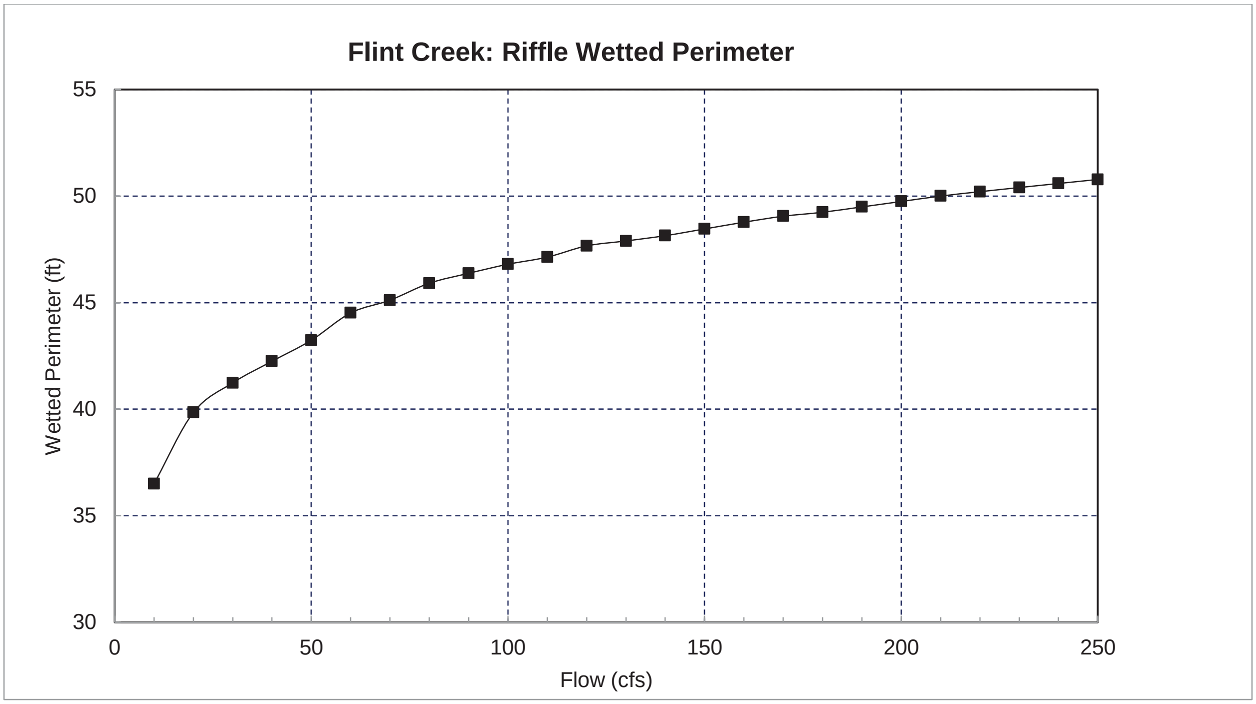


Figure 3-31. Wetted Perimeter versus Discharge Relationship for Riffle Transects in the Flint Creek Study Site

SECTION 4

Discussion

This section provides an interpretation of fish habitat modeling results, a discussion of ecological flow needs, and an assessment of decision-making considerations.

4.1 Interpretation of Fish Habitat Modeling Results

The habitat – flow curves (AWS) presented in the PHABSIM modeling portion of this report are simply relationships between fish rearing habitat and stream flow; they do not provide specific flows values that can be simply converted to numerical instream flow prescriptions. To make reasonable instream flow recommendations for fish habitat, the study results must be interpreted as to their biological meaning to the fish community as a whole.

The AWS curves were developed only for fish rearing habitat. As such, they do not address spawning, food production, competition, predation, and other important biological factors that can be affected by streamflow conditions. Also, AWS curves depict habitat conditions as related to flow under the existing channel condition. They do not address the flows that actually create the physical habitat in the first place. The need for these ecological process flows are discussed later.

