US Army Corps of Engineers

The Nature Conservancy

Sustainable Rivers Program:

Kiamichi River Watershed State of the Science

February 25, 2023

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Introduction & Background

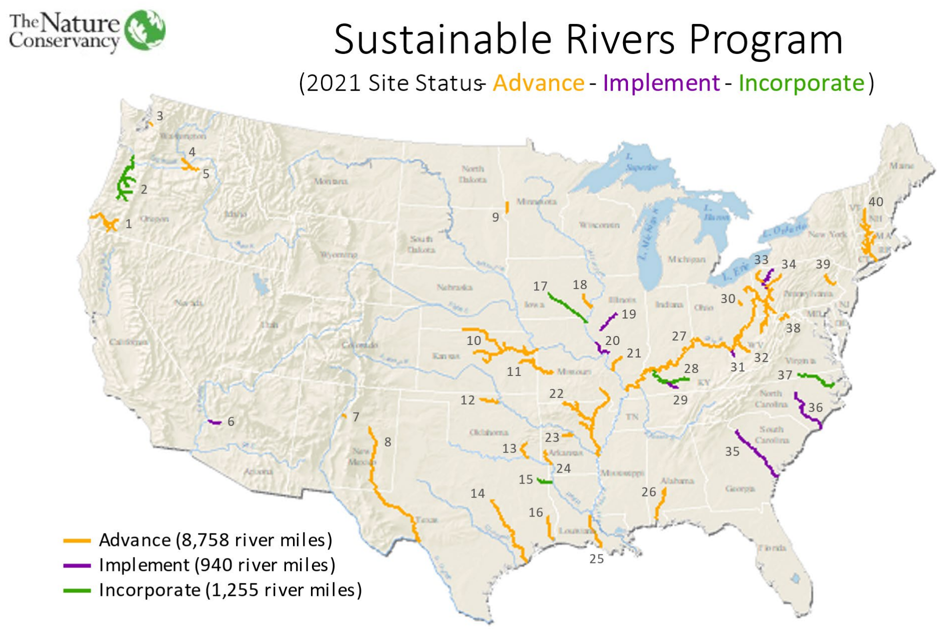
The Sustainable Rivers Program (SRP) has been in existence since 2000. It is a joint effort between the United States Army Corps of Engineers (Corps) and The Nature Conservancy (TNC). The Nature Conservancy approached the Corps about modifying the flows on the Green River in Kentucky in the 1990~~’~~s which helped launch the Memorandum of Understanding (MOU) between the Corps and TNC in 2002. The Green River was the first SRP project and led to projects on 40 sites through 2021 (Figure 1). This effort on the Green River led to discussions about flow regimes and how to manage the reservoir to improve flows for fish and mussels, maintain flood control, and improve the recreation season. This process of determining environmental flows (e-flows) is a five-step approach (Figure 2).

The SRP is important because of the need to modernize dams and infrastructure for environmental benefits. It is also important to balance human and nature needs in an adaptive management process. The SRP also engages local Corps districts and stakeholders to develop new water management plans for infrastructure. The Nature Conservancy-Oklahoma Chapter started discussions with the Corps-Tulsa District about potential sites for an SRP project in 2019. We decided on the Kiamichi River.

The Kiamichi River was added to the SRP in 2020. This river was chosen because of the high biological diversity, expert stakeholders in the watershed, cultural interests, and demand for water in the watershed. Environmental flows are important to consider in this watershed because of endangered mussel species and their fish hosts. Specific flow regimes are needed to maintain this biological diversity as well as meet the current and future water demands in the watershed. Environmental flows, or e-flows, incorporate the biology and ecology of a system as well as the hydrologic components that keep this system functioning at high biological diversity. The timing and magnitude of flows are important hydrologic components to consider for e-flows. Fish and mussels need flows at certain times of the year to aid in completing their life cycles. Dams have impacted the life cycles of many aquatic species.

Dams and reservoirs have fragmented our river systems to the point where 70% of aquatic species have declined. It is important to consider the impacts our management of dams has on aquatic ecosystems. This not only impacts aquatic species, but the humans that depend on these ecosystems for their livelihood. Oklahoma started working on environmental flows in the Barren Fork in Northeastern Oklahoma in the early 2000’s and started working on the Illinois River in Northeastern Oklahoma in the mid-2000’s.

Olahoma is one of only two states without a formal environmental flows program. This has been a contentious issue with attempts to pass legislation in previous years. Now, we are trying to work with stakeholders in the basin to show them the state of the science and what is possible in terms of water management changes from reservoirs in the Kiamichi River watershed.



1. Rogue River
2. Willamette River
3. Ballard Locks
4. Yakima River Delta (McNary)
5. Walla Walla River (Mill Creek)
6. Bill Williams River
7. Galisteo Creek
8. Pecos River
9. Bois de Sioux River
10. Kansas River
11. Osage River
12. Salt Fork Arkansas River
13. Kiamichi River
14. Brazos River
15. Big Cypress Bayou
16. Neches River
17. Des Moines River
18. Iowa River
19. Farm Creek
20. Mississippi River
21. Kaskaskia River
22. White/Black/Little Red Rivers
23. Fourche LaFave River
24. Cossatot River
25. Atchafalaya River
26. Alabama River
27. Ohio River
28. Green River
29. Barren River
30. Sugar Creek
31. Twelve Pole Creek
32. Kanawha River
33. French Creek
34. Upper Ohio River
35. Savannah River
36. Cape Fear River
37. Roanoke River
38. Potomac River
39. Lehigh River
40. Connecticut River

Figure 1. Sustainable Rivers Program (SRP) project sites through 2021

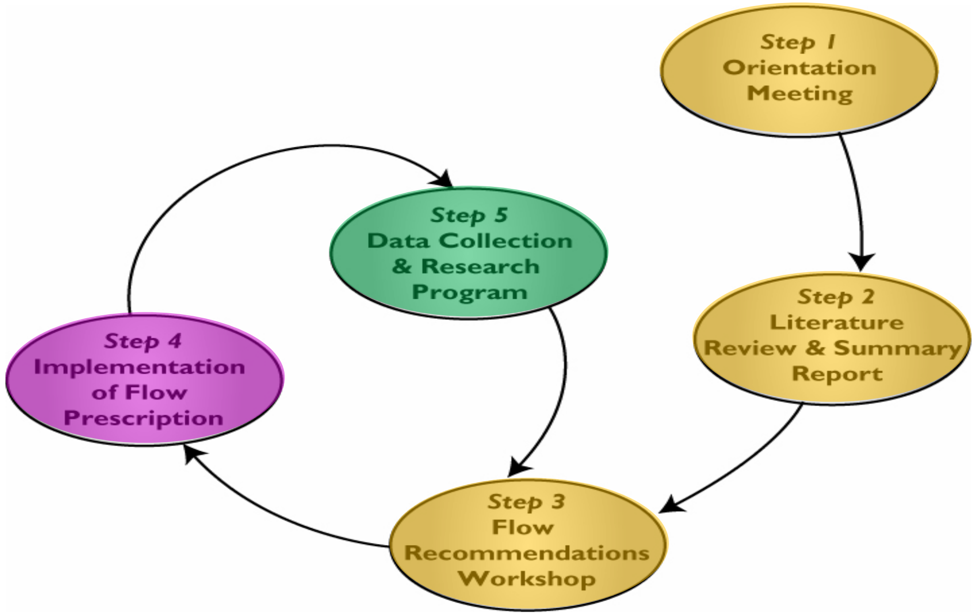


Figure 2. SRP process for considering environmental flow prescriptions (Richter, 2006)

Hydrology of the Kiamichi River

The Kiamichi River Basin is located in Choctaw, Atoka, Pushmataha, Pittsburg, Latimer, and LeFlore Counties, Oklahoma, and has a drainage area of 1,830 square miles (Figure 3A). The river originates in southeastern LeFlore County, flows west and southwest across western Pushmataha County, and then turns southeast across Choctaw County to the Red River. The basin is 110 miles long, and the width varies from 5 to 30 miles. The northern two thirds of the basin lie in the Ouachita Mountains physiographic province. This location represents an ecotonal region between the Prairie Parklands to the west and the Southern Floodplain Forest to the east. As such, the faunal assemblages of the Kiamichi Basin are highly diverse with several western species at the eastern most edge of their ranges and many eastern forms near the edge of their western most ranges.

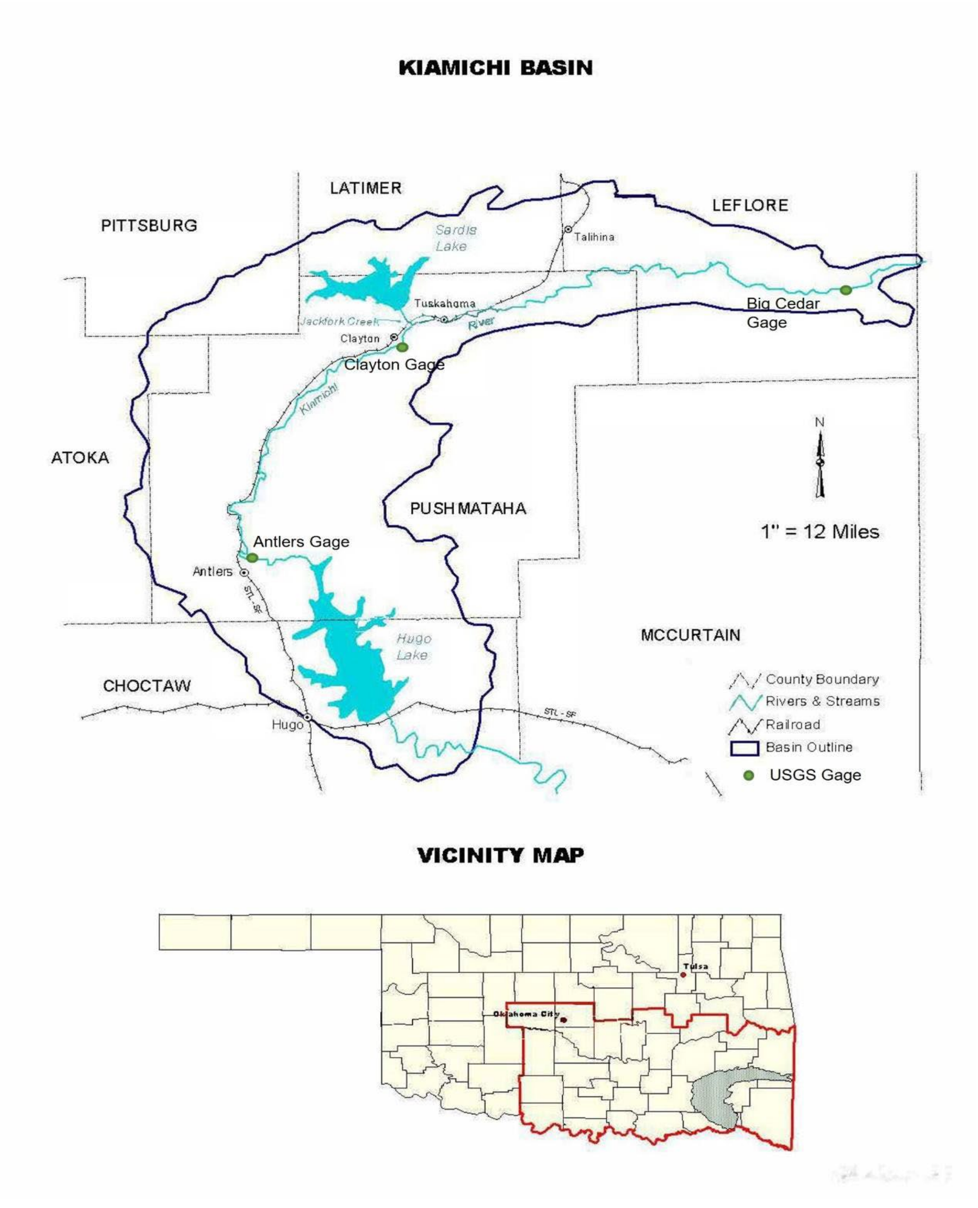


Figure 3A. Kiamichi River basin and vicinity.

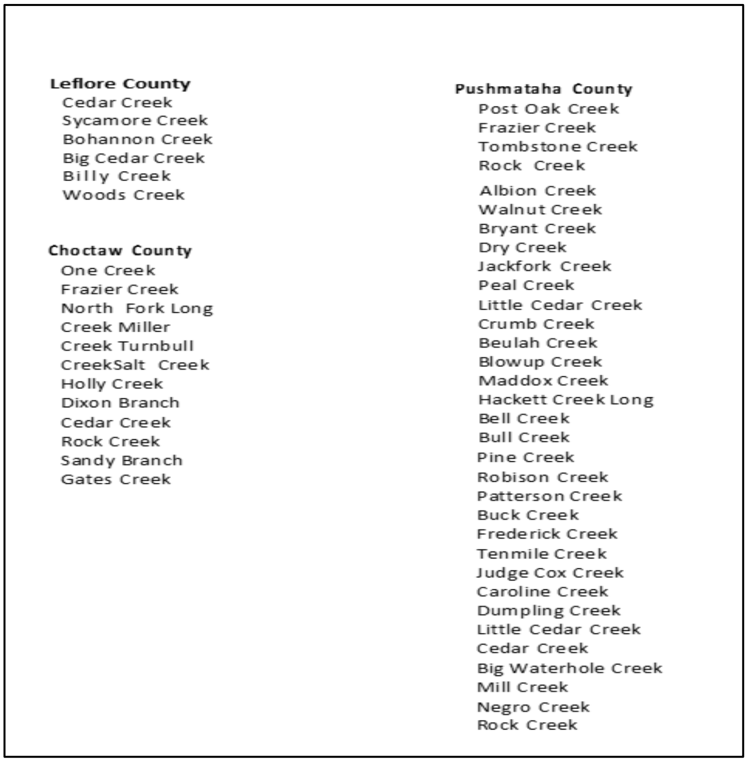
Since the 1970's, many land use changes have been gradually occurring within the watershed that appear to be impacting the habitat and water quality of the Kiamichi River Basin for indigenous species. Non-point source runoff from ranching and chicken production facilities has contributed to nutrient loading in the basin. Increased sediment loading and use of selected herbicides from silviculture practices within the upper watershed may also be impacting the water quality of the river. Construction and operation of reservoirs within the basin have reduced the amount of physical habitat for some species, and operation of the reservoirs may be impacting the natural flood cycles and the thermal regime of the Kiamichi River. The two federal reservoirs within the basin are Hugo Lake and Sardis Lake.

Hugo Lake is located on the Kiamichi River at river mile 17.6, about 7 miles northeast of Hugo in Choctaw County, Oklahoma and 30 miles north of Paris, Texas. Hugo Lake was authorized by the Flood Control Act approved July 24, 1946, Project Document HD 602, 79th Congress, 2nd Session. Construction began on September 6, 1968, and embankment closure was completed on October 29, 1971. Impoundment of the lake began on January 18, 1974, and the conservation pool filled to elevation 404.5 feet on March 12, 1974. Authorized purposes include flood control, water supply, water quality, recreation, and fish and wildlife.

Sardis Lake is located at river mile 2.8 on Jackfork Creek, a tributary of the Kiamichi River, about 2.5 miles north of Clayton and 5 miles northwest of Tuskahoma in Pushmataha County, Oklahoma. Sardis Lake was authorized by the Flood Control Act approved October 23, 1962, Project Document SD 45, 87th Congress, 2nd Session. Public Law 97-88 approved December 4, 1981, changed the name from Clayton Lake to Sardis Lake. Public Law 99-88, approved August 15, 1985, authorized access road improvements, and Public Law 98-63, approved July 30, 1983, authorized an intake structure. Construction of the reservoir began in August 1975 and the project became operational in December 1982. The impoundment started in January 1983, and the conservation pool filled to elevation 596.00 feet in March 1984. The authorized purposes include flood control, water supply, recreation, and fish and wildlife.

Four major tributaries of the Kiamichi River are located between the confluence of Jackfork Creek (Sardis Lake) and the Highway 3 bridge (Hugo Lake) southeast of Antlers. These tributaries account for approximately 30% of inflows into Lake Hugo with the majority of the flow, with another approximately 25% of inflows being contributed by Jackfork Creek. The tributaries are Pine Creek (John's Valley), Buck Creek, Tenmile Creek, and Cedar Creek. Each tributary provides habitat for a warm water aquatic community. The OWRB considers the Kiamichi River a source of high-quality water. The water quality along this segment of the river is generally good, with primarily agricultural runoff providing nutrient load to the river. See below a list of tributaries by county in Table 1.

Table 1. Names tributaries of the Kiamichi River with continuous flow by county (From Pyron and Vaughn 1994)



Leflore County
- Cedar Creek
- Sycamore Creek
- Bohannon Creek
- Big Cedar Creek
- Billy Creek
- Woods Creek

Choctaw County
- One Creek
- Frazier Creek
- North Fork Long
- Creek Miller
- Creek Turnbull
- CreekSalt Creek
- Holly Creek
- Dixon Branch
- Cedar Creek
- Rock Creek
- Sandy Branch
- Gates Creek

Pushmataha County
- Post Oak Creek
- Frazier Creek
- Tombstone Creek
- Rock Creek
- Albion Creek
- Walnut Creek
- Bryant Creek
- Dry Creek
- Jackfork Creek
- Peal Creek
- Little Cedar Creek
- Crumb Creek
- Beulah Creek
- Blowup Creek
- Maddox Creek
- Hackett Creek Long
- Bell Creek
- Bull Creek
- Pine Creek
- Robison Creek
- Patterson Creek
- Buck Creek
- Frederick Creek
- Tenmile Creek
- Judge Cox Creek
- Caroline Creek
- Dumpling Creek
- Little Cedar Creek
- Cedar Creek
- Big Waterhole Creek
- Mill Creek
- Negro Creek
- Rock Creek

Hydrologic data sources, within the basin, are available from the U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers (USACE). USGS data sources include observed (measured) discharge at the Big Cedar (USGS 07335700), Clayton (USGS 07335790), and Antlers (USGS 07336200) gages. USACE data sources include observed (measured) discharge from the Sardis Lake and Hugo Lake dams. The daily discharge period-of-record (POR) for the Big Cedar gage is March 3, 1992, to present, for the Clayton gage it is November 11, 1980, to present, and for the Antlers gage it is October 1, 1972, to present. Discharge, between the Big Cedar and Jackfork Creek confluence, consists of unregulated flows. Flows entering the Kiamichi River from Jackfork Creek are regulated by Sardis Lake and those regulated flows affect discharge observed at the Clayton and Antlers gages. Flows in the lower portions of the basin are regulated by Hugo Lake. Additional data is available from USACE via the Riverware Kiamichi Basin model used to produce pre-impoundment discharges at all gaged locations, USGS and USACE, over POR from January 1, 1938, to December 31, 2019.

Hydrologic Engineering Center (HEC) Ecosystem Functions Model (EFM) assessment of the Kiamichi River

The HEC-EFM is a software tool that helps analyze ecosystem responses to changes in flow regimes of rivers. HEC-EFM computes river flow and state-related statistics to characterize ecosystem dynamics of the flow regime. The tool's most notable strength is its capability of testing ecological change for multiple relationships and flow regimes. For the Kiamichi River hydrologic data available, HEC-EFM was applied to evaluate average annual discharge to identify wet, average, and dry hydrologic periods (see Appendix 2).

Indicators of Hydrologic Alteration assessment of the Kiamichi River

The Indicators of Hydrologic Alteration (IHA) software was used to perform a hydrologic assessment of the Kiamichi River. IHA was run using the standard US water year (WY), 01 Oct – 30 Sep. Gaged data were used wherever possible. There are two primary sources of gage data for this study. First, USACE monitors outflows and pool levels at Sardis and Hugo reservoirs. Gaged outflows and pool levels at Sardis were used to compute Sardis inflows. Second, the USGS operates stream gages at Clayton and Antlers. Unregulated flows at Clayton, Antlers, and Hugo were obtained from data prepared for and computed by Riverware, which is a model used to simulate river and reservoir systems. Those unregulated time series were computed with a simple mass balance approach that also used the USACE and USGS gage data mentioned above. Water years with partial data were omitted.

A common application of IHA is to perform “two-period” analyses. Two-period analyses compare hydrologic statistics and characteristics within a single time series that is split into two parts, typically before and after a change to river management or infrastructure. In the Kiamichi basin, construction of Hugo was completed in 1971 with pool filled in 1974; construction of Sardis was completed in 1982 with pool filled in 1984. Two-period analyses were done for the following locations in the Kiamichi basin: 1) Jackfork Creek at Sardis Reservoir, 2) Kiamichi River at Clayton, 3) Kiamichi River at Antlers, and 4) Kiamichi River at Hugo Reservoir using the following time series and periods-of-record:

1) Sardis Reservoir computed inflows compared to outflows (USACE), WY1985 to WY2021
2) Clayton unregulated flows (Riverware) compared to gaged flows (USGS), WY1985 to WY2019
3) Antlers unregulated flows (Riverware) compared to gaged flows (USGS), WY1985 to WY2019
4) Hugo unregulated flows (Riverware) compared to gaged flows (USGS), WY1985 to WY2019

To merge these different scenarios into the single time series required for each analysis, the first part was time shifted to begin in WY1945 instead of WY1985. For example, for the first analysis, Sardis inflows were shifted back in time by 40 years and merged with the unshifted Sardis outflows. The resulting time series had the two-periods that were subsequently assessed with IHA: WY1945 to WY1981 (inflows) and WY1985 to WY2021 (outflows).

Hydrologic alteration was most pronounced at Sardis and then Hugo, Clayton, and Antlers. Maximum flows were reduced at all locations. Minimum flows were reduced at Sardis and increased at Hugo. Appendix 3 presents IHA plots for each location: 1) Environmental Flow Components, 2) Range of Variability Analysis (RVA) scorecard, 3) 1-day annual maximums, 4) 3-day annual maximums, 5) 7-day annual maximums, 6) 1-day annual minimums, 7) 3-day annual minimums, 8) 7-day annual minimums, 9) 30-day annual minimums, 10) 90-day annual minimums, 11) zero-day counts, 12) reversal counts, 13) annual flow duration curves, 14) monthly median flows. Additional IHA results are available upon request. The results of the IHA analysis are found in Figure 13 through Figure 68.

Reversals are calculated by dividing the hydrologic record into rising/increasing and falling/decreasing periods, which correspond to periods in which daily changes in flows are either positive or negative, respectively. The number of reversals is the number of times that flow switches from one type of period to another (e.g., changing from increasing discharge to decreasing discharge).

Reservoir Operation within the Kiamichi River Basin

Water management, of USACE reservoirs, is governed by the Water Control Manual (WCM) and, more specifically, the Water Control Plan incorporated into the WCM for each reservoir. The Sardis Lake WCM was most recently updated in August 2010. The Hugo Lake WCM was most recently updated in August 2013. These updates help to better inform the Water Control Plans for reservoirs using observed data related to the hydrologic cycle including characteristics of the watershed, monthly average precipitation and monthly average rates of evaporation.

The Sardis Lake watershed is 275 square miles and is a part of the 1,709 square mile Hugo Lake watershed. The watershed is generally characterized by mild winters and comparatively long summers. Summer precipitation usually occurs as short duration thunderstorms with intense rainfall and limited areal extent. Winter precipitation events generally are several days in duration and more extensive in areal distribution. For the POR, at Sardis Lake's average annual precipitation is 45.23 inches and ranges from a high of 83.19 inches (1990) to 23.45 inches (1963). Average annual snowfall is 4.5 inches. Average monthly precipitation and runoff at Sardis Dam indicates a low flow period from June through November with 64.3% of average annual runoff occurring from January through May (Table 2). Average monthly precipitation and runoff at Hugo Dam indicates a low flow period from July through October (Table 4). IHA analysis suggests a low-flow period extending from May through December for Sardis Lake and July through December at Hugo Lake. For the POR, the average annual precipitation for Hugo Lake is 48.04 inches and ranges from a high of 72.55 inches (1957) to 32.98 inches (1956).

For the POR, the average annual air temperature within the Kiamichi River basin is 63°F and ranges from a maximum 113°F, measured at Tuskahoma, Oklahoma in 1937, to a minimum of -14°F measured at Clayton, Oklahoma in 1951.

Wind speed, solar radiation, air temperature, and relative humidity are the primary drivers of evaporation. From the end of construction to 1996, evaporation at Sardis Dam was physically measured using an evaporation pan. Since 1996, a mathematical formula, using meteorological data collected at Sardis Dam has been used to calculate evaporation at Sardis Lake using the above parameters. Average monthly evaporation at Sardis Dam, for the period January 1982 through December 2009, is presented in Table 2. Average monthly evaporation at Hugo Dam, for the period January 1930 through December 1973, is presented in Table 5.

Table 2. Average monthly and annual precipitation and runoff upstream of Sardis Dam (January 1926 – December 2009).

Month	Average Precipitation (inches)	Percent of Average Annual Precipitation	Average Volume (acre-feet)	Average Runoff (inches)	Percent of Average Annual Runoff
January	2.53	5.6	23,670	1.61	9.0
February	2.98	6.6	27,870	1.9	10.7
March	3.69	8.2	33,600	2.29	12.9

April	4.66	10.3	40,770	2.78	15.6
May	6.16	13.6	42,100	2.87	16.1
June	4.27	9.4	19,730	1.35	7.6
July	3.52	7.8	7,920	0.54	3.0
August	3.17	7.0	3,250	0.22	1.2
September	4.38	9.7	9,090	0.62	3.5
October	3.61	8.0	10,800	0.74	4.2
November	3.45	7.6	18,750	1.25	7.2
December	2.81	6.2	23,730	1.62	9.0
Total	45.23	100.00	261,280	17.82	100.00

Table 3. Estimated monthly evaporation at Sardis Dam (January 1982 – December 2009).

Month	Normal (inches)	Drought Periods (inches)
January	2.26	2.29
February	2.85	3.10
March	4.75	4.68
April	6.28	6.65
May	6.97	6.86
June	7.88	8.59
July	9.39	9.82
Aug	8.79	9.27
September	6.30	7.07
October	4.80	5.32
November	3.16	3.42
December	2.39	2.13
Total Inches Per Year	65.82	69.20

Table 4. Average monthly and annual precipitation and runoff upstream of Hugo Dam (January 1930– December 1973).

Month	Average Precipitation (inches)	Percent of Average Annual Precipitation	Average Volume (acre-feet)	Average Runoff (inches)	Percent of Average Annual Runoff
January	2.99	6.22	150,200	1.65	9.76
February	3.42	7.12	171,470	1.88	11.12
March	3.82	7.95	181,100	1.99	11.77
April	5.16	10.74	258,460	2.84	16.79
May	6.06	12.62	249,200	1.32	7.81
June	4.25	8.85	120,480	1.32	7.81
July	3.71	7.72	47,760	0.52	3.08
August	3.38	7.04	17,810	0.20	1.18
September	4.46	9.28	60,590	0.67	3.96
October	3.72	7.74	51,310	0.56	3.31

November	3.76	7.83	99,550	1.09	6.45
December	3.31	6.89	133,420	1.46	8.63
Total	48.04	100.00	1,541,350	16.91	100.00

Table 5. Estimated monthly evaporation at Hugo Dam (January 1930 – December 1973).

Month	Normal (inches)	Drought Periods (inches)
January	2.35	2.53
February	3.18	3.94
March	5.31	5.93
April	6.69	7.22
May	7.94	8.64
June	8.81	9.66
July	9.62	11.81
Aug	9.38	11.32
September	7.14	9.02
October	5.27	6.26
November	3.32	4.00
December	2.46	2.88
Total Inches Per Year	71.47	83.21

The regulating capacity of the 2.8 miles of Jackfork Creek below Sardis Dam is 4,000 cfs and discharges in excess of 4,000 cfs from Sardis Dam warrant concern due to the potential for agricultural impacts downstream. The channel capacity downstream of the Jackfork Creek confluence with the Kiamichi River varies from approximately 7,000 cfs near Tuskahoma to approximately 21,300 cfs near Antlers. Crest travel time from Sardis Dam to the Clayton gage is 3 hours, from the Clayton gage to the Antlers gage is 22 hours, and from the Antlers gage to Hugo Dam is 12 hours. The regulating capacity of the channel below Hugo Dam is 20,000 cfs. Crest travel time from Hugo Dam to the Kiamichi River confluence with the Red River is 6 to 9 hours.

Red River 1938-2019 period-of-record RiverWare model

The Red River model was developed using RiverWare, which is a software developed by CADSWES (Center for Advanced Decision Support for Water and Environmental Systems) at the University of Colorado in Boulder.

The SWT Red River model, schematic shown, in Figure 3B, covers from Lake Texoma (Denison Dam) to Shreveport, LA including the Kiamichi River system, the Little River system, the Sulphur River system, Muddy Boggy and Clear Boggy Creeks, Sanders Creek, McGee Creek, and Cypress Creek. There are five control points in the model where only period-of-record hydrology is provided. The control points are locations where planning projects for dams occurred but were never built; those points are Parker, Boswell, Durant, Tuskahoma, and Lukfata. This model is a daily timestep model with a period-of-record model (1938-2019).

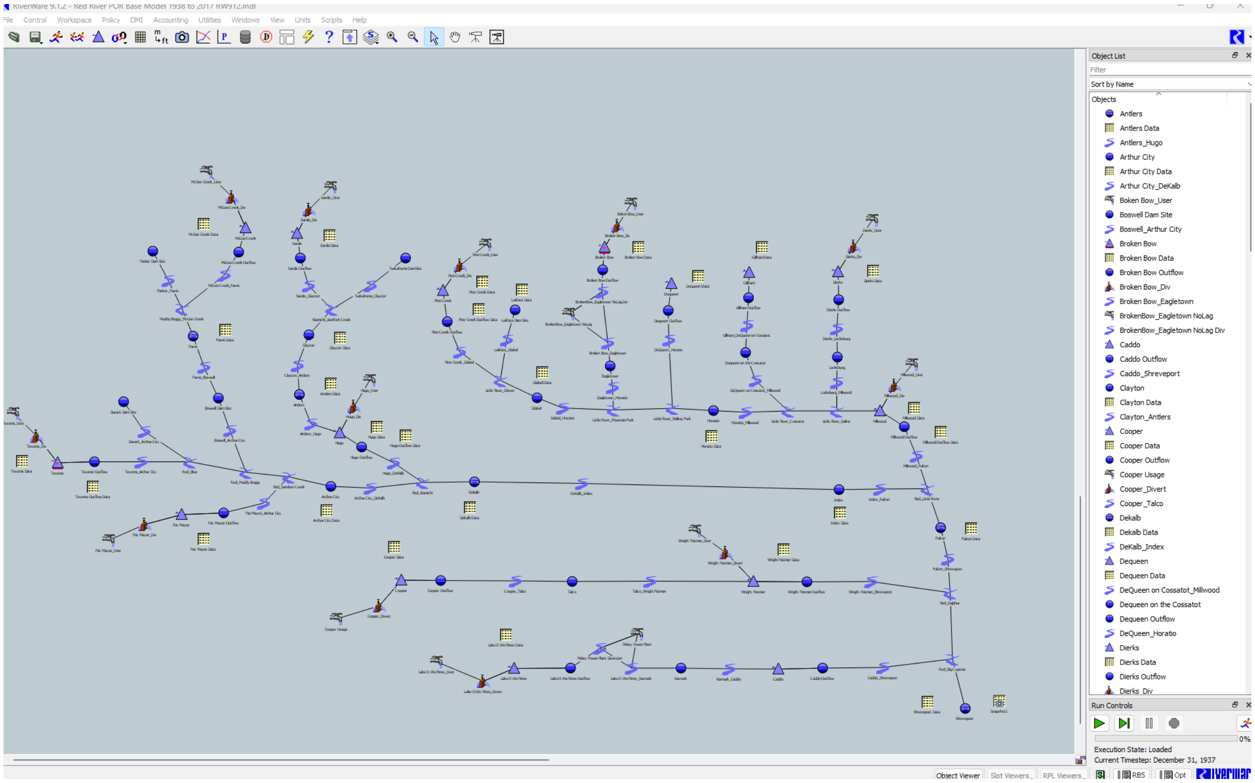


Figure 3B. SWT Lower Red POR Riverware Model.

The simulation assumes all reservoirs are in place for the entire specified period, January 1938 to December 2019, with current operational criteria used for the entire period. Using historic data, the period of record headwater flows, and intervening area flows are developed through preprocessing techniques before the rule-based simulation is done. The preprocessing includes running a separate local model in RiverWare that uses observed headwater flows and releases from reservoirs. These are routed downstream and subtracted from observed flow data at downstream gage sites. These locals are then used in the rule-based simulation model.

The RiverWare model contains operational and physical data inputs including established pool limits, regulation criteria to model system operational constraints, and spillway and outlet works ratings. When applicable the model contains hydropower, water supply, and water quality criteria. The goal of the rule-based simulation is to maximize use of the channel storage space and minimize flooding. For the simulation, flood control releases are given priority and then conservation pool releases such as low flow or environmental releases and diversions for water supply. Lastly, for hydropower projects, daily load requirements are analyzed, and any additional releases required to meet the load. When the model simulation is running, the preprocessed hydrologic data is routed through the river system starting with the headwater reservoirs. Subsequent releases are determined based on current and future forecast downstream conditions. Simulated releases are sent downstream to be combined with the intervening area flows until all hydrologic flows for the period-of-record are routed through the model area. Initially, mandatory releases, required to maintain structural integrity at each reservoir, are determined, and then these releases are routed to downstream control points. Each downstream control point examines their regulation criteria, and they determine how much channel space is going to be occupied and empty based on the incoming intervening area flow and the mandatory upstream releases. This sets the reach storage parameters for the simulated releases for flood control and conservation purposes.

Sardis Lake dependable yield analysis using the Tulsa District Red River RiverWare Model

Sardis Lake is located on the Kiamichi River system which is included in the SWT Red River model developed in RiverWare. A yield study is used to determine the largest average diversion from a reservoir where the reservoir will not drop below the bottom of the conservation pool at any time during the run period. For the dependable yield study of Sardis Lake, the existing period-of-record model was modified in RiverWare changing from a single-run model to an iterative MRM (multiple-run model). When needed, other operating policies such as surcharge, regulation discharge, flood control, low-flow release, and hydropower can be included in this analysis.

To create the dependable yield analysis, a yield study ruleset and object provided from Riverware-support in Colorado was integrated into the model. In the yield study object, the reservoir data for Sardis was input into the yield study as well as other parameters needing to be set. The ruleset requires lower and upper limits for the yield, and for this study, the default limits the algorithm provides were used. The lower limit starts off as 0.0cfs and the upper limit is the average inflow over the run. The convergence from above and below is set to 0.1 feet and -0.1 feet, respectively, and this determines how accurate the yield value should be above or below the exact answer. The distribution of the yield for this study is constant, so the average yield is distributed evenly over the run. After the parameters are set, the diversion and water user objects of Sardis were disabled because the diversion is controlled by directly setting the reservoir diversion slot values.

The yield study ruleset is set up for the user to choose between three different algorithms. The Sardis Lake yield study is done using a Bisection algorithm. The bisection algorithm uses the minimum and maximum yields first, and then it averages them to find the intermediate yield. The intermediate yield is used for the third run. Once the third run is complete, the algorithm modifies the upper and lower bounds based on the yield being too high or too low. This is continued until the solution is found. For the bisection algorithm, no additional information from the reservoir or physical processes are used, making this the simplest algorithm to use. The yield is found when the minimum level difference is between the above and below convergence parameters that were set.

For the Sardis Lake dependable yield analysis, the results show that a yield of 213.95cfs is being repeated with a minimum level difference of -1.00ft starting on the 18th run. The 17th run shows the same yield of 213.95cfs, but the minimum level difference is 9.41ft. After working with experts at CADSWES, it was determined that the yield should be near 214cfs, but it cannot completely converge because there is not enough storage on the lower end of the elevation-storage table during that critical period (May 8, 1962, to April 25, 1968). During the 17th run, the iteration gets down to 9.41ft above the bottom of conservation, but any additional withdrawals quickly drain the reservoir causing the yield to not converge which is shown in the runs following. At 9ft above the bottom of conservation, the storage difference is about 1000AF of water. Using 1000AF of water divided by the critical period duration of 2,178 days, only increases the diversion by 0.23cfs which would be the additional amount needed to drawdown the reservoir to the bottom of conservation over that critical period. Looking at the results from the runs and talking with the experts at CADSWES, it was determined that the dependable yield for Sardis Lake is about 214cfs.

To verify the dependable yield results from Riverware, the Rippl Method was used with the period-of-record data to graphically demonstrate why, May 8, 1962 to April 25, 1968, is the critical period for Sardis Lake. Along with the Rippl Method, a Mass Balance was completed using the period-of-record outflows, deterministic inflows, a starting storage of 274,192AF, and a yield of 424AF (214cfs). The mass balance shows what the minimum difference is between the storage and the bottom of conservation of Sardis and when it occurs during the critical period.

The Critical Period (Figure 4) shows the deterministic inflow Period of Record and a yield line of 214cfs. Looking at the graph, the lowest inflows, or the dry periods throughout the record, are within the grey shaded areas. For the dependable yield, the program identifies these areas, and the period with the longer timeframe of low inflows is used to find the yield.

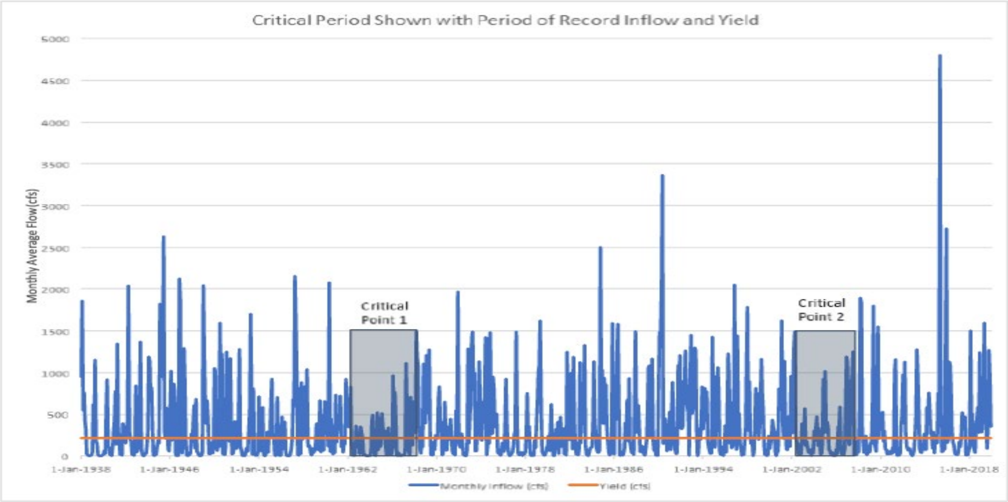


Figure 4. Period of record inflow and dependable yield of Sardis Lake, Oklahoma plotted with Sardis Lake critical periods shown in grey.

These critical periods can also be seen in the cumulative inflow graph, shown below. On this graph, the critical points (Figure 5) are found where the line seems to flatten out because the inflows are lower than normal for an extended period. These critical points are used to determine how much storage is needed or how much storage is left over when using that specific yield.

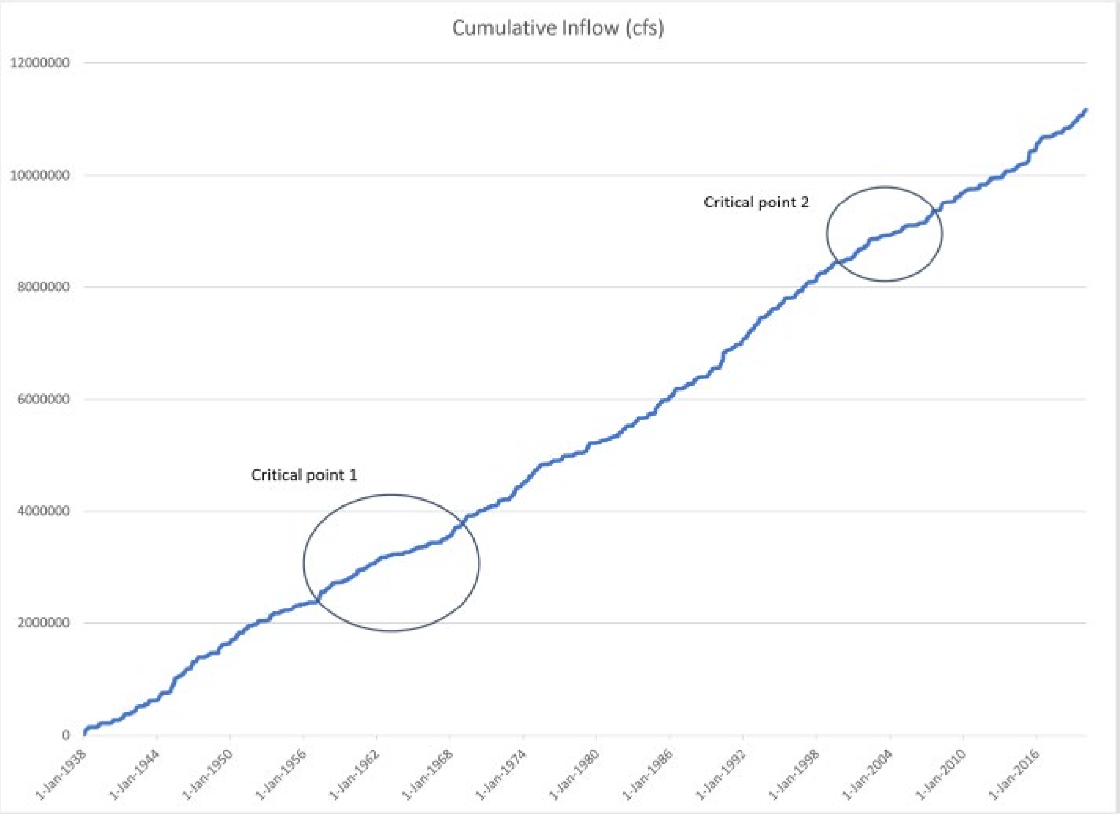


Figure 5. Cumulative period of record inflow, Sardis Lake, Oklahoma.

Figure 6 shows the convergence of the mass balance storage and the Bottom of Conservation (BOC) for Sardis Lake which is 542ft or 124AF. Keeping in mind that the dependable yield being used for the verification is 214cfs, the critical date appears different than April 9, 1967, which was found using ~~the~~ 213.95cfs as the yield. Also, when verifying the data by mass balance, the results appear a little different because there is no perfect operation being performed by the RiverWare applications. Looking at the graph around the given minimum level difference date, it shows that the closest positive storage to the bottom of conservation line is around March 29, 1967, and the storage found is 144.76AF. The difference of the storage and the BOC for Sardis at this date is about 20AF. The 20AF difference proves that the convergence to the bottom of conservation using a yield of 214cfs is closer than the 1000AF difference that was found when using a yield of 213.95cfs.

