FINAL PERFORMANCE REPORT

Federal Aid Grant No. F10AF00172 (T-53-R-1)

Effects of Hydrologic Alteration on Species of Greatest Conservation Need in Lee Creek, Oklahoma

Oklahoma Department of Wildlife Conservation

July 1, 2010 through June 30, 2013

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State: Oklahoma **Grant Number:** F10AF00172 (T-53-R-1)

Grant Program: State Wildlife Grant

Grant Title: Effects of Hydrologic Alteration on Species of Greatest Conservation Need in Lee Creek, Oklahoma.

Grant Period: 1 July 2010 – 30 June 2013

Reporting Period: 1 July 2010 – 30 June 2013

I. OBJECTIVES:

1. To determine the status of fish communities in Lee Creek, Oklahoma with emphasis on species of greatest conservation need including state-endangered longnose darter.—RFP Priority Need #12

2. To determine the changes in Lee Creek hydrology due to Lee Creek Reservoir and to forecast changes in Lee Creek hydrology due to the proposed Pine Mountain Reservoir.

Abstract

Streams are influenced by human activities which can alter those ecosystems and jeopardize their ability to support a diverse array of organisms. In an attempt to mitigate these effects, states, including Oklahoma, enacted laws that preserve select rivers (i.e. scenic rivers) in their free flowing condition. However, these streams may still be vulnerable to perturbations. To determine the effects of anthropogenic impacts on the stream fish community structure in Lee Creek, a scenic river in Oklahoma, two objectives were developed and pursued: 1) determine the current community structure of fishes in relation to habitat and pre-dam fish assemblage and 2) determine to what extent

Lee Creek's hydrology has changed since impoundment as well as determine the cause of those changes. Fish were sampled during the summer of 2011, spring 2012, and summer 2012 using backpack electrofishing and gillnets from riffles, runs, glides, and pools. Concurrent with fish sampling, environmental parameters were collected at 5 uniformly-distributed points at each sample site. Relationships between fish and their environments were assessed using canonical correspondence analysis. The pre-impoundment fish community was determined from historic Lee Creek collections. Comparisons between pre- and post-impoundments were made using the Jaccard similarity index. The hydrology in Lee Creek, OK was assessed using Indicators of Hydrologic (IHA) software for pre- (1970-1991) and post-impoundment (1992-2013) periods. Land cover and precipitation patterns within the Lee Creek watershed were investigated to elucidate changes in hydrology. The fish community in Lee Creek, OK has been moderately impacted since impoundment with most species occurring pre- and post-impoundment. Changes in community structure are likely the result of the barrier effect. Furthermore, Lee Creek's hydrology has become flashier and flood events are occurring earlier in the year since impoundment. The altered streamflow appears to be driven by long-term changes in precipitation (i.e., increased rain-event magnitude coupled with decreased rain-event frequency) rather than by land cover or direct effects of the impoundment. The continued influence of the barrier effect, coupled with altered hydrology and precipitation, may have a profound effect on the stream fish community structure in Lee Creek, Oklahoma into the future.

II. SUMMARY OF PROGRESS

See attached Appendix I.

III. SIGNIFICANT DEVIATIONS

During the course of this project, the proposed Pine Creek Hydropower project to impound Lee Creek was cancelled. Data was collected and included in this report that could be used in the event that a similar project is again proposed. Therefore, objective 2 could not be fully addressed.

III. RECOMMENDATIONS

None.

PREPARED BY Michael R. Gatlin, James M. Long, and Donald J. Turton
Oklahoma State University

DATE 15 August 2013

APPROVED BY ______________________________
Fisheries Division Administration
Oklahoma Department of Wildlife Conservation

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Andrea K. Crews, Federal Aid Coordinator
Oklahoma Department of Wildlife Conservation

Appendix I

THE EFFECTS OF HYDROLOGIC ALTERATION ON STREAM FISH COMMUNITY STRUCTURE IN LEE CREEK, OKLAHOMA

By

MICHAEL R. GATLIN

Bachelor of Science in Natural Resource Ecology and Management

Oklahoma State University

Stillwater, Oklahoma

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in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 2013

THE EFFECT OF HYDROLOGIC ALTERATION ON STREAM FISH COMMUNITY STRUCTURE IN LEE CREEK, OKLAHOMA

Thesis Approved:

