FINAL REPORT

FEDERAL AID GRANT NO. T-7-P-1

REVIEW AND SUMMARIZATION OF LITERATURE PERTAINING TO THE ECOSYSYTEM FLOW REQUIREMENTS FOR THE KIAMICHI RIVER ABOVE HUGO LAKE AND LITTLE RIVER WATERSHED IN OKLAHOMA

OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

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FINAL REPORT

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GRANT TITLE: Review and Summarization of Literature Pertaining to the Ecosystem Flow Requirements for the Kiamichi River above Hugo Lake and Little River Watershed in Oklahoma

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I. OBJECTIVE:

To summarize the available body of knowledge on the natural flow regime, the ecosystem flow requirements of the fish and mussel assemblage, the riparian system, and the physical and chemical characteristics of the stream channel for rivers in southeastern Oklahoma.

II. SUMMARY

We summarized available literature on the flow regime, biota, and habitats of the Kiamichi River and Little River basins in southeastern Oklahoma to develop ecosystem flow requirements. The report consists of nine sections, which were written by different authors. These sections are: introduction, hydrology, geomorphology, physicochemical conditions, floodplain habitats and terrestrial biota—birds and mammals, floodplain habitats and terrestrial biota—amphibians and reptiles, aquatic habitats and biota—fishes, aquatic habitats and biota—mussels, and conclusions and recommendations. We offer the following preliminary recommendations about the location and timing of water withdrawals from the Kiamichi and Little rivers. For the Kiamichi River: (1) water should be taken from the Kiamichi River only during wet parts of the year (i.e., December 1 to June 1), except during dry periods, to maintain mussel beds and fluvial-specialist

fish species; (2) water should be taken from Hugo Reservoir and not from the Kiamichi River at Moyers, where mussel beds would be affected; and (3) water should be released from Sardis Lake into the Kiamichi River at rise and fall rates (i.e., as determined by IHA analyses) that mimic the natural flow regime to maintain geomorphic process. For the Little River: (1) water should be taken from the Little River below the confluence of the Mountain Fork River, and not from the Little River above the confluence near Idabel, only during the wet parts of the year (i.e., December 1 to June 1) to maintain mussel beds and fluvial-specialist fish species; and (2) flooding should be allowed in the Little River during the wet parts of the year (i.e., spring) to maintain bottomland forests and terrestrial and semi-aquatic vertebrates that require it for reproduction and survival. These recommendations should be considered preliminary and require substantiation by conducting further research on these stream ecosystems.

REVIEW OF ECOSYSTEM FLOW REQUIREMENTS FOR THE KIAMICHI AND LITTLE RIVERS BASINS IN SOUTHEASTERN OKLAHOMA

Final Report

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INTRODUCTION

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Rivers worldwide have been affected by dams and water diversions. There are an estimated 42,000 large dams (>15 m high) and 800,000 small dams in the world (Rosenberg et al. 2000). These dams fragment river systems and affect their natural hydrologic regime (Poff et al. 1997). Seventy-three percent of the total discharge of the 139 largest river systems in the northern third of the world has been significantly affected by fragmentation of rivers by dams and water regulation from reservoir operations, interbasin diversions, and irrigation (Dynesius and Nilsson 1994). In the U. S., the hydrologic regime of streams and rivers was dramatically altered in the 20th century, particularly in the later half. Of the 5,200,000 km of rivers in the contiguous 48 states, there are only 42 free-flowing rivers greater than 200 km in length and only 2% (<100,000 km) of them are of high enough quality to deserve federal protection status (i.e., Wild and Scenic or National Rivers) (Benke 1990). All large rivers and many small streams in Oklahoma have been dammed. In fact, the Blue River in southern Oklahoma is one of the 42 free-flowing rivers >200 km in the U.S. and the only one in Oklahoma (Benke 1990).

Alteration of the hydrologic regime of rivers from impoundments and flow diversions modifies the structure and function of river ecosystems (Poff et al. 1997, Rosenberg et al. 2000, Postel and Richter 2003). Hydrologic alterations are any anthropogenic disruptions that alter the magnitude and timing of natural river flows (Rosenberg et al. 2000). These alterations affect the physical and chemical properties and processes of rivers. For example, dams capture sediment moving downstream, which results in channel erosion, streambed armoring, and tributary headcutting downstream. Dam and water diversions also reduce the magnitude and frequency of high flow events resulting in channel stabilization and narrowing and reduced formation of point bars, secondary channels, and oxbows (Poff et al. 1997). Similarly, hydrologic alterations modify the ecological characteristics of rivers. Alterations such as flow stabilization, prolonged low flows, loss of seasonal flow peaks, rapid changes in river stage, and low or high water temperatures downstream disrupt life cycles of aquatic plants, invertebrates, and fishes resulting in a reduction in species diversity and modifying reproduction and growth rates that oftentimes lead to local extinctions of native species and the invasion and establishment of exotic species (Poff et al. 1997). Large water diversions deplete streamflows, sometimes to damaging levels that affect aquatic and floodplain habitats, aquatic biodiversity, sport and commercial fisheries, natural floodplain fertility, and natural flood control (Postel and Richter 2003). The development of water resources to meet the demands of urban population centers is growing and threatens the ecological integrity of many freshwater ecosystems (Fitzhugh and Richter 2004).

Water management goals in the new millennium have broadened from traditional societal goals of water supply, flood control, channel maintenance, power production, and commerce to include maintenance and enhancement of natural aquatic communities and ecosystem services. This has resulted in a paradigm shift from the simple question of "How much water can be taken from streams and lakes for human use?" to the more complex question of "How much water needs to be left in streams and lakes to sustain critical water-dependent natural resources?" (USFWS and USGS 2004). Evaluation of water development projects now requires consideration of effects at multiple scales, including consideration of the whole hydrograph and not simply minimum flows, the dynamic river channel rather than the static channel, the linkage between surface and ground water, and ecological communities rather than single species.

Surface and ground water in southeastern Oklahoma are under consideration for water development and diversion projects to meet future urban water needs. Recent reports by the Oklahoma Water Resources Board (OWRB) describe proposed water resource development projects and joint state-tribal water compact and water marketing proposals for southeastern Oklahoma (OWRB 2000, 2002). Directed by state legislation passed in 1999, the Kiamichi River Basin water resources development plan authorized the OWRB to negotiate with the Choctaw and Chickasaw Tribes, whose land encompasses the basin, to facilitate development of water supplies and identify potential benefits of those resources to Oklahoma citizens (OWRB 2000). Part of the impetus for the legislation was to help settle the ongoing legal dispute between the State of Oklahoma and the federal government (U.S. Army Corps of Engineers) over repayment of the project's construction costs attributed to the water supply. In 1999, the OWRB adopted a permanent rule that set aside 20,000 acre-feet/year from Sardis Lake for future water use in the 10-county area incorporating the Kiamichi River Basin. Purchase of the stored water by the State of Oklahoma will pay the outstanding debt to the federal government. The 2002 joint state-tribal water compact and water marketing proposal established a plan to supply water from the Kiamichi River Basin to Oklahoma City and from the Kiamichi and Little River basins to the North Texas area (OWRB 2002). Water for the Oklahoma City Water Utilities Trust (OCWUT) would be diverted from either the Kiamichi River near Moyers or below the Highway 3 bridge or from Hugo Lake and transferred via pipeline to McGee Creek Lake where the Atoka pipeline to the Oklahoma City area originates. Depending on whether water is withdrawn from available flows in the Kiamichi River or obtained from Sardis Lake water yields, either 55,000 or 149,762 acre-feet/year would be diverted from the Kiamichi River above Hugo Lake. The monetary benefit to Oklahoma for this water would be approximately $38 million by 2040, which would assume the debt owed to the federal government for the Sardis Lake contract obligation. Water for the North Texas Water Agency (NTWA) would be diverted via pipelines in phases from the Kiamichi River downstream of Hugo Lake (120,000 acre-feet/year; phase 1), the Little River upstream from the confluence of the Mountain Fork River (additional 40,000 acre-feet/year; phase 2), and the Little River downstream from the confluence of the Mountain Fork River (additional 200,000 acre-feet/year; phase 3). The monetary benefit to Oklahoma for this water would be $339 million over the next 100-years, which when amortized to include a commodity charge could yield an estimated $5.1 billion. The Kiamichi River Basin water resources development plan states that "the integrity of the Kiamichi River shall be protected" (OWRB 2000). A similar decree for the Little River Basin is in the joint state-tribal water compact and water marketing proposal (OWRB 2002).

Impacts of proposed water withdrawals from the Little River and Kiamichi River on the hydrology, physiochemical characteristics, aquatic biota, and floodplain habitats need to be identified to define river flows needed to sustain them and the integrity of these waters. In February 2003, an Ecologically Sustainable Water Management workshop was held in Edmond, Oklahoma to introduce the Oklahoma Freshwater Initiative. The initiative was established to help protect the ecological health of the Kiamichi and Little rivers as well as meet human uses for water provided by those rivers. In a series of breakout sessions, workshop attendees identified information needs for these rivers. One such need was information on the ecosystem flow requirements for the Kiamichi and Little rivers, which was the impetus for this project.

The objective of this report is to summarize the available body of knowledge on the natural flow regime, the ecosystem flow requirements of the fish and mussel assemblages, the riparian system and associated flora and fauna, and the physical and chemical characteristics of the stream channel for the Kiamichi and Little rivers in southeastern Oklahoma. In this report, we (1) define spatial extent of study area and temporal extent of hydrologic alterations to these rivers, (2) define baseline conditions for assessing hydrologic alterations for both pre-impoundment (historical) and post-impoundment (current) periods, (3) summarize literature on hydrologic alterations on terrestrial and aquatic vertebrates and mussels and their habitats, (4) develop ecosystem flow recommendations for both rivers based on proposed hydrologic alterations, and (5) identify research needs and information gaps for adaptive processes to refine flow recommendations.

Project Area

We defined the spatial and temporal extent of the proposed project to help frame our review and evaluation. The project as proposed will potentially impact three river reaches: upper Kiamichi River, lower Kiamichi River, and lower Little River. The OCWUT proposes to purchase water supply storage from Sardis Lake (OWRB 2002). The proposed water transfer scenario would involve water withdrawals of a minimum of approximately 55,000 acre-feet/year from available streamflows (or from downstream water released from Sardis Lake) from the upper Kiamichi River at a point near Moyers north of Antlers or from Hugo Lake if the occurrence and flow requirements of endangered species (e.g., Ouachita Rock Pocketbook mussel, *Arkansia wheeleri*) preclude taking water at Moyers (Figure 1, bottom panel). This water would be transferred westward through a pipeline to McGee Creek Lake and onto Oklahoma City via the Atoka Pipeline (Figure 1, top panel). Water withdrawals by the NTWA of approximately 120,000 to 160,000 acre-feet/year would be taken from the lower Kiamichi River below Hugo Dam (Figure 2, top panel) through a pipeline that would drain into Indian Creek, a tributary of Lake Lavon in north Texas (Figure 2, bottom panel). Additional water withdrawals of 200,000 acre-feet/year would occur in the lower Little River below Pine Creek Lake near Idabel and downstream from the confluence of the Mountain Fork River (Figure 2, top panel). We were uncertain of the types of water withdrawal structures that would be used in each river reach. Lowhead dams across the Kiamichi and Little rivers would have local effects on the habitat and biota at each withdrawal site, including blocking the migration of fish hosts of mussels. Drain pipes in the rivers would also have localized impacts.

The temporal extent of the proposed water withdrawals is much more difficult to define. We attempted to evaluate both the historical and current conditions of the riverine ecosystems in southeastern Oklahoma. Historical conditions were operationally defined as prior to the construction of mainstem impoundments on the Kiamichi River and in the Little River Basin. Major impoundments were built on the mainstem Kiamichi River, Little River, and Mountain Fork River in southeastern Oklahoma in the late 1960s and early 1970s for the purpose of flood control, water supply, water quality, recreation, and fish and wildlife. Hugo Lake, which was completed in 1974, is a 13,958-ha reservoir located on the Kiamichi River 28 river km upstream from its confluence with the Red River. Pine Creek Lake is a 1,538 ha reservoir on the Little River that was completed in 1969 and is located 1,843 river km upstream from its confluence with the Red River. Broken Bow Lake on the Mountain Fork River was completed in 1970 and is located 33 km upstream of the river's confluence with the Little River. The dam impounds a 5,746-ha reservoir, from which water is used to generate hydroelectric power. In addition to these mainstem reservoirs, a 5,811-ha reservoir, Sardis Lake, was created in 1983 on Jackfork

Creek, a tributary of the Kiamichi River, for the purpose of flood control, water supply, and recreation. The dam is located 4.5 km upstream from the confluence of the creek with the Kiamichi River. Current conditions were defined as post-impoundment (ca. 1975) to the present.

Evaluating future conditions and impacts of the project is much more difficult. Availability of water for OCWUT, depending on the withdrawal site on the Kiamichi River, could occur as late as 2070. Given concerns about future human population growth and global climate change (Postel and Richter 2003), predictions of water yield 50 to 100 years from now that are based on present conditions may be highly inaccurate.

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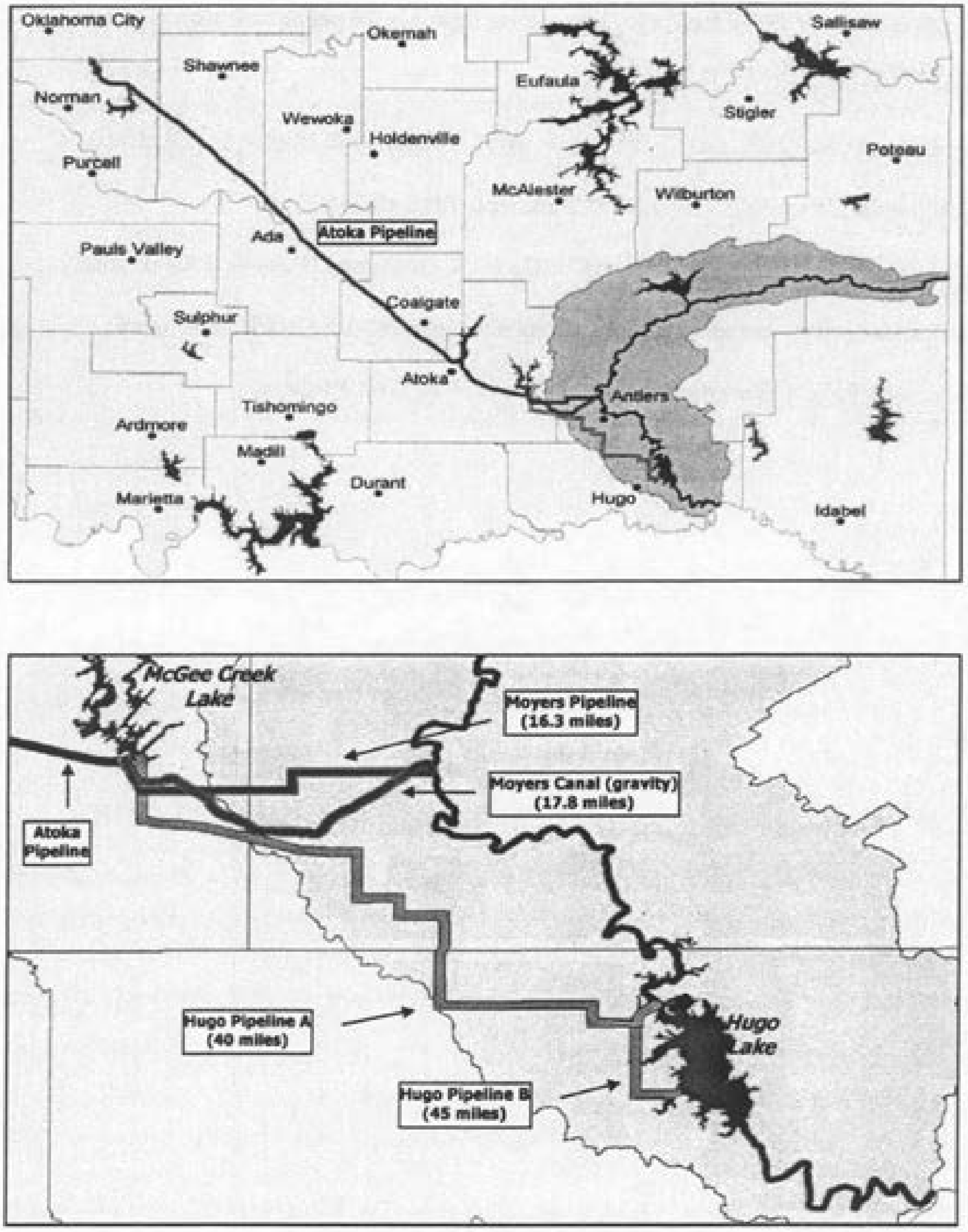

Figure 1. Proposed water withdrawal sites for OCWUT pipeline to Oklahoma City. Top panel shows connection with Atoka pipeline, bottom panel show possible withdrawal sites. Figure scanned from OWRB (2002).

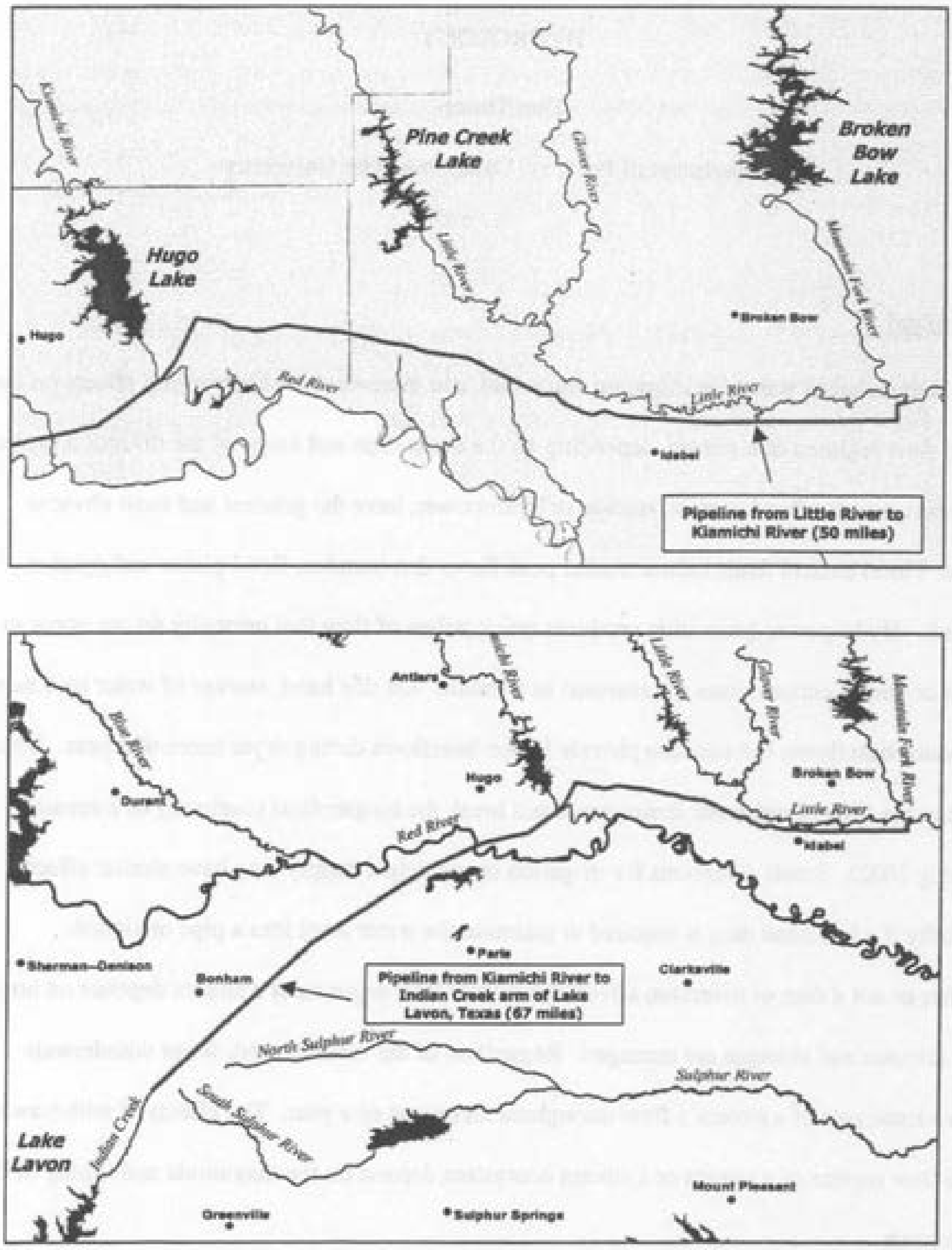

Figure 2. Proposed water withdrawal sites for the NTWA pipeline to north Texas. Top panel shows the pipeline connections in southern Oklahoma, bottom panel shows the pipeline entering Indian Creek in Texas. Figure scanned from OWRB (2002).

HYDROLOGY

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Background

Diversion of water for irrigation, industrial, and municipal use has varying effects on the natural flow regimen of a stream, depending on the magnitude and scope of the diversion project. Dams designed for flood control, storage or hydropower, have the greatest and most obvious effects. Flood control dams reduce annual peak flows that inundate flood plains and riparian wetlands. Hydropower generation produces quick pulses of flow that normally do not occur in a stream or during certain times (or seasons) in a stream. On one hand, storage of water by a dam can reduce baseflows, but can also provide longer baseflows during dryer times of a year. Dams also stop the flow of sediment downstream and break the longitudinal continuity of a stream (Whiting 2002). Small diversions for irrigation or municipal supply may have similar effects, especially if a low head dam is required to maintain the water level into a pipe or siphon. Whether or not a dam or diversion affects the natural flow regimen of a stream depends on how water releases and storages are managed. Regardless of the method used, water withdrawals remove some part of a stream's flow throughout all or part of a year. The effects of withdrawals on the flow regime of a stream or a stream ecosystem depend on the magnitude and timing of the withdrawals.

In order to maintain the ecological integrity of a stream, flows should be managed in a way that reflects the natural flow regimen (Poff et al. 1997 and Richter et al. 2003). The flow regime of a stream is characterized by streamflow magnitude, frequency, duration, timing (daily and seasonal), and rates of change. All of these factors control to some extent the water quality, sources of energy, physical habitat, and biotic interactions of stream ecosystems (Poff et al. 1997). The parameters that characterize the flow regime of a stream such as, streamflow magnitude, frequency, duration and timing, vary greatly in response to storm precipitation and seasonal changes in soil moisture and precipitation. It would be difficult to make a flow prescription to maintain aquatic ecosystems based on average conditions without considering the natural variability of the system.

Richter et al. (1996) developed a set of biologically relevant parameters that describe the flow components of a stream's hydrologic regime. These parameters are related to the different flow needs of aquatic organisms during their life cycles. The parameters are broken into 5 groups, the magnitude of monthly water conditions, the magnitude and duration of annual extreme water conditions, the timing of annual extreme water conditions, the frequency and duration of high and low pulses, and the rate and frequency of water condition changes (Richter et al. 1996). The parameters form the basis for a computer model developed to determine the effects of water management on a stream's flow regime called the Indicators of Hydrologic Alteration (IHA) (Richter et al. 1996). The IHA model evaluates 33 parameters (Table 1) that are indicators of hydrologic alteration (The Nature Conservancy and Smythe Scientific Software, 2001). Long-term mean 24 hour discharge values from US Geological Survey gaging stations are the primary source of input data for the model. If the streamflow record is long enough, alterations in a stream's flow regime can be assessed after the installation of a dam, water diversion or other activity. The program does not perform hypothesis testing of whether or not a change has occurred; rather it evaluates each parameter and its variability and magnitude of change as indicators of alteration. If a parameter value following an activity on the stream falls outside its natural range of variability, or if variability is less than expected based on pre-activity data, then that parameter is presumed to be affected by the activity. The program uses parametric or non-parametric methods for evaluating changes in the parameters. See Richter et al. (1996) and the IHA User's Guide (The Nature Conservancy and Smythe Scientific Software, 2001) for additional details.

Streamflow Data

The availability of streamflow data for the Little River Basin in Oklahoma and the Kiamichi River Basin was investigated. Table 2 summarizes the gaging station names and dates of available mean daily flows. The data was obtained on-line from the United States Geological Survey Surface-Water Data for the Nation Web Site (http://waterdata.usgs.gov/usa/nwis/sw, May 24, 2005). The analysis described in this report uses data from only 3 stations, Little River below Lukfata Creek near Idabel (07338000), Kiamichi River near Belzoni (07336500) and Kiamichi River near Antlers (07336200).

Methods

Streamflow Data

Basic descriptive hydrologic data were collected and developed for the Kiamichi and Little Rivers. Graphs of annual flows, monthly flows, annual peak flows, daily flows and daily statistics, mean daily with maximum and minimum daily flows, and flow duration curves are shown in Figures 1-6 for the Little River below Lukfata Creek near Idabel and Figures 7-14 for the Kiamichi River near Antlers. In order to properly evaluate hydrologic alterations with the IHA model, at least 20 years of data before and after an impact are required. An IHA analysis was run to determine the effects of Pine Creek Reservoir and dam on the flow regime of the Little River and to quantify the natural flow regime (pre-dam). Pine Creek Lake and dam was operational in 1969. Twenty one years of data were available before the dam and 34 years after dam construction. The Belzoni gaging station on the Kiamichi River was in operation from 1926 to 1972 (46 years). Unfortunately, after the completion of Hugo Lake downstream of Belzoni, the gaging station was closed because it was in the lake's backwater. The station was moved to a location upstream (about 17.7 km) near Antlers. The move resulted in a loss of about51,800 ha of drainage area. The Antlers station began recording data in 1973. We wished to analyze the effects of Sardis Lake on the flow regime of the Kiamichi River using the IHA model. The Antlers station provides only 10 years of pre-dam data. Ten years of data is less than the 20 year minimum required by the IHA model.

Therefore, the Belzoni data was adjusted and combined with the Antlers data to create a record for the Kiamichi River from 1926 to 2003. This procedure produced 57 years of pre-Sardis Lake and 20 years of post-Sardis Lake data. To make the adjustment the Belzoni mean daily flow data was divided by a factor of 1.1. This adjustment did not make the daily flows at Belzoni and Antlers equal because the record represented different dates. However it made the magnitudes of the mean annual and mean monthly flows equal. It was assumed that because both stations were on the same river, the natural flow variability of the Kiamichi River at Belzoni would be roughly equal to that at Antlers. The combined and adjusted data set is called the Kiamichi River at Antlers Combined Data. Mean daily flow statistics (Figures 10 and 12), and mean daily with maximum and minimum flows data (Figures 11 and 13) for the Kiamichi river are reported individually for the Antlers and Belzoni gaging stations.

IHA Analysis

An IHA analysis was run for both the Little and Kiamichi Rivers. The non-parametric analysis method was chosen for both rivers. One IHA run produces a tremendous amount of information in both table and graphical form. Two summary tables, the non-parametric IHA scorecard and the IHA non-parametric Range of Variance Analysis (RVA) scorecard contain most of the information required to determine impacts on the 33 IHA parameters (Tables 3,4,5 and 6). One IHA run also generates over 60 graphs from the standard and RVA analysis of the data. The Hydrologic Alteration graph and the Greatest Hydrologic Alteration graphs provide most of the graphical information needed to determine impacts. They are shown for both rivers in Figures 15, 16, 17 and 18.

The non-parametric IHA score card (Tables 3 and 5) presents results based on percentile distributions of the data. The pre and post medians, pre and post coefficients of dispersion, deviation factor and significance count is calculated for each IHA parameter. The coefficient of dispersion is defined as (75%tile-25%tile)/50%tile. The deviation factor = [(Post-impact value)-(Pre-impact value)] ÷ (Pre-impact value). Medians and coefficients of variance (CV) are calculated for the deviation factors and significance counts.

The IHA non-parametric RVA scorecard shows statistics for the 33 parameters including medians, coefficients of variance, and the range for the pre-impact period. The same parameters plus the low and high RVA category values and the hydrologic alteration factors (HAF) (middle RVA category) are shown for the post-impact years (Tables 4, 5, 7 and 8). The second half of the RVA scorecard displays the expected and observed frequencies at which the parameters fall in the low, middle, and high RVA categories and the HAF for each category. The middle RVA

Table 1: The statistics groups, the 33 hydrologic parameters, and ecosystem influences of each parameter used in the Indicators of Hydrologic Alteration methodology.

IHA Statistics Group	***Hydrologic Parameters***	***Ecosystem Influences***
Magnitude of monthly water conditions	Mean value for each calendar month	• Habitat availability for aquatic organisms • Soil moisture availability for plants • Availability of water for terrestrial animals • Availability of food/cover for fur-bearing mammals • Reliability of water supplies for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, photosynthesis in water column
	Subtotal 12 parameters	
Magnitude and duration of annual extreme water conditions	Annual 1-day minima	• Balance of competitive, ruderal, and stress- tolerant organisms
	Annual minima, 3-day means	• Creation of sites for plant colonization
	Annual minima, 7-day means	• Structuring of aquatic ecosystems by abiotic vs. biotic factors
	Annual minima, 30-day means	• Structuring of river channel morphology and physical habitat conditions
	Annual minima, 90-day means	• Soil moisture stress in plants
	Annual 1-day maxima	• Dehydration in animals
	Annual maxima, 3-day means	• Anaerobic stress in plants
	Annual maxima, 7-day means	• Volume of nutrient exchanges between rivers and floodplains
	Annual maxima, 30-day means	• Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments
	Annual maxima, 90-day means	• Distribution of plant communities in lakes, ponds, floodplains
	Number of zero-flow days (zero flow)	• Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
	7-day minimum flow/mean for year (base flow)	
	Subtotal 12 parameters	

Table 1 (continued):

IHA Statistics Group	***Hydrologic Parameters***	***Ecosystem Influences***
Timing of annual extreme water conditions	Julian date of each annual 1-day maximum	• Compatibility with life cycles of organisms • Predictability/avoidability of stress for organisms
	Julian date of each annual 1-day minimum	• Access to special habitats during reproduction or to avoid predation • Spawning cues for migratory fish Evolution of life history strategies, behavioral mechanisms
	Subtotal 2 parameters	
Frequency and duration of high and low pulses	Number of low pulses within each year	• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants
	Mean duration of low pulses within each year	• Availability of floodplain habitats for aquatic organisms • Nutrient and organic matter exchanges between river and floodplain
	Number of high pulses within each year	• Soil mineral availability • Access for waterbirds to feeding, resting, reproduction sites
	Mean duration of high pulses within each year	• Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
	Subtotal 4 parameters	
Rate and frequency of water condition changes	Means of all positive differences between consecutive daily values	• Drought stress on plants (falling levels)
	Means of all positive differences between consecutive daily values Number of hydrological reversals	• Entrapment of organisms on islands, floodplains (rising levels) • Desiccation stress on low-mobility streamedge (varial zone) organisms
	Subtotal 3 parameters	
	Grand total 33 parameters	

Table 2. Summary of streamflow data available from US Geological Survey gaging stations in the Little and Kiamichi Rvier basins.

Station Name	USGS ID#	Water Years Available	Notes
Kiamichi near Big Cedar	07335700	1965-2003	Good background information for headwaters
Kiamichi near Clayton	07335790	1980-2003	Little pre-Sardis Lake data
Kiamichi near Antlers	07336200	1972-2003	Replaced station at Belzoni after Hugo Lake
Kiamichi near Belzoni	07336500	1925-1972	Combined with Antlers station for long-term analysis
Glover River near Glover	07337900	1962-2003	41 years of natural flows
Little River near Wright City	07337500	1945-1989	Between Pine Creek Dam and Glover confluence
Little River near Idabel	07338000	1929-1946	Upstream of LRNWR
Little River below Lukfata Creek	07338500	1946-2003	On Highway 3 bridge upstream of LRNWR
Little River near Horatio, AR	07340000	1915-2003	Upstream of Millwood Lake, downstream of Mountain Fork and Lake DeQueen
Mountain Fork near Smithville	07338750	1991 – 2003	Record too short for IHA analysis
Mountain Fork near Eagletown	07339000	1924-2003	Record affected by Broken Bow Dam

category is bounded by the median of the pre-impact ± 17 percentiles (default value used in this analysis). The hydrologic parameters are variable year to year in both the pre and post-impact periods. IHA calculates the number of times a parameter falls within the low, middle and high RVA categories for each year in the pre-treatment period. This is defined as the expected frequency. The IHA also calculates the frequency at which each parameter falls in the low, middle, and high RVA categories for the post-impact period. This is defined as the observed frequency (Tables 5 and 8). The HAF for each parameter and each RVA category is given by:

$$HAF = \frac{Observed - Expected}{Expected}$$

It is an indicator of the change in frequency of a parameter within ranges of magnitudes (low, middle, and high categories). If the observed frequency equals the expected, the alteration factor is 0. Therefore, the closer the HAF is to zero, the less impact. The greater the impact is, the greater the HAF. A negative (positive) HAF indicates the observed frequency is less (more) than expected. If a post-impact value falls more often than expected in the middle RVA category it indicates the parameter is less variable than before the impact. If the post-impact values fall more often than expected in the low RVA category, it indicates a reduction in the magnitudes of that parameter. The opposite is true if the observed value falls more often in the high RVA category. There may be cases where a post-impact value falls more or less often in all 3 categories. This indicates increased variability in that parameter from the impact.