Much of the PHABSIM modeling was done for smallmouth bass because it is the most sought after game fish in the basin. But one should not interpret this as meaning that smallmouth bass is the most important fish species relative to others. In fact, there are more than 60 other species that make up the fish community of the Illinois River basin. Results of the habitat use assemblages (guilds) provide a much more comprehensive assessment of the relationship between streamflow and habitat for the fish community as a whole.

Of the various mesohabitat types, riffles are often considered most important because they provide conditions conducive to the production of algae and macroinvertebrates in addition to being preferred habitat for many fish species. Algae and macroinvertebrates are the primary source of food for most riverine fish species. So while low flows may provide good conditions for pool dwelling species, such as suckers and sunfishes, these fish largely rely on the algae and macroinvertebrates produced in the riffles for food. Also, many of the pool-classified species spawn in gravel areas, which are more commonly associated with riffles. Because of these factors, habitat conditions for the shallow-fast fish assemblage, which represents those fish species preferring riffles, should be given particular attention when considering instream flow prescriptions.

The results of the PHABSIM modeling suggests that relatively low flows favor suckers and sunfishes (deep-slow guild) in the Illinois River compared to other species. While this pattern may be true in isolation, one must be careful in how to interpret these results. One must take into account the fact that pools make up by far the most predominant mesohabitat type in the Illinois River, accounting for 58 percent of the total (see Tables 3-6 and 3-7 of Results Section 3.4). Therefore, it is unlikely that the amount of pool habitat at any flow is a population-limiting factor to the species preferring pools. It is more likely that food, spawning habitat, or behavioral interactions with other species limit these pool-preference species. This provides a good example of the need to look at the entire fish community and the nonhabitat biological factors affecting the community when interpreting PHABSIM results.

In general, the results of the fish habitat modeling suggest that flows between 100 cfs and 300 cfs provide good rearing habitat conditions for most fish species in the Illinois River. For the shallow-fast and intermediate fish assemblages as well as smallmouth bass adults, maximum habitat occurs at 200 cfs. Habitat values drop precipitously at flows below 100 cfs for these assemblages. Juvenile smallmouth bass show a preference for higher flows (maximum at 400-500 cfs) but with 80 percent of the maximum habitat still available at 200 cfs.

For Flint Creek, good habitat conditions occur when flows range from 10 cfs to 60 cfs with maximum habitat for the shallow-fast and intermediate fish assemblages occurring at 30 cfs and 40 cfs, respectively. Adult smallmouth bass habitat is maximized at 40 cfs.

Habitat modeling results for Barren Fork Creek were obtained from Fisher and Remshadt (2000). The habitat criteria used in the modeling were the same as those used for the Illinois River and Flint Creek. Results indicate that good habitat conditions occur from about 40 cfs to 100 cfs for most species. Maximum habitat for the shallow-fast and intermediate fish assemblages as well as smallmouth bass adults occurs at 50 cfs.

4.2 Need for Ecological Flows

Instream flow prescriptions that include the various natural components of the hydrograph are most desired when the goal is to provide long-term protection of the ecological processes that maintain the stream's natural environmental values. Although many components of the natural hydrograph can be defined, for practical purposes they are often categorized as base flows, channel maintenance flows, and overbank flows. For each of these flow components, consideration should be given to their magnitude, duration, frequency, seasonal timing, and rate of change (Annear et al. 2004). These three flow components are defined below:

> **Base flows** represent the normal flows between significant precipitation events. For setting of instream flow management prescriptions, emphasis is typically placed on the summer or fall base-flow period. Most instream flow setting methods focus on the base flow needs.
>
> **Channel Maintenance Flows** are those moderate-to-high flows that occur about once every year or two. They correspond to bank-full conditions. They serve to create and maintain important habitat conditions and connectivity along the stream corridor.
>
> **Overbank Flows** are the infrequent flood events that produce water levels that exceed those of the river bank. These flood flows help maintain riparian areas, transport sediment and nutrients onto the floodplain, recharge floodplain aquifers, and provide lateral connectivity to off-channel water bodies. Floods typically occur in defined seasons.