Dr. James M. Long

Thesis Adviser

Dr. Don J. Turton

Dr. Chris Zou

Name: MICHAEL R. GATLIN

Date of Degree: JULY, 2013

Title of Study: THE EFFECT OF HYDROLOGIC ALTERATION ON STREAM FISH COMMUNITY STRUCTURE IN LEE CREEK, OKLAHOMA

Major Field: NATURAL RESOURCES ECOLOGY AND MANAGEMENT

ABSTRACT: Streams are influenced by human activities which can alter those ecosystems and jeopardize their ability to support a diverse array of organisms. In an attempt to mitigate these effects, states, including Oklahoma, enacted laws that preserve select rivers (i.e. scenic rivers) in their free flowing condition. However, these streams may still be vulnerable to perturbations. To determine the effects of anthropogenic impacts on the stream fish community structure in Lee Creek, a scenic river in Oklahoma, I developed and pursued two objectives: 1) determine the current community structure of fishes in relation to habitat and pre-dam fish assemblage and 2) determine to what extent Lee Creek's hydrology has changed since impoundment as well as determine the cause of those changes. Fish were sampled during the summer of 2011, spring 2012, and summer 2012 using backpack electrofishing and gillnets from riffles, runs, glides, and pools. Concurrent with fish sampling, environmental parameters were collected at 5 uniformly-distributed points at each sample site. Relationships between fish and their environments were assessed using canonical correspondence analysis. The pre-impoundment fish community was determined from historic Lee Creek collections. Comparisons between pre- and post-impoundments were made using the Jaccard similarity index. The hydrology in Lee Creek, OK was assessed using Indicators of Hydrologic (IHA) software for pre- (1970-1991) and post-impoundment (1992-2013) periods. Land cover and precipitation patterns within the Lee Creek watershed were investigated to elucidate changes in hydrology. The fish community in Lee Creek, OK has been moderately impacted since impoundment with most species occurring pre- and post-impoundment. Changes in community structure are likely the result of the barrier effect. Furthermore, Lee Creek's hydrology has become flashier and flood events are occurring earlier in the year since impoundment. The altered streamflow appears to be driven by long-term changes in precipitation (i.e., increased rain-event magnitude coupled with decreased rain-event frequency) rather than by land cover or direct effects of the impoundment. The continued influence of the barrier effect, coupled with altered hydrology and precipitation, may have a profound effect on the stream fish community structure in Lee Creek, Oklahoma into the future.

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CHAPTER I

INTRODUCTION TO THESIS

Streams are influenced by human activities, which can alter those ecosystems and jeopardize their ability to support a diverse array of organisms (Marchetti and Moyle 2001, Poff 2002, Kemp et al. 2011). Anthropogenic alterations are wide ranging and can impact aquatic ecosystems both directly (e.g., impoundments; Miller et al. 1989, Dudgeon et al. 2006, Wang 2011) and indirectly (e.g., land cover and climate change; Schindler 1997, Xenopoulos et al. 2005, Weijters et al. 2009). While the mechanisms of direct and indirect effects can be much different, they can be equally detrimental to freshwater organisms such as fish. Because of the economic, recreational, and cultural importance of fishes, it is imperative to understand how anthropogenic alterations affect fish communities.

To partially mitigate the cumulative impact of human alterations to streams and their watersheds many states have enacted laws prescribing free-flowing waters and maintenance of high water quality (i.e., scenic rivers). In Oklahoma, the Oklahoma Scenic Rivers Act (SRA) designates “scenic river areas” to be preserved in their free-flowing condition and that such rivers shall not be impounded by any large dam or structure except when authorized by the state Legislature (OSRC 2010). However, municipalities that are in the immediate vicinity of the scenic river area may, in fact, build a dam or structure for domestic or municipal water supply without legislative approval if said structure does not significantly interfere with the river's free-flowing condition (OSRC 2010). Oklahoma has six rivers designated as "scenic river areas" including Lee Creek located in far east-central on the Oklahoma-Arkansas border. Lee Creek is a 5th order stream with head-waters originating in the Boston Mountains of northwestern Arkansas, flowing through Oklahoma and returning to Arkansas before reaching its confluence with the Arkansas River near Van Buren, AR (FERC 1987). Because the Oklahoma SRA is a state mandate and not nationally recognized (i.e., National Wild and Scenic Rivers), its authority ends at the state line. Therefore, in 1992, Arkansas was able to construct Lee Creek Dam and Reservoir at the lower end of Lee Creek as a means to increase water supply for the growing populace of nearby Fort Smith, AR. Once completed, Lee Creek dam was 6.5 m tall and impounded 257 hectares, which fragmented the stream and threatened the persistence of some lotic-specialist fish species.

Of particular concern with Lee Creek dam construction was that Lee Creek was the last remaining river in Oklahoma that contained the state-endangered longnose darter (*Percina nasuta*). The longnose darter is one of Oklahoma's rarest fish species (Robison et al. 1974, Miller and Robison 2004), designated by the state as "endangered" (ODWC), and "threatened" throughout its range (Jelk et al. 2008). Historically, the longnose darter was known to exist in the Poteau River drainage; however, since the construction of Wister dam in 1952, attempts at capturing this darter have failed (Cross and Moore 1952, Lindsey et al. 1983, Wagner et al. 1985). The extirpation of this species from the Poteau

River was likely a result of Wister Dam and Reservoir (Page 1974, Wagner 1985). Prior to the construction of the Lee Creek dam, Lee Creek had the largest existing population of longnose darters in its range (Robison 1992). Aside from the longnose darter, Lee Creek also supported at least 4 additional lotic fishes "of greatest conservation need" (wedgespot shiner *Notropis greenei*; Ozark minnow *Notropis nubilis*; sunburst darter *Etheostoma mihileze*; blackside darter *Percina maculata*; ODWC 2005) as well as a variety of transient "big-river" fishes (e.g., walleye and sauger *Stizostedion spp.*, gars *Lepisosteus spp.*, and goldeye *Hiodon alosoides*). Fish that migrate during parts of their life history are particularly vulnerable to habitat fragmentation by dams. When fishes are unable to successfully navigate around dams, local extirpation in areas with suitable habitat in above-dam streams can occur (Gehrke et al. 2002).

While impacts to Lee Creek's fishery were evaluated prior to dam construction, there was little concern given to non-sport fish inhabitants except for the longnose darter (Funk 1979). The value of the Lee Creek fishery thus seemed attributed more to the variety of catchable sport fishes rather than an intact ecosystem comprised of as many as 78 fish species (Funk 1979, FERC 1987). Since the construction of the dam and reservoir no comprehensive fish survey has been attempted. Because the fate of native fishes in Lee Creek since impoundment was unknown, I developed and pursued two objectives that are addressed in the following chapters of this thesis: 1) determine the current community structure of fishes in relation to habitat and pre-dam fish assemblage and 2) determine to what extent Lee Creek's hydrology has changed since impoundment after accounting for land cover and precipitation regime changes.