For example, observe the hydrologic alteration analysis for the 3 and 7 day minimum flows (baseflows) on the Little River (Tables 4 and 5). The impact on the Little River was the construction of Pine Creek Dam in 1969. The pre-impact medians and coefficients of variance for the 3 and 7 day minimum flows are 9.3 and 2.78 and 9.6 and 3.02 respectively. The post-impact medians and coefficients of variance for the 3 and 7 day minimum flows are 30.3 and 0.77 and 30.7 and 0.76 respectively. These results alone show that the 3 and 7 day minimum flows have increased and become less variable following dam construction. The HAF for the middle RVA category for both the 3 and 7 day minimum flows is -0.61. This indicates the 3 and 7 day minimum flows occur more often near the median and are more constant following dam construction than before. The HAF for the high RVA category for both the 3 and 7 day minimum flows is 1.69. This indicates that the minimum flows occur more often than expected at a higher magnitude (expected = 11.14, observed = 30.0). The HAF for the low RVA category for both the 3 and 7 day minimum flows is -1.00. This indicates that low magnitude flows occur less frequently following the dam construction than before when flows were natural. Based on the IHA analysis of 3 and 7 day minimum flows on the Little River before and after Pine Creek Dam, we can conclude that the baseflow regime has changed, the median flows are greater and the flow is more constant. More than likely, water stored in Pine Creek Lake is being released during low flow periods to maintain some magnitude of minimum flow. The purpose of this minimum flow may be to meet fisheries objectives or to dilute or flush nutrients and wastes to maintain water quality. The RVA analysis for the 3 and 7 day minimum flows for the Little River are also displayed graphically by IHA (Figures 19 and 20).

The same type of analysis as discussed in the paragraph above must be performed for all of the parameters. The IHA provides both an estimate of the magnitude and frequency of alteration. For some parameters the frequency of occurrences may be more important than an actual magnitude, ie: the number of zero flow days, the high and low pulse counts, and the number of flow reversals. For other parameters, the magnitude of change may be more important, ie: rise and fall rates, monthly flows and minimum and maximum flows. Whether or not change in any of the parameters is significant depends on the needs of aquatic organisms in the stream.

Results

Little River below Lukfata Creek near Idabel, Oklahoma

The IHA analysis for the Little River was run to determine the effects of Pine Creek Lake and dam on the hydrologic regime and to quantify the natural flow regime (pre-dam) to assist us in evaluating the effects of proposed water withdrawals from the Little River. Pine Creek dam became operational in 1969. Therefore, the pre-impact period was 1947–1968 and the post-impact period was 1969-2003. Hydrologic alteration data from the IHA analysis are shown in Figures 15 and 16 and Tables 3, 4 and 5. Basic hydrologic characteristics and flow duration curves before and after the dam were graphed to supplement the IHA analysis (Figures 1-6).

Monthly flows (Parameter Group 1)—Median monthly flows increased for all months except April, May, and September in the post-dam period. Coefficients of dispersion decreased for all months except October and June (Table 3). This indicates that the monthly flow has increased and become less variable. The Hydrologic Alteration Factor (HAF) analysis indicates that all monthly flows have been altered to some extent (Figures 15 and 16 and Tables 4 and 5). The HAF analysis for the months of October, November, December, January, February, March, June, July, and August (Figure 16) indicated that monthly flows occur more often than expected at a higher magnitude (+HAF in high RVA category and –HAF in low and middle categories in most cases) in the post dam period. The HAF analysis in the monthly flows for April, May and September indicated that flows occur more frequently at a lower magnitude (-HAF in high RVA category and +HAF in higher in the middle or low RVA categories). April and May are normally the wettest months of the year, yet monthly flows were reduced in the post-dam period. It is likely that water was being stored in Pine Creek Lake in the high rainfall periods.

Magnitudes and frequencies of minimum and maximum flows (Parameter Group 2).— The median 1, 3, 7, 30, and 90-day minimum flows increased and the coefficients of variation decreased after the dam (Table 4). This indicates that minimum flows are higher and less variable. The HAF analysis for the 1, 3, 7, 30, and 90-day minimum flows indicated that these flows occur more frequently than expected at a higher magnitude (+HAF in high RVA category and –HAF in low and middle categories). The before and after dam flow duration curves also show an increase in low flows (Figure 6). For example, flows that typically exceeded 99% of the time before the dam were less than 10 cfs. After the dam they were approximately 20-30 cfs. This change is likely caused by stored water being released from the dam to provide some minimum flow in the river.

The median 1, 3, 7, and 30-day maximum flows decreased and the coefficients of dispersion decreased in the post-dam period (Table 3). The median 90-day maximum flow increased and the coefficients of dispersion decreased in the post-dam period (Table 3). Coefficients of variance also decreased for all maximum flow parameters (Table 4). The HAF analysis for the 1, 3, 7, and 30 day maximum flows indicated that these flows occurred more frequently at a lower magnitude than in the pre-dam period (+HAF in low RVA category and – HAF in the middle and low categories). The HAF analysis for the 90-day maximum flow indicated an increase in the post-dam period (+HAF in RVA high category and –HAF in low RVA category). Pine Creek Dam was constructed in part for flood control. The results above indicate a reduction in short-term peak flows (1, 3, and 7-day maximums) that result from flood producing storms. The graph of annual peak flows for the Little River (Figure 3) shows a reduction in annual peaks following the construction of Pine Creek Dam. The 30 and 90-day maximum flows represent the highest flows averaged across 30 (monthly) or 90 (seasonal) days. The median 90-day maximum increased in the post-dam period. The increase is likely the result of the release of water stored in Pine Creek Lake over time.

There were no zero-flow days in the pre-and post dam periods, although flow did sometimes drop below 1 cfs. Baseflow is defined as the 7-day minimum flow divided by the mean flow for the year. The median baseflow increased and variability decreased in the post-dam period (Tables 3 and 4). The HAF analysis for baseflow indicated that it occurs more frequently at a greater magnitude in the post-dam period (+HAF in high RVA category and –HAF in middle and low categories). The increase in baseflow is likely due to the release of stored water from Pine Creek Lake to maintain a minimum flow (see Minimum Flows above).

<u>Timing of annual extreme water conditions (Parameter Group 3)</u> — These parameters represent the Julian dates on which the 1-day minimum and maximum flows occur and their associated variances. The median date of minimum changed from day 265.5 (late September) in the pre-dam to day 246 (early September) in the post-dam period. The coefficient of variance increased from 0.09 to 0.14. The HAF analysis indicated that the date of minimum occurs more frequently at an earlier date (+HAF in low RVA category and –HAF in middle category). The median date of maximum increased from 128.59 in the pre-dam (early May) to 339 (early December) in the post-dam period (Table 4). The coefficient of variance also increased. The HAF analysis indicated that the day of minimum occurred earlier in the year in the post-dam period (-HAF in middle RVA category and +HAF in the high category). These changes are likely due to the presence of the dam. A flood producing flow may be completely stored by the

dam depending on the amount of storage available to the beginning of the storm. Annual peak flows on the Little River ranged from approximately 10,000 cfs to 70,000 cfs in the pre-dam period (Figure 3). The IHA does not distinguish between the size of the annual peaks, only the day on which they occur. The smaller annual peak flows may be completely captured by the lake, but part or most of the larger annual peak flows may be released. Regardless of the reason, an alteration of the date of maximum is indicated.

Frequency and duration of high and low pulses (Parameter group 4)—Hydrologic pulses are defined as periods in which mean daily flow either rises above the 75th percentile or falls below the 25th percentile of all the mean daily flows in the pre-dam period. The IHA RVA scorecard indicated that there was little change in the median number of low pulse counts and coefficients of variance between the pre and post-dam periods (Table 4). Low pulse duration decreased somewhat (17.2 to 12.2) with little change in the coefficients of variance. The medians of the high pulse counts (10 to 11) and high pulse durations (8 to 10.7) and their variances increased slightly between the pre and post-dam periods (Table 4). The HAF analysis shows more high pulses occurring in the post-dam period (+HAF in High RVA category and –HAF in middle category). The HAF analysis for high pulse duration showed the same trend.

Rate and frequency of water condition changes (Parameter Group 5)—The median rise rate decreased between the pre and post-dam periods from 1,135.2 cfs/day to 688 cfs/day (Tables 3 and 4). Coefficients of variance remained about the same. The HAF analysis (Figure 15 and Table 5) shows rise rates decreasing as well (-HAF in high category and +HAF in low category). The median fall rate also decreased between the pre and post-dam periods from -387.7 to -354.3 cfs/day. Coefficients of variance remained about the same. These results indicate that Pine

Creek Dam is attenuating the flows in the Little River. There are fewer and smaller peak flows, and rates of and falls are slower as well.

The median number of flow reversals per year increased between the pre and post-dam periods from 64 to 86 (Table 4). The coefficients of variance remained about the same. The HAF analysis (Figure 15 and Table 5) indicated that the number of reversals increased in the post-dam period (+HAF in high RVA category and –HAF in the low and middle categories). The increase in flow reversals is likely due to releases of water from Pine Creek Dam.

Kiamichi River near Antlers, Oklahoma

The IHA analysis for the Kiamichi River was run to determine the effects of Sardis Lake and dam on the hydrologic regime and to quantify the natural flow regime (pre-dam) to assist us in evaluating the effects of proposed water withdrawals from the Kiamichi River. Sardis dam became operational in 1983. Therefore, the pre-impact period was 1926–1982 and the post-impact period was 1983-2003. Hydrologic alteration data from the IHA analysis are shown in Figures 117 and 18 and Tables 6, 7, and 8. Basic hydrologic characteristics and flow duration curves before and after the dam were graphed to supplement the IHA analysis (Figures 7-14).

<u>Monthly flows (Parameter Group 1)</u>—Median monthly flows both increased and decreased in the post-Sardis dam period (Table 6 and 7). Coefficients of variance (Table 7) and coefficients of dispersion (Table 8) increased, decreased, or remained approximately the same for individual months. The median monthly flows for August, September, and October decreased between the pre and post dam periods. Variances increased for August and October, but decreased for September (Tables 6 and 7). The HAF analysis also indicates lower monthly flows for the months of August (+HAF in low RVA category and –HAF in middle category), September (+HAF in middle category and –HAF in high RVA category), and October (+HAF in

high and low categories and –HAF in middle category). August and September usually have the lowest monthly flows (Figure 8). Storage of water in Sardis Lake during these dry months may be responsible for reducing the monthly flows.

Median flows for July, typically one of the driest months of the year (Figure 8) increased between the pre and post dam periods from 66 to 154 cfs. Variance decreased (Table 6). The HAF analysis shows that the July monthly flow is attenuated, more flows clustering around the median (+HAF in middle RVA category and –HAF in the low and high categories). The higher and more consistent flow is likely the result of releases from Sardis Lake.

Median flows for November, December, January, March, May, and June increased between the pre and post dam periods (Table 6). Variances increased or decreased a small amount. The HAF analysis also indicates increases in monthly flows for these months. Median monthly flows for February and April decreased in the post-dam period. Variances changed little for these months. The HAF analysis also indicated decreased monthly flows for February and April.

<u>Magnitudes and frequencies of minimum and maximum flows (Parameter Group 2)</u>-- Median 1, 3, 7, 30, and 90-day minimum flows increased in the post-dam period. Variances for these parameters decreased (Tables 6 and 7). The HAF analysis indicated that the 1, 3, 7, 30, and 90-day minimum flows decreased in the post-dam period as well (-HAF in low RVA category and +HAF in the middle and high categories). The before and after dam flow duration curves for the Kiamichi River (Figure 14) also show a small increase in low flows resulting form Sardis Lake. Increases in minimum flows are likely due to releases of water from Sardis Lake during periods when natural flows did not exist.

The median 1, 3 and 7 maximum flows increased in the post-dam period. Variances decreased slightly (Table 6 and 7). The HAF analysis also indicated a decrease in the 1, 3 and 7 day maximum flows during the post-dam period (Figure 17 and Table 8) (-HAF in high category and +HAF in the middle and low categories). Sardis dam was built for flood control, so 1, 3 and 7 day peak flows are reduced by flood storage. The magnitude of reduction in the 1, 3, and 7 day peaks on the Kiamichi River was not as great as the reduction on the Little River (compare Figures 3 and 9). About 50 % of the Little River drainage area is upstream of the dam, whereas about 25% of the Kiamichi River drainage area is upstream of Sardis Lake.

The median 30-day maximum flow remained the same and the median 90-day minimum flow increased slightly in the post-dam period. The variances of both parameters decreased (Tables 6 and 7). The HAF analysis indicated that the 30-day maximum flow remained unaffected (+HAF middle category and –HAF in high and low categories). The HAF analysis of the 90-day maximum flows indicated an increase in 90-day maximum flows near the median value and a decrease in higher peaks (+HAF in middle category and –HAF in the high category). The 30 and 90-day maximum flows represent the highest flows averaged across 30 (monthly) or 90(seasonal) days. The slight increase in 90-day maximum flows is likely due to releases of flow from Sardis Lake.

The median number of zero flow days was 0.0 for both the pre and post-dam periods (Table 6). The HAF analysis (Figure 17 and Table 8) indicated that fewer zero flow days can be expected in the post-dam period than in the pre-dam period (-HAF in high RVA category and +HAF in middle category). This finding is consistent with the observed increases in minimum flows. The median baseflow was 0.0 for both the pre and post-dam periods (Table 6). The variance, however, decreased (Table 7). The HAF analysis (Figure 17 and Table 8) indicated a slight shift upward in baseflow (-HAF in low RVA category and +HAF in the middle and high categories).

Timing of annual extreme water conditions (Parameter Group 3)—The median dates of the minimum and maximum flows increased slightly, + 4 days and +15 days respectively. Variances increased and decreased slightly in the post-dam period (Tables 6 and 7). The HAF analysis indicated that the Julian date of the minimum and maximum flows increased a small amount as well (-HAF in low RVA category and +HAF in high RVA category) (Figure 17 and Table 8). However, the dates of the minimum and maximum flows remained in the same months, September and May respectively. Sardis Dam had little effect on these parameters.

Frequency and duration of high and low pulses (Parameter group 4)—The IHA RVA scorecard indicated that there was little change in the median number of low pulse counts and coefficients of variance between the pre and post-dam periods (Table 6). Low pulse duration decreased somewhat (15.8 to 14.6) with about a -0.10 change in the coefficients of variance. The HAF analysis showed little alteration in the low flow count. The HAF analysis of low pulse duration (Table 8 and Figure 17) indicated a shift towards the median value with less variability (+HAF in middle category and –HAF in low and high categories). The median high pulse count decreased by 1.0 in the post-dam period. Variance decreased by about one-half (Table 6 and 7). The HAF analysis (Table 8 and Figure 17) indicated a shift in the high pulse count towards the median with less variation in the post-dam period. The median high pulse duration exhibited a slight increase in magnitude and a slight increase in variance in the post dam period (Tables 6 and 7). The HAF analysis of high pulse duration indicates an increase in duration during the post-dam period (+HAF in high category and –HAF in middle and low categories). Even tough some alteration is indicated; the changes observed in the Parameter Group 4 medians, variances, and HAFs are small in magnitude. It is likely these changes have had an effect on aquatic life in the Kiamichi River.

Rate and frequency of water condition changes (Parameter Group 5)—The median rise rate decreased between the pre and post-dam periods from 1595.0 to 1447.2 cfs/day (Tables 3 and 4). Coefficients of variance remained approximately the same. The HAF analysis (Figure 17 and Table 8) shows rise rates decreasing as well (-HAF in high category and +HAF in middle category). The median fall rate remained approximately the same between the pre and post-dam periods (-479.5 and -480.3 cfs/day, respectively). Coefficients of variance remained about the same as well (Table 7). The HAF analysis of fall rates indicated little alteration. These results indicate that Sardis Dam is having little effect on rates of rise and fall in the Kiamichi River. The median number of flow reversals per year increased slightly between the pre and post-dam periods from 71 to 79 (Table 6 and 7). The coefficients of variance remained approximately the same as well. The HAF analysis (Figure 17 and Table 8) indicated that the number of reversals increased in the post-dam period (+HAF in high RVA category and –HAF in the low and middle categories). The increase in flow reversals is likely due to releases of water from Sardis Dam, but the change is small in magnitude.

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Table 3: The non-parametric IHA scorecard for the Little River below Lukfata Creek near Idabel

	Pre-impact period: 1947-1968 (22 years)	Post-impact period: 1969-2003 (35 years)
Watershed area	1173.00	
Mean annual flow	1550.83	1909.08
Mean flow/area	1.32	1.63
Annual C. V.	.55	1.15
Flow predictability	.30	.26
Constancy/predictability	.40	.48
% of floods in 60d period	.29	.27
flood-free season	6.00	4.00

	MEDIANS		COEFF. Of DISP.		DEVIATION FACTOR		SIGNIFICANCE COUNT	
	Pre	Post	Pre	Post	Medians	C.V.	Medians	C.V.
Parameter Group #1								
October	244.3	480.5	2.40	4.18	.97	.74	.16	.17
November	502.5	1237.6	2.58	2.16	1.46	.16	.10	.80
December	918.5	1741.3	2.62	1.98	.90	.24	.01	.39
January	1338.3	1979.0	1.52	.98	.48	.36	.16	.37
February	1988.1	2423.6	1.30	1.20	.22	.07	.51	.82
March	2039.8	3307.6	.96	.75	.62	.22	.02	.53
April	2080.7	2044.9	1.27	.97	.02	.23	.93	.52
May	3563.5	2516.2	1.34	1.31	.29	.02	.41	.96
June	298.7	1040.0	2.42	2.70	2.48	.12	.00	.87
July	160.3	233.9	7.84	1.25	.46	.84	.20	.28
August	94.8	113.8	3.24	1.88	.20	.42	.56	.58
September	231.7	184.4	3.77	3.50	.20	.07	.60	.87
Parameter Group #2								
1-day minimum	9.1	29.0	2.78	.79	2.20	.72	.00	.06
3-day minimum	9.3	30.3	2.78	.77	2.28	.72	.00	.06
7-day minimum	9.6	30.7	3.02	.76	2.21	.75	.00	.05
30-day minimum	22.3	42.7	2.30	.77	.91	.66	.00	.04
90-day minimum	73.7	121.1	1.77	.86	.64	.51	.24	.22
1-day maximum	24000.0	12800.0	1.00	.47	.47	.53	.00	.24
3-day maximum	20533.3	11966.7	.77	.35	.42	.55	.00	.17
7-day maximum	16312.1	9327.1	.61	.31	.43	.50	.00	.21
30-day maximum	5611.4	6434.3	.82	.48	.15	.42	.57	.13

Table 3. (continued)

90-day maximum	3207.8	4156.8	.62	.56	.30	.10	.04	.68
Number of zero days	.0	.0	.00	.00	999999.00	999999.00	.00	.00
Base flow	.0	.0	1.28	.92	.97	.28	.00	.51
Parameter Group #3								
Date of minimum	265.5	246.0	.09	.14	.11	.59	.05	.05
Date of maximum	128.5	339.0	.20	.44	.85	1.18	.24	.01
Parameter Group #4								
Low pulse count	4.5	5.0	.50	.80	.11	.60	.90	.23
Low pulse duration	17.2	12.3	.71	.73	.28	.03	.16	.92
High pulse count	10.0	11.0	.30	.36	.10	.21	.05	.47
High pulse duration	8.0	10.7	.50	.69	.33	.38	.00	.54
The low pulse threshold is	90.00							
The high pulse level is	1300.00							
Parameter Group #5								
Rise rate	1135.2	688.0	.54	.48	.39	.11	.00	.77
Fall rate	-385.7	-354.3	-.62	-.60	.08	.03	.43	.92
Number of reversals	64.0	86.0	.15	.16	.34	.10	.00	.77

Table 4. The IHA non-parametric range of variance analysis scorecard for the Little River below Lukfata Creek near Idabel

Hydrologic Alteration (Middle Category)	Pre-impact period: 1947-1968 Medians	Coeff. Of Variance	Range Limits Low	Range Limits High	Post-impact period: 1969-2003 Medians	Coeff. Of Variance	Range Limits Low	Range Limits High	RVA Categories Low	RVA Categories High	
Parameter Group #1											
October	244.3	2.40	.8	4354.0	480.5	4.18	26.4	4453.0	72.73	468.42	-.14
November	502.5	2.58	8.8	5423.1	1237.6	2.16	38.2	8381.0	186.92	1260.13	.02
December	918.5	2.62	27.3	5505.9	1741.3	1.98	37.3	10320.3	467.72	1512.28	-.14
January	1338.3	1.52	18.6	8456.3	1979.0	.98	156.6	7746.5	885.05	2314.43	.18
February	1988.1	1.30	190.5	9320.4	2423.6	1.20	175.6	6546.1	1171.83	3282.75	.41
March	2039.8	.96	225.4	6488.0	3307.6	.75	209.3	7730.0	1503.32	2857.79	-.45
April	2080.7	1.27	380.9	9983.3	2044.9	.97	374.1	7842.7	1381.29	3264.64	.10
May	3563.5	1.34	677.5	9820.0	2516.2	1.31	143.4	8976.5	1470.15	4814.58	.57
June	298.7	2.42	65.3	5714.0	1040.0	2.70	46.9	6044.0	202.93	536.91	-.29
July	160.3	7.84	16.4	3854.1	233.9	1.25	31.0	2058.3	47.40	408.10	.89
August	94.8	3.24	2.0	3677.5	113.8	1.88	18.5	2299.3	60.45	167.77	.41
September	231.7	3.77	.6	6338.8	184.4	3.50	25.0	6991.8	83.59	575.89	.10
Parameter Group #2											
1-day minimum	9.1	2.78	.4	59.0	29.0	.79	7.8	77.0	6.28	16.05	-.37
3-day minimum	9.3	2.78	.4	61.7	30.3	.77	9.1	78.7	6.72	16.72	-.61
7-day minimum	9.6	3.02	.4	75.7	30.7	.76	11.3	82.3	7.23	19.34	-.61
30-day minimum	22.3	2.30	.5	182.8	42.7	.77	16.1	765.2	8.57	41.10	.26
90-day minimum	73.7	1.77	1.0	492.6	121.1	.86	20.4	1340.4	30.33	131.88	.57
1-day maximum	24000.0	1.00	8560.0	72600.0	12800.0	.47	6240.0	66800.0	14759.00	32720.00	-.29
3-day maximum	20533.3	.77	7796.7	50400.0	11966.7	.35	5860.0	49100.0	13581.33	27391.33	-.37
7-day maximum	16312.1	.61	5057.1	32828.6	9327.1	.31	4820.0	26187.1	11136.37	18119.87	-.53
30-day maximum	5611.4	.82	2135.3	11566.0	6434.3	.48	2416.6	11931.0	4856.51	8469.22	.57
90-day maximum	3207.8	.62	1505.1	8410.6	4156.8	.56	1804.3	6984.1	2832.78	4170.72	.02
Number of zero days	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Base flow	.01	1.28	.00	.05	.02	.92	.00	.06	.00	.01	-.53
Parameter Group #3											
Date of minimum	265.5	.09	186.0	313.0	246.0	.14	182.0	361.0	252.77	274.00	-.79
Date of maximum	128.5	.20	26.0	348.0	339.0	.44	1.0	362.0	119.36	146.69	-.69
Parameter Group #4											
Low Pulse Count	4.5	.50	1.0	8.0	5.0	.80	1.0	10.0	4.00	5.00	-.31
Low Pulse Duration	17.2	.71	3.8	61.7	12.3	.73	3.4	48.0	10.94	20.35	.34

Table 4. (continued)

High Pulse Count	10.0	.30	5.0	17.0	11.0	.36	4.0	17.0	9.59	11.00	-.44
High Pulse Duration	8.0	.50	4.3	15.8	10.7	.69	5.5	35.8	6.88	9.25	-.53

The low pulse threshold is 90.00
The high pulse level is 1300.00

Parameter Group #5											
Rise rate	1135.2	.54	558.2	2578.1	688.0	.48	226.0	1052.5	773.90	1239.69	.10
Fall rate	-385.7	-.62	-980.2	-168.7	-354.3	-.60	-582.4	-141.5	-464.69	-298.76	.02
Number of reversals	64.0	.15	50.0	83.0	86.0	.16	74.0	105.0	60.59	67.00	-1.00

Table 5: The IHA non-parametric Hydrologic Alteration Analysis for the Little River below Lukfata Creek near Idabel

	Middle RVA Category			High RVA Category			Low RVA Category		
	Expected	Observed	Alter.	Expected	Observed	Alter.	Expected	Observed	Alter.
Parameter Group #1									
October	12.73	11.00	-.14	11.14	18.00	.62	11.14	6.00	-.46
November	12.73	13.00	.02	11.14	17.00	.53	11.14	5.00	-.55
December	12.73	11.00	-.14	11.14	20.00	.80	11.14	4.00	-.64
January	12.73	15.00	.18	11.14	13.00	.17	11.14	7.00	-.37
February	12.73	18.00	.41	11.14	11.00	-.01	11.14	6.00	-.46
March	12.73	7.00	-.45	11.14	20.00	.80	11.14	8.00	-.28
April	12.73	14.00	.10	11.14	8.00	-.28	11.14	13.00	.17
May	12.73	20.00	.57	11.14	6.00	-.46	11.14	9.00	-.19
June	12.73	9.00	-.29	11.14	22.00	.98	11.14	4.00	-.64
July	12.73	24.00	.89	11.14	8.00	-.28	11.14	3.00	-.73
August	12.73	18.00	.41	11.14	11.00	-.01	11.14	6.00	-.46
September	12.73	14.00	.10	11.14	9.00	-.19	11.14	12.00	.08
Parameter Group #2									
1-day minimum	12.73	8.00	-.37	11.14	27.00	1.42	11.14	.00	-1.00
3-day minimum	12.73	5.00	-.61	11.14	30.00	1.69	11.14	.00	-1.00
7-day minimum	12.73	5.00	-.61	11.14	30.00	1.69	11.14	.00	-1.00
30-day minimum	12.73	16.00	.26	11.14	19.00	.71	11.14	.00	-1.00
90-day minimum	12.73	20.00	.57	11.14	13.00	.17	11.14	2.00	-.82
1-day maximum	12.73	9.00	-.29	11.14	2.00	-.82	11.14	24.00	1.16
3-day maximum	12.73	8.00	-.37	11.14	2.00	-.82	11.14	25.00	1.24
7-day maximum	12.73	6.00	-.53	11.14	1.00	-.91	11.14	28.00	1.51
30-day maximum	12.73	20.00	.57	11.14	5.00	-.55	11.14	10.00	-.10
90-day maximum	12.73	13.00	.02	11.14	17.00	.53	11.14	5.00	-.55
Number of zero days	35.00	35.00	.00	.00	.00	.00	.00	.00	.00
Base flow	12.73	6.00	-.53	11.14	28.00	1.51	11.14	1.00	-.91
Parameter Group #3									
Date of minimum	14.32	3.00	-.79	9.55	10.00	.05	11.14	22.00	.98
Date of maximum	12.73	4.00	-.69	11.14	17.00	.53	11.14	14.00	.26
Parameter Group #4									
Low Pulse Count	17.50	12.00	-.31	9.55	11.00	.15	7.95	12.00	.51
Low Pulse Duration	12.73	17.00	.34	11.14	7.00	-.37	11.14	11.00	-.01
High Pulse Count	14.32	8.00	-.44	9.55	15.00	.57	11.14	12.00	.08
High Pulse Duration	12.73	6.00	-.53	11.14	26.00	1.33	11.14	3.00	-.73
Parameter Group #5									
Rise rate	12.73	14.00	.10	11.14	.00	-1.00	11.14	21.00	.89
Fall rate	12.73	13.00	.02	11.14	14.00	.26	11.14	8.00	-.28

Table 5: (continued)

Number of reversals	14.32	.00	-1.00	9.55	35.00	2.67	11.14	.00	-1.00

6 Messages:

Parameter Low pulse count : 12 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Low pulse count : 11 yearly values are equal to the lower RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter High pulse count : 8 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Number of falls : 6 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Number of reversals : 2 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Date of minimum : 3 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.

Table 6. The non-parametric IHA scorecard for the Kiamichi River near Antlers (combined with flow data from Belzoni)

Pre-impact period: 1930-1972 (43 years) Post-impact period: 1973-2003 (31 years)

	Pre	Post
Watershed area	1138.00	
Mean annual flow	1539.70	1607.47
Mean flow/area	1.35	1.41
Annual C. V.	.51	.77
Flow predictability	.28	.29
Constancy/predictability	.48	.55
% of floods in 60d period	.26	.27
Flood-free season	3.00	13.00

	MEDIANS		COEFF. Of DISP.		DEVIATION FACTOR		SIGNIFICANCE COUNT	
	Pre	Post	Pre	Post	Medians	C.V.	Medians	C.V.
Parameter Group #1								
October	260.3	99.2	3.18	11.76	.62	2.70	.57	.02
November	408.8	793.8	2.67	4.50	.94	.69	.13	.16
December	1209.3	1485.4	1.54	2.11	.23	.37	.57	.34
January	1139.6	1320.2	1.63	1.25	.16	.23	.61	.53
February	1861.0	1604.3	1.47	1.49	.14	.02	.73	.96
March	1813.9	2508.6	1.12	.81	.38	.28	.07	.35
April	2553.6	1775.8	1.13	1.49	.30	.32	.24	.26
May	2062.0	2488.9	1.57	1.00	.21	.36	.68	.33
June	529.3	1189.1	2.62	1.64	1.25	.37	.08	.46
July	66.0	154.0	8.47	1.50	1.33	.82	.08	.20
August	65.5	32.8	2.81	5.13	.50	.82	.57	.19
September	125.8	124.7	5.43	3.44	.01	.37	1.00	.54
Parameter Group #2								
1-day minimum	.5	1.7	10.00	2.94	2.65	.71	.08	.23
3-day minimum	.4	1.9	16.36	2.78	3.30	.83	.05	.18
7-day minimum	.4	2.6	26.07	2.19	5.99	.92	.01	.18
30-day minimum	4.6	6.5	3.67	1.39	.42	.62	.29	.25
90-day minimum	37.9	50.8	2.66	1.75	.34	.34	.60	.52
1-day maximum	27627.9	26700.0	.66	.55	.03	.17	.77	.53
3-day maximum	23658.9	21100.0	.71	.60	.11	.15	.41	.55
7-day maximum	13627.9	13345.7	.78	.60	.02	.23	.85	.44
30-day maximum	6467.9	6467.0	.68	.55	.00	.19	.99	.46
90-day maximum	3412.9	3693.6	.51	.54	.08	.06	.43	.86
Number of zero days	.0	.0	.00	.00	999999.00	999999.00	.00	.00
Base flow	.0	.0	17.49	2.21	4.52	.87	.01	.16

Table 6. (continued)

Parameter Group #3								
Date of minimum	253.0	257.0	.14	.13	.02	.12	.83	.71
Date of maximum	123.0	138.0	.49	.46	.08	.06	.41	.77
Parameter Group #4								
Low pulse count	5.0	4.0	.60	.75	.20	.25	.44	.44
Low pulse duration	15.8	14.6	.98	.83	.08	.16	.68	.57
High pulse count	12.0	13.0	.50	.23	.08	.54	.20	.16
High pulse duration	7.1	7.9	.45	.61	.11	.35	.25	.08
The low pulse threshold is		55.81						
The high pulse level is	1097.67							
Parameter Group #5								
Rise rate	1595.0	1447.2	.63	.62	.09	.02	.54	.95
Fall rate	-479.5	-480.3	-.65	-.68	.00	.05	1.00	.85
Number of reversals	71.0	79.0	.21	.27	.11	.26	.04	.21

Table 7. The IHA non-parametric range of variance analysis scorecard for the Kiamichi River near Antlers, OK (combined with flow data from Belzoni).