Discussion of these three instream flow components as they relate to the Illinois River basin and results of this study is presented below.

Base flows. Establishing base flow prescriptions for the Illinois River, and Barren Fork and Flint Creeks, is perhaps the most important need among the various flow components. Establishment of such flows would represent a minimum flow management prescription for use by the OWRB in assessing future out-of-stream water right applications. Having adequate base flow protection during the summer and fall months is especially important because 1) fish populations tend to be limited by conditions during the warm low-flow period, 2) recreational use of streams (e.g. fishing, boating) is greatest during this period, and 3) demands for out-of-stream water use such as irrigation are highest during the summer low flow season.

Channel maintenance flows. Channel maintenance or channel forming flows are those high flows that erode banks, move large quantities of substrate, shift gravel bars, and scour vegetation. When such flows occur in unconfined reaches, which typifies much of the Illinois River, secondary side channels are formed. At multichannel sites, riffles often occur at the upstream end and pools at the downstream end or to one side of the riffle. Backwaters are formed at the downstream end of many side channels when inflow ceases at the upstream end as runoff subsides. It is common for eddies to form at the interface of the backwater mouth and the main channel. All of these channel features can be seen on the available aerial photographs of the Illinois River corridor (see the appendix). These features provide the complexity and diversity of habitats preferred by the fish community as well as other water dependent wildlife.

In an unregulated stream, the channel maintenance flows typically corresponds to the bank-full flow. A commonly accepted and universally applicable definition of bank-full is provided by Dunne and Leopold (1978):

"The bank-full stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics of channels." It is this discharge, along with the range of flows that make up an annual hydrograph, which governs the shape and size of the active channel. Bank-full discharge is associated with a momentary maximum flow that has an average recurrence interval of 1.5 years as determined using a flood frequency analysis (Dunne and Leopold 1978). Although greater erosion and enlargement of steep incised channels may occur during more extreme fluvial events, it is the modest flow regimes that transport the greatest quantity of sediment material over time, due to the higher frequency of occurrence for such events (Wolman and Miller 1960).

The 1.5-year recurrence flows for the three study steams (four sites) are as follows:

- Illinois River at Tahlequah 14,112 cfs
- Illinois River at Watts 13,912 cfs
- Barren Fork creek at Eldon 11,099 cfs
- Flint Creek near Kansas 2,520 cfs

In terms of maintenance of the channel itself, it probably does not matter which month the high flow event occurs. However, there are other ecological functions associated with these high flow events that do depend on their season of occurrence. These may include fish spawning and migration, seed and plant germination in riparian areas, and wildlife life history needs. Annual peak flow events that exceed the 1.5-year recurrence probability (14,112 cfs) in the Illinois River at Tahlequah can occur in any month (see Table 2-4). However, most occur in the winter and spring months (December to June). The least likely months for these events to occur are August and September.

Overbank flows. It is important that natural streams have access to their floodplains. As floodwater spreads over a floodplain, velocities and thus erosive force are reduced. As the water overflows onto the floodplain, water velocities tend to drop thus attenuating downstream flooding. If flood flows are contained within a stream channel, water velocities remain high and cause channel degradation in the forms of incision or excess lateral migration (bank erosion).

Higher flood events also are important from an ecological process standpoint (floodplain maintenance), but recommending or prescribing the maintenance of flow levels/events that are above the bankfull level is problematic in a regulatory sense if there is considerable human encroachment onto the floodplain (roads, homes, businesses, farms). For the Illinois River, Flint Creek, and Barren Fork Creek a quantified prescription for a flood flow may not be necessary because of the presumed protection of these natural flood events embodied in the language of the OSRA. Furthermore, the need to protect floodplain maintenance flows would only be an issue if a major flood control dam were to be proposed in the basin, and that appears to be unlikely in the foreseeable future.