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CHAPTER II

INFLUENCE OF A DOWNSTREAM DAM ON STREAM FISH COMMUNITY STRUCTURE 20 YEARS POST IMPOUNDMENT

INTRODUCTION

Freshwater streams support some of the most diverse fish communities in the world (Dudgeon et al. 2006), but this diversity is threatened by anthropogenic alterations. Ultimately, the climate and geology of the region (Hynes 1975) shapes the natural flow regime and creates the habitats available to support highly diverse fish communities (Poff et al. 1997). However, the alteration of streams and associated watersheds by human activities jeopardizes these processes (McAllister et al. 2001, Dudgeon et al. 2006) and are often intentional. For example, channel straightening for navigation, de-watering for irrigation, and the construction of dams for the creation of reservoirs (Graf 1999) are all direct and intentional alterations to streams that affect the resident composition of biota.

Dams arguably account for the preponderance of stream alterations, with more than 84,000 dams in the United States alone (NID 2007). The large scale construction of dams is considered to be the single greatest direct threat to stream biodiversity because it reduces species richness and alters community composition (Vörösmarty et al. 2010).

The most visible impact of dams on stream ecosystems is the rapid shift in habitat type and availability as the stream becomes a reservoir (Poff et al. 1997, Nislow et al. 2002, Magilligan and Nislow 2005). This abrupt change of habitat causes a shift in the community composition of fishes such that a community once dominated by lotic specialists, such as darters (*Etheostoma* spp., *Percina* spp.) and smallmouth bass (*Micropterus dolomieu*), becomes comprised of lentic generalists, such as sunfishes (*Lepomis* spp.) and bullheads (*Amieurus* spp.; Phillips and Johnston 2004, Guenther and Spacie 2006, Kashiwagi and Miranda 2009). While dams perturb the stream habitat directly upstream of the structure itself through impoundments, they also severely alter the downstream environment (e.g., hydrology and bed scouring; Baxter 1977) which, in some cases, has caused the complete extirpation of native fishes (Winston et al. 1991, Watters 1996, Guenther and Spacie 2006). Furthermore, the construction of dams fragment streams, which impedes the upstream movement of migratory fish species and further influences the fish community by preventing native, yet transient, species from accessing portions of their native range (Porto et al. 1999, Pringle 2003). Additionally, decreased abundances or extirpation of lotic specialists from the unregulated riverine habitats above reservoirs has been documented in numerous studies (Blair 1959, Greathouse et al. 2006, Catalano et al. 2007, Slawski et al. 2008, Kashiwagi and Miranda 2009).

To partially mitigate the cumulative impact of human alterations to streams, many states, including Oklahoma, have enacted laws protecting free-flowing streams (i.e., scenic rivers), but even those are not immune to damming. Lee Creek is one of six scenic rivers in Oklahoma (OSRC 2010); however, in 1992 Lee Creek Dam and Reservoir was completed in Arkansas, which fragmented the stream and threatened the structure and function of the fish community. Lee Creek is a 5th order stream with head-waters in the Boston Mountains of northwestern Arkansas, flowing through Oklahoma and emptying into the Arkansas River near Van Buren, AR (Figure 1; FERC 1987).

Historically, Lee Creek was known to support at least 4 lotic fishes "of greatest conservation need" (wedgespot shiner *Notropis greenei*; Ozark minnow *Notropis nubilis*; sunburst darter *Etheostoma mihileze*; blackside darter *Percina maculata*; ODWC 2005) in addition to the longnose darter (*Percina* nasuta), which is Oklahoma's only state-listed endangered fish, as well as a number of transient big river fish species (e.g., goldeye *Hiodon alosoides* and sauger *Sander canadensis*; Funk 1979). Lee Creek was the last remaining river in Oklahoma that contained the longnose darter, which was extirpated from the Poteau River because of dam construction (Page 1974, Wagner 1985). It was feared that longnose darter would become extirpated from Oklahoma after the Lee Creek Dam and Reservoir were constructed.

While impacts to Lee Creek's fishery were considered prior to dam construction, there was little concern to non-sport-fish species except for the longnose darter (Funk 1979). Because most state game agencies rely on fishing- and hunting-license sales for their operating budgets, the fate of non-game species are often not truly considered (Mangum and Shaw 1984, Clarkson et al. 2005). Thus, it seemed the value of the Lee Creek fishery was attributed to the variety of catchable sport fishes rather than an intact ecosystem comprised of as many as 78 fish species (Funk 1979, FERC 1987). To better understand the cumulative effect of the Lee Creek Dam, I sought to determine how the community composition and structure of fishes and their habitats were affected.

Specifically, I examined how overall fish community structure was different between pre- and post-impoundment surveys of Lee Creek and how species were structured among the available habitat.