Kiamichi River Adjusted Belzoni and Antlers Data

	Pre-impact period: 1930-1972				Post-impact period: 1973-2003				RVA Categories		Hydrologic Alteration
			Range Limits				Range Limits				
	Medians	Coeff. of Variance	Low	High	Medians	Coeff. of Variance	Low	High	Low	High	(Middle Category)
Parameter Group #1											
October	260.3	3.18	.0	3194.7	99.2	11.76	2.4	7763.5	48.19	592.33	-.17
November	408.8	2.67	.6	7712.6	793.8	4.50	5.2	8614.3	213.44	993.54	-.26
December	1209.3	1.54	8.2	9668.4	1485.4	2.11	7.8	5288.5	462.73	1817.13	-.08
January	1139.6	1.63	6.3	9035.2	1320.2	1.25	109.1	7158.7	691.58	1787.88	.02
February	1861.0	1.47	72.1	9100.1	1604.3	1.49	153.6	6316.4	828.87	3149.07	.57
March	1813.9	1.12	163.5	10009.0	2508.6	.81	253.3	6249.2	1279.46	2572.64	.02
April	2553.6	1.13	137.6	12023.3	1775.8	1.49	247.8	7400.6	1686.45	3656.28	-.17
May	2062.0	1.57	274.6	10133.4	2488.9	1.00	77.9	12703.9	1472.22	3959.38	.48
June	529.3	2.62	22.2	11478.4	1189.1	1.64	21.5	5876.5	242.78	1205.26	.20
July	66.0	8.47	.9	6467.4	154.0	1.50	10.1	1703.9	40.43	223.96	.48
August	65.5	2.81	.0	2987.1	32.8	5.13	.0	2016.9	27.29	124.62	-.45
September	125.8	5.43	.0	5392.0	124.7	3.44	.2	5913.7	30.23	375.84	.11
Parameter Group #2											
1-day minimum	.5	10.00	.0	40.9	1.7	2.94	.0	21.0	.05	3.20	.29
3-day minimum	.4	16.36	.0	42.2	1.9	2.78	.0	21.7	.03	3.54	.39
7-day minimum	.4	26.07	.0	44.5	2.6	2.19	.0	27.3	.01	4.03	.39
30-day minimum	4.6	3.67	.0	134.1	6.5	1.39	.0	144.9	.36	6.69	.11
90-day minimum	37.9	2.66	.0	599.5	50.8	1.75	.1	1052.0	18.05	98.95	.11
1-day maximum	27627.9	.66	10418.6	63441.9	26700.0	.55	8190.0	57000.0	22798.14	36316.28	.11
3-day maximum	23658.9	.71	8759.7	55317.8	21100.0	.60	6926.7	51733.3	19817.68	32008.69	.20
7-day maximum	13627.9	.78	5201.3	36990.0	13345.7	.60	4990.0	33028.6	12577.75	20151.02	.20
30-day maximum	6467.9	.68	2432.5	13997.5	6467.0	.55	2169.3	15292.0	4631.88	7556.99	.29
90-day maximum	3412.9	.51	1339.5	9103.4	3693.6	.54	1327.0	8509.1	2990.76	4470.50	.29
Number of zero days	.00	.00	.00	67.00	.00	.00	.00	50.00	.00	3.36	.24
Base flow	.00	17.49	.00	.02	.00	2.21	.00	.02	.00	.00	.29
Parameter Group #3											
Date of minimum	253.0	.14	183.0	318.0	257.0	.13	193.0	316.0	232.04	272.00	.04
Date of maximum	123.0	.49	9.0	360.0	138.0	.46	6.0	362.0	101.64	164.48	.02

Table 7. (continued)

Parameter Group #4

Low Pulse Count	5.0	.60	2.0	9.0	4.0	.75	1.0	11.0	4.00	5.00	.00
Low Pulse Duration	15.8	.98	4.7	68.3	14.6	.83	4.0	83.0	9.58	20.06	.48
High Pulse Count	12.0	.50	7.0	19.0	13.0	.23	5.0	20.0	11.00	14.00	.31
High Pulse Duration	7.1	.45	3.6	18.9	7.9	.61	4.2	36.0	5.59	8.41	-.08

The low pulse threshold is 55.81
The high pulse level is 1097.67

Parameter Group #5

Rise rate	1595.0	.63	723.2	3470.9	1447.2	.62	340.7	3111.8	1269.05	1830.23	.02
Fall rate	-479.5	-.65	-1225.6	-184.5	-480.3	-.68	-1124.6	-125.1	-594.94	-410.97	-.08
Number of reversals	71.0	.21	31.0	93.0	79.0	.27	45.0	104.0	66.00	76.48	-.35

Table 8: The IHA non-parametric Assessment of hydrologic alteration for the Kiamichi River near Antlers, OK (combined with flow data from Belzoni).

Assessment of Hydrologic Alteration

	Middle RVA Category			High RVA Category			Low RVA Category		
	Expected	Observed	Alter.	Expected	Observed	Alter.	Expected	Observed	Alter.
Parameter Group #1									
October	10.81	9.00	-.17	10.09	11.00	.09	10.09	11.00	.09
November	10.81	8.00	-.26	10.09	14.00	.39	10.09	9.00	-.11
December	10.81	10.00	-.08	10.09	15.00	.49	10.09	6.00	-.41
January	10.81	11.00	.02	10.09	11.00	.09	10.09	9.00	-.11
February	10.81	17.00	.57	10.09	8.00	-.21	10.09	6.00	-.41
March	10.81	11.00	.02	10.09	15.00	.49	10.09	5.00	-.50
April	10.81	9.00	-.17	10.09	7.00	-.31	10.09	15.00	.49
May	10.81	16.00	.48	10.09	8.00	-.21	10.09	7.00	-.31
June	10.81	13.00	.20	10.09	14.00	.39	10.09	4.00	-.60
July	10.81	16.00	.48	10.09	9.00	-.11	10.09	6.00	-.41
August	10.81	6.00	-.45	10.09	10.00	-.01	10.09	15.00	.49
September	10.81	12.00	.11	10.09	9.00	-.11	10.09	10.00	-.01
Parameter Group #2									
1-day minimum	10.81	14.00	.29	10.09	12.00	.19	10.09	5.00	-.50
3-day minimum	10.81	15.00	.39	10.09	11.00	.09	10.09	5.00	-.50
7-day minimum	10.81	15.00	.39	10.09	11.00	.09	10.09	5.00	-.50
30-day minimum	10.81	12.00	.11	10.09	14.00	.39	10.09	5.00	-.50
90-day minimum	10.81	12.00	.11	10.09	8.00	-.21	10.09	11.00	.09
1-day maximum	10.81	12.00	.11	10.09	7.00	-.31	10.09	12.00	.19
3-day maximum	10.81	13.00	.20	10.09	4.00	-.60	10.09	14.00	.39
7-day maximum	10.81	13.00	.20	10.09	5.00	-.50	10.09	13.00	.29
30-day maximum	10.81	14.00	.29	10.09	8.00	-.21	10.09	9.00	-.11
90-day maximum	10.81	14.00	.29	10.09	7.00	-.31	10.09	10.00	-.01
Number of zero days	20.91	26.00	.24	10.09	5.00	-.50	.00	.00	.00
Base flow	10.81	14.00	.29	10.09	12.00	.19	10.09	5.00	-.50

Table 8. (continued)

Parameter Group #3									
Date of minimum	11.53	12.00	.04	9.37	11.00	.17	10.09	8.00	-.21
Date of maximum	10.81	11.00	.02	10.09	12.00	.19	10.09	8.00	-.21
Parameter Group #4									
Low Pulse Count	12.98	13.00	.00	9.37	9.00	-.04	8.65	9.00	.04
Low Pulse Duration	10.81	16.00	.48	10.09	8.00	-.21	10.09	7.00	-.31
High Pulse Count	12.98	17.00	.31	8.65	10.00	.16	9.37	4.00	-.57
High Pulse Duration	10.81	10.00	-.08	10.09	15.00	.49	10.09	6.00	-.41
Parameter Group #5									
Rise rate	10.81	11.00	.02	10.09	8.00	-.21	10.09	12.00	.19
Fall rate	10.81	10.00	-.08	10.09	11.00	.09	10.09	10.00	-.01
Number of reversals	12.26	8.00	-.35	10.09	18.00	.78	8.65	5.00	-.42

9 Messages:

Parameter Low pulse count : 15 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Low pulse count : 16 yearly values are equal to the lower RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter High pulse count : 10 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter High pulse count : 7 yearly values are equal to the lower RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Number of falls : 8 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Number of falls : 4 yearly values are equal to the lower RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Number of reversals : 5 yearly values are equal to the lower RVA limit. Use caution in interpreting expected and observed compliance rates.
Parameter Date of minimum : 2 yearly values are equal to the upper RVA limit. Use caution in interpreting expected and observed compliance rates.
Dates of extreme flows are widely distributed through the year. Use date statistics with caution

Figure 1. Annual streamflows and mean annual streamflow for the Little River below Lukfata Creek near Idabel, OK, water years 1947-2003.

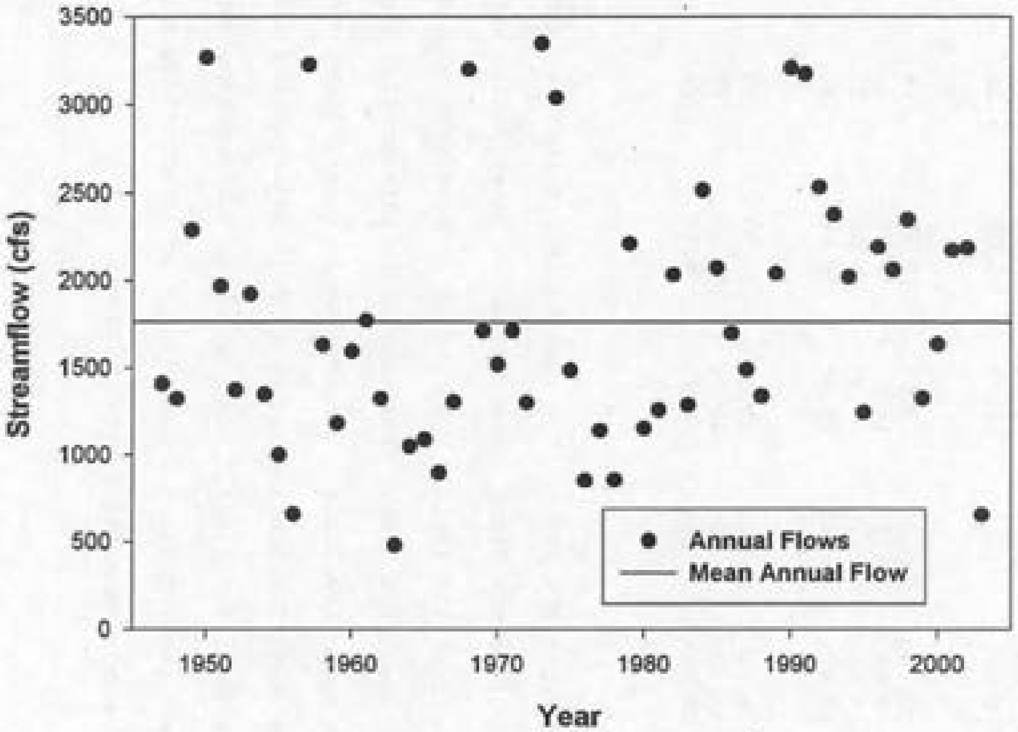


Figure 2. Monthly flows (dots) and the mean monthly flow (line) for the Little River below Lukfata Creek near Idabel, OK, water years 1947-2003.

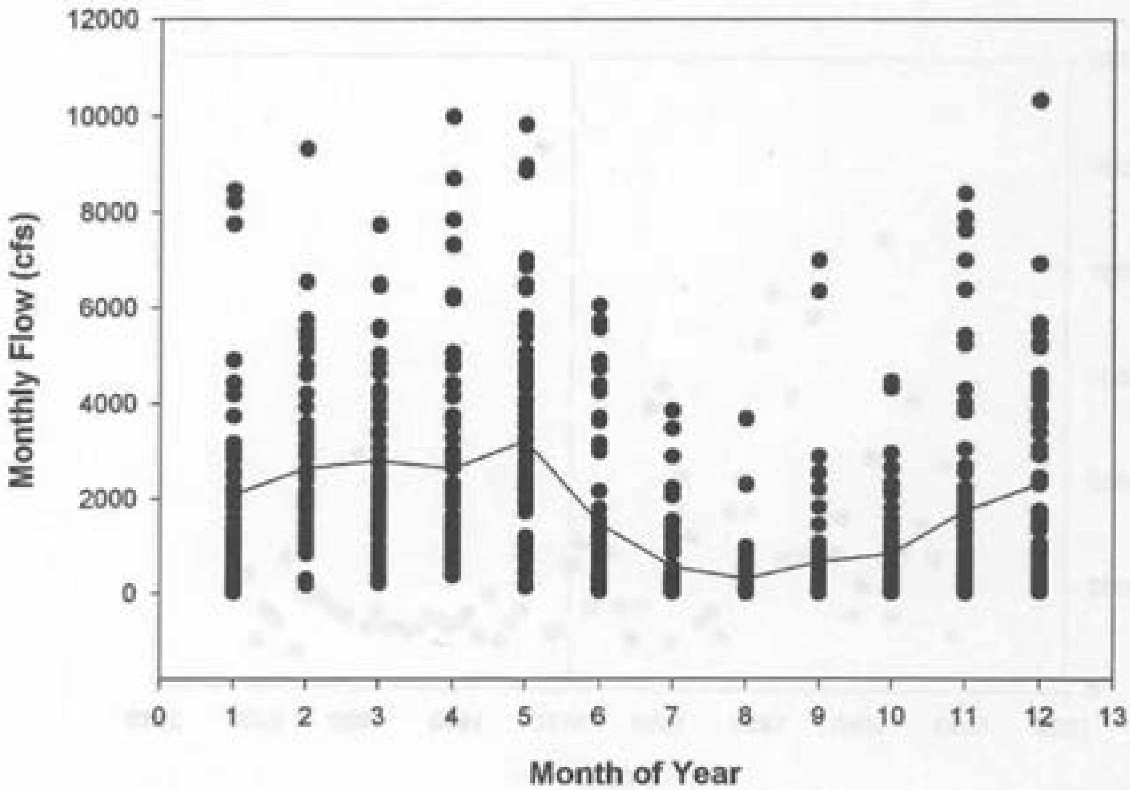


Figure 3. Annual peak flows for the Little River below Lukfata Creek near Idabel, OK, water years 1947-2003. Note: Peak flows after 1969 are affected by Pine Creek Dam.

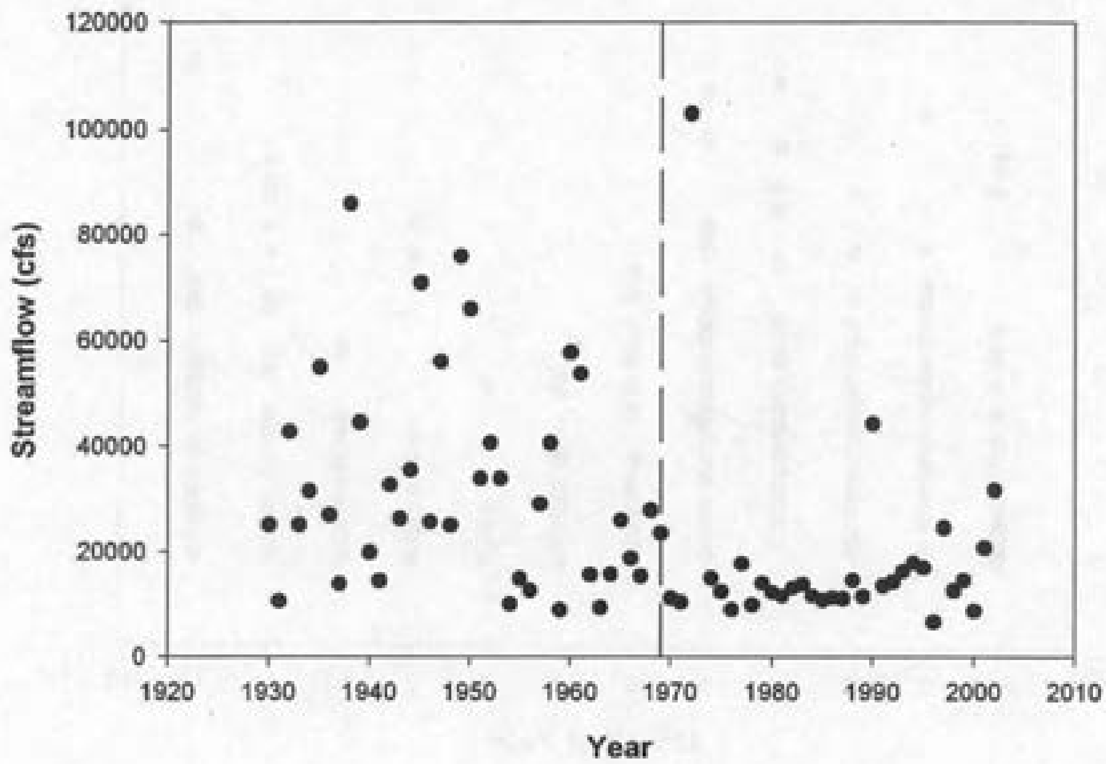


Figure 4. Daily streamflow statistics for the Little River below Lukfata Creek near Idabel, OK, water years 1947-2003. The lines show the median (50%) and the 25 and 75% percentiles for which each daily flow is equaled or exceeded. Note that this data is affected by Pine Creek Dam.

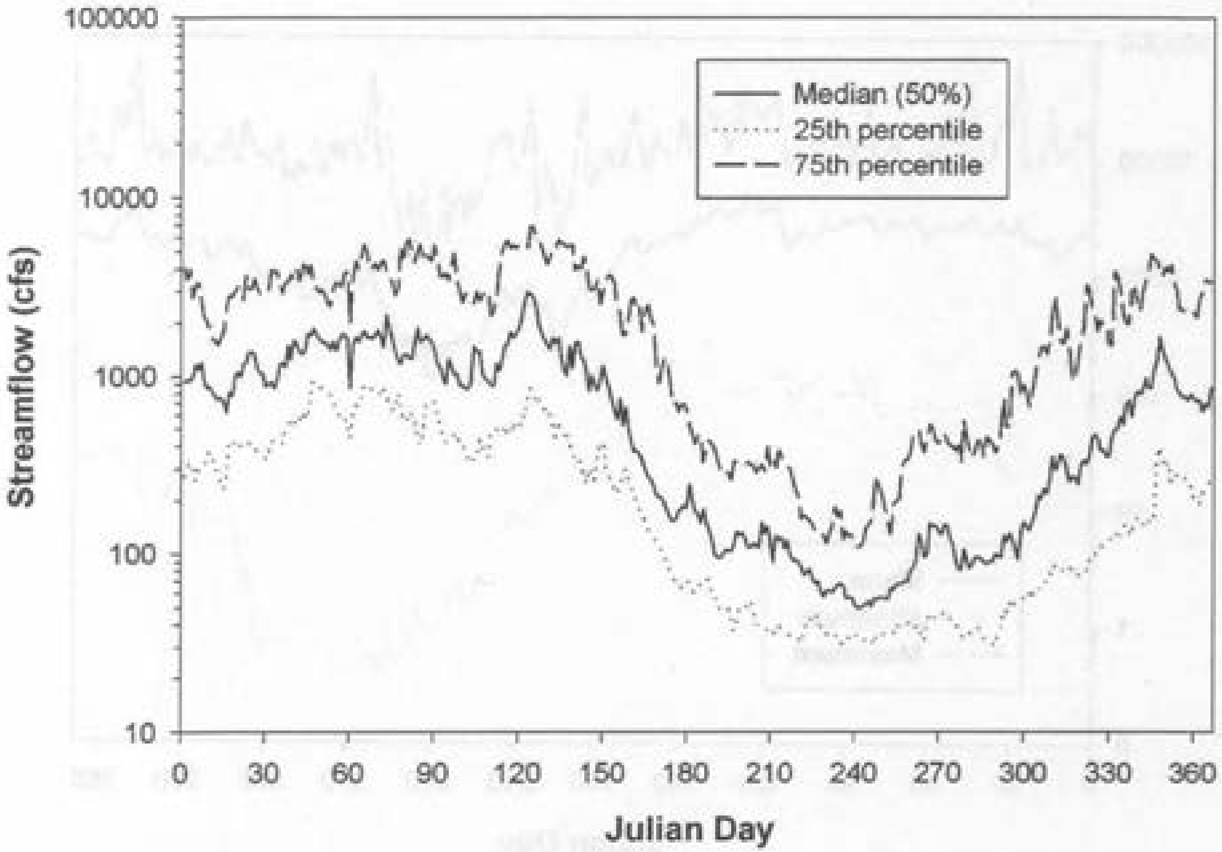


Figure 5. Daily streamflow means, minimums, and maximums for the Little River below Lukfata Creek near Idabel, OK, water years 1947-2003. Note that this data is affected by Pine Creek Dam.

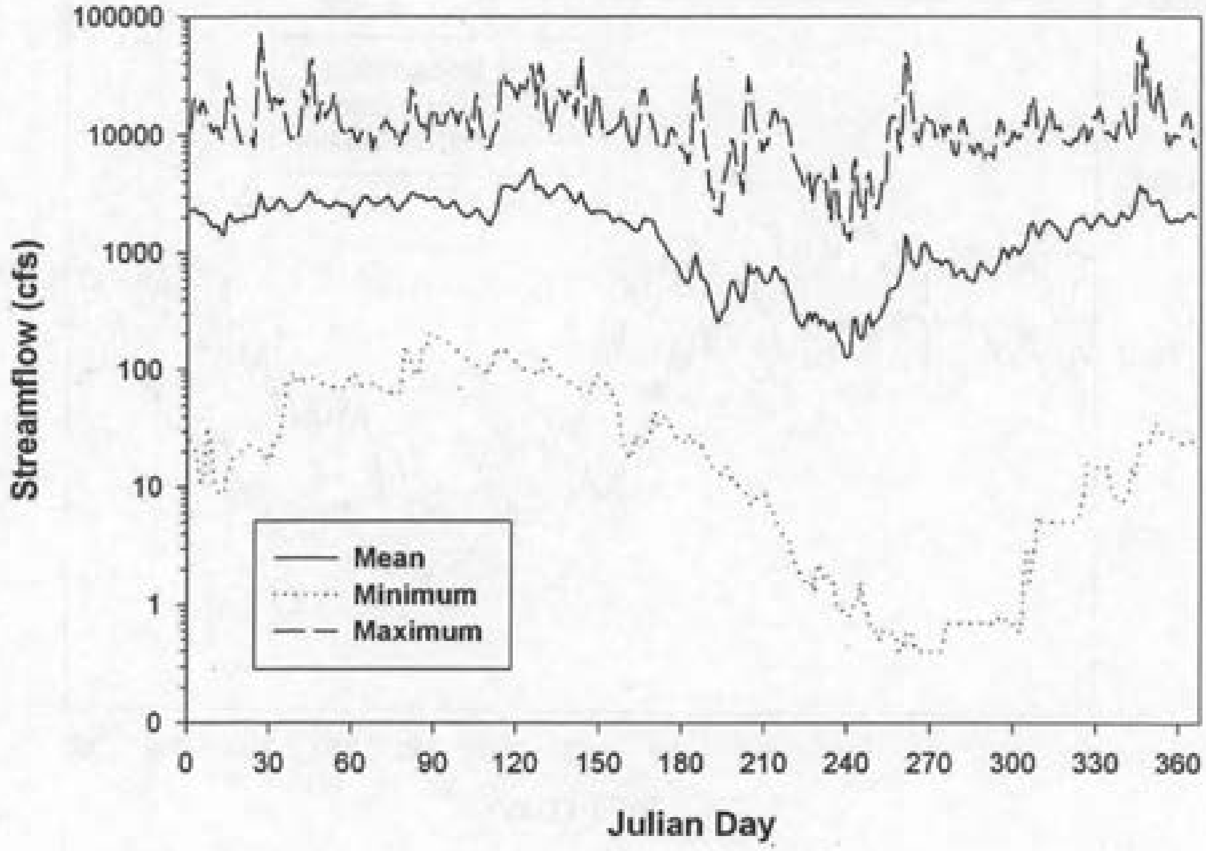


Figure 6. Flow duration curves before and after the construction of Pine Creek Dam on the Little River below Lukfata Creek near Idabel, OK.

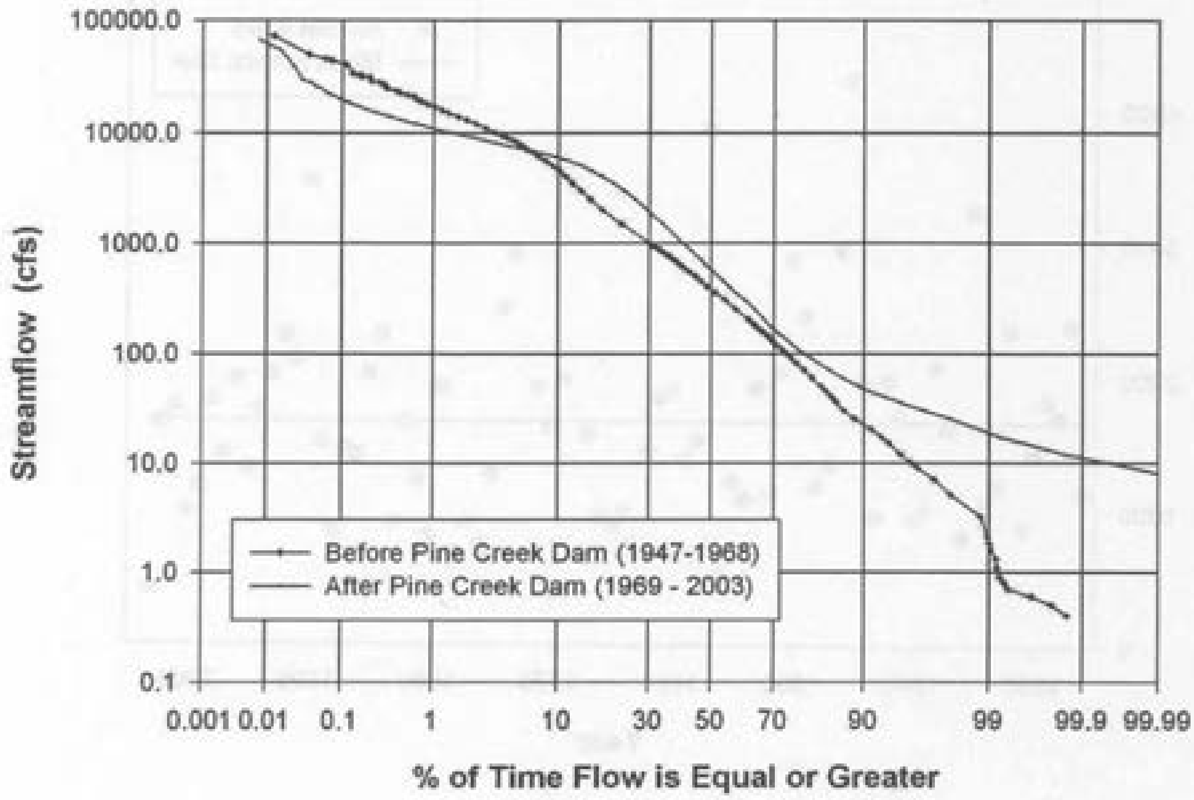


Figure 7. Annual flows and the mean annual flow for the Kiamichi River near Antlers, OK, and water years 1926-2003 (combined with adjusted Belzoni data).

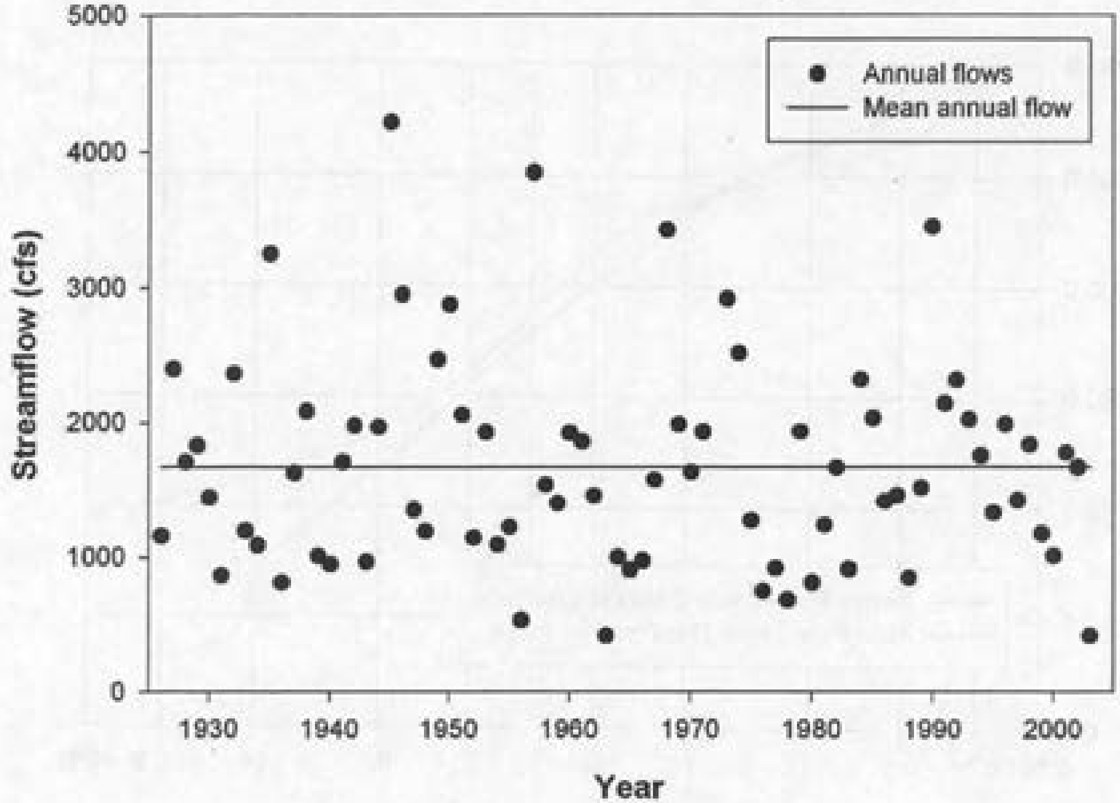


Figure 8. Monthly flows (dots) and the mean monthly flow (line) for the Kiamichi River near Antlers, OK, water years 1926-2003 (combined with adjusted Belzoni data).

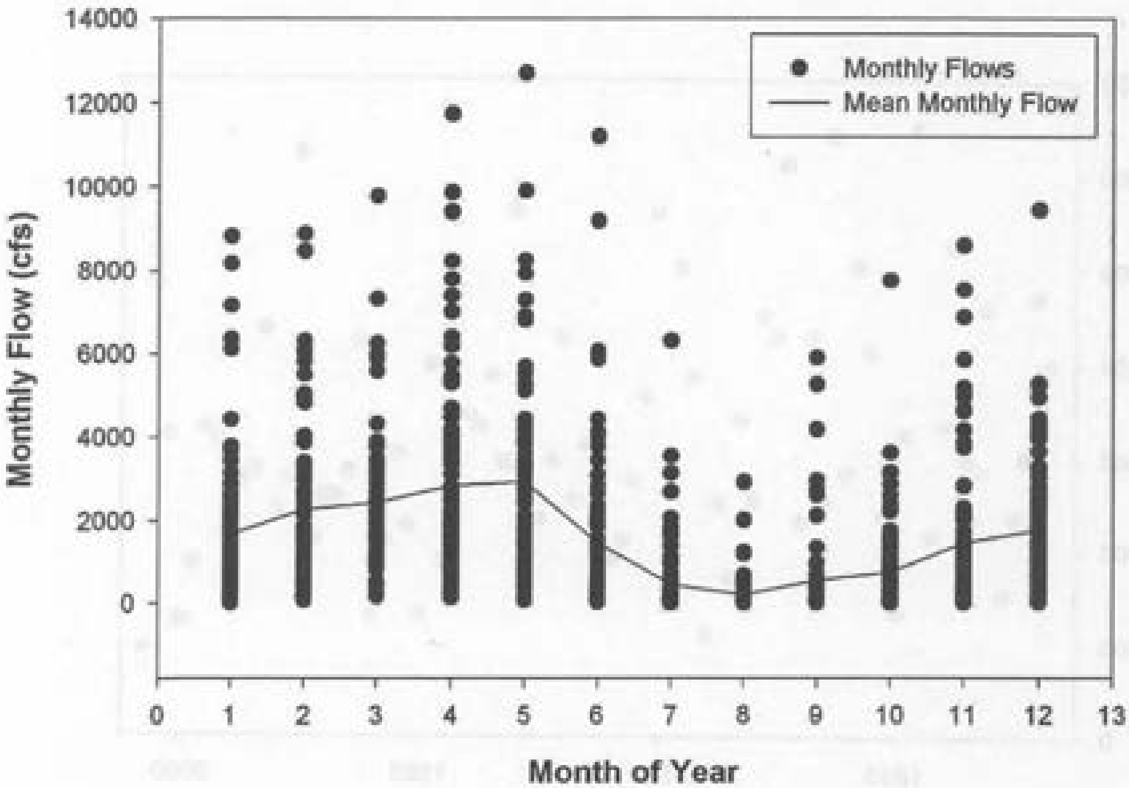


Figure 9. Annual peak flows for the Kiamichi River near Antlers, OK, water years 1926-2003. Note: Peak flows after 1983 may be affected by Sardis Lake and Dam (data before 1973 uses adjusted Belzoni gaging station data).