4.3 Decision-making Considerations

4.3.1 Need to Consider Basin Goals

Understanding the established goals of the stream basin is critical in supporting instream flow management prescriptions. The expressed goals of the OSRA for the Illinois River basin streams related to instream flows are as follows:

1. Conserve and enhance instream biological and physical resources such as native fish and their habitats, and water quality,
2. Maintain long-term protection of important instream and shoreline resources, including free-flowing character, water quality and quantity, and fish habitat, and

3. Provide a diversity of high-quality recreation opportunities that are compatible with each other and with river resources.

These goals are consistent with the OWRB statewide definition of instream flows as presented in the 2012 Oklahoma Comprehensive Water Plan (OWRB 2012): "flows necessary to provide for a healthy ecosystem and support water related recreation such as fishing, hunting, swimming and boating as well as tourism." Considering these goals as well as the unregulated and low-development nature of these streams, priorities clearly favor protection of the "free-flowing" character of the streams. With these unregulated streams, there may not be a need to quantify the "free-flowing" high flow events, such as floods, since they will happen naturally. For base flows, however, prescribing minimum instream flows is needed because this is where water use conflicts would be most likely to occur in the future. Furthermore, the use of the term "free-flowing" in the OSRA may not be enough by itself to provide the desired base flow protection.

4.3.2 Need to Consider All Resources and Their Priorities

Much of this report is focused on fish habitat and how it relates to stream flow. This resource commanded most of the field work and modeling effort. However, this emphasis on fish habitat does not necessarily mean that fish should be the primary resource of consideration for establishing instream flow prescriptions. Clearly, recreational boating/floating is a predominant resource value for the Illinois River and should be given high priority when considering flow prescriptions.

The water management decision process by which the various components of this technical study are to be integrated and the relative importance they are assigned is a matter of professional judgement and established policy. As such, the decisions themselves are beyond the scope of this study. However, select study results should be given considerable weight in informing the decision-making process. To highlight these results, a brief discussion of the study findings in each resource area is provided.

<u>Recreation</u>. Recreational values should be given high priority based on heavy documented use and economic contribution to the area. Primary recreational uses include fishing, hunting, wildlife viewing, camping, and especially watercraft floating. Water needs for recreational floating should not be in conflict with the water needs for other resources. It is often a challenge to identify instream flows for recreational boating because different people prefer different conditions. Some may want a "white water" experience while others may prefer a quiet easy float in a raft or canoe. Fortunately, the Illinois River has supported significant floating activity for many years with most participants using commercial outfitters. The flows that provide minimal, preferred, and unsafe conditions are well established through experience (see Table 2-4). Because rafting is becoming the most popular means of floating, the identified minimum flow for rafting, 250 cfs, should be given strong consideration in the decision-making process.

<u>Fish habitat</u>. Fish habitat, although important in itself, is also considered an indicator of the health of the aquatic environment and thus should be given high priority. In most instream flow studies the flows needs for the fish community are often the highest priority because of their indication of environmental health as well as the importance that the public places on fish, especially game fish. Of the >60 species of fish found in the Illinois River basin nearly all are native species. This is quite remarkable for any stream, and certainly deserves attention when considering instream flow prescriptions. Sport fishing is an important recreational activity in the Illinois River and its tributaries.

<u>Wildlife</u>. Wildlife, for viewing, hunting, and their ecological value, is an important resource value in the basin. Maintaining good wildlife habitat along the stream corridors is most closely associated with maintaining the health of the riparian areas. Maintaining these areas, in turn, can only be accomplished by preserving the magnitude, duration, seasonal timing, and frequency of the channel maintenance flows, which generally correspond to the 1.5-year recurrence peak flow event in an unregulated system such as the Illinois River above Tenkiller Ferry Reservoir.