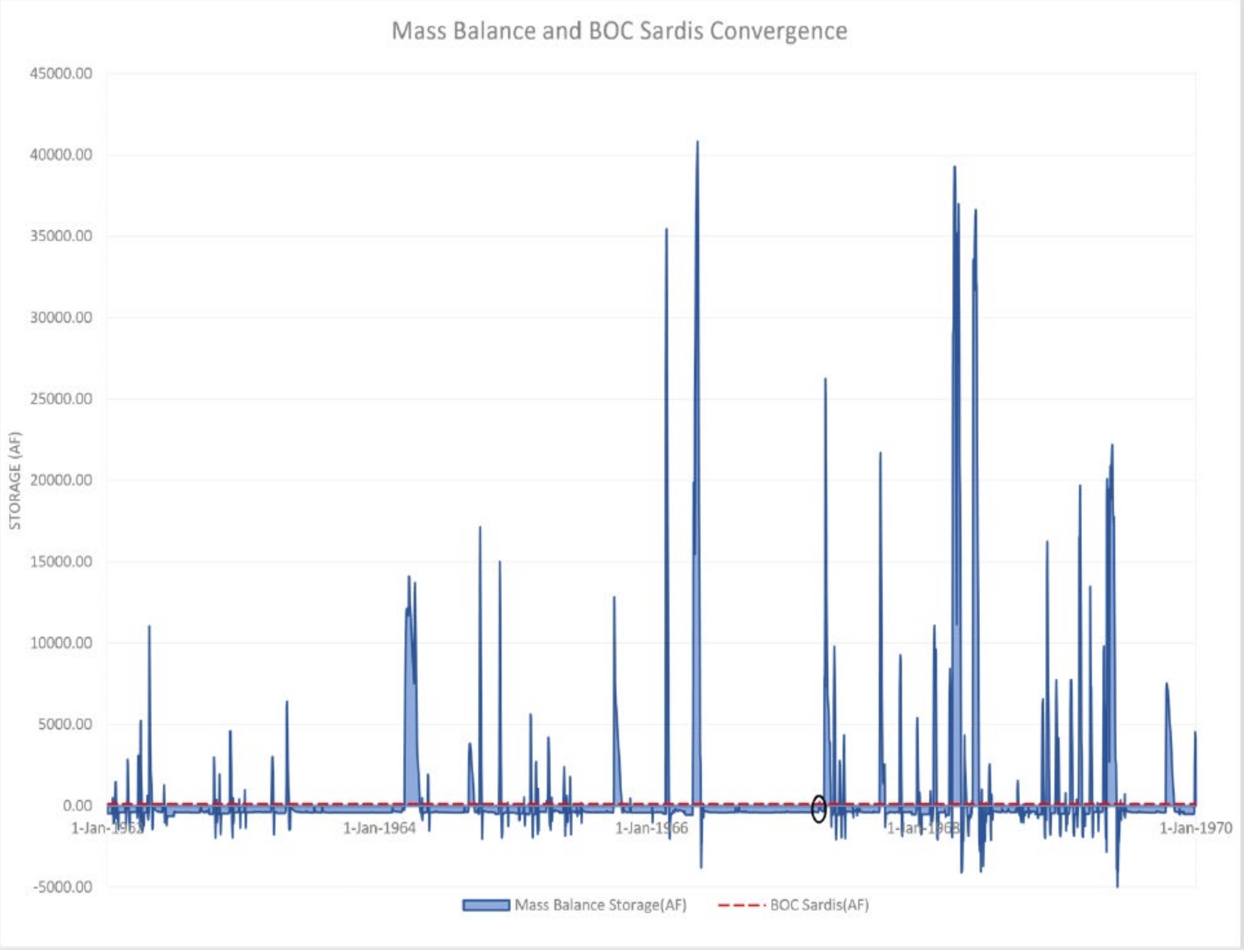


Figure 6. Mass balance and bottom of conservation convergence for Sardis Lake, Oklahoma

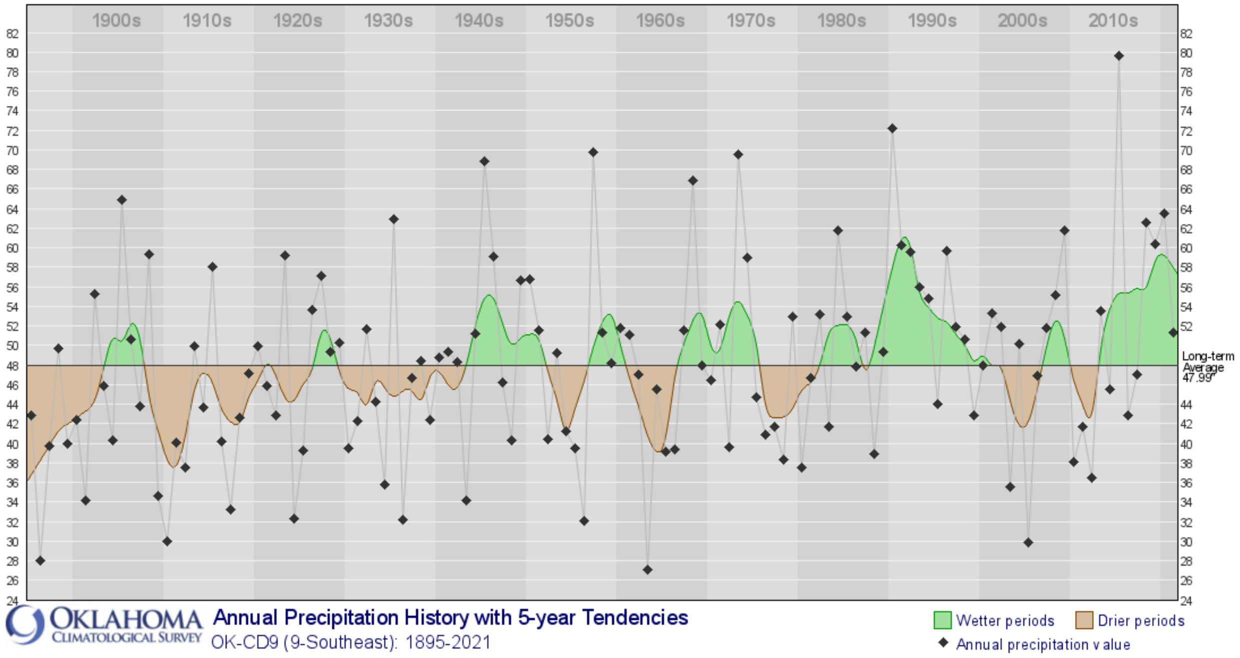


Figure 7. Average annual precipitation history in southeast Oklahoma with 5-year tendencies 1895-2021 (NOTE: The diamonds represent the average of the measured precipitation in the region for each year. Green-brown trace represents the five-year weighted average of these precipitation values over time).

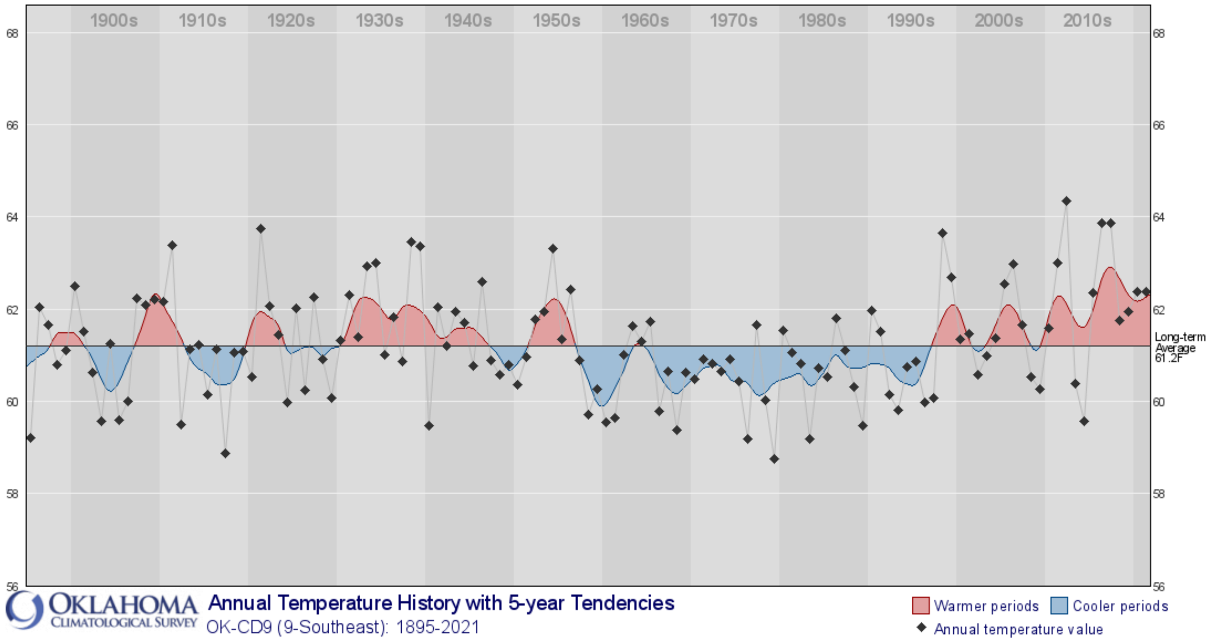


Figure 8. Average annual temperature history in southeast Oklahoma with 5-year tendencies 1895-2021 (NOTE: The diamonds represent the average of the measured precipitation in the region for each year. Red-blue trace represents the five-year weighted average of these precipitation values over time).

LITERATURE REVIEW OF THE BIOLOGY AND ECOLOGY OF THE KIAMICHI RIVER

This document reviews and synthesizes the available information on the biology and ecology of the Kiamichi River basin to help inform the development of sustainable environmental flows for the river. A complete, annotated bibliography is provided at the end of the report (Literature Cited – pg. 40).

The Kiamichi River arises just east of the Arkansas-Oklahoma border, flows westward into Oklahoma, then south to join the Red River on the Oklahoma-Texas border. From its source, it flows 285 km to the border through the Ouachita and Coastal Plain physiographic provinces (Figure 1). It flows through a narrow river valley floor, bordered on both sides by the Kiamichi Mountains, with steep slopes of long ridge-and-valley mountains. In 1998, The Nature Conservancy identified the Kiamichi River as one of the most critical rivers 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 River was included in this highly select group (Master et al. 1998). The name "Kiamichi" likely comes from the French "kamichi", which means "horned screamer" and may refer to woodpeckers along the river (Vaughn et al. 2023).

The Kiamichi River valley was a north-south travel corridor for Native Americans, particularly Caddo. Archeological finds go back to 1200 BC, and over 220 pre-European settlement archeological sites have been identified. The river was first documented by French explorer Bernard de la Harpe in 1719. Naturalists Thomas Nuttall and Stephen H. Long both explored the river in the early 1800s. Starting in 1832, the valley was settled by the Choctaw tribe from Mississippi after they were displaced by the Indian Removal Act of 1830. In 1825, Fort Towson was established near the confluence with the Red River; the last confederate troops surrendered there in 1865. The population in the valley grew in the 1880s with the establishment of rail service, which also led to timber extraction. Most of the old growth forest in the area was harvested in the early 20th century (Vaughn et al. 2023).

The headwaters of the Kiamichi flow through the Upper Kiamichi River Wilderness, which is protected as part of the National Wilderness Preservation System. Lower portions of the river are largely unprotected. The river is influenced by two impoundments, mainstem Hugo Lake (impounded in 1974) and a tributary impoundment, Sardis Lake (impounded in 1983), which together are the water supply for people in 29 Oklahoma counties. Water availability to these reservoirs is predicted to decrease in the future because of increased drought and increased water demand from an increasing human population.

PHYSIOGRAPHY, CLIMATE, AND LAND USE

The headwaters of the Kiamichi originate in the Ouachita Province and flow through ridges formed by Mississippian and Pennsylvanian sandstones above subparallel shale valleys. The lower river lies within the Coastal Plain Province and is composed of unlithified, south-dipping Cretaceous sands, gravels, and clays (Johnson 2006).

Average annual air temperature is 17.4°C at Antlers, Oklahoma. Air temperature is lowest in January (5.4°C) and highest in July (27.8°C). Average annual precipitation is 118 cm/yr. Precipitation is greatest in

May (16 cm/mo) and lowest in August (7 cm/mo). However, temperature and precipitation can vary widely from year to year (Vaughn et al. 2023).

Currently, the basin is 64% forest, 18% pasture, 11% grassland/shrubland, 3% urban, 3% open water, and 1% wetlands (Castro et al. 2015). While most of the basin is temperate deciduous forest (primarily oak-hickory), there are several conifer plantation forests throughout. Before timber harvest began in the 1880s, the basin was 94% forest. Much of the upper basin is covered by a thin layer of relatively low fertility soils on stony mountain slopes, whereas the lower basin has deeper soils that can support agriculture (Hoagland 2006). In the lower basin, most agriculture production is focused on raising cattle and growing hay.

RIVER GEOMORPHOLOGY, HYDROLOGY, AND CHEMISTRY

The Kiamichi River is a 6th order river at its outflow, with irregular meanders originating at 480 m above sea level in the Ouachita Mountains of Oklahoma near the Arkansas border. The river flows 285 km to the Red River, meandering through three southeastern Oklahoma counties~~,~~; Le Flore, Pushmataha, and Choctaw. Much of the river is contained by a series of narrow valleys with steep, rocky slopes, ranging from 4 to 20-km wide (Rust et al. 2006). The river is classifed as a Rosgen F type stream and has a basin relief ratio (relief/length) of 0.00345. Meander wavelength increases significantly in the downstream direction, with decreased gradient, increased discharge, and a corresponding decrease in sediment size. Channel slope varies from 20 m/km in the headwaterss to 0.3 m/km near Hugo Lake. Above Hugo Lake, the river consists of long, clear pools and extended riffles with a benthic substrate of sand, gravel and large sandstone rocks. The major tributaries to the Kiamichi are Cedar, Pine, Gates, Anderson, Buck, Jackfork, Buffalo, and Tenmile Creeks. Jackfork Creek supplies ~25% of the inflow to the river.

Discharge is highly spatially and temporally variable in the river. Average annual discharge ranges from 2.4 m^3/s at Big Cedar (1965 to 2020) in the headwaters, to 29.2 m^3/s midway down the river near Clayton (1980 to 2020), to 43.8 m^3/s downstream at Antlers (1972 to 2020), with high interannual variability across the basin (109% at Big Cedar, 112 % at Clayton, and 117% at Antlers). Flow is typically highest in May (83.1 m^3/s the Antlers gauge with 75% variability) and lowest in August (7.7 m^3/s with 174% variability) (Vaughn et al. 2023). The high variability among years reflects the cyclical wet-dry periods typical of the southern plains (Stambaugh et al. 2011). For example, 2011 was a year of "exceptional drought" with mean discharge at the Antlers gauge of 29.2 m^3/s while 2015 was considered a 100-year flood with mean discharge of 99.4 m^3/s. These extreme wet and dry periods are predicted to become more frequent with climate warming in the southern plains (Vaughn et al. 2015). In addition, water management has exacerbated drought conditions in the lower river. Since the construction of Sardis Dam in 1983, lack of releases from the dam during hot, summer months has increased the magnitude and severity of hydrologic drought (defined as flows < 10th percentile) in downstream reaches. In the exceptional drought of 2011 and 2012, this led to drying of some portions of the lower river and water temperatures as high as 40ºC in shallow areas (Vaughn et al. 2015). Under these conditions, the river becomes a losing stream in summer months.

The Kiamichi is a clear upland stream in the headwaters and more turbid downstream. Nutrient concentrations are low, with total nitrogen averaging 0.46 mg/L and total phosphorus averaging < 0.042 mg/L. Conductivity averages 42 µS/cm and pH averages 7.24. Hardness (19 mg/L as $CaCO_3$) and total dissolved solids (29 mg/L) are low. Average annual water temperature is 19.4°C, with a range of 3.4°C to 34°C. Water quality data from the Oklahoma Water Resources Board from 1998- 2020 can be found on the National Water Quality Monitoring Council's Water Quality Portal (https://www.waterqualitydata.us/provider/STORET/OKWRB-STREAMS_WQX/OKWRB-STREAMS_WQX-410310010010-001AT/).

Biodiversity

The Kiamichi River flows through the Ouachita Mountains and South-Central Plains Level III terrestrial ecoregions. The Ouachita Mountains are an area of high hills and low mountains, containing sharply defined east-west trending ridges, formed through erosion of compressed sedimentary rock formations. Numerous high to moderate gradient perennial streams flow through the region. The South-Central Plains is an area of mostly rolling plains that are broken by nearly flat fluvial terraces, bottomlands, sandy low hills, and low cuestas. There is a high density of low to moderate gradient perennial streams. Differences in river gradients of the two ecoregions account for the high species diversity, particularly of fish and invertebrates. Differences in riverbed composition, ranging from fine to course materials, influences species diversity (Vaughn et al. 2023). Appendix 1 includes species lists for the Kiamichi River.

Plants and Plant Communities

The headwaters and upper mainstem of the Kiamichi are bordered by pine forest dominated by loblolly pine. Riparian species include sycamore, river birch, sweet gum, maples, oaks, and hazel alder. Middle and lower reaches of the river are bordered by bottomland forest dominated by water oaks, willow oaks, hickories, sweet gum, and black gum. These forests are tall, and the canopy can reach 30 m in height. Understory trees and shrubs include flowering dogwood, ironwood, spicebush, and buttonbush (Diamond and Elliott 2015).

Wetland plants can be classified as species that almost always occur in wetlands under natural conditions (obligate species), species that usually occur in wetlands, but that can occasionally be found in non-wetland areas (facultative wetland species), and species that are equally likely to occur in wetland and non-wetland areas (facultative species). The Kiamichi River watershed harbors 190 obligate wetland species, 212 facultative wetland species, and 209 facultative species (Table 6). While most of these species are globally common, some are rare in the state and of conservation interest including cypress-knee sedge (*Carex decomposita*), Oklahoma sedge (*Carex oklahomensis*), and largeleaf grass-of-parnassus (*Parnassia grandiflora*).

Small-headed pipewort (*Eriocaulon koernickianum*) is globally imperiled with one of its best populations in the Kiamichi watershed (Watson et al. 1994). American water willow (*Justicia americana*) forms extensive stands in gravel and sand bars throughout the river (Lopez et al. 2020).

Bottomland forests could be affected by altered stream flows. Viability of these forests are linked to periodic flooding during late winter and early spring months, which are critical for creating optimal moisture conditions for seed germination and seedling recruitment as well as mature tree growth (Fisher et al. 2005). Any significant alteration to the natural flow regime could also impact cypress swamps along the lower river. Bald cypress can tolerate prolonged flooding, but seed germination and establishment can only occur on exposed, saturated soils (Fisher et al. 2005).

Amphibians and Reptiles

The Kiamichi River watershed harbors a very rich collection of amphibians and reptiles. There are 16 species of salamanders, six toad species, 12 frog species, 12 aquatic turtle species, two terrestrial tortoise species, one alligator, 10 species of lizards, and 30 snake species known from the watershed. Frogs include crawfish frog, green frog, pickerel frog, southern leopard frog, bullfrog, and gray tree frog and toads include American toad, eastern narrowmouth toad, and Woodhouse's toad. Cottonmouths are very abundant as are diamondback and northern water snakes (Fisher et al. 2005).

Species considered Oklahoma Species of Concern include western lesser siren, three-toed amphiuma, ringed salamander, Ouachita dusky salamander, many-ribbed salamander, four-toed salamander, Kiamichi slimy salamander, Rich Mountain salamander, southern red-backed salamander, Hurter's spadefoot toad, southern crawfish frog, eastern spiny softshell turtle, midland smooth softshell turtle, western chicken turtle, alligator snapping turtle, Mississippi mud turtle, razon-backed musk turtle, Ouachita map turtle, Mississippi map turtle, eastern river cooter, American alligator, Gulf crayfish snake, milksnake, and western diamond-backed rattlesnake (Table 7).

Habitat loss is a significant factor in the decline of amphibians and reptiles. Water diversion and flow alteration 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 (Fisher et al. 2005). Frogs and salamanders that would likely be impacted by the loss of wetland habitat with altered flows include crawfish frog, green tree frog, and lesser siren (Fisher et al. 2005). Reptiles that would likely be impacted include American alligator, Graham's crayfish snake, Alligator snapping turtle, and chicken turtle (Fisher et al. 2005).

Birds

There are 265 species of birds that either reside in the Kiamichi River watershed or migrate through the watershed, including 43 Oklahoma Species of Concern (Table 8). Federal endangered species in the watershed include Red-cockaded woodpecker and Least tern. Common species that use the riparian areas include herons, egrets, ducks, coots, loons, gulls, and Belted kingfisher. Species of state concern that use or inhabit riparian areas include northern pintail, canvasback, yellow rail, little blue heron, snowy egret, bald eagle, wood stork, and least tern.

Fisher et al. (2005) discussed the impacts of altered flows in the river on bird communities in the riparian areas of the Kiamichi and Little rivers and suggested that species that prefer flooded areas could be severely impacted by loss of habitat due to low flows. For example, prothonotary warblers nest in cavities over standing water and Acadian flycatchers prefer to forage in open habitat of flooded forests. The bald cypress trees in the lower part of the river provide natural cavities for cavity-nesting birds such as wood duck, Carolina chickadee, and tufted titmouse. These birds could be impacted if changing hydroperiods lead to the replacement of bald cypress by mesic and upland tree species. Altered flows could also impact the food resources of fish-eating birds such as herons and ducks.

Mammals

There are 57 species of mammals known from the Kiamichi River watershed, including 18 Oklahoma Species of Concern (Table 9). Common species using the riparian area include beaver, muskrat, and reintroduced river otter. Ten bat species are of conservation concern, including the federally endangered Indiana myotis bat. Other species of concern include long-tailed weasel, gray fox, eastern spotted skunk, southern flying squirrel, golden mouse, and Texas rice rat.

Bats relay on river corridors for foraging on aerial insects, and thus could be impacted by changes in riparian areas brought about by altered flow regimes. Changing flows could impact fish food resources for otter. Golden mouse live in riparian forests and Texas rice rates inhabit wetlands. Both of these species could be potentially impacted by altered flow regimes (Fisher et al. 2005).

Algae and Cyanobacteria

Eighty-five genera of algae and cyanobacteria (blue-green algae) have been documented in the river (Atkinson and Cooper 2016; Wilhm et al. 1979) (Table 10). Common genera include *Gomphonema, Navicula, Scenedesmus, Oscillatoria, Achnanthidium, Anabaena, Nitzchia, Eunotia, Melosira, Aulacoseira* and *Lyngbya*. Algal community composition is governed primarily by light penetration and conductivity (Atkinson and Cooper 2016).

Freshwater mussels influence the composition of algae communities in the river. Mussels supply nutrients that stimulate primary production by algae. A collaborative project between the University of Oklahoma and the EPA's Office of Research and Development documented that river sites without mussels were nitrogen limited with ~26% higher relative abundances of nitrogen-fixing cyanobacteria, while sites with high mussel densities were co-limited by both nitrogen and phosphorus and dominated by diatoms. Cyanobacteria are known for forming toxic algae blooms, while diatoms are a high-quality food for stream insects (Atkinson et al. 2013a; Atkinson et al. 2013b).

Aquatic Invertebrates (excluding freshwater mussels)

The Ouachita Mountains, including the upper Kiamichi basin, are a center of speciation for both aquatic and terrestrial species and contain many endemic species (Mayden 1985). Nonetheless, only a few invertebrate taxonomic groups have been well studied. Common caddisflies include several genera each of Hydropsychidae, Hydroptilidae, and Leptoceridae (Galbraith et al. 2008b). Caddisfly assemblages are influenced equally by regional factors such as average discharge, land use, and disturbance and local habitat variables (Galbraith et al. 2008b). Baumgardner and Kennedy (1999) documented 56 species of mayflies in 11 families and 29 genera in the basin (Table 11). The greatest diversity occurs in the family Baetidae, followed by Heptageniidae, Leptophlebiidae, and Caenidae. *Haprophlebiodes annulata* is an endemic member of the Leptophlebiidae. Dobsonflies in the genus *Corydalus* are common, as are riffle beetles. At least 25 species of Chironomidae occur in the river (Wilhm et al. 1979). Seventy-four species of odonates have been identified from the basin (Table 12). The highly endemic Kiamichi crayfish occurs in the upper 45 km of the Kiamichi (Jones 2004; Jones and Bergey 2007). Other crayfish species that occur in the river and are endemic to the Ouachita region are the Mena crayfish and Little River Creek Crayfish, and Ouachita Mountain Crayfish (Table 13) (Morehouse and Tobler 2013).

Freshwater Mussels

Freshwater mussels, bivalve mollusks in the order Unionoida, are sedentary, burrowing, filter feeders (Vaughn and Hakenkamp 2001). Mussels are one of the world's most imperiled faunas, largely because their life history traits make them highly vulnerable to environmental change (Haag and Williams 2014) and are experiencing both species losses and significant declines in abundance of even common species globally (Ferreira-Rodriguez et al. 2019; Hornbach et al. 2018).

Mussels are foundational, ecosystem engineers in rivers and lakes globally and their biomass can exceed that of other benthic organisms by an order of magnitude (Vaughn and Hoellein 2018). Mussels spend their adult life in dense (up to 100 ind/m^2), multi-species aggregations called mussel beds that are patchily distributed in rivers (Atkinson and Vaughn 2015; Haag 2012). Mussel beds typically occur in areas that are protected from high flows and subsequent shear stress during flood events, but that maintain enough flow for adequate oxygen and food delivery at base flows (Strayer 2008; Vaughn 2005).

Mussels have a complex life history where their larvae (glochidia) are obligate ectoparasites on the fins or gills of fish (Vaughn 2012). Glochidia metamorphose into juveniles that excyst from the host and sink to the bottom, where they grow into adults. Adult mussels are highly sedentary; they move very slowly and only short distances if they move at all (Allen and Vaughn 2009; Nickerson et al. 2019). Thus, mussels depend on fish for development and dispersal, and factors than impact host fish also impact mussels. Mussels vary in the type and number of fish hosts used, the mechanism employed in infecting the fish host(s), and the timing of glochidial development and release (Barnhart et al. 2008). This variation has consequences for dispersal ability and mussel population dynamics, and the distribution and abundance of mussels can be strongly influenced by the composition of the co-occurring fish community (Vaughn 2012; Vaughn and Taylor 2000).

Mussel species exhibit a range of life spans (6 – 60 years) but are very long-lived compared to many aquatic organisms and most species don't become sexually mature until around age 6 or older. Although fecundity is high, survival from the larval stage to adulthood is low. Disturbances that affect larvae or juveniles can lead to the loss of entire year classes or populations. Thus, mussel populations are very slow to recover from population declines. Mussels are particularly sensitive to changes in flow regimes because of their unusual life history and habitat needs. Increases in the magnitude of high flows can prevent juveniles from setting in new habitat or dislodge newly settled juveniles. Increases in flow magnitude can also create sediment scour that interferes with mussel feeding, reproduction and survival. In contrast, low flows in summer can lead to high water temperatures that are lethal to mussels or compress habitat and prevent fish hosts from being present at the proper time to carry larvae (Gates et al. 2015b). Optimum flows for mussels maintain habitat continuously for juveniles and adults and seasonally for fish hosts (Gates et al. 2015b).

The Kiamichi River is home to a diverse fauna of 31 mussel species (Table 14) (Galbraith et al. 2008a; Vaughn et al. 1996) which represents ~56% of the Oklahoma mussel fauna. The location of most mussel beds in the river have been mapped and their species composition and abundance documented (Atkinson and Vaughn 2015)(Figure 1). Unlike many North American rivers, there are no known species extirpations of mussels from the river, although abundance has declined substantially (discussed below). Common species include the threeridge, mucket, pimpleback, and Wabash Pigtoe.

The Kiamichi harbors two federally listed endangered mussel species and the presence of a third endangered species requires more research. The Kiamichi contains the most substantial population of the Ouachita rock-pocketbook (*Arcidens* (*Arkansia*) *wheeleri*) of the five streams where it has been found (Galbraith et al. 2008a; Vaughn and Pyron 1995; Vaughn et al. 1993). Of these locations, 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 & 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 ind/m^2. The youngest individual *A. wheeleri* encountered was approximately 12 years of age, indicating that recruitment is low (Vaughn and Pyron 1995). Galbraith et al. (2005, 2008a) resurveyed the Kiamichi River from 2003 – 2005. They were unable to locate *A. wheeleri* individuals at any of the 1990s monitoring sites but did find three individuals at a site near Moyers, just upstream from where Oklahoma City plans to withdraw water from the river.

The river also harbors a small population of Scaleshell (*Leptodea leptodon*) (Galbraith et al. 2008a). The scaleshell was historically distributed throughout much of the Interior Basin but has been extirpated from much of its range (Natureserve 2021). 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 (Galbraith et al. 2005; Galbraith et al. 2008a)

Some unusual morphs of the mapleleaf (*Quadrula quadrula*) may have been misidentified in early surveys and may actually be the endangered winged Mapleleaf (*Quadrula fragosa).* The winged mapleleaf historically occurred in the Interior Basin from Minnesota to Alabama. Currently, the best population is in the St. Croix River in Wisconsin. A population of this species was discovered in the Little River in the 2000s (Allen and Vaughn 2008; Galbraith et al. 2008a), and recent work has shown that the species occurs at multiple locations in that river (Vaughn et al. 2017). Specimens now believed to be *Q. fragosa* have been observed in the Kiamichi River, but 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.

The Kiamichi River has been a focal river globally for the study of ecosystem processes and services provided by freshwater mussels. Mussel beds in the Kiamichi are speciose with high biomass and act as biogeochemical hotspots (Atkinson and Vaughn 2015). Mussels filter the water and excrete and biodeposit nutrients (Atkinson et al. 2013b; Vaughn 2018), fertilizing algae and increase the production of macroinvertebrates, which are important food for fish (Spooner and Vaughn 2006; Vaughn and Spooner 2006). Mussel shells provide habitat for macroinvertebrates and fish (Hopper et al. 2019; Spooner and Vaughn 2006). Sansom et al. (2017) found that a higher proportion of nest-building fish associated with mussel beds compared to non-mussel areas in the Kiamichi River. In a study using remote underwater video within a Kiamichi stream reach, Hopper et al. (2019) detected more fish in areas with live mussels or mussel shells than in areas with sediment alone. Mussel soft tissue and shells provide long-term nutrient storage, which in turn alters nutrient limitation (Atkinson and Vaughn 2015). Experimental work shows that mussel excretion can account for 40 to 74% of nitrogen demand in small rivers (Atkinson et al. 2014b). Mussel die-offs from droughts result in large nutrient pulses, which can lead to negative effects such as cyanobacterial blooms (DuBose et al. 2019). Ecosystem effects of freshwater mussels are summarized in Vaughn (2018) and Vaughn and Hoellein (2018).

Kiamichi River mussel declines, drought, and water management

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 that river in the 2000s (Vaughn and Spooner 2004). The mussel fauna of the Kiamichi River has been documented for over 100 years. It was first described by Frederick Isely who conducted a comprehensive distributional survey of the mussel fauna of the Red River drainage in 1910-12, 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 1924). Later sampling was done by Valentine as part of class collecting trips from the University of Oklahoma Biological Station (Valentine and Stansbery 1971). The river was harvested for commercial shell in the 1960s and 1970s. 2,020 pounds of mussels were harvested from the river in 1967 (Mensinger 1972). Extensive surveys of the mussels in the river have been conducted by Caryn Vaughn and her students at the University of Oklahoma, beginning in 1990 and continuing to the present (Atkinson et al. 2012; Atkinson et al. 2014a; Galbraith et al. 2005; Galbraith et al. 2008a; Gates et al. 2015a; Vaughn et al. 2015; Vaughn et al. 1996; Vaughn and Pyron 1995; Vaughn et al. 1993).

Over the past 30 years, overall abundance of mussels in the Kiamichi River has declined ~60% and species composition has changed. These changes seem to be linked to very low summer flows and accompanying high water temperatures during periods of severe drought, which have been exacerbated by human water management (Atkinson et al. 2014a; Galbraith et al. 2010; Spooner and Vaughn 2000; Vaughn et al. 2015)

Mussels are very sensitive to changes in flow regimes and temperature (Galbraith et al. 2012; Randklev et al. 2019; Spooner et al. 2011; Strayer et al. 2004). Because adult mussels are sedentary and move very slowly, they cannot move to a new habitat, such as the bottom of a pool when flows are inappropriate. Mussels are thermoconformers whose physiological processes are constrained by water temperature. Mussel species metabolic rates and body condition vary across a range of optimal natural temperatures (Spooner and Vaughn 2008). In the Kiamichi River, mussel species can generally be placed into two thermal guilds that tend to follow phylogeny: thermally tolerant species filter and respire at a broader range of temperatures than thermally sensitive species that are stressed at warm temperatures (Table 15)(Atkinson et al. 2018; Spooner and Vaughn 2008).

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 (Galbraith et al. 2010; Vaughn and Julian 2013), and leading to high water temperatures. Jackfork Creek, a tributary of the Kiamichi, flows into the river approximately halfway down its length (Figure 3A). Jackfork Creek is impounded by Sardis Reservoir. This creek is the largest tributary of the Kiamichi, contributing ~25% of the average river flows at the confluence of the two streams (Vaughn and Julian 2013). The lower segment of the river (measured by the gage at Antlers) was a perennial river most years before 1983 when Sardis Dam was completed. The average length of severe hydrologic droughts for the Kiamichi Basin is 27 days. Construction of the dam was followed by two relatively wet decades, and there were only 75 no-flow days during this period. Several droughts occurred between 2004-2011. During this 7-year period, the river had 249 days of zero-dischage at the Antlers gage. This exceeded the previous number of no-flow days for the past 37 years by 9 days. On 221 of these 249 no-flow days, there were no releases from Sardis Dam. During this same 7-year period, severe hydrologic drought (flow < 10th percentile) became more frequent in the lower river below Sardis Dam (annual mean of 65 days) than the upper river above Sardis Dam (annual mean of 56 days). The lack of releases from Sardis Dam during droughts increased the magnitude and fequency of hydrologic drought in the lower river. This intensive hydrologic drought during hot summer months led to patchy drying of the lower river and high water temperatures. Water temperatures sometimes exceeded 40°C because of high air temperatures and very shallow water (Vaughn et al. 2015; Vaughn and Julian 2013).

In summer 2000, Spooner and Vaughn (2000) monitored the effect of extremely low water levels on a mussel assemblage in the lower Kiamichi near Moyers for which they had two previous years of population data; at this particular site, there was no flow and water temperature during the 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 Engineers 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.

Galbraith et al. (2010) compared mussel abundance and species richness in the Kiamichi, between 1990-1992 and 2003-2005, across ten monitoring sites. Mussel communities in the river changed over the 15-year period of this study, with overall densities and species richness decreasing and community structure shifting from assemblages dominated by thermally sensitive to thermally tolerant species. High summer water temperatures led to higher mortality rates of thermally sensitive compared to tolerant species. Vaughn et al. (2015) compared these data with sites sampled in 2011, and found that mussel populations in the river continued to decline.

During the 2011 drought, Vaughn et al. (2015) conducted extensive sampling at a large mussel bed on the lower river near Dunbar that had also been sampled in previous decades. This mussel bed contains both a deeper pool and shallower riffle area. In late July 2011-12, the upper pool portion of this mussel bed was covered by water depths of 30-to-100 cm, with midday water temperatures < 30°C. In contrast the portion of the riffle that still had water covering it was extremely shallow with hot water temperatures. On July 31, 2011 the average depth in the riffle was 10 cm and the midday temperature was 40°C, well above the thermal tolerances for both juvenile and adult mussels (Pandolfo et al. 2010, Galbraith et al. 2012). In past surveys mussel densities in the pool and riffle/run portion of this site had been approximately equal (Vaughn and Pyron 1995), however in 2011-12 live mussel densities in the pool were approximately 12 times higher than in the shallower riffle. In the riffle, freshly dead mussels (tissue still attached) were twice as abundant in quadrats as live mussels. In the completely dry lower riffle, 19 species of freshly dead mussels were recorded (Vaughn et al. 2015).

In response to the observed mussel mortality in 2011, Vaughn contacted the U.S. Fish and Wildlife Service and they requested that releases be made from Sardis Dam to protect endangered mussel species in the river. A managed daily water release of 0.59 cms (21 cfs) from Sardis Dam beginning on August 2, 2011 did not increase discharge at the Antlers site until August 27, 2011 (25 days later). The likely reason for this lack of conveyance is that the water table was considerably lower than the stream bed at the end of July 2011, and thus all water released by Sardis Dam was quickly lost to the subsurface until the local water table rose high enough to intersect the channel bed, which occurred on August 27, 2011. There were three small rainfall events (> 1 cm) during this period that also helped to raise the water table. These data indicate that the Kiamichi River is a losing stream (i.e., discharge is lost to the subsurface due to the water table being lower than the stream bed) during extended periods of drought, particularly when 25% of its watershed runoff is held behind Sardis Dam without daily releases (Vaughn et al. 2015; Vaughn and Julian 2013).

Allen et al. (2013) compared mussel outcomes between the Kiamichi River and the adjacent Little River during the droughts described above. During a 13-year period, water releases into the Kiamichi River from Sardis Reservoir were halted during droughts~~,~~ while minimum releases from Pine Creek Reservoir were maintained in the Little River. Consequently, the Kiamichi River observed nearly twice as many low-flow events known to cause mussel mortality than the Little River, and regression tree analyses suggest that this difference was influenced by reduced releases. During this period mussel communities in the Kiamichi declined in species richness and abundance, changes that were not observed in the Little River. These results suggest that reduced releases during droughts likely led to mussel declines in the Kiamichi River, while maintaining reservoir releases likely sustained mussel populations in the Little River.

These mussel declines have consequences for river health and ecosystem services. Vaughn et al. (2015) asked how observed changes in mussel biomass and community composition resulting from drought-induced changes in flow regimes might lead to changes in river ecosystem services between 1991 – 2012. They used data on mussel declines discussed above. They combined these data with laboratory-derived physiological rates and river-wide estimates of species-specific mussel biomass to estimate three aggregate ecosystem services provided by mussels over this time period: biofiltration, nutrient recycling (nitrogen and phosphorus), and nutrient storage (nitrogen, phosphorus, and carbon). Mussel populations declined over 60%, and declines were directly linked to drought-induced changes in flow regimes. All ecosystem services declined over time and mirrored biomass losses.

Once mussels die it may take decades for populations to recover and provide lost ecosystem services, assuming flows are maintained in the river (DuBose et al. 2019). Mussels have very long life spans (up to 60 years), don’t reach reproductive maturity until around age 6, and often don’t reproduce every year. In mussel beds hard hit by the 2011-12 drought, it will likely take decades to achieve enough mussel biomass to restore ecosystem services.

Environmental flows for freshwater mussels

Establishing environmental flows that safeguard mussel populations will protect the endangered mussel species and hopefully prevent future litigation related to these species. In addition, because mussels provided important habitat and other services for other river organisms such as insects and fish, protecting mussels also protects these other groups (Vaughn 2018).

Most environmental flows have been developed for fish and other mobile organisms, and don’t work well for the mixed sedentary and mobile life histories of mussels. Mussels are adapted to a flow regime that maintains wetted habitat for the sedentary adults and host fish, but also buffers water quality and provides adequate food replenishment. Mussels are particularly sensitive to releases from impoundments that differ from the natural flow regime in their timing, magnitude, duration, and rate of change. Increases in the magnitude of high flows can prevent juvenile mussels from settling after they excyst from the host fish or dislodge newly settled juveniles. Increases in flow magnitude can also create sediment scour that interferes with mussel feeding and reproduction. Variation in the timing of low and high flows can expose mussels to altered temperature regimes or prevent encounters between mussels and their host fish (Gates et al. 2015b). Thus, optimum flows for mussels should maintain habitat continuously for juvenile and adult mussels, and seasonally for host fish.

Jones and Fisher (2005) “mapped and modeled instream flow habitat for mussels, including endangered species” in the Kiamichi River to make recommendations concerning water withdrawals from the river. They used the PHABSIM module of IFIM, a technique normally used for mobile organisms such as fish, to develop hydraulic models for each site. They recommended that when when the discharge at the USGS gage at Clayton minus releases from Sardis Reservoir is < 50 cfs, water withdrawals should be halted. This study is problematic for several reasons. First, in their analysis they used ten monitoring sites (mussel beds) established by Vaughn in 1990 to monitor the population of *Arcidens (Arkansia*) *wheeleri* in the river. These mussel beds are well-established, large, and species-rich and in areas most protected from changes in flow (several are atypically deep) and thus not necessarily representative of the many mussel beds in the river (Atkinson and Vaughn 2015)(Figure 1). The recommended flows are based on mussel bed emersion, or whether or not mussels will be covered with water. As detailed in the above section, during summer when flows are low and air temperatures high, mussels will begin to suffer mortality long before they become exposed to air and desiccation. Second, they recommended that releases from Sardis Lake should mimic “the historic, natural flow regime”. Natural flow regimes assume a naturally functioning river, which is no longer the case in the Kiamichi because of impoundment. In the past when droughts occurred and there was mussel mortality the river could be recolonized from host fish in the Red River system. This is no longer possible because of Hugo Dam. Mussel populations in the Kiamichi River above Hugo Dam are isolated , and post-drought recovery can only come from within this reach of the river. Finally, as also detailed in the above section, the Kiamichi River between Clayton and Antlers is a losing stream in summer during drought, thus 50 cfs releases at Clayton don’t guarantee that amount of water lower in the river.

Mussels vary in their biological traits, such as adult size, thermal tolerance, and reproductive characteristics, that can influence how they respond to changes in flow regimes. These traits can be used to help inform discussions of environmental flow needs (Gates et al. 2015b). Important traits for mussel species from the Kiamichi River are listed in Table 15 and were compiled from Haag (2012) Spooner and Vaughn (2008), and Vaughn (2012). Adult size is important because smaller species have higher metabolic rates and can be more thermally sensitive, and they are also more likely to be predated at low flows. Thermally tolerant species are more likely to survive higher water temperatures. Mussels have different strategies for infecting fish with their larvae, ranging from broadcasting free glochidia to elaborate mantle lures. Glochidia are generally bound by mucus into packets that dissolve releasing glochidia or remain intact as “conglutinates” that can mimic the structure and color pattern of a favored prey item of the host, such as insect larvae. When the fish bites into the conglutinate, glochidia are released and carried on to the fish gills by respiratory currents. Mantle lures, found in the Lampsilini, are pigmented modifications of mantle that mimic prey items (i.e., fish) of predacious fish (Vaughn 2012). Short-term brooders retain glochidia in the gills only until they reach maturity. They usually produce gametes in the spring and release glochidia in late spring or summer. Long-term brooders continue to brood their glochidia after they become infectious. They typically spawn in late summer, brood glochidia over the winter, and release them in late spring (Vaughn 2012). Following Haag (2012), opportunistic species have shorter life spans, early maturity, and high fecundity which would allow populations to recover more rapidly from flow-related disturbances. Equilibrium species have long lifespans, later maturity, and generally low fecundity, but also have high adult survival and are more resistant to disturbance. Periodic species have lifespans and reproductive traits that are intermediate to the other two strategies.

Vaughn et al. (2014) and Gates et al. (2015b) evaluated the environmental flow requirements for mussels in the Kiamichi River. They suggested that environmental flow models for mussels include habitat permanence for existing mussel beds, optimal shear stress, appropriate water quality (temperature, dissolved oxygen, and ammonia), and promote overlap with fish hosts during appropriate seasons to ensure connectivity between mussel beds. They suggested that the threat of extreme temperature exposure could be mitigated by focusing on water quality during the warmest and lowest flow-months of the year and setting temperature and dissolved oxygen criteria for the most thermally sensitive mussel guild. To encourage successful reproduction and recruitment, mussels can be separated into guilds based on reproductive cycles (as described above) that can be used to assess temporal flow needs. They further recommended monitoring existing mussel beds in the region while environmental flow criteria are being developed. Monitoring existing beds will reduce uncertainties regarding how mussels respond to changing flow conditions and will also allow for an adaptive management approach for managing the federally listed species. They suggested that minimum instream flows can be based on discharge-rating temperature models developed for the Oklahoma Water Resources Research Institute by (Vaughn and Julian 2013). These models use air temperature and water depth to predict water temperature, which allows managers to determine how much water to release to keep water temperature below a certain threshold during summer low flow periods. They recommended that at the bare minimum, maximum water temperatures be kept below 35°C, which is the temperature at which almost all juvenile mussels and many adult mussels start to die (Archambault et al. 2014; Galbraith et al. 2012; Ganser et al. 2015; Khan et al. 2019; Pandolfo et al. 2009; Pandolfo et al. 2010). They recommended that during droughts, enough water should be released from Sardis Dam to maintain flow at both the Clayton and Antlers gages, as the reach between these two gages is critical mussel habitat with two federally listed endangered species (*Arcidens wheeleri* and *Leptodea leptodon*).

Environmental flow recommendations should take into account that climate change will alter stream flows and temperatures in the future. Ertrand and McPherson (2019) used statistical down-scaling of global climate model outputs to create estimates of air temperature and precipitation in the Red River basin for 2010 - 2099 for nine climate scenarios based on three general circulation models and three representative concentration pathways. Fovargue et al. (2020) used these downscaled estimates in a hydrologic model to predict future stream flows and temperatures in rivers across the region, and subsequently predicted lengths of future droughts and heat stress events that mussels might experience. For example, projections from downscaled climate model GCM CCCSM4, RCP 8.5 indicate that severe drought will increase from roughly every five years to roughly every two years and will last 5.7 days rather than 4.5 days in the Kiamichi River, resulting in increased water temperatures and longer periods in which mussels are thermally stressed.

FISH

The Kiamichi River watershed is home to a diverse fish fauna that has been well documented, beginning with a survey by Meek in 1894 (Meek 1896). In the 1920s, expeditions by Ortenburger documented fish species at several tributary sites and in the mainstem river (Hubbs and Ortenburger 1929; Ortenburger and Hubbs 1926). Pigg and Hill (1974) collected fish from 90 sites in the watershed and compiled information from previous studies. Echelle and Schnell (1976) examined abundance patterns among 48 fish species in the river. Tejan and Fisher (2001) compiled fish collection information from various sources into a database (Oklahoma Streams Information System, OSIS).

There are 100 species that have been reported from the watershed (W.J. Matthews, personal communication, Table 16) including 32 minnows, 11 suckers, seven catfish, 13 sunfish, and 17 darters. Abundant species include orangebelly darter, dusky darter, highland stoneroller, bigeye shiner, redfin shiner, rocky shiner, steelcolor shiner, spotted sucker, smallmouth bass, spotted bass, largemouth bass, blackstriped topminnow, red shiner, gizzard shad, gars, and river carpsucker (Tables 16 – 18)(Matthews et al. 2016; Porter and Patton 2015). Non-native species include common carp, threadfin shad, and striped bass in the lower river (Matthews et al. 2016).

Many of the species known from the watershed are quite rare, although no extirpations of species from the watershed have been documented and there are no federally listed species. However, it's likely that the peppered shiner is now extirpated as it has not been collected in many years despite intensive sampling effort (W.J. Matthews, personal communication). Species designated by the Oklahoma Department of Wildlife Conservation as Oklahoma Species of Concern in category C-II include crystal darter, Kiamichi shiner, blue sucker, mooneye, pallid shiner, cypress minnow, harlequin darter, ribbon shiner, river darter and black buffalo (Table 16). Other rare species include blackspot shiner, paddlefish, silverband shiner, river redhorse, and lamprey (Matthews et al. 2016; Porter and Patton 2015). Brewer (2018) commonly observed blue suckers in the Hugo dam tailwaters. Based on their 2014 – 16 surveys, Matthews et al. (2016) stated that blackspot shiner are apparently secure in the watershed. They found Kiamichi shiner at numerous locations but thought populations of this species were less secure because of localized headwater occurrences. Pallid shiner was only found once in the survey and should be considered scarce.

Fish assemblages in the river have changed very little over the last few decades, and fish that were present before dams were built are largely still there (Matthews and Marsh-Matthews 2015). Matthews et al. (1988) found that the rank order of fish abundance was stable across 5 years in the 1980s in the river. Fisher et al. (2005) compared species richness between collections made in 1969-73 and 1996 for 8 sites in the river before and after the construction of impoundments and found no difference in the number of fluvial specialist species. In contrast, Pyron et al. (1998) collected fish from 12 sites in the river in 1992 and compared this date with previous surveys in 1972. They found that species richness was higher prior to reservoir construction and that sites further from the Sardis reservoir outflow were more similar in composition over time than sites closer to the outflow. Matthews et al. (2016) compared fish collections from six mainstem sites in the 1980s with new collections in 2014. Overall, species' abundances were similar between the two time periods with low coefficients of variation (Table 19). Bigeye shiner was the most common species collected at these sites in both time periods, followed by steelcolor shiner and redfin shiner. An exception was the rocky shiner, which increased over ten-fold in abundance during this time.