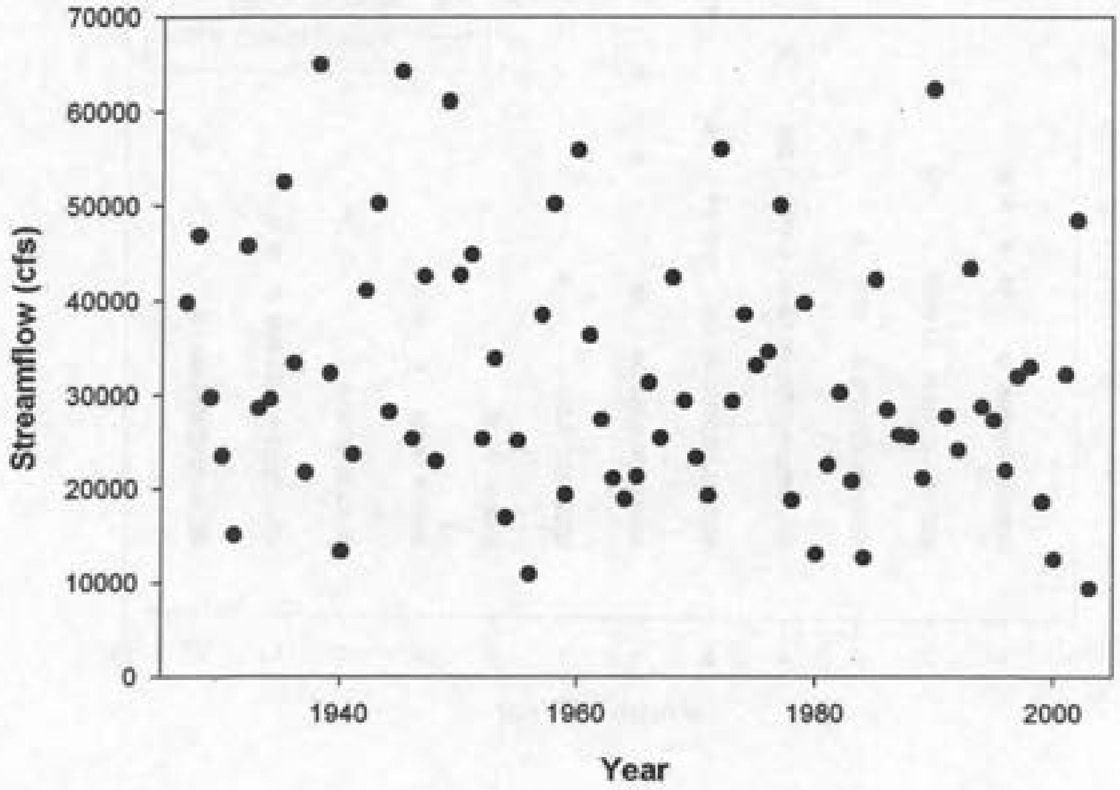


Figure 10. Daily streamflow statistics for the Kiamichi River near Antlers, OK, water years 1973-2003. The lines show the median and the 25, and 75% percentiles for which each daily flow is equaled or exceeded. Note that this data mat be affected by Sardis Lake and Dam.

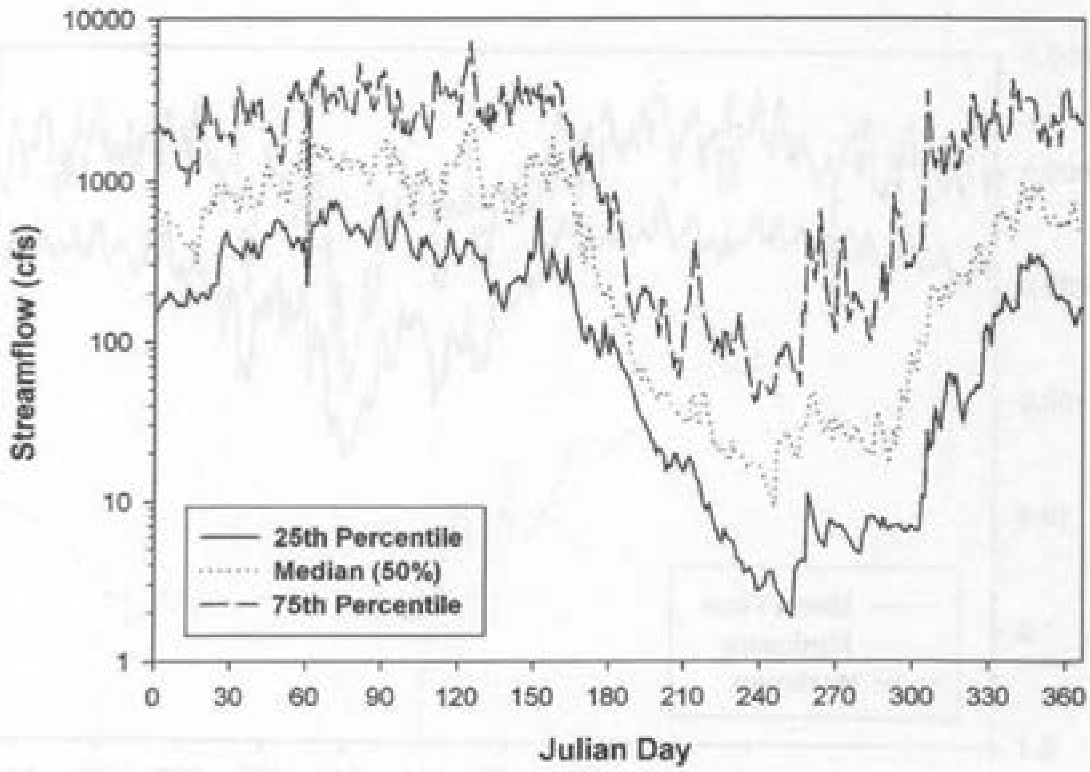


Figure 11. Daily streamflow means, minimums, and maximums for the Kiamichi River near Antlers, OK, water years 1973-2003. Note that this data may be affected by Sardis Lake and Dam. Minimum daily flows not shown are either 0 or less than 0.1 cfs.

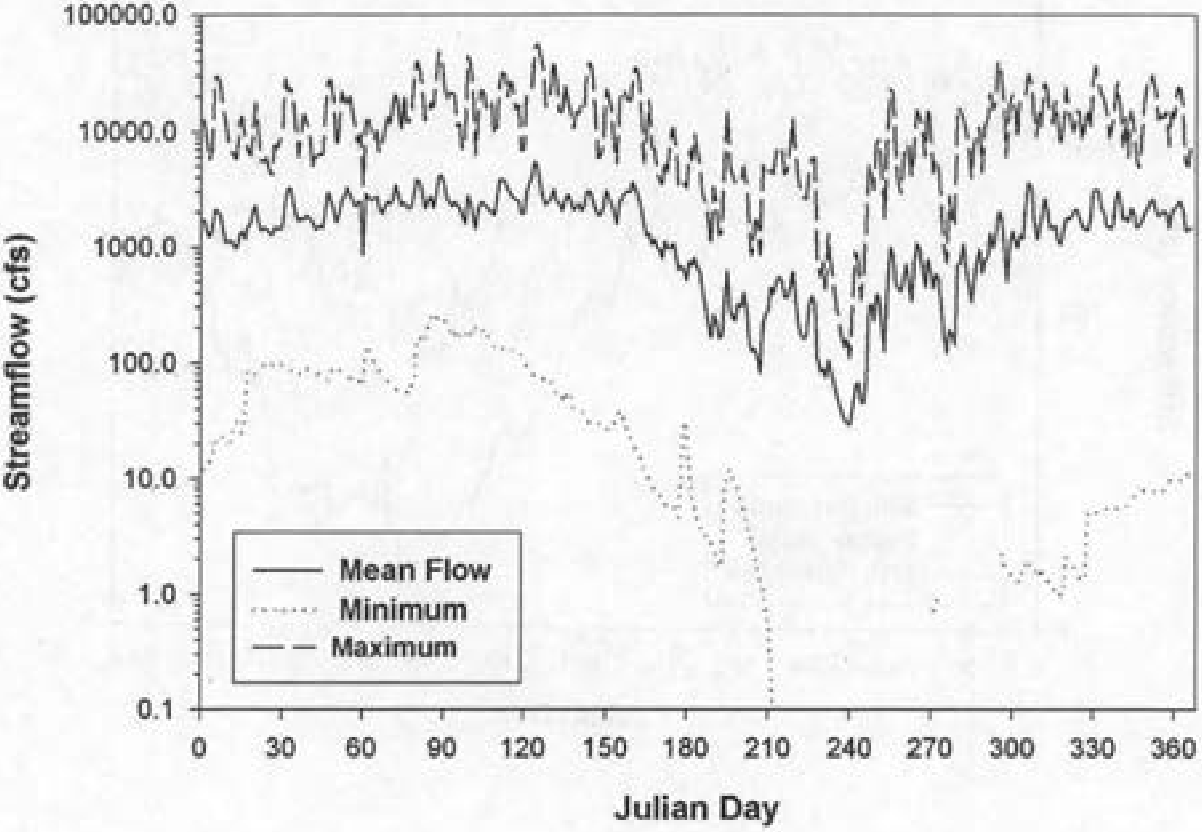


Figure 12. Daily streamflow statistics for the Kiamichi River near Belzoni, OK, water years 1926-1972. The lines show the mean and the 25[th], 50[th], and 75% percentiles for which each daily flow are equaled or exceeded (Data is unadjusted).

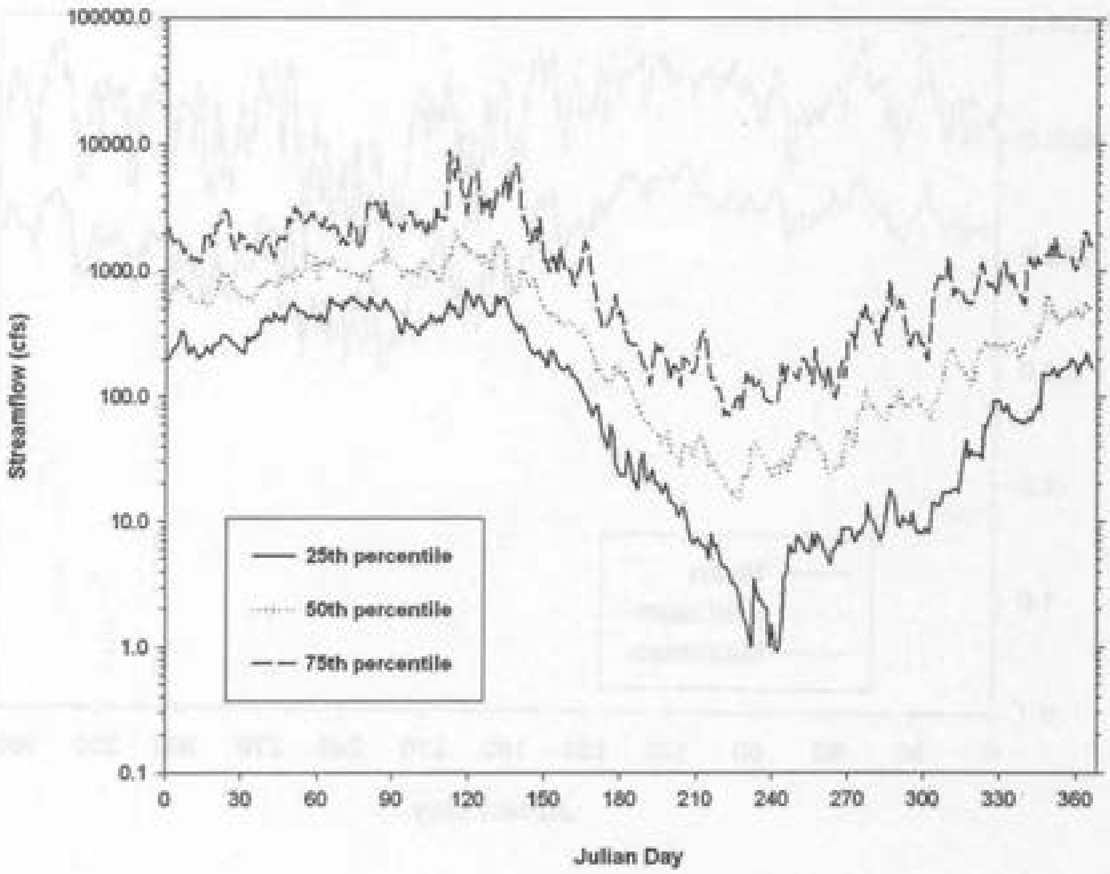


Figure 13. Daily streamflow means, minimums, and maximums for the Kiamichi River near Belzoni, OK, water years 1926-1972 (Data is unadjusted). Minimum daily flows not shown are either 0 or less than 0.1.

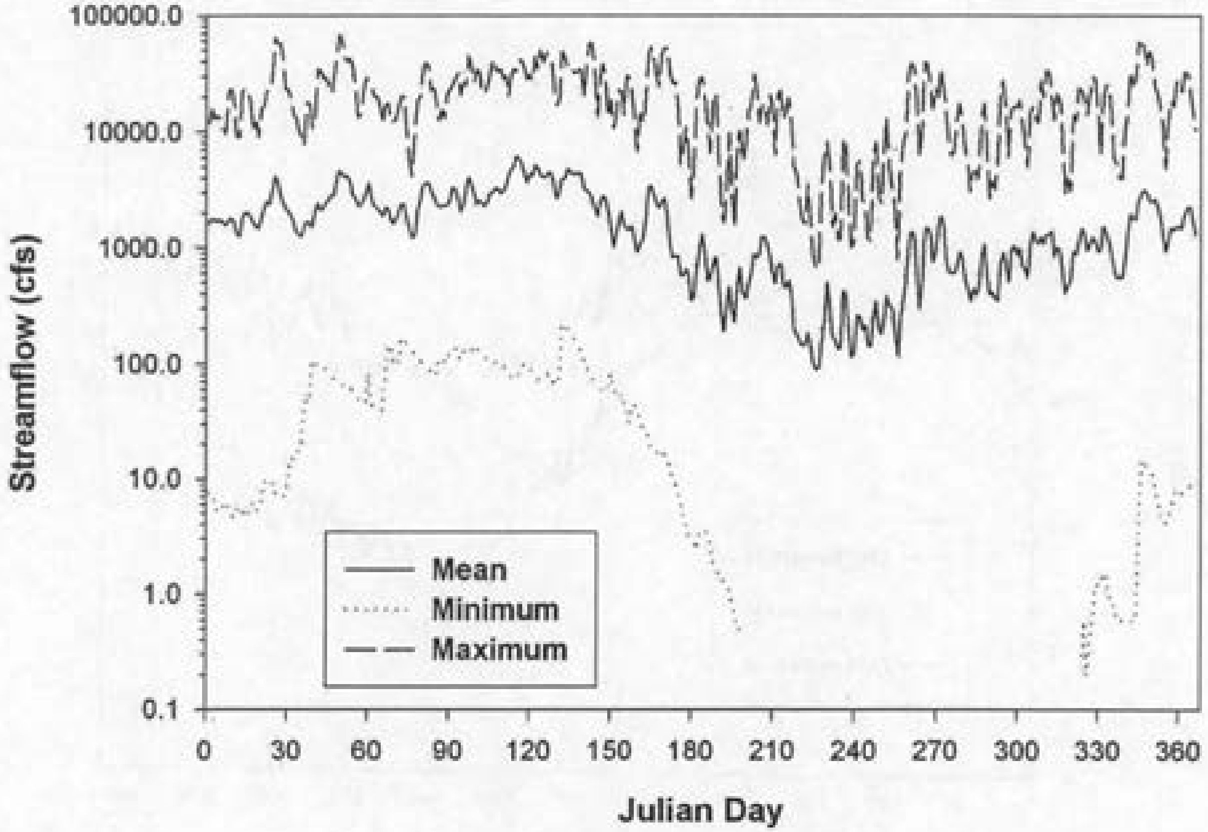


Figure 14. Flow duration curves before and after the construction of Sardis Lake and Dam on the Kiamichi River near Antlers, OK.

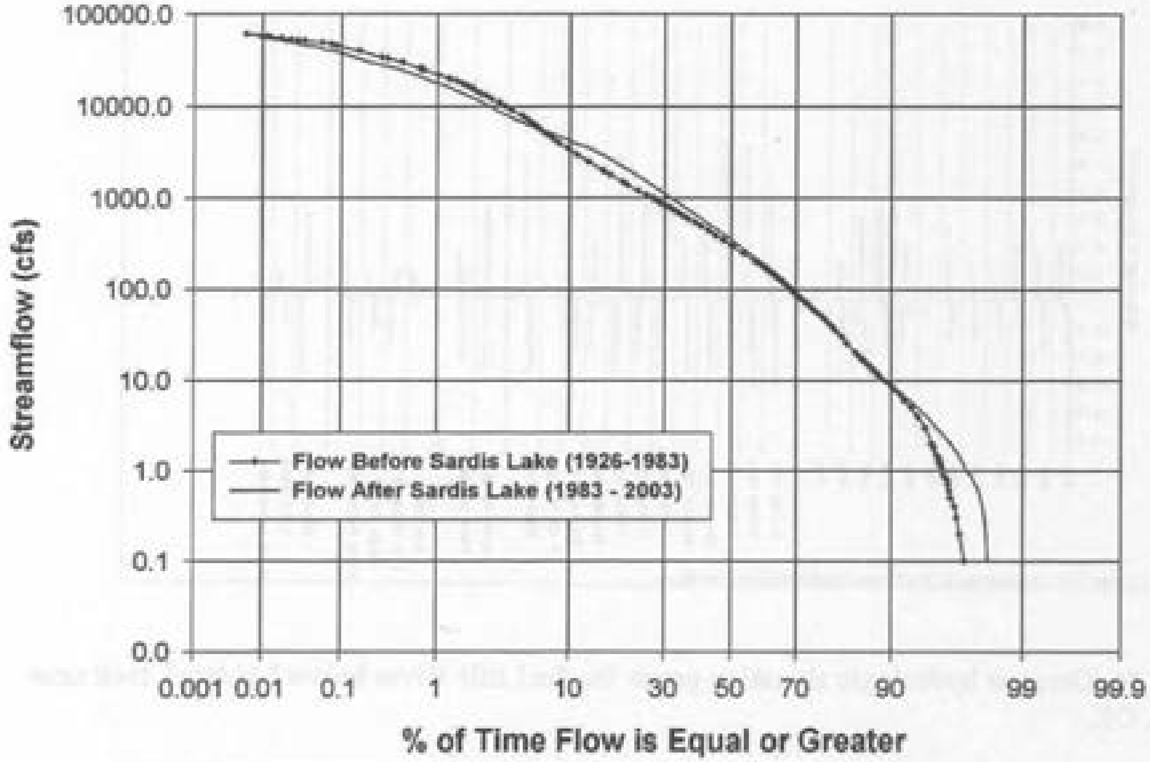


Figure 15. Hydrologic alteration graph for the Little River below Lukfata Creek near Idabel, OK.

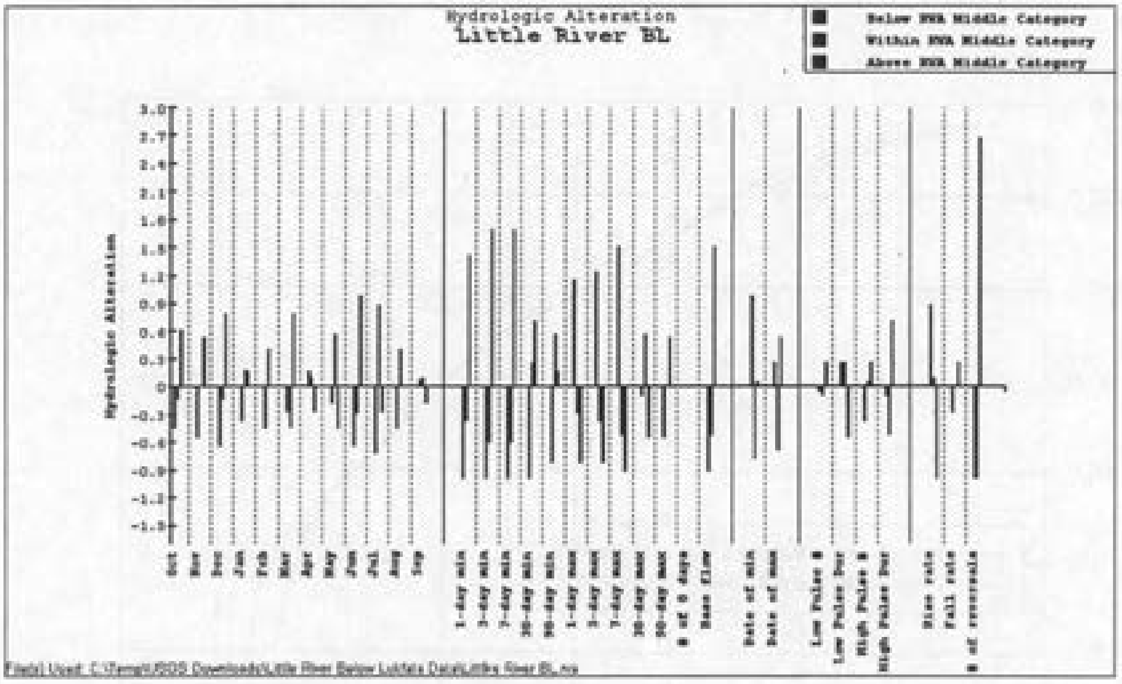


Figure 16. Greatest hydrologic alteration graph for the Little River below Lukfata Creek near Idabel, OK.

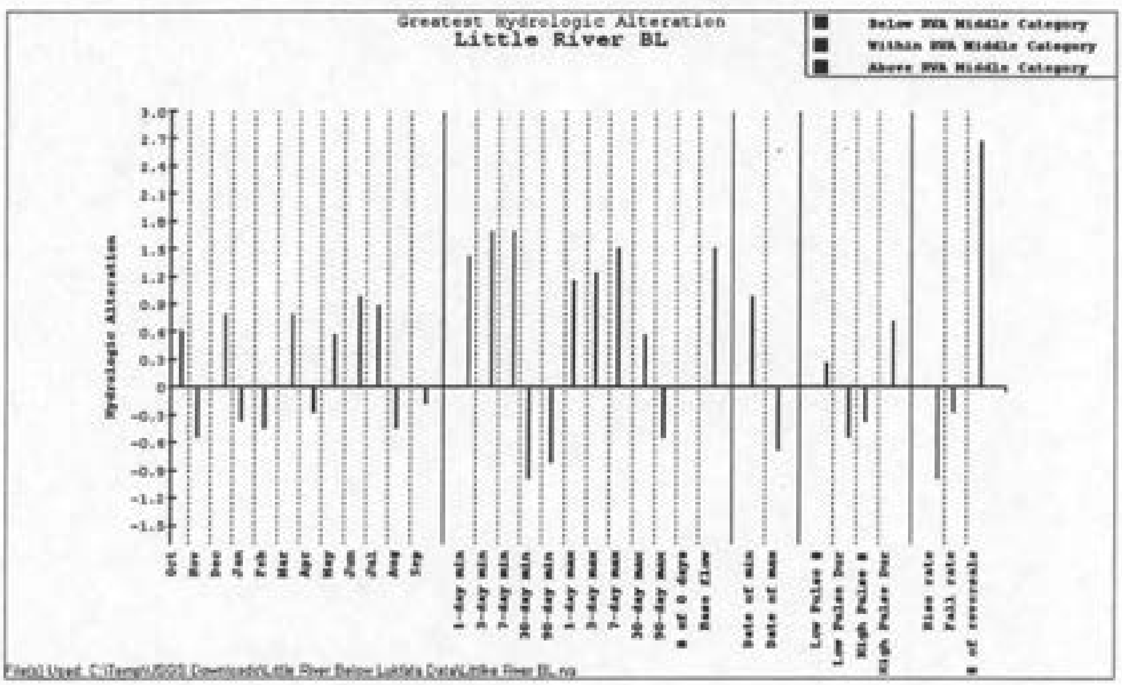


Figure 17. Hydrologic alteration graph for the Kiamichi River near Antlers, OK. (Combined with Belzoni data.)

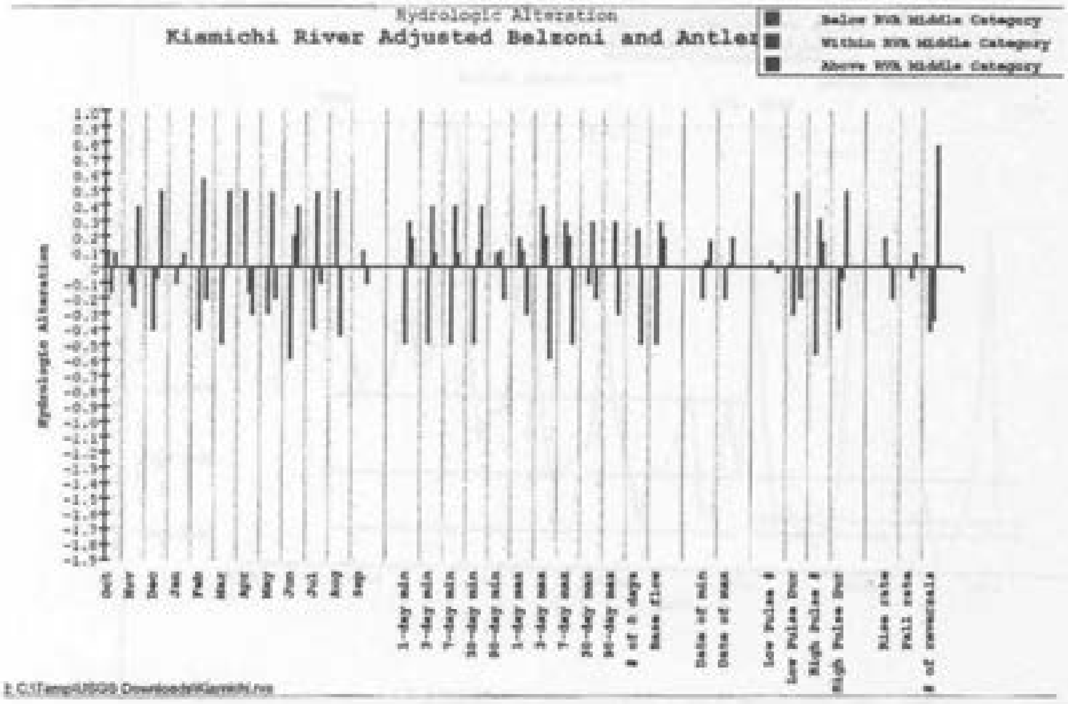


Figure 18. The greatest hydrologic alteration graph for the Kiamichi River near Antlers, OK. (Combined with Belzoni data.)

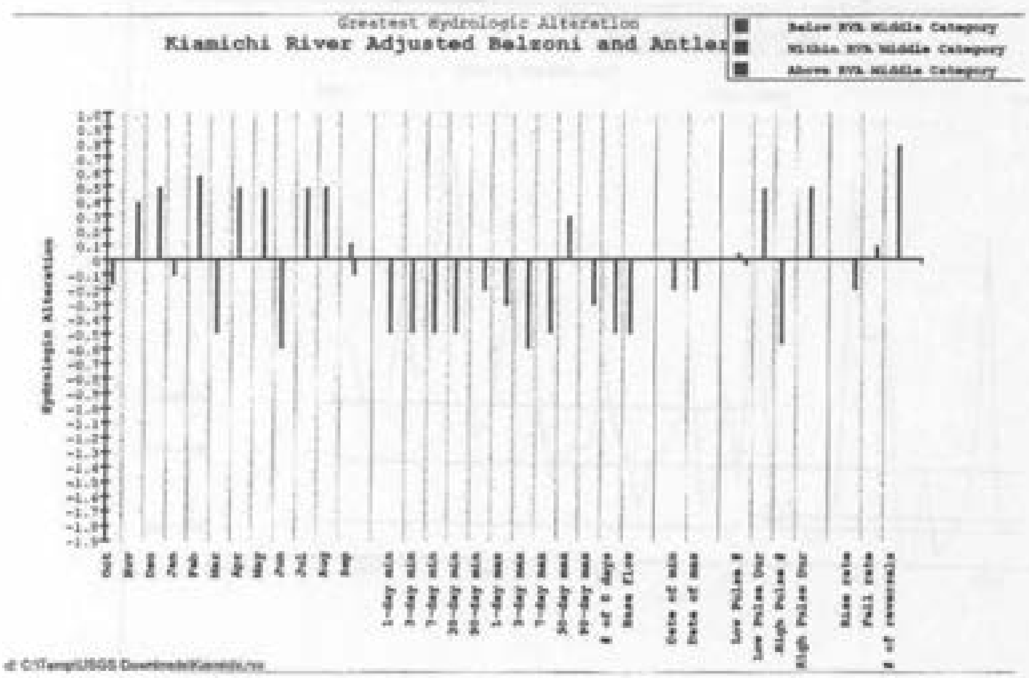


Figure 19. The non parametric Range of Variance Analysis for the Little River below Lukfata Creek near Idabel 3 –day minimum flows.

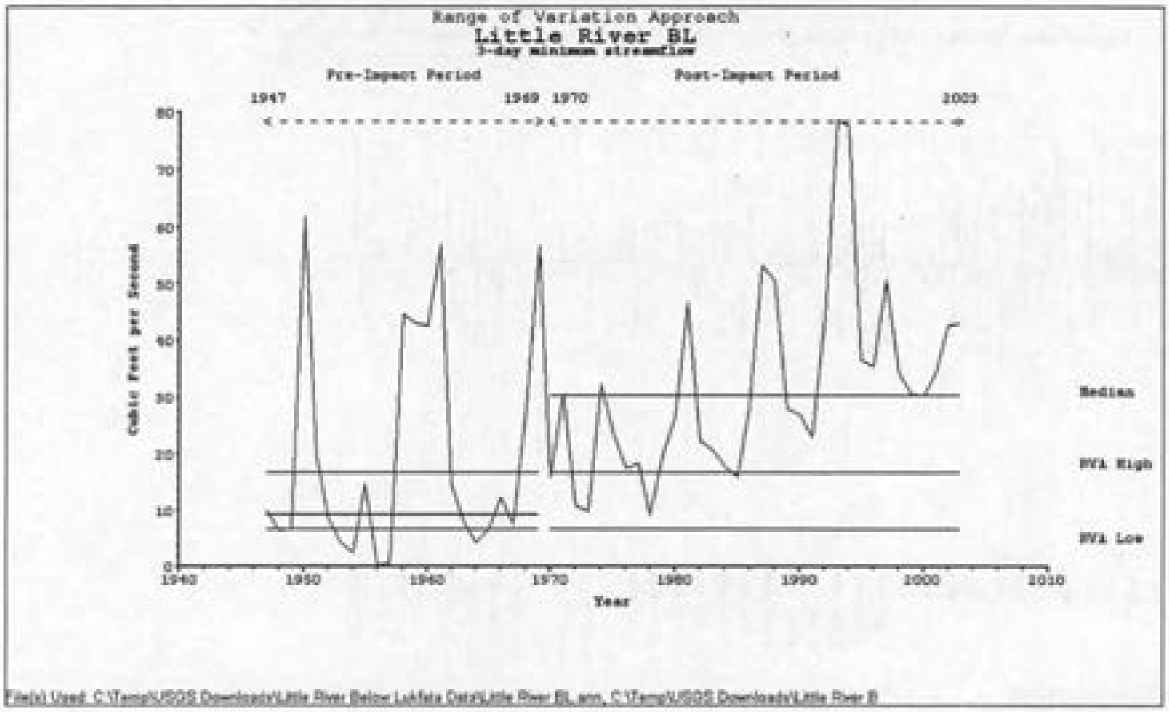
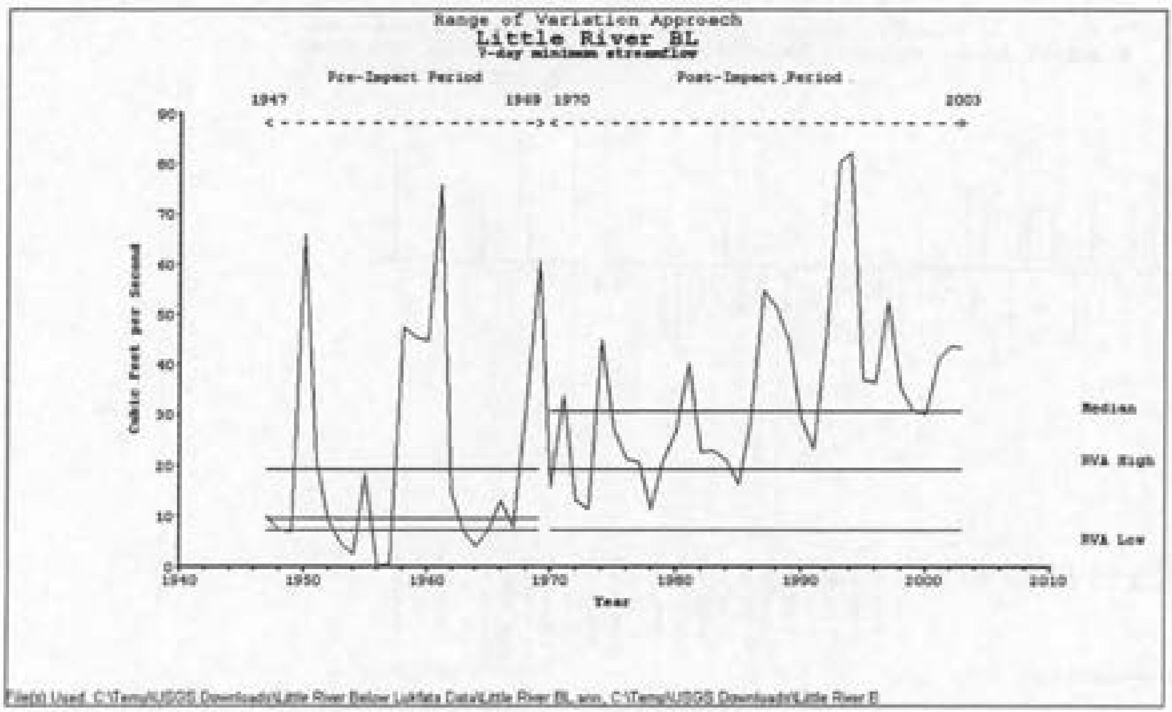


Figure 20. The non parametric Range of Variance Analysis for the Little River below Lukfata Creek near Idabel 7 –day minimum flows.