Water quality. Water quality should not be a high priority when considering instream flow prescriptions for base flows in the Illinois River and its tributaries. Phosphorous loading is the primary water quality concern in the basin. While phosphorous concentrations tend to increase with streamflow, this primarily is due to the increased runoff that also produces higher flows. The base flows themselves appear to have little impact on phosphorus loading. Higher pulsed flows that initiate bedload movement and bank scour do tend to resuspend phosphorus that has accumulated in these areas, but these flow events will occur naturally so long as the streams remain free of significant impoundments. Water temperature is another water quality attribute that can be affected by stream flow. However, results of temperature modeling for extreme-case conditions (hot air, low flows) indicate that water temperatures on a stream-reach basis would be only minimally affected by stream flow even under these extreme environmental conditions (see Section 2.4).

Ecological processes (environmental flows). The need to protect the primary components of the natural hydrograph of the Illinois River to preserve the ecological process that create and maintain habitat cannot be over-emphasized. Allowing continuance of channel maintenance flows, discussed above, is most evident. However, in terms of establishing instream flow management prescriptions, there may not be a need to actually quantify these flows. The goals identified for these streams in the OSRA may be enough to protect these higher flow events.

4.3.3 Need to Consider Water Availability

In the process of establishing instream flow management prescriptions, especially for unregulated streams, it is important to consider the availability of water for meeting resource value goals associated with instream flows. Flow prescriptions that frequently exceed the availability of water in the stream tend to be difficult to justify to the public, particularly in a stream with conflicting water uses. For the Illinois River the typical late summer base flows (median) are in the 200 – 300 cfs range (Table 4-1). The results of this study indicate these base flows also correspond to good habitat conditions for the native fish community. Similarly, for Barren Fork and Flint Creek and Barren Fork Creek, the flows that provide good habitat conditions for the fish community correspond closely to the median base flows during the summer and fall. Habitat availability at these base flows are what fish populations tend to track over time.

Table 4-1. Median Stream Flows (cfs) in the Illinois River (Tahlequah gage), Flint Creek (Kansas gage), and Barren Fork Creek (Eldon Gage) during the Low-flow Season July - November.

Stream	Month					Average Median Flow
	July	August	September	October	November	
Illinois River	297	217	200	225	308	249
Flint Creek	40	31	29	31	49	36
Barren Fork Cr.	69	45	40	50	83	57

In conclusion, regarding the various flow components, establishing base flow prescriptions for the Illinois River, Flint Creek, and Barren Fork Creek is of most importance. These base flows would represent standards for use by the OWRB in assessing future out-of-stream water right applications. The fact that the flows providing good habitat conditions for the fish communities in all three streams also correspond closely to the typical summer base flows (represented by median monthly flow) is reassuring to a biologist knowing that base flows and the associated habitat at those flows are what fish populations track over time. Minimum flows that have been identified for recreational floating by canoe, raft, and kayak in the Illinois River also are similar to those flows supporting good fish habitat conditions.

Protecting the high flows components of the natural flow regime in the Illinois River and tributaries also is important in order to maintain the ecological processes that define the streams. These processes support the environmental values embodied in the goals established for these state-designated Scenic Rivers. Legal protection of these flows may be provided by the OSRA. However, it may be helpful from a regulatory standpoint to include protection of these ecological process flows, even if only in narrative form, in any instream flow prescription for the Illinois River, Barren Fork Creek, and Flint Creek.