Fish traits and environmental flow needs

Most stream fishes are adapted to the natural flow regimes in the systems where they evolved (Lytle and Poff 2004). Fish have biological traits, including habitat preferences, dietary preferences, life history characteristics, and physiological traits such as thermal optima, that underly their survival, growth, and reproduction (Tonkin et al. 2019). When stream conditions, such as flow and temperature, deviate in magnitude, duration or frequency from what is typical under the natural flow regime, fish may not be able to adapt these new conditions. Fish traits can be used to predict how individual species or groups with similar traits (guilds) might respond to environmental changes related to the planned water withdrawals (Mims and Olden 2012; Mims and Olden 2013). This report presents comprehensive information on the traits of fish species in the Kiamichi River to inform discussions of environmental flow needs for these species. Information on fish habitat and habits (Table 20), feeding traits (Table 21), and life history traits (Table 22) was compiled from Fisher et al. (2005), Miller and

Robison (2004), Robison and Buchanan (1988) and Natureserve (2021). Available data on fish thermal tolerances (Table 23) are from Brewer et al. (2019).

Fish species in the Kiamichi River vary widely in their habitat needs and habits, ranging from species that rely on riffles, to pool dwellers, to those that live over mud and detritus at the stream margins (Table 20). However, most species can be generally classified as either fluvial specialists that need flowing water at some life stage or generalists that can inhabit flowing or standing water (Fisher et al. 2005)(Table 20). Many of the fish species that inhabit the reach of the Kiamichi river that could be impacted by water withdrawals are fluvial specialists, including 16 minnow species, one madtom, and six darter species, paddlefish, and blue sucker (Fisher et al. 2005). 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 flow (Fisher et al. 2005). Low water levels in summer can compress fish habitat and make species such as minnows more vulnerable to predation.

Fish species in the Kiamichi River also vary in their feeding behavior and diets (Table 20) and life history traits (Table 22), including when and where fish spawn. Spawning is often cued by particular water temperatures, light levels, flow events or a combination. When these factors are altered, fish may not reproduce successfully. For example, large, wide ranging river species such as catfish, paddlefish and gar are spring spawners that respond to cues for temperature and rising water levels (Blann et al., 2017)(Table 22). Suckers and redhorses require connectivity in the spring between overwintering habitats and upstream riffles where they spawn. Gar will also move upstream to spawn in riffles of tributary streams, thus connectivity is likely important for them as well. Nest building species such as bass and stoneroller minnows are sensitive to flow changes during spring and summer nesting.

As described above in the mussels section, low water levels in the Kiamichi River in the summer can lead to very high water temperatures. These temperatures can affect fish performance and lead to mortality. Critical thermal maxima are a measure of species' upper temperature tolerance. Alexander (2017) and Brewer et al. (2019) determined the critical thermal maxima (CTMax) for 14 fish species from the Kiamichi River (Table 23). These ranged from a low of 32.5˚C for the Kiamichi shiner (*Notropis ortenburgeri*) to a high of 38.28˚C for the blackspotted topminnow (*Fundulus olivaceus*). These temperatures are frequently exceeded in shallow water habitats in the Kiamichi River during drought summers (Vaughn and Julian 2013).

Brewer et al. (2019) developed a Water Quality Analysis Simulation Program model to predict downstream temperature conditions in response releases from Sardis Reservoir that corresponded to 0.00 (control), 0.34, 0.59, 0.76, 1.13, and 1.5 m^3/s and water release temperatures of 27.64, 26.00, and 24.07˚C (average reservoir temperatures at gate locations on the dam). They then compared the predicted water temperature time series with the CTMax of benthic and mid-column fishes to quantify the cumulative time fish experienced severe thermal stress downstream of Sardis Reservoir during the summer baseflow period. The control of no releases resulted in 130 hours of thermal stress for benthic species and 73 hours of thermal stress for mid-column species. As expected, thermal relief increased with increasing release magnitude and decreasing release water temperature. The 0.034 m^3/s release reduced thermal stress by 8-12% for benthic species and 11-18% for mid-column species, with and effective distance of 1 – 2 km for both guilds. The 0.59 m^3/s releases reduced stress by 12-20% for benthic fishes and 18-25% for mid-column species, with effective distances of 2 – 7 km and 4 – 8 km, respectively. Three releases represented pre-dam flow magnitudes – 0.76, 1.13, and 1.50 m^3/s. These releases reduced thermal stress up to 41% for benthic fishes and 46% for mid-column fishes. This study shows that managed reservoir releases could be used to alleviate thermal stress to fish in the river during the summer.

Environmental flow recommendations for fish should take into account that climate change will alter stream flows and temperatures in the future. Bertrand and McPherson (2019) used statistical down-scaling of global climate model outputs to create estimates of air temperature and precipitation in the Red River basin for 2010 - 2099 for nine climate scenarios based on three general circulation models and 3 representative concentration pathways. Gill et al. (2020) used these estimates and species distribution models to predict the future distribution of fishes in the Red River basin, including the Kiamichi River. They concluded that the range extent of most species will contract over the new few decades with increasing mean summer air temperature as an important driver of this phenomenon.

Social and Cultural Aspects of Environmental Flows in the Kiamichi Basin

Multiple recent studies have examined socio-cultural and socio-economic perceptions of water availability in the region in response to the conflicting water demands on the river (Castro et al. 2018). Castro et al. (2015, 2016b) used face-to-face surveys to assess the perceptions of different stakeholder groups (e.g., Kiamichi watershed residents, those with businesses in the watershed, tourists, Oklahoma City residents) to ecosystem services provided by the river. They found that habitat for species and water regulation were services that most stakeholders thought were important (Castro et al. 2016b). People residing in the watershed were willing to pay more for ecosystem services than Oklahoma City residents benefitting from the water (Castro et al. 2016a). Burch et al. (2020) followed up on the work by Castro and others and found that the results were upheld. Overall, Oklahoma City residents are not aware of where their water is coming from (or will be) and are not interested in paying to protect ecosystem services.

Wineland et al. (2021) surveyed water and natural resource managers in the Red River basin in Oklahoma about implementing environmental flows in the region. They found that decision makers could be placed into two groups. One group was pessimistic~~:~~ in that they believed that current flow conditions are inadequate, there are socio-political barriers to implementing e-flows, water conflicts will likely increase in the future, and climate change is likely to exacerbate these issues. The other group was more optimistic~~;~~ for they foresaw fewer future water conflicts and fewer socio-political barriers to implementing e-flows.

Fish in the Kiamichi River are contaminated with mercury. Tweedy (2017) sampled fish at ten sites in the river and found elevated levels of mercury across taxa including large smallmouth bass with concentrations (2986 ±1053 ng/g) above the Environmental Protection Agency (EPA) limit. Furthermore, he observed high concentrations in darters and logperch (1133 ±464 ng/g). Because people in the watershed eat bass and other sportfish, this could pose a hazard to human health. Ferreira-Rodriguez et al. (2020) conducted surveys exploring human fish consumption habits and perceived risks in the watershed. They found that although many people in the local population were aware of the risks of eating contaminated fish, only women of reproductive age were willing to adopt safe consumption habits.

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Appendix 1. Plant and Animal Species Tables in Kiamichi River Basin

Table 6. Wetland plant species known from the Kiamichi River watershed based on records from the Oklahoma Biodiversity Information System (2021). Obligate wetland species almost always occur in wetlands under natural conditions, facultative wetland species usually occur in wetlands but can occasionally be found in non-wetland areas, and facultative species are equally likely to occur in wetlands and non-wetlands. Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. SNR – conservation status not assessed.

Species	**Habitat**	**State rank**	**Global rank**
Alisma subcordatum	Obligate wetland		G5
Alnus serrulata	Obligate wetland		G5
Alternanthera paronychioides	Obligate wetland		G5
Ammannia auriculata	Obligate wetland		G5
Ammannia coccinea	Obligate wetland		G5
Ammannia robusta	Obligate wetland		G5
Asclepias incarnata	Obligate wetland		G5
Azolla microphylla	Obligate wetland	SNR	G5
Bacopa rotundifolia	Obligate wetland		G5
Bartonia paniculata	Obligate wetland		G5
Brasenia schreberi	Obligate wetland	S4	G5
Burmannia capitata	Obligate wetland	SH	G5
Cabomba caroliniana	Obligate wetland	SH	G5
Callitriche heterophylla	Obligate wetland		G5
Cardamine bulbosa	Obligate wetland		G5
Cardamine pensylvanica	Obligate wetland		G5
Carex alata	Obligate wetland		G5
Carex crinita	Obligate wetland		G5
Carex crus-corvi	Obligate wetland		G5
Carex decomposita	Obligate wetland	S1	G3G4
Carex emoryi	Obligate wetland		G5
Carex frankii	Obligate wetland		G5
Carex gigantea	Obligate wetland	S1	G4
Carex hyalinolepis	Obligate wetland		G4G5
Carex leptalea	Obligate wetland	S1	G5
Carex louisianica	Obligate wetland		G5
Carex lupulina	Obligate wetland		G5
Carex lurida	Obligate wetland		G5
Carex oklahomensis	Obligate wetland	S2	G4
Carex ozarkana	Obligate wetland		G4
Carex stricta	Obligate wetland	SU	G5
Carex vulpinoidea	Obligate wetland		G5
Carya aquatica	Obligate wetland	S1	G5
Cephalanthus occidentalis	Obligate wetland		G5
Ceratophyllum demersum	Obligate wetland		G5
Cicuta maculata	Obligate wetland		G5

Cirsium muticum	Obligate wetland	S1	G5
Crataegus brachyacantha	Obligate wetland		G4
Cyperus acuminatus	Obligate wetland		G5
Cyperus flavescens	Obligate wetland		G5
Didiplis diandra	Obligate wetland	S1	G5
Drosera brevifolia	Obligate wetland	S1	G5
Dulichium arundinaceum	Obligate wetland	S2	G5
Echinodorus berteroi	Obligate wetland		G5
Echinodorus cordifolius	Obligate wetland		G5
Eleocharis acicularis	Obligate wetland		G5
Eleocharis compressa	Obligate wetland		G4
Eleocharis obtusa	Obligate wetland		G5
Eleocharis palustris	Obligate wetland	SNR	G5
Eleocharis quadrangulata	Obligate wetland		G5
Eragrostis hypnoides	Obligate wetland		G5
Eriocaulon decangulare	Obligate wetland	S1	G5
Eriocaulon koernickianum	Obligate wetland	S1	G2
Eryngium prostratum	Obligate wetland		G5
Fimbristylis puberula	Obligate wetland		G5
Fimbristylis vahlii	Obligate wetland		G5
Forestiera acuminata	Obligate wetland	S2	G5
Fuirena simplex	Obligate wetland		G5
Fuirena squarrosa	Obligate wetland		G4G5
Galium tinctorium	Obligate wetland		G5
Glyceria septentrionalis	Obligate wetland		G5
Glyceria striata	Obligate wetland		G5
Gratiola neglecta	Obligate wetland		G5
Gratiola virginiana	Obligate wetland		G5
Habenaria repens	Obligate wetland	S1	G5
Heteranthera limosa	Obligate wetland		G5
Hibiscus laevis	Obligate wetland		G5
Hibiscus moscheutos	Obligate wetland		G5
Hottonia inflata	Obligate wetland	S2	G4
Hydrocotyle ranunculoides	Obligate wetland		G5
Hydrocotyle umbellata	Obligate wetland		G5
Hydrocotyle verticillata	Obligate wetland		G5
Hydrolea ovata	Obligate wetland		G5
Hydrolea uniflora	Obligate wetland		G5
Hymenocallis liriosme	Obligate wetland	S2	G4?
Hypericum gymnanthum	Obligate wetland		G4
Iris virginica	Obligate wetland	S1	G5
Isoetes melanopoda	Obligate wetland	S2	G5
Isolepis pseudosetacea	Obligate wetland		GNR
Itea virginica	Obligate wetland	S1	G4
Juncus acuminatus	Obligate wetland		G5
Juncus nodatus	Obligate wetland		G5
Juncus repens	Obligate wetland	S1	G5
Justicia americana	Obligate wetland		G5

Leersia oryzoides	Obligate wetland		G5
Lemna aequinoctialis	Obligate wetland	SNR	G5
Lemna minor	Obligate wetland		G5
Leucospora multifida	Obligate wetland		G5
Lindernia dubia	Obligate wetland		G5
Lipocarpha drummondii	Obligate wetland		G4G5
Ludwigia decurrens	Obligate wetland		G5
Ludwigia glandulosa	Obligate wetland		G5
Ludwigia hirtella	Obligate wetland	S1	G5
Ludwigia leptocarpa	Obligate wetland		G5
Ludwigia palustris	Obligate wetland		G5
Ludwigia peploides	Obligate wetland		G5
Ludwigia repens	Obligate wetland		G5
Lycopus americanus	Obligate wetland		G5
Lycopus rubellus	Obligate wetland		G5
Lycopus virginicus	Obligate wetland		G5
Lysimachia hybrida	Obligate wetland		G5
Mimulus alatus	Obligate wetland		G5
Mimulus glabratus	Obligate wetland	S2	G5
Myriophyllum heterophyllum	Obligate wetland		G5
Myriophyllum pinnatum	Obligate wetland		G5
Najas guadalupensis	Obligate wetland		G5
Nelumbo advena	Obligate wetland		G4
Nuphar advena	Obligate wetland		G5T5
Nymphaea odorata	Obligate wetland		G5
Oxypolis rigidior	Obligate wetland		G5
Packera glabella	Obligate wetland		G5
Parnassia grandifolia	Obligate wetland	S1	G3
Paspalum dissectum	Obligate wetland	SH	G4?
Paspalum repens	Obligate wetland		G5?
Peltandra virginica	Obligate wetland	S1	G5
Penthorum sedoides	Obligate wetland		G5
Persicaria amphibia	Obligate wetland		G5
Persicaria hydropiperoides	Obligate wetland		G5
Persicaria punctata	Obligate wetland		G5
Persicaria sagittata	Obligate wetland		G5
Persicaria setacea	Obligate wetland		G5
Phyla lanceolata	Obligate wetland		G5
Planera aquatica	Obligate wetland	S2	G5
Podostemum ceratophyllum	Obligate wetland	S2	G5
Pogonia ophioglossoides	Obligate wetland	SH	G5
Pontederia cordata	Obligate wetland	S1	G5
Potamogeton diversifolius	Obligate wetland		G5
Potamogeton illinoensis	Obligate wetland		G5
Potamogeton natans	Obligate wetland	SNR	G5
Potamogeton nodosus	Obligate wetland		G5
Potamogeton pulcher	Obligate wetland		G5
Potamogeton pusillus	Obligate wetland		G5

Proserpinaca palustris	Obligate wetland		G5
Ptilimnium capillaceum	Obligate wetland		G5
Quercus lyrata	Obligate wetland		G5
Ranunculus laxicaulis	Obligate wetland		G5?
Ranunculus pusillus	Obligate wetland	S4	G5
Ranunculus sceleratus	Obligate wetland		G5
Rhexia mariana	Obligate wetland		G5
Rhexia virginica	Obligate wetland		G5
Rhynchospora capillacea	Obligate wetland	S1	G4G5
Rhynchospora capitellata	Obligate wetland		G5
Rhynchospora corniculata	Obligate wetland		G5
Rhynchospora glomerata	Obligate wetland		G5
Rhynchospora gracilenta	Obligate wetland	S1	G5
Rhynchospora macrostachya	Obligate wetland		G4
Rhynchospora rariflora	Obligate wetland	SNR	G5
Rhynchospora scirpoides	Obligate wetland	S1	G4
Rorippa palustris	Obligate wetland		G5
Rotala ramosior	Obligate wetland		G5
Rumex verticillatus	Obligate wetland	S3	G5
Saccharum brevibarbe	Obligate wetland		G3G5
Sacciolepis striata	Obligate wetland	S3	G5
Sagittaria ambigua	Obligate wetland	S2	G2?
Sagittaria brevirostra	Obligate wetland		G5
Sagittaria graminea	Obligate wetland		G5
Sagittaria latifolia	Obligate wetland		G5
Sagittaria platyphylla	Obligate wetland		G5
Salix caroliniana	Obligate wetland		G5
Salix nigra	Obligate wetland		G5
Saururus cernuus	Obligate wetland		G5
Schoenoplectus americanus	Obligate wetland		G5
Schoenoplectus californicus	Obligate wetland		G5
Schoenoplectus pungens	Obligate wetland		G5
Scirpus atrovirens	Obligate wetland		G5?
Scirpus georgianus	Obligate wetland		G5
Scirpus pallidus	Obligate wetland		G5
Scirpus pendulus	Obligate wetland		G5
Scleria verticillata	Obligate wetland	S1	G5
Smilax laurifolia	Obligate wetland		G5
Sparganium americanum	Obligate wetland	S3	G5
Sparganium androcladum	Obligate wetland	S1	G4G5
Sparganium eurycarpum	Obligate wetland	SH	G5
Spartina pectinata	Obligate wetland		G5
Spiranthes odorata	Obligate wetland	S1	G5
Styrax americanus	Obligate wetland	S1	G5
Taxodium distichum	Obligate wetland	S2	G5
Thalia dealbata	Obligate wetland	S3	G4
Typha angustifolia	Obligate wetland		G5
Typha domingensis	Obligate wetland		G4G5

Typha latifolia	Obligate wetland		G5
Utricularia gibba	Obligate wetland		G5
Utricularia juncea	Obligate wetland	S1	G5
Utricularia radiata	Obligate wetland	S1	G4
Utricularia subulata	Obligate wetland	SH	G5
Xyris difformis	Obligate wetland		G5
Xyris jupicai	Obligate wetland		G5
Xyris torta	Obligate wetland		G5
Zannichellia palustris	Obligate wetland		G5
Zizaniopsis miliacea	Obligate wetland		G5
Acer saccharinum	Faculative wetland		G5
Agrimonia parviflora	Faculative wetland		G5
Aletris aurea	Faculative wetland	S1	G5
Alopecurus carolinianus	Faculative wetland		G5
Amaranthus tuberculatus	Faculative wetland		G4G5
Amorpha fruticosa	Faculative wetland		G5
Ampelopsis arborea	Faculative wetland		G5
Andropogon glomeratus	Faculative wetland		G5
Apios americana	Faculative wetland		G5
Arisaema dracontium	Faculative wetland		G5
Arisaema triphyllum	Faculative wetland		G5
Arnoglossum plantagineum	Faculative wetland		G4G5
Arundinaria gigantea	Faculative wetland		G5
Axonopus fissifolius	Faculative wetland	S1	G5
Baccharis halimifolia	Faculative wetland		G5
Berchemia scandens	Faculative wetland		G5
Betula nigra	Faculative wetland		G5
Bidens aristosa	Faculative wetland		G5
Bidens discoidea	Faculative wetland		G5
Bidens frondosa	Faculative wetland		G5
Boehmeria cylindrica	Faculative wetland		G5
Boltonia asteroides	Faculative wetland		G5
Brunnichia ovata	Faculative wetland		G4G5
Calamovilfa arcuata	Faculative wetland	S2	G2G3
Callitriche terrestris	Faculative wetland	SNR	G5
Calopogon tuberosus	Faculative wetland	S1	G5
Calycocarpum lyonii	Faculative wetland	S2	G5
Carex albolutescens	Faculative wetland		G5
Carex annectens	Faculative wetland		G5
Carex atlantica	Faculative wetland		G5
Carex bulbostylis	Faculative wetland		GNR
Carex bushii	Faculative wetland		G4
Carex caroliniana	Faculative wetland		G5
Carex cherokeensis	Faculative wetland		G4G5
Carex crawei	Faculative wetland	SH	G5
Carex fissa	Faculative wetland	S3	G4?
Carex granularis	Faculative wetland		G5
Carex gravida	Faculative wetland		G5

Carex grayi	Faculative wetland		G4
Carex intumescens	Faculative wetland		G5
Carex lupuliformis	Faculative wetland		G4
Carex microdonta	Faculative wetland		G4
Carex opaca	Faculative wetland		G5T4
Carex oxylepis	Faculative wetland	S2	G5?
Carex reniformis	Faculative wetland		G4?
Carex squarrosa	Faculative wetland		G4G5
Carex torta	Faculative wetland		G5
Carex triangularis	Faculative wetland		G5
Carex tribuloides	Faculative wetland		G5
Carex typhina	Faculative wetland	S1	G5
Carya myristiciformis	Faculative wetland	S1	G4
Celtis laevigata	Faculative wetland		G5
Chaerophyllum procumbens	Faculative wetland		G5
Cinna arundinacea	Faculative wetland		G5
Commelina diffusa	Faculative wetland		G5
Commelina virginica	Faculative wetland		G5
Cornus amomum	Faculative wetland		G5
Cornus foemina	Faculative wetland	S2	G5
Crataegus viridis	Faculative wetland		G5
Cynosciadium digitatum	Faculative wetland		G4G5
Cyperus erythrorhizos	Faculative wetland		G5
Cyperus odoratus	Faculative wetland		G5
Cyperus pseudovegetus	Faculative wetland		G5
Cyperus squarrosus	Faculative wetland		G5
Cyperus strigosus	Faculative wetland		G5
Cyperus surinamensis	Faculative wetland		G5
Cypripedium parviflorum	Faculative wetland		G5
Dichanthelium scoparium	Faculative wetland		G5
Dichondra carolinensis	Faculative wetland		G5
Dicliptera brachiata	Faculative wetland		G5
Diodia virginiana	Faculative wetland		G5
Doellingeria sericocarpoides	Faculative wetland	S1	G3G5
Echinochloa muricata	Faculative wetland		G5
Eleocharis engelmannii	Faculative wetland		G4G5
Eleocharis lanceolata	Faculative wetland		G4G5
Eleocharis montevidensis	Faculative wetland		G5
Eleocharis tenuis	Faculative wetland		G5
Eleocharis tortilis	Faculative wetland	S1	G5
Elymus virginicus	Faculative wetland		G5
Eragrostis frankii	Faculative wetland		G5
Eragrostis reptans	Faculative wetland		G5
Eryngium integrifolium	Faculative wetland	S1	G5
Eupatorium perfoliatum	Faculative wetland		G5
Euphorbia serpens	Faculative wetland		G5
Euploca procumbens	Faculative wetland	S1	G5
Eustoma exaltatum	Faculative wetland		G5

Euthamia leptocephala	Faculative wetland	S1	G5
Eutrochium fistulosum	Faculative wetland		G5?
Fimbristylis autumnalis	Faculative wetland		G5
Fraxinus pennsylvanica	Faculative wetland		G5
Galium obtusum	Faculative wetland		G5
Gentiana saponaria	Faculative wetland	S1	G5
Gonolobus suberosus	Faculative wetland		G5
Gratiola brevifolia	Faculative wetland		G4
Helenium autumnale	Faculative wetland		G5
Helianthus angustifolius	Faculative wetland		G5
Helianthus nuttallii	Faculative wetland		G5
Hypericum mutilum	Faculative wetland		G5
Hypericum nudiflorum	Faculative wetland		G5
Ilex decidua	Faculative wetland		G5
Impatiens capensis	Faculative wetland		G5
Iodanthus pinnatifidus	Faculative wetland	S2	G5
Ipomoea lacunosa	Faculative wetland		G5?
Iresine rhizomatosa	Faculative wetland		G5
Isoetes butleri	Faculative wetland	S1	G4
Isolepis carinata	Faculative wetland		G5
Juncus brachycarpus	Faculative wetland		G4G5
Juncus bufonius	Faculative wetland		G5
Juncus coriaceus	Faculative wetland		G5
Juncus diffusissimus	Faculative wetland		G5
Juncus dudleyi	Faculative wetland		G5
Juncus effusus	Faculative wetland		G5
Juncus marginatus	Faculative wetland		G5
Juncus scirpoides	Faculative wetland		G5
Juncus torreyi	Faculative wetland		G5
Juncus validus	Faculative wetland		G5
Kyllinga brevifolia	Faculative wetland		G5
Kyllinga odorata	Faculative wetland		G5
Kyllinga pumila	Faculative wetland		G5
Lathyrus venosus	Faculative wetland		G5
Leersia virginica	Faculative wetland		G5
Leptochloa panicea	Faculative wetland		GNR
Leptochloa panicoides	Faculative wetland		G5
Lepuropetalon spathulatum	Faculative wetland	SH	G4G5
Limnosciadium pinnatum	Faculative wetland		G5?
Linum striatum	Faculative wetland		G5
Lobelia cardinalis	Faculative wetland		G5
Lobelia puberula	Faculative wetland		G5
Lobelia siphilitica	Faculative wetland		G5
Ludwigia alternifolia	Faculative wetland		G5
Lycopodiella appressa	Faculative wetland	S1	G5
Lyonia ligustrina	Faculative wetland	S1	G5
Lysimachia ciliata	Faculative wetland		G5
Lysimachia quadriflora	Faculative wetland	S1	G5?

Lythrum alatum	Faculative wetland		G5
Maianthemum stellatum	Faculative wetland	SH	G5
Mikania scandens	Faculative wetland		G5
Mitreola petiolata	Faculative wetland	SNR	G5
Mitreola sessilifolia	Faculative wetland	S1	G4G5
Myosurus minimus	Faculative wetland		G5
Neottia bifolia	Faculative wetland	S1	G4
Oldenlandia boscii	Faculative wetland		G5
Oldenlandia uniflora	Faculative wetland	S1	G5
Onoclea sensibilis	Faculative wetland		G5
Ophioglossum vulgatum	Faculative wetland		G5
Osmundastrum cinnamomeum	Faculative wetland		G5
Packera aurea	Faculative wetland		G5
Packera tampicana	Faculative wetland		G5
Panicum dichotomiflorum	Faculative wetland		G5
Panicum verrucosum	Faculative wetland	SH	G4
Paspalum floridanum	Faculative wetland		G5
Persicaria bicornis	Faculative wetland		GNR
Persicaria lapathifolia	Faculative wetland		G5
Persicaria pensylvanica	Faculative wetland		G5
Phalaris caroliniana	Faculative wetland		G5?
Phyla nodiflora	Faculative wetland		G5
Physostegia angustifolia	Faculative wetland		G4G5
Physostegia intermedia	Faculative wetland	S1	G5
Pilea pumila	Faculative wetland		G5
Plantago elongata	Faculative wetland		G4
Platanthera ciliaris	Faculative wetland	S1	G5
Platanthera flava	Faculative wetland		G4?
Platanthera lacera	Faculative wetland	S1	G5
Platanus occidentalis	Faculative wetland		G5
Pluchea camphorata	Faculative wetland		G5
Pluchea odorata	Faculative wetland		G5
Poa sylvestris	Faculative wetland		G5
Polygala cruciata	Faculative wetland		G5
Ptilimnium costatum	Faculative wetland	S1	G4
Ptilimnium nuttallii	Faculative wetland		G5?
Pycnanthemum tenuifolium	Faculative wetland		G5
Quercus pagoda	Faculative wetland	S2	G5
Quercus palustris	Faculative wetland		G5
Ranunculus abortivus	Faculative wetland		G5
Rhododendron canescens	Faculative wetland	S2	G5
Rhododendron viscosum	Faculative wetland	S1	G5
Rhynchospora globularis	Faculative wetland		G5?
Rhynchospora recognita	Faculative wetland		G5?
Rudbeckia laciniata	Faculative wetland		G5
Rumex altissimus	Faculative wetland		G5
Saccharum giganteum	Faculative wetland	S1	G5
Salix interior	Faculative wetland		G5

Scirpus cyperinus	Faculative wetland		G5
Scutellaria integrifolia	Faculative wetland	SH	G5
Scutellaria lateriflora	Faculative wetland		G5
Selaginella apoda	Faculative wetland		G5
Sisyrinchium angustifolium	Faculative wetland		G5
Sisyrinchium sagittiferum	Faculative wetland		G4?
Solidago gigantea	Faculative wetland		G5
Spermacoce glabra	Faculative wetland		G4G5
Spiranthes cernua	Faculative wetland		G5
Stachys tenuifolia	Faculative wetland		G5
Steinchisma hians	Faculative wetland		G5
Symphyotrichum lanceolatum	Faculative wetland		G5
Symphyotrichum lateriflorum	Faculative wetland		G5
Symphyotrichum praealtum	Faculative wetland		G5
Teucrium canadense	Faculative wetland		G5
Thalictrum dasycarpum	Faculative wetland		G5
Thyrsanthella difformis	Faculative wetland		GNR
Trepocarpus aethusae	Faculative wetland		G4G5
Tridens strictus	Faculative wetland		G5
Trillium pusillum	Faculative wetland		G3
Tripsacum dactyloides	Faculative wetland		G5
Ulmus americana	Faculative wetland		G5
Vaccinium corymbosum	Faculative wetland	S2	G5
Veratrum virginicum	Faculative wetland	S1	G5
Verbena hastata	Faculative wetland		G5
Vernonia lettermannii	Faculative wetland	S2	G3
Vitis cinerea	Faculative wetland		G4G5
Vitis palmata	Faculative wetland		G4
Vitis riparia	Faculative wetland		G5
Wisteria frutescens	Faculative wetland	S1	G5
Woodwardia areolata	Faculative wetland		G5
Acalypha gracilens	Faculative		G5
Acer negundo	Faculative		G5
Acer rubrum	Faculative		G5
Adiantum pedatum	Faculative		G5
Aesculus pavia	Faculative	SNR	G5
Agalinis fasciculata	Faculative		G5
Agalinis tenuifolia	Faculative	S2	G5
Agrostis hyemalis	Faculative		G5
Aletris farinosa	Faculative	S1	G5
Ambrosia psilostachya	Faculative		G5
Ambrosia trifida	Faculative		G5
Amelanchier arborea	Faculative		G5

Table 7. Amphibians and reptiles known from the Kiamichi River watershed and their conservation status. Information compiled from ONHI (2021), Elkin (2018), Fisher et al. (2005), and Pyron and Vaughn (1994). Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. T ranks refer to subspecies. SNR – conservation status not assessed. Oklahoma Species of Concern, threat tiers C I – C III. FE – listed as federally threatened.

Species	**Common name**	**Conservation status**
Siren intermedia nettingi	Western lesser siren	G5T5, S4?, C III
Amphiuma tridactylum	Three-toed amphiuma	G5, S1, C II
Necturus maculosus louisianensis	Red River mudpuppy	G5, S3
Notophthalmus viridescens louisianensis	Central newt	G5T5, SNR
Ambystoma tigrinum	Eastern tiger salamander	G5, S3S4
Ambystoma opacum	Marbled salamander	G5, S4
Ambystoma annulatum	Ringed salamander	G4, S2S3, C II
Ambystoma texanum	Small-mouthed salamander	G5, S5
Ambystoma maculatum	Spotted salamander	G5, S3
Desmognathus brimleyorum	Ouachita dusky salamander	G5, S3, C I
Eurycea multiplicata	Many-ribbed salamander	G4, S4, C II
Hemidactylium scutatum	Four-toed salamander	G5, S1, C III
Plethodon kiamichi	Kiamichi slimy salamander	G2, S2 , C I
Plethodon ouachitae	Rich Mountain salamander	G3, S2, C I
Plethodon serratus	Southern red-backed salamander	G5, S3S4, C II
Plethodon albagula	Western slimy salamander	G5, S4
Bufo americanus charlesmiti	Dwarf American toad	G5T5, SNR
Anaxyrus americanus	American toad	G5, S5
Bufo woodhousii	Woodhouse's toad	G5, S5
Scaphiopus hurterii	Hurter's spadefoot	G5, S2S3, C III
Gastrophryne carolinensis	Eastern narrow-mouthed toad	G5, S4
Gastrophryne olivacea	Western narrow-mouthed toad	G5, S5
Acris blanchardi	Blanchard's cricket frog	G5, S5
Hyla cinerea	Green treefrog	G5, S3
Hyla chrysoscelis	Cope's gray treefrog	G5, S4
Hyla versicolor	Gray treefrog	G5, S4
Pseudacris crucifer	Spring Peeper	G5, S4
Pseudacris streckeri	Strecker's chorus frog	G5, S3
Pseudacris fouquettei	Cajun chorus frog	G5, S3
Lithobates areolatus areolatus	Southern crawfish frog	G4T4, SNR, C II
Lithobates catesbeianus	American bullfrog	G5, S5
Lithobates clamitans	Green frog	G5, S4
Lithobates palustris	Pickerel frog	G5, S2S3
Lithobates sphenocephalus	Southern leopard frog	G5, S5
Apalone spinifera	Eastern spiny softshell	G5, S5, C III
Apalone mutica mutica	Midland smooth softshell	G5T5, SNR, C III
Deirochelys reticularia miaria	Western chicken turtle	G5T5, SNR, C II
Macrochelys temminckii	Alligator snapping turtle	G3G4, S2, C I
Chelydra serpentina	Snapping turtle	G5, S5

Kinosternon subrubrum hippocrepis	Mississippi mud turtle	G5T5, SNR
Sternotherus odoratus	Stinkpot	G5, S4
Sternotherus carinatus	Razor-backed musk turtle	G5, S4, C III
Graptemys ouachitensis	Ouachita map turtle	G5, S4?, C III
Graptemys pseudogeographica kohnii	Mississippi map turtle	G5T4, SNR, C III
Pseudemys concinna concinna	Eastern river cooter	G5T5, SNR, C III
Trachemys scripta elegans	Red-eared slider	G5T5, SNR
Terrapene carolina triunguis	Three-toed box turtle	G5T5, SNR
Terrapene ornata ornata	Ornate turtle	G5T5, SNR
Ophisaurus attenuatus attenuatus	Western slender glass lizard	G5T5, SNR
Sceloporus undulatus consobrinus	Prairie lizard	G5, S5
Plestiodon anthracinus pluvialis	Southern coal skink	GRT5, SNR
Crotaphytus collaris	Eastern collared lizard	G5, S4
Anolis carolinensis	Green anole	G5, S4
Scincella lateralis	Little brown skink	G5, S4
Plestiodon fasciatus	Common five-lined skink	G5, S5
Aspidoscelis sexlineata sexlineata	Eastern six-lined racerunner	G5TNR, SNR
Plestiodon laticeps	Broad-headed skink	G5, S3
Hemidactylus turcicus	Mediterranean gekko	G5, SNA
Alligator mississippiensis	American alligator	FT, G5, S4?, C III
Storeria dekayi texana	Texas brownsnake	G5T5, SNR
Storeria occipitomaculata	Red-bellied snake	G5, S3
Masticophis flagellum	Coachwhip	G5, S5
Coluber constrictor	North American racer	G5, S5
Thamnophis sirtalis	Common garter snake	G5, S5
Thamnophis proximus proximus	Orange-striped ribbonsnake	G5T5, SNR
Agkistrodon contortrix contortrix	Southern copperhead	G5T5, SNR
Agkistrodon piscivorus leucostoma	Western cottonmouth	G5T5, SNR
Nerodia rhombifer rhombifer	Northern diamond-backed watersnake	G5T5, SNR
Nerodia fasciata confluens	Broad-banded watersnake	G5T5, SNR
Nerodia erythrogaster	Plain-bellied watersnake	G5, S4
Nerodia sipedon	Common watersnake	G5, S4
Regina rigida sinicola	Gulf crayfish snake	G5T5, S4?, C II
Regina grahamii	Graham's crayfish snake	G5, S3
Carphophis vermis	Western wormsnake	G5, S3
Lampropeltis triangulum	Milksnake	G5, S3, C II
Lampropeltis holbrooki	Speckled kingsnake	G5, S5
Lampropeltis calligaster calligaster	Prairie kingsnake	G5T5, SNR
Crotalus atrox	Western diamond-backed rattlesnake	G5, S4, C III
Crotalus horridus	Timber rattlesnake	G4, S3
Sistrurus miliarius streckeri	Western pygmy rattlesnake	G5T5, SNR
Virginia valeriae elegans	Western smooth earthsnake	G5T5, SNR
Virginia striatula	Rough earthsnake	G5, S4
Diadophis punctatus	Ring-necked snake	G5, S5
Heterodon platirhinos	Eastern hog-nosed snake	G5, S5
Opheodrys aestivus	Rough greensnake	G5, S5
Pantherophis emoryi	Great Plains ratsnake	G5, S5
Pantherophis obsoletus	Western ratsnake	G5, S5

Sonora semiannulata	Western groundsnake	G5, S5
Tantilla gracilis	Flat-headed snake	G5, S5

Table 8. Bird species known from the Kiamichi River watershed and their conservation status. Information compiled from ONHI (2021), Elkin (2018), Fisher et al. (2005), and Pyron and Vaughn (1994). Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. SNR – conservation status not assessed, SU – unrankable due to lack of information, B – breeding population in the state, N – nonbreeding, M – migrant. Oklahoma Species of Concern, threat tiers C I – C III. FE – listed as federally endangered.

Species	**Common name**	**Conservation status**
Accipiter cooperii	Cooper's Hawk	G5, S2S3
Accipiter striatus	Sharp-shinned Hawk	G5, S4N
Actitis macularius	Spotted Sandpiper	G5, S1S3
Agelaius phoeniceus	Red-winged Blackbird	G5, S5B
Aix sponsa	Wood Duck	G5, S4B
Ammodramus savannarum	Grasshopper Sparrow	G5, S4B
Anas acuta	Northern Pintail	G5, S3S5, C III
Anas americana	American Wigeon	G5, S5N
Anas clypeata	Northern Shoveler	G5, S4N
Anas crecca	Green-winged Teal	G5, S5N
Anas cyanoptera	Cinnamon Teal	G5, S3N
Anas discors	Blue-winged Teal	G5, S4S5
Anas platyrhynchos	Mallard	G5, SU
Anas strepera	Gadwall	G5, S5N
Anhinga anhinga	Anhinga	G5, S1B
Anser albifrons	Greater White-fronted Goose	G5, S3N
Anthus rubescens	American Pipit	G5, S4N
Anthus spragueii	Sprague's Pipit	G4, S3S4, C III
Antrostomus carolinensis	Chuck-will's-widow	G5, S5B
Antrostomus vociferus	Eastern Whip-poor-will	G5, S2B, C II
Archilochus colubris	Ruby-throated Hummingbird	G5, S5B
Ardea alba	Great Egret	G5, S4B
Ardea herodias	Great Blue Heron	G5, S5
Arenaria interpres	Ruddy Turnstone	G5, S2N
Asio flammeus	Short-eared Owl	G5, S3N, C III
Asio otus	Long-eared Owl	G5, S1
Aythya affinis	Lesser Scaup	G5, S5N, C III
Aythya americana	Redhead	G5, S5N
Aythya collaris	Ring-necked Duck	G5, S4N
Aythya marila	Greater Scaup	G5, SNR
Aythya valisineria	Canvasback	G5, S4N, C III
Baeolophus bicolor	Tufted Titmouse	G5, S5B
Bartramia longicauda	Upland Sandpiper	G5, S3S4, C III
Bombycilla cedrorum	Cedar Waxwing	G5, SU
Botaurus lentiginosus	American Bittern	G5, S1S3
Branta canadensis	Canada Goose	G5, SU
Branta hutchinsii	Cackling Goose	G5, SNR
Bubo virginianus	Great Horned Owl	G5, S5B
Bubulcus ibis	Cattle Egret	G5, SNA

Bucephala albeola	Bufflehead	G5, S4N
Bucephala clangula	Common Goldeneye	G5, SNR
Buteo jamaicensis	Red-tailed Hawk	G5, S5B
Buteo lineatus	Red-shouldered Hawk	G5, S5B
Buteo platypterus	Broad-winged Hawk	G5, S4B
Buteo swainsoni	Swainson's Hawk	G5, S3B, C II
Butorides virescens	Green Heron	G5, S2B
Calcarius lapponicus	Lapland Longspur	G5, S4N
Calidris alba	Sanderling	G5, S3N
Calidris alpina	Dunlin	G5, S2N
Calidris bairdii	Baird's Sandpiper	G5, SU
Calidris fuscicollis	White-rumped Sandpiper	G5, S3N
Calidris himantopus	Stilt Sandpiper	G5, S3N
Calidris melanotos	Pectoral Sandpiper	G5, S4N
Calidris minutilla	Least Sandpiper	G5, S4N
Calidris pusilla	Semipalmated Sandpiper	G5, S4N
Calidris subruficollis	Buff-breasted Sandpiper	G4, S3M, C II
Cardellina canadensis	Canada Warbler	G5, S1N
Cardellina pusilla	Wilson's Warbler	G5, S5N
Cardinalis cardinalis	Northern Cardinal	G5, S5B
Cathartes aura	Turkey Vulture	G5, S5
Catharus fuscescens	Veery	G5, SNR
Catharus guttatus	Hermit Thrush	G5, S3N
Catharus minimus	Gray-cheeked Thrush	G5, S2N
Catharus ustulatus	Swainson's Thrush	G5, S4N
Certhia americana	Brown Creeper	G5, S5N
Chaetura pelagica	Chimney Swift	G5, S5B
Charadrius semipalmatus	Semipalmated Plover	G5, S4N
Charadrius vociferus	Killdeer	G5, S5B
Chen caerulescens	Snow Goose	G5, S5N
Chen rossii	Ross's Goose	G5, SU
Chlidonias niger	Black Tern	G4, S4?N
Chondestes grammacus	Lark Sparrow	G5, S3S5B
Chordeiles minor	Common Nighthawk	G5, S5B
Chroicocephalus philadelphia	Bonaparte's Gull	G5, S2N
Circus cyaneus	Northern Harrier	G5, S3S5
Cistothorus palustris	Marsh Wren	G5, S2N
Cistothorus platensis	Sedge Wren	G5, S2N
Coccyzus americanus	Yellow-billed Cuckoo	PT, G5, S5B
Coccyzus erythropthalmus	Black-billed Cuckoo	G5, S1B
Colaptes auratus	Northern Flicker	G5, S4S5B
Colinus virginianus	Northern Bobwhite	G4G5, S5B, C III
Columba livia	Rock Dove	G5, SNA
Columbina inca	Inca Dove	G5, SNR
Contopus cooperi	Olive-sided Flycatcher	G5, S2N
Contopus virens	Eastern Wood-Pewee	G5, S5B
Coragyps atratus	Black Vulture	G5, S2B
Corvus brachyrhynchos	American Crow	G5, S5B

Corvus ossifragus	Fish Crow	G5, S4B
Coturnicops noveboracensis	Yellow Rail	G4, SNA, C III
Cyanocitta cristata	Blue Jay	G5, S5B
Dendrocygna autumnalis	Black-bellied Whistling-Duck	G5, SNR
Dolichonyx oryzivorus	Bobolink	G5, S2N
Dryocopus pileatus	Pileated Woodpecker	G5, S3
Dumetella carolinensis	Gray Catbird	G5, S4B
Egretta caerulea	Little Blue Heron	G5, S5B, C II
Egretta thula	Snowy Egret	G5, S5B,C III
Empidonax alnorum	Alder Flycatcher	G5, S2N
Empidonax flaviventris	Yellow-bellied Flycatcher	G5, S2N
Empidonax minimus	Least Flycatcher	G5, S5N
Empidonax traillii	Willow Flycatcher	G5, S4M,C III
Empidonax virescens	Acadian Flycatcher	G5, S4B
Eremophila alpestris	Horned Lark	G5, S5B
Euphagus carolinus	Rusty Blackbird	G5, S3N, C III
Euphagus cyanocephalus	Brewer's Blackbird	G5, S3S5
Falco columbarius	Merlin	G5, SU
Falco peregrinus	Peregrine Falcon	G5, S4M, C III
Falco sparverius	American Kestrel	G5, S4S5B
Fulica americana	American Coot	G5, S3S5B
Gallinago delicata	Wilson's Snipe	G5, S5N
Gallinula galeata	Common Gallinule	G5, S2B
Gavia immer	Common Loon	G5, S3M
Geococcyx californianus	Greater Roadrunner	G5, S5B
Geothlypis formosa	Kentucky Warbler	G5, S4B, C III
Geothlypis philadelphia	Mourning Warbler	G5, S2N
Geothlypis trichas	Common Yellowthroat	G5, S5B
Haemorhous mexicanus	House Finch	G5, S4B
Haemorhous purpureus	Purple Finch	G5, S5N
Haliaeetus leucocephalus	Bald Eagle	G5, S1S3, C III
Helmitheros vermivorum	Worm-eating Warbler	G5, S1B, C II
Himantopus mexicanus	Black-necked Stilt	G5, SNR
Hirundo rustica	Barn Swallow	G5, S5B
Hydroprogne caspia	Caspian Tern	G5, S2N
Hylocichla mustelina	Wood Thrush	G5, S2B, C II
Icteria virens	Yellow-breasted Chat	G5, S4B
Icterus galbula	Baltimore Oriole	G5, S2S4
Icterus spurius	Orchard Oriole	G5, S4B
Ictinia mississippiensis	Mississippi Kite	G5, S5B
Ixobrychus exilis	Least Bittern	G5, S4?
Junco hyemalis	Dark-eyed Junco	G5, S5N
Lanius ludovicianus	Loggerhead Shrike	G5, S4B, C I
Larus argentatus	Herring Gull	G5, S4N
Larus delawarensis	Ring-billed Gull	G5, S5N
Leucophaeus pipixcan	Franklin's Gull	G5, S5N
Limnodromus griseus	Short-billed Dowitcher	G5, S1N
Limnodromus scolopaceus	Long-billed Dowitcher	G5, S4N