GEOMORPHOLOGY

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This section focuses on the potential effects of water diversion on stream geomorphology. Fluvial structures found in stream channels, such as pools, riffles, runs, sand and gravel bars, and woody debris dams form the different types of habitat required by aquatic life. Small changes in the flow regimen even when stream morphology is stable can affect aquatic life. These effects are discussed in the previous and following sections. This section focuses on the potential for flow diversions to affect streamflow regimen that maintain stable fluvial structures and hence aquatic habitat.

The morphology of streams and stream networks result from the long-term interaction between watershed and physiographic factors such as geology, topography, vegetation, and climate (Leopold et al. 1964, Leopold 1997). These factors determine the hydrologic regimen of a stream. Changes in stream morphology occur as the result of natural events and anthropogenic activities. The extent of change can occur over a wide range of spatial and temporal scales Frisell et al. (1986) classified these changes in 5 scales, the geomorphic province, river basin, valley segment, reach and habitat. Changes at the geomorphic province and river basin scales occur at temporal scales > 1,000 years and are not affected by water diversion. Changes at the channel reach and habitat scale often occur over periods of less than 1 year (Montgomery and Bolton, 2003). Stream structures are dynamic, moving from one location to another in response to changes in streamflow and sediment loads. In stable, natural channels their frequency and occurrence over a stream reach remain relatively constant in a state of dynamic equilibrium.

Through time, a stable channel has no net aggradation or degradation (Leopold et al. 1964; Rosgen 1996).

The geomorphology of stable alluvial channels is the result of a balance between the sediment load provided by the watershed, sediment size, stream slope, and discharge (Leopold et al. 1964, Rosgen, 1996). It is generally accepted, that "bankfull" streamflows (or those similar in magnitude and return frequency) are the flows that configure and maintain the morphology of alluvial stream channels and hence aquatic habitat (Leopold et al. 1964, Rosgen, 1996; Montgomery and Bolton 2003). Streamflows or a regimen of streamflows, that maintain a stable fluvial morphology (and desirable aquatic habitat) are often called "channel maintenance flows" (Leaf 1998, Whiting 2002). Channel maintenance flows maintain the form, frequency, and diversity of physical habitat instreams.

The morphology of a stream is the result of the flow regimen and the character, supply, and transport of sediment in the channel, as controlled by regional climate, geology, and topography. Changes in the supply or character of sediment (increase or decrease in size) can disrupt a stream's equilibrium. Increases or decreases in flows near the magnitude and frequency of bankfull discharge can also disrupt equilibrium. Land use activities within a stream's watershed, dams and reservoirs and water diversions can significantly change the flow regimen and hence the morphology of a stream.

Water diversions range in size and scope from large dams on major rivers (e.g., Grand Coulee, Hoover Dam) to small diversion structures on headwater streams. Usually water diversion structures, even on small streams, require the construction of a low head dam to maintain water levels for a pipeline or canal.

Dams have the greatest effects on streamflow regimen and channel morpohology. Dams also block the transport of sediment down a stream. The reduction of sediment downstream of a dam can result in the erosion of structures such as bars and riffles and the loss of aquatic habitat diversity (Ligon et al. 1995, Whiting 2002). Dams and reservoirs built for flood control and water storage reduce the large infrequently occurring flows that cause flooding. The reduction of floods and the inundation of floodplains may harm riparian vegetation, drain riparian wetlands, and reduce baseflow from bank storage of water (Whiting 2002). A loss of riparian vegetation could decrease streambank stability and increase bank erosion, leading to morphological changes in a channel (Whiting 2002). The reduction of flooding following the construction of a flood control dam on the Mountain Fork River, OK is shown in Figure 1. Impoundment behind the dam began in October, 1968. Prior to the dam being constructed, annual peak flows ranged randomly from greater than 20,000 cfs to above 100,000 cfs. Following construction of the dam, annual peaks stayed below 20,000 cfs and rarely exceed the pre-dam bankfull discharge (about 10,000-13,000 cfs).

Dams may also reduce the magnitude and frequency of channel maintenance flows, depending on how flows from a dam are managed. A reduction in magnitude or frequency of channel maintenance flows can cause fine sediment to aggregate in gravel bed streams if sufficient "flushing flows" are not provided (Williams and Wolman 1984, Whiting, 2002). Fine sediment accumulation can change the form and diversity of aquatic habitat in a channel and directly affect aquatic life. If channel maintenance flows are reduced, the likely response of a stream is to aggrade, resulting in the loss of deep water habitat and eventually channel braiding (Rosgen 1996).

The general effect of water diversion, either with or without a dam, is a reduction in streamflow. The magnitude of reduction depends on the quantity of water diverted. The timing of water diversion (during storm flows, baseflows, or season) may also affect stream geomorphology and aquatic life. From the standpoint of stream geomorphology, diversions that significantly affect high flows (floodplain and riparian maintenance) and channel maintenance flows (habitat stability) are likely the most important.

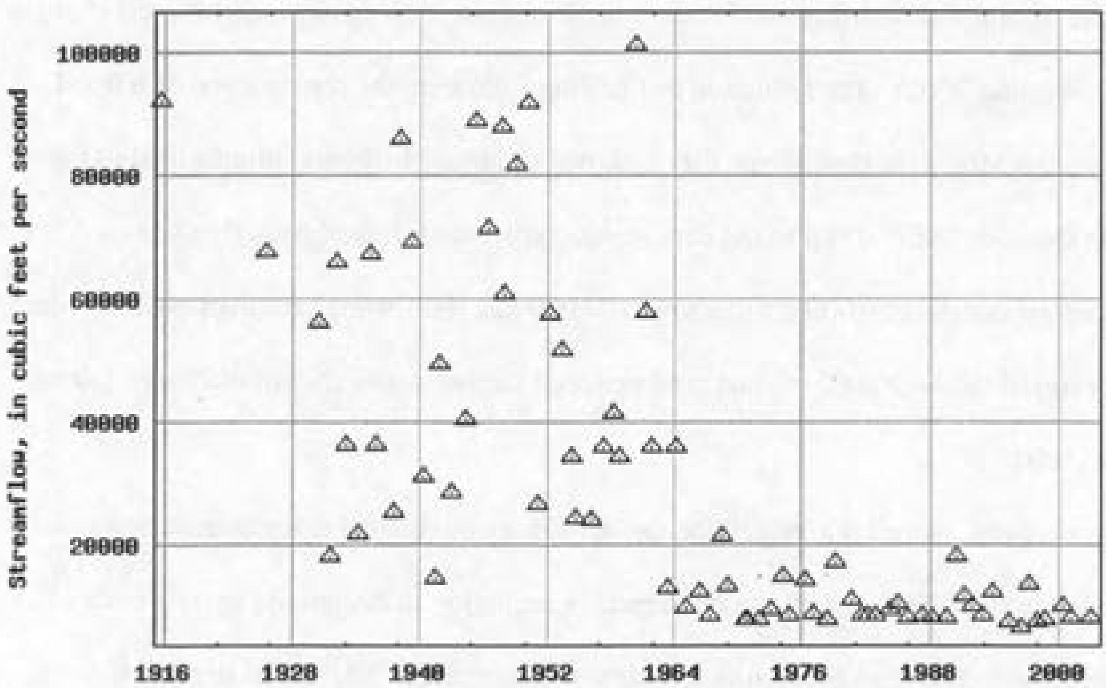

Figure 1. The reduction in annual peak flows on the Mountain Fork River, OK following the construction of the Broken Bow Dam and Beaver's Bend Lake, completed in 1968. The Eagletown gaging station is located downstream of the Broken Bow Dam. The reservoir was filled in 1968. (From: USGS NWIS Surface Water of the United States, 2005)

Water diversions for irrigation or municipal supply, especially on small streams, may de-water the stream channel downstream of the diversion. De-watering of streams by diverting flow for water supply allows vegetation to encroach into stream channels. The result is a loss of channel conveyance capacity and aquatic habitat area (Williams and Wolman 1984 and Gordon 1995). Johnson (1994) documented vegetative encroachment in the North and South Platte Rivers due to reduced flow from irrigation water diversion. Rates of channel loss were as high as 10% per year after the late 1930's, by which time most dams and diversions were constructed. Bohn and King (2000) evaluated the effects of water diversion for irrigation in small mountain streams in the Snake River Basin on flow conveyance, substrate size distribution, and streamside vegetation. They found no substantial change in the parameters studied. Evidence of vegetative encroachment and loss of channel conveyance was presented by the plaintiffs in the Colorado Water Division 1 Trial of 1990. This trial was one of the most significant federal instream flow rights trials to occur in the United States. Technical evidence about the effects of water diversion on stream geomorphology was presented by both sides. In the end, the judge ruled in 1993 that the Forest Service failed to show that the diversions affected stream geomorphology to the point where "favorable flows" of water were impaired (Gordon 1995). At the time of the trial, there were few if any research projects that made a direct link between water diversion (on small streams in the Front Range of Colorado) and stream geomorphology. The same is true today, and with a lack of scientific data it is difficult to determine if water diversion does or does not have an effect on stream geomorphology, and what steps need to be taken to protect streams under water development or restore streams already affected.

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PHYSIOCHEMICAL CONDITIONS

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Wilhm et al. (1976) conducted a literature survey and field study as part of an environmental impact assessment for the placement of a coal fired power plant in southeastern Oklahoma that would require an intake for raw cooling water. The study included a characterization of physicochemical conditions at sampling stations in the Blue, Kiamichi, and Arkansas Rivers. Based on data collected from five USGS sampling stations along the Kiamichi, they reported average values of 54 umhos/cm for conductivity, 5.8 mg/l for chloride, and 16 mg/l for hardness and alkalinity. Dissolved oxygen values collected in September 1976 from two sites on the river in Choctaw County were 6.2 and 4.1 mg/l, while pH in a sample from one of these sites was 6.5. The water chemistry characteristics indicate the river is a soft water system with relatively limited buffer capacity.

In a more recent analysis of water chemistry data for the Kiamichi River, Mast and Turk (1999) summarized a range of physical properties and values for major dissolved constituents in samples collected between 1966 and 1995 from the US Geological Survey Hydrologic Benchmark network station near Big Cedar, Oklahoma (Station 07335700). They also characterized the river water as "dilute and weakly buffered", and reported ranges for pH, conductivity and alkalinity of 4.7 to 9.0, 12 to 58 uS, and 20-320 meq/l as $CaCO_3$, respectively. Kress et al. (1988) stated that alkalinity levels in the Kiamichi at this site were among the lowest of those reported for USGS Benchmark sites in the United States. In comparing concentrations of specific inorganic ions between sites along the Kiamichi River, Mast and Turk (1999) reported slight variation, with differences attributed to geology of the local drainage.

Water quality in the Kiamichi River appears to have been more extensively characterized than that for systems such as the Glover, Little, and Mountain Fork Rivers. Bass (1995) conducted a macroinvertebrate survey of Cucumber Creek which is located in the upper reaches of the Mountain Fork Drainage and reported low conductivity and pH and dissolved oxygen levels that were similar to those from the Kiamichi River study by Wilhm et al. (1976). Some monitoring data for other localities have been generated through the Oklahoma Water Resources Board's Beneficial Use Monitoring Program (BUMP). Based on these limited data, water quality characteristics in the Kiamichi, Glover, Little, and Mountain Fork Rivers appear similar at least at the continuous monitoring sites from which the BUMP samples were taken and for the specific parameters measured (Table 1).

Impact of Water Diversions of Water Chemistry Characteristics

The impact of water diversion on the chemical characteristics of a stream is an important consideration since changes in the abiotic profile ultimately drive changes in the biotic component (Fabbro and Duivenvoorden 2000, Lagarrigue et al. 2001, Lessard and Hayes 2003). A key impact of water removal on general water quality is the elevation of dissolved salts that may result from flow alteration. For example, the removal of water for municipal use from the Mill River watershed in New England led to elevated levels of inorganic ions and nutrients at downstream sites due to a reduced capacity for dilution (Rhodes et al. 2001). Similar increases in inorganic ions were reported downstream from a diversion on the Ishite River of Japan (Kagawa 1992). In addition to concentration effects, altered flow regimes have been reported to influence the dynamics of benthic organic matter due to changes in flow patterns through the sediment interstitium (Wanner et al. 2002).

Meier et al. (2003) modeled the impact of water diversion for hydroelectric generation on temperature of small mountain streams and found that the severity of effects was related to the slope of the river bed. Those sections with a gradual slope experienced more drastic temperature increases since the stream bed received greater incident solar radiation under the shallower, low flow conditions. The construction of small impoundments to facilitate water withdrawal may also influence water temperature. Lessard and Hayes (2003) observed elevated surface water temperatures along stream reaches below small surface release dams due to warming of the water in the pooled area above the impoundment. Increases in water temperature may cause changes in other temperature-dependant parameters such as dissolved oxygen and pH. In contrast to those studies reporting water quality effects associated with flow regime alteration and/or impoundment, flow reductions caused by water transfers from three rivers in Quebec, Canada were reported to have limited effects, even though the post-diversion flows were in some cases 50% of pre-diversion levels (Roy and Messier 1989). However, these are cool- or cold-water rivers.

With respect to the potential effect of water diversion on chemical parameters in the rivers considered here, elevations in levels of dissolved solids is a concern for the streams of southeastern Oklahoma since, as particularly dilute systems, increasing concentrations of dissolved ions could have a significant impact on the biota. The potential impact of elevated levels of nutrients and other chemical contaminants must also be evaluated in light of beneficial use designations for selected stream segments. Of the systems evaluated by Wilhm et al. (1976), the Kiamichi River below Hugo Lake was considered best able to tolerate water diversion since any impacts on flow or water quality could be eliminated by managed releases of water from the Hugo Dam.

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Table 1. Water quality ranges for selected sites on the Kiamichi, Glover, Little, and Mountain Fork Rivers. Values were generated for monitoring stations that are part of the Oklahoma Water Resources Board's Beneficial Use Monitoring Program (BUMP) and derived for the present table from graphs presented in the 2003-2004 BUMP Report (available online at http://www.owrb.state.ok.us/studies/reports/bump/2004/2004bumpreport.php). Ranges represent the approximate maximum and minimum values for the parameters. Since the numerical values listed could only be estimated from the BUMP Report graphs, they should be treated as approximations only.

	Temperature (°C)	Dissolved oxygen (mg/l)	pH	Turbidity (NTU)	TDS (mg/l)	Sulfates (mg/l)	Chlorides (mg/l)	Total Phosphorous (mg/l)	Nitrite + Nitrate (mg/l)
Kiamichi River near Big Cedar 1999-2004	5-30	3-15	5.5-8.5	<5-20	0-41	1-10	1-22	≤0.1	≤0.2
Kiamichi River near Tuskahoma 1999-2004	0-35	3-18	5.5-8.2	<5-70	0-120	0->200	<10	<0.1-0.5	<0.1
Kiamichi River near Antlers 1999-2004	5-35	3-10.5	5.0-8.0	5-47	<100	1-32	1-10	0.01-0.34	0-0.05
Kiamichi River near Fort Towson 2002-2004	5-30	4-14	6.5-8.1	25-70	<100	10-40	5-15	0.05-0.25	0-0.01
Glover River near Glover 1999-2004	10-35	1-10	6.0-8.5	2.5-20	≤100	0-30	0-10	0-0.5	0-0.1
Little River near Holly Creek 2003-2004	5-27	10-25	6.5-8.0	1.0-10	≤100	10-20	10-25	0.025-0.15	0-0.025

FLOODPLAIN HABITATS AND TERRESTRIAL BIOTA—BIRDS AND MAMMALS

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General Impacts of Hydrologic Alterations on Floodplain Habitats and Terrestrial Biota

Floodplain habitats are structured by the duration, frequency, and timing of flood events, and any changes in the hydrologic regime of a river can greatly affect the ecological processes (e.g., nutrient cycling, primary productivity, decomposition rates, and energy flow) of these habitats as well as the flora and fauna associated with these habitats (Mitsch and Gosselink 2000). The pulsing of river discharge (i.e., seasonal flooding) is the principal force controlling the biota of the floodplain (Junk et al. 1989). The construction of dams and diversion projects has had an impact on the ecological processes of these habitats through altering the timing and frequency of the pulse river discharges. These pulse river discharges are critical to floodplain habitats because they transport nutrients and sediments into the system, "flush" away waste products, and recharge shallow aquifers and capillary water reservoirs (Brinson et al. 1981).

A number of researchers have described the effects of impoundments on downstream riparian habitats (Bradley and Smith 1986, Rood and Mahoney 1990, Johnson 1994, Scott et al. 1997). Depending on the severity of changes to the hydrologic regime of the river, the effects on downstream riparian habitats can range from slight (e.g., very few changes to plant species composition and growth rates) to substantial (e.g., elimination of the entire plant community). Several studies have attributed changes in the composition, abundance, growth, and recruitment of riparian plant species to alterations in streamflows. Construction of Garrison Dam on the

Missouri River has resulted in a decline in tree growth and recruitment of many riparian tree species (e.g., boxelder [*Acer negundo*], American elm [*Ulmus americana*], green ash [*Fraxinus pennsylvanica*], and prairie cottonwood [*Populus deltoides*]) (Johnson et al. 1976, Reily and Johnson 1982). These changes in the riparian tree community can be attributed to the removal of periodic spring flooding that are critical for creating optimal moisture and nutrient conditions for tree growth and establishment of seedlings. Nilsson et al. (1991) evaluated the long-term effects of river regulation on riparian vegetation in Sweden and concluded that plant species richness and cover were lower along regulated rivers than unregulated rivers. They suggested the reduction in species richness and cover was due to the loss of the natural regime of water-level fluctuations in the regulated rivers. In the case of the Platte River, dams and water diversion projects on the Platte River and its tributaries in Wyoming, Colorado, and Nebraska have actually resulted in an increase in riparian forest abundance (Johnson 1994). The loss of peak flooding events that scoured seedlings from exposed sandbars facilitated the expansion of riparian vegetation along the Platte River.

The impact of flow alterations on the riparian fauna is also highly variable depending on how severely the alterations affect the riparian vegetation. Bird and mammal species that rely on riparian forests for reproductive and foraging habitat are at risk from loss and degradation of this habitat. As riparian forests are lost and altered, the remaining tracts become smaller and more isolated. Because these riparian forests are often used as travel corridors by many bird and mammal species, fragmentation of these habitats may significantly alter migration and dispersal patterns of these species (Diffendorfer et al. 1995, Faaborg 2002). The reduced size of the forests may impact area-sensitive bird species such as Acadian flycatchers (*Empidonax virescens*), red-eyed vireos (*Vireo olivaceous*), and Kentucky warblers (*Oporornis formosus*)

(Kilgo et al. 1998) as well as some small mammals (Yates et al. 1997). Additionally, changes in the timing and duration of pulse discharge may also impact riparian fauna. Many of these species have synchronized their breeding with low instream flows. Consequently, flooding during the breeding season may result in an increase in failed reproductive efforts, especially for species that are ground nesters.

In the Kiamichi and Little River systems, two floodplain plant communities (eastern Oklahoma bottomland forest and cypress swamp) could be affected by altered streamflows. The eastern Oklahoma bottomland forests are dominated by overcup oak (*Quercus lyrata*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and willow oak (*Quercus phellos*), while the cypress swamps are dominated by bald cypress (*Taxodium distichum*), sugar maple (*Acer saccharum*), blackgum (*Nyssa sylvatica*), and American hornbeam (*Carpinus caroliniana*) (Brabander et al. 1985, Hoagland et al. 1996). Although sugar maple was reported as a predominant tree species in the cypress swamps, it is typically not considered an associate of bald cypress (Hoagland et al. 1996). Depending on tolerance to flooding of the dominant tree species, changes to the hydrologic regime can significantly alter the composition and structure of these plant communities. In general, the dominant tree species of the Oklahoma bottomland forest are less tolerant to flooding than the dominant tree species of the cypress swamp. The eastern Oklahoma bottomland forest are typically associated with shorter hydroperiods and better-drained soils than the cypress swamps which are associated with wetter sites with finer-textured soils and more stable moisture conditions (Brabander et al. 1985). The long-term viability of the eastern Oklahoma bottomland forest is linked to periodic flooding during late winter and early spring months. These periodic floods are critical for creating optimal moisture conditions for seed germination and seedling recruitment as well as mature tree growth (Brinson et al. 1981, Jones et al. 1994, Mitch and Gosselink 2000). Additionally, the periodic floods during this period are important for transporting seeds and enhancing seed bank and seedling diversity throughout this floodplain habitat (Schneider and Sharitz 1988).

Cypress swamps along the Kiamichi and Little Rivers are restricted to sloughs, oxbows, and meander scars along the rivers (Henley and Harrison 2001). The hydroperiod of cypress swamps can be relatively long with the substrate being inundated or saturated throughout the growing season (Wharton et al. 1982). Although bald cypress communities can tolerate deep prolonged flooding for more than one year, seed germination and establishment can only occur on exposed, saturated soils (Middleton 1999, O'Neil et al. 2001). Currently, the impact of altered streamflows in the Kiamichi and Little River to eastern Oklahoma bottomland forests and cypress swamps is difficult to determine because the magnitude and timing of withdrawal is not clear. However, any significant alteration to the natural hydrologic regime could substantially impact these plant communities.

Birds and Mammals

Floodplain habitats (includes associated wetland and riverine habitats) along the Kiamichi and Little Rivers provide habitat for 149 bird species and 46 mammal species. Of the 149 bird species, 19 of the species are designated as a species of greatest conservation concern according to the Oklahoma Comprehensive Wildlife Conservation Strategy and 1 species (bald eagle [*Haliaeetus leucocephalus*]) is federally and state threatened (Table 1). Of the 46 mammal species, 6 species are designated as an Oklahoma species of concern category II, 10 species are designated as a species of greatest concern according to the Oklahoma Comprehensive Wildlife Conservation Strategy, and 1 species (Indiana myotis bat [*Myotis sodalis*]) is federally and state endangered (Table 2). These habitats are important to bird species during breeding and migratory periods. Nearly half of the bird species occur in these habitats during the breeding season, and most of the species occur in these habitats during spring and/or fall migration.

It is difficult to determine the impact that altered flows in the Kiamichi and Little Rivers will have on the bird and mammal communities that rely on riparian habitats for at least a portion of the annual cycle because it is not clear how these habitats will be affected by altered flows. However, the overall decline and possible loss of these habitats pose a serious risk to some of these species. In particular, species that prefer flooded conditions may be severely impacted. For example, prothonotary warblers (*Protonotaria citrea*) and Acadian flycatchers prefer flooded habitats (Gabbe et al. 2002). Prothonotary warblers typically nest in cavities over standing water (Petit 1999), while Acadian flycatchers prefer the relatively open habitat conditions of flooded forests for foraging (Whitehead and Taylor 2002). For both of these species, the impact of altered flows on the bald cypress is relevant because these habitats provide the preferred flooded conditions for these species. The effects of altered flows on Acadian flycatchers and prothonotary warblers could be minimal if the hydroperiod of bald cypress swamps is unaffected, but could be severe if the hydroperiod is significantly altered such that the bald cypress community is replaced by mesic and upland tree species. Additionally, because bald cypress trees provide natural cavities, the loss of this community could also impact other cavity nesting birds (e.g., wood duck [*Aix sponsa*], Carolina chickadee [*Poecile carolinensis*], tufted titmouse [*Baeolophus bicolor*]). Altered flows may also impact the food resources of aquatic bird species, particularly piscivorous species (e.g., anhinga [*Anhinga anhinga*], double-crested cormorant (*Phalacrocorax auritus*), herons, diving ducks). Declines in food resources could result in some of these species abandoning affected areas of the Kiamichi and Little River watersheds in search of more abundant food resources.

Several mammal species could be impacted by altered flows to the Kiamichi and Little Rivers. Although many of listed bat species do not tend to use these floodplain habitats for roosting, nurseries, and hibernacula (Caire et al. 1989), these species do rely on these habitats, particularly open bald cypress swamps and river corridors, for foraging on aerial insects (e.g., flies, mosquitos, moths, and night-flying ants [Schmidly 1991]). The alteration of flows could potentially affect these food resources for bats, particularly aerial insects (i.e., dipterans and lepidopterans) that require flooded conditions for ovipositing of eggs and development of larvae. Similarly, river otters (*Lutra canadensis*) may be impacted by the effect of altered flows on their aquatic food resources (i.e., primarily fish and to lesser extent crayfish, frogs, and other aquatic animals [Melquist and Dronkert 1987]). Declines in fish abundances due to altered flows could negatively impact river otter. Two small mammals of conservation concern in Oklahoma, the golden mouse (*Ochrotomys nuttalli*) and marsh rice rat (*O. palustris*), occur in floodplain habitats along the Kiamichi and Little Rivers. The golden mouse inhabits riparian forests, while the marsh rice rat inhabits wetlands and moist areas (Oklahoma Biological Survey 1992). Although it is not known what impact altered flows may have on golden mice and marsh rice rats, the potential loss and degradation of floodplain habitats due to altered flows likely would negatively affect these species.

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Table 1. Bird species occurring in riverine, wetland, and riparian forest habitats along the Kiamichi and Little Rivers in southeastern Oklahoma. Species list based on reported sighting at Little River National Wildlife Refuge (U.S. Fish and Wildlife Service 2002a).

Species	Scientific Name	Residency in Southeastern OK[a]	State and Federal Status[b]
Pied-billed grebe	*Podilymbus podiceps*	O-Sp, Su, W U-F	
Double-crested cormorant	*Phalacrocorax auritus*	U-Sp, F, W	
Anhinga	*Anhinga anhinga*	O-Sp, Su, F	
American bittern	*Botaurus lentiginosus*	R-Sp, F	
Least bittern	*Ixobrychus exilis*	R-Sp, F	
Great blue heron	*Ardea herodias*	C-Sp, Su, F O-W	
Great egret	*Ardea alba*	O-Sp, Su U-F	
Snowy egret	*Egretta thula*	O-Sp, Su, F	
Little blue heron	*Egretta caerulea*	C-Sp, Su U-F	GC
Cattle egret	*Bubulcus ibis*	U-Sp, Su, F	
Green heron	*Butorides virescens*	U-Sp, Su, F	
Yellow-crowned night-heron	*Nyctanassa violacea*	O-Sp, Su, F	
White-faced ibis	*Plegadis chihi*	R-Sp, F	
Wood duck	*Aix sponsa*	C-Sp, F, W U-Su	
Green-winged teal	*Anas crecca*	U-Sp, F	
Mallard	*Anas platyrhynchos*	U-Sp C-F, W	
Northern pintail	*Anas acuta*	O-Sp, F	GC
Blue-winged teal	*Anas discors*	U-Sp, F R-Su	
Northern shoveler	*Anas clypeata*	U-Sp, F O-W	
Gadwall	*Anas strepera*	U-Sp, F C-W	
American wigeon	*Anas americana*	U-Sp, F C-W	
Ring-necked duck	*Aytha collaris*	O-Sp, F, W	
Lesser scaup	*Aythya affinis*	O-Sp, F, W	GC
Common goldeneye	*Bucephala clangula*	O-Sp, F, W	
Bufflehead	*Bucephala albeola*	O-Sp, F, W	
Hooded merganser	*Lophyodytes cucullatus*	U-Sp, F, W	

Ruddy duck	*Oxyura jamaicensis*	O-Sp, F, W	
Black vulture	*Coragyps atratus*	C-Sp, Su, F, W	
Turkey vulture	*Cathartes aura*	C-Sp, Su, F, W	
Osprey	*Pandion haliaetus*	O-Sp, F	
Mississippi kite	*Ictinia mississippiensis*	U-Sp, Su	
Bald eagle	*Haliaeetus leucocephalus*	O-Sp, F U-W	T*, GC
Sharp-shinned hawk	*Accipter striatus*	U-Sp, F, W	
Cooper's hawk	*Accipter cooperii*	U-Sp, F, W	
Red-shouldered hawk	*Buteo lineatus*	C-Sp, F, W U-Su	
Red-tailed hawk	*Buteo jamaicensis*	U-Sp, Su, F, W	
Merlin	*Falco columbarius*	R-Sp, F	
Wild turkey	*Meleagris gallopavo*	O-Sp, Su, F, W	
Virginia rail	*Rallus limicola*	R-Sp, F O-W	
Sora	*Porzana Carolina*	R-Sp, F	
Common moorhen	*Gallinula chloropus*	R-Sp, Su, F	
American coot	*Fulica americana*	O-Sp, F, W	
Killdeer	*Charadrius vociferus*	O-Sp, Su, F, W	
Greater yellowlegs	*Tringa melanoleuca*	R-Sp, F	
Lesser yellowlegs	*Tringa flavipes*	R-Sp, F	
Solitary sandpiper	*Tringa solitaria*	R-Sp, F	GC
Spotted sandpiper	*Actitis macularia*	R-Sp, F	
Least sandpiper	*Calidris minutilla*	R-Sp, F	
Long-billed dowitcher	*Limnodromus scolopaeus*	R-Sp, F	
American woodcock	*Scolopax minor*	O-Sp, F, W R-Su	GC
Yellow-billed cuckoo	*Coccyzus americanus*	C-Sp, Su, F	
Black-billed cuckoo	*Coccyzus erythropthalmus*	O-Sp, F	
Barred owl	*Strix varia*	C-Sp, Su, F, W	
Chuck-will's-widow	*Caprimulgus carolinensis*	C-Sp, Su, F	
Belted kingfisher	*Ceryle alcyon*	O-Sp, Su, F, W	
Ruby-throated hummingbird	*Archilochus colubris*	C-Sp, Su, F	
Red-headed woodpecker	*Melanerpes erythrocephalus*	U-Sp, W O-Su, F	GC
Red-bellied woodpecker	*Melanerpes carolinus*	C-Sp, Su, F, W	
Yellow-bellied sapsucker	*Sphyrapicus varius*	U-Sp, F, W	
Downy woodpecker	*Picoides pubescens*	C-Sp, Su, F, W	
Hairy woodpecker	*Picoides villosus*	O-Sp, Su, F, W	
Northern flicker	*Colaptes auratus*	C-Sp, F, W U-Su	
Pileated woodpecker	*Dryocopus pileatus*	U-Sp, Su, F, W	