METHODS

Habitat Assessment

Because many fish species have affinities for different habitat types, I quantified the available underwater habitat with a global positioning system (GPS) and remotely-sensed side-scan sonar technology to optimize fish sampling. Surveys were conducted during June 2011 when water levels made travel by canoe safe and maximal underwater habitat was available for sonar imaging (approx. 38 – 107 m^3/sec). I modified methods outlined by Kaeser and Litts (2010) by capturing side-scan images with a Humminbird © 998c SI sonar unit, rectifying them with DrDepth® software, importing the images into a geographic information system (GIS; ArcVIEW 9.3), and delineating substrate types. In areas too shallow (< 0.25 m) to be sampled with the sonar unit, I visually assessed substrate type. I visually determined geomorphic channel units (GCU; e.g., riffle, run, and pool) concurrently with side-scan sonar imaging following characteristics outlined by Arend (1999). I determined substrate type within each contiguous area with a minimum mapping unit (MMU) greater than 78 m^2 (Kaeser and Litts 2010; Table 1). The MMU was used to ensure that randomly selected substrate centroids were within the accuracy error of the GPS during groundtruthing surveys, which were conducted at 50 randomly assigned points per substrate class (Congalton and Green 1999). All substrate classes with fewer than 50 areas were inspected. The surveys were conducted one week after side-scan images were collected to ensure that a stochastic disturbance (e.g., large spate) would not alter the spatial orientation of substrate types. Substrate types were combined when appropriate (e.g., an area that met requirements for boulder classification and had ≥ 25% of the area between the boulders filled with rocks < 500-mm in size were classified as "rocky-boulder"). I used error matrix and kappa analyses (KHAT) to determine classification accuracy (Congalton and Green 1999).

Fish Community Assessment

Pre-Impoundment – Using data compiled by Funk (1979), I ascertained the fish community in Oklahoma's Lee Creek prior to impoundment and compared it to this present survey. Data were converted into incidence (presence/absence) format because of differences in sampling methods and the Jaccard similarity index (Phillips and Johnston 2004) was used to determine similarity between surveys. The Jaccard index (S_j) varies from 0.0 (no species occur in both samples) to 1.0 (all species are present in both samples) with $S_j < 0.4$ considered very dissimilar and $S_j > 0.7$ very similar (Matthews et al. 1988, Phillips and Johnston 2004).

Post-Impoundment – To ensure representation of habitats for fish sampling in the Oklahoma portion of Lee Creek, I selected a total of 26 evenly distributed channel units in proportion to their abundance: riffle (7), run (6), pool (7), and glide (6). Fish sampling occurred during summer 2011, spring 2012, and summer 2012 and was stratified according to channel unit type. I sampled pools with three standard core-mesh gillnets (Pope et al. 2009; Miller Net Memphis, TN) placed evenly throughout each pool perpendicular to flow for 24 hours. Attempts to sample pools using boat electrofishing and benthic-trawls were abandoned due to access limitations (Guy et al. 2009). I sampled riffle, run, and glide channel units with a Smithroot® LR-24 backpack electrofisher adjusted to maintain 4 amperes output (Rabeni et al. 2009). The upper and lower margins of non-pool channel units were blocked prior to sampling with 6 mm mesh seine material secured to the substrate to prevent migration of fish during sampling (Peterson et al. 2005). Electrofishing was conducted in two passes in the upstream direction from the lower block-net (Meador et al. 2003, Rabeni et al. 2009). Stunned fish were collected during electrofishing and from the downstream block net. When possible, all fish were identified to species in the field and released alive. When field identification was not possible, I preserved fish in 10% buffered formalin and identified them to species in the laboratory.

To maximize species detection I used a species accumulation curve (Quist et al. 2009) and the Chao 1 species richness estimator (Chao 1984, Walther and Moore 2005, Hortal et al. 2006) calculated with EstimateS® 8.2 biodiversity software. The Chao 1 estimator uses species abundance information from each sample to determine the probability of detecting a new species in subsequent samples (rarefication) with 95% confidence. I considered sampling effort sufficient once species accumulation curves reached asymptote and when observed species richness was within one standard deviation of the mean Chao 1 estimate.

Concurrent with fish sampling, water temperature, water clarity, conductivity, specific conductance, depth, velocity, percent oxygen saturation, and dissolved oxygen concentration were measured at 5 uniformly-distributed points in each sampling unit. Velocity was measured using a Marsh-McBirney Flowmate® portable flowmeter at 0.60 of total depth when depth was < 0.75 m and at 0.2 and 0.8 total depth when depth exceeded 0.75 m (Gallagher and Stevenson 1999). All other variables were measured using a calibrated YSI® Pro 2030 multiparameter meter.

To determined associations between the fish community and measured environmental variables (e.g., temperature and channel unit), I used canonical correspondence analysis (CCA; ter Braak, C.J.F. 1986, Palmer 1993, ter Braak, C.J.F. and P.F.M. Verdonschot 1995) in the CANOCO® statistics software package. Analyses focused on inter-species distances using bi-plot scaling and I transformed species abundance data to their square root to reduce the effect of highly-abundant species (Lepš and Šmilauer 2003, O'Connell et al. 2004). Because I wanted to focus on how species were segregated according to habitat only, season-year combinations were input as co-variables to account for their variation in seasonal abundance. The significance of canonical axes was tested using an unrestricted Monte Carlo test with 499 permutations.

Results

Habitat Assessment

Riffles numerically dominated the geomorphic channel units (GCUs); however, these comprised a minority of the habitat in terms of length, which was dominated by slow-water (i.e., pool or glide) units (Table 2). For example, the pools were large and made up over 70 % of the total stream length whereas riffles accounted for less than 12% (Table 2).

I distinguished five distinct substrate classes based on side-scan sonar image analysis (Table 3), which totaled 109 ha of habitat (at discharge between 38 and 107 m^3/sec). Coarse bed material (rocky, rocky boulder, and boulder) made up the bulk of substrate types (91%); bedrock and fine sediments made up less than 9%. Overall map classification accuracy was 64% (Congalton and Green 1999; Table 4) and significantly different from random expectations (KHAT = 0.43). Classification accuracy was highest for boulder and bedrock substrates (Table 4).