Limnothlypis swainsonii	Swainson's Warbler	G5, S1B, C II
Limosa haemastica	Hudsonian Godwit	G4, S2N, C III
Lophodytes cucullatus	Hooded Merganser	G5, S3N
Megaceryle alcyon	Belted Kingfisher	G5, S3S5
Megascops asio	Eastern Screech-Owl	G5, S4S5
Melanerpes carolinus	Red-bellied Woodpecker	G5, S5B
Melanerpes erythrocephalus	Red-headed Woodpecker	G5, S4S5B, C II
Meleagris gallopavo	Wild Turkey	G5, S5B
Melospiza georgiana	Swamp Sparrow	G5, S2N
Melospiza lincolnii	Lincoln's Sparrow	G5, S5N
Melospiza melodia	Song Sparrow	G5, S5N
Mergus merganser	Common Merganser	G5, S4N
Mergus serrator	Red-breasted Merganser	G5, SNR
Mimus polyglottos	Northern Mockingbird	G5, S5B
Mniotilta varia	Black-and-white Warbler	G5, S4B
Molothrus ater	Brown-headed Cowbird	G5, S5B
Mycteria americana	Wood Stork	G5, S4N, C III
Myiarchus crinitus	Great Crested Flycatcher	G5, S5B
Nyctanassa violacea	Yellow-crowned Night-Heron	G5, S4B
Nycticorax nycticorax	Black-crowned Night-Heron	G5, S3B
Oreothlypis celata	Orange-crowned Warbler	G5, S5N
Oreothlypis peregrina	Tennessee Warbler	G5, S4N
Oreothlypis ruficapilla	Nashville Warbler	G5, S5N
Oxyura jamaicensis	Ruddy Duck	G5, S5
Pandion haliaetus	Osprey	G5, S2N
Parkesia motacilla	Louisiana Waterthrush	G5, S4B, C III
Parkesia noveboracensis	Northern Waterthrush	G5, S2N
Passer domesticus	House Sparrow	G5, SNA
Passerculus sandwichensis	Savannah Sparrow	G5, S5
Passerella iliaca	Fox Sparrow	G5, S3N
Passerina caerulea	Blue Grosbeak	G5, S5B
Passerina ciris	Painted Bunting	G5, S5B, C II
Passerina cyanea	Indigo Bunting	G5, S5B
Pelecanus erythrorhynchos	American White Pelican	G5, S3N
Petrochelidon pyrrhonota	Cliff Swallow	G5, S5B
Phalaropus lobatus	Red-necked Phalarope	G4G5, S2N
Phalaropus tricolor	Wilson's Phalarope	G5, S5N, C III
Pheucticus ludovicianus	Rose-breasted Grosbeak	G5, S2B
Picoides borealis	Red-cockaded Woodpecker	FE, G3, S1B , C I
Picoides pubescens	Downy Woodpecker	G5, S5B
Picoides villosus	Hairy Woodpecker	G5, S5B
Pipilo erythrophthalmus	Eastern Towhee	G5, S3S5
Piranga olivacea	Scarlet Tanager	G5, S2B
Piranga rubra	Summer Tanager	G5, S4B
Plegadis chihi	White-faced Ibis	G5, SNR
Pluvialis dominica	American Golden Plover	G5, S2N, C III
Pluvialis squatarola	Black-bellied Plover	G5, S2N
Podiceps auritus	Horned Grebe	G5, S2N

Podilymbus podiceps	Pied-billed Grebe	G5, S5
Poecile carolinensis	Carolina Chickadee	G5, S5B
Polioptila caerulea	Blue-gray Gnatcatcher	G5, S5B
Pooecetes gramineus	Vesper Sparrow	G5, S4N
Porphyrio martinicus	Purple Gallinule	G5, S1
Porzana carolina	Sora	G5, S5B
Progne subis	Purple Martin	G5, S5B
Protonotaria citrea	Prothonotary Warbler	G5, S4B, C III
Quiscalus mexicanus	Great-tailed Grackle	G5, S5B
Quiscalus quiscula	Common Grackle	G5, S5B
Rallus elegans	King Rail	G5, S1B, C III
Rallus limicola	Virginia Rail	G5, S1B, C II
Recurvirostra americana	American Avocet	G5, S2B
Regulus calendula	Ruby-crowned Kinglet	G5, S5N
Regulus satrapa	Golden-crowned Kinglet	G5, S3N
Riparia riparia	Bank Swallow	G5, S2B?
Sayornis phoebe	Eastern Phoebe	G5, S5B
Scolopax minor	American Woodcock	G5, S3, C III
Seiurus aurocapilla	Ovenbird	G5, S2B?
Setophaga americana	Northern Parula	G5, S3B
Setophaga castanea	Bay-breasted Warbler	G5, S2N
Setophaga cerulea	Cerulean Warbler	G5, S2B, C II
Setophaga citrina	Hooded Warbler	G5, S2B, C II
Setophaga coronata	Myrtle Warbler	G5, S5N
Setophaga discolor	Prairie Warbler	G5, S3B, C II
Setophaga dominica	Yellow-throated Warbler	G5, S2B
Setophaga fusca	Blackburnian Warbler	G5, S2N
Setophaga magnolia	Magnolia Warbler	G5, S2N
Setophaga palmarum	Palm Warbler	G5, S1N
Setophaga pensylvanica	Chestnut-sided Warbler	G5, S2N
Setophaga petechia	Yellow Warbler	G5, S3B
Setophaga pinus	Pine Warbler	G5, S4
Setophaga ruticilla	American Redstart	G5, S3B
Setophaga striata	Blackpoll Warbler	G5, S2N
Setophaga virens	Black-throated Green Warbler	G5, S3N
Sialia sialis	Eastern Bluebird	G5, S5B
Sitta canadensis	Red-breasted Nuthatch	G5, S2N
Sitta carolinensis	White-breasted Nuthatch	G5, S5B
Sitta pusilla	Brown-headed Nuthatch	G5, S1B, C II
Sphyrapicus varius	Yellow-bellied Sapsucker	G5, S3N
Spinus pinus	Pine Siskin	G5, S4N
Spinus tristis	American Goldfinch	G5, S5B
Spiza americana	Dickcissel	G5, S4B
Spizella pallida	Clay-colored Sparrow	G5, S4N
Spizella passerina	Chipping Sparrow	G5, S4S5B, C II
Spizella pusilla	Field Sparrow	G5, S5
Spizelloides arborea	American Tree Sparrow	G5, S5N
Stelgidopteryx serripennis	Northern Rough-winged Swallow	G5, S4B

Sterna forsteri	Forster's Tern	G5, S4N
Sternula antillarum	Least Tern	FE, G4, S2B, C II
Streptopelia decaocto	Eurasian Collared-Dove	G5, SNA
Strix varia	Barred Owl	G5, S4S5B
Sturnella magna	Eastern Meadowlark	G5, S5B
Sturnella neglecta	Western Meadowlark	G5, S5B
Sturnus vulgaris	European Starling	G5, SNA
Tachybaptus dominicus	Least Grebe	G5, SNR
Tachycineta bicolor	Tree Swallow	G5, S2B
Thryomanes bewickii	Bewick's Wren	G5, S4S5
Thryothorus ludovicianus	Carolina Wren	G5, S5B
Toxostoma rufum	Brown Thrasher	G5, S5B
Tringa flavipes	Lesser Yellowlegs	G5, S5N
Tringa melanoleuca	Greater Yellowlegs	G5, S5N
Tringa semipalmata	Willet	G5, S3N
Tringa solitaria	Solitary Sandpiper	G5, S5N, C III
Troglodytes aedon	House Wren	G5, S4S5B
Troglodytes hiemalis	Winter Wren	G5, S2N
Turdus migratorius	American Robin	G5, S5B
Tyrannus forficatus	Scissor-tailed Flycatcher	G5, S5B
Tyrannus tyrannus	Eastern Kingbird	G5, S5B
Tyrannus verticalis	Western Kingbird	G5, S5B
Tyto alba	Barn Owl	G5, S3, C III
Vermivora chrysoptera	Golden-winged Warbler	G4, S3?N
Vermivora cyanoptera	Blue-winged Warbler	G5, S1B, C II
Vireo bellii	Bell's Vireo	G5, S3B
Vireo flavifrons	Yellow-throated Vireo	G5, S2B
Vireo gilvus	Warbling Vireo	G5, S4B
Vireo griseus	White-eyed Vireo	G5, S5B
Vireo olivaceus	Red-eyed Vireo	G5, S5B
Vireo philadelphicus	Philadelphia Vireo	G5, S1N
Vireo solitarius	Blue-headed Vireo	G5, S2N
Zenaida macroura	Mourning Dove	G5, S5B

Table 9. Mammal species known from the Kiamichi River watershed and their conservation status. Information compiled from ONHI (2021), Elkin (2018), Fisher et al. (2005), and Pyron and Vaughn (1994). Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. SNR – conservation status not assessed, SE – exotic. Oklahoma Species of Concern, threat tiers C I – C III. FE – listed as federally endangered.

Species	**Common name**	**Conservation Status**
Didelphis virginiana	Virginia opossum	G5, S5
Dasypus novemcinctus	Nine-banded armadillo	G5, S4
Blarina carolinensis	Southern short-tailed shrew	G5, S2S3
Blarina hylophaga	Elliot's Short-tailed shrew	G5, S4
Cryptotis parva	North American least shrew	G5, S5
Scalopus aquaticus	Eastern mole	G5, S2
Eptesicus fuscus	Big brown bat	G5, S4
Lasionycteris noctivagans	Silver-haired bat	G3G4, S2
Lasiurus borealis	Eastern red bat	G3G4, S4
Lasiurus cinereus	Hoary bat	G3G4, S4
Lasiurus seminolus	Seminole bat	G5, S3, C III
Myotis austroriparius	Southeastern myotis bat	G4, S1, C II
Myotis leibii	Eastern small-footed myotis bat	G4, S1, C II
Myotis lucifugus	Little brown bat	G3, S1
Myotis septentrionalis	Northern long-eared bat	G1G2, S2, C II
Myotis sodalis	Indiana myotis bat	G2, S1, C III, FE
Nycticeius humeralis	Evening bat	G5, S4, C II
Corynorhinus rafinesquii	Rafinesque's big-eared bat	G3G4, S3, C II
Perimyotis subflavus	Tricolored bat	G2G3, S3S4, C II
Tadarida brasiliensis	Brazilian free-tailed bat	G5,S3, C II
Canis latrans	Coyote	G5, S5
Urocyon cinereoargenteus	Gray fox	G5,S3S4, C II
Vulpes vulpes	Red fox	G5, SNA
Lynx rufus	Bobcat	G5, S4
Procyon lotor	Raccoon	G5, S5
Mustela frenata	Long-tailed weasel	G5, S2, C III
Neovison vison	American mink	G5, S4
Mephitis mephitis	Striped skunk	G5, S5
Spilogale putorius	Eastern spotted skunk	G4, S2, C III
Lutra canadensis	North American river otter	G5, S3
Sus scrofa	Feral pig	G5, SNR
Ursus americanus	American black bear	G5, S3S4
Odocoileus virginianus	White-tailed deer	G5, S5
Cervus elaphus	Elk	G5
Glaucomys volans	Southern flying squirrel	G5, S3, CII
Sciurus carolinensis	Eastern gray squirrel	G5, S5
Sciurus niger	Eastern fox squirrel	G5, S5
Geomys breviceps	Baird's pocket gopher	G5, S4?, CII
Castor canadensis	American beaver	G5, S4

Neotoma floridana	Eastern woodrat	G5, S5
Ochrotomys nuttalli	Golden mouse	G5, S2, C III
Oryzomys palustris texensis	Texas rice rat	G5, S3, C III
Peromyscus attwateri	Texas deermouse	G5, S5
Peromyscus gossypinus	Cotton deermouse	G5, S4
Peromyscus leucopus	White-footed deermouse	G5, S5
Peromyscus maniculatus	North American deermouse	G5, S5
Reithrodontomys fulvescens	Fulvous harvest mouse	G5, S4
Reithrodontomys humulis	Eastern harvest mouse	G5, S2S3, C III
Chaetodipus hispidus	Hispid pocket mouse	G5, SNR
Sigmodon hispidus	Hispid cotton rat	G5, S5
Microtus pinetorum	Woodland vole	G5, S5
Mus musculus	House mouse	G5, SE
Rattus norvegicus	Norway rat	G5, SE
Rattus rattus	Black rat	G5, SE
Myocastor coypus	Nutria	G5, SE
Ondatra zibethicus	Common muskrat	G5, S4
Marmota monax	Woodchuck	G5, S3

Table 10. Algae known from the Kiamichi River. From Wilhm (1979) and Atkinson and Cooper (2016).

Achnantidium sp.
Amphanizomenon flos-aquae
Anabaena sp.
Aphanocapsa sp.
Aulacoseira sp.
Oscillatoria sp.
Euglena sp.
Closterium sp.
Asterionella formosa Hass
Caloneis bacillum
Caloneis ventricosa
Cocconeis placentula
Chaetophora sp.
Chlamaydomonas sp.
Chlorella sp.
Cyclotella meneghiniana
Cymbella turgida
Cymbella minuta.
Diatoma vulgare
Diploneis smithii
Ellerbeckia sp.
Epithemia sorex
Eunotia curvata
Fragilaria crotenensis
Frustulia vulgaris
Gomphonema acuminatum
Gomphonema olivaceum
Gyrosigma spenceri
Mallomonas sp.
Melosira distans
Melosira granulata
Merismopedia sp.
Microcystis sp.
Mougeotia sp.
Navicula capitata
Navicula cryptocephala
Navicula cuspidata
Navicula exigua
Navicula pupula
Navicula tripunctata
Nitzschia acicularis
Achnantidium sp.
Nitzschia acicularis
Pinnularia brauni
Rhizoclonium sp.
Scendesmus sp.
Selenastrum sp.
Snowella ps.
Stauroneis anceps
Stigeoclonium sp.
Surirella anceps
Surirella angus
Surirella angustata
Synedra ulna
Pinnularia brauni
Rhizoclonium sp.
Scendesmus sp.
Selenastrum sp.
Snowella ps.

Table 11. Aquatic insects collected from the Kiamichi River. Compiled from Pyron and Vaughn (1994) and Galbraith et al. (2008b). Odonates are listed in a separate table.

Order and Family	**Species**
Coleopotera, Dryopidae	*Helichus fastigiatus*
Coleopotera, Dryopidae	*Helichus lithophilus*
Coleopotera, Dryopidae	*Helichus suturalis*
Coleopotera, Elmidae	*Acyronyx variegatus*
Coleopotera, Elmidae	*Dubiraphia browni*
Coleopotera, Elmidae	*Macrohychus glabratus*
Coleopotera, Elmidae	*Microcylloepus pusillus*
Coleopotera, Elmidae	*Stenelmis crenata*
Coleopotera, Elmidae	*Stenelmis exigua*
Coleopotera, Elmidae	*Stenelmis exilis*
Coleopotera, Elmidae	*Stenelmis grossa*
Coleopotera, Elmidae	*Stenelmis parva*
Coleopotera, Elmidae	*Stenelmis xylonastis*
Coleopotera, Elmidae	*Ectopria thoracica*
Coleopotera, Elmidae	*Psephenus herricki*
Diptera, Chironomidae	*Palpomyia* sp.
Diptera, Chironomidae	*Ablabesmyia janta*
Diptera, Chironomidae	*Ablabesmyia mallochi*
Diptera, Chironomidae	*Chironomus* sp.
Diptera, Chironomidae	*Cryptochironomus* sp.
Diptera, Chironomidae	*Dicrotendipes* sp.
Diptera, Chironomidae	*Einfeldia* sp.
Diptera, Chironomidae	*Glyptotendipes* sp.
Diptera, Chironomidae	*Micropsectra* sp.
Diptera, Chironomidae	*Polypedilum fallax*
Diptera, Chironomidae	*Polypedilum* sp.
Diptera, Chironomidae	*Procladius* sp.
Diptera, Chironomidae	*Xenochironomus* sp.
Ephemeroptera, Baetidae	*Acentrella carolina*
Ephemeroptera, Baetidae	*Acerpenna pygmaea*
Ephemeroptera, Baetidae	*Acerpenna macdunnoughi*
Ephemeroptera, Baetidae	*Baetis armillatus*
Ephemeroptera, Baetidae	*Baetis intercalaris*
Ephemeroptera, Baetidae	*Baetis dubius*
Ephemeroptera, Baetidae	*Baetis flavistriga*
Ephemeroptera, Baetidae	*Baetis futile*
Ephemeroptera, Baetidae	*Calllbaetis floridanus*
Ephemeroptera, Baetidae	*Diphetor hageni*
Ephemeroptera, Baetidae	*Procloeon insignificans*
Ephemeroptera, Baetidae	*Procloeon minor*
Ephemeroptera, Baetidae	*Procloeon rubropictum*
Ephemeroptera, Baetidae	*Procoeon texanum*
Ephemeroptera, Baetiscidae	*Baetisca jacustris*
Ephemeroptera, Caenidae	*Caenis amica*

Ephemeroptera, Caenidae	*Caenis anceps*
Ephemeroptera, Caenidae	*Caenis diminuta*
Ephemeroptera, Caenidae	*Caenis hilaris*
Ephemeroptera, Caenidae	*Caenis jatipennis*
Ephemeroptera, Caenidae	*Caenis punctata*
Ephemeroptera, Ephemerellidae	*Danella simplex*
Ephemeroptera, Ephemerellidae	*Eurylophella bicolor*
Ephemeroptera, Ephemerellidae	*Eurylophela funeralis*
Ephemeroptera, Ephemerellidae	*Eurylophella temporalis*
Ephemeroptera, Ephemerellidae	*Hexagenia limbata*
Ephemeroptera, Ephemeridae	*Pentagenia vittigera*
Ephemeroptera, Heptageniidae	*Leucrocuta aphrodite*
Ephemeroptera, Heptageniidae	*Leucrocuta maculipennis*
Ephemeroptera, Heptageniidae	*Leucrocuta juno*
Ephemeroptera, Heptageniidae	*Nixe perfida*
Ephemeroptera, Heptageniidae	*Stenacron interpunctatum*
Ephemeroptera, Heptageniidae	*Stenonema exiguum*
Ephemeroptera, Heptageniidae	*Stenonema femoratum*
Ephemeroptera, Heptageniidae	*Stenonema modestum*
Ephemeroptera, Heptageniidae	*Stenonema terminatum*
Ephemeroptera, Isonychiidae	*Isonychia rufa*
Ephemeroptera, Leptophlebiidae	*Habrophlebiodes annulata*
Ephemeroptera, Leptophlebiidae	*Leptophlebia grandis*
Ephemeroptera, Leptophlebiidae	*Paraleptophlebia guttata*
Ephemeroptera, Leptophlebiidae	*Paraleptophlebia volitans*
Ephemeroptera, Polymitarcyidae	*Ephoron album*
Ephemeroptera, Potamanthiidae	*Anthopotamus myops*
Ephemeroptera, Tricorythidae	*Tricorythodes stratus*
Megaloptera, Corydalidae	*Corydalus cornutus*
Plecoptera	*Allocapnia granulata*
Plecoptera	*Zealeuctra claasseni*
Plecoptera	*Strophopteryx cucullata*
Plecoptera	*Allocapnia peltoides*
Plecoptera	*Zealeuctra warreni*
Plecoptera	*Perlesta placida*
Plecoptera	*Hydroperla crosbyi*
Plecoptera	*Isoperla mohri*
Plecoptera	*Isoperla clio*
Trichoptera, Philopotamoidea	*Chimarra fraternus*
Trichoptera, Philopotamoidea	*Chimarra obscura*
Trichoptera, Philopotamoidea	*Chimarra feria*
Trichoptera, Philopotamoidea	*Chimarra* sp.
Trichoptera, Philopotamoidea	*Wormaldia* sp.
Trichoptera, Hydropsychidae	*Macrostemum carolina*
Trichoptera, Hydropsychidae	*Potamyia llava*
Trichoptera, Hydropsychidae	*Hydropsyche arinale*
Trichoptera, Hydropsychidae	*Hydropsyche orris* Ross
Trichoptera, Hydropsychidae	*Hydropsyche rossi*

Trichoptera, Hydropsychidae	*Hydropsyche simulans*
Trichoptera, Hydropsychidae	*Hydropsyche* sp.
Trichoptera, Hydropsychidae	*Cheumatopsyche minuscula*
Trichoptera, Hydropsychidae	*Cheumatopsyche burksi*
Trichoptera, Hydropsychidae	*Cheumatopsyche pettiti*
Trichoptera, Hydropsychidae	*Cheumatopsyche campla*
Trichoptera, Polycentropidae	*Cemotina calcea*
Trichoptera, Polycentropidae	*Cernotina* sp.
Trichoptera, Polycentropidae	*Polycentropus centralis*
Trichoptera, Polycentropidae	*Nyctiophylax affinis*
Trichoptera, Polycentropidae	*Cyrnellus fraternus*
Trichoptera, Glossosomatidae	*Agapetus illini*
Trichoptera, Glossosomatidae	*Ochrotrichia anises*
Trichoptera, Glossosomatidae	*Ochrotrichia robisoni*
Trichoptera, Glossosomatidae	*Protoptila* sp.
Trichoptera, Hydroptilidae	*Hydroptila grandiosa*
Trichoptera, Hydroptilidae	*Hydroptila hamata*
Trichoptera, Hydroptilidae	*Hydroptila virgata*
Trichoptera, Hydroptilidae	*Metrichia* sp.
Trichoptera, Hydroptilidae	*Oxyethira* sp.
Trichoptera, Helicopsychidae	*Helicopsyche borealis*
Trichoptera, Helicopsychidae	*Helicopsyche limnella*
Trichoptera, Leptoceridae	*Triaenodes pemus*
Trichoptera, Leptoceridae	*Triaenodes injustus*
Trichoptera, Leptoceridae	*Triaenodes* sp.
Trichoptera, Leptoceridae	*Oecetis avara*
Trichoptera, Leptoceridae	*Oecetis cinerascens*
Trichoptera, Leptoceridae	*Oecetis eddlestoni*
Trichoptera, Leptoceridae	*Oecetis nocturna*
Trichoptera, Leptoceridae	*Oecetis ouachita*
Trichoptera, Leptoceridae	*Ceraclea ancylus*
Trichoptera, Leptoceridae	*Ceraclea cancl/lata*
Trichoptera, Leptoceridae	*Ceracea flava*
Trichoptera, Leptoceridae	*Ceraclea tarsipunctata*
Trichoptera, Leptoceridae	*Ceraclea transversa*
Trichoptera, Leptoceridae	*Ceraclea maculata*
Trichoptera, Leptoceridae	*Ceraclea punctata*
Trichoptera, Leptoceridae	*Ceraclea* sp.
Trichoptera, Leptoceridae	*Nectopsyche candids*
Trichoptera, Leptoceridae	*Nectopsyche exquisita*
Trichoptera, Leptoceridae	*Nectopsyche pavida*

Table 12. Odonata collected from the Kiamichi River and wetlands within 1 km of the river. Data from Michael Patten and Brenda Smith. C- common, U- uncommon, R – rare.

Calopteryx maculata	C
Hetaerina americana	C
Lestes australis	C
Lestes vigilax	U
Lestes inaequalis	U
Enallagma civile	U
Enallagma geminatum	U
Enallagma exsulans	C
Enallagma daeckii	R
Enallagma traviatum	U
Enallagma basidens	C
Enallagma dubium	R
Enallagma signatum	C
Ischnura kellicotti	U
Ischnura ramburii	U
Ischnura posita	C
Ischnura hastata	C
Nehalennia integricollis	U
Argia bipunctulata	R
Argia apicalis	U
Argia moesta	C
Argia fumipennis	C
Argia tibialis	U
Argia translata	C
Tachopteryx thoreyi	R
Epiaeschna heros	C
Nasiaeschna pentacantha	U
Basiaeschna janata	C
Coryphaeschna ingens	R
Anax junius	U
Progomphus obscurus	R
Phanogomphus oklahomensis	U
Phanogomphus lividus	R
Phanogomphus militaris	U
Phanogomphus graslinellus	C
Gomphurus ozarkensis	U
Gomphurus vastus	R
Stylurus plagiatus	R
Dromogomphus spinosus	C
Dromogomphus spoliatus	U
Hagenius brevistylus	C
Stylogomphus sigmastylus	U
Cordulegaster obliqua	U
Didymops transversa	C
Macromia illinoiensis georgina	U

Macromia taeniolata	U
Somatochlora linearis	U
Neurocordulia molesta	R
Neurocordulia xanthosoma	C
Epitheca cyanosura	C
Epitheca semiaquea	U
Epitheca costalis	C
Epitheca princeps	C
Plathemis lydia	C
Ladona deplanata	C
Libellula pulchella	U
Libellula luctuosa	C
Libellula cyanea	C
Libellula incesta	C
Libellula vibrans	C
Perithemis tenera	C
Celithemis fasciata	U
Celithemis eponina	C
Celithemis verna	U
Erythemis simplicicollis	C
Erythrodiplax umbrata	R
Sympetrum ambiguum	U
Sympetrum vicinum	U
Pachydiplax longipennis	C
Dythemis velox	U
Tramea onusta	U
Tramea lacerata	C
Pantala flavescens	C
Pantala hymenaea	U

Table 13. Crayfish collected from the Kiamichi watershed and their conservation status. Data provided by Elizabeth Bergey. Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. SNR – conservation status not assessed. Oklahoma Species of Concern, threat tiers C I – C III.

Species	**Common name**	**Conservation status**
Faxonius lancifer	Shrimp crayfish	G5, S1
Orconectes palmeri longimanus	Gray speckled crayfish	G5, SNR
Orconectes saxatilis	Kiamichi crayfish	G2, S1, C I
Procambarus acutus	White River crayfish	G5, SNR
Procambarus simulans	Southern Plains crayfish	G5, SNR
Procambarus tenuis	Ouachita Mountain crayfish	G3, S1, C II

Table 14. Mussel species from the Kiamichi River and their conservation status (ONHI 2021). Data from Caryn Vaughn. Taxonomy follows Williams et al. (2017). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. SNR – conservation status not assessed. Oklahoma Species of Concern, threat tiers C I – C III. FE – listed as federally endangered.

Scientific name	**Common name**	**Conservation status**
Actinonaias ligamentina	Mucket	G5, S3
Amblema plicata	Threeridge	G5, S3
Arcidens wheeleri	Ouachita Rock Pocketbook	G1, S1, C I, FE
Ellipsaria lineolata	Butterfly	G4G5, S2, C II
Fusconaia flava	Wabash Pigtoe	G5, SNR
Lampsilis cardium	Plain Pocketbook	G5, SNR
Lampsilis siliquoidea	Fatmucket	G5, SNR
Lampsilis teres	Yellow Sandshell	G5, SNR
Leptodea fragilis	Fragile Papershell	G5, SNR
Leptodea leptodon	Scaleshell	G1G2, S1, C II, FE
Ligumia subrostrata	Pondmussel	G5, SNR
Megalonaias nervosa	Washboard	G5, S2, C III
Obliquaria reflexa	Threehorn Wartyback	G5, S3
Obovaria arkansasensis	Ouachita Creekshell	GNR, S2, C II
Plectomerus dombeyanus	Bankclimber	G5, S2
Pleurobema rubrum	Pyramid Pigtoe	G2G3, SNR, C II
Potamilus purpuratus	Bleufer	G5, S4
Ptychobranchus occidentalis	Ouachita Kidneyshell	G3G4, S2, C I
Pyganodon grandis	Giant Floater	G5, SNR
Quadrula apiculata	Southern Mapleleaf	G5, SNR
Quadrula fragosa	Winged Mapleleaf	G1, S1, C I, FE
Cyclonaias pustulosa	Pimpleback	G5, SNR
Quadrula quadrula	Mapleleaf	G5, SNR
Strophitus undulatus	Creeper	G5, S3
Toxolasma parvum	Lilliput	G5, S4
Tritogonia verrucosa	Pistolgrip	G4G5, SNR
Truncilla donaciformis	Fawnsfoot	G5, SNR
Truncilla truncata	Deertoe	G5, SNR
Uniomerus tetralasmus	Pondhorn	G5, SNR
Utterbackia imbecillis	Paper Pondshell	G5, SNR
Villosa lienosa	Little Spectaclecase	G5, S2, C III

Table 15. Important traits of Kiamichi River mussel species. Adult size from Vaughn (2012): small (length < 60 mm), medium (60 – 100 mm), large (> 100 mm). Thermal guild from Spooner and Vaughn (2008) and Vaughn unpublished data. Brooding length, primary host group, and primary host infection mode from Vaughn (2012) and Haag (2012). Life history strategy from Haag (2012).

Scientific name	**Tribe**	**Adult size**	**Thermal guild**	**Brooding length**	**Primary host group**	**Primary host infection mode**	**Life history strategy**
Actinonaias ligamentina	Lampsilini	Large	Sensitive	Long	Centrarchids	Conglutinate	Equilibrium
Amblema plicata	Amblemini	Large	Tolerant	Short	Generalist	Free glochidia	Equilibrium
Arcidens wheeleri	Alasmidontini	Medium	Unknown	Long?	Generalist	Unknown	Periodic
Ellipsaria lineolata	Lampsilini	Medium to large	Unknown	Long	Drum	Unknown	Periodic
Fusconaia flava	Pleurobemini	Small to medium	Tolerant	Short	Minnows	Conglutinate	Equilibrium
Lampsilis cardium	Lampsilini	Large	Sensitive	Long	Centrarchids	Mantle lure	Periodic
Lampsilis siliquoidea	Lampsilini	Small	Sensitive	Long	Centrarchids	Mantle lure	Periodic
Lampsilis teres	Lampsilini	Large	Sensitive	Long	Gar	Mantle lure	Opportunistic
Leptodea fragilis	Lampsilini	Medium	Sensitive	Long	Drum	Free glochidia	Opportunistic
Leptodea leptodon	Lampsilini	Medium	Unknown	Long	Drum	Female sacrifice	Opportunistic
Ligumia subrostrata	Lampsilini	Small to medium	Unknown	Long	Centrarchids	Mantle lure	Periodic
Megalonaias nervosa	Quadrulini	Very large	Tolerant	Short	Generalist	Free glochidia	Equilibrium
Obliquaria reflexa	Lampsilini	Small	Tolerant	Short	Minnows	Conglutinate	Periodic
Obovaria arkansasensis	Lampsilini	Small	Unknown	Long	Unknown	Mantle lure	Periodic
Plectomerus dombeyanus	Amblemini	Large	Tolerant	Short	Unknown	Unknown	Equilibrium
Pleurobema rubrum	Pleurobemini	Medium	Unknown	Short	Minnows	Conglutinate	Equilibrium
Potamilus purpuratus	Lampsilini	Large	Tolerant	Long	Drum	Free glochidia	Opportunistic
Ptychobranchus occidentalis	Lampsilini	Small to medium	Unknown	Long	Darters	Conglutinate	Equilibrium
Pyganodon grandis	Alasmidontini	Large	Unknown	Short	Generalist	Free glochidia	Opportunistic
Quadrula apiculata	Quadrulini	Medium	Unknown	Short	Catfishes	Conglutinate	Equilibrium
Quadrula fragosa	Quadrulini	Medium	Unknown	Short	Catfishes	Conglutinate	Equilibrium
Cyclonaias pustulosa	Quadrulini	Small to medium	Sensitive	Short	Catfishes	Conglutinate	Equilibrium
Quadrula quadrula	Quadrulini	Medium	Unknown	Short	Catfishes	Conglutinate	Equilibrium
Strophitus undulatus	Alasmidontini	Medium	Unknown	Long	Generalist	Free glochidia	Periodic
Toxolasma parvum	Lampsilini	Very small	Unknown	Long	Centrarchids	Mantle lure	Opportunistic

Tritogonia verrucosa	Quadrulini	Medium to large	Sensitive	Short	Catfishes	Conglutinate	Equilibrium
Truncilla donaciformis	Lampsilini	Small	Sensitive	Long	Drum	Unknown	Opportunistic
Truncilla truncata	Lampsilini	Small	Sensitive	Long	Drum	Unknown	Opportunistic
Uniomerus tetralasmus	Pleurobemini	Medium	Unknown	Long	Minnows	Conglutinate	Periodic
Utterbackia imbecillis	Alasmidontini	Medium to large	Unknown	Long	Generalist	Free glochidia	Opportunistic
Villosa lienosa	Lampsilini	Small	Unknown	Long	Unknown	Mantle lure	Opportunistic

Table 16. Fish species known from the Kiamichi River watershed listed in order of conservation status. Information compiled from ONHI (2021) and William J. Matthews (pers comm). Conservation Status from ONHI (2021). Global ranks: G1 – Critically imperiled, G2 – Imperiled, G3 – Vulnerable, G4 – Apparently secure, G5 - Secure. State ranks: as above, but at the state level. T ranks refer to subspecies. SNR – conservation status not assessed. Oklahoma Species of Concern, threat tiers C I – C III.

Species	**Common name**	**Conservation status**
Crystallaria asprella	Crystal darter	G3, S1, C-II
Notropis ortenburgeri	Kiamichi shiner	G3, S3, C-II
Cycleptus elongatus	Blue sucker	G3G4, S2S3, C-II
Hiodon tergisus	Mooneye	G5, S2S3, C-II
Hybopsis amnis	Pallid shiner	G4, S1S2, C-II
Hybognathus hayi	Cypress minnow	G4G5, S1, C-II
Etheostoma histrio	Harlequin darter	G5, S3, C-II
Lythrurus fumeus	Ribbon shiner	G5, S3, C-II
Percina shumardi	River darter	G5, S3, C-II
Ictiobus niger	Black buffalo	G5, SU, C-II
Notropis atrocaudalis	Blackspot shiner	G4, S1
Notropis perpallidus	Peppered shiner	G3, S2
Polyodon spathula	Paddlefish	G4, S2
Notropis shumardi	Silverband shiner	G5, S2
Moxostoma carinatum	River redhorse	G4, S2S3
Notropis suttkusi	Rocky shiner	G3G4, S3
Ichthyomyzon gagei	Southern brook lamprey	G5, S2S3
Ammocrypta vivax	Scaly sand darter	G5, S2S3
Anguilla rostrata	American eel	G4, S3
Hybognathus placitus	Plains minnow	G4, S3S4
Etheostoma radiosum	Orangebelly darter	G4, S3S4
Carpiodes velifer	Highfin carpsucker	G4G5, S3S4
Percina maculata	Blackside darter	G5, S2S3, T
Notropis potteri	Chub shiner	G4, S4
Percina copelandi	Channel darter	G4, S4
Percina phoxocephala	Slenderhead darter	G5, S3
Hybognathus nuchalis	Silvery minnow	G5, S3
Morone mississippiensis	Yellow bass	G5, S3?
Amia calva	Bowfin	G5, S3S4
Alosa chrysochloris	Skipjack herring	G5, S3S4
Macrhybobsis hyostoma	Shoal chub	G5, S3S4
Opsopoeodus emiliae	Pugnose minnow	G5, S3S4
Campostoma spadiceum	Highland stoneroller	G4G5, SNR
Etheostoma parvipinne	Goldstripe darter	G4G5, SNR
Lepisosteus oculatus	Spotted gar	G5, S4
Lepisosteus platostomus	Shortnose gar	G5, S4
Hiodon alosoides	Goldeye	G5, S4
Notropis buchanani	Ghost shiner	G5, S4
Notropis volucellus	Mimic shiner	G5, S4
Phenacobius mirabilis	Suckermouth minnow	G5, S4
Ictiobus cyprinellus	Bigmouth buffalo	G5, S4

Minytrema melanops	Spotted sucker	G5, S4
Moxostoma duquesnei	Black redhorse	G5, S4
Noturus gyrinus	Tadpole madtom	G5, S4
Noturus nocturnus	Freckled madtom	G5, S4
Pylodictus olivaris	Flathead catfish	G5, S4
Elassoma zonatum	Banded pygmy sunfish	G5, S4
Etheostoma gracile	Slough darter	G5, S4
Etheostoma nigrum	Johnny darter	G5, S4
Percina macrolepida	Bigscale logperch	G5, S4
Percina sciera	Dusky darter	G5, S4
Etheostoma proeliare	Cypress darter	G5, S4?
Lepisosteus osseus	Longnose gar	G5, S5
Dorosoma cepedianum	Gizzard shad	G5, S5
Cyprinella lutrensis	Red shiner	G5, S5
Cyprinella venustus	Blacktail Shiner	G5, S5
Cyprinella whipplei	steelcolor shiner	G5, S5
Lythrurus umbratilis	Redfin shiner	G5, S5
Notropis boops	Bigeye shiner	G5, S5
Pimephales notatus	Bluntnose minnow	G5, S5
Pimephales promelas	Fathead minnow	G5, S5
Pimephales vigilax	Bullhead minnow	G5, S5
Carpiodes carpio	River carpsucker	G5, S5
Ictiobus bubalus	Smallmouth buffalo	G5, S5
Moxostoma erythrurum	Golden redhorse	G5, S5
Ameiurus melas	Black bullhead	G5, S5
Ameiurus natalis	Yellow bullhead	G5, S5
Ictalurus furcatus	Blue catfish	G5, S5
Ictalurus punctatus	Channel catfish	G5, S5
Esox americanus	Grass or redfin pickerel	G5, S5
Aphredoderus sayanus	Pirate perch	G5, S5
Fundulus notatus	Blackstripe topminnow	G5, S5
Fundulus olivaceus	Blackspotted topminnow	G5, S5
Gambusia affinis	Western mosquitofish	G5, S5
Labidesthes sicculus	Brook silverside	G5, S5
Menidia beryllina	Inland silverside	G5, S5
Morone chrysops	White bass	G5, S5
Lepomis cyanelllus	Green sunfish	G5, S5
Lepomis gulosus	Warmouth	G5, S5
Lepomis humilis	Orangespotted sunfish	G5, S5
Lepomis macrochirus	Bluegill	G5, S5
Lepomis megalotis	Longear sunfish	G5, S5
Lepomis microlophus	Redear sunfish	G5, S5
Lepomis miniatus	Redspotted sunfish	G5, S5
Micropterus dolomieui	Smallmouth bass	G5, S5
Micropterus punctulatus	Spotted bass	G5, S5
Micropterus salmoides	Largemouth bass	G5, S5
Pomoxis annularis	White crappie	G5, S5
Pomoxis nigromaculatus	Black crappie	G5, S5

Etheostoma spectabile	Orangethroat darter	G5, S5
Percina caprodes	Logperch	G5, S5
Aplodinotus grunniens	Freshwater drum	G5, S5
Notemigonus crysoleucas	Golden shiner	G5, S5
Notropis atherinoides	Emerald shiner	G5, S5
Carassius auratus	Goldfish	G5, SNA
Cyprinus carpio	Carp	G5, SNA
Dorosoma petenense	Threadfin shad	G5, SNR
Erimyzon claviformis	Western creek chubsucker	G5, SNR
Etheostoma chlorosomum	Bluntnose darter	G5, SNR
Notropis stramineus	Sand shiner	G5, SNR

Table 17. Total and relative abundance of fish species collected across 41 sites in the Kiamichi River watershed in 2014 – 15 by Dr. William J. Matthews and Zach Zbinden, listed in order of abundance. These data include both mainstem and tributary sites described in Matthews et al. (2016). Sites were sampled by seining all habitats within approximately 100 m of wadeable stream reach using one or two sizes of net, depending on the width of the stream (4.57 m × 1.22 m × 4.88 mm mesh and/or 2.44 m × 1.22 m × 4.88 mm mesh). Channel and pool habitats were sampled by pulling seines downstream; riffle and edge habitat were sampled by kickseining. Data provided by W.J. Matthews.

Species	**Common name**	**Number of individuals**	**Relative abundance (%)**
Lythrurus umbratilis	Redfin shiner	2400	31.14
Notropis boops	Bigeye shiner	966	12.54
Notropis suttkusi	Rocky shiner	680	8.82
Gambusia affinis	Western mosquitofish	499	6.48
Campostoma spadiceum	Highland stoneroller	488	6.33
Labidesthes sicculus	Brook silversides	394	5.11
Cyprinella whipplei	Steelcolor shiner	391	5.07
Lepomis macrochirus	Bluegill	367	4.76
Lepomis megalotis	Longear sunfish	300	3.89
Notropis ortenburgeri	Kiamichi shiner	195	2.53
Micropterus salmoides	Largemouth bass	179	2.32
Etheostoma radiosum	Orangebelly darter	109	1.41
Lepomis cyanellus	Green sunfish	92	1.19
Fundulus olivaceous	Blackspotted topminnow	75	0.97
Fundulus notatus	Blackstriped topminnow	74	0.96
Erimyzon oblongus	Creek chubsucker	72	0.93
Pimephales notatus	Bluntnose minnow	50	0.65
Lepomis microlophus	Redear sunfish	47	0.61
Notemigonus crysoleucas	Golden shiner	39	0.51
Notropis atrocaudalis	Blackspot shiner	33	0.43
Notropis atherinoides	Emerald shiner	30	0.39
Etheostoma gracile	Slough darter	28	0.36
Esox americanus	Redfin pickeral	26	0.34
Moxostoma erythrurum	Golden redhorse	24	0.31
Notropis volucellus	Mimic shiner	19	0.25
Dorosoma cepedianum	Gizzard shad	17	0.22
Etheostoma nigrum	Johnny darter	12	0.16
Cyprinella venusta	Blacktail shiner	11	0.14
Pomoxis annularis	White crappie	10	0.13
Lepomis humilus	Orangespot sunfish	9	0.12
Moxostoma duquesnei	Black redhorse	7	0.09
Dorosoma petenense	Threadfin shad	6	0.08
Minytrema melanops	Spotted sucker	6	0.08
Lepomis gulosus	Warmouth	6	0.08
Lepisosteus oculatus	Spotted gar	5	0.06
Aphredoderus sayanus	Pirate perch	5	0.06

Etheostoma chlorosum	Bluntnose darter	5	0.06
Ameiurus melas	Black bullhead	4	0.05
Percina copelandi	Channel darter	4	0.05
Pimephales vigilax	Bullhead minnow	3	0.04
Ameurus natalis	Yellow bullhead	3	0.04
Percina caprodes	Logperch	3	0.04
Percina sciera	Dusky darter	3	0.04
Ictiobus bubalus	Smallmouth buffalo	2	0.03
Ichthyomyzon sp.	Lamprey ammocoete	1	0.01
Lepisosteus osseus	Longnose gar	1	0.01
Elassoma zonatum	Pygmy sunfish	1	0.01
Micropterus punctulatus	Spotted bass	1	0.01
Pomoxis nigromaculatus	Black crappie	1	0.01
Etheostoma sp.	Darter	1	0.01
Etheostoma proeliare	Cypress darter	1	0.01
Aplodinotus grunniens	Freshwater drum	1	0.01

Table 18. Total and relative abundance at 11 mainstem Kiamichi sites in 2012-2013, listed in order of abundance. Fish were collected by 30 minutes of electrofishing and 200 meter seine hauls at each site, as well as experimental gill netting for large-bodied fish. Data from Porter and Patton (2015).

Species	**Common name**	**Total abundance**	**Relative abundance**
Labidesthes sicculus	Brook Silverside	1920	19.96
Pimephales notatus	Bluntnose Minnow	812	8.44
Lepomis macrochirus	Bluegill	795	8.26
Cyprinella whipplei	Steelcolor Shiner	720	7.48
Lepomis megalotis	Longear Sunfish	699	7.27
Etheostoma radiosum	Orangebelly Darter	646	6.72
Percina caprodes	Log Perch	523	5.44
Lepomis cyanellus	Green Sunfish	488	5.07
Notropis boops	Bigeye Shiner	401	4.17
Notropis atherinoides	Emerald Shiner	316	3.28
Gambusia affinis	Mosquito Fish	266	2.77
Campostoma spadiceum	Highland stoneroller	262	2.72
Lythrurus umbratilis	Redfin Shiner	175	1.82
Pomoxis annularis	White Crappie	147	1.53
Fundulus olivaceus	Blackspotted topminnow	137	1.42
Notropis ortenburgeri	Kiamichi Shiner	126	1.31
Ictalurus furcatus	Blue Catfish	119	1.24
Lepomis humilis	Orangespotted Sunfish	94	0.98
Etheostoma nigrum	Johnny Darter	86	0.89
Micropterus punctulatus	Spotted Bass	86	0.89
Dorosoma cepedianum	Gizzard Shad	78	0.81
Ictalurus punctatus	Channel Catfish	72	0.75
Ictiobus bubalus	Smallmouth Buffalo	70	0.73
Lepisosteus osseus	Longnose Gar	64	0.67
Morone mississippiensis	Yellow Bass	49	0.51
Percina copelandi	Channel Darter	48	0.50
Etheostoma spectabile	Orangethroat Darter	43	0.45
Percina sciera	Dusky Darter	36	0.37
Notropis volucellus	Mimic Shiner	31	0.32
Percina phoxocephala	Slenderhead Darter	29	0.30
Fundulus notatus	Blackstripe Topminnow	27	0.28
Micropterus salmoides	Largemouth Bass	23	0.24
Noturus nocturnus	Freckled Madtom	22	0.23
Moxostoma carinatum	River Redhorse	22	0.23
Lepomis microlophus	Redear Sunfish	20	0.21
Etheostoma chlorosoma	Bluntnose Darter	17	0.18
Lepisosteus oculatus	Spotted Gar	15	0.16
Minytrema melanops	Spotted Sucker	15	0.16
Carpiodes carpio	River Carpsucker	14	0.15
Pylodictis olivaris	Flathead Catfish	13	0.14
Moxostoma erythrurum	Golden Redhorse	13	0.14
Ictiobus cyprinellus	Bigmouth Buffalo	11	0.11

Pomoxis nigromaculatus	Black Crappie	11	0.11
Percina maculata	Blackside Darter	10	0.10
Aplodinotus grunniens	Drum	10	0.10
Morone chrysops	White Bass	10	0.10
Cyprinus carpio	Common Carp	8	0.08
Etheostoma proeliare	Cypress Darter	5	0.05
Atractosteus spatula	Alligator Gar	4	0.04
Lepomis gulosus	Warmouth Sunfish	4	0.04
Noturus gyrinus	Tadpole Madtom	3	0.03
Ameiurus melas	Black Bullhead	1	0.01
Amia calva	Bowfin	1	0.01
Ichthyomyzon castaneus	Chestnut Lamprey	1	0.01
Morone chrysops x saxatilis	Hybrid Striped Bass	1	0.01
Polyodon spathula	Paddlefish	1	0.01

Table 19. Fish abundance from six mainstem sites in the Kiamichi River. Data for the 1980s are means for fish collected by W.J. Matthews and students in 1981, 1985, 1986, and 1987. Data for 2014 are from collections by W.J. Matthews and Z. Zbinden. Fish are listed in order of their coefficient of variation, which represents how much fish abundance varied across the five sampling periods. Sites were sampled by seining. Data provided by W.J. Matthews

Species	**Common name**	**1980s**	**2014**	**CV**
Etheostoma radiosum	Orangebelly darter	32.5	38	0.34
Lepomis macrochirus	Bluegill	8.8	9	0.38
Gambusia affinis	Western mosquitofish	28.5	48	0.44
Cyprinella whipplei	Steelcolor shiner	327.5	355	0.47
Fundulus sp.	Top minnows	24.3	53	0.50
Lythrurus umbratilis	Redfin shiner	285.8	439	0.58
Lepomis megalotis	Longear sunfish	87.5	46	0.59
Lepomis cyanellus	Green sunfish	3.0	7	0.60
Micropterus salmoides	Largemouth bass	10.0	25	0.61
Labidesthes sicculus	Brook silversides	75.3	211	0.67
Micropterus punctulatus	Spotted bass	14.0	1	0.68
Notropis boops	Bigeye shiner	695.5	406	0.71
Percina sciera	Dusky darter	15.3	1	0.71
Percina copelandi	Channel darter	15.5	6	0.83
Etheostoma gracile	Slough darter	4.5	1	0.86
Notropis ortenburgeri	Kiamichi shiner	13.5	0	0.87
Pimephales vigilax	Bullhead minnow	2.0	3	0.87
Campostoma spadiceum	Highland stoneroller	98.5	54	0.89
Notropis volucellus	Mimic shiner	5.0	19	0.89
Cyprinella venusta	Blacktail shiner	26.8	1	0.92
Etheostoma nigrum	Johnny darter	2.5	5	0.94
Opsopoeodus emiliae	Pugnose minnow	4.8	0	0.97
Notropis perpallidus	Pallid shiner	7.5	0	1.00
Pimephales notatus	Bluntnose minnow	14.3	8	1.00
Pomoxis annularis	White crappie	0.8	4	1.08
Percina caprodes	Logperch	7.0	0	1.34
Ictalurus punctatus	Channel catfish	0.5	0	1.37
Pomoxis nigromaculatus	Black crappie	0.3	1	1.37
Esox americanus	Redfin pickerel	0.5	4	1.37
Ameiurus melas	Black bullhead	5.8	0	1.37
Lepisosteus osseus	Longnose gar	1.3	0	1.41
Lythrurus fumeus	Ribbon shiner	1.3	0	1.41
Noturus nocturnus	Freckled madtom	4.3	0	1.46
Ictiobus bubalus	Smallmouth buffalo	0.3	2	1.49
Notemigonus crysoleucas	Golden shiner	0.3	2	1.49
Notropis atherinoides	Emerald shiner	2.5	28	1.51
Notropis suttkusi	Rocky shiner	58.0	658	1.51
Percina phoxocephala	Slenderhead darter	7.3	0	1.60

Moxostoma erythrurum	Golden redhorse	0.5	9	1.74
Dorosoma cepedianum	Gizzard shad	20.5	8	1.75
Noturus gyrinus	Tadpole madtom	2.8	0	1.99
Aphredoderus sayanus	Pirate perch	0.3	0	2.24
Cyprinus carpio	Carp	0.3	0	2.24
Dorosoma petenense	Threadfin shad	0.0	2	2.24
Lepomis humilus	Orangespot sunfish	0.3	0	2.24
Lepomis microlophus	Redear sunfish	0.3	0	2.24
Notropis buchanani	Ghost shiner	5.5	0	2.24
Pylodictus olivaris	Flathead catfish	0.3	0	2.24

Table 20. Habitat of fish species known from the Kiamichi River watershed. List of fish species complied by William J. Matthews. Classification of habitat generalist (G) or fluvial specialist (F) according to Fisher et al. (2005) with some modifications. Habitat descriptions compiled from Miller and Robison (2004), Robison and Buchanan (1988), and NatureServe (2021).