SECTION 5

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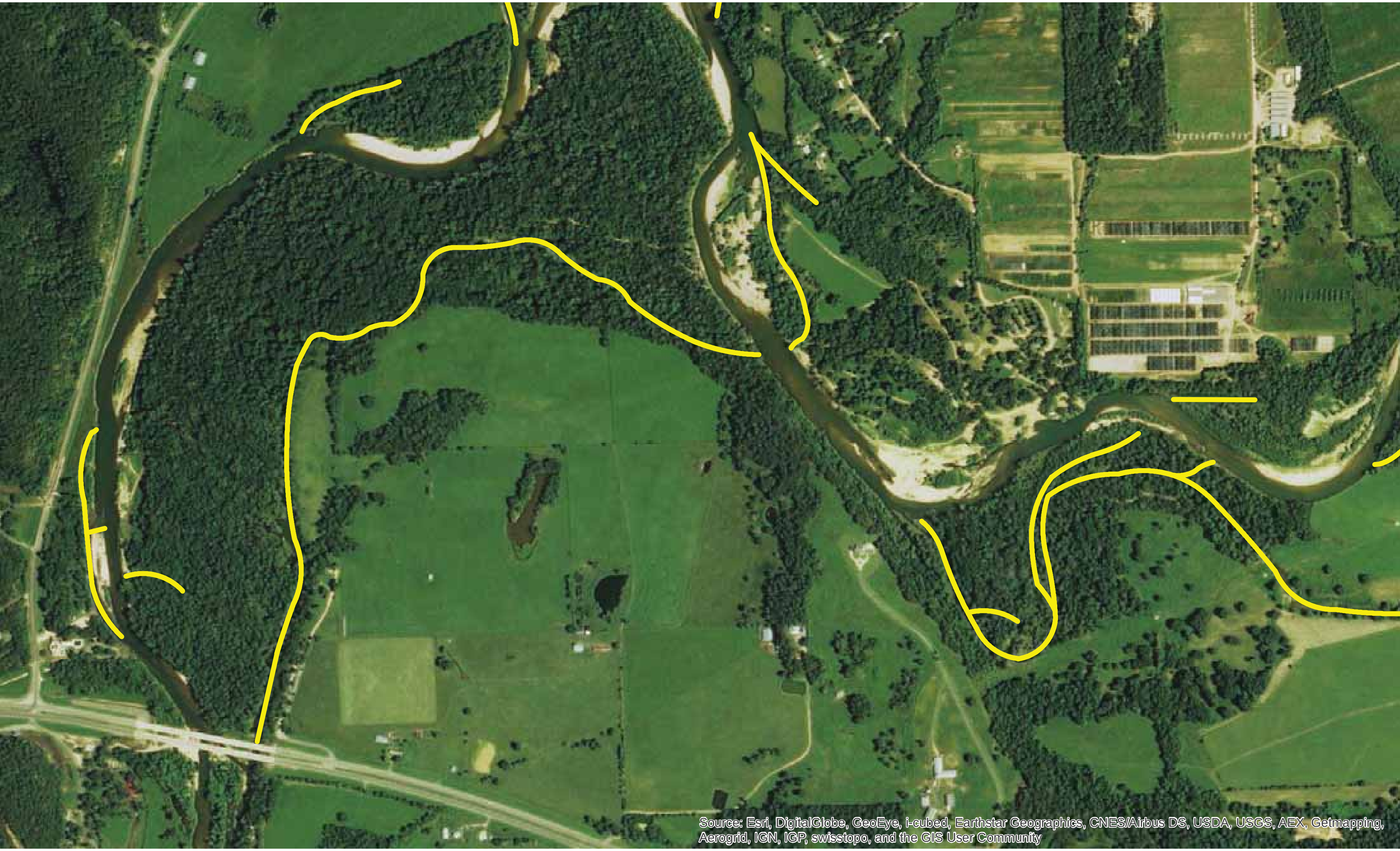
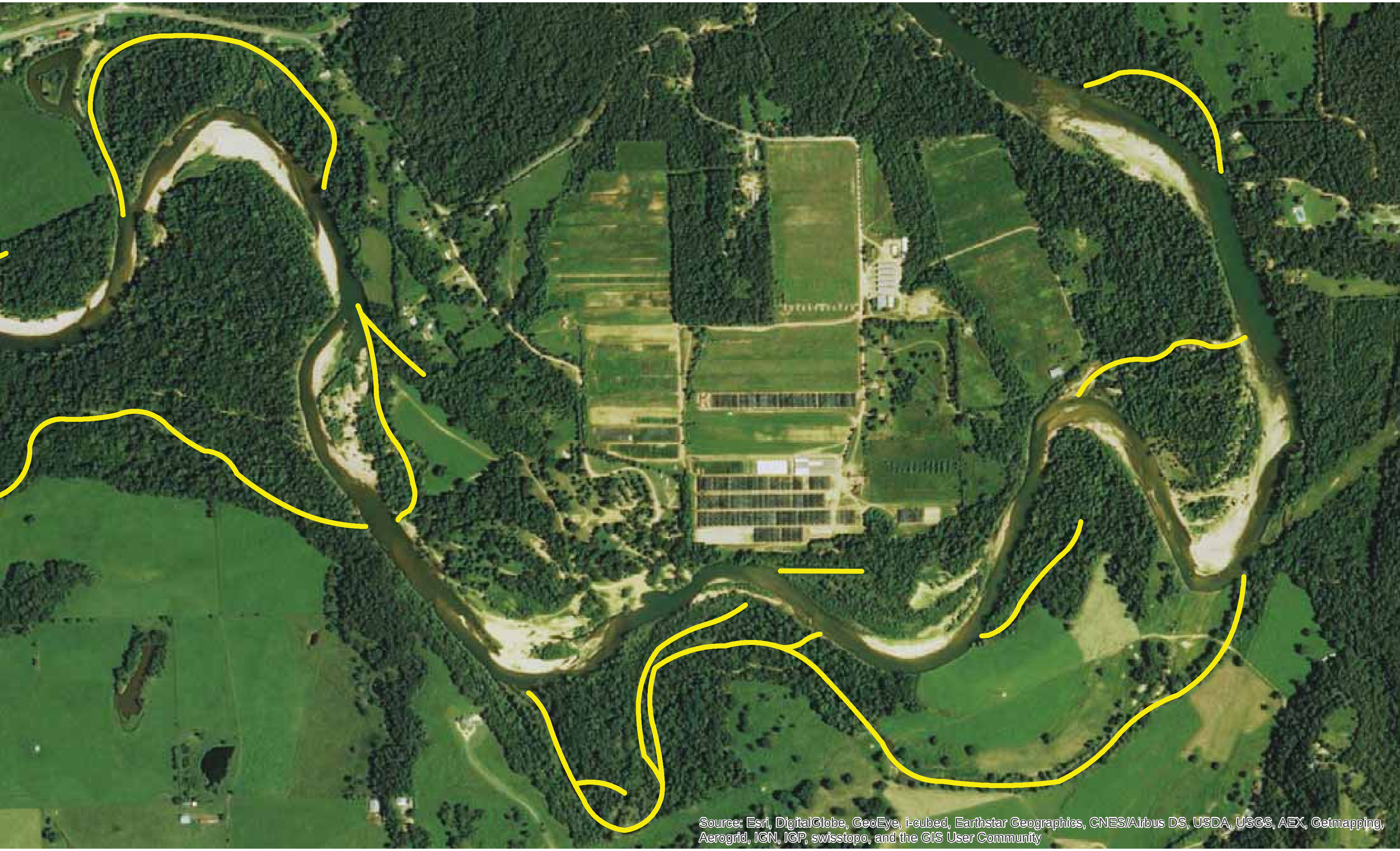
Appendix
Aerial Maps of the Illinois River Corridor between Tahlequah and Watts, Oklahoma, with Secondary Channels Highlighted