Olive-sided flycatcher	*Contopus cooperi*	O-Sp, F	
Eastern wood-pewee	*Contopus virens*	C-Sp, Su, F	
Acadian flycatcher	*Empidonax virescens*	C-Sp, Su	
		F-U	
Least flycatcher	*Empidonax minimus*	O-Sp, F	
Eastern phoebe	*Sayornis phoebe*	U-Sp, F, W	
		O-Su	
Great crested flycatcher	*Myiarchus crinitus*	C-Sp, Su, F	
Blue jay	*Cyanocitta cristata*	C-Sp, Su	
		U-F	
Fish crow	*Corvus ossifragus*	C-Sp, Su, F	
		O-W	
Carolina chickadee	*Poecile carolinensis*	C-Sp, Su, F, W	
Tufted titmouse	*Baeolophus bicolor*	C-Sp, Su, F, W	
White-breasted nuthatch	*Sitta carolinensis*	U-Sp, Su, F, W	
Brown creeper	*Certhia americana*	U-F, W	
Carolina wren	*Thryothorus ludovicianus*	C-Sp, Su, F, W	
Bewick's wren	*Thryothorus bewickii*	O-Sp, F, W	
House wren	*Troglodytes aedon*	R-Sp, F	
Winter wren	*Troglodytes troglodytes*	U-Sp, F, W	
Sedge wren	*Cistothorus platensis*	O-Sp, F, W	
Golden-crowned kinglet	*Regulus satrapa*	U-Sp, F, W	
Ruby-crowned kinglet	*Regulus calendula*	C-Sp, F, W	
Blue-gray gnatcatcher	*Polioptila caerulea*	C-Sp, Su	
		U-F	
Eastern bluebird	*Sialia sialis*	U-Sp, Su, F, W	
Veery	*Catharus fuscescens*	R-Sp, F	
Gray-cheeked thrush	*Catharus minimus*	O-Sp, F	
Swainson's thrush	*Catharus ustulatus*	U-Sp, F	
Hermit thrush	*Catharus guttatus*	C-Sp, F, W	
Wood thrush	*Hylocichla mustelina*	U-Sp, Su	GC
American robin	*Turdus migratorius*	C-Sp, Su, W	
		U-F	
Gray catbird	*Dumetella carolinensis*	U-Sp, Su, F	
		R-W	
Brown thrasher	*Toxostoma rufum*	C-Sp, Su, F	
		U-W	
Cedar waxwing	*Bombycilla cedrorum*	U-Sp, F, W	
White-eyed vireo	*Vireo griseus*	C-Sp, Su	
		U-F	
Blue-headed vireo	*Vireo solitarius*	O-Sp, F, W	
Yellow-throated vireo	*Vireo flavifrons*	U-Sp, Su, F	
Warbling vireo	*Vireo gilvus*	U-Sp, Su, F	
Philadelphia vireo	*Vireo philadelphicus*	R-Sp, F	
Red-eyed vireo	*Vireo olivaceus*	C-Sp, Su	

		U-F	
Blue-winged warbler	*Vermivora pinus*	R-F	GC
Orange-crowned warbler	*Vermivora celata*	U-Sp, F	
Nashville warbler	*Vermivora ruficapilla*	U-Sp, F	
Northern parula	*Parula americana*	U-Sp, Su	
		O-F	
Yellow warbler	*Dendroica petechia*	O-Sp, F	
Chestnut-sided warbler	*Dendroica pensylvanica*	O-Sp, F	
Magnolia warbler	*Dendroica magnolia*	O-Sp, F	
Yellow-rumped warbler	*Dendroica coronata*	U-Sp, W	
		C-F	
Black-throated green warbler	*Dendroica virens*	O-Sp, F	
Blackburnian warbler	*Dendroica fusca*	O-Sp, F	
Yellow-throated warbler	*Dendroica dominica*	C-Sp	
		U-Su, F	
Blackpoll warbler	*Dendroica striata*	O-Sp	
Black-and-white warbler	*Mniotilta varia*	U-Sp, Su, F	
American redstart	*Setophaga ruticilla*	U-Sp, F	
		O-Su	
Prothonotary warbler	*Protonotaria citrea*	C-Sp, Su	GC
		U-F	
Worm-eating warbler	*Helmitheros vermivora*	R-Sp, F	GC
Swainson's warbler	*Limnothlypis swainsonii*	O-Sp, Su	GC
		R-F	
Ovenbird	*Seiurus aurocapillus*	U-Sp, F	
Northern waterthrush	*Seiurus noveboracensis*	O-Sp, F	
Louisiana waterthrush	*Seiurus motacilla*	U-Sp, Su, F	GC
Kentucky warbler	*Oporornis formosus*	U-Sp, Su, F	GC
Common yellowthroat	*Geothylypis trichas*	U-Sp, Su, F	
		R-W	
Hooded warbler	*Wilsonia citrine*	U-Sp, Su	GC
Wilson's warbler	*Wilsonia pusilla*	O-Sp, F	
Summer tanager	*Piranga rubra*	C-Sp, Su, F	
Scarlet tanager	*Piranga olivacea*	R-Sp, F	
Northern cardinal	*Cardinalis cardinalis*	C-Sp, Su, F, W	
Rose-breasted grosbeak	*Pheucticus ludovicianus*	O-Sp, F	
Blue grosbeak	*Guiraca caerulea*	U-Sp, Su	
		O-F	
Indigo bunting	*Passerina cyanea*	C-Sp, Su, F	
Painted bunting	*Passerina ciris*	R-Sp, Su, F	GC
LeConte's sparrow	*Ammodramus leconteii*	R-Sp, F, W	GC
Fox sparrow	*Passerella iliaca*	O-Sp	
		U-F, W	
Song sparrow	*Melospiza melodia*	C-Sp, F, W	

Lincoln's sparrow	*Melospiza lincolnii*	U-Sp, F O-W	
Swamp sparrow	*Melospiza georgiana*	U-Sp, F, W	
White-crowned sparrow	*Zonotrichia leucophrys*	U-Sp, F O-W	
White-throated sparrow	*Zonotrichia albicollis*	C-Sp, F, W	
Harris sparrow	*Zonotrichia querula*	O-Sp, F, W	GC
Dark-eyed junco	*Junco hyemalis*	C-Sp, F, W	
Red-winged blackbird	*Agelaius phoeniceus*	U-Sp, Su, F, W	
Rusty blackbird	*Euphagus carolinus*	O-F U-W	GC
Great-tailed grackle	*Quiscalus mexicanus*	O-Sp, F R-Su, W	
Common grackle	*Quiscalus quiscula*	C-Sp, F O-Su U-W	
Brown-headed cowbird	*Molothrus ater*	U-Sp, Su, W O-W	
Orchard oriole	*Icterus spurious*	U-Sp, Su O-W	
Baltimore oriole	*Icterus galbula*	U-Sp, Su O-F	
Purple finch	*Carpodacus purpureus*	O-Sp U-F, W	
Pine siskin	*Carduelis pinus*	O-Sp, F U-W	
American goldfinch	*Carduelis tristis*	U-Sp, Su, F, W	

[a] C: common species often observed in high numbers, U: uncommon species often observed in small numbers, O: occasional species that is seldom seen in suitable habitat, R: rare species that fluctuate in occurrence and numbers from year to year.

[b] E: Oklahoma endangered species, T: Oklahoma threatened species, SCI: Oklahoma species of concern category I, SCII: Oklahoma species of concern category II, *: indicates species is also federally, threatened, or of special concern, GC: designated as an Oklahoma species of greatest conservation concern according to the Oklahoma Comprehensive Wildlife Conservation Strategy.

Table 2. Mammal species occurring in riverine, wetland, and riparian forest habitats along the Kiamichi and Little Rivers in southeastern Oklahoma. Species list based on reported sighting at Little River National Wildlife Refuge (U.S. Fish and Wildlife Service 2002b).

Species	Scientific Name	State and Federal Status[a]
Virginia opossum	*Didelphis virginiana*	
Nine-banded armadillo	*Dasypus novemcinctus*	
Short-tailed shrew	*Blarina brevidcauda*	
Least shrew	*Cryptotis parva*	
Eastern mole	*Scalopus aquaticus*	
Big brown bat	*Estesicus fuscus*	
Silver-haired bat	*Lasionycteris noctivagans*	
Red bat	*Lasiurus borealis*	
Seminole bat	*Lasiurus seminolus*	SCII, GC
Southeastern myotis bat	*Myotis austroriparius*	SCII, GC
Keen's myotis bat	*Myotis keenii*	SCII
Little brown myotis bat	*Myotis lucifugus*	
Indiana myotis bat	*Myotis sodalis*	E*, GC
Evening bat	*Mycticeius humeralis*	
Big-eared bat	*Plecotus rafinesquii*	SCII, GC
Coyote	*Canis latrans*	
Gray fox	*Urocyon cinereoargenteus*	
Red fox	*Vulpes vulpes*	
Raccoon	*Procyon lotor*	
Long-tailed weasel	*Mustela frenata*	GC
Mink	*Mustela vison*	
Striped skunk	*Mephitis mephitis*	
River otter	*Lutra canadensis*	SCII, GC
Bobcat	*Felis rufus*	
Pig	*Sus scrofa*	
White-tailed deer	*Odocoileus virginianus*	
Southern flying squirrel	*Glaucomys volans*	
Gray squirrel	*Sciurus carolinensis*	
Fox squirrel	*Sciurus niger*	
Plains pocket gopher	*Geomys bursarius*	
Beaver	*Castor canadensis*	
Eastern woodrat	*Neotoma floridana*	
Golden mouse	*Ochrotomys nuttalli*	GC
Marsh rice rat	*Oryzomys palustris*	GC
Cotton mouse	*Peromyscus gossypinus*	
Fulvous harvest mouse	*Reithrodontomys fulvescens*	
Eastern harvest mouse	*Reithrodontomys humulis*	SCII, GC
Hispid cotton rat	*Sigmodon hispidus*	

Woodland vole	*Microtus pinetorum*	
House mouse	*Mus musculus*	
Norway rat	*Rattus norvegicus*	
Black rat	*Rattus rattus*	
Nutria	*Myocastor coypus*	
Swamp rabbit	*Sylvilagus aquaticus*	GC
Eastern cottontail	*Sylvilagus floridanus*	

[a] E: Oklahoma endangered species, T: Oklahoma threatened species, SCI: Oklahoma species of concern category I, SCII: Oklahoma species of concern category II, *: indicates species is also federally, threatened, or of special concern, GC: designated as an Oklahoma species of greatest conservation concern according to the Oklahoma Comprehensive Wildlife Conservation Strategy.

FLOODPLAIN HABITATS AND TERRESTRIAL BIOTA—REPTILES AND AMPHIBIANS

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Amphibians and Reptiles

Habitat loss has been identified as a significant factor leading to population declines of both amphibians and reptiles (Lannoo, 1998; see also references cited by Goode et al. 2005). Water diversion and flow alteration in streams can impact these groups by reducing suitable habitat within the stream channel itself or through altered flood regimes that influence water levels in riparian wetlands and backwater areas. The amphibians that could occur in the riparian zones of the rivers considered for water withdrawal in Southeast Oklahoma include groups that are of special concern or which have been identified as having low population densities. The majority of these species could experience some habitat impact if riparian wetlands were lost as a result of altered river flows, but due either to large population densities or a broad habitat range, the population-level effects would probably be minimal (Tables 1 and 2). However, there are six species of frogs and salamanders which could be negatively influenced if riparian wetland habitat was lost and which should be considered further with regard to water removal impacts. These include the crawfish frog (*Rana areolata*), Western bird-voiced tree frog (*Hyla avivoca*), green treefrog (*Hyla cinerea*), mole salamander (*Ambystoma tapoideum*), four-toed salamander (*Hemidactylum scutatum*), and lesser siren (*Siren intermedia*).

As with the amphibians, the majority of reptiles that may occur within the southeastern rivers or associated riparian zones would probably experience minimal effects of water withdrawal. There are seven taxa which, due to low population densities and listed status, should also be considered further with regard to potential riparian zone or in-stream effects. These include the American alligator (*Alligator mississippiensis*), glossy crayfish snake (*Regina regida*), Graham's crayfish snake (*Regina grahamii*), mud snake (*Farancia abacura*), alligator snapping turtle (*Macrochelys temminckii*), chicken turtle (*Deirochelys reticularia*), and painted turtle (*Chrysemys picta*).

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Table 1. Occurrence by county, habitat description, conservation status, and predicted risk from flow alteration for amphibian species most likely to be encountered within the drainages of the Kiamichi, Little, Glover, and Mountain Fork Rivers of southeastern Oklahoma.

Order	Genus-species	Common name	Counties[1]	General Habitat[2]	Status[3]	Risk from flow alteration[4]
Anura	*Rana areolata*	Crawfish frog	Choctaw Latimer LeFlore McCurtain* Pushmataha*	Temporary aquatic habitats, river floodplains. Uses crayfish and reptile burrows as refugia.	IUCN-near threatened	A1
	Rana clamitans	Green frog	Choctaw Latimer LeFlore McCurtain Pushmataha	Temporary and permanent standing and slow flowing water	IUCN-least concern	A2
	Rana palustris	Pickerel frog	Choctaw Latimer LeFlore McCurtain* Pushmataha	Wooded ponds, sloughs and flooded ditches	IUCN-least concern	A2
	Rana sphenocephala	Southern leopard frog	Choctaw Latimer* LeFlore McCurtain* Pushmataha*	Standing shallow waters	IUCN-least concern	A2
	Rana catesbeiana	Bullfrog	Choctaw Latimer LeFlore* McCurtain* Pushmataha*	Lakes, ponds, rivers, sluggish portions of streams in forests, prairies, and disturbed habitats	IUCN-least concern	A2
	Hyla versicolor	Gray treefrog	Choctaw Latimer* LeFlore* McCurtain*	Shallow, temporary and permanent woodland ponds and marshes.	IUCN-least concern	A2

		Pushmataha*			
Hyla chrysoscelis	Cope's gray treefrog	Choctaw Latimer LeFlore McCurtain* Pushmataha	Wooded areas and woodland edges, usually within a few hundred meters of water. Temporary or permanent waters of flooded ditches, puddles, river sloughs, creeks, and small ponds.	IUCN-least concern	A2
Hyla avivoca	Western bird-voiced tree frog	LeFlore McCurtain*	Bald cypress-tupelo swamps and nearby wet hardwood forests.	State of OK- S2 status, OK Species of Special Concern, Category II	A1
Hyla cinerea	Green treefrog	Choctaw LeFlore McCurtain* Pushmataha	Wetlands and edges along standing aquatic habitat. Floating and emergent vegetation.	State of OK-S3 status-rare	A1
Scaphiopus hurterii	Hurter's spadefoot toad	Choctaw Latimer LeFlore McCurtain Pushmataha	Found in wooded to open terrain and into arid regions. Eggs and larvae develop in temporary rain-filled pools	IUCN-least concern	D
Acris crepitans	Northern cricket frog	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha*	Wetlands, slow moving streams, ephemeral pools	IUCN-least concern	A2
Pseudacris feriarum	Southern chorus frog	Latimer* LeFlore McCurtain*	Ephemeral wetlands, woodland and bottomland swamps	IUCN-least concern	A2
Pseudacris crucifer	Spring peeper	Latimer LeFlore* McCurtain Pushmataha	Moist wooded pools and wetlands, temporary or permanent. Largely terrestrial	IUCN-least concern	A2
Pseudacris	Strecker's chorus frog	Choctaw*	Moist wooded habitat and temporal	IUCN-least	A2

streckeri		Latimer LeFlore Pushmataha	pools and wetlands.	concern	
Pseudacris triseriata	Western chorus frog	Choctaw Latimer* LeFlore McCurtain* Pushmataha	Permanent and temporary pools and wetlands in both open and wooded areas	IUCN-least concern	A2
Bufo americanus	American toad	Latimer Leflore	Small ditches, small ponds, or slow, shallow streams	IUCN-least concern	A2
Bufo fowleri	Fowlers toad	Choctaw Latimer LeFlore McCurtain Pushmataha	Wooded areas, floodplain wetlands floodplains, Eggs and larvae develop in shallow temporary and permanent standing or low-current water bodies.	IUCN-least concern	A2
Gastrophyrne carolinensis	Eastern narrow-mouthed toad	Choctaw Latimer* LeFlore* McCurtain* Pushmataha*	Uses both temporary and permanent waters. Moist shaded habitats- lakes, ponds, sloughs, flooded roadside ditches, wetlands, stream margins, rain puddles, etc.	IUCN-least concern	A2
Gastrophryne olivacea	Western narrow-mouthed toad	Choctaw Latimer* LeFlore McCurtain Pushmataha	Arid and semi-arid lowlands, moist edges near springs, streams, and rain pools, river floodplains. Eggs and larvae often develop in temporary, rain-filled pools	IUCN-least concern	A2
Bufo woodhousii	Woodhouse's toad	Choctaw Latimer LeFlore McCurtain Pushmataha	Widespread across open grasslands, semi-arid areas, floodplains and agricultural areas, particularly with deep friable soils. Eggs and larvae develop in shallow temporary and permanent standing or low-current water bodies.	IUCN-least concern	A2
Spea bombifrons	Plains spadefoot toad	LeFlore McCurtain*	Open, semi-arid habitat, temporary and permanent waters. It is almost always found around temporary pools formed by rainfall.	IUCN-least concern	A2

Caudata	*Ambystoma opacum*	Marbled salamander	Choctaw* Latimer LeFlore* McCurtain* Pushmataha*	Wooded habitats, near small wetlands, temporary and permanent pools and slow-moving streams.	IUCN-least concern	A2
	Ambystoma talpoideum	Mole salamander	Choctaw McCurtain*	Wooded temporary and permanent ponds. Reproductive success has been correlated with duration of standing water in breeding pond.	IUCN-least concern, OK- S1, SSC II	A1
	Ambystoma annulatum	Ringed salamander	Latimer LeFlore McCurtain Pushmataha	Shallow, turbid ponds with no fish	IUCN-least concern, OK-S2S3, SSC II	D
	Ambystoma texanum	Small-mouthed salamander	Choctaw* Latimer LeFlore McCurtain* Pushmataha*	Broad habitat range from open prairie to woodland, Breeding sites include temporary and permanent ponds, ditches, slow moving water.	IUCN-least concern	A2
	Ambystoma maculatum	Spotted salamander	Choctaw* Latimer LeFlore McCurtain* Pushmataha*	Wooded, temporary pools.	IUCN-least concern, OK-S3	D
	Amphiuma tridactylum	Three-toed amphiuma	McCurtain	Wooded wetlands, calcareous streams.	IUCN-least concern, OK-S1, SSC II	D
	Desmognathus brimleyorun	Ouachita Dusky salamander	Choctaw Latimer LeFlore* McCurtain* Pushmataha	Rocky, gravelly streams.	IUCN-least concern, OK-S3, SSC II	D
	Eurycea longicauda	Longtail salamander	LeFlore McCurtain Pushmataha	Temporary pools and streams, woodland ponds, caves.	IUCN-least concern, OK-S2S3	D
	Eurycea	Many-ribbed	Choctaw	Cave springs, cold, clear streams.	IUCN-least	D

multiplicata	salamander	Latimer LeFlore McCurtain Pushmataha		concern	
Hemidactylium scutatum	Four-toed salamander	Choctaw McCurtain Pushmataha	Small wetlands, boggy stream sides, standing pools.	IUCN-least concern, OK- SSC II	A1
Plethodon kiamichi	Kiamichi slimy salamander	LeFlore	Forest species- terrestrial breeder	IUCN-data deficient. OK-S2	D
Plethodon ouachitae	Rich mountain salamander	Latimer LeFlore* McCurtain* Pushmataha	Mesic hardwood forests, terrestrial breeder with direct development.	IUCN-near threatened, OK- SSC II	D
Plethodon sequoyah	Sequoyah slimy salamander	McCurtain	Probably forested habitat-terrestrial breeder with direct development	IUCN-data deficient, OK-S2	D
Plethodon serratus	Southern redback salamander	Choctaw LeFlore McCurtain* Pushmataha	Moist wooded areas, direct terrestrial development	IUCN-Least concern	D
Plethodon albagula	Western slimy salamander	Latimer LeFlore McCurtain Pushmataha	Moist wooded hillsides, terrestrial breeder.	IUCN-Least concern, OK- S3	D
Necturus maculosus	Mudpuppy	Choctaw Latimer LeFlore McCurtain Pushmataha	Permanent aquatic habitats, slow and fast moving water, standing water bodies over a broad size range.	IUCN-Least concern, OK-S3	C1
Notophthalmus viridescens	Central Newt	Choctaw* Latimer LeFlore* McCurtain* Pushmataha*	Permanent and temporal standing water, slow stream pools.	IUCN-Least concern	A2,C2

Siren intermedia	Lesser siren	Choctaw McCurtain* Pushmataha	Swamps, sloughs, ponds, lakes, ditches, and to a lesser degree rivers and streams.	IUCN-least concern, OK-S2S3, SSC II	A1,C1

1: Locality data derived from the Amphibian Research and Monitoring Initiative (ARMI) Atlas (http://www.pwrc.usgs.gov/armiatlas/, accessed June 2005). An asterisk (*) indicates a reported occurrence of the species for that county in the Oklahoma Biological Survey's Information Database as well (http://www.biosurvey.ou.edu/dbsrch/dokaform.php, accessed June 2005).
2: Habitat data obtained online from the Global Amphibian Assessment Database (http://www.globalamphibians.org/index.html, accessed June 2005).
3: IUCN Conservation designations available online at http://www.redlist.org/info/categories_criteria2001.html (accessed June 2005). Rankings and status for the state of Oklahoma obtained from the following documents available online from the Oklahoma Natural Heritage Inventory (http://www.biosurvey.ou.edu/heritage/publicat.html, accessed June 2005): "Guide to rare species status and rarity ranking codes", "ONHI working list of rare vertebrates", "Federal and state endangered and threatened species by county". SSCII- Listing as a Species of Special Concern, Category II (ODWC, http://www.wildlifedepartment.com/endanger2.htm, accessed June 2005).
4. Potential risk from flow alteration:

A. Localized population effects possible due to riparian wetland loss from reduced water table and recharge due to altered flood regime. Loss of side channel habitat due to reduced flow.
B. Localized population effects possible due to prolonged inundation of habitat resulting from impoundment.
C. Localized population effects possible due to loss of in-stream habitat.
D. Population effects unlikely due to habitat preference.

Sub-codes- implications of population effects

1. Population effects of significant concern due to small population size.
2. Population effects of minor concern due to broad habitat requirements and/or population size.

Table 2. Habitat description, conservation status, and predicted risk from flow alteration for reptilian species most likely to be associated with waters of the Kiamichi, Little, Glover, and Mountain Fork Rivers of southeastern Oklahoma.

Order	Genus-species	Common name	Counties[1]	General Habitat[2]	Status[3]	Risk from flow alteration[4]
Crocodylia	*Alligator mississippiensis*	American Alligator	Choctaw[1a] McCurtain[1a]	Riverine wetlands, lakes, bayous	IUCN-least concern, OK-T	A1, C1
Squamata	*Storeria dekayi*	Brown snake	Latimer* LeFlore* Pushmataha* McCurtain* Pushmataha	Wetlands, moist woods, hillsides	[3a]National-N5, OK-S5	A2
	Masticophis flagellum	Coachwhip	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha*	Swamps, creek valleys	National-N5, OK-S5	A2
	Thamnophis sirtalis	Common garter snake	Choctaw Latimer* LeFlore* McCurtain* Pushmataha	Meadows, marshes, woodlands, hillsides, along streams and drainage ditches	National-N5, OK-S5	A2
	Agkistrodon contortix	Copperhead	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha*	Lowlands, low ground near wetlands, cypress bordered streams, brushy areas along creeks	National-N5, OK-S4	A2
	Agkistrodon piscivorus	Cottonmouth	Choctaw* Latimer LeFlore McCurtain* Pushmataha	Wetlands, lakes, rivers, ditches	National-N5, OK-S4	A2
	Nerodia rhombifer	Diamondback	Choctaw*	Widespread in many aquatic	National-	A2

	water snake	Latimer Leflore McCurtain* Pushmataha	habitats	N5, OK-S5	
Regina regida	Glossy crayfish snake	McCurtain* Pushmataha*	Wetlands, stream sides	National-N5, OK-S1	A1,C1
Regina grahamii	Graham's crayfish snake	Choctaw* McCurtain*	Margins of ponds and streams, wetlands	National-N5, OK-S3	A1,C1
Farancia abacura	Mud snake	McCurtain	Southern wetlands and lowlands	National-N5, OK-S1	A1
Nerodia sipedon	Northern water snake	Choctaw Latimer* Leflore McCurtain Pushmataha	Widespread, wetlands, ponds, streams	National-N5, OK-S4	A2,C2
Sistrurus miliarius	Pigmy rattlesnake	Choctaw Latimer LeFlore* McCurtain* Pushmataha	Areas near water, river floodplains, swamps, marshes and wet prairies	National-N5, OK-S4	A2
Nerodia erythrogaster	Plainbelly water snake	Choctaw Latimer LeFlore McCurtain Pushmataha	Riverine wetlands and numerous other aquatic habitats	National-N5, OK-S4	A2
Storeria occipitomaculata	Redbelly snake	Choctaw Latimer LeFlore McCurtain Pushmataha	In/near open woods, in/near sphagnum bogs	National-N5, OK-S3	A2
Opheodrys aestivus	Rough green snake	Choctaw* Latimer* LeFlore McCurtain* Pushmataha*	Dense vegetation along stream and lake borders	National-N5, OK-S5	A2

	Nerodia fasciata	Southern water snake	Choctaw* Latimer LeFlore McCurtain* Pushmataha*	Virtually all types of freshwater habitats, including streams, ponds, lakes and marshes	National-N5, OK-S2	A2
	Thamnophis proximus	Western ribbon snake	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha*	Semiaquatic - close to streams and ditches, edges of ponds and lakes, and other bodies of water	National-N5, OK-S5	A2
Chelonia	*Macrochelys temminckii*	Alligator snapping turtle	McCurtain* Pushmataha*	Lake/river bottoms	National-N3/N4, IUCN-Vulnerable, OK-S2, SSC II	A1,C1
	Deirochelys reticularia	Chicken turtle	Choctaw* Latimer LeFlore McCurtain* Pushmataha	Shallow ponds and lakes with thick vegetation, cypress swamps, ditches, temporary pools; usually not in flowing water.	National-N5, OK-S2	A1
	Sternotherus odoratus	Common musk turtle	Choctaw Latimer* LeFlore* McCurtain* Pushmataha*	Shallow water, low grade rivers and streams	National-N5, OK-S4	A2,C2
	Chelydra serpentina	Common snapping turtle	Choctaw Latimer LeFlore McCurtain Pushmataha	Widespread in permanent waters	National-N5, OK-?	A2,C2
	Kinosternon subrubrum hippocrepis	Mississippi mud turtle	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha*	Ditches, wet meadows, small ponds, marshes	National-N5, OK-S4	A2

Graptemys kohnii	Mississippi map turtle	Choctaw* LeFlore* McCurtain*	Rivers, lakes, and sloughs with soft bottom and abundant aquatic vegetation.	National-N5, OK-S2	A2,C2
Pseudemys concinna	Missouri River cooter	Eastern Oklahoma	Rivers with moderate current and abundant vegetation	National-N4	C2
Graptemys ouachitensis	Ouachita map turtle	Choctaw* Latimer LeFlore* McCurtain* Pushmataha*	Mainly riverine (also in impoundments), usually in areas with submerged aquatic vegetation.	National-N4, OK-SNR	C2
Chrysemys picta	Painted turtle	McCurtain*	Shallow water with soft bottom and abundant aquatic vegetation	National-N5, OK-S2	A1,C1
Sternotherus carinatus	Razorback musk turtle	Choctaw Latimer LeFlore McCurtain* Pushmataha*	Slow-moving rivers and streams, swamps; areas with soft bottom, abundant aquatic vegetation, and basking sites.	National-N5, OK-S4	A2,C2
Trachemys scripta elegans	Red-eared slider	Choctaw* Latimer* LeFlore* McCurtain* Pushmataha	Usually in quiet water with abundant aquatic vegetation, soft bottom, and basking sites.	National-N5, OK-S5	A2,C2
Apalone muticus	Smooth softshell turtle	Choctaw Latimer LeFlore* McCurtain* Pushmataha*	Large rivers and streams; in some areas also found in lakes, impoundments, and shallow bogs. Usually in water with sandy or mud bottom and few aquatic plants.	National-N5, OK-S5	A2,C2
Apalone spinifera	Spiny softshell turtle	Choctaw Latimer LeFlore* McCurtain* Pushmataha	Large rivers, river impoundments, lakes, ponds along rivers, pools along intermittent streams, bayous, oxbows; usually in areas with open sandy or mud banks and	National-N5, OK-S5	A2,C2

soft bottom.

1: Locality data derived from NatureServe (http://www.natureserve.org/explorer/servlet/NatureServe, accessed July 2005) and Conant and Collins (1998)). Alligator locality data obtained from Oklahoma Department of Wildlife Conservation website (http://www.wildlifedepartment.com/alligator.htm, accessed July 2005). An asterisk (*) indicates a reported occurrence of the species for that county in the Oklahoma Biological Survey's Information Database as well (http://www.biosurvey.ou.edu/dbsrch/dokaform.php, accessed July 2005).

2: Habitat data obtained online from NatureServe (http://www.natureserve.org/explorer/servlet/NatureServe, accessed July 2005) and Conant and Collins (1998).

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AQUATIC HABITATS AND BIOTA—FISHES

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General impacts of hydrological alterations on fishes

The effects of impoundments on riverine fishes are well documented. Impoundments decrease hydrologic variability of rivers, alter channel morphology, reduce sediment transport, and increase vegetative cover (Williams and Wolman 1984; Andrews 1986; Hadley and Emmett 1998), all of which affect fish habitat and other aquatic biota (Orth 1990). Habitat heterogeneity decreases (Lienesch et al. 2000) and the structure of fish assemblages changes in the channel immediately below and downstream from the impoundment (Edwards and Contreras-Balderas 1991; Martinez et al. 1994; Pyron et al. 1998; Lienesch et al. 2000; Rahel 2000). The diversity and abundance of fluvial-dependent fish species decrease in impounded streams (Timmons et al. 1978; Bain et al. 1988; Martinez et al. 1994; Herbert and Gelwick 2003), whereas habitat generalist species often increase in diversity and abundance (Lienesch et al. 2000; Galat and Zweimuller 2001). Kinsolving and Bain (1993) defined three general fish habitat-use classes (fluvial specialists, fluvial dependent, and habitat generalists) to assess the relative dependence of fish on flowing (lotic) and standing (lentic) water habitats.

Impoundments also influence fishes upstream of reservoirs. Habitat generalists from the reservoir invade upstream riverine habitats (Martinez et al. 1994), upstream fish populations become isolated from downstream refugia, colonizing sources, and habitats required for specific life-history stages (Winston et al. 1991; Kelsch 1994; Herbert and Gelwick 2003); and over time fluvial dependent species may disappear from impounded streams (Kinsolving and Bain 1993; Kelsch 1994; Lienesch et al. 2000). Downstream of an impounded Alabama river (Thurlow Dam on the Tallopoosa River), the abundance and species richness of fluvial specialists increased proportional to distance downstream from the impoundment (Kinsolving and Bain 1993; Travnichek et al. 1995). Upstream of an impounded Oklahoma river (Hugo Reservoir on the Kiamichi River), Pyron et al. (1998) found no decline in riverine fish species upstream the reservoir when comparing historic records with more recent collections; however, they only examined the presence or absence and not the abundance of fish species. Pringle (1997) found that the dynamics of fish assemblages upstream from impoundments are poorly understood and require further study.

The impacts of water withdrawals are less understood than those of impoundments. Water withdrawal and diversion projects are used to provide water for communities, agricultural irrigation, and industry. These projects disrupt the natural flow regime and decrease water depths. These changes can result in increases in fish predation (Herbert and Gelwick 2003), water temperatures, and concentrations of downstream pollutants, and a decrease in suitable habitat for native species at low flows. These impacts have the potential to degrade aquatic habitats and lead to species extirpations from a region. In Georgia, Freeman and Marcinek (2005) found that the species richness of fluvial specialists decreased downstream of water withdrawal sites directly proportional to the amount of the withdrawal. They also found that this reduction in species richness was greater in water withdrawals that included an impoundment structure rather than direct withdrawal from the stream channel. Habitat generalists were not associated with an extinction gradient under either circumstance.

The altered hydrologic regime resulting from impoundments and water withdrawals greatly impacts the ecosystems present within the affected river both upstream and downstream from the disturbance site. Although fish are one component of a river ecosystem, they are often of greatest concern for conservation. Most of the fish species that increase in abundance as a result of hydrologic alterations are habitat generalists, whereas most species of greatest concern for conservation are fluvial dependent for at least a portion of their life cycle (Galat and Zweimuller 2001).