Fish Community Assessment

Pre- and post-impoundment comparison – Historic surveys complied by Funk (1979) reported 51 species representing 12 families in Lee Creek, Oklahoma prior to dam construction (Table 5). Most of these species were considered typical of the Ozark ecoregion (30%) or wide-ranging (28%; Table 5). Combining all samples from the current, post-impoundment sampling effort, I documented 46 fish species from 11 families (Table 5; Table 6), with Ozark and wide-ranging species again best represented. However, Ozark species made up a greater proportion of the current fish community (48%) than documented by Funk (1979). Furthermore, Funk (1979) documented 19 species that I did not detect during this survey from six groups of habitat associates, including four big-river (BR) species. Additionally, I collected 13 species during this survey that were not documented by Funk (1979); the majority (10) of which were Ozark habitat associates. My sampling effort appeared sufficient to detect most rare species with species accumulation curves reaching an asymptote (Figure 2) and peaking at my observed richness of 46. The Chao 1 estimator ($\bar{x} = 48.5$; 95% CI 46.9-62.9) with 95% confidence suggests an additional seven species may be present, albeit probably rare in occurrence. Species richness was similar between historic ($S = 52$) and current ($S = 46$) surveys, although only 33 species occurred in both surveys (Table 5). Jaccard's similarity index comparing the two surveys indicated moderate similarity ($S_j = 0.51$).

Post-impoundment survey – I captured a total 4,248 individuals representing 46 species from summer 2011 to summer 2012. Central stoneroller (*C. anomalum*), green sunfish (*L. cyanellus*), and longear sunfish (*L. megalotis*) were the most numerous species and accounted for 53% of all individuals. Except for blackside darter, I captured all of the potentially occurring species of greatest conservation need, including the state-endangered longnose darter. The most abundant of these species were the wedgespot shiner (40) and Ozark minnow (35), which came from a variety of channel units during all seasons. All eight longnose darters were captured exclusively from glide habitats, mostly during spring 2012. I was also able to collect two sunburst darter individuals both of which were found during sampling during summer 2011.

Numerical dominance among fish species varied among habitats and seasons, although summer samples always yielded the highest catch rates (Table 6). I caught most fish in swift, shallow-water units (i.e., riffle and run) during both summer seasons, but caught an equal amount from all shallow-water units (including glides) during spring

2012. Shallow-water summer samples were dominated by central stonerollers, green sunfish, and longear sunfish in both years. Spring samples, however, were dominated by longear sunfish and bigeye shiner (*N. boops*). Pools, which were sampled with gill-nets, yielded 4.7-8.4 fish/net/night, the greatest occurring during summer 2011, but species predominance varied among sampling seasons. For example, gizzard shad (*D. cepedianum*) and smallmouth bass were predominately abundant during summer 2011, but river redhorse (*M. carinatum*) and channel catfish (*I. punctatus*) dominated spring 2012 and summer 2012 pool samples.

Canonical Correspondence Analysis

Canonical correspondence analysis was significant (P = 0.002, F-ratio = 3.038, Table 7) with measured environmental variables explaining 82.2% of the variation in species distributions along four canonical axes. The first two canonical axes explained nearly 70% of the variation in the species-environment relationship: axes three and four each explained less than 8% and I did not interpret them further. Pool channel-units and depth were positively correlated along the first axis and explained 55.1% of variation in species distribution (Figure 3). Shallow-water channel units were segregated along axis 2, explaining 14.8% of the variation in the species-environment relationship, with riffles and runs separated from glides.

Fish species varied in their habitat association (Figure 3). Several species were only captured in one channel unit type as indicated by the close proximity of species and channel unit points. For example, longnose darter (LNDT) was only captured in glide habitats whereas longnose gar (*L. osseus*, LNGR) and gizzard shad (GSHD) were captured exclusively in pools (Figure 3). Conversely some species were not strongly associated with any particular channel unit. For example, flathead catfish (*P. olivaris*, FHCF) and smallmouth bass (SMBS) were found in all habitat types, with species centroids between deep-, shallow-, fast-, and slow-water units.

Because pool habitats created an overwhelming dichotomy among species and habitat, I performed an additional CCA without pools to elucidate variables associated with shallow-water habitat types. Canonical axes without pool samples were significant ($P = 0.002$, F-ratio = 1.644) and explained 75.2% of the variation in the species-environment relationship (Table 8). Habitat types as affected by depth and water velocity explained the greatest amount of variation, along axis one, with glide habitats, which were deeper, separated from riffles and runs, which were generally shallower (Figure 4). Axis two reflected differences in dissolved oxygen, substrate type, and fast-water units (i.e., riffles and runs). For instance, glide channel units were typically deep with rocky bolder substrate, relatively high dissolved oxygen concentrations, and low water velocity. Of the species of greatest conservation need, two (wedgespot shiner WSSH and sunburst darter SBDT) were associated with shallow glides with low water velocity and high water temperatures. Ozark minnow (OZMW) was associated with deep-rocky runs, high conductivity, and low dissolved oxygen, and the state-endangered longnose darter (LNDT) was found exclusively in glide habitats with rocky-boulder substrate, high dissolved oxygen, and low water velocity.