Maps are ordered from downstream to upstream.


Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community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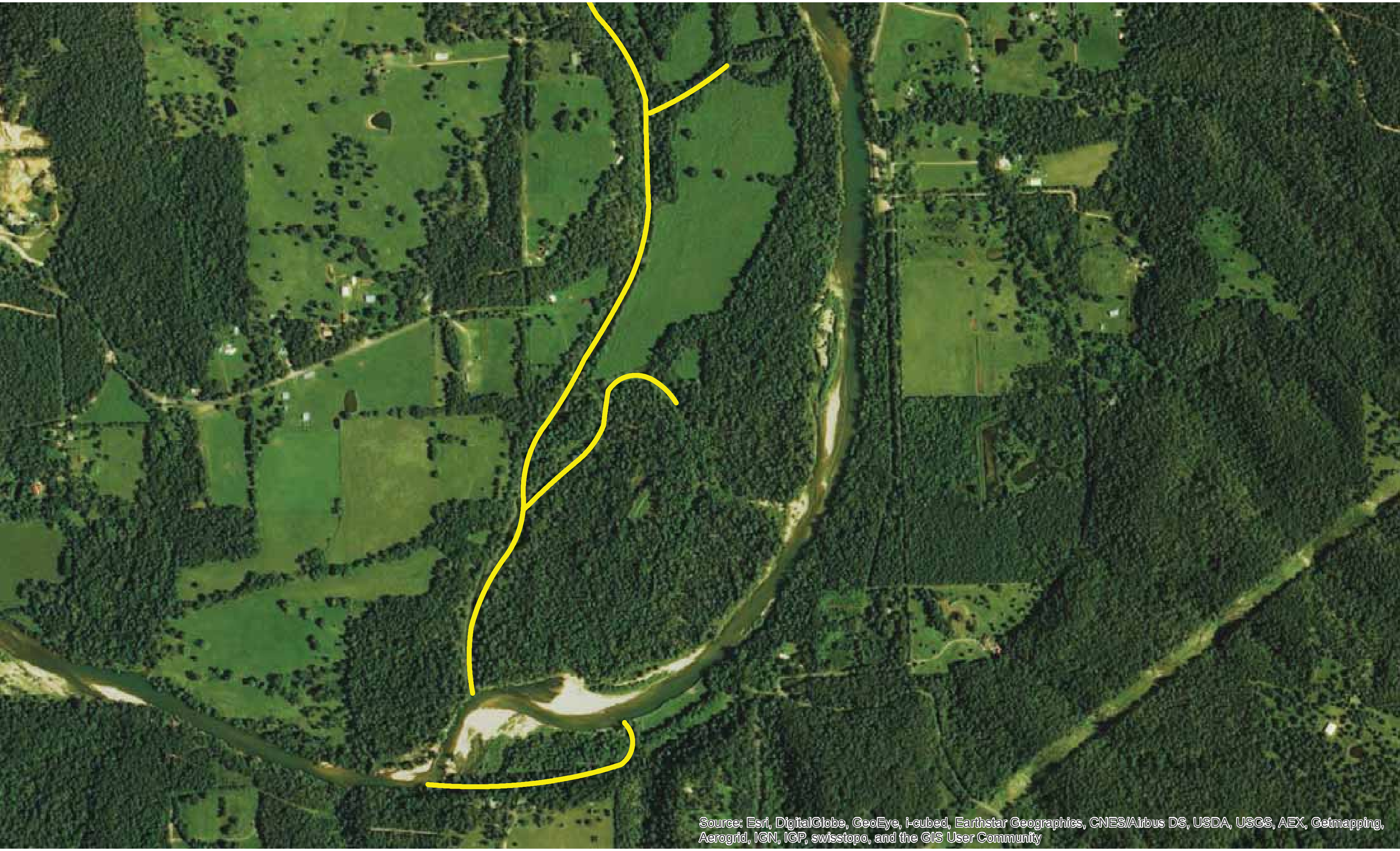
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community