Historical and recent fish collections

Fishes of the Kiamichi River and Little River system in southern Oklahoma have been documented by several comprehensive investigations since the early 1950s. Reeves (1953) surveyed the fishes of the Little River system and reported 96 species from 91 sites. Finnell et al. (1956) conducted a survey of fisheries resources of the Little River system and collected 87 species from 34 sites. Pigg and Hill (1974) collected fishes from 90 sites in the Kiamichi River drainage and compiled collection information from previous studies. They reported 98 species from the drainage. Pyron et al. (1998) collected fishes from 12 sites in the Kiamichi River and compared them with previous fish surveys in the river. They reported 101 species of fish from the Kiamichi River. These surveys comprise the most comprehensive historical information about fishes in these rivers; however, at least two other data sources contain comprehensive fish collection information for these river systems. The Oklahoma Streams Information System (OSIS) is a compilation of fish collection data from 1980 to 1999 from 498 sites on 139 streams in eastern Oklahoma (Tejan and Fisher 2001). These data were from various sources, with the vast majority from the Oklahoma Department of Environmental Quality database but also included Rutherford's (1988) fish collections in southeastern Oklahoma. A second comprehensive data source that we used was NatureServe (http://natureserve.org/). NatureServe is a non-profit conservation organization that provides the scientific information and tools needed to help guide effective conservation action. NatureServe and its network of natural heritage programs provide searchable databases about rare and endangered species and threatened ecosystems, as well as information about commonly-occurring and invasive species. Finally, Miller and Robison (2004) list 176 species of fish in Oklahoma, including several species that are endemic to southeastern Oklahoma such as the Golden Topminnow (*Fundulus chrysotus*), Western Starhead Topminnow (*Fundulus blairae*), and the Redspot Darter (*Etheostoma artesiae*), which we did not find records of in the publications and databases listed above.

Assessment of southeastern Oklahoma impoundments on riverine fishes

We used information from four publications (Reeves 1953; Finnell et al. 1956; Pigg and Hill 1974; Pyron et al. 1998) and two databases (OSIS, Tejan and Fisher 2001; NatureServe, http://natureserve.org/) to examine changes in the occurrence of fish species in the Kiamichi River and Little River system before and after their impoundment. We did not use Miller and Robison (2004) as a source, however, because we could not differentiate between collection before and after impoundments on the Kiamichi and Little rivers. We classified each species as either a fluvial specialist or generalist following the definitions of Kinsolving and Bain (1993). For our analysis, we grouped fluvial specialists and fluvial dependents and defined them as fish species that usually inhabit streams and rivers and need flow water at some life history stage. Generalists are fish species that can inhabitat flowing (lotic) or lentic (standing) waters. Classification of fishes into these groups was based on information in Kinsolving and Bain (1993), Travinichek et al. (1995), Galat et al. (2004), and our professional judgement. Because we did not have an abundance of data for each fish species, we compared the presence or absence of species in each group.

Of the 176 species of fish known to occur in Oklahoma (Miller and Robison 2004), over 134 have been collected from the Kiamichi River and the Little River systems (Table 1). The greatest number of fish species have been reported from the Little River (119 species) followed by the Mountain Fork (108 species), and the Kiamichi River (105 species). These estimates of species richness are based on the six sources of data used to assess changes in relation to impoundments and do not include all species reported for these rivers by Miller and Robison (2004). Of the 134 species, we classified 63 species as fluvial specialists and the remaining 71 as generalists. The majority of fluvial specialists were minnow and darter species.

We did not detect a decline in the number of fluvial specialist species following impoundment of the Kiamichi, Little, and Mountain Fork Rivers (Table 2). Total species richness was slightly greater in post-impoundment surveys (mean = 95.7 species) than pre-impoundment surveys (mean = 92.7 species). On average, less than half (45%) of the total species collected before (mean = 39.3) and after (mean = 45.0) impoundment of the three rivers were fluvial specialists, whereas more than half (55%) collected before (mean = 53.3) and after (mean = 50.7) impoundment were generalist species.

We identified fluvial specialist fish species that occur within the reaches of the Little and Kiamichi rivers where the water withdrawal structures have been proposed (OWRB 2002). We compiled information from OSIS (Tejan and Fisher 2001) for fish collections made between 1976 and 1996 at 10 sites on the lower Little River between the Oklahoma-Arkansas state line and Antlers, Oklahoma; collections made in 1973 at three sites on lower Kiamichi River from the confluence with the Red River upriver to Hugo Dam; and collections made between 1969 and

1996 at five sites on the upper Kiamichi River from the upper end of Hugo Lake near Apple, Oklahoma upriver to Dunbar, Oklahoma. Species that have been designated by ODWC as State Endangered, Threatened, or Species of Special Concern were identified for both fluvial specialists and generalists.

Between a third to half of the fish species in the three reaches are fluvial specialists (Table 3). Fifty-one percent of the species in the lower Little River were fluvial specialists, including 5 sucker (redhorse), 17 minnow species, 3 catfish (madtom) species, and 15 perch (darter) species. One of these species, the Blackside Darter, is State Threatened and eight others (Shorthead Redhorse, Ironcolor Shiner, Kiamichi Shiner, Mountain Madtom, Stonecat, Crystal Darter, Harlequin Darter, and River Darter) are State Species of Special Concern—Category II. In addition, two generalist species (Pallid Shiner and Plains Topminnow) in this reach are also Category II species. Thirty-two percent of the species in the lower Kiamichi River were fluvial specialists, including several large river species such as the American eel, paddlefish, and two Category II species, blue sucker and ribbon shiner. Black buffalo, Cypress Minnow, and Mooneye were generalist species in this reach that are also Category II species. Forty-one percent of the species in the upper Kiamichi River were fluvial specialists, including 16 minnow species, 1 madtom species, and 6 darter species. Kiamichi Shiner, Pallid Shiner, and Mooneye were the only three Category II species in this reach.

Flow recommendations

Our analysis of fish collections before and after the construction of major mainstem impoundments on three southeastern Oklahoma rivers did not detect a change in fish species dependent on flowing water (i.e., fluvial specialists). This may be the result of several factors. Collections were made throughout these river systems both near and away from the impoundments, possibly masking the effects of the impoundments. Pyron et al. (1998) found that fish collections from sites further from outflows of Hugo Lake were more similar in species composition over time than were sites closer to the outflow. Collecting effort was not consistent between the two time periods; many of the earlier pre-impoundment collections were more extensive than the recent collections. In a comparison of fish collections at the same sites before and after construction of Hugo and Sardis lakes in the Kiamichi River, Pyron et al. (1998) observed greater species richness prior to reservoir construction.

Our compilation of fish collection data for the three reaches of the Kiamichi and Little rivers where water withdrawal structures are planned revealed that up to half of the species known to occur there are fluvial specialists. Many of these species would be particularly vulnerable to disturbance caused by the construction of low-head dams for water withdrawals and susceptible to subsequent alterations in the flow regime, including a reduction in species richness and restricted movements for mussel fish hosts. Freeman and Marcinek (2005) found that fishes downstream from reservoirs had lower abundances of fluvial specialists and a reduction in species as water withdrawals increased from 0 to 12 times the 7Q10 (i.e., the minimum average flow for a period of seven consecutive days that has an average recurrence of once in ten years). It is probable that several fluvial specialist species in the lower Little River and upper Kiamichi River, and potentially the large river species in the lower Kiamichi river would be impacted by the proposed water withdrawal project.

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Table 1. Fishes collected in the Kiamichi River, Little River, and Mountain Fork River before (Pre) and after (Post) their impoundment. The Hugo Lake on the Kiamichi River was impounded in 1974, Pine Creek Lake on the Little River was impounded in 1969, and Broken Bow Lake on the Mountain Fork was impounded in 1968. Numerically coded sources are: 1 = NatureServe (http://natureserve.org/) pre-impoundment, 2 = Finnell et al. (1956), 3 = Reeves (1953), 4 = Pigg and Hill (1974), 5 = OSIS (Tejan and Fisher 2001) pre-impoundment), 6 = NatureServe (http://natureserve.org/) post-impoundment, 7 = OSIS (Tejan and Fisher 2001) post-impoundment), 8 = Pyron et al (1998).

			Kiamichi River		Little River		Mountain Fork River	
Scientific Name	Common Name	Habitat	Pre	Post	Pre	Post	Pre	Post
Amia calva	Bowfin	G	4, 5		2	7	2, 3	7
Anguilla rostrata	American Eel	F	4, 5		3		2, 3	
Aphredoderus sayanus	Pirate Perch	G	4, 5	7	2, 3, 5	6, 7	2, 3	6, 7
Labidesthes sicculus	Brook Silverside	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Menidia beryllina	Inland Silverside	G	4, 5	7		7		7
Carpiodes carpio	River Carpsucker	G	4, 5	6	2, 3	6	2	6
Carpiodes velifer	Highfin Carpsucker	G	4, 5					
Cycleptus elongatus	Blue Sucker	F	4, 5					
Erimyzon oblongus	Creek Chubsucker	F	4, 5	6	2, 3, 5	6, 7	2, 3	6, 7
Erimyzon sucetta	Lake Chubsucker	G				7		
Ictiobus bubalus	Smallmouth Buffalo	G	4, 5	7	2, 3		2	6
Ictiobus cyprinellus	Bigmouth Buffalo	G	4, 5	6, 7	2	7	2	6
Ictiobus niger	Black Buffalo	G	4, 5		2, 3	7	2	
Minytrema melanops	Spotted Sucker	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Moxostoma carinatum	River Redhorse	F	4	6, 7	3	6, 7	2, 3	6

Moxostoma duquesnei	Black Redhorse	F		6, 7	3	6, 7	3	6, 7
Moxostoma erythrurum	Golden Redhorse	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Centrarchus macropterus	Flier	G			2, 3, 5	7	2, 3	7
Lepomis cyanellus	Green Sunfish	G	4, 5	6, 7	2, 3, 5	6	2, 3	6, 7
Lepomis gulosus	Warmouth	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6
Lepomis humilis	Orangespotted Sunfish	G	4, 5	6, 7	2	6, 7	2, 3	6, 7
Lepomis macrochirus	Bluegill	G	4, 5	6, 7	2, 5	6, 7	2	6, 7
Lepomis marginatus	Dollar Sunfish	G	4	7, 8	2, 3, 5	6, 7	2, 3	6, 7
Lepomis megalotis	Longear Sunfish	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Lepomis microlophus	Redear Sunfish	G	4, 5	6, 7	2, 5	6, 7	2	6, 7
Lepomis miniatus	Redspotted Sunfish	G				6		6
Lepomis punctatus	Spotted Sunfish	G	4		2, 3, 5	7	3	7
Lepomis symmetricus	Bantam Sunfish	G				7	3	7
Micropterus dolomieu	Smallmouth Bass	F	4, 5	7	2, 3	7	2, 3	6, 7
Micropterus punctulatus	Spotted Bass	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Micropterus salmoides	Largemouth Bass	G	4, 5	6, 7	2, 5	6, 7	2	6, 7
Pomoxis annularis	White Crappie	G	4, 5	7	2, 3, 5	6, 7	2	7
Pomoxis nigromaculatus	Black Crappie	G	4, 5	7	2, 3	6, 7	2, 3	6, 7
Alosa alabamae	Alabama Shad	G			1			
Alosa chrysochloris	Skipjack Herring	G	4, 5		2, 3	6	2, 3	
Alosa chrysochloris	River Herring	G			2		2	
Dorosoma cepedianum	Gizzard Shad	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Dorosoma petenense	Threadfin Shad	G	4	7	2	6, 7	2	7
Campostoma anomalum	Central Stoneroller	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Carassius auratus	Goldfish	G	4		2			
Cyprinella camurus	Bluntface Shiner	F	4			7		
Cyprinella lutrensis	Red Shiner	F	4, 5	6, 7				
Cyprinella venusta	Blacktail Shiner	F	4, 5	6, 7	2, 5	6, 7	2, 3	7

Cyprinella whipplei	Steelcolor Shiner	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Cyprinus carpio	Common Carp	G	4	7	2, 3	7		
Hybognathus hayi	Cypress Minnow	G	4, 5			7		
Hybognathus nuchalis	Mississippi Silvery Minnow	G	4, 5		2, 5		2, 3	
Hybognathus placitus	Plains Minnow	G	4, 5					
Hybopsis amnis	Pallid Shiner	G	4, 5	6, 7	2, 3	6, 7	2, 3	7
Luxilus chrysocephalus	Striped Shiner	F			2, 3, 5	6, 7	2, 3	7
Lythrurus fumeus	Ribbon Shiner	F	4, 5	6, 7	2, 3	7	2, 3	7
Lythrurus snelsoni	Ouachita Shiner	F		7		6, 7		6, 7
Lythrurus umbratilis	Redfin Shiner	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Notropis blennius	River Shiner	F	4			7		
Notropis boops	Bigeye Shiner	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Notropis buchanani	Ghost Shiner	G	4, 5	6, 7		6, 7		6, 7
Notropis chalybaeus	Ironcolor Shiner	F			2	7	2, 3	
Notropis girardi	Arkansas River Shiner	F			1, 5	7		
Notropis hubbsi	Bluehead Shiner	G				6	7	7
Notropis maculatus	Taillight Shiner	G			2, 3	6	2, 3	6, 7
Notropis ortenburgeri	Kiamichi Shiner	F	4, 5	6, 7	2, 3	6, 7	2	6, 7
Notropis perpallidus	Peppered Shiner	F	4, 5	6, 7	2	6, 7	2, 3	6
Notropis potteri	Chub Shiner	G	5	7				
Notropis shumardi	Silverband Shiner	F	4, 5	7		7		
Notropis stramineus	Sand Shiner	F		7	3	7	3	
Notropis suttkusi	Rocky Shiner	F	4, 5	6, 7, 8	3, 5	6, 7	2, 3	6, 7
Notropis volucellus	Mimic Shiner	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6
Opsopoeodus emiliae	Pugnose Minnow	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	
Phenacobius mirabilis	Suckermouth Minnow	F		7		7		
Pimephales notatus	Bluntnose Minnow	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Pimephales promelas	Fathead Minnow	G	4	7				

Pimephales tenellus	Slim Minnow	F		7				
Pimephales vigilax	Bullhead Minnow	G	4, 5	6, 7	2, 3, 5	6, 7		6, 7
Semotilus atromaculatus	Creek Chub	F			2, 5	6, 7	2, 3	
Elassoma zonatum	Banded Pygmy Sunfish	G	4		2, 3	6, 7	2, 3	6, 7
Esox americanus	Redfin Pickerel	G	4	6	2, 3, 5	6, 7	2, 3	6, 7
Esox niger	Chain Pickerel	G	4	4				6, 7
Fundulus blairae	Lowland Topminnow	G				6		6
Fundulus catenatus	Northern Studfish	F				6		
Fundulus dispar	Starhead Topminnow	G			2, 3		2, 3	7
Fundulus notatus	Blackstripe Topminnow	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6
Fundulus olivaceus	Blackspotted Topminnow	F	4, 5	6, 7	3	6, 7		6, 7
Fundulus sciadicus	Plains Topminnow	G		7				
Fundulus zebrinus	Plains killifish	G						7
Hiodon alosoides	Goldeye	G	4	4	3		3	
Hiodon tergisus	Mooneye	G	4, 5				2	
Ameiurus melas	Black Bullhead	G	4, 5	6, 7	2, 3	6, 7	3	6, 7
Ameiurus natalis	Yellow Bullhead	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Ameiurus nebulosus	Brown Bullhead	G	4		2	6	2	
Ictalurus furcatus	Blue Catfish	G	4, 5		5	7		7
Ictalurus punctatus	Channel Catfish	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Noturus eleutherus	Mountain Madtom	F				7	3	
Noturus exilis	Slender Madtom	F						6
Noturus flavus	Stonecat	F			2	7	2	
Noturus gyrinus	Tadpole Madtom	G	4, 5	6, 7	3, 5	6, 7	3	7
Noturus nocturnus	Freckled Madtom	F	4, 5	6, 7	3, 5	6, 7	2, 3	6, 7
Pylodictis olivaris	Flathead Catfish	G	4, 5	6, 7	2, 3	6, 7	2, 3	6, 7
Atractosteus spatula	Alligator Gar	F					2	
Lepisosteus oculatus	Spotted Gar	G	4, 5	7	2, 3	6, 7	2	7

Lepisosteus osseus	Longnose Gar	G	4, 5	6, 7	2, 3	6, 7	2, 3	6, 7
Lepisosteus platostomus	Shortnose Gar	G	4, 5			6, 7		7
Morone chrysops	White Bass	G	4, 5	7, 8		7	2, 3	
Morone mississippiensis	Yellow Bass	G		7		7		
Ammocrypta clara	Western Sand Darter	F				7		
Ammocrypta vivax	Scaly Sand Darter	F	4, 5	6, 7, 8	2, 5	6, 7	2, 3	6
Crystallaria asprella	Crystal Darter	F		6, 8		6, 7		
Etheostoma asprigene	Mud Darter	F			2	6, 7	2, 3	6, 7
Etheostoma chlorosoma	Bluntnose Darter	G	4, 5	6, 7, 8	2, 3	6, 7	2, 3	7
Etheostoma collettei	Creole Darter	F				7		7
Etheostoma flabellare	Fantail Darter	F						7
Etheostoma fusiforme	Swamp Darter	G			2, 3	6, 7	3	7
Etheostoma gracile	Slough Darter	G	4, 5	6, 7	2, 5	6, 7	2	6, 7
Etheostoma histrio	Harlequin Darter	F				6, 7	2, 3	7
Etheostoma microperca	Least Darter	F	4	7	3		3	7
Etheostoma nigrum	Johnny Darter	G	4, 5	6, 7	2, 3	6, 7	2, 3	6, 7
Etheostoma parvipinne	Goldstripe Darter	F	4	7	2	7	2, 3	7
Etheostoma proeliare	Cypress Darter	F	4, 5	7, 8	2	6, 7	3	6, 7
Etheostoma radiosum	Orangebelly Darter	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Etheostoma spectabile	Orangethroat Darter	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Percina caprodes	Logperch	G	4, 5	6, 7	2, 3	6, 7	2, 3	6, 7
Percina copelandi	Channel Darter	F	5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Percina macrolepida	Bigscale Logperch	F		7				
Percina maculata	Blackside Darter	F	4	6, 7		6, 7	1, 2	7
Percina pantherina	Leopard Darter	F				6, 7	2	6, 7
Percina phoxocephala	Slenderhead Darter	F	4, 5	6, 7	2	6, 7	2, 3	7
Percina sciera	Dusky Darter	F	4, 5	6, 7	2, 3, 5	6, 7	2, 3	7
Percina shumardi	River Darter	F		6		6, 7		7

Percina uranidea	Stargazing Darter	F	4			7		
Sander canadensis	Sauger	F				7		
Ichthyomyzon castaneus	Chestnut Lamprey	F			2, 3	6, 7	2, 3	7
Ichthyomyzon gagei	Southern Brook Lamprey	F	4, 5	6		6, 7		7
Gambusia affinis	Western Mosquitofish	G	4, 5	6, 7	2, 3, 5	6, 7	2, 3	6, 7
Polyodon spathula	Paddlefish	F	4, 5	6	3			
Aplodinotus grunniens	Freshwater Drum	G	4, 5	6, 7	2, 3	6, 7	2, 3	6, 7

Table 2. Number of total fish species and number and percent of fluvial specialist and generalist species collected pre- and post-impoundment of the Kiamichi River, Little River, and Mountain Fork River in southeastern Oklahoma.

River	Total species		Fluvial specialists				Generalists			
	Pre	Post	Pre		Post		Pre		Post	
Kiamichi River	95	86	38	40.0%	41	47.7%	57	60.0%	45	52.3%
Little River	91	109	39	42.9%	53	48.6%	52	57.1%	56	51.4%
Mountain Fork River	92	92	41	44.6%	41	44.6%	51	55.4%	51	55.4%

Table 3. Fish species grouped by habitat type (F = fluvial specialist, G = generalist) and Oklahoma conservation status rank (T = Threatened, C-II = State Species of Special Concern – Category II) collected from sites in reaches of the lower Little River, lower Kiamichi River, and upper Kiamichi River (see Figure 1) where water withdrawal structure have been proposed. Data compiled from OSIS (Tejan and Fisher 2001).

Family	Scientific Name	Common Name	Habitat	OK Status	Lower Little River	Lower Kiamichi River	Upper Kiamichi River
Anguillidae	*Anguilla rostrata*	American Eel	F			X	
Catostomidae	*Cycleptus elongatus*	Blue Sucker	F	C-II		X	
Catostomidae	*Erimyzon oblongus*	Creek Chubsucker	F		X		
Catostomidae	*Minytrema melanops*	Spotted Sucker	F		X		
Catostomidae	*Moxostoma carinatum*	River Redhorse	F		X		
Catostomidae	*Moxostoma duquesnei*	Black Redhorse	F		X		
Catostomidae	*Moxostoma erythrurum*	Golden Redhorse	F		X		X
Catostomidae	*Moxostoma macrolepidotum*	Shortnose Redhorse	F	C-II	X		
Centrarchidae	*Lepomis megalotis*	Longear Sunfish	F		X	X	X
Centrarchidae	*Micropterus dolomieu*	Smallmouth Bass	F		X	X	X
Cyprinidae	*Campostoma anomalum*	Central Stoneroller	F		X	X	X
Cyprinidae	*Cyprinella lutrensis*	Red Shiner	F		X	X	X
Cyprinidae	*Cyprinella venusta*	Blacktail Shiner	F		X	X	X
Cyprinidae	*Cyprinella whipplei*	Steelcolor Shiner	F		X		X
Cyprinidae	*Luxilus chrysocephalus*	Striped Shiner	F		X		
Cyprinidae	*Lythrurus fumeus*	Ribbon Shiner	F	C-II		X	
Cyprinidae	*Lythrurus umbratilis*	Redfin Shiner	F		X		X
Cyprinidae	*Notropis atherinoides*	Emerald Shiner	F		X	X	X
Cyprinidae	*Notropis autrocaudalis*	Blackspot Shiner	F		X	X	

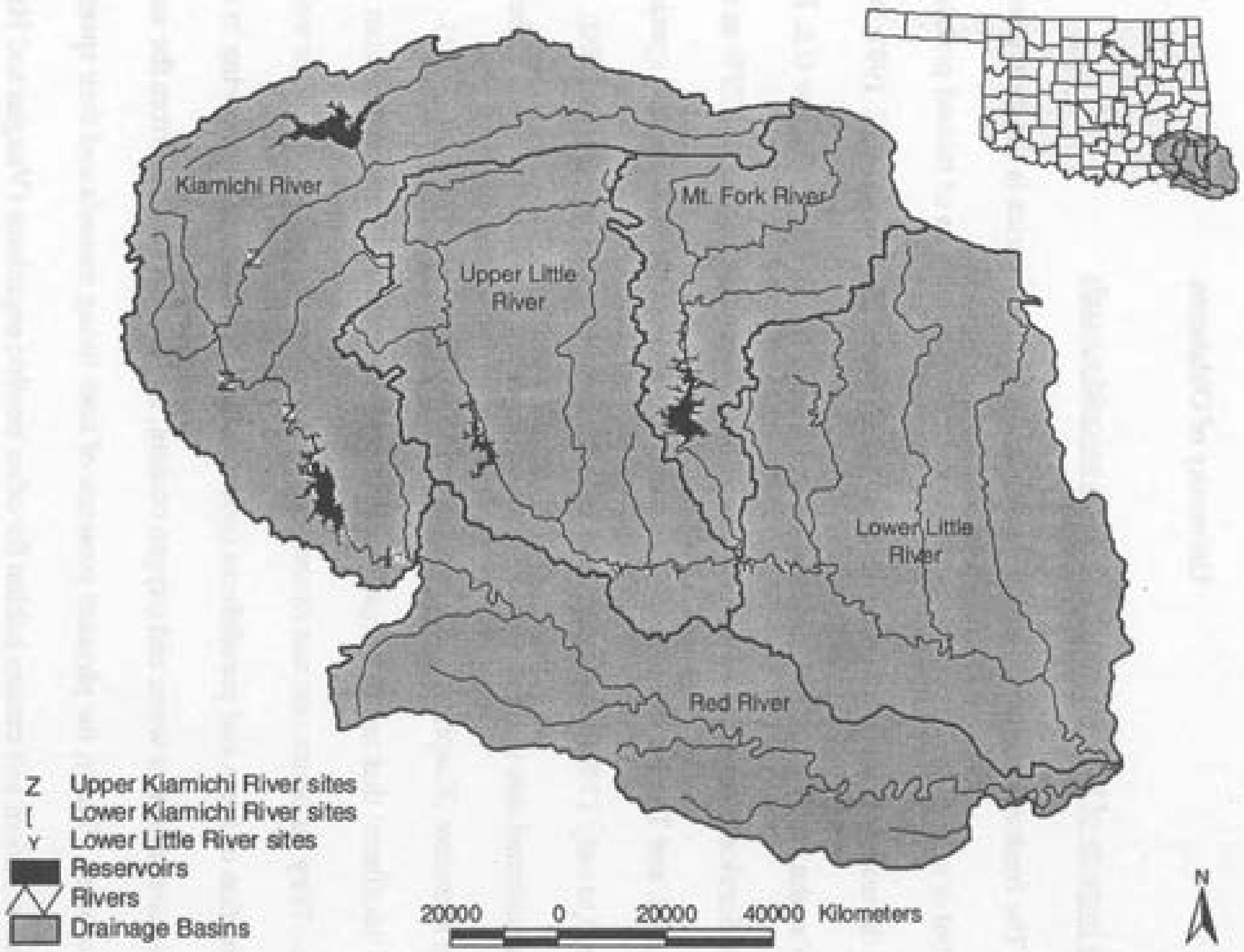
Cyprinidae	*Notropis blennius*	River Shiner	F		X		
Cyprinidae	*Notropis boops*	Bigeye Shiner	F		X	X	X
Cyprinidae	*Notropis chalybaeus*	Ironcolor Shiner	F	C-II	X		
Cyprinidae	*Notropis ortenburgeri*	Kiamichi Shiner	F	C-II	X		X
Cyprinidae	*Notropis perpallidus*	Peppered Shiner	F		X		X
Cyprinidae	*Notropis shumardi*	Silverband Shiner	F		X	X	X
Cyprinidae	*Notropis stramineus*	Sand Shiner	F		X		X
Cyprinidae	*Notropis suttkusi*	Rocky Shiner	F		X	X	X
Cyprinidae	*Notropis volucellus*	Mimic Shiner	F		X		X
Cyprinidae	*Pimephales tenellus*	Slim Minnow	F				X
Fundulidae	*Fundulus notatus*	Blackstripe Topminnow	F		X	X	X
Fundulidae	*Fundulus olivaceus*	Blackspotted Topminnow	F		X	X	X
Ictaluridae	*Noturus eleutherus*	Mountain Madtom	F	C-II	X		
Ictaluridae	*Noturus flavus*	Stonecat	F	C-II	X		
Ictaluridae	*Noturus nocturnus*	Freckled Madtom	F		X		X
Percidae	*Ammocrypta clara*	Western Sand Darter	F		X		
Percidae	*Ammocrypta vivax*	Scaly Sand Darter	F		X		X
Percidae	*Crystallaria asprella*	Crystal Darter	F	C-II	X		
Percidae	*Etheostoma asprigene*	Mud Darter	F		X		
Percidae	*Etheostoma collettei*	Creole Darter	F		X		
Percidae	*Etheostoma histrio*	Harlequin Darter	F	C-II	X		
Percidae	*Etheostoma proeliare*	Cypress Darter	F		X		
Percidae	*Etheostoma radiosum*	Orangebelly Darter	F		X	X	X
Percidae	*Etheostoma spectabile*	Orangethroat Darter	F		X	X	X
Percidae	*Percina copelandi*	Channel Darter	F		X		X
Percidae	*Percina macrolepida*	Bigscale Logperch	F		X		
Percidae	*Percina maculata*	Blackside Darter	F	T	X		
Percidae	*Percina phoxocephala*	Slenderhead Darter	F		X		X
Percidae	*Percina sciera*	Dusky Darter	F		X		X

Percidae	*Percina shumardi*	River Darter	F	C-II	X		
Percidae	*Sander canadensis*	Sauger	F		X		
Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut Lamprey	F		X		
Polyodontidae	*Polyodon spathula*	Paddlefish	F			X	
Amiidae	*Amia calva*	Bowfin	G		X	X	
Aphredoderidae	*Aphredoderus sayanus*	Pirate Perch	G		X		
Atherinopsidae	*Labidesthes sicculus*	Brook Silverside	G		X	X	X
Atherinopsidae	*Menidia beryllina*	Inland Silverside	G		X	X	X
Catostomidae	*Carpiodes carpio*	River Carpsucker	G			X	
Catostomidae	*Carpiodes velifer*	Highfin Carpsucker	G			X	
Catostomidae	*Ictiobus bubalus*	Smallmouth Buffalo	G			X	X
Catostomidae	*Ictiobus cyprinellus*	Bigmouth Buffalo	G			X	X
Catostomidae	*Ictiobus niger*	Black Buffalo	G	C-II		X	
Centrarchidae	*Centrarchus macropterus*	Flier	G		X		
Centrarchidae	*Lepomis cyanellus*	Green Sunfish	G		X	X	X
Centrarchidae	*Lepomis gulosus*	Warmouth	G		X	X	X
Centrarchidae	*Lepomis humilis*	Orangespotted Sunfish	G		X	X	X
Centrarchidae	*Lepomis macrochirus*	Bluegill	G		X	X	X
Centrarchidae	*Lepomis marginatus*	Dollar Sunfish	G		X		
Centrarchidae	*Lepomis microlophus*	Redear Sunfish	G		X	X	X
Centrarchidae	*Lepomis punctatus*	Spotted Sunfish	G		X		
Centrarchidae	*Lepomis symmetricus*	Bantam Sunfish	G		X		
Centrarchidae	*Micropterus punctulatus*	Spotted Bass	G		X	X	
Centrarchidae	*Micropterus salmoides*	Largemouth Bass	G		X	X	X
Centrarchidae	*Pomoxis annularis*	White Crappie	G		X	X	X
Centrarchidae	*Pomoxis nigromaculatus*	Black Crappie	G		X		X
Clupeidae	*Alosa chrysochloris*	Skipjack Herring	G			X	
Clupeidae	*Dorosoma cepedianum*	Gizzard Shad	G		X	X	X
Clupeidae	*Dorosoma petenense*	Threadfin Shad	G		X		X

Cyprinidae	*Cyprinus carpio*	Common Carp	G			X	X
Cyprinidae	*Hybognathus hayi*	Cypress Minnow	G	C-II		X	
Cyprinidae	*Hybognathus nuchalis*	Mississippi Silvery Minnow	G			X	
Cyprinidae	*Hybognathus placitus*	Plains Minnow	G				X
Cyprinidae	*Hybopsis amnis*	Pallid Shiner	G	C-II	X		X
Cyprinidae	*Notemigonus crysoleucas*	Golden Shiner	G		X	X	X
Cyprinidae	*Notropis buchanani*	Ghost Shiner	G		X	X	X
Cyprinidae	*Notropis potteri*	Chub Shiner	G				
Cyprinidae	*Opsopoeodus emiliae*	Pugnose Minnow	G		X		
Cyprinidae	*Pimephales notatus*	Bluntnose Minnow	G		X		X
Cyprinidae	*Pimephales promelas*	Fathead Minnow	G				X
Cyprinidae	*Pimephales vigilax*	Bullhead Minnow	G		X	X	X
Elassomatidae	*Elassoma zonatum*	Banded Pygmy Sunfish	G		X		
Esocidae	*Esox americanus*	Redfin Pickerel	G		X		X
Fundulidae	*Fundulus dispar*	Starhead Topminnow	G		X		
Fundulidae	*Fundulus sciadicus*	Plains Topminnow	G	C-II	X		
Hiodontidae	*Hiodon tergisus*	Mooneye	G	C-II		X	X
Ictaluridae	*Ameiurus melas*	Black Bullhead	G			X	
Ictaluridae	*Ameiurus natalis*	Yellow Bullhead	G		X	X	X
Ictaluridae	*Ictalurus furcatus*	Blue Catfish	G		X	X	
Ictaluridae	*Ictalurus punctatus*	Channel Catfish	G		X	X	X
Ictaluridae	*Noturus gyrinus*	Tadpole Madtom	G		X		X
Ictaluridae	*Pylodictis olivaris*	Flathead Catfish	G		X	X	
Lepisostediae	*Lepisosteus oculatus*	Spotted Gar	G		X	X	X
Lepisostediae	*Lepisosteus osseus*	Longnose Gar	G		X	X	X
Lepisostediae	*Lepisosteus platostomus*	Shortnose Gar	G		X	X	X
Moronidae	*Morone chrysops*	White Bass	G		X	X	X
Moronidae	*Morone mississippiensis*	Yellow Bass	G		X		X
Percidae	*Etheostoma chlorosoma*	Bluntnose Darter	G		X		

Percidae	*Etheostoma gracile*	Slough Darter	G	X	X	X
Percidae	*Etheostoma nigrum*	Johnny Darter	G	X		X
Percidae	*Percina caprodes*	Logperch	G	X	X	X
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	G	X	X	X
Sciaenidae	*Aplodinotus grunniens*	Freshwater Drum	G	X	X	X

Figure 1. Map of fish collections sites in reaches of the lower Little River, lower Kiamichi River, and upper Kiamichi River where water withdrawal structures have been proposed.