Species	**Common name**	**G or F**	**Habitat & Habits**
Ichthyomyzon gagei	Southern brook lamprey	F	Burrows in mud and detritus at stream margins
Polyodon spathula	Paddlefish	F	Low-gradient backwater areas
Lepisosteus oculatus	Spotted gar	G	Quiet waters with vegetation,
Lepisosteus osseus	Longnose gar	G	Typically in sluggish areas or backwaters
Lepisosteus platostomus	Shortnose gar	G	Most common in muddy or sandy backwaters
Amia calva	Bowfin	G	Slow water with vegetation
Alosa chrysochloris	Skipjack herring	G	Usually in current over sand or gravel
Hiodon alosoides	Goldeye	G	Nocturnal, river pools and reservoirs
Hiodon tergisus	Mooneye	G	Clear area of rivers over hard substrate
Anguilla rostrata	American eel	F	Nocturnal
Dorosoma cepedianum	Gizzard shad	G	Schools, prefers deep, calm water
Dorosoma petenense	Threadfin shad	G	Pelagic schooler, prefers warm water
Campostoma spadiceum	Highland stoneroller	F	Riffles and shallow areas over hard substrates
Carassius auratus	Goldfish	G	Shallow, warm pools with vegetation
Cyprinella lutrensis	Red shiner	F	Widespread and tolerant of many habitat conditons
Cyprinella venustus	Blacktail Shiner	F	Schools in areas with strong current over sandy sediment
Cyprinella whipplei	steelcolor shiner	F	Most often over gravel in large riffles, midwater schooler
Cyprinus carpio	Carp	G	Pools, reservoirs, tolerant of most bottom conditions
Hybognathus hayi	Cypress minnow	G	Muddy backwaters
Hybognathus nuchalis	Silvery minnow	G	Schools, Quiet or rapid water over sandy or muddy sediments
Hybognathus placitus	Plains minnow	G	Main channel over silt of sand sediments
Hybopsis amnis	Pallid shiner	G	Quiet water over sandy silty sediments
Lythrurus fumeus	Ribbon shiner	F	Quiet pools and backwaters over sandy or muddy sediments
Lythrurus umbratilis	Redfin shiner	F	Pool dweller, tolerates turbidity
Macrhybobsis hyostoma	Shoal chub	F	Shallow riffles over sand or mud
Notemigonus crysoleucas	Golden shiner	G	Quiet water with vegetation, pollution and turbidity tolerant
Notropis atherinoides	Emerald shiner	G?	Schools, midwater to surface, sandy substrates
Notropis atrocaudalis	Blackspot shiner	F?	Shallow, flowing areas

Notropis boops	Bigeye shiner	F	Gravel and rock-bottomed pools
Notropis buchanani	Ghost shiner	G	Midwater schooler in pools and backwaters, tolerates reservoirs
Notropis ortenburgeri	Kiamichi shiner	F	
Notropis perpallidus	Peppered shiner	F	Slow areas > 20 inches deep
Notropis potteri	Chub shiner	G	Main channel over silt of sand sediments
Notropis shumardi	Silverband shiner	F	Schools in flowing pools and runs over sand, gravel, silt and mud
Notropis stramineus	Sand shiner	F	Schools in midwater or near bottom, shallow sandy areas
Notropis suttkusi	Rocky shiner	F	High gradient, flowing areas over gravel and rubble
Notropis volucellus	Mimic shiner	F	Schools in midwater over gravel and sand
Opsopoeodus emiliae	Pugnose minnow	G	Quiet, vegetated areas
Phenacobius mirabilis	Suckermouth minnow	F	Riffle dweller, but tolerates turbidity
Pimephales notatus	Bluntnose minnow	G	Pools and backwaters, in clear water over gravel
Pimephales promelas	Fathead minnow	G	Thrives in many habitats, including ponds
Pimephales vigilax	Bullhead minnow	G	Pools and backwaters, turbidiy tolerant
Carpiodes carpio	River carpsucker	G	Pools and backwaters, turbidity tolerant
Carpiodes velifer	Highfin carpsucker	G	Quiet, clear water
Cycleptus elongatus	Blue sucker	F	Bottom of main channel in rapid water, reservoirs
Erimyzon claviformis	Western creek chubsucker		Sandy or gravel-bottomed streams, intolerant of turbidity
Ictiobus bubalus	Smallmouth buffalo	G	Pools and deeper areas
Ictiobus cyprinellus	Bigmouth buffalo	G	Deep pools in rivers, reservoirs, turbidity tolerant
Ictiobus niger	Black buffalo	G	Pools and deeper areas
Minytrema melanops	Spotted sucker	F	Slow water in long deep pools, intolerant of siltation
Moxostoma carinatum	River redhorse	F	Main channel in clear waters
Moxostoma duquesni	Black redhorse	F	Medium-sized clear streams, rocky pools with current
Moxostoma erythrurum	Golden redhorse	F	Pools and runs over hard bottom
Ameiurus melas	Black bullhead	G?	Soft-bottomed backwaters and pools
Ameiurus natalis	Yellow bullhead	G	Prefers clear water with some vegetation
Ictalurus furcatus	Blue catfish	G	Main channels in swift water, reservoirs
Ictalurus punctatus	Channel catfish	G	Generalist, often in deep pools in day and shallow water at night
Noturus gyrinus	Tadpole madtom	G	Slow water with vegetation,
Noturus nocturnus	Freckled madtom	F	Riffles, runs, and shallow pools, ususally over hard substrate
Pylodictus olivaris	Flathead catfish	G	Deep holes and channels, but generalists and turbidity tolerant
Esox americanus	Grass or redfin pickerel	G	Quiet water with vegetation

Aphredoderus sayanus	Pirate perch	G	Slow water, generally over soft bottoms or in vegetation
Fundulus notatus	Blackstripe topminnow	F	Quiet water along the edges of pools or backwaters
Fundulus olivaceus	Blackspotted topminnow	F	Quiet water along the edges of pools or backwaters
Gambusia affinis	Western mosquitofish	G	Generalist
Labidesthes sicculus	Brook silverside	G	Prefers calm pools and backwaters, schools
Menidia beryllina	Inland silverside	G	Lower river in shallow water, reservoirs
Morone chrysops	White bass	G	Typically occur in large schools, open water in pools & reservoirs
Morone mississippiensis	Yellow bass	G	Open water
Elassoma zonatum	Banded pygmy sunfish	G	Quiet backwaters, usually with vegetation
Lepomis cyanelllus	Green sunfish	G	Prefers small streams
Lepomis gulosus	Warmouth	G	River pools and ponds and reservoirs
Lepomis humilis	Orangespotted sunfish	G	Sandy and mud-bottomed streams
Lepomis macrochirus	Bluegill	G	Clear quiet water with limited vegetation
Lepomis megalotis	Longear sunfish	G	Quiet pools in clear low-gradient areas over hard substrate
Lepomis microlophus	Redear sunfish	G	Tends to congregate around stumps and brush
Lepomis miniatus	Redspotted sunfish	G	Clear quiet and often turbid water
Micropterus dolomieui	Smallmouth bass	F	Cool, clear, rocky streams
Micropterus punctulatus	Spotted bass	G	Do best in small, clear streams, but tolerate some turbidity
Micropterus salmoides	Largemouth bass	G	Quiet pools in streams and rivers, ponds, reservoirs
Pomoxis annularis	White crappie	G	Turbidity tolerant generalist, often around submerged trees or brush
Pomoxis nigromaculatus	Black crappie	G	Prefer clear water, usually with vegetation
Ammocrypta vivax	Scaly sand darter	F	Moderate current over shifting sand bottoms
Crystallaria asprella	Crystal darter	F	Deep riffles over silt-free sandy or fine gravel
Etheostoma chlorosomum	Bluntnose darter	G	Quiet water with soft bottoms
Etheostoma gracile	Slough darter	G	Quiet water with soft bottoms, often with detritus and vegetation
Etheostoma histrio	Harlequin darter	G	Sand-detritus microhabitats adjacent to riffles
Etheostoma nigrum	Johnny darter	G	Clear water over sand or gravel, moderate to high gradient
Etheostoma parvipinne	Goldstripe darter	F	Shallow tributary streams or spring fed streams

Etheostoma proeliare	Cypress darter	F	Vegetated areas along the edges of the stream
Etheostoma radiosum	Orangebelly darter	F	Riffles and runs over gravel and rubble
Etheostoma spectabile	Orangethroat darter	F	Riffles in small, gravel-bottomed streams
Percina caprodes	Logperch	F	Usually over gravel in fairly deep riffle areas
Percina copelandi	Channel darter	F	Quiet, clear areas over sand or gravel
Percina macrolepida	Bigscale logperch	F	Gravel and sand runs and pools
Percina maculata	Blackside darter	F	Gravel bottomed pools and riffles with moderate current
Percina phoxocephala	Slenderhead darter	F	Swift water over clear gravel and sand
Percina sciera	Dusky darter	F	Rivers and raceways, often associated with cover (boulders, plants)
Percina shumardi	River darter	F	Deeper riffles and raceways
Aplodinotus grunniens	Freshwater drum	G	Deeper pools

Table 21. Feeding traits of fish species known from the Kiamichi River watershed. List of fish species complied by William J. Matthews. Information compiled from Miller and Robison (2004), Robison and Buchanan (1988), and NatureServe (2021).

Species	**Common name**	**Feeding mode and diet**
Ichthyomyzon gagei	Southern brook lamprey	Amnocoetes larvae are filter feeders. Adults don't feed
Polyodon spathula	Paddlefish	Planktivore
Lepisosteus oculatus	Spotted gar	Piscivore as adult; fry feed on invertebrates
Lepisosteus osseus	Longnose gar	Piscivore
Lepisosteus platostomus	Shortnose gar	Primarily piscivorous
Amia calva	Bowfin	Nocturnal predator
Alosa chrysochloris	Skipjack herring	Feeds primarily on minnows and insect larvae
Hiodon alosoides	Goldeye	General predator
Hiodon tergisus	Mooneye	General predator
Anguilla rostrata	American eel	Bottom feeder and scavenger
Dorosoma cepedianum	Gizzard shad	Planktivore
Dorosoma petenense	Threadfin shad	Planktivore
Campostoma spadiceum	Highland stoneroller	Algal grazer
Carassius auratus	Goldfish	
Cyprinella lutrensis	Red shiner	Omnivore feeding on algae and insects
Cyprinella venustus	Blacktail Shiner	Terrestrial insects and plant material
Cyprinella whipplei	steelcolor shiner	Sight feeder on drifting insects
Cyprinus carpio	Carp	Omnivore
Hybognathus hayi	Cypress minnow	Detritivore
Hybognathus nuchalis	Silvery minnow	Grazer on algae and vegetation
Hybognathus placitus	Plains minnow	Herbivore
Hybopsis amnis	Pallid shiner	
Lythrurus fumeus	Ribbon shiner	Midwater schooler, surface feeder
Lythrurus umbratilis	Redfin shiner	Omnivore on algae and invertebrates
Macrhybobsis hyostoma	Shoal chub	Feeds on invertebrates
Notemigonus crysoleucas	Golden shiner	Schools midwater to surface, sight feeder at surface
Notropis atherinoides	Emerald shiner	Feeds on zooplankton
Notropis atrocaudalis	Blackspot shiner	
Notropis boops	Bigeye shiner	Feeds mainly on insects
Notropis buchanani	Ghost shiner	
Notropis ortenburgeri	Kiamichi shiner	
Notropis perpallidus	Peppered shiner	Feeds on insects
Notropis potteri	Chub shiner	Feeds primarily on benthic insects
Notropis shumardi	Silverband shiner	
Notropis stramineus	Sand shiner	Omnivorous, but feeds primarily on insects
Notropis suttkusi	Rocky shiner	
Notropis volucellus	Mimic shiner	Omnivorous on algae, insects, and detritus
Opsopoeodus emiliae	Pugnose minnow	Feeds in midwater on insects and algae

Phenacobius mirabilis	Suckermouth minnow	Aquatic insects and plants
Pimephales notatus	Bluntnose minnow	Feed on algae and insect larvae
Pimephales promelas	Fathead minnow	Feeds on plankton, insect larvae and some plant material
Pimephales vigilax	Bullhead minnow	Omnivorous
Carpiodes carpio	River carpsucker	Omnivorus bottom feeder
Carpiodes velifer	Highfin carpsucker	Omnivorus bottom feeder
Cycleptus elongatus	Blue sucker	Bottom feeder on insect larve and mollusks
Erimyzon claviformis	Western creek chubsucker	Feed on insects and alage on the stream bottome
Ictiobus bubalus	Smallmouth buffalo	Opportunistic bottom feeders
Ictiobus cyprinellus	Bigmouth buffalo	Feeds on zooplankton, insect larvae, insects
Ictiobus niger	Black buffalo	Feeds on benthic macroinvertebrates and mollusks
Minytrema melanops	Spotted sucker	Omnivorous, detritus and invertebrates
Moxostoma carinatum	River redhorse	Feeds mainly on small bivalves, also eats insects
Moxostoma duquesni	Black redhorse	Feeds on insect larvae, crustaceans, and works
Moxostoma erythrurum	Golden redhorse	Feeds on insect larvae and small mollusks
Ameiurus melas	Black bullhead	Omnivorous bottom feeder
Ameiurus natalis	Yellow bullhead	Bottom feeder on invertebrates and small fish
Ictalurus furcatus	Blue catfish	Omnivorous
Ictalurus punctatus	Channel catfish	Omnivorous on organic material
Noturus gyrinus	Tadpole madtom	Forages at night on macroinvertebrates
Noturus nocturnus	Freckled madtom	Feeds on macroinvertebrates
Pylodictus olivaris	Flathead catfish	Young are invertivores, adults are piscivorous
Esox americanus	Grass or redfin pickerel	Piscivore as adult; fry feed on invertebrates
Aphredoderus sayanus	Pirate perch	Predator on small fish and invertebrates
Fundulus notatus	Blackstripe topminnow	Feeds on insects and other invertebrates near the surface
Fundulus olivaceus	Blackspotted topminnow	Feeds on insects and other invertebrates near the surface
Gambusia affinis	Western mosquitofish	Surface feeder on terrestrial insects and other invertebrates
Labidesthes sicculus	Brook silverside	Feeds near surface on insects
Menidia beryllina	Inland silverside	Feeds on insects and plankton
Morone chrysops	White bass	Feed on small fish such as shad
Morone mississippiensis	Yellow bass	Feed on small fish and invertebrates
Elassoma zonatum	Banded pygmy sunfish	Feeds on small crustaceans and insect larvae
Lepomis cyanelllus	Green sunfish	Feeds on insects and fish
Lepomis gulosus	Warmouth	Feeds on fish, crayfish, and larval insects
Lepomis humilis	Orangespotted sunfish	Feeds on insect larvae and small crustaceans
Lepomis macrochirus	Bluegill	Feeds on microcrustaceans and insects
Lepomis megalotis	Longear sunfish	Feeds mainly on aquatic and terrestrial insects
Lepomis microlophus	Redear sunfish	Feeds on invertebrates, particularly snails
Lepomis miniatus	Redspotted sunfish	Feeds on aquatic insects and other invertebrates
Micropterus dolomieui	Smallmouth bass	Feeds on fish, crayfish, and aquatic insects

Micropterus punctulatus	Spotted bass	Feeds on fish, crayfish, and aquatic insects
Micropterus salmoides	Largemouth bass	Feeds on fish, crayfish, and aquatic insects
Pomoxis annularis	White crappie	Adults are piscivores
Pomoxis nigromaculatus	Black crappie	Feeds on small fish and aquatic insects
Ammocrypta vivax	Scaly sand darter	Feeds on small aquatic insects
Crystallaria asprella	Crystal darter	Feeds on small aquatic insects
Etheostoma chlorosomum	Bluntnose darter	Feeds on aquatic insects
Etheostoma gracile	Slough darter	Feeds on aquatic insects and small crustaceans
Etheostoma histrio	Harlequin darter	Feeds on aquatic insect larvae
Etheostoma nigrum	Johnny darter	Feed on insect larvae and other small invertebrates
Etheostoma parvipinne	Goldstripe darter	
Etheostoma proeliare	Cypress darter	Feeds on aquatic insects and small crustaceans
Etheostoma radiosum	Orangebelly darter	Young feed on small crustaceans, adults on insects
Etheostoma spectabile	Orangethroat darter	Feeds on insect larvae and fish eggs
Percina caprodes	Logperch	Feeds on larval insects and other small invertebrates
Percina copelandi	Channel darter	Feed on small aquatic insects and microcrustaceans
Percina macrolepida	Bigscale logperch	Opportunistic: Feeds on invertebrates and fish eggs
Percina maculata	Blackside darter	Feeds on insect larvae, sometimes from midwater
Percina phoxocephala	Slenderhead darter	Feeds on insect larvae
Percina sciera	Dusky darter	Feeds on aquatic insects
Percina shumardi	River darter	Feeds on aquatic insect larvae, esp. midges and caddiflies
Aplodinotus grunniens	Freshwater drum	Feed on bottom on aquatic insects and crustaceans

Table 22. Life history traits of fish species known from the Kiamichi River watershed. List of fish species compiled by William J. Matthews. Information compiled from Miller and Robison (2004), Robison and Buchanan (1988), and NatureServe (2021).

Species	**Common name**	**Life history traits**
Ichthyomyzon gagei	Southern brook lamprey	Adults spawn in tributaries in the spring, then die; Larvae live in sediments for several years
Polyodon spathula	Paddlefish	Move upstream in spring to spawn over gravel when temp > 60 F
Lepisosteus oculatus	Spotted gar	Spawn in shallow water in the spring
Lepisosteus osseus	Longnose gar	Spawn in shallow areas in the spring
Lepisosteus platostomus	Shortnose gar	Spawn in shallow areas in the spring
Amia calva	Bowfin	Early spring spawner, nests in shallow, weedy areas
Alosa chrysochloris	Skipjack herring	Schools; travels upstream in spring to spawn
Hiodon alosoides	Goldeye	Spawns in April
Hiodon tergisus	Mooneye	Spawns March - May
Anguilla rostrata	American eel	Migrate to ocean to spawn
Dorosoma cepedianum	Gizzard shad	Spawn in shallow water near shore in the spring
Dorosoma petenense	Threadfin shad	Spawns in spring when water temp > 70 F
Campostoma spadiceum	Highland stoneroller	Dig nests in riffles in spring, spawn March - May
Carassius auratus	Goldfish	Spring spawner in vegetation, however most often released as bait and not reproducing
Cyprinella lutrensis	Red shiner	Late spring through summer spawner
Cyprinella venustus	Blacktail Shiner	Summer spawner, males defend spawning territories, eggs deposited in crevices
Cyprinella whipplei	steelcolor shiner	Late spring to summer spawner near riffles, eggs in crevices or tree roots, males defend spawning territories
Cyprinus carpio	Carp	Spawns in spring to early summer, generally in groups over vegetation
Hybognathus hayi	Cypress minnow	Spawns in spring
Hybognathus nuchalis	Silvery minnow	Spawns late spring and early summer
Hybognathus placitus	Plains minnow	Spawns spring to summer, demersal eggs
Hybopsis amnis	Pallid shiner	Spawns late winter to early spring
Lythrurus fumeus	Ribbon shiner	Likely spawns in summer
Lythrurus umbratilis	Redfin shiner	Spawns late April to summer; spawns over sunfish nests
Macrhybobsis hyostoma	Shoal chub	Spring and summer spawner when water temp > 70 F
Notemigonus crysoleucas	Golden shiner	Spring spawner over submerged vegetation
Notropis atherinoides	Emerald shiner	Spawns late spring to early summer after water temps > 72 F
Notropis atrocaudalis	Blackspot shiner	

Notropis boops	Bigeye shiner	Summer spawner
Notropis buchanani	Ghost shiner	Summer spawner
Notropis ortenburgeri	Kiamichi shiner	
Notropis perpallidus	Peppered shiner	Likely spawns in summer
Notropis potteri	Chub shiner	
Notropis shumardi	Silverband shiner	Likely spawns in summer
Notropis stramineus	Sand shiner	Spawns in late spring through summer over gravel and sand
Notropis suttkusi	Rocky shiner	
Notropis volucellus	Mimic shiner	Spawns late spring and summer, nocturnal
Opsopoeodus emiliae	Pugnose minnow	Likely spawns in early summer
Phenacobius mirabilis	Suckermouth minnow	Breeds in riffles, April through August
Pimephales notatus	Bluntnose minnow	Males territorial and defend nests, spawn May - August
Pimephales promelas	Fathead minnow	Spawns April - July, males defend nests
Pimephales vigilax	Bullhead minnow	Males territorial, spawns late spring and early summer
Carpiodes carpio	River carpsucker	Breeds May - June in shallow water
Carpiodes velifer	Highfin carpsucker	Spawns later spring or early summer
Cycleptus elongatus	Blue sucker	
Erimyzon claviformis	Western creek chubsucker	Spawns in spring
Ictiobus bubalus	Smallmouth buffalo	Spawns April - June in shallow backwaters or flooded riparian areas
Ictiobus cyprinellus	Bigmouth buffalo	Schools, Spawns during spring floods over shallow, weedy areas
Ictiobus niger	Black buffalo	Spawns April - June in shallow backwaters or flooded riparian areas
Minytrema melanops	Spotted sucker	Spawns in riffles in soring
Moxostoma carinatum	River redhorse	Spawn in shallow water in spring when water temperature > 70 F
Moxostoma duquesni	Black redhorse	April spawner
Moxostoma erythrurum	Golden redhorse	Spawns in shallow riffles April - May
Ameiurus melas	Black bullhead	Spawn in cleared holes in vegetation or other cover May - June
Ameiurus natalis	Yellow bullhead	Spawns (builds nest) next to logs or banks in late spring - early summer
Ictalurus furcatus	Blue catfish	
Ictalurus punctatus	Channel catfish	Spawn in holes near bank (build by male) in May - June
Noturus gyrinus	Tadpole madtom	Spawns June and July, parents guard eggs
Noturus nocturnus	Freckled madtom	Spawns in shallow areas in summer
Pylodictus olivaris	Flathead catfish	Spawn late spring to early summer in nest depressions and holes
Esox americanus	Grass or redfin pickerel	Spawns in February and March
Aphredoderus sayanus	Pirate perch	Spawns in spring, builds nest and protects young

Fundulus notatus	Blackstripe topminnow	Spawns in spring and summer in tree roots, vegetation, or other structure
Fundulus olivaceus	Blackspotted topminnow	
Gambusia affinis	Western mosquitofish	Livebearer, can produce several broods a year
Labidesthes sicculus	Brook silverside	Spawns late spring to summer, eggs attached to plants or other objects by adhesive threads
Menidia beryllina	Inland silverside	Spawns March - May
Morone chrysops	White bass	Move into shallow areas in tributary streams to spawn in March and April
Morone mississippiensis	Yellow bass	Breed in spring over gravel and rocky shallows
Elassoma zonatum	Banded pygmy sunfish	Spawn in spring in vegetation; males guard territories
Lepomis cyanelllus	Green sunfish	Builds shallow nests and spawns in May - early summer; males guard nests
Lepomis gulosus	Warmouth	Builds shallow nests and spawns in May - early summer
Lepomis humilis	Orangespotted sunfish	Spawns spring to early sumer
Lepomis macrochirus	Bluegill	Builds and defends nests in large colonies, spawning typically in May and June
Lepomis megalotis	Longear sunfish	Builds nests, spawns May - August
Lepomis microlophus	Redear sunfish	Builds nests, spawns April - August
Lepomis miniatus	Redspotted sunfish	Builds nests, spawns April - August
Micropterus dolomieui	Smallmouth bass	Builds nests, spawns April - May, male guards eggs and hatchlings
Micropterus punctulatus	Spotted bass	Builds nests, spawn Apri - May
Micropterus salmoides	Largemouth bass	Spawns in spring when water temp > 65 F, males guard nests and schools of young fish
Pomoxis annularis	White crappie	Spawn in April over nests, usually around vegetation
Pomoxis nigromaculatus	Black crappie	Spawn in April over nests, usually around vegetation
Ammocrypta vivax	Scaly sand darter	Likely spring or early summer spawner, but data lacking for Oklahoma
Crystallaria asprella	Crystal darter	
Etheostoma chlorosomum	Bluntnose darter	Likely spawns in late April or May
Etheostoma gracile	Slough darter	Breeds in April
Etheostoma histrio	Harlequin darter	Spawns February - March
Etheostoma nigrum	Johnny darter	Spawing migrations in April - May, males establish breeding territories under stones
Etheostoma parvipinne	Goldstripe darter	Spawns in spring
Etheostoma proeliare	Cypress darter	Breeds in spring
Etheostoma radiosum	Orangebelly darter	Spawns March - May
Etheostoma spectabile	Orangethroat darter	Spawn in shallow gravel riffles in spring
Percina caprodes	Logperch	Spawns in riffles in late March or April
Percina copelandi	Channel darter	Spawns in June in swift current, males defend territories

Percina macrolepida	Bigscale logperch	
Percina maculata	Blackside darter	Spawns in spring over sand or gravel when water temperature > 60 F
Percina phoxocephala	Slenderhead darter	Breeds March - June in moderately deep, swift riffles
Percina sciera	Dusky darter	Spring spawner
Percina shumardi	River darter	Spring spawner
Aplodinotus grunniens	Freshwater drum	Schooling, pelagic spawner in late spring (April - May)

Table 23. Critical thermal maxima of some fish species from the Kiamichi River. Critical thermal maxima is a measure of a species' upper temperature tolerance. Species are listed from least to most tolerant. Data from Brewer et al. (2019).

Species	**Common name**	**CTMax**
Notropis ortenburgeri	Kiamichi shiner	32.50
Etheostoma radiosum	Orangebelly darter	33.97
Percina copelandi	Channel darter	34.09
Percina sciera	Dusky darter	34.30
Percina phoxocephala	Slenderhead darter	34.32
Notropis boops	Bigeye shiner	34.43
Notropis atherinoides	Emerald shiner	34.49
Cyprinella whipplei	Steelcolor shiner	34.71
Pimephales vigilax	Bullhead minnow	34.73
Percina caprodes	Logperch	35.00
Campostoma spadiceum	Highland stoneroller	35.08
Pimephales notatus	Bluntnose minnow	35.13
Micropterus dolomieui	Smallmouth bass	37.71
Fundulus olivaceus	Blackspotted topminnow	38.28

Appendix 2. Overview of the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC) Regime Prescription Tool (RPT) for the Sustainable Rivers Program, Kiamichi River Project

RPT ANALYSIS

An analysis using the HEC-RPT (Hydrologic Engineering Center - Regime Prescription Tool) program was completed on the Kiamichi River at Sardis Dam, to facilitate the development of some possible river management alternatives on the Kiamichi River below Sardis Dam. The basic development of the RPT model included determining defining the water year, defining the states that the model would work within, determining and creating systems (ecological, hydrological, spatial, etc.) that are the target of the river management alternatives, and then developing flow components (Llow flow, Ppulse flow, flood flow etc.) to visualize those alternatives.

RPT Build Out/Input Data

RPT Buildout

Water Year

The model was set up defining the Water Year as a typical Water Year (10/01-09/30).

RPT States

The states desired in the Kiamichi model were determined to be Wet, Average, and Dry years. The original plan was to rank the yearly average data by 25% wettest years, 50% average years, and 25% driest years, but after the data had been analyzed in HEC-EFM (Ecosystems Functions Model) it was determined that a better representation of the ranking was ~18% wettest years, ~ 58% average years, and ~ 24% driest years.

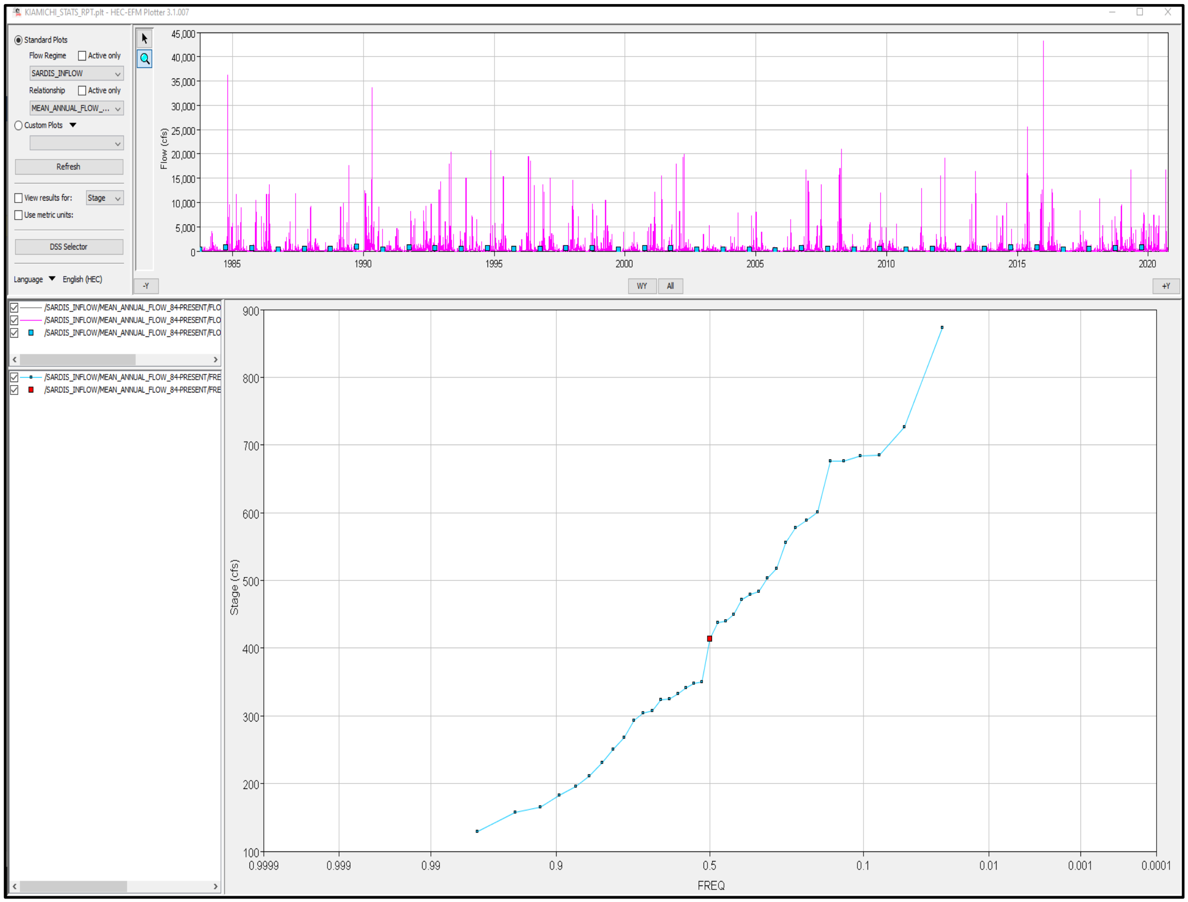
WET	1985, 1990, 1992, 2015-2016, 2020	Wettest: ~18% of years (based on annual volume)
AVERAGE	1986, 1988-1989, 1993-1999, 2001-2002, 2005, 2007-2010, 2012-2014, 2018-2019	Average: 58% of years (based on annual volume)
DRY	1984, 1987, 1991, 2000, 2003-2004, 2006, 2011, 2017	Driest: ~ 24% of years (based on annual volume)

Table 24. Wet, Average, and Dry Years in the Kiamichi Basin

HEC-EFM

HEC-EFM is a planning tool that aids in analyzing ecosystem response to changes in flow regime. It enables project teams to visualize existing ecological conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative change in ecosystems aspects. Central to HEC-EFM analyses are “functional relationships”. These relationships link characteristics of hydrologic and hydraulic time series (flow in the Kiamichi project) to the elements of the ecosystem through a combination of four basic criteria: season, duration, rate of change, and percent exceedance. After these relationships are developed, EFM performs statistical computations to analyze flow data for the specified criteria and produces a single flow value for each relationship. This tool was used to determine what years would be categorized as “wet, average and dry” for state modeling in HEC-RPT.

Because the Kiamichi team is interested in the reaches below Sardis Lake, the period of record evaluated in the statistical analysis was chosen to be 1984-2020, which is the year that Sardis was filled to elevation 596 ft and reliable inflow data was calculated and collected.


KIAMICHI_STATS_RPT.plt - HEC-EFM Plotter 3.1.007

● Standard Plots
Flow Regime ☐ Active only
SARDIS_INFLOW
Relationship ☐ Active only
MEAN_ANNUAL_FLOW_...
○ Custom Plots
☐ View results for: Stage
☐ Use metric units:
Language English (HEC)

☑ /SARDIS_INFLOW/MEAN_ANNUAL_FLOW_84-PRESENT/FLO
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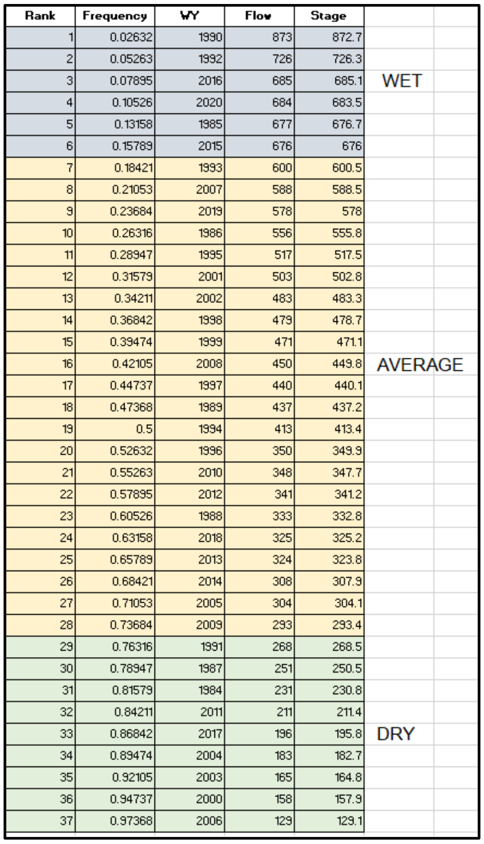
Figure 9. HEC-EFM Statistical Ranking Output



Rank	Frequency	WY	Flow	Stage	
1	0.02632	1990	873	872.7	
2	0.05263	1992	726	726.3	
3	0.07895	2016	685	685.1	WET
4	0.10526	2020	684	683.5	
5	0.13158	1985	677	676.7	
6	0.15789	2015	676	676	
7	0.18421	1993	600	600.5	
8	0.21053	2007	588	588.5	
9	0.23684	2019	578	578	
10	0.26316	1986	556	555.8	
11	0.28947	1995	517	517.5	
12	0.31579	2001	503	502.8	
13	0.34211	2002	483	483.3	
14	0.36842	1998	479	478.7	
15	0.39474	1999	471	471.1	
16	0.42105	2008	450	449.8	AVERAGE
17	0.44737	1997	440	440.1	
18	0.47368	1989	437	437.2	
19	0.5	1994	413	413.4	
20	0.52632	1996	350	349.9	
21	0.55263	2010	348	347.7	
22	0.57895	2012	341	341.2	
23	0.60526	1988	333	332.8	
24	0.63158	2018	325	325.2	
25	0.65789	2013	324	323.8	
26	0.68421	2014	308	307.9	
27	0.71053	2005	304	304.1	
28	0.73684	2009	293	293.4	
29	0.76316	1991	268	268.5	
30	0.78947	1987	251	250.5	
31	0.81579	1984	231	230.8	
32	0.84211	2011	211	211.4	
33	0.86842	2017	196	195.8	DRY
34	0.89474	2004	183	182.7	
35	0.92105	2003	165	164.8	
36	0.94737	2000	158	157.9	
37	0.97368	2006	129	129.1	

Table 25. HEC-EFM Statistical Ranking Output

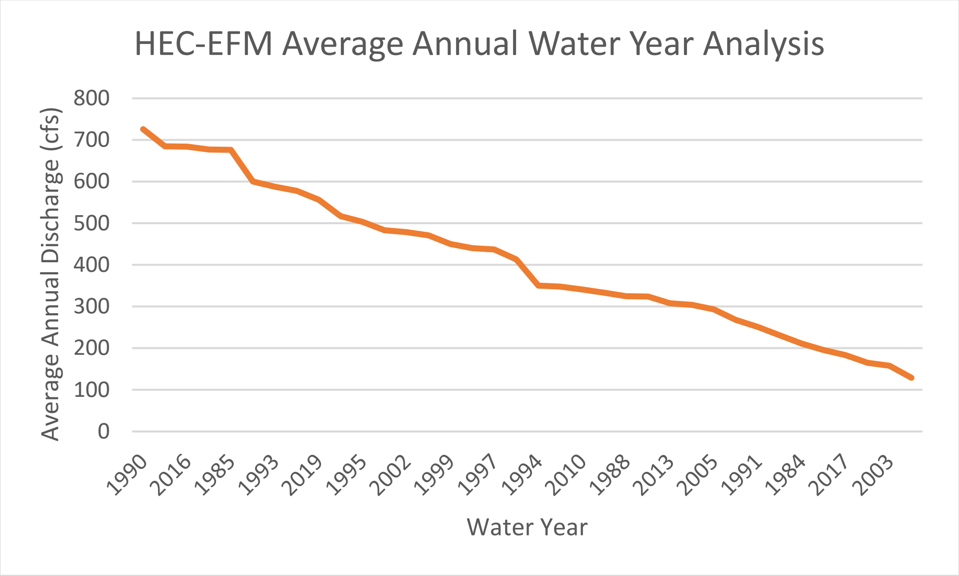


Figure 10. Average annual discharge (cfs) analysis by water year from HEC-EFM.

RPT Systems

The original systems discussed to be modeled in the Kiamchi_SRP_E_FLOWS_WRKSHOP model included the Kiamichi River broken in to into 3 reaches (Reach 0 – Sardis to Kiamichi, Reach 1 – Kiamichi to Hugo, and Reach 2 – Kiamichi to below Hugo) to model the spatial component of the study; and 3 ecological components of the study, (Mussels, Spawning, and Glochidia) to model the ecological component of the study.

After discussion of the set-up of the workshop, it was determined that only one breakout session would be required, so only the spatial systems would be set up in the model, and the ecological systems will would be modeled with flow components in the model during the workshop.

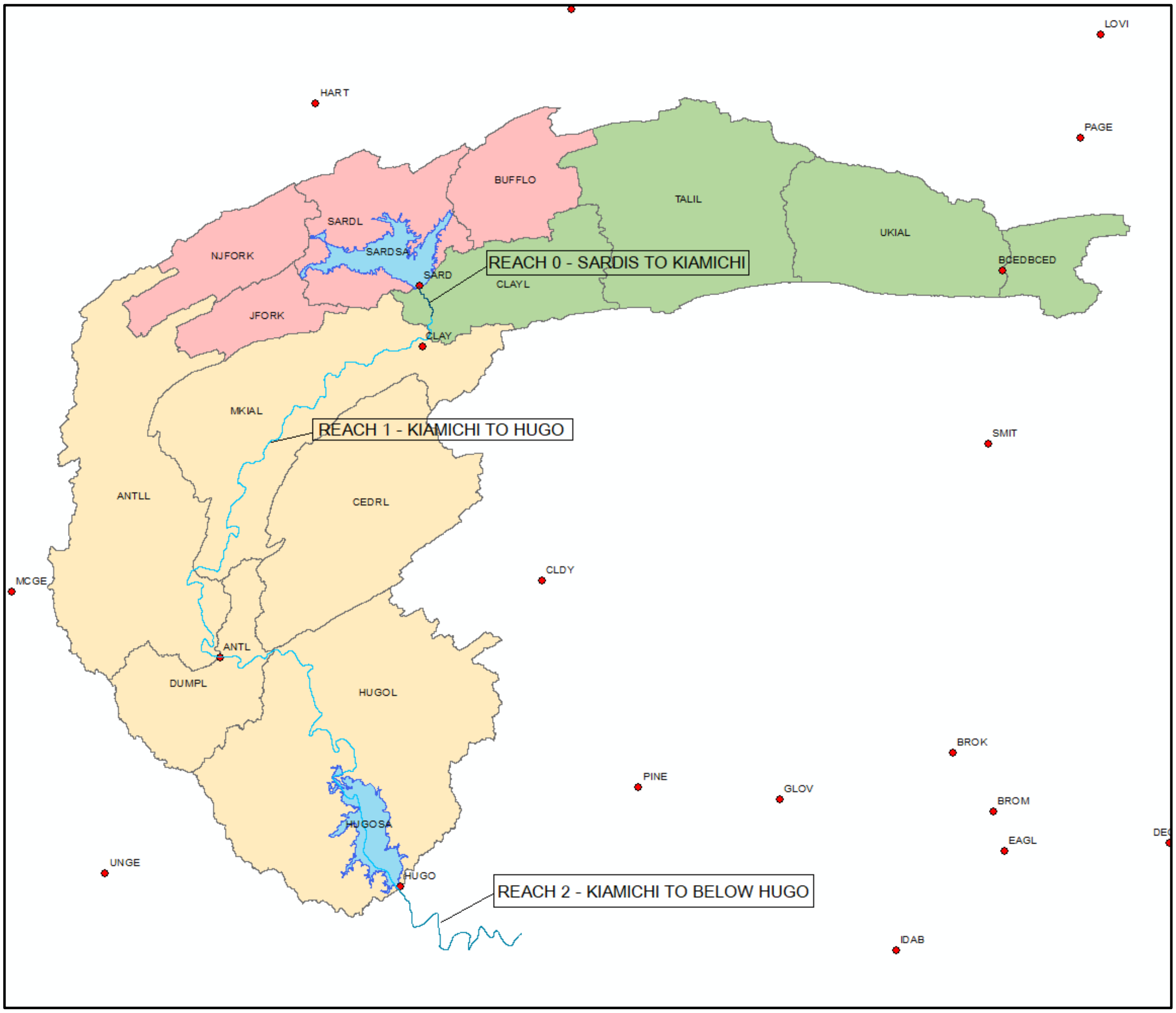


Table 11. Reaches for Kiamichi System Breakouts in RPT Model

Flow Components

The flow components may include low flows, flood flows, and pulse flows. These flow components will be determined based on input during the workshop.

Input Data

The original plan for input data used to build the base hydrology in the model started with the idea of using the RiverWare-Period-of-Record (RW-POR) simulated data. RiverWare is a river system simulation software created out of by CADWES in Boulder CO Colorado, and with the Red River model is housed in at the Tulsa District Corps of Engineers' Hydrology and Hydraulics Branch. It uses historic hydrology and current conditions to model the river system. However, after some discussion it was determined that it was preferable to use actual observed data in the RPT modeling. The observed data set used encompassed the 1984-2020 time span which includes the time period that Sardis filled to close to present time.

Location	Parameter	Data Type	Time Frame	Time Interval	Source
Hugo	Flow-Res In	Observed	1984-2020	1 DAY	COE
Hugo	Flow- Res out	Observed	1984-2020	1 DAY	COE
Sardis	Flow-Res In	Observed	1984-2020	1 DAY	COE
Sardis	Flow- Res out	Observed	1984-2020	1 DAY	COE
Antlers	Flow	Observed	1984-2020	1 DAY	USGS
Clayton	Flow	Observed	1984-2020	1 DAY	USGS

Table 26. Observed data available for Antlers, Clayton, Hugo, and Sardis.