Discussion

The fish community in Lee Creek, Oklahoma appeared to be moderately impacted from the construction of Lee Creek Dam, with most species of greatest conservation accounted for in the post-impoundment survey, but notably lacking big-river species that would normally migrate between Lee Creek and the Arkansas River. Although comparisons between surveys that utilize different sampling protocols can be difficult (Bonar et al. 2009) because the ability to detect species is attributed to sampling effort, season, gear type, and other factors (Angermeier and Smogor 1993, Peterson and Rabeni 1995), trends were evident. The most abundant species (i.e., longear sunfish and green sunfish) were similar between surveys and species only detected in pre- or post-impoundment surveys were generally rare, represented by fewer than 10 individuals (e.g., northern hogsucker *Hypentelium nigricans*). Although determining impacts on rare species can be difficult, because of low detection probabilities (Hagler et al. 2011), several species were completely absent post-impoundment, which seems significant. For instance, the orangespotted sunfish (*L. humilis*), brindle madtom (*N. miurus*), and golden redhorse (*M. erythrurum*) were abundant in the Oklahoma portion of Lee Creek before dam construction, yet I was unable to document a single individual. Furthermore, all large-bodied big-river fishes such as freshwater drum (*Aplodinotus grunniens*), goldeye, white bass (*Morone chrysops*), and shortnose gar (*Lepisosteus platostomus*) were present before impoundment but absent since. There is a chance that these species occurred within Lee Creek and I was unable to capture them; however, this is unlikely because my sampling efforts were sufficient to capture similar species (e.g., longear sunfish, slender madtom *N. exilis*, and river redhorse) including those low in abundance (e.g., spotted gar *L. oculatus*). Importantly, Funk (1979) summarized pre-impoundment data from Lee

Creek in which a greater variety of gears were used (i.e., seines, fyke nets, gillnets, electrofishers, minnow traps, prima cord, and rotenone), at four sampling locations whereas I utilized fewer gear types (i.e., backpack electrofisher and gillnets) but sampled nearly eight times as many sites to access post-impoundment status of the fish community. In contrast, I collected several species in large numbers that were not reported in the pre-impoundment survey, including the Ozark minnow, which is a species of conservation need. The most abundant species captured during this survey and not documented before (Funk 1979) were all Ozark ecoregion associates (e.g., greenside darter *E. blennoides* and fantail darter *E. flabellare*) and habitat generalists, suggesting they likely occurred in Lee Creek but the pre-impoundment sampling effort was not sufficient.

Extirpation of large-bodied big-river fishes is likely the result of the barrier the dam itself created. The "barrier effect" has been shown to reduce or extirpate transient species above barriers (Poff and Hart 2002, Shea and Peterson 2007). For example, migratory white-spotted charr (*S. leucomaenis*) populations were reduced because migration was eliminated by the construction of dams in southwestern Hokkaido, Japan (Morita and Yamamoto 2002). Similarly, Gido et al. (2010) documented a population decline for goldeye in the heavily impacted Kansas River Basin in eastern Kansas, USA. However, the reduction of some species could be caused by the isolation of populations above dams because of the barrier effect (Neves and Angermeier 1990, Morita and Yamamoto 2002, Katano et al. 2006). Fishes isolated from source populations because of a barrier become more susceptible to stochastic events. For example, Lindsey et al. (1983) were unable to collect brindle madtom during a follow-up survey of the Poteau

River, Oklahoma likely due to the construction of a dam. Furthermore, the inability to recolonize after severe drought, due to lack of connectivity with below-dam source populations may explain the absence of blackside darter in the upstream portions of impounded Mississippi (Kashiwagi and Miranda 2009) and Oklahoma streams (Lindsey et al. 1983). Notably, the blackside darter is the only species of conservation need that I was unable to collect during this survey, suggesting that it may have become extirpated from Lee Creek.

Alternatively, the reduced abundance or extirpation of small-bodied fishes above impoundments has been attributed to increased predation pressure from sport-fish migrating upstream from the reservoir (Winston et al. 1991, Matthews and Marsh-Matthews 2007). For example, the reduced abundance of several lotic species, including extirpation of four, after construction of a dam and reservoir on the North Fork of the Red River, Oklahoma was attributed to increased predation pressure (Winston et al. 1991). However, my data do not support such a hypothesis in Lee Creek because the piscivorous community is comprised of similar species between pre- and post-impoundment periods.

I was able to collect the state endangered longnose darter during this survey. While comparisons between pre- and post-impoundment abundance of longnose darter cannot be made, a more recent report, using similar methods, found longnose darter in much greater numbers (Gatlin and Long 2011). The longnose darters I collected were found in similar habitats as described in previous studies (Robison 1992, Gatlin and Long 2011). Because most longnose darter individuals were collected during 2012, we suspect that record flooding during fall 2010 and spring 2011 might have displaced many of Lee

Creek's fishes. While extreme flooding in Ozark streams has little effect on species richness it can alter species abundances after the flood waters recede (Mathews 1986).

The persistence of fish above a barrier is likely the result of sufficient upstream habitat (Letcher et al. 2007, Whiteley et al. 2010). The rocky and boulder substrate within Lee Creek creates a great deal of habitat heterogeneity, which can support high species diversity (Guenther and Spacie 2006). Rocky substrates provide interstitial space for invertebrate production, which many fish species rely on for food (Powers 1992), and allows for the accumulation of organic matter on the stream bottom (Neebling and Quist 2010), further increasing productivity and diversity (Elwood et al. 1983). Lee Creek appears to continue to provide adequate habitat and energy to support most resident fish although a dam has fragmented the system. Lee Creek reservoir is not much different than the wide, deep pools upstream in which these resident species evolved, possibly limiting the impacts from the dam on the fish community. However, the fish community above the dam may still adapting to its relatively new state, precluding one from observing greatly divergent systems. Additional studies will likely be needed to determine the true extent of change as a result of the dam on Lee Creek, Oklahoma.