AQUATIC HABIATS AND BIOTA—MUSSELS

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General impacts of hydrologic alterations on unionid mussels

The freshwater mussel (Unionidae) fauna of North America is the most diverse in the world, but is highly threatened (Bogan 1993), with major declines of mussel populations and species diversity occurring over the past century (Neves 1992; Neves *et al.* 1997; Ricciardi *et al.* 1998; Vaughn and Taylor 1999; McMahon and Bogan 2001). Currently, the U.S. Fish and Wildlife Service recognizes 12% of the native mussel fauna as extinct and 23% as threatened or endangered, and The Nature Conservancy considers 68% of the U.S. unionid species at risk, compared to only 17% for mammals and 15% for birds (Biggins and Butler 2000). Recent work has demonstrated that unionid mussels provide important ecosystem services in the rivers where they are abundant (Kasprzak 1986; Welker and Walz 1998; Vaughn *et al.* 2004a). Mussels are natural 'biofilters' that remove algae, bacteria, and particulate organic matter from the water column. They influence nutrient dynamics in freshwaters through excretion, as well as, biodeposition of feces and pseudofeces (rejected food particles). By burrowing in the sediment they increase sediment water and oxygen content, and release nutrients from the sediment to the water column. Finally, the physical presence of both living mussels and their spent shells stabilizes sediment and creates habitat for other benthic organisms (Vaughn and Hakenkamp 2001; Spooner 2002; Strayer *et al.* 2004). Thus, the overall decline of this fauna may have long-term, negative consequences for the functioning of river ecosystems (Strayer *et al.* 1999; Vaughn and Hakenkamp 2001; Vaughn *et al.* 2004a).

Table 1. Life history traits of unionid mussels. Modified from McMahon and Bogan (2001) and Mehlhop and Vaughn (1994).

Life span	< 6 to > 100 yr
Age at maturity	6 – 12 yr
Strategy	Iteroparous
Fecundity	200,000 – 17,000,000
Reproductive efforts per year	Typically 1
Juvenile size	50 – 400 um
Relative juvenile survivorship	Very low
Relative adult survivorship	High in undisturbed habitats
Larval habitat	Obligate parasite on fish

Unionid mussels possess a suite of traits that make them highly vulnerable to habitat disturbance (Table 1). Although fecundity is high, the odds of an egg successfully becoming an adult mussel are quite low. Unionids have a complex life history in which the larvae (glochidia) are obligate ectoparasites on the gills and fins of fish. The glochidia of many mussel species can only survive on a narrow range of fish-host species (Kat 1984; Watters 1993; McMahon and Bogan 2001). Once they have metamorphosed from the glochidial stage, juveniles must be deposited in favorable habitat in order to survive. Successful settlement of juveniles appears to be particularly affected by disturbance (Layzer and Madison 1995), and the demography of many mussel populations in disturbed areas is marked by periods when entire year classes are not recruited (Payne and Miller 1989). Because only larvae (attached to fish) can move between mussel beds and juvenile survival is low (Yeager *et al.* 1994; Sparks and Strayer 1998), potential mussel colonization rates are low (Vaughn 1993). Reproductive maturity of unionid mussels is not reached until at least age 6 and most species live greater than 10 years, with some living as long as 100 years (Imlay 1982; McMahon and Bogan 2001). Once mature, adults in undisturbed habitat exhibit high survivorship (McMahon and Bogan 2001). However, adult mussels are sedentary; movements are seasonal and on a scale of a few to an estimated maximum 100 meters (Green *et al.* 1985; Waller *et al.* 1999). Therefore, unlike many stream organisms such as fish and aquatic insects (Townsend 1989; Matthews 1998), adult mussels have limited refugia from disturbance events in streams. In addition, the filter-feeding habits of mussels make them especially vulnerable to sedimentation and chemical pollution events (Havlik and Marking 1987).

The majority of mussel species are most successful where water velocities are low enough to allow substrate stability but high enough to prevent excessive siltation (Vannote and Minshall 1982; Hartfield and Ebert 1986; Strayer 1993; Strayer 1999). Because of this dependence on appropriate substrate and flow conditions, mussels are naturally patchily distributed in many rivers, often occurring in densely aggregated multi-species "beds" separated by areas where mussels occur sporadically or not at all (Strayer *et al.* 1994; Strayer *et al.* 2004). These habitat characteristics have been difficult to quantify, and mussels are often absent from areas that visually appear to be good habitat (Strayer 1993; Strayer and Ralley 1993; Vaughn *et al.* 1995; Strayer *et al.* 2004). Conventional methods for estimating instream flow preferences for mussels have been largely unsuccessful (Gore et al. 2001). Layzer and Madison (1995) investigated the use of instream flow incremental methodology (IFIM) for determining microhabitat preferences of mussels in Horse Lick Creek, Kentucky. They found that results were flow conditional; i.e. because mussels are non-mobile and have highly clumped distributions, they appeared to prefer different hydraulic conditions at different stream discharges. However, unlike simple hydraulic variables such a depth and velocity, complex hydraulic characteristics such as shear stress were significantly correlated with mussel abundance (Layzer and Madison 1995). Strayer (1999) found that mussel beds were located in areas protected from high flows and subsequent shear stress and Hardison and Layzer (2001) found that shear velocity varies on a small spatial scale within mussel beds and is negatively correlated with mussel density.

The major cause of mussel decline in the U.S. is from the alteration of the natural flow regime of rivers, primarily by impoundments and channelization (Neves 1992; Allan and Flecker 1993; Bogan 1993; Watters 1996; Neves *et al.* 1997; Master *et al.* 1998; Vaughn and Taylor 1999; Watters 1999). The ways in which impoundments alter existing stream habitat and processes have been extensively described (Baxter 1977; Petts 1984; Yeager 1993; Ligon *et al.* 1995; Sparks 1995). Many mussels do poorly in the altered conditions within impoundments, which include general lack of flow, sedimentation, and frequent anoxic conditions in deeper areas (Haag and Thorp 1991; Watters 1999). Several dozen mussel species have been driven to extinction wholly or in large part by the construction of dams (Layzer *et al.* 1993; Lydeard and Mayden 1995; Watters 1999); nearly without exception impounded rivers have lost or changed their mussel faunas (Blalock and Sickel 1996; Watters 1999). For example, the mussel fauna of the Chickamauga Reservoir portion of the Tennessee River remained essentially unchanged for 2000 years prior to impoundment. After impoundment, over 30 species were extirpated and several are now extinct (Parmalee *et al.* 1982; Watters 1999).

Mussel populations also are impacted upstream and downstream of impoundments. River sections below impoundments are substantially different than free-flowing rivers (Yeager 1993; Poff *et al.* 1997). Effects include altered seasonality of flow and temperature regimes, changed patterns of sediment scour and deposition (Anderson et al. 1991), and altered transport of particulate organic matter, the food base for mussels (Petts 1984; Frissell *et al.* 1986; Ward and Stanford 1987; Ligon *et al.* 1995). Numerous studies have documented mussel declines below impoundments (Suloway *et al.* 1981; Miller *et al.* 1984; Williams *et al.* 1992a; Layzer *et al.* 1993; Vaughn and Taylor 1999; Garner and McGregor 2001). For example, the Kaskaskia River supported 40 mussel species prior to impoundment; eight years after impoundment the species count was down to 24 species, some sites no longer supported any mussels, and abundance had declined (Suloway *et al.* 1981; Watters 1999).

Hydrologic alterations impact mussels both directly through physical stress, such as temperature, siltation, and scour, and indirectly through changes in habitat, food, and fish-host availability. Fluctuating discharge alters the transport of the particulate material in the water column that is the primary food source for mussels. Depending on season and normal seston loads, this can impact mussels. Releases from impoundments often result in both abnormally high and low flows, sometimes on a daily basis, and these often occur at the "wrong" time of year (Yeager 1993; Poff *et al.* 1997; Richter and Richter 2000). Discharge that is either high during the wrong season or high too frequently can have devastating impacts on mussels. High discharge can displace settling juveniles before they have burrowed into the streambed or attached their byssal threads to sediment (Neves and Widlak 1987; Holland-Bartels 1990; Layzer and Madison 1995; Hardison and Layzer 2001). Increased discharge alters the distribution of sediment through scour, flushing, and deposition of newly eroded material from the banks. Mussels are often killed by sediment scour directly below dams (Layzer et al. 1993) and scour is a major reason for the failure of mussel re-introductions (Layzer and Gordon 1993). Sediment deposition clogs mussel siphons and gills (i.e., smothers them) and interferes with feeding and reproduction (Young and Williams 1983; Dennis 1984; Aldridge *et al.* 1987). Erosion caused by increased discharge at one location in a stream results in deposition of the eroded material further downstream, increasing the width-depth ratio of that portion of the channel and the potential for further bedload transport (Frissell et al. 1986). Therefore, increased discharge can cause habitat loss through both sediment deposition and increased bed mobility. Over time, higher base discharge levels and reduced periods between peak flood events decrease habitat complexity by preventing the formation of areas of stabilized sediments (Frissell et al. 1986). As stated above, sediment stability is a critical habitat requirement for most mussels (Di Maio and Corkum 1995; Strayer 1999; Hardison and Layzer 2001).

Discharge that is either low during the wrong season or abnormally low for extended periods of time also negatively impacts mussels. Extended periods of low flow below impoundments results in the stranding of mussels (Fisher and Lavoy 1972; Spooner and Vaughn 2000); mortality in such cases is usually a result of desiccation and/or thermal stress as the temperature buffering capacity of the water is decreased with reduced water volumes (Watters 1999; Spooner and Vaughn 2000). Numerous mussel dieoffs related to the dewatering of tailwaters below dams and subsequent high water temperatures in the remaining shallow water have been documented (Riggs and Webb 1956; Watters 1999) If stranding does not result in mortality, the associated physiological stress reduces mussel condition and ultimately reproductive potential (McMahon and Bogan 2001). Long periods of excessively reduced discharge often result in the fragmentation of rivers into shallow pools isolated by long reaches of dry riverbed. Within these shallow pools mussels can be exposed to water temperatures exceeding 40°C. In dry stretches, stranded mussels are exposed to air and to solar insolation. Given that mussels are thermo-conformers without the ability to regulate body temperature, these conditions often result in high mortality rates (Spooner and Vaughn 2000). Mussels in shallow, isolated pools also are exposed to hypoxia from algal production. Unionids are typically tolerant of moderate bouts of hypoxia (as low as 2 mg/l) (Chen 2002); however, other bivalves, such as invasive *Corbicula* have reduced anaerobic capacity resulting in massive die-offs (White and White 1977; Milton and Matthews 1999; Cherry et al. 2005). Ammonia pulses from decaying bivalves kill juvenile unionids and potentially reduce the condition of adult mussels (Cherry et al. 2005; Cooper et al. 2005).

Water temperature is especially critical to mussels and they deal with thermal stress in a variety of ways. In the event of dewatering, some species can move either vertically into the sediment or horizontally to deeper areas; this strategy can be energetically costly depending on substrate texture and the distance to cooler water (McMahon and Bogan 2001). A second strategy to contend with emersion is direct transfer of oxygen across the mantle edge exposed to the air, which mussels control by gaping. This approach is limited to environments with high humidity and moderate temperature (Dietz 1974). A third strategy is to close the valves and anaerobically catabalyze stored energy reserves. The success of this strategy depends on the amount of energy reserves available and the duration of dewatering (McMahon and Bogan 2001). The main anaerobic storage pathway for mussels is glycogen catabolism. Glycogen is easily transferred to glucose through glucogenesis and its metabolites are non-toxic (Chen 2003) (unlike catabolism of protein which produces toxic ammonia by products); however, shifts in hemolymph pH due to metabolites produced by glycogen catabolism must be buffered by the sequestration of carbonates from the shell (Byrne et al. 1991; McMahon 2000). Given that anaerobic catabolism is an underlying mechanism for emersion survival, factors that control glycogen storage capacity should directly influence the ability of mussels to survive drought events.

Reductions in water temperature below hypolimnetic release dams have been shown to reduce and even eliminate mussel populations for long distances (Ahlstedt 1983; Miller *et al.* 1984; Yeager 1993; Lydeard and Mayden 1995; Vaughn and Taylor 1999). Release of cold water during the summer, when water temperatures should be warm, suppresses mussel metabolic rates during a time of year when growth should be high (McMahon and Bogan 2001) and inhibits reproduction (Layzer et al. 1993). Coldwater releases also may eliminate or inhibit reproduction of some species of warmwater fishes (Layzer *et al.* 1993; Yeager 1993) and increase the success of introduced coldwater species such as trout. Therefore, abnormally cold discharge, particularly in summer, may act as a permanent colonization barrier to mussels (Vaughn and Taylor 1999).

Because mussels are dependent on fish hosts, any effects of hydrologic alterations on fish hosts also impacts mussel populations. Distribution, abundance, and movement patterns of fish hosts have been shown to be critical to the distribution and abundance of mussels (Watters 1993; Vaughn 1997; Haag and Warren 1998; Vaughn and Taylor 2000). The disappearance of mussel species from several rivers has been linked to the disappearance of the appropriate fish host (Kat and Davis 1984), and mussels have re-colonized rivers after their fish hosts were re-introduced (Smith 1985). Lowhead dams have been shown to block fish-host migration and lead to the extirpation of mussels in reaches above the dams (Watters 1996). Altered flow regimes can decrease both the species richness and abundance of fish communities (Gore and Bryant 1986; Kinsolving and Bain 1993; Scheidegger and Bain 1995), potentially eliminating mussel hosts. Impacts likely vary both seasonally and with river microhabitat. For example, a high proportion of nest-building fish species, such as centrarchids, are common mussel hosts (Kat 1984; Watters

1994). Thus, altered hydrology that impacts or prevents nesting could result in mussel glochidia failing to attach to hosts, and reduced mussel recruitment.

Mussels evolved in rivers that typically experienced seasonal periods of low and high flow. Recent studies indicate that instream flow needs are not the same for all mussel species (Hardison and Layzer 2001) and that natural, temporal variability in flows is important to maintaining diverse mussel assemblages. For example, recruitment of some species seems to be greatest at below average discharges, while other species require a more normal flow rate for successful recruitment (Gore et al. 2001). To maintain diverse mussel communities, annual hydrographs may need to vary seasonally and annually to provide optimal flows for different groups of species (Gore et al. 2001).

<u>Mussels of southeastern Oklahoma Rivers</u>

Historical information

Based on archeological evidence, the overall mussel species composition of southeastern Oklahoma rivers has changed little over the last several thousand years. For example, all mussel species identified from a Caddo Indian midden (ca. 3500-1000 B.P.) near the Poteau River, were found in the Poteau River in the last decade (Bell 1953; Wyckoff 1976; White 1977; Vaughn and Spooner 2004). No mussel species are known to be entirely extirpated from either the Kiamichi (Vaughn et al. 1996) or Little Rivers (Vaughn and Taylor 1999), the two rivers in the region that have been studied the most extensively.

While few rivers in the region have lost species outright, within rivers both the number of sites at which species occur and species abundances have declined. The recent fauna was first surveyed by Isely in the early 1900s (Isely 1911, 1914; Isely 1924; Isely 1931). He conducted a comprehensive distributional survey of the mussel fauna of the Red River drainage, focusing on the eastern half of Oklahoma, as part of a nation-wide effort by the U.S. Bureau of Fisheries to find mussel populations to harvest for the pearl-button industry. Isely sampled 20 sites in the Red River drainage from 1910-1912 (Isely 1924); six of these sites are now under impoundments. In the 1960s, Valentine and Stansbery (1971) collected from 9 sites, including one that had previously been sampled by Isely; one of these sites has been inundated by an impoundment. From 1990-1995 Vaughn (2000) re-sampled 19 sites in the Red River drainage, the majority in southeastern Oklahoma that had been sampled historically by Isely and Valentine and Stansbery. She found that species richness decreased at 89% of the sites and that 86% of species occurred at fewer sites than in the past. Vaughn used these data to calculate local extinction rates (extinction rate from a local patch or site, not the river as a whole). Local extinction rates were significantly greater than colonization rates, indicating that mortality of mussels is exceeding recruitment in the region (Vaughn 2000).

In the early 1990s Vaughn and Taylor (1999) examined the distribution and abundance of mussels along a 240 km length of the Little River in Oklahoma, from above Pine Creek reservoir to the state line. They observed a mussel extinction gradient downstream from impoundments in the watershed. With increasing distance from Pine Creek Reservoir, an impoundment of the mainstem Little River, there was a gradual, linear increase in mussel species richness and abundance. Rare species only occurred at sites furthest from the reservoir. These same trends were apparent below the inflow from the Mountain Fork River, which is impounded upstream as Lake Broken Bow, and mussel abundance was greatly reduced. In both situations, below reservoir inflows abundance of even common, widespread mussel species was greatly reduced. Thus, even though no species extirpations are known from the Little River, the biological integrity of numerous subpopulations has been greatly decreased by the loss of individuals (Vaughn and Taylor 1999).

The lower Kiamichi River is impounded by Hugo Reservoir. Jackfork Creek, a tributary of the Kiamichi, flows into the river approximately half way down its 180 km length. Jackfork Creek is impounded by Sardis Reservoir. This creek is the largest tributary of the Kiamichi, contributing nearly 30% of the average river flows at the confluence of the two streams. During recent drought years, water that would normally drain into the Kiamichi has been held in Sardis Reservoir, exacerbating drought conditions and causing sections of the Kiamichi to stop flowing and in some cases go completely dry. The summer of 2000 was particularly harsh because of higher than average air temperatures and no rain. During the summer of 2000, Spooner and Vaughn (2000) monitored the effect of these extremely low water levels on a mussel assemblage in the lower Kiamichi near Moyers for which two previous years of population data was available; at this particular site, there was no flow and water temperature during our sampling exceeded 40°C. Mussel mortality was significantly correlated with water depth, with the highest survival in the deepest, coolest water. Mortality was species-specific, with smaller mussels appearing to be hardest hit. Mortalities of federally endangered species were observed (*A. wheeleri* [1 individual] and *L. leptodon* [1 individual]); both individuals were found freshly dead, with tissue still attached, suggesting that the recent mortality was due to the drought and high water temperature. In an effort to minimize mortality, The Army Corps of Engineering released a series of 12 cfs (cubic feet per second) surges of water from Sardis Reservoir resulting in a 4.4 cfs spike in discharge at Clayton and a 1.2 cfs spike at Antlers. Unfortunately, because the riverbed was already very dry, most of the flow was lost to the water table, and the release was insufficient to reduce water temperature for mussels.

Current mussel fauna

Despite the declines discussed above, the four rivers of far southeastern Oklahoma (Kiamichi, Little, Glover and Mountain Fork) continue to harbor a rich and overall healthy mussel fauna. There are approximately 52 extant unionid mussel species known to presently occur in Oklahoma waters (Williams et al. 1992b; Oklahoma Natural Heritage Inventory database), and 41 of these (80%) occur in these rivers (Table 2). In 1998, The Nature Conservancy identified the Interior Highlands (which includes the four rivers in question) as one of the most critical regions in the U.S. for protecting freshwater biodiversity, based on its rich fish and mussel fauna. Based on a comprehensive national assessment of available data, The Nature Conservancy determined that all of the at-risk freshwater fish and mussel species in the U.S. could be conserved by protecting and restoring 327 watersheds (15% of total US watersheds) across the country; the Kiamichi and Little River watersheds were included in this highly select group (Master et al. 1998).

Three federally endangered species occur in these rivers, the Ouachita rock pocketbook *Arkansia wheeleri*, the winged mapleleaf *Quadrula fragosa*, and the scaleshell *Leptodea leptodon*. The Ouachita rock pocketbook mussel occurs in only three rivers in the world, the Kiamichi and Little rivers in Oklahoma, and in the Ouachita River in Arkansas (Vaughn *et al.* 1993; Vaughn 1994; Vaughn and Pyron 1995; Vaughn *et al.* 1995; Vaughn *et al.* 2004b). The Kiamichi population is considered the most viable; subpopulations are patchily located over a 128 km stretch of the river from near Whitesboro to directly above Lake Hugo. Within these subpopulations, the species is quite rare. Vaughn and Pyron (1995) found that in the Kiamichi River, *A. wheeleri* occurs only in the largest, most species-rich mussel beds. Even in its optimal habitat the species was always rare; mean relative abundance varied from 0.2 to 0.7% and the mean density within large mussel beds was 0.27 individuals / m^2. The youngest individual *A. wheeleri* encountered was approximately 12 years of age, indicating that recruitment is low (Vaughn and Pyron 1995). One of the *A. wheeleri* subpopulations in the Kiamichi is located near the proposed water outtake at Moyers (Vaughn *et al.* 2004b). Two subpopulations of *A. wheeleri* have been identified in the Little River; both of these are located on the U.S. Fish and Wildlife Service Little River Wildlife Refuge (Vaughn *et al.* 1995).

The scaleshell mussel was historically distributed throughout much of the Interior Basin but has been extirpated from much of its range (Natureserve 2005). The species is now restricted to 13 streams in the Interior Highlands, including the Kiamichi River, where it is known from the same site near Moyers that contains the *A. wheeleri* subpopulation discussed above (Vaughn *et al.* 2004b).

The winged mapleleaf *Q. fragosa*, historically occurred in the Interior Basin from Minnesota to Alabama. Currently, the best population is in the St. Croix River in Wisconsin. A viable population is thought to exist in the Ouachita River in Arkansas (Hove *et al.* 2003). Specimens believed to be *Q. fragosa* have been observed in the Kiamichi River. Genetic studies need to be conducted to determine if these are indeed *Q. fragosa*. Vaughn has a permit to collect Q. *fragosa* specimens in the Kiamichi River and send them to the team conducting the genetic studies; however, no specimens have been located since she has had the permit.

Several of the mussel species occurring in the four rivers are endemic to the Ouachita Highlands or Interior Highlands. These include *Arkansia wheeleri*, discussed above, *Ptychobranchus occidentalis* and *Villosa arkansasensis*. *Ptychobranchus occidentalis*, the Ouachita kidneyshell, occurs sporadically throughout the Kiamichi and Little rivers (Vaughn *et al.* 1996; Vaughn and Taylor 1999), and is a dominant species in the Mountain Fork (Vaughn and Spooner 2000) and Glover rivers (Vaughn 2003b). *Villosa arkansasensis*, the Ouachita creekshell, occurs in the Little, Glover, and Mountain Fork rivers (Vaughn and Taylor 1999; Vaughn and Spooner 2000; Vaughn 2003b).

Quadrula cylindrica, the rabbitsfoot mussel, is being considered for listing as an endangered species by the U.S. Fish and Wildlife Service (USFWS 2005). The range of this species has declined significantly. One of the most viable remaining populations is in the Little River in Oklahoma (USFWS 2005) where at least 5 subpopulations exist from just above Idabel through upper portions of Little River Wildlife Refuge (Vaughn et al., unpublished data). A small population occurs in the Glover River above the Highway 3 crossing (Vaughn 2003b).

Summary of field and experimental studies of mussel responses to altered hydrology in southeastern Oklahoma

Spooner and Vaughn have been examining the physiological response of mussels to reduced water flows, and subsequent temperature increases, with the goal of predicting when mussel populations are stressed prior to mortality events, and managing stream discharge to prevent mortality events and maintain the reproductive fitness of mussel populations. This study is nearly complete and involves three components: laboratory experiments documenting the physiological response of mussels to various temperatures, field verification of mussel physiological condition under various, seasonal flow and temperature conditions, and a predictive model based on the experiments and field data that allows flow management for healthy mussel populations. Field work was conducted in 2003 and 2004 in the Kiamichi River. Laboratory experiments were performed in 2003 and 2004 on the University of Oklahoma campus. In both cases common mussel species were used rather than rare or endangered species. The results of this project will be presented as a report to ODWC for project T-10-P; however, we think the results to date for this project are critical to making flow recommendations for mussels so we are briefly summarizing some pertinent results below.

Results from the laboratory experiments indicate that mussel tissue glycogen content declines at temperatures above 30°C. This could be due to the fact that mussels are either catabolyzing glycogen or storing less glycogen. In either case, this is an indication of thermal stress, as discussed above, and indicates that mussels are approaching their upper thermal limit. For example, *Actinonaias*, a dominant species in the Kiamichi River, had quite low glycogen levels at 35°C, and began dying at 38°C.

To manage mussel populations into the future, we need to ensure reproduction. Reproduction is energetically costly; mussels typically do not invest energy into reproduction until they have met a threshold condition level (Bauer 1998). Mussels that are relying on stored energy to stay alive are highly unlikely to be able to reproduce successfully. In other words, we should be managing for mussel fitness, not just survival. Therefore, we should manage the river to not exceed water temperatures that cause declines in mussel condition, which based on our work, is approximately 30°C. For a given stream reach in the Kiamichi River, we found that air temperature was the best predictor of water temperature. Thus, one management strategy is to keep water temperatures at 30°C or below, which can be maintained by controlling discharge and calibrating releases with air temperature, which is readily available.

Flow recommendations

Based on what we have learned from the literature and our own experimental studies, we recommend the following:

1. Whenever possible, it is safest to mimic the natural flow regime of the river (Poff *et al.* 1997). There is still a great deal that we do not understand about mussels and their habitat and life

history needs. Mimicking the natural flow regime ensures that mussels are living in the environment in which their life habits and life history evolved.

2. During warm seasons, it is critical to maintain sufficient discharge to keep water temperatures at a level at which most mussel species can maintain body condition and thus can reproduce. Our work to date indicates that a reasonable temperature goal may be 30°C. Because water temperature is dependent on and can be predicted from air temperature (for a given location and depth), managers may be able to perform controlled releases from reservoirs (such as Sardis) when air temperature meets a specific threshold. For example, in our monitoring of conditions in the Kiamichi River we have found that a 100 cfs sustained increase in discharge can result in a 2°C decrease in water temperature. It will be important that such releases be conducted to maintain a continuous discharge level. The releases in 2000 in the Kiamichi (Spooner and Vaughn 2000) likely did not work because they were spikes, and discharge rapidly returned to its previous low levels.

3. During all seasons, it is best to avoid large, pulsed releases that result in scour.

4. Cold water temperatures from releases are probably not a problem in the Kiamichi River because Sardis Reservoir is not a hypolimnetic release reservoir. This is a potential problem on the Little River because both Pine Creek and Broken Bow reservoirs have cold water releases, and these already have been demonstrated to have negatively impacted mussel populations (Vaughn and Taylor 1999). If releases are to be performed in the Little River it would be best to either restrict releases to winter when the water is already cold, or perform releases from the epilimnion. While high water temperatures are detrimental for mussels, as discussed above, cold water temperature at times of the year when water is supposed to be warm is also deleterious, and in particular prevents reproduction of both mussels and their fish hosts.

Table 2. Mussel species that currently occur in the Kiamichi, Little, Glover, and Mountain Fork rivers along with their global and state conservation rank and state and federal protection status. These species represent 80% of the known Oklahoma mussel fauna. Data are from Vaughn and Pyron (1995); Vaughn *et al.* (1996); Vaughn (1997); Vaughn *et al.* (1997); Vaughn and Taylor (1999); Vaughn (2000); Vaughn and Taylor (2000); Vaughn (2003a); Vaughn (2003b); Vaughn *et al.* (2004a); Vaughn and Spooner (2004); Vaughn *et al.* (2004b)

Species	Common name	Kiamichi River	Little River	Glover River	Mt. Fork River	Global Rank	State Rank	Fed Status	State Status
Actinonaias ligamentina	mucket	X	X	X	X	G5	S3		
Amblema plicata	threeridge	X	X	X	X	G5	S3		
Arkansia wheeleri	Ouachita rock pocketbook	X	X			G1	S1	E	E
Ellipsaria lineolata	butterfly	X	X	X		G4	S2		
Elliptio dilatata	spike		X			G5	S1		
Fusconaia flava	Wabash pigtoe	X	X	X	X	G5	S4		
Lampsilis cardium	plain pocketbook	X	X	X	X	G5	S4		
Lampsilis hydiana	Louisiana fatmucket				X	G3G4	S1		
Lampsilis satura	sandbank pocketbook		X			G3	S?		
Lampsilis siliquoidea	fatmucket	X	X	X	X	G5	S?		
Lampsilis teres	yellow sandshell	X	X		X	G5	S5		
Lasmigona complanata	white heelsplitter	X	X			G5	S5		
Lasmigona costata	flutedshell	X	X	X	X	G5	S1		
Leptodea fragilis	fragile papershell	X	X	X		G5	S4		
Leptodea leptodon	scaleshell	X				G1	S1	E	SS2
Ligumia subrostrata	pondmussel	X	X		X	G4	S4		
Megalonaias nervosa	washboard	X	X			G5	S2		
Obliquaria reflexa	threehorn wartyback	X	X			G5	S3		
Obovaria jacksoniana	southern hickorynut	X			X	G1G2	S2		
Plectomerus dombeyanus	bankclimber		X	X		G4	S2		
Pleurobema sintoxia	round pigtoe		X			G4	S2		
Pleurobema rubrum	pyramid pigtoe	X	X			G3	S2		
Potamilus purpuratus	bleufer	X	X	X		G5	S4		

Ptychobranchus occidentalis	Ouachita kidneyshell	X	X	X	X	G3G4	S2		
Pyganodon grandis	giant floater	X	X			G5	S5		
Quadrula apiculata	southern mapleleaf		X			G5	S4		
Quadrula fragosa	winged mapleleaf	X				G1	S1	E	
Quadrula cylindrica	rabbitsfoot		X	X		G3	S1		SS2
Quadrula nodulata	wartyback		X			G4	S1		
Quadrula pustulosa	pimpleback	X	X	X	X	G5	S4		
Quadrula quadrula	mapleleaf	X	X	X	X	G5	S5		
Strophitus undulatus	creeper	X	X	X	X	G5	S3		
Toxolasma parvus	lilliput	X	X	X	X	G4	S4		
Toxolasma texasensis	Texas lilliput		X		X	G4	S1		
Tritogonia verrucosa	pistolgrip	X	X	X	X	G4	S4		
Truncilla truncata	deertoe	X	X	X		G4	S4		
Truncilla donaciformis	fawnsfoot		X		X	G4	S4		
Uniomerus tetralasmus	pondhorn			X		G4	S4		
Utterbackia imbecillis	paper pondshell		X			G5	S5		
Villosa arkansasensis	Ouachita creekshell		X	X	X	G2	S1S2		
Villosa iris	rainbow		X	X	X	G5	S1		
Villosa lienosa	little spectaclecase		X	X	X	G5	S2		

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CONCLUSIONS AND RECOMMENDATIONS

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Conclusions

Many disputes have arisen because of conflicting instream flow needs of aquatic and semiaquatic fauna and their habitats and the needs of offstream water users (Postel 1996; Postel 2000; Kowalewski et al. 2000; Collares-Pereira et al. 2000; Levy 2003; Lewis 2003; Ward and Booker 2003; Cooperman and Markle 2003). To aid in resolving water resource conflicts and achieve desirable results ecologically, scientists must join resource managers, policy makers, and other stakeholders to make collaborative efforts towards integrating their scientific findings with management strategies to meet societal goals. The challenge now facing aquatic scientists is to define ecosystem needs clearly enough to guide policy formulation and management actions that strive to balance competing demands and visions (Poff et al. 2003).

Our summarization and analysis of the available literature pertaining to the ecosystem flow requirements for the Kiamichi River above Hugo Lake and Little River Basin in southeastern Oklahoma identified many species and several habitats that would be susceptible to alterations in the flow regime related to water withdrawals. However, with the exception of the mussel assemblages, many of the flow recommendations contained within each section of the report are based on circumstantial information and not empirical evidence. Therefore, these recommendations should be considered preliminary and require substantiation by conducting further research on these stream ecosystems. Such research, coupled with specific information about the proposed water withdrawal structures and their operation, would provide site and reach specific evaluations of project impacts. Furthermore, any predictions of project impacts must consider global climate change, which has the potential to significantly alter on both the stream temperatures of and water yield from the Kiamichi and Little River basins.

Recommendations

We offer the following general recommendations about the location and timing of water withdrawals from the Kiamichi and Little rivers. As stated above, these recommendations should be considered preliminary.

Kiamichi River

- Take water from the Kiamichi River only during wet parts of the year (i.e., December 1 to June 1), except during dry periods, to maintain mussel beds and fluvial-specialist fish species.
- Take water from Hugo Reservoir and not from the Kiamichi River at Moyers, where mussel beds would be affected.
- Release water from Sardis Lake into the Kiamichi River at rise and fall rates (i.e., as determined by IHA analyses) that mimic the natural flow regime to maintain geomorphic process.

Little River

- Take water from the Litter River below the confluence of the Mountain Fork River, and not from the Little River above the confluence near Idabel, only during the wet parts of the year (i.e., December 1 to June 1) to maintain mussel beds and fluvial-specialist fish species.

- Allow flooding in the Little River during the wet parts of the year (i.e., spring) to maintain bottomland forests and terrestrial and semi-aquatic vertebrates that require it for reproduction and survival.

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