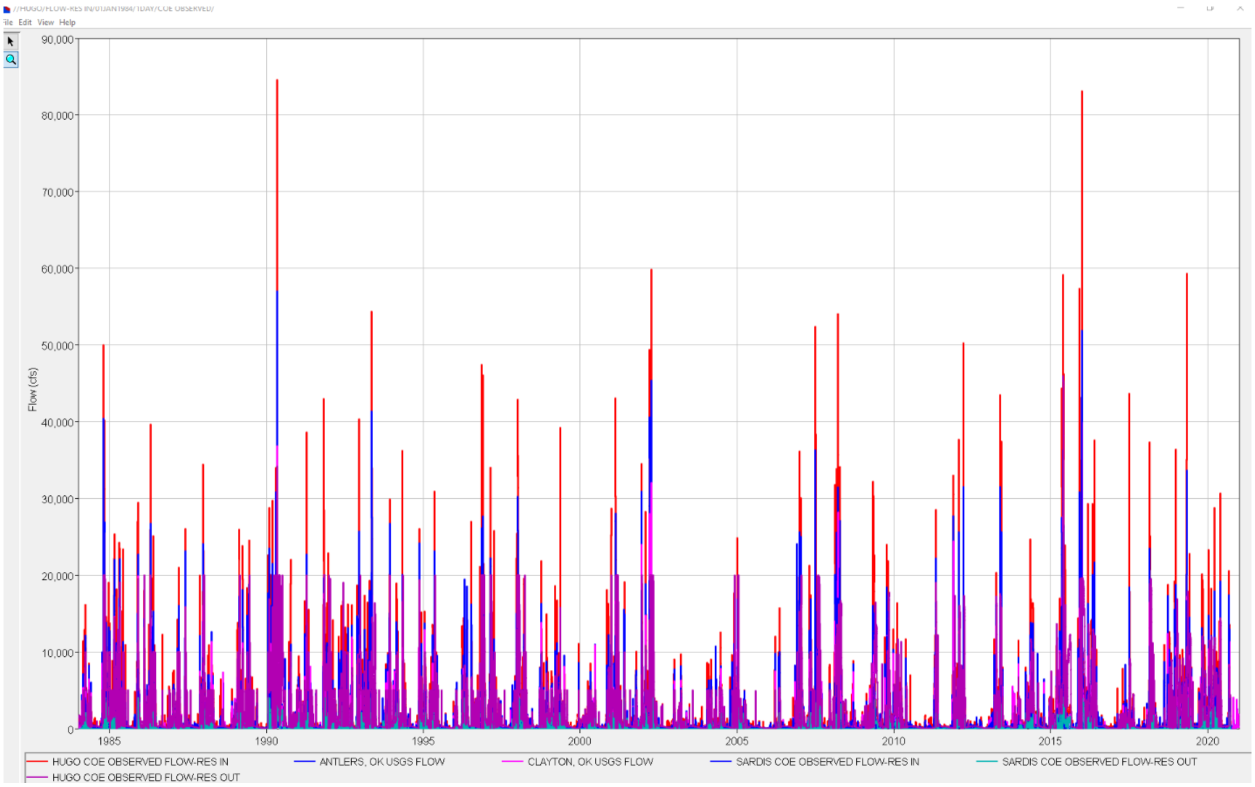


Figure 12. Observed data for Antlers, Clayton, Hugo, and Sardis.

Appendix 3. Indicators of Hydrologic Alteration assessment of the Kiamichi River

IHA Analysis

Indicators of Hydrologic Alteration (IHA) is useful in understanding the human impacts of dams and for understanding environmental flow regime recommendations for water managers. There are 67 ecologically relevant statistics that are generated from IHA using daily hydrologic data. These statistics help understand the degree of hydrologic alteration between them. Hydrologic data for this analysis consisted of USGS gage data along with gage data from the Corps. IHA statistics can be looked at to determine hydrologic impacts from dams and reservoirs. IHA looks at magnitude, timing, frequency, and rate-of-change for flows.

The comparison at Sardis showed that the number of zero-flow days post-impoundment increased, which may be an important statistic to consider when defining environmental flow recommendations. The Range of Variability (RVA) scorecard shows the different hydrologic statistics for both pre and post impoundment at Sardis Reservoir.

The comparison at Hugo showed that high flow events have been reduced since the construction of Hugo Reservoir.

Pre- and post-impact median flows, for both Sardis and Hugo Reservoirs seem to be similar from June through September based on the IHA output. Flow duration curves post-impoundment at Sardis appear the most dramatic in flow changes compared to Hugo Reservoir. One and three-day maximum annual averages have changed dramatically since the Sardis Reservoir impoundment.

Since the construction of the Sardis Reservoir, the number of reversals has changed. The number of increasing flows to decreasing flows and then decreasing flows to increasing flows defines reversals on a regulated system.

Zero-discharge days also occur at the Clayton gage which is influenced by the Sardis Reservoir.

IHA appears to be good at picking up the climatological events that have occurred over the decades in the Kiamichi River watershed. These events have ranged from flooding to droughts.

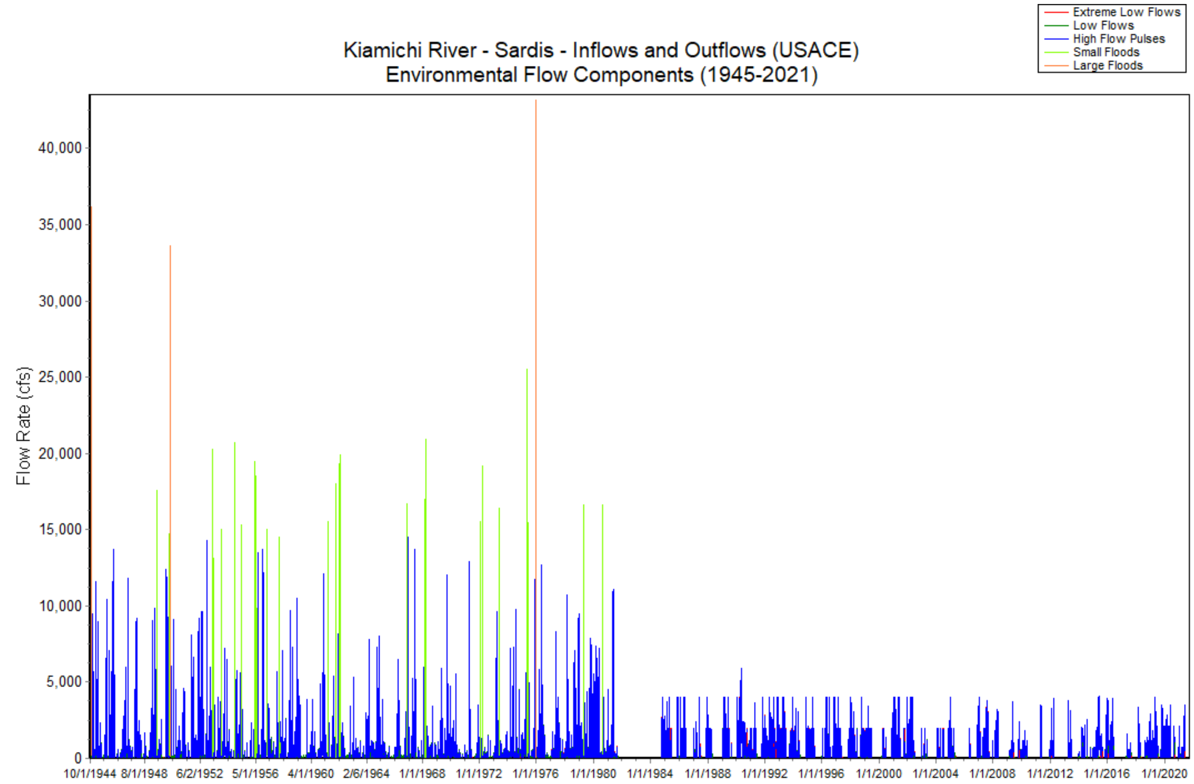


Figure 13. Sardis Lake, Oklahoma pre-impoundment hydrograph (left half) and post-impoundment hydrograph (right half).

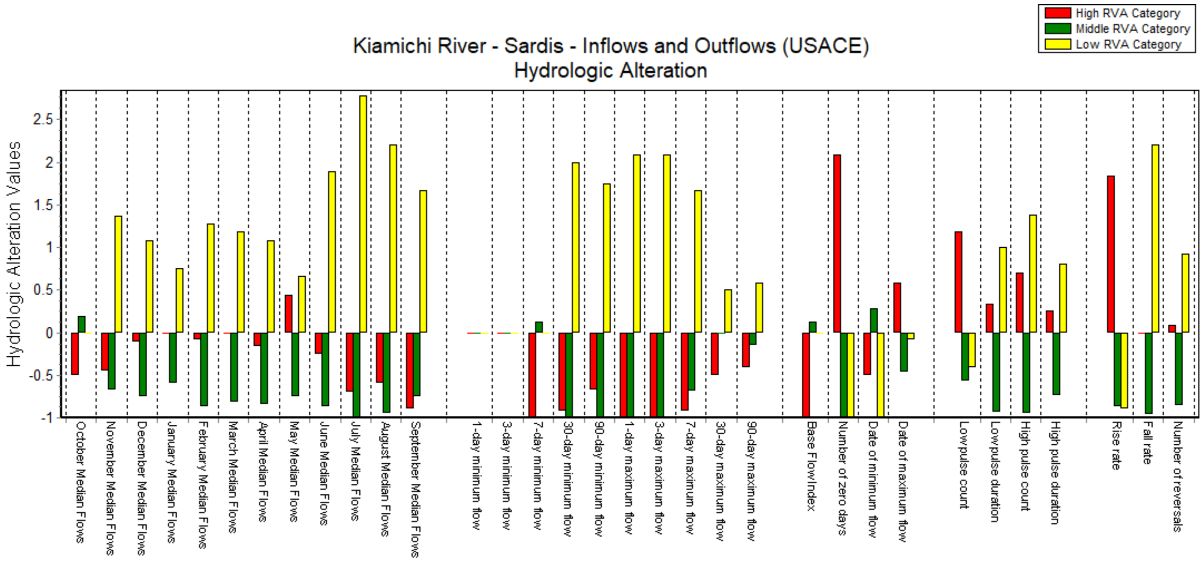


Figure 14. Range of Variability Application (RVA) scorecard overview of pre- and post-impoundment discharge at Sardis Lake, Oklahoma.

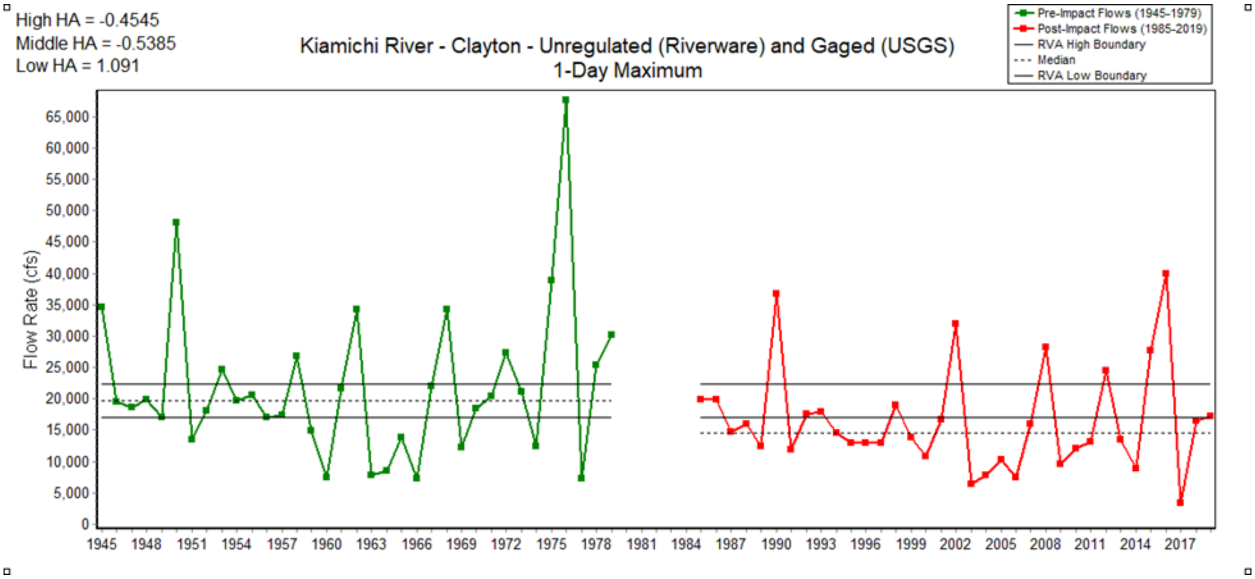


Figure 15. Pre- and post-impoundment 1-day maximum average annual discharge at Sardis Dam, Oklahoma.

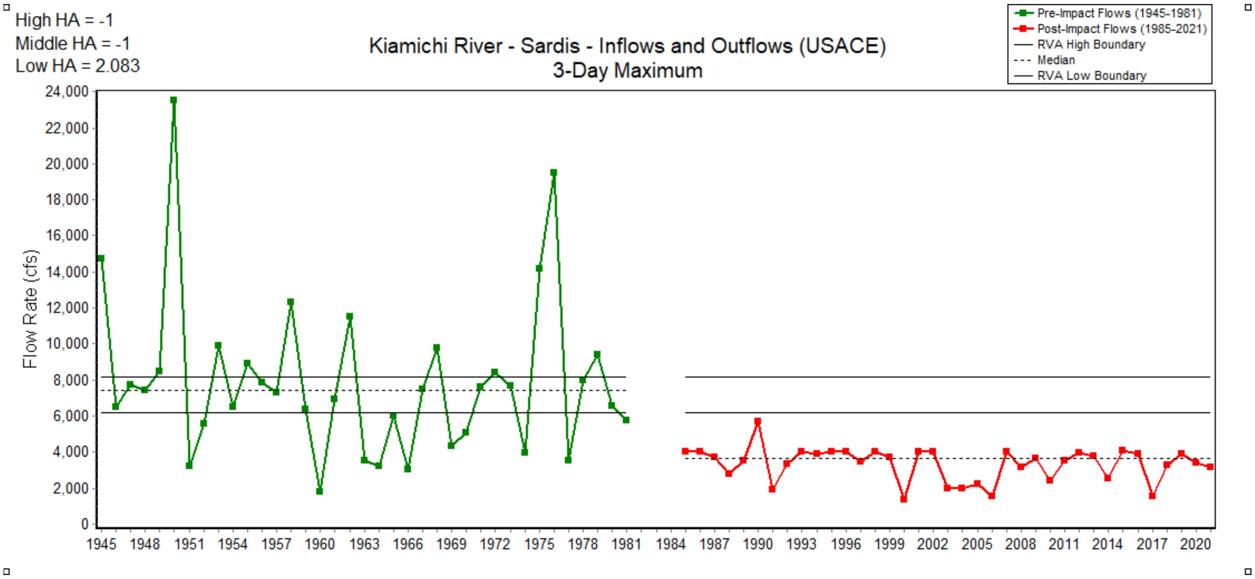


Figure 16. Pre- and post-impoundment 3-day maximum average annual discharge at Sardis Dam, Oklahoma.

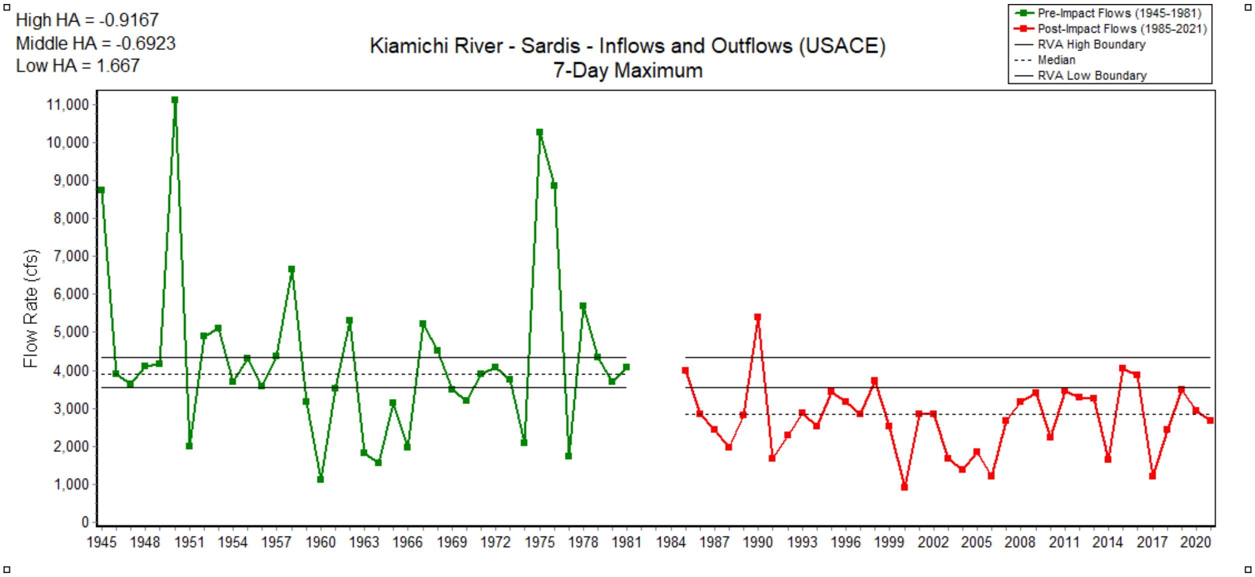


Figure 17. Pre- and post-impoundment 7-day maximum average annual discharge at Sardis Dam, Oklahoma.

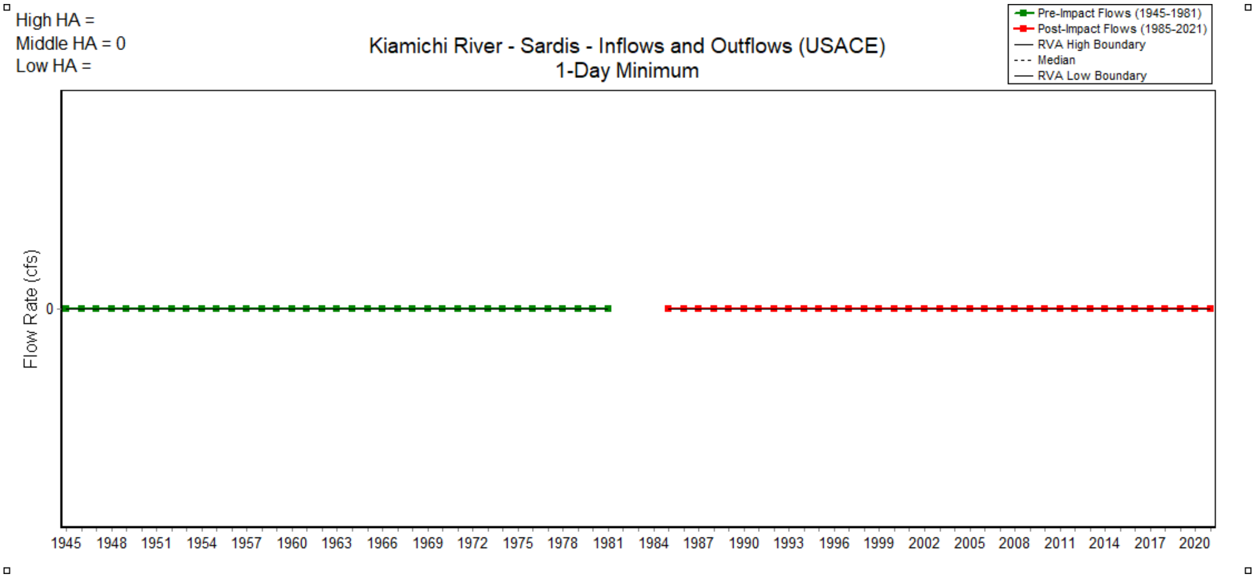


Figure 18. Pre- and post-impoundment 1-day minimum average annual discharge at Sardis Dam, Oklahoma.

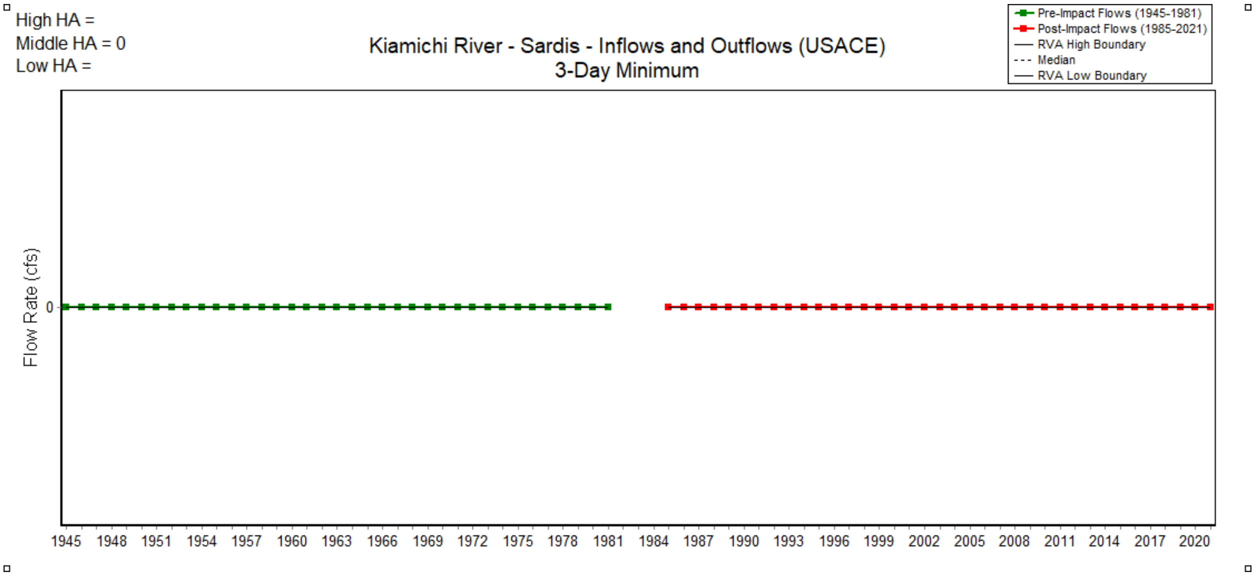


Figure 19. Pre- and post-impoundment 3-day minimum average annual discharge at Sardis Dam, Oklahoma.

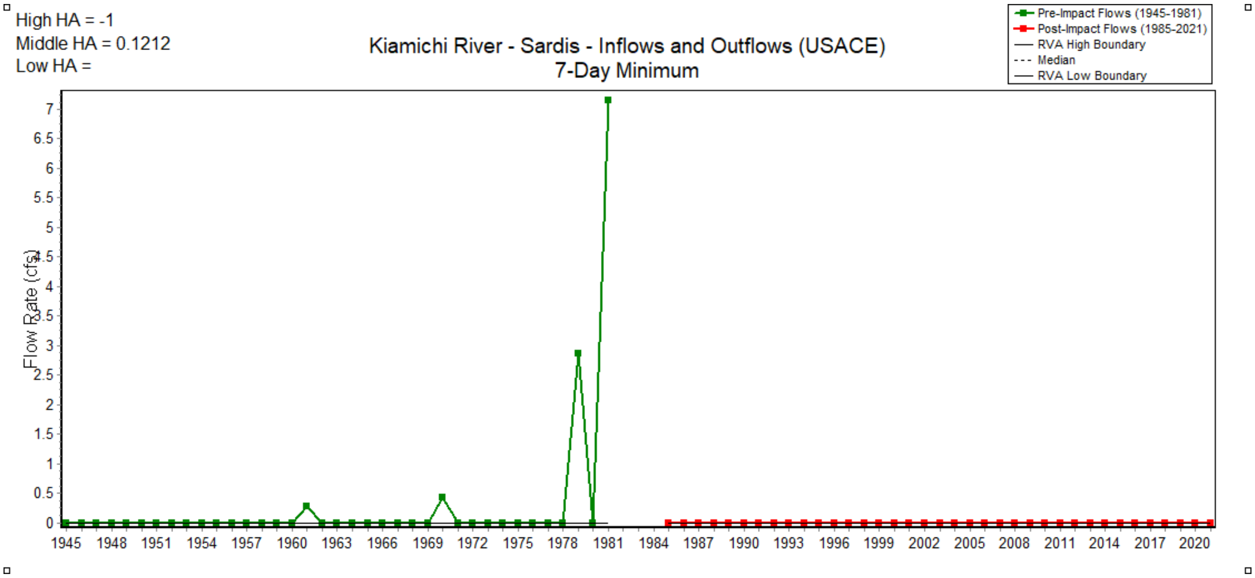


Figure 20. Pre- and post-impoundment 7-day minimum average annual discharge at Sardis Dam, Oklahoma.

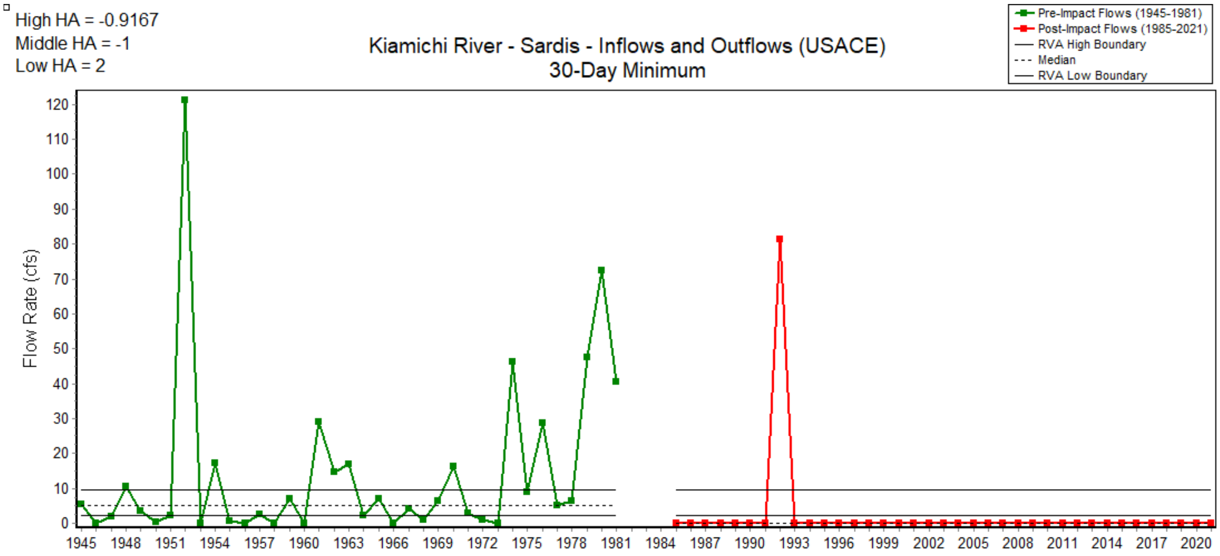


Figure 21. Pre- and post-impoundment 30-day minimum average annual discharge at Sardis Dam, Oklahoma.

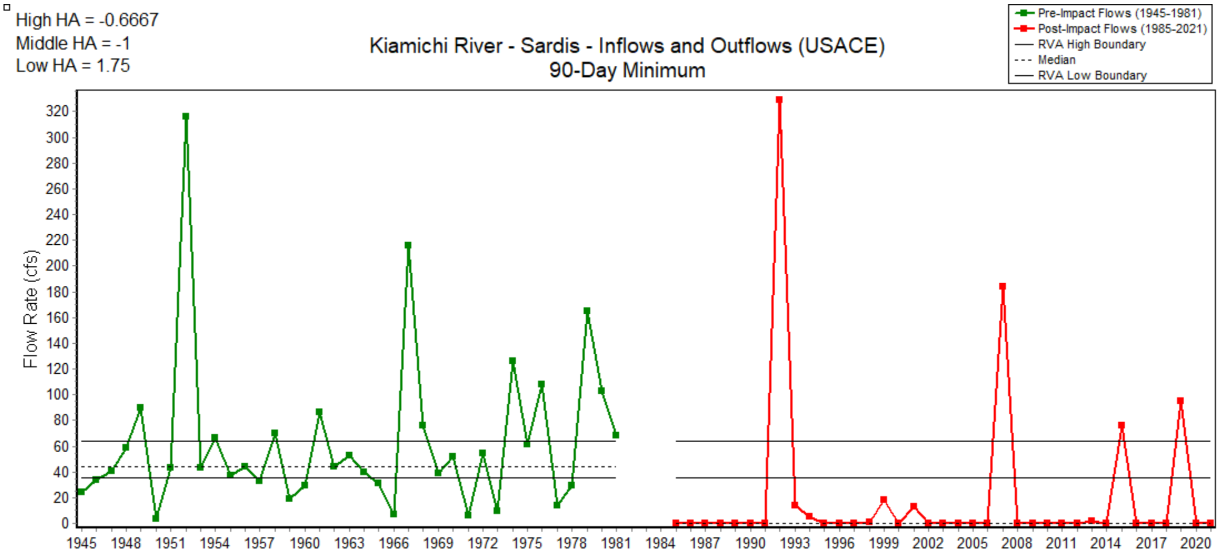


Figure 22. Pre- and post-impoundment 90-day minimum average annual discharge at Sardis Dam, Oklahoma.

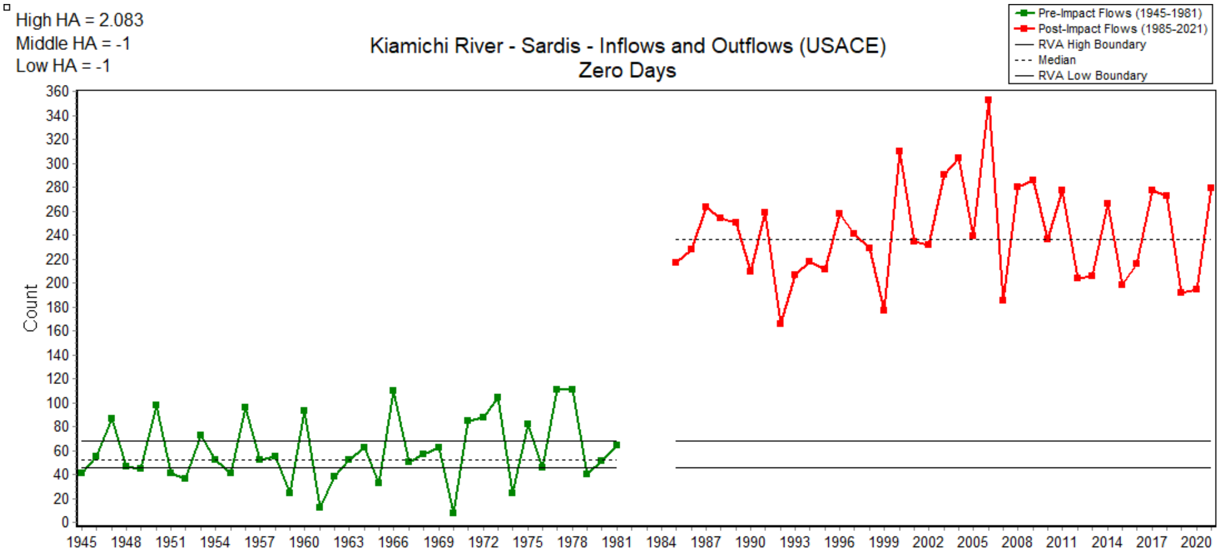


Figure 23. Pre- and post-impoundment number of days with zero discharge (flow) at Sardis Dam, Oklahoma.

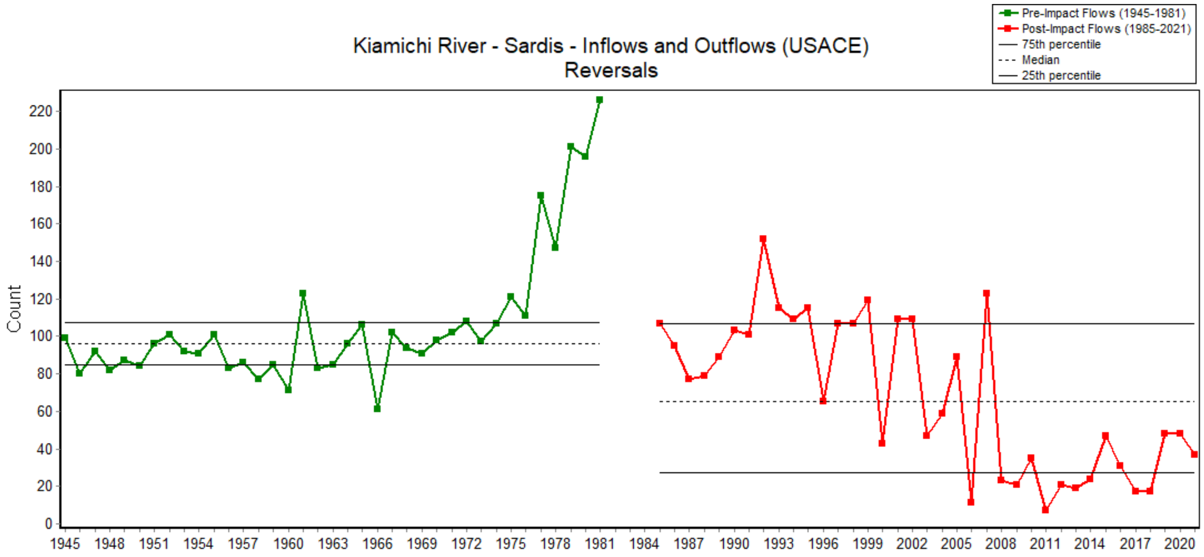


Figure 24. Pre- and post-impoundment number of reversals in flow conditions (i.e.~~,~~ changes from increasing flow rates to decreasing flow rates and vice versa) at Sardis Dam, Oklahoma.

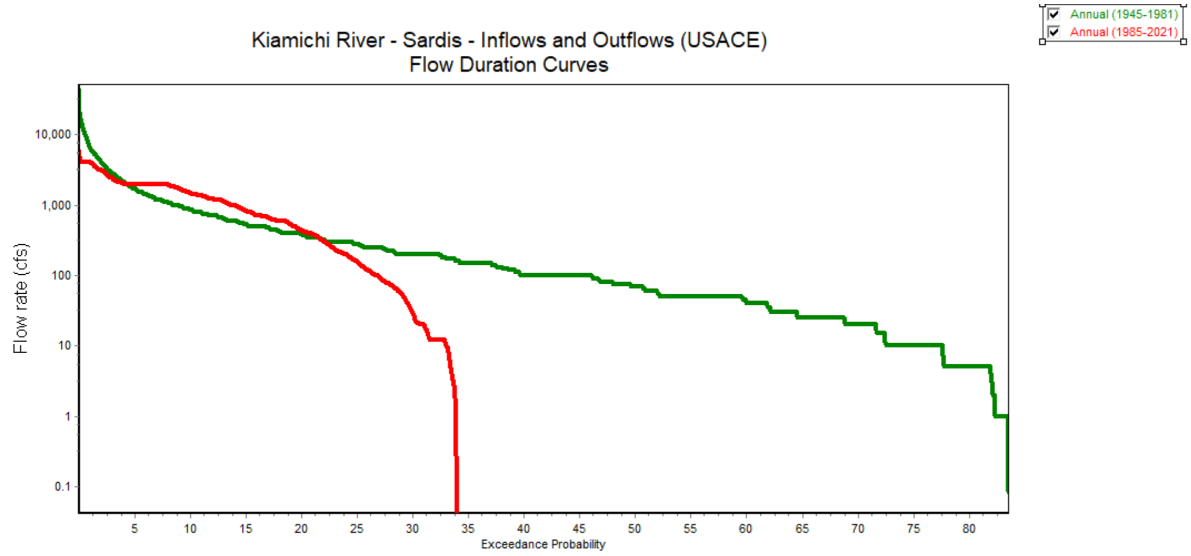


Figure 25. Pre- and post-impoundment reservoir flow-duration curves at Sardis Dam, Oklahoma.

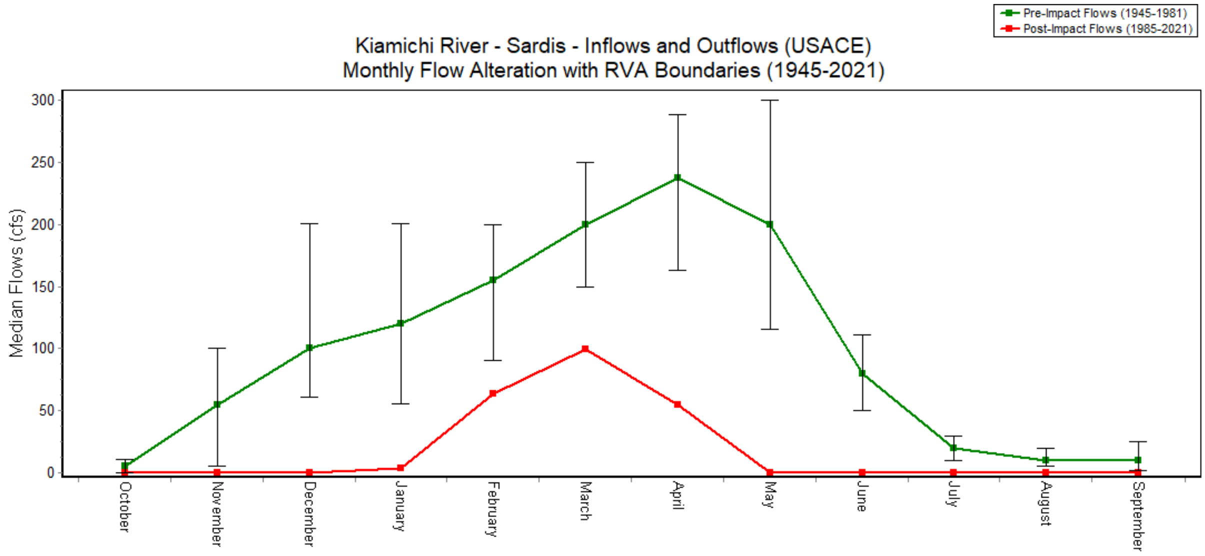


Figure 26. Pre- and post-impoundment monthly median flows at Sardis Dam, Oklahoma.

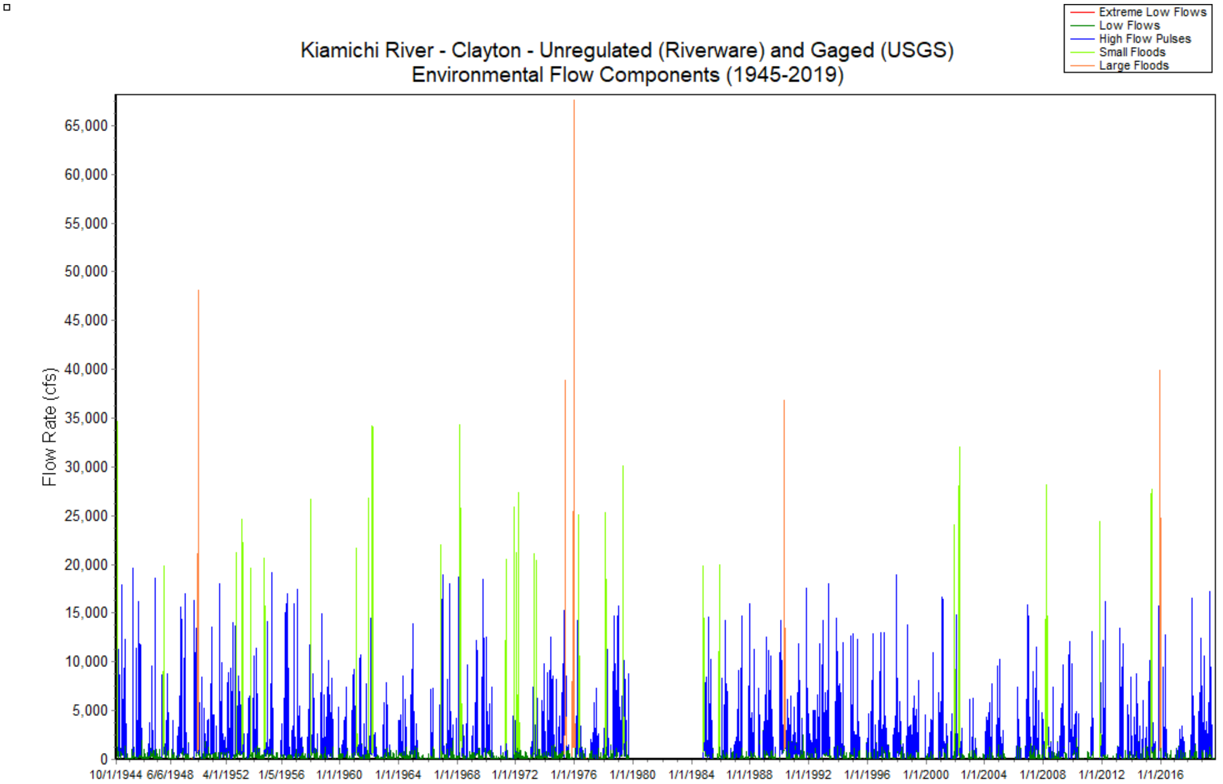


Figure 27. USGS 07335790 Kiamichi River near Clayton, Oklahoma pre-impoundment (left half) and post-impoundment hydrograph (right half).