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Tables and Figures

Table 1. Classification scheme and descriptions used to delineate substrate types from side-scan sonar images in Lee Creek, Oklahoma; adapted from Kaeser and Litts (2010).

Class	Description
Fine	≥ 75% of area composed of particles < 2-mm diameter (sand, silt, clay or fine detritus).
Rocky	≥ 25% of area composed of rocks > 2-mm, but < 500-mm (gravel, pebble, or cobble).
Boulder	An area that includes > 3 boulders, each > 500-mm, each within 2-m of the next adjacent boulder will be classified as boulder.
Bedrock	≥ 75% of area composed of bedrock or outcropping with relatively smooth texture; including bedrock in fractured blocks > 3-m.
Unsure-Fine	Any area of sonar map difficult to classify due to poor image quality, but suspected to be predominately fine material.
Unsure-Rocky	Any area of sonar map difficult to classify due to poor image quality, but suspected to be predominately rocky material.

Table 2. Geomorphic Channel Unit (GCU) summary statistics derived from habitat surveys conducted in Lee Creek, Oklahoma during summer 2011.

		Length (m)					
GCU	# of Units	Mean	SD	Min	Max	Total	%
Riffle	139	24.6	15.5	4.7	108.8	3,420.6	11.2
Run	89	34.1	29.3	5.2	209.3	3,002.5	9.8
Pool	86	254.6	297.2	14.2	1,747.2	21,894.3	71.4
Glide	61	38.3	23.3	7.1	119.6	2,336.3	7.6
Total	375					30,653.7	

Table 3. Substrate classification summary statistics derived from side-scan sonar image analysis using habitat surveyed in Lee Creek, Oklahoma during summer 2011.

		Area (m^2)					
Substrate Class	# of Units	Mean	SD	Min	Max	Total	%
Bedrock	27	3,564	2,813	109	10,546	96,238	8.8
Rocky	209	2,441	5,026	37	51,251	510,101	46.5
Rocky-Boulder	171	2,853	4,655	160	32,830	487,854	44.5
Fine	1	--	--	--	--	578	< 0.00
Boulder	1	--	--	--	--	1,618	0.14
Total	409					1,096,389	100

Table 4. Error matrix comparing reference and side-scan classified substrate types surveyed in Lee Creek, Oklahoma during summer 2011.

	Reference						
Classified	Fine	Rocky	Rocky Boulder	Bedrock	Boulder	Row Total	User's
Fine	0	0	0	1	0	1	0%
Rocky	0	33	12	4	0	49	68%
Rocky- Boulder	0	14	28	6	2	50	56%
Bedrock	1	3	0	12	0	16	75%
Boulder	0	0	0	0	1	1	100%
Column Total	1	50	40	23	3	117	
Producer's	0%	66%	33%	52%	0%		Overall 64%

Table 5. List of fish species from historic surveys (Funk 1979) and those collected (N = number captured) during 2011 and 2012 from Lee Creek, Oklahoma. Species of greatest conservation need are represented by #. Habitat types indicate affinities by fish species and follow Funk (1979): P = prairie, L = lowland, O = Ozark, BR = big river, OP = Ozark-prairie, OL = Ozark-lowland and WR = wide ranging.

Common Name (code)	Scientific Name	Habitat Type	Funk (1979)	2011-2012 (*N*)
	Atherinidae			
brook silverside (BSSD)	*Labidesthes sicculus*	OL	Y	Y(1)
	Catostomidae			
river carpsucker	*Carpiodes carpio*	P	Y	N
northern hogsucker (NOHS)	*Hypentelium nigricans*	O	N	Y(7)
smallmouth buffalo	*Ictiobus bubalus*	WR	Y	N
bigmouth buffalo	*Ictiobus cyprinellus*	WR	Y	N
golden redhorse	*Moxostoma erythrurum*	O	Y	N
black redhorse (BKRH)	*Moxostoma duquesnei*	O	N	Y(3)
river redhorse (RIRH)	*Moxostoma carinatum*	O	N	Y(33)
shorthead redhorse (SHRH)	*Moxostoma macrolepidotum*	OP	Y	Y(1)
spotted sucker (SPSK)	*Minytrema melanops*	WR	N	Y(20)
	Centrarchidae			
bluegill (BLGL)	*Lepomis macrochirus*	WR	Y	Y(83)
green sunfish (GRSF)	*Lepomis cyanellus*	WR	Y	Y(438)
orangespotted sunfish	*Lepomis humilis*	P	Y	N
longear sunfish (LESF)	*Lepomis megalotis*	OL	Y	Y(656)
redear sunfish (RESF)	*Lepomis microlophus*	O	Y	Y(95)
warmouth (WAMO)	*Lepomis gulosus*	L	Y	Y(2)
largemouth bass (LMBS)	*Micropterus salmoides*	WR	Y	Y(5)
smallmouth bass (SMBS)	*Micropterus dolomieu*	O	Y	Y(89)
spotted bass (SPBS)	*Micropterus punctulatus*	OL	Y	Y(24)
black crappie	*Pomoxis nigromaculatus*	WR	Y	N
white crappie (WTCR)	*Pomoxis annularis*	WR	Y	Y(1)
	Clupeidae			