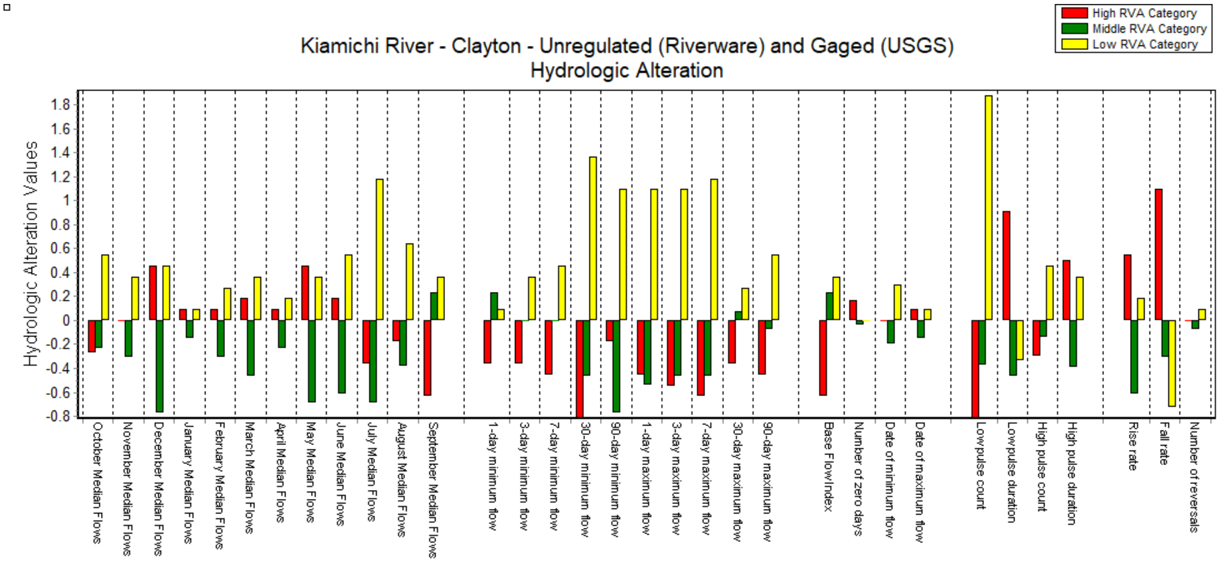


Figure 28. Range of Variability Application (RVA) scorecard overview of pre- and post-impoundment discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

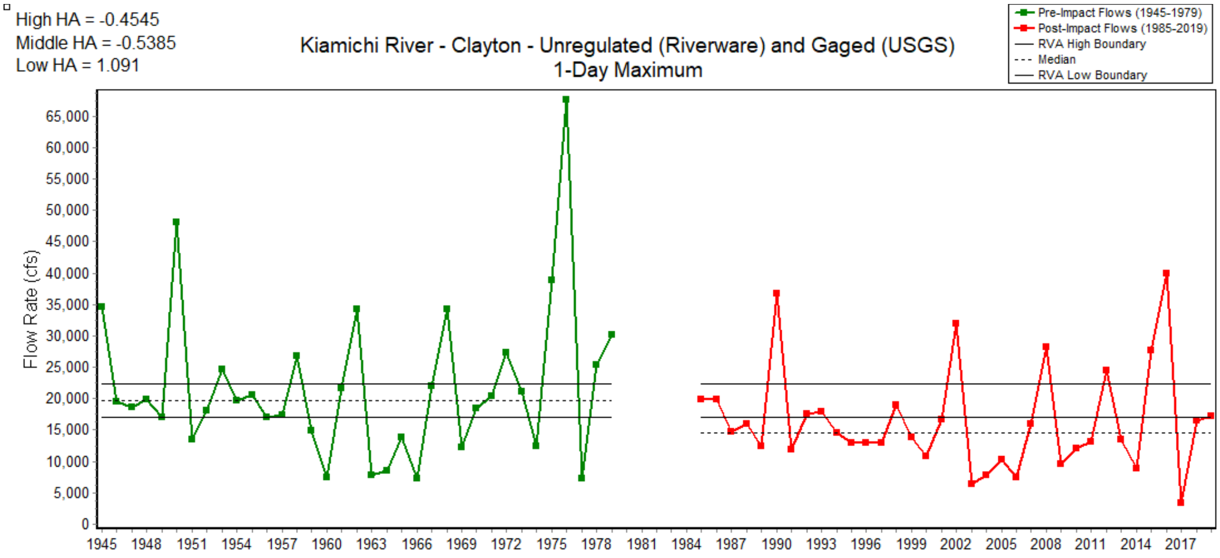


Figure 29. Pre- and post-impoundment 1-day maximum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

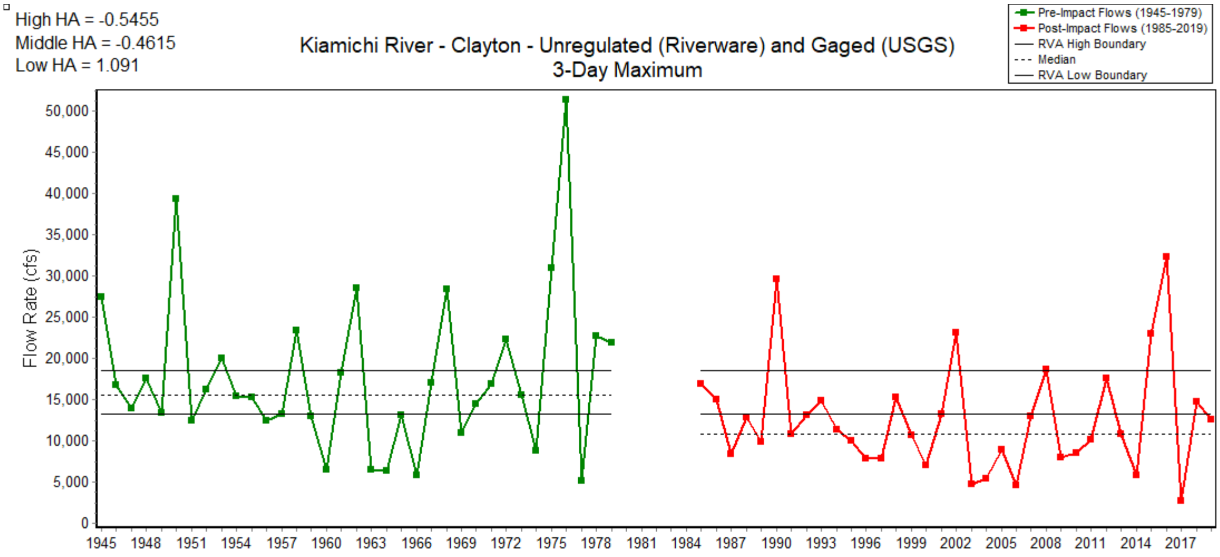


Figure 30. Pre- and post-impoundment 3-day maximum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

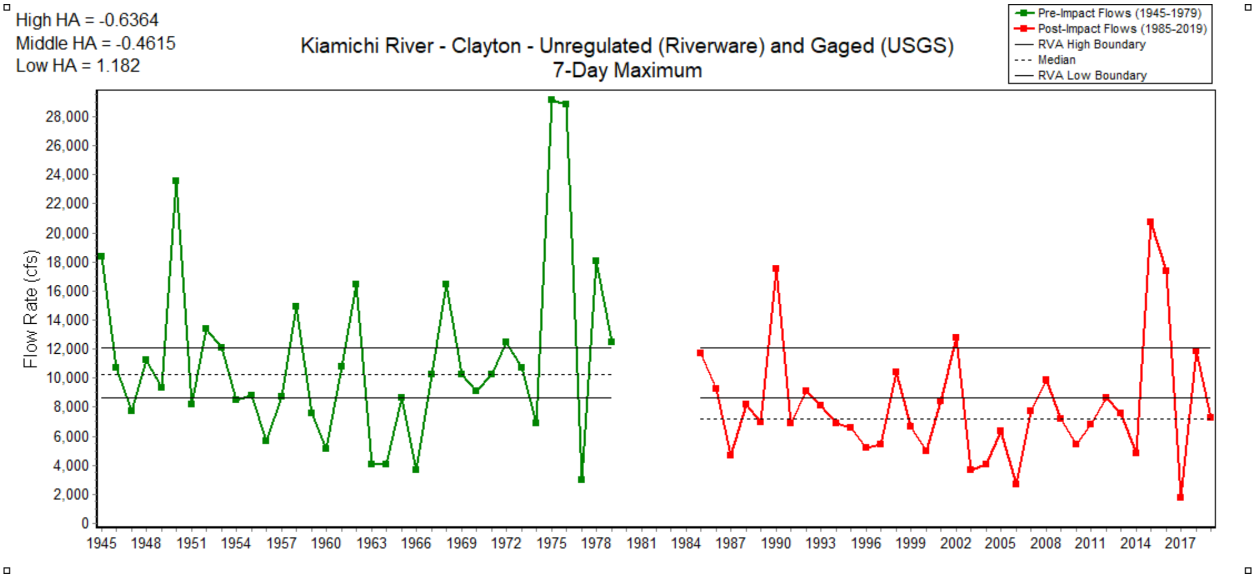


Figure 31. Pre- and post-impoundment 7-day maximum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

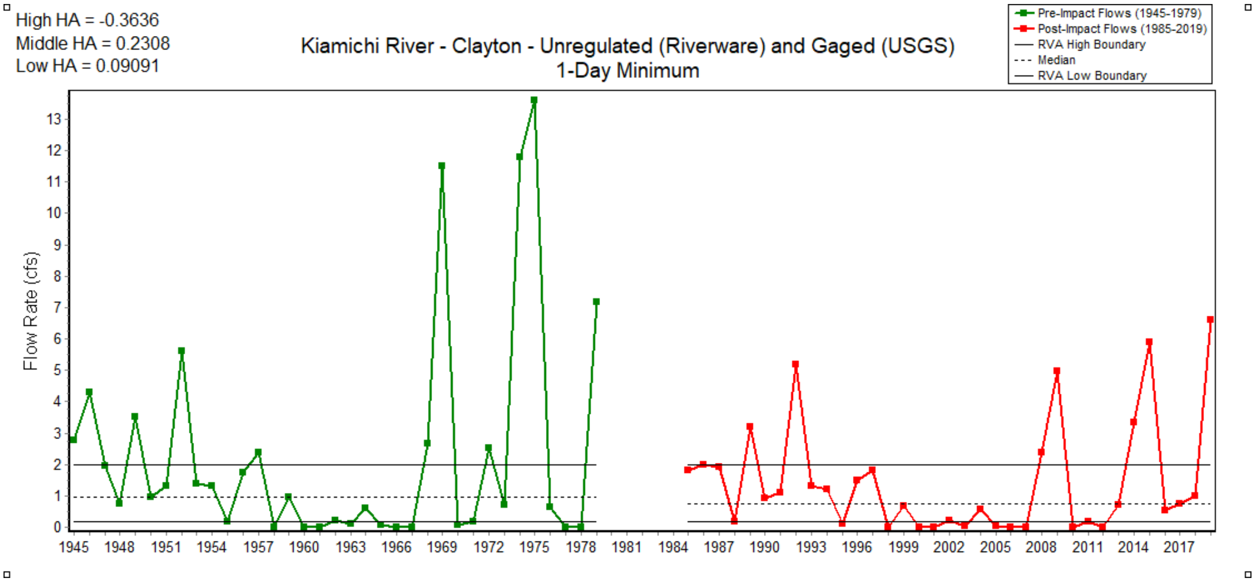


Figure 32. Pre- and post-impoundment 1-day minimum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

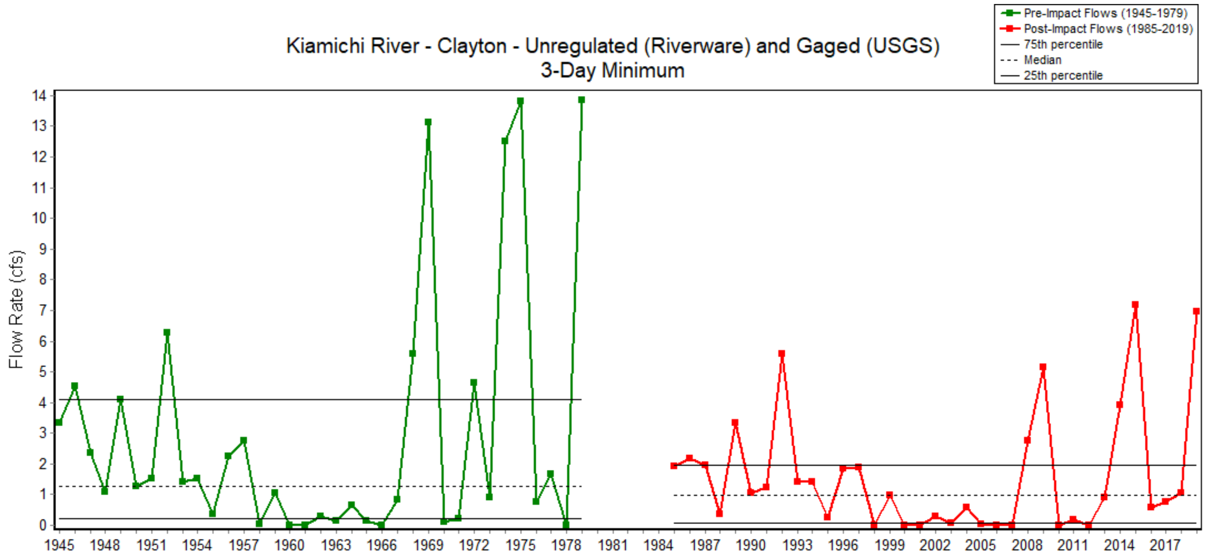


Figure 33. Pre- and post-impoundment 3-day minimum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

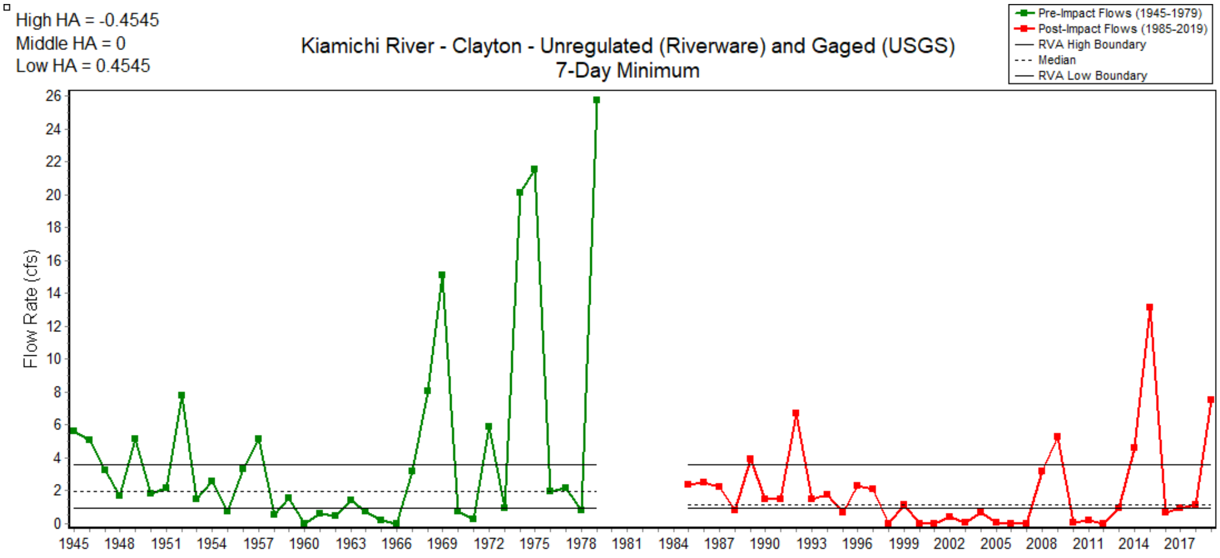


Figure 34. Pre- and post-impoundment 7-day minimum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

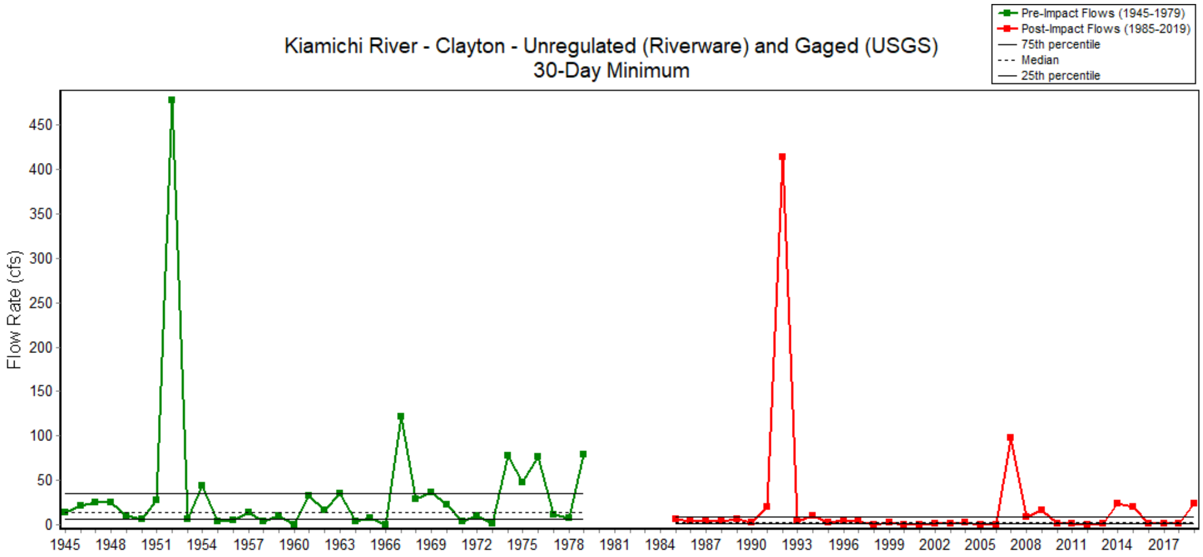


Figure 35. Pre- and post-impoundment 30-day minimum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

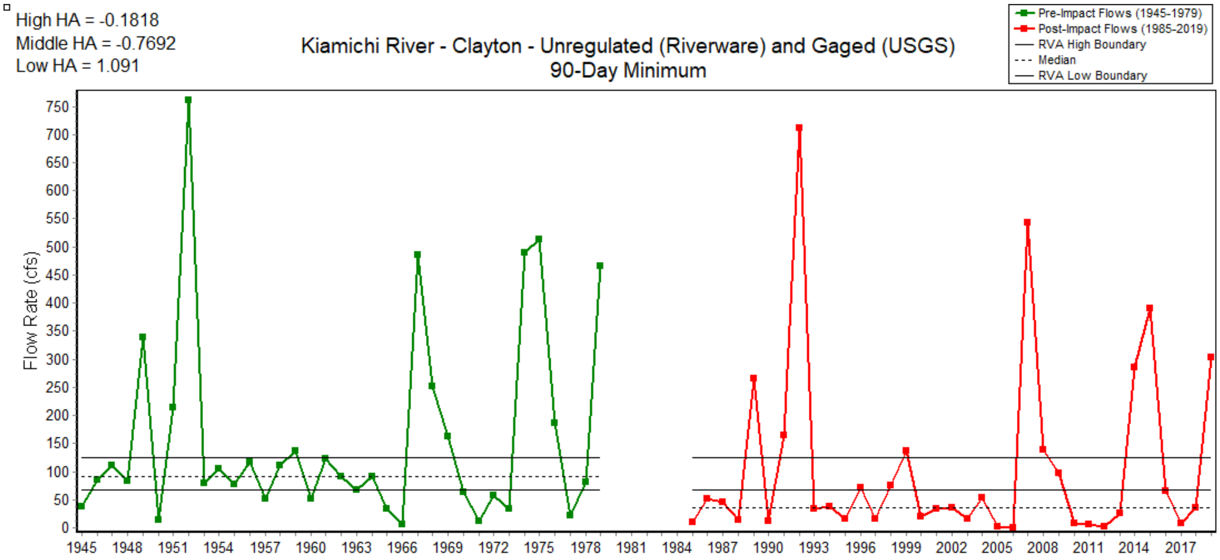


Figure 36. Pre- and post-impoundment 90-day minimum average annual discharge at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

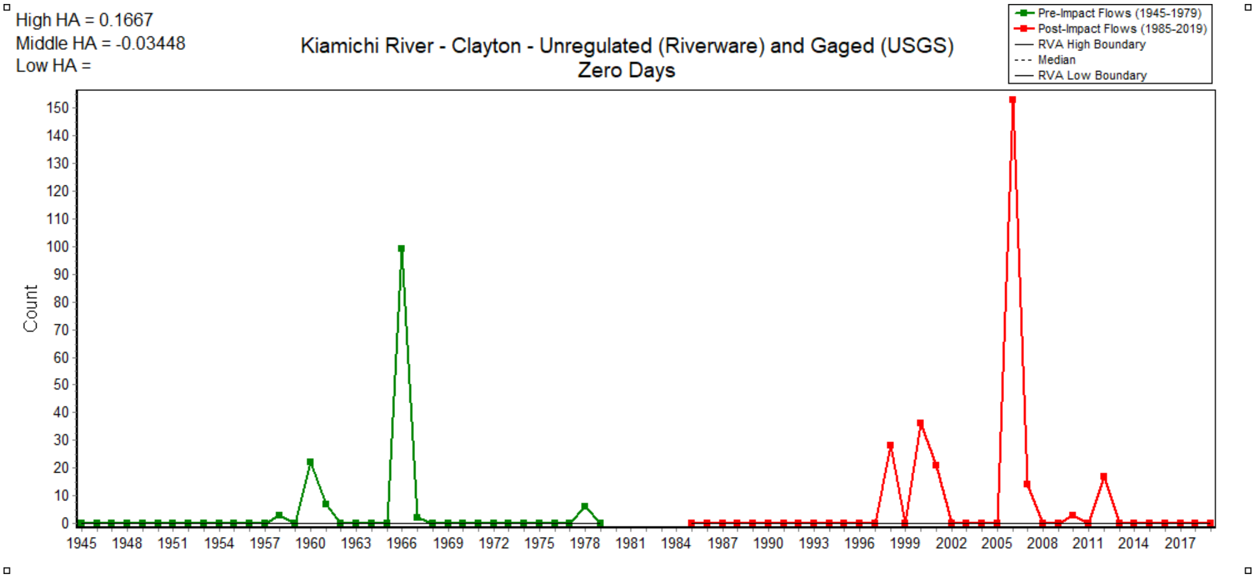


Figure 37. Pre- and post-impoundment number of days with zero discharge (flow) at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

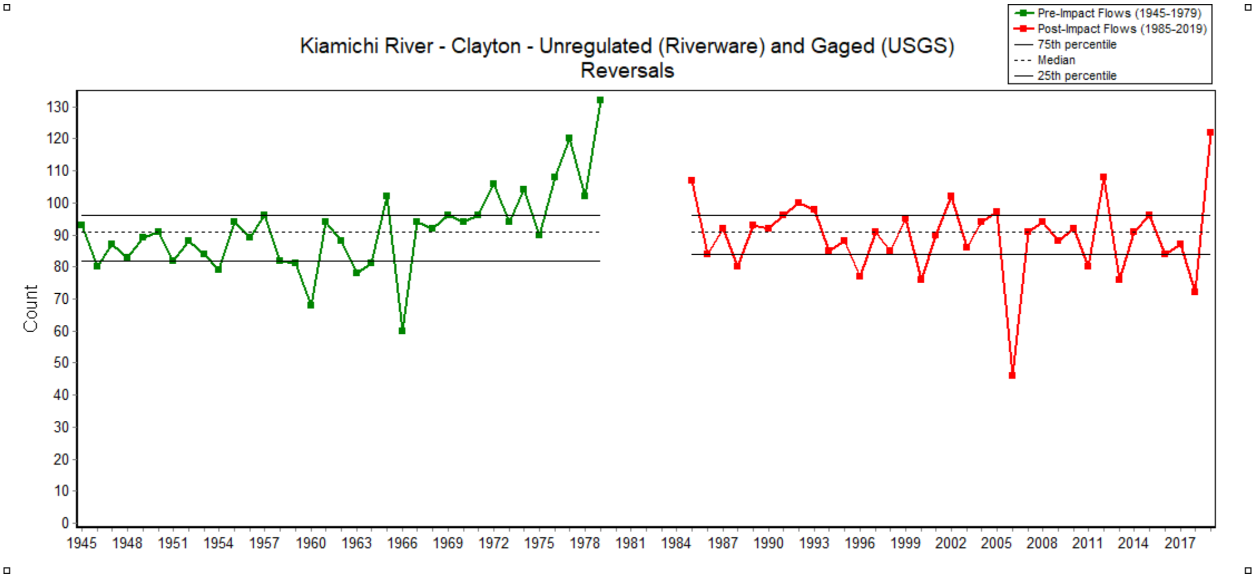


Figure 38. Pre- and post-impoundment number of reversals in flow conditions (i.e., changes from increasing flow rates to decreasing flow rates and vice versa) at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

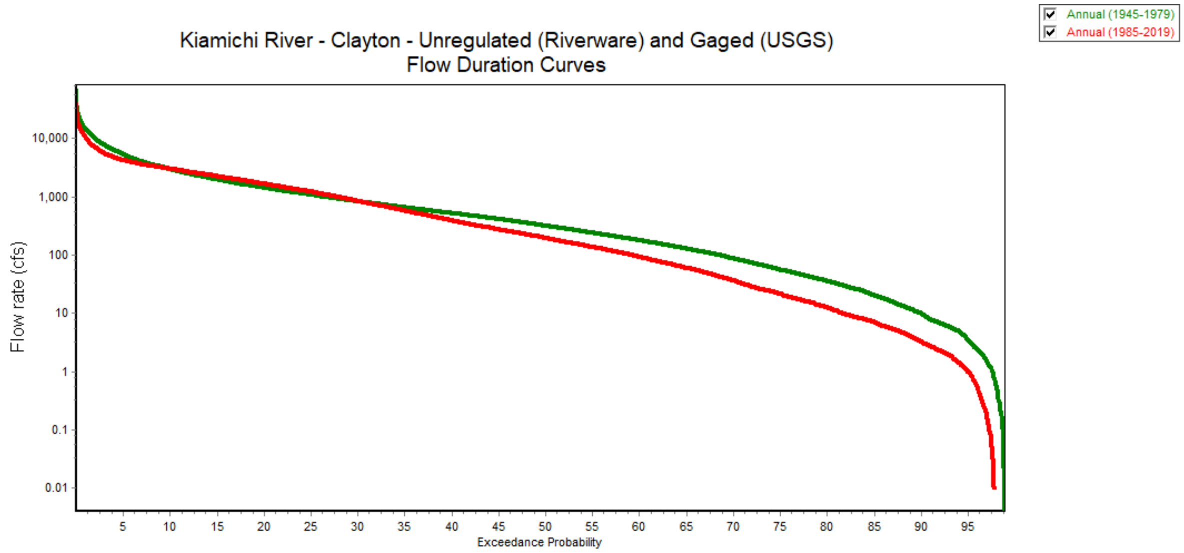


Figure 39. Pre- and post-impoundment flow-duration curves at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

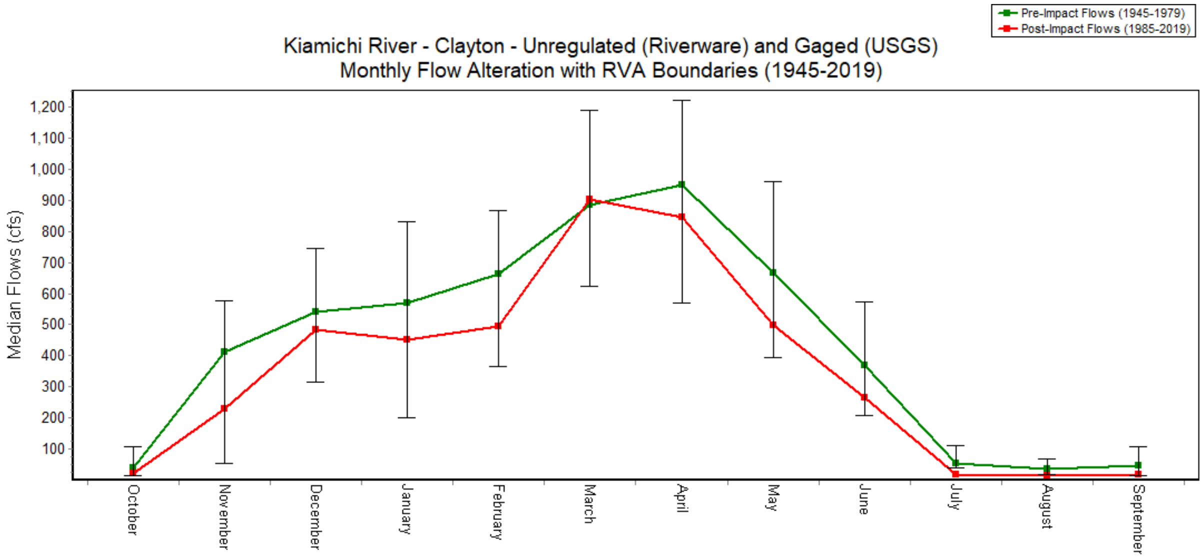


Figure 40. Pre- and post-impoundment monthly median flows at USGS 07335790 Kiamichi River near Clayton, Oklahoma.

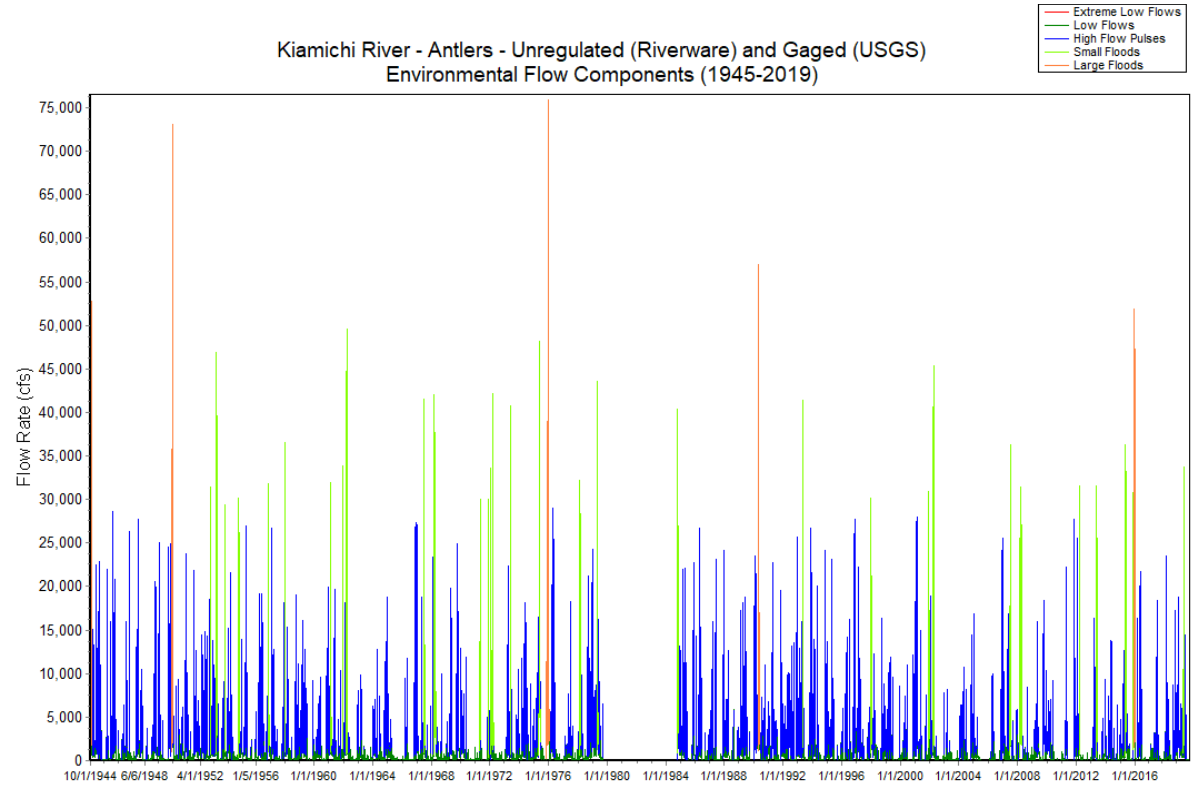


Figure 41. USGS 07336200 Kiamichi River near Antlers, Oklahoma pre-impoundment (left half) and post-impoundment hydrograph (right half).

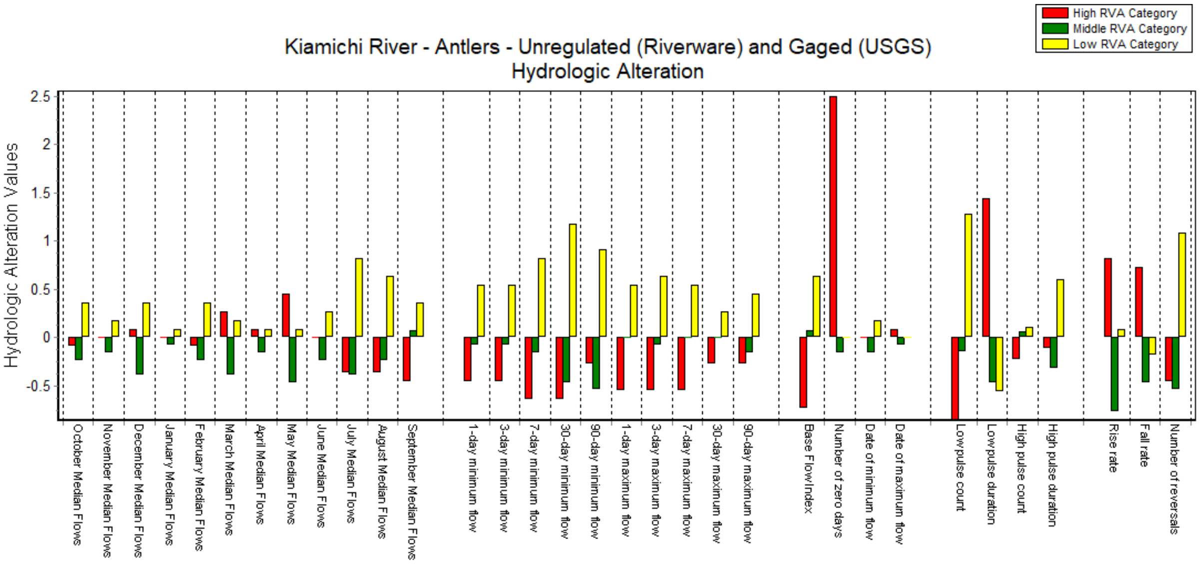


Figure 42. Range of Variability Application (RVA) scorecard overview of pre- and post-impoundment discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

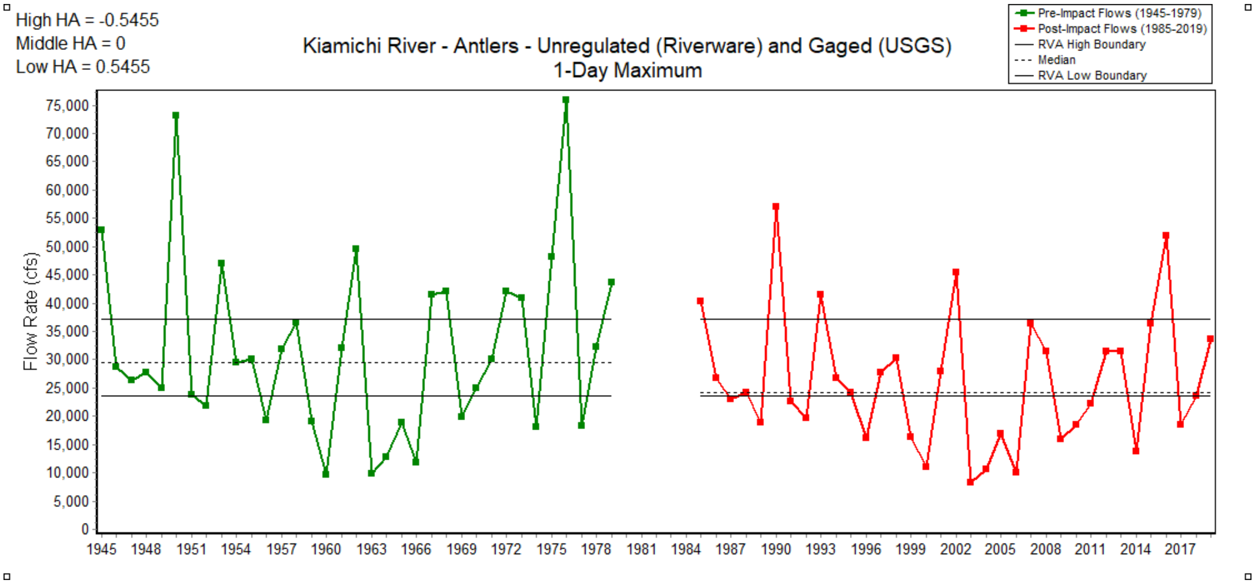


Figure 43. Pre- and post-impoundment 1-day maximum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

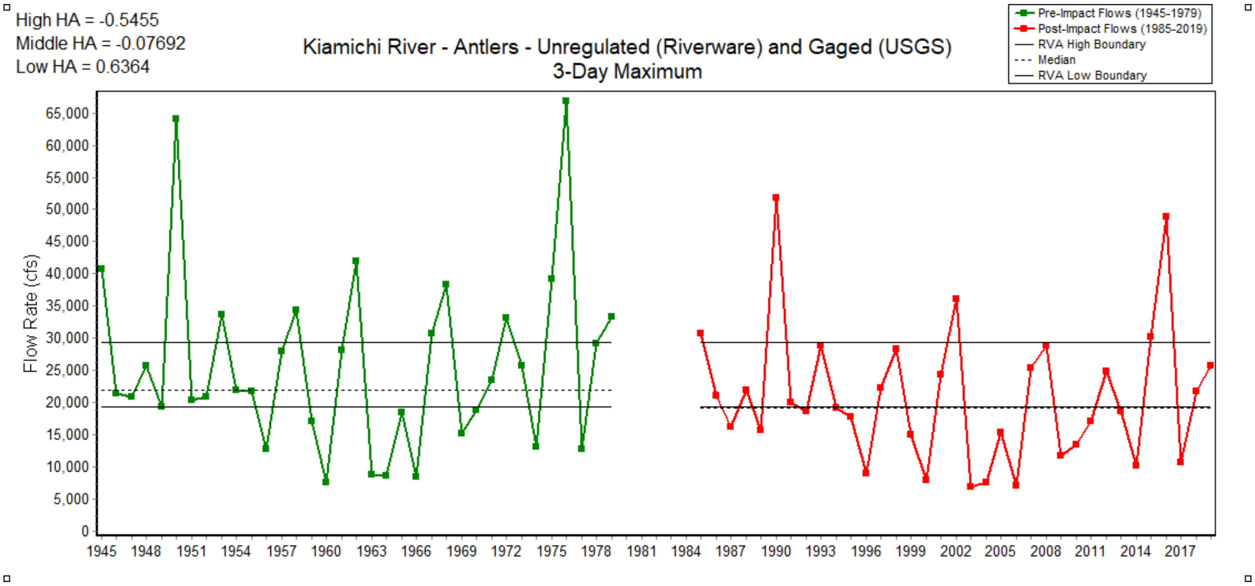


Figure 44. Pre- and post-impoundment 3-day maximum average annual discharge at 07336200 Kiamichi River near Antlers, Oklahoma.

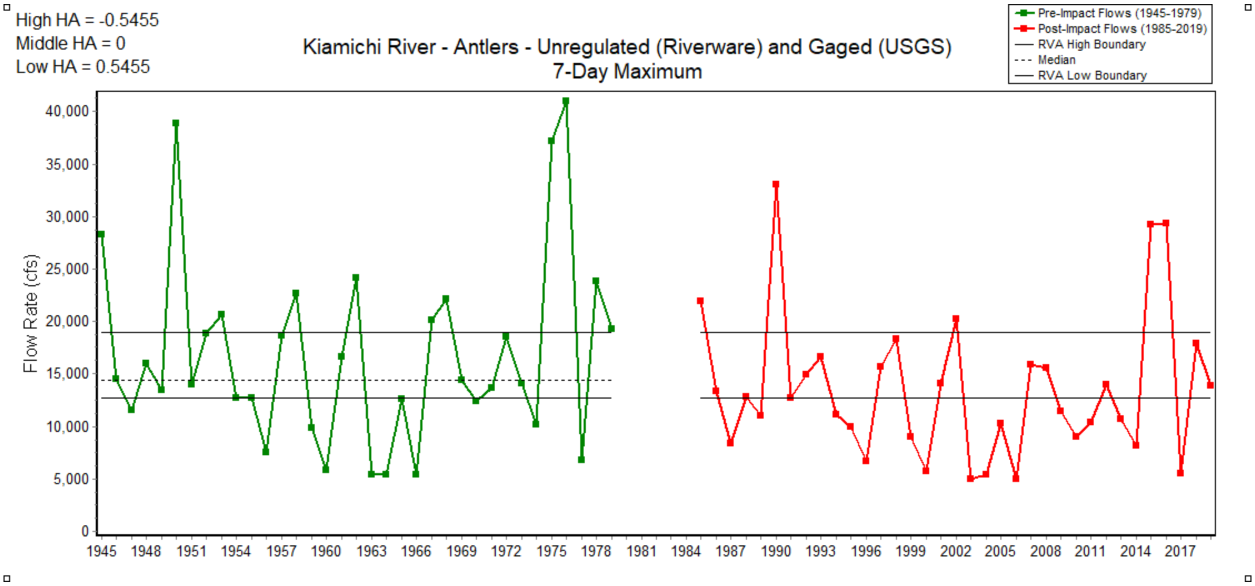


Figure 45. Pre- and post-impoundment 7-day maximum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

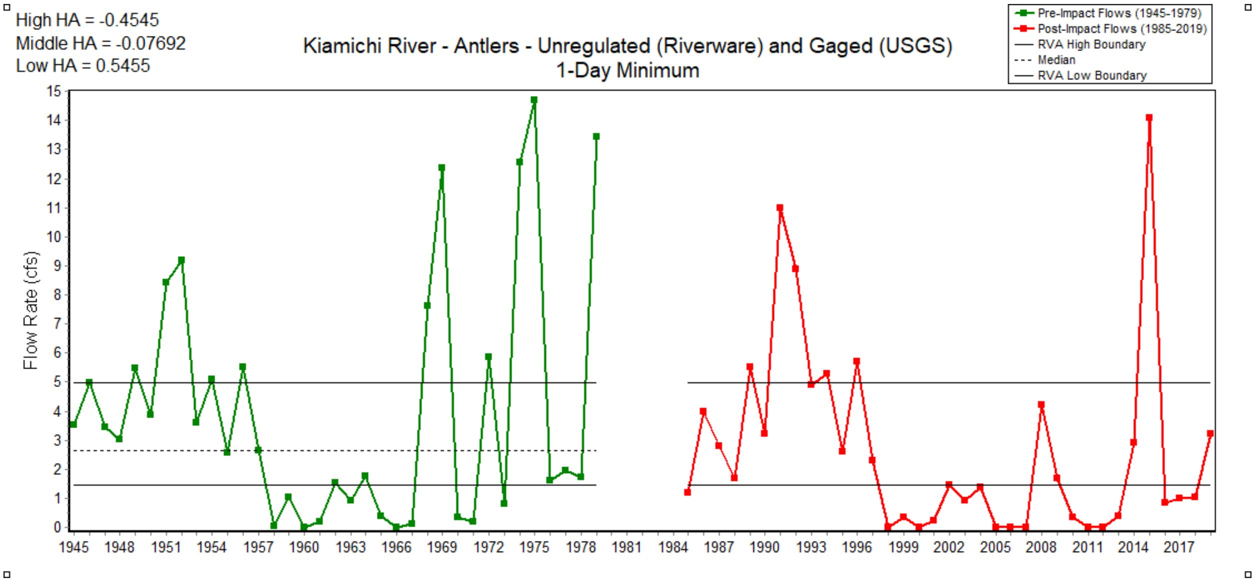


Figure 46. Pre- and post-impoundment 1-day minimum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

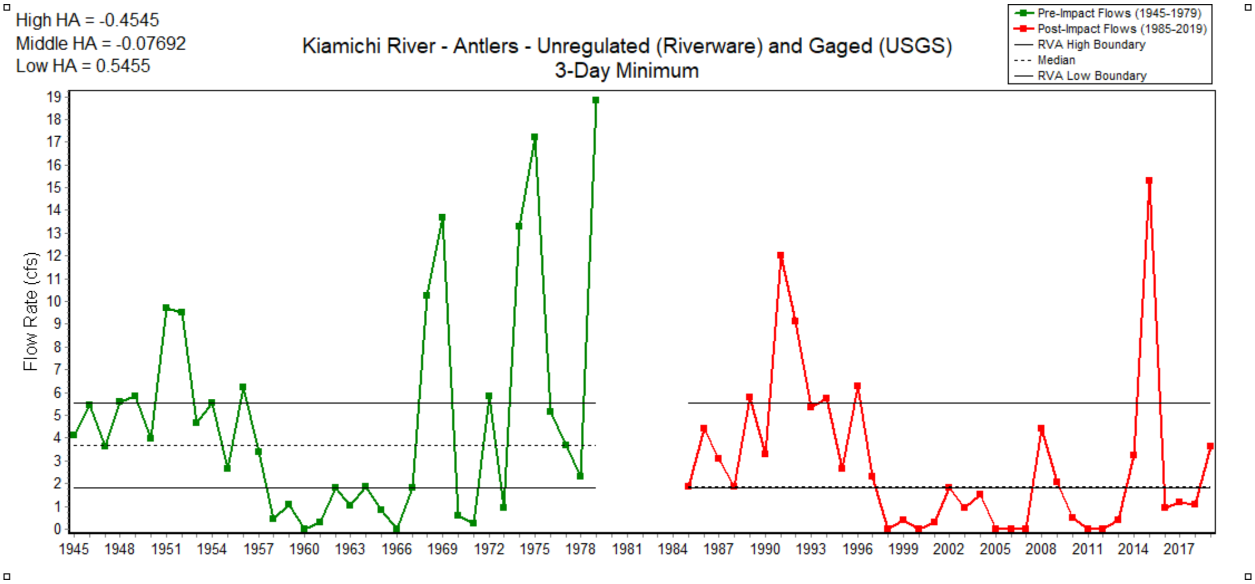


Figure 47. Pre- and post-impoundment 3-day minimum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

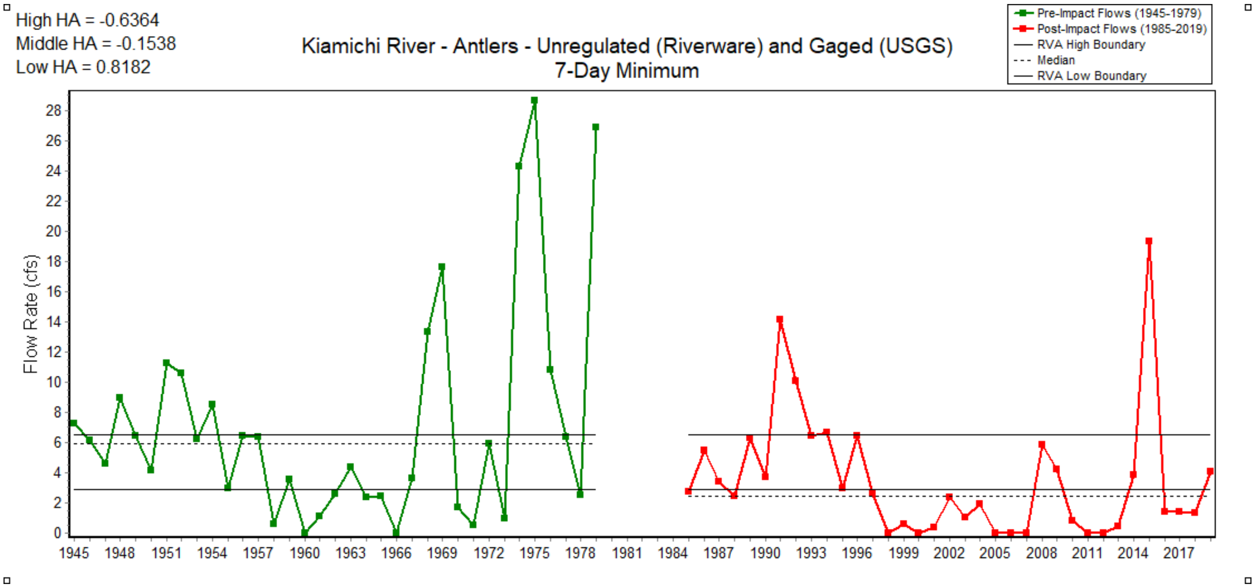


Figure 48. Pre- and post-impoundment 7-day minimum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

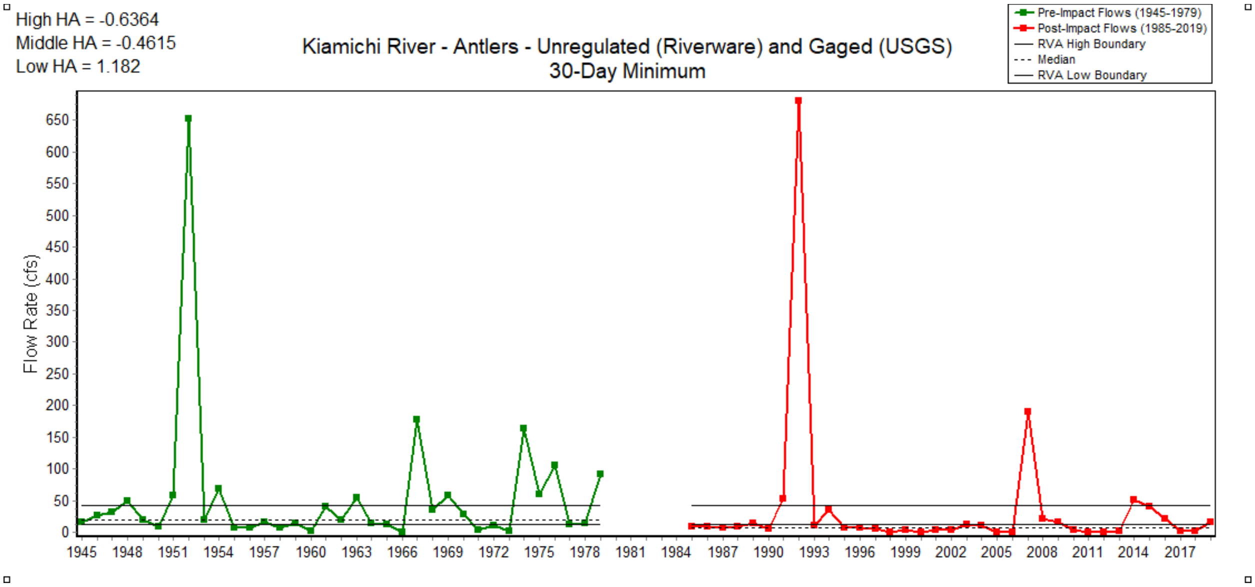


Figure 49. Pre- and post-impoundment 30-day minimum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

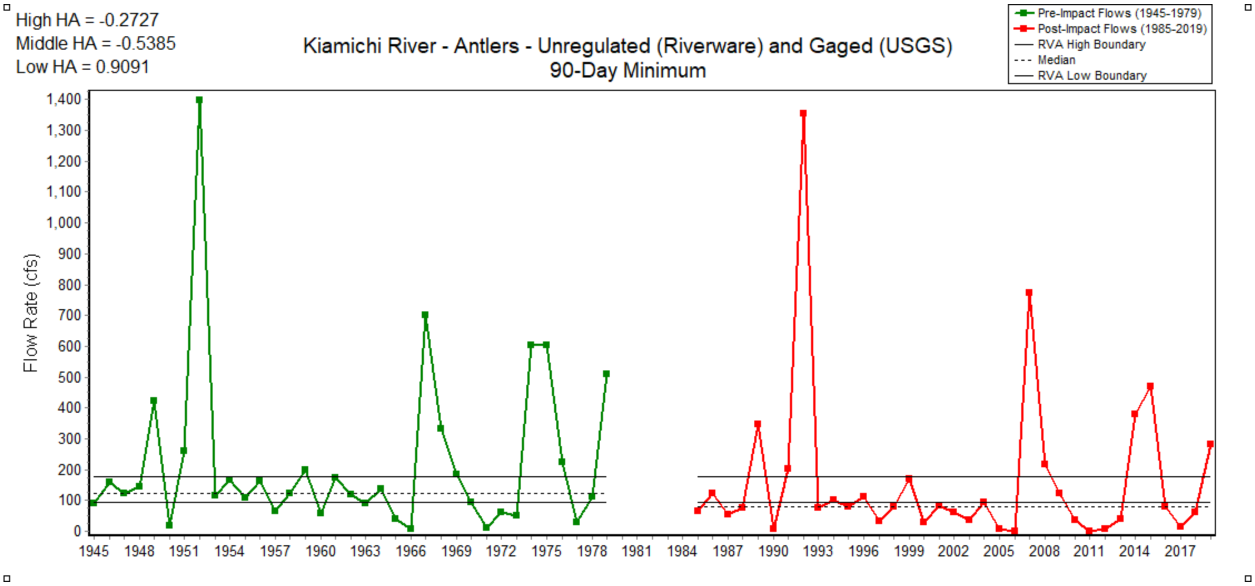


Figure 50. Pre- and post-impoundment 90-day minimum average annual discharge at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

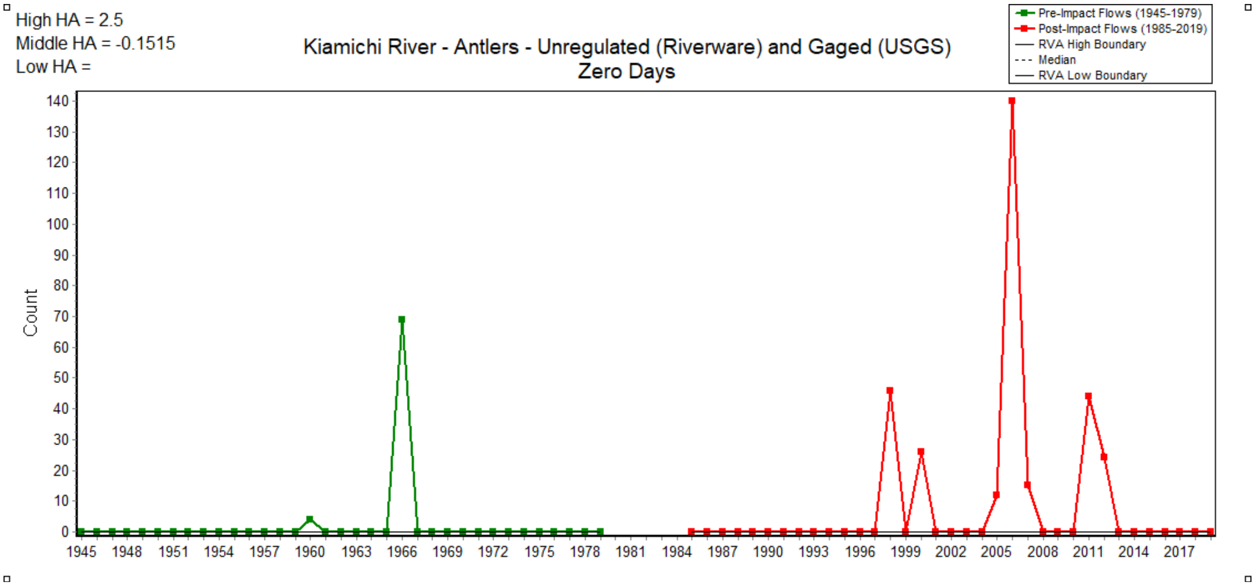


Figure 51. Pre- and post-impoundment number of days with zero discharge (flow) at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

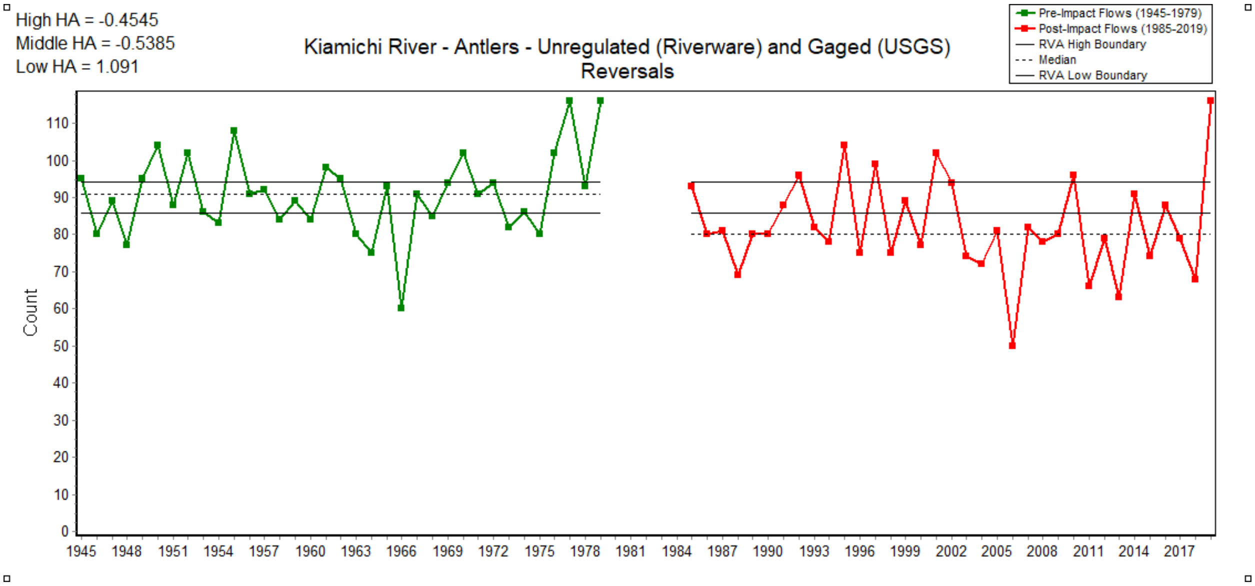


Figure 52. Pre- and post-impoundment number of reversals in flow conditions (i.e., changes from increasing flow rates to decreasing flow rates and vice versa) at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

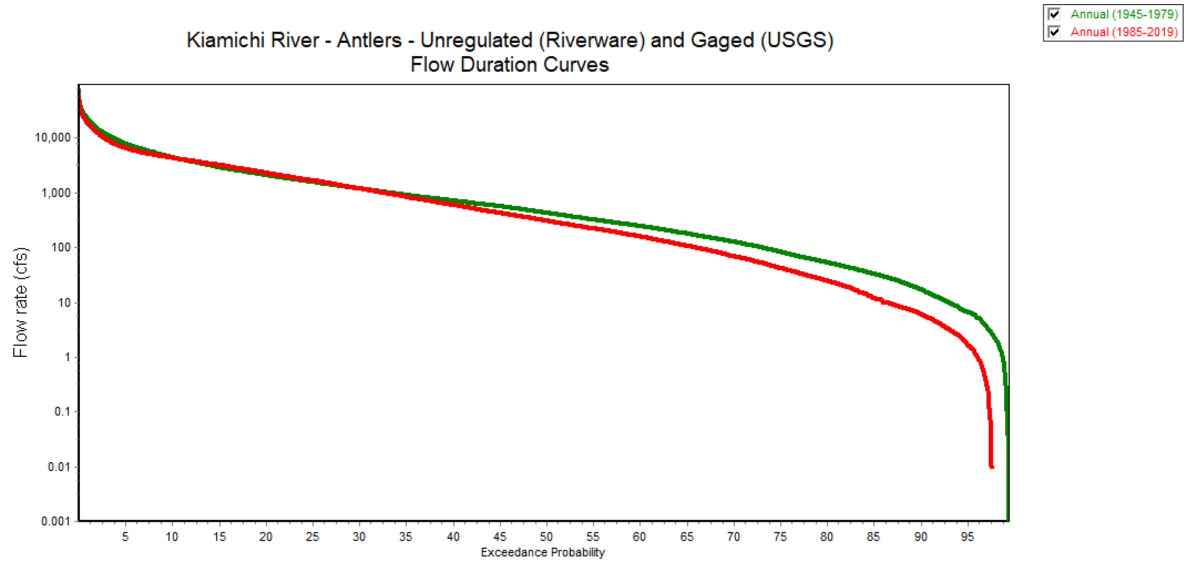


Figure 53. Pre- and post-impoundment flow-duration curves at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

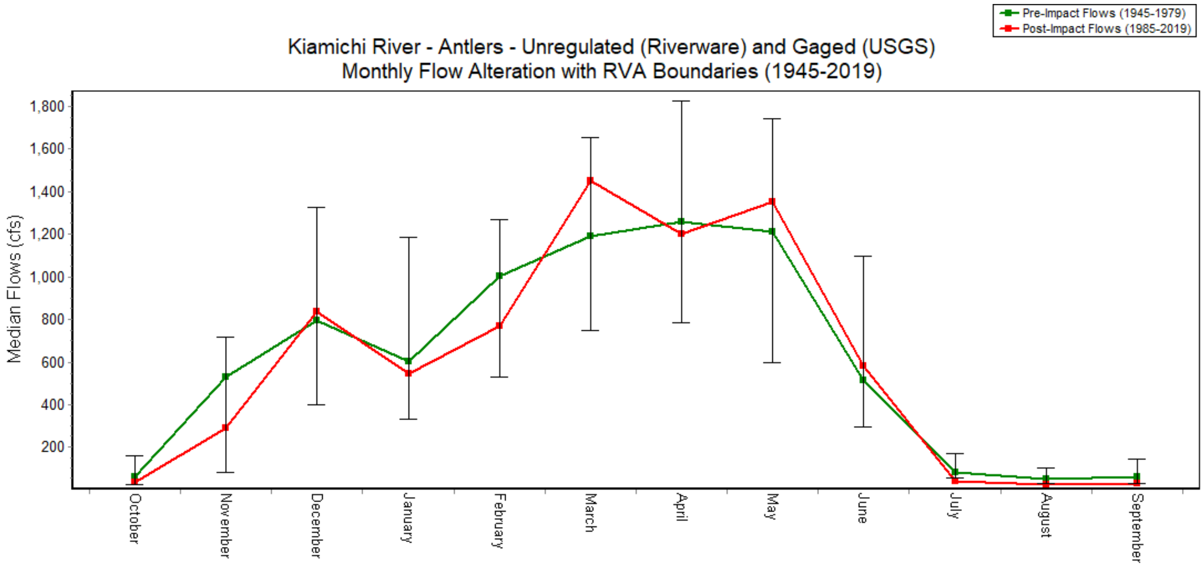


Figure 54. Pre- and post-impoundment monthly median flows at USGS 07336200 Kiamichi River near Antlers, Oklahoma.

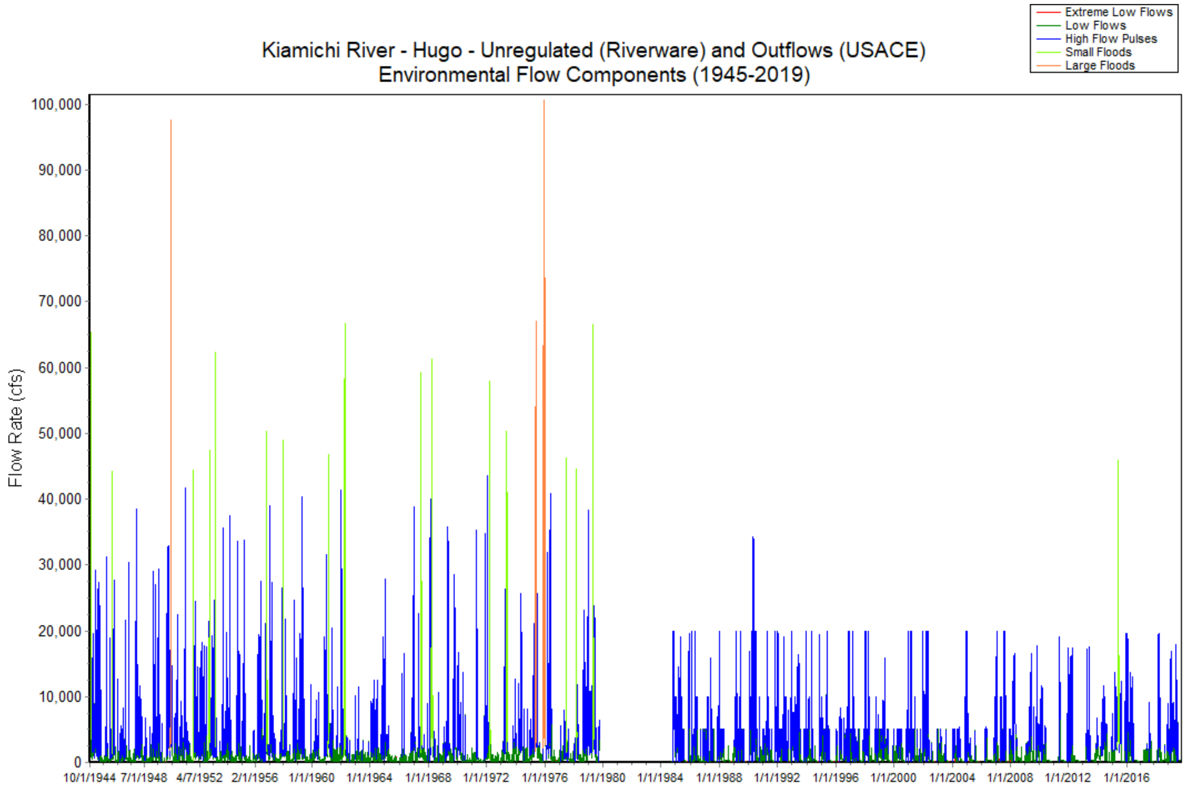


Figure 55. Hugo Lake, Oklahoma pre-impoundment hydrograph (left half) and post-impoundment hydrograph (right half).

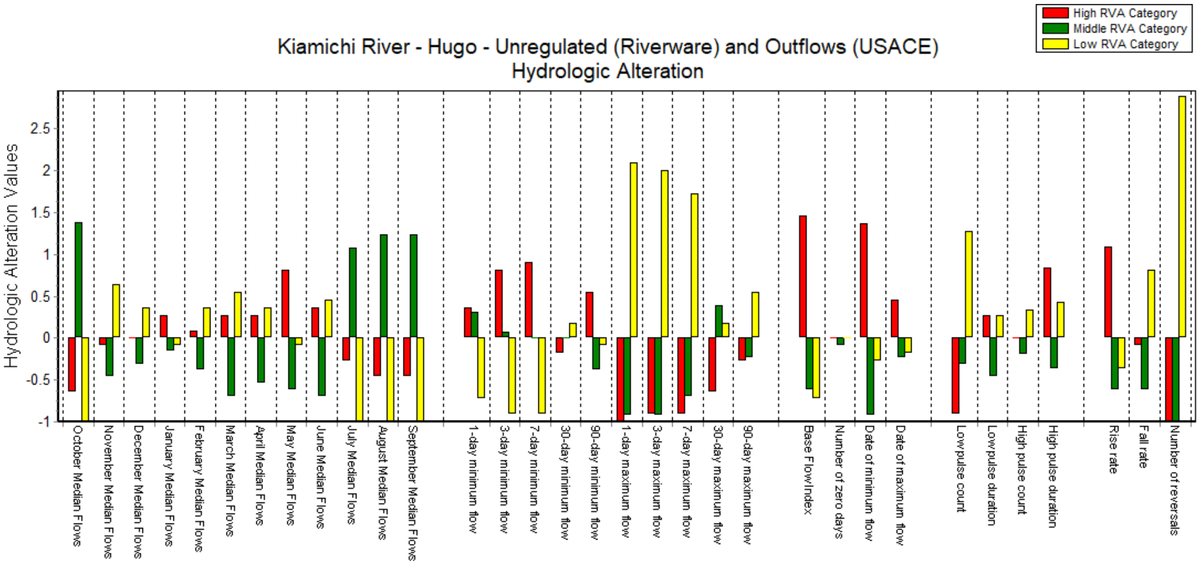


Figure 56. Range of Variability Application (RVA) scorecard overview of pre- and post-impoundment discharge at Hugo Lake, Oklahoma.

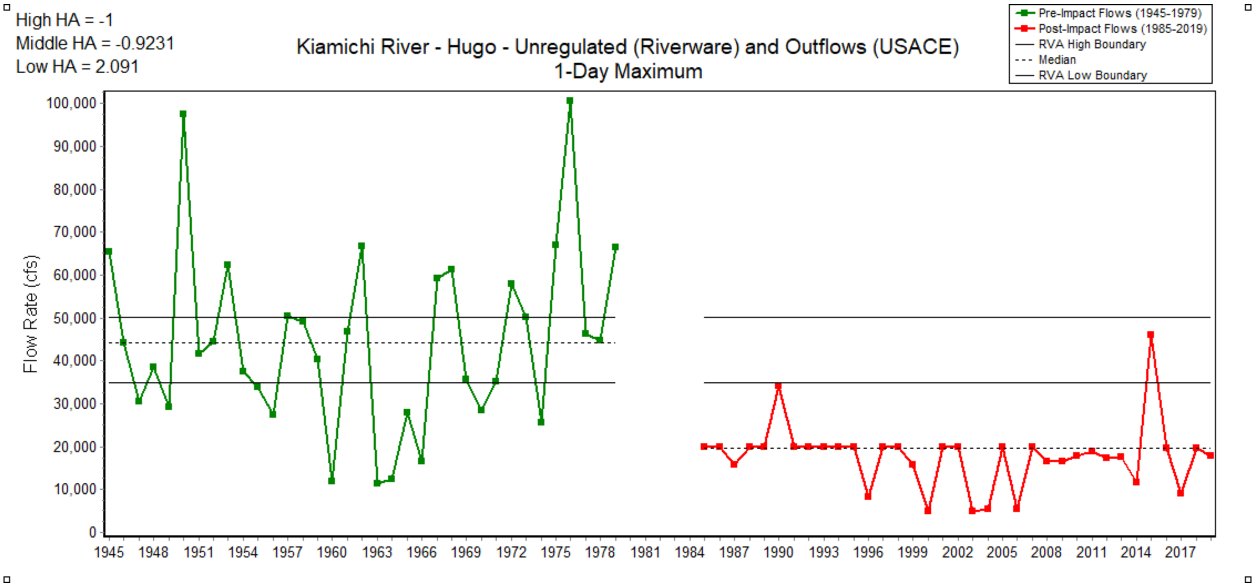


Figure 57. Pre- and post-impoundment 1-day maximum average annual discharge at Hugo Dam, Oklahoma.

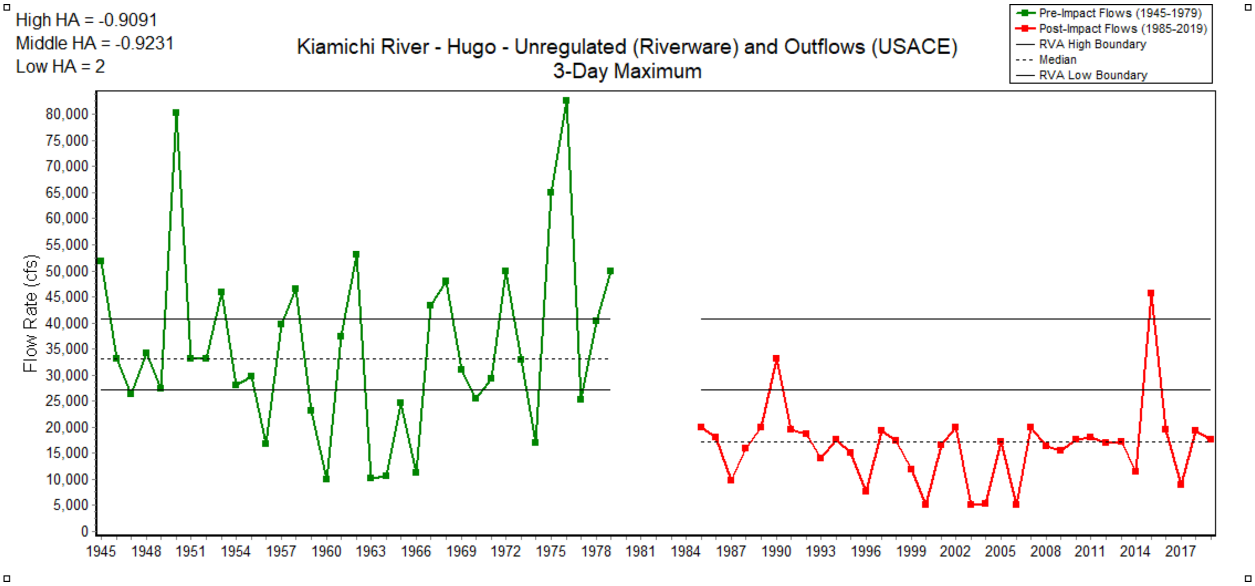


Figure 58. Pre- and post-impoundment 3-day maximum average annual discharge at Hugo Dam, Oklahoma.

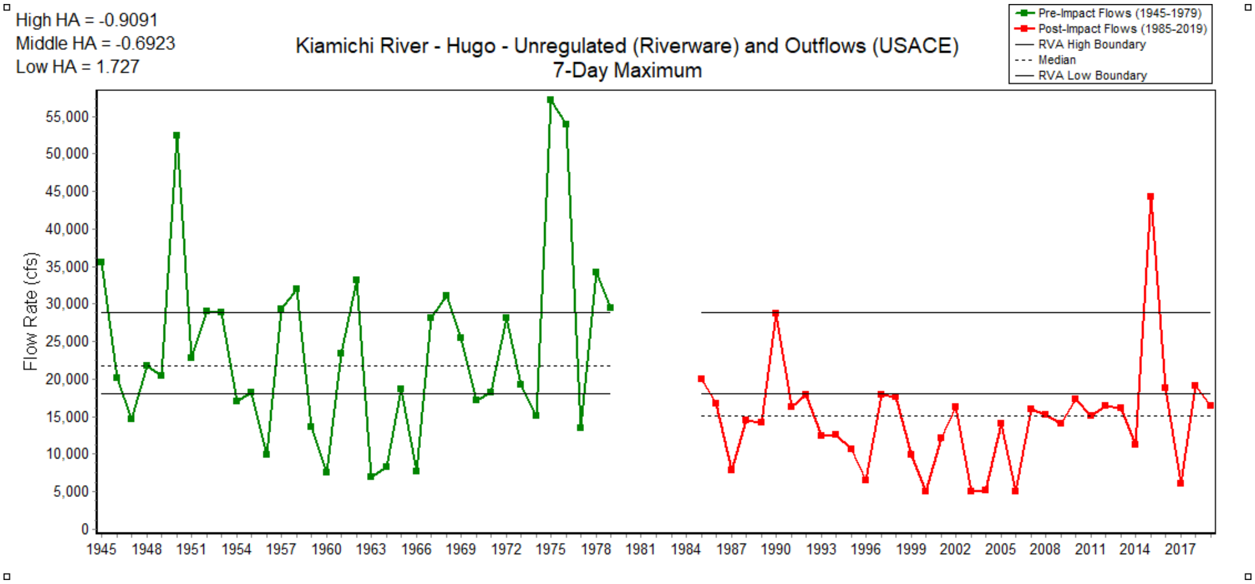


Figure 59. Pre- and post-impoundment 7-day maximum average annual discharge at Hugo Dam, Oklahoma.

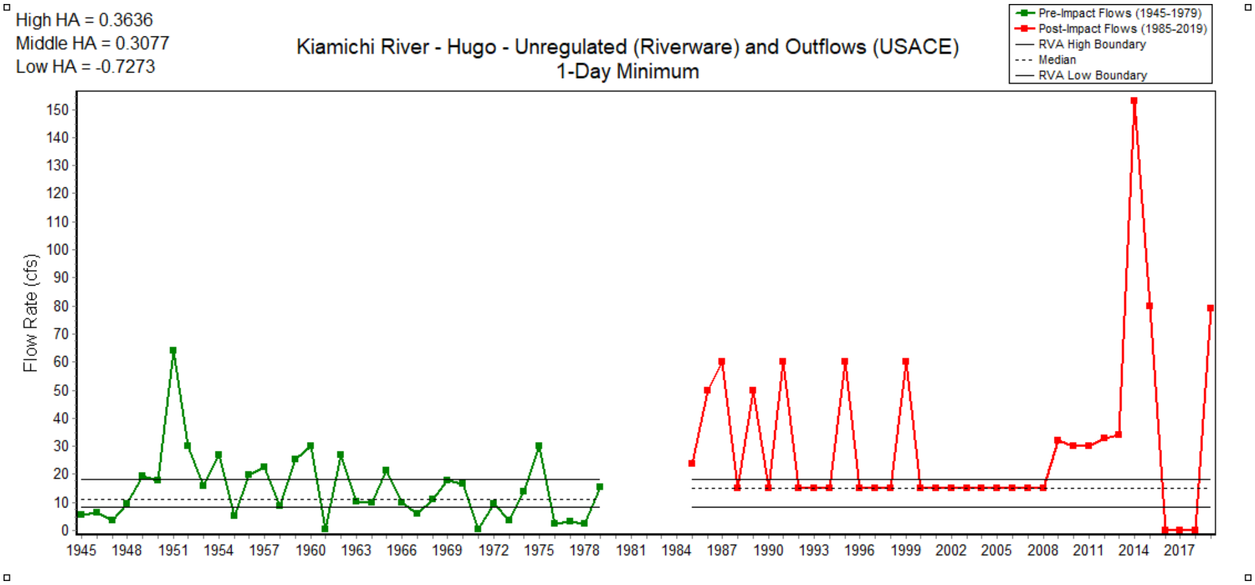


Figure 60. Pre- and post-impoundment 1-day minimum average annual discharge at Hugo Dam, Oklahoma.

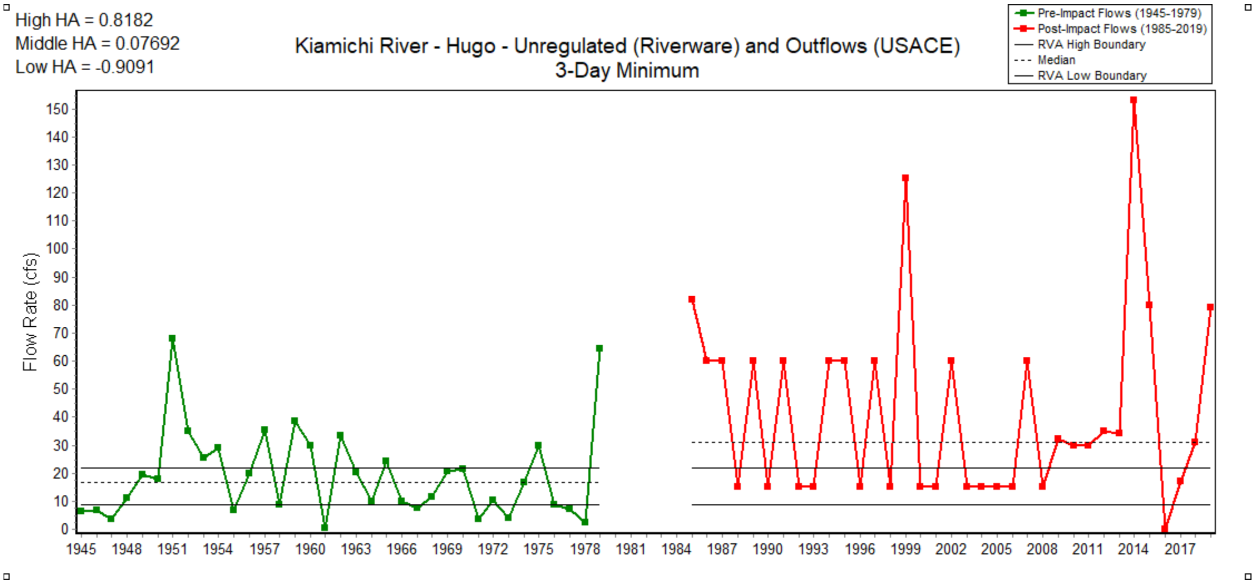


Figure 61. Pre- and post-impoundment 3-day minimum average annual discharge at Hugo Dam, Oklahoma.

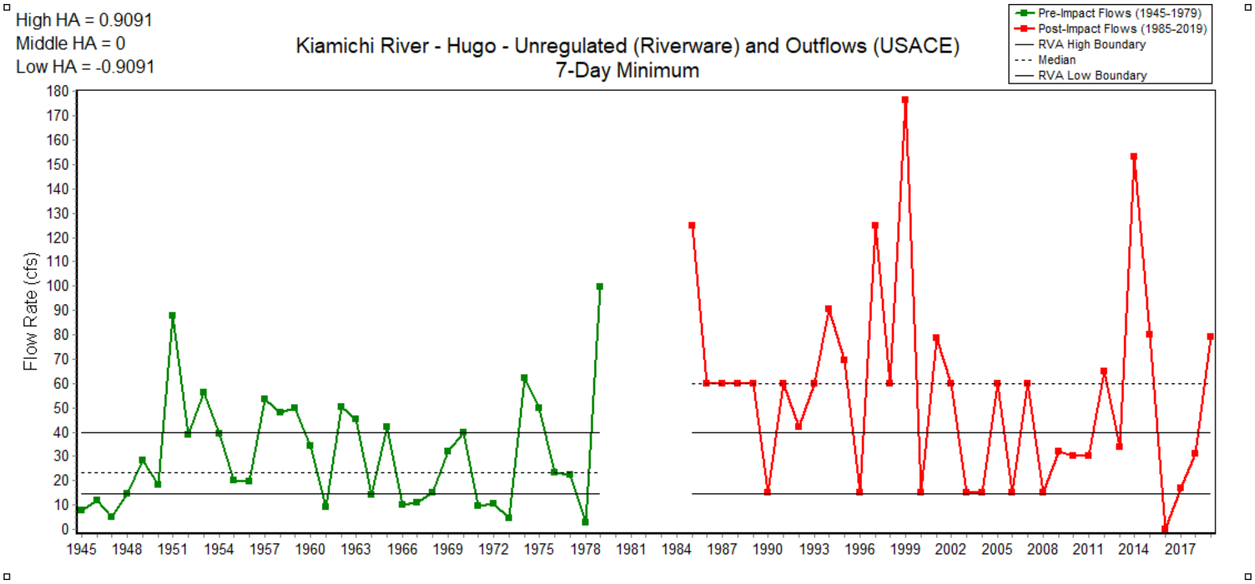


Figure 62. Pre- and post-impoundment 7-day minimum average annual discharge at Hugo Dam, Oklahoma.

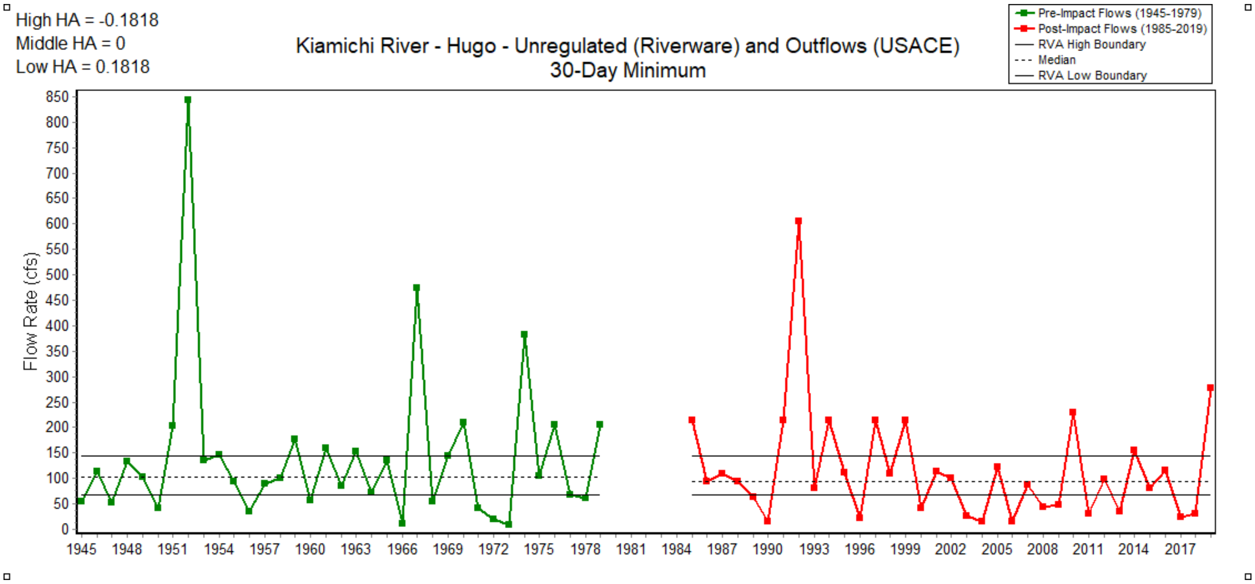


Figure 63. Pre- and post-impoundment 30-day minimum average annual discharge at Hugo Dam, Oklahoma.

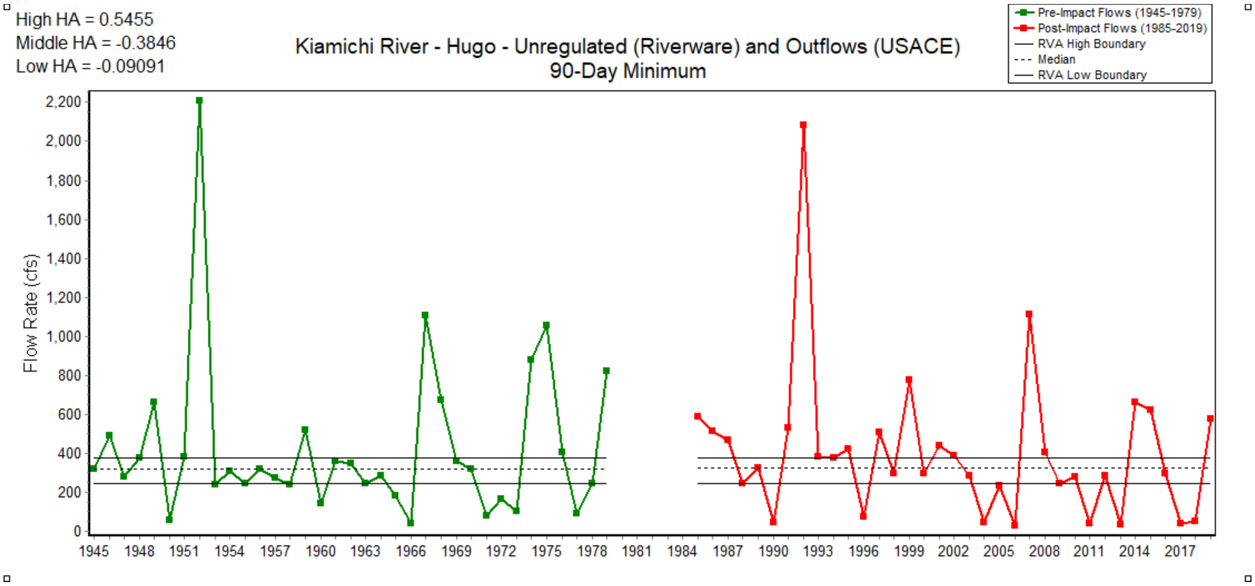


Figure 64. Pre- and post-impoundment 90-day minimum average annual discharge at Hugo Dam, Oklahoma.

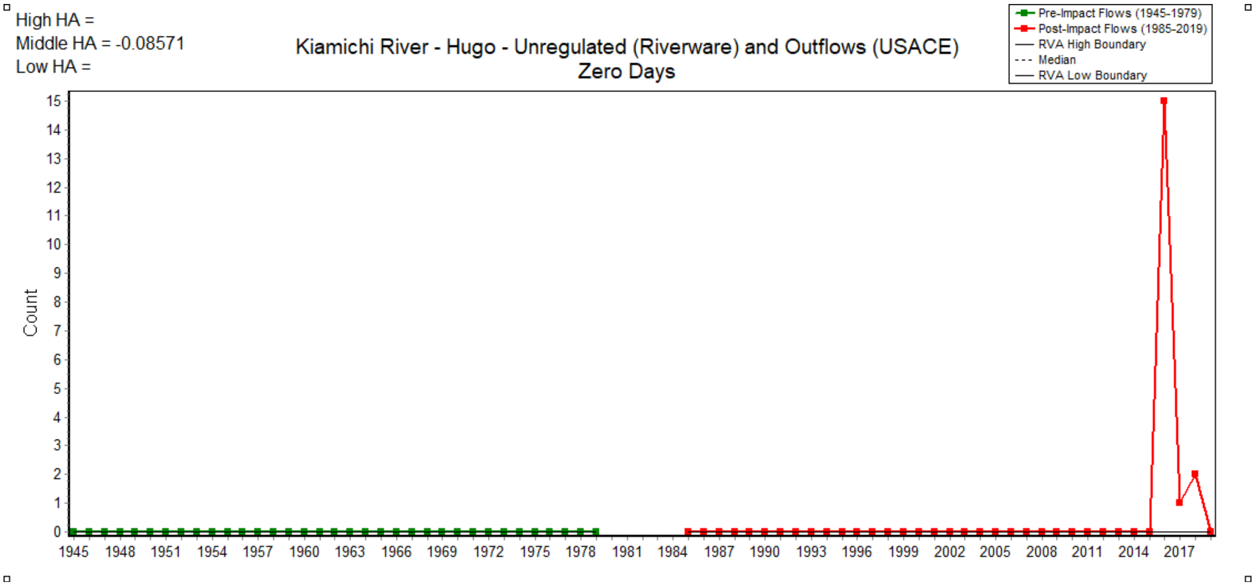


Figure 65. Pre- and post-impoundment number of days with zero discharge (flow) at Hugo Dam, Oklahoma.

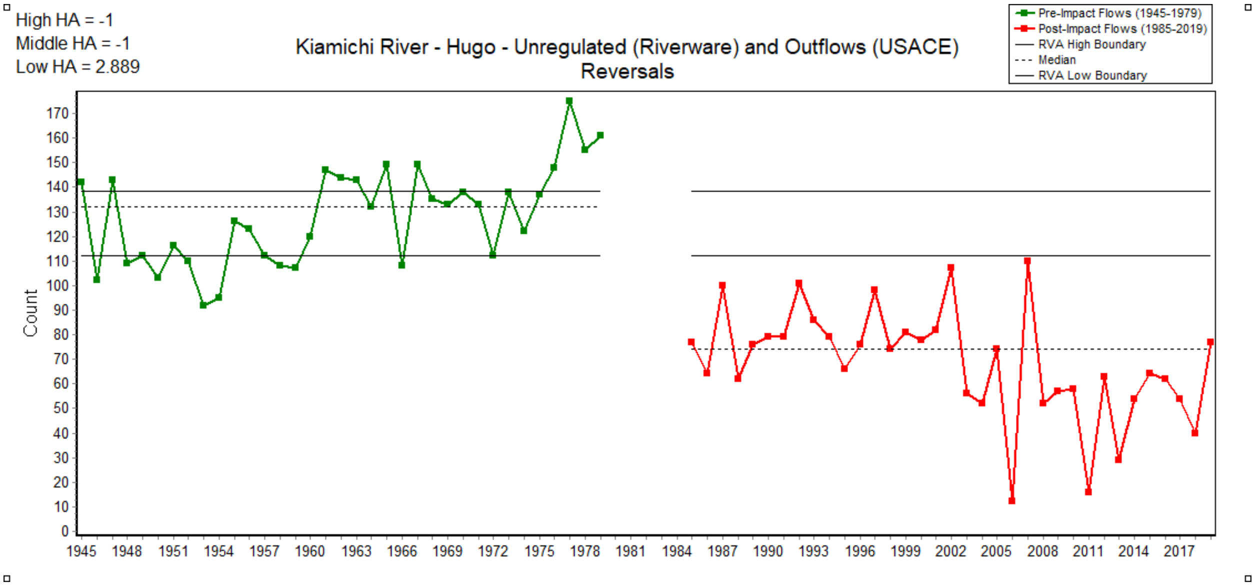


Figure 66. Pre- and post-impoundment number of reversals in flow conditions (i.e., changes from increasing flow rates to decreasing flow rates and vice versa) at Hugo Dam, Oklahoma.

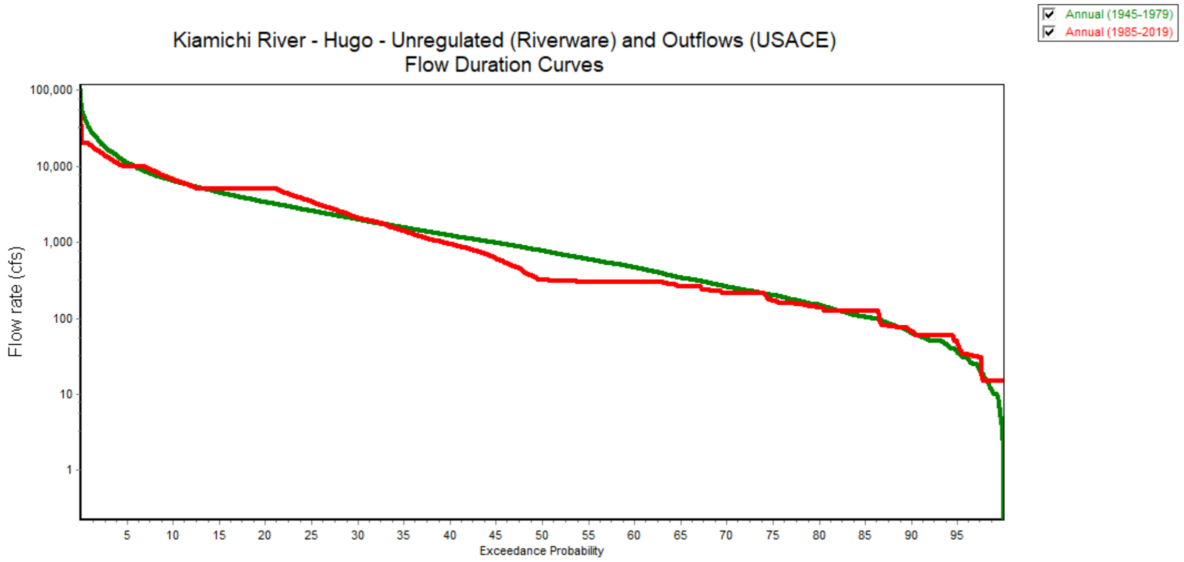


Figure 67. Pre- and post-impoundment reservoir flow-duration curves at Hugo Dam, Oklahoma.

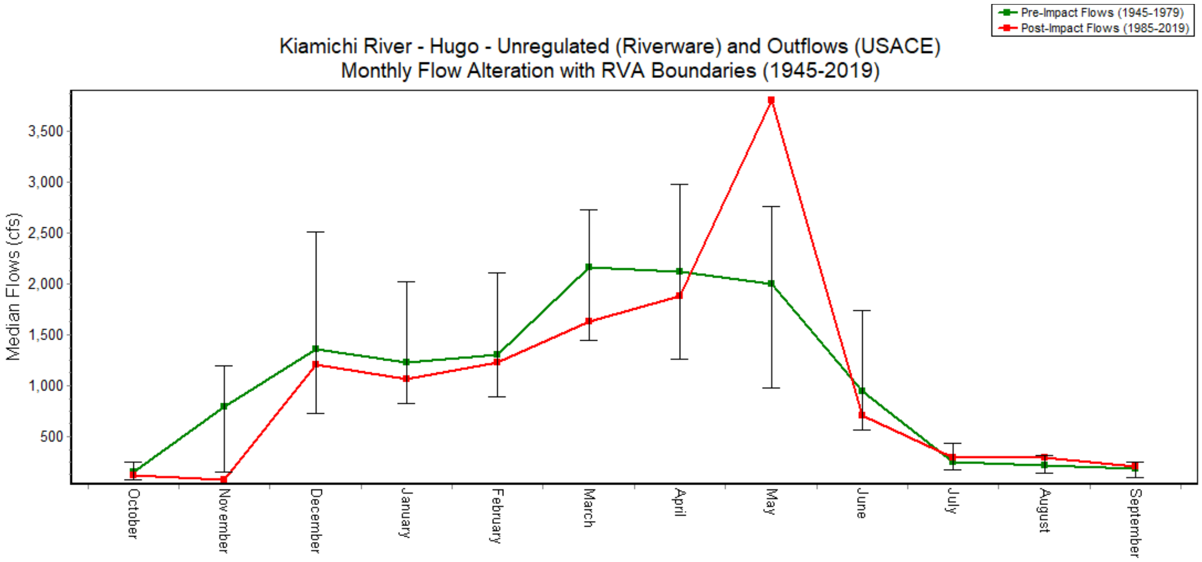


Figure 68. Pre- and post-impoundment monthly median flows at Hugo Dam, Oklahoma.