gizzard shad (GSHD)	*Dorosoma cepedianum*	WR	Y	Y(66)
	Cyprinidae			
central stoneroller (CTSR)	*Campostoma anomalum*	OP	Y	Y(1,168)
steelcolor shiner (SCSH)	*Cyprinella whipplei*	O	Y	Y(81)
bluntface shiner	*Cyprinella camura*	O	Y	N
common carp (COCP)	*Cyprinus carpio*	WR	Y	Y(3)
cardinal shiner (CASH)	*Luxilus cardinalis*	O	Y	Y(289)
bigeye shiner (BESH)	*Notropis boops*	O	Y	Y(144)
mimic shiner (MISH)	*Notropis volucellus*	BR	N	Y(3)
ozark minnow[#] (OZMW)	*Notropis nubilus*	O	N	Y(44)
wedgespot shiner[#] (WSSH)	*Notropis greenei*	O	Y	Y(40)
bluntnose minnow (BNMW)	*Pimephales notatus*	WR	Y	Y(35)
slim minnow	*Pimephales tenellus*	O	Y	N
bullhead minnow	*Pimephales vigilax*	L	Y	N
	Fundulidae			
blackspotted topminnow (BSPT)	*Fundulus olivaceus*	OL	Y	Y(18)
blackstriped topminnow (BSTT)	*Fundulus notatus*	OL	N	Y(9)
northern studfish (NOSF)	*Fundulus catenatus*	O	N	Y(4)
	Hiodontidae			
goldeye	*Hiodon alosoides*	BR	Y	N
	Ictaluridae			
black bullhead	*Ameiurus melas*	WR	Y	N
yellow bullhead (YEBH)	*Ameiurus natalis*	WR	Y	Y(3)
channel catfish (CHCF)	*Ictalurus punctatus*	WR	Y	Y(54)
slender madtom (SLMT)	*Noturus exilis*	O	Y	Y(187)
brindled madtom	*Noturus miurus*	L	Y	N
freckled madtom	*Noturus nocturnus*	L	Y	N
flathead catfish (FHCF)	*Pylodictis olivaris*	WR	Y	Y(66)
	Lepisosteidae			
longnose gar (LNGR)	*Lepisosteus osseus*	WR	Y	Y(43)
spotted gar (SPGR)	*Lepisosteus oculatus*	L	Y	Y(9)
shortnose gar	*Lepisosteus platostomus*	BR	Y	N
	Moronidae			
white bass	*Morone chrysops*	BR	Y	N

	Percidae			
banded darter (BDDT)	*Etheostoma zonale*	O	Y	Y(108)
greenside darter (GSDT)	*Etheostoma blennioides*	O	N	Y(122)
fantail darter (FTDT)	*Etheostoma flabellare*	O	N	Y(119)
johnny darter	*Etheostoma nigrum*	OP	Y	N
orangethroat darter (OTDT)	*Etheostoma spectabile*	O	Y	Y(100)
redfin darter (RFDT)	*Etheostoma whipplei*	P	Y	Y(36)
sunburst darter# (SBDT)	*Etheostoma mihileze*	O	Y	Y(2)
channel darter (CHDT)	*Percina copelandi*	O	N	Y(2)
logperch (LOGP)	*Percina caprodes*	O	Y	Y(19)
blackside darter#	*Percina maculata*	P	Y	N
longnose darter# (LNDT)	*Percina nasuta*	O	Y	Y(8)
slenderhead darter	*Percina phoxocephala*	OP	Y	N
	Petromyzontidae			
chestnut lamprey (CNLP)	*Ichthyomyzon castanues*	O	N	Y(1)
southern brook lamprey (BRLP)	*Ichthyomyzon gagei*	O	N	Y(1)
	Poeciliidae			
mosquitofish (MOFH)	*Gambusia affinis*	L	Y	Y(6)
	Sciaenidae			
freshwater drum	*Aplodinotus grunniens*	BR	Y	N

Table 6. Post-impoundment fish survey statistics by season and geomorphic channel unit (GCU) in Lee Creek, Oklahoma during 2011-2012. U = number of units sampled; S = number of species captured; N = number of individuals captured

GCU	Summer 2011			Spring 2012			Summer 2012			Unit Total		
	U	S	N	U	S	N	U	S	N	U	S	N
Glide	6	25	320	6	16	225	5	21	497	17	32	1,042
Pool	7	17	178	5	11	70	5	11	72	17	18	320
Riffle	7	22	612	8	20	267	5	13	528	20	27	1,407
Run	6	25	632	5	18	213	3	23	634	14	29	1,479
Total	26	39	1,742	24	34	775	18	38	1,731	68	46	4,248

Table 7. Summary of canonical correspondence analysis calculated using species and habitat types collected in Lee Creek, Oklahoma from 2011-2012.

	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues	0.747	0.201	0.095	0.072	3.768
Species-environment correlations	0.991	0.913	0.796	0.681	
Cumulative percentage variance:					
explained of species data	21.1	26.7	29.4	31.4	
of species-environment relation	55.1	69.9	76.9	82.2	
Sum of all eigenvalues					3.546
Sum of all canonical eigenvalues					1.356

Table 8. Summary of canonical correspondence analysis calculated without pool samples using species and habitat type collected in Lee Creek, Oklahoma from 2011-2012.

	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues	0.211	0.101	0.089	0.061	2.289
Species-environment correlations	0.918	0.798	0.821	0.653	
Cumulative percentage variance:					
of species data	10.4	15.3	19.7	22.7	
of species-environment relation	34.4	50.8	65.2	75.2	
Sum of all eigenvalues					2.036
Sum of all canonical eigenvalues					0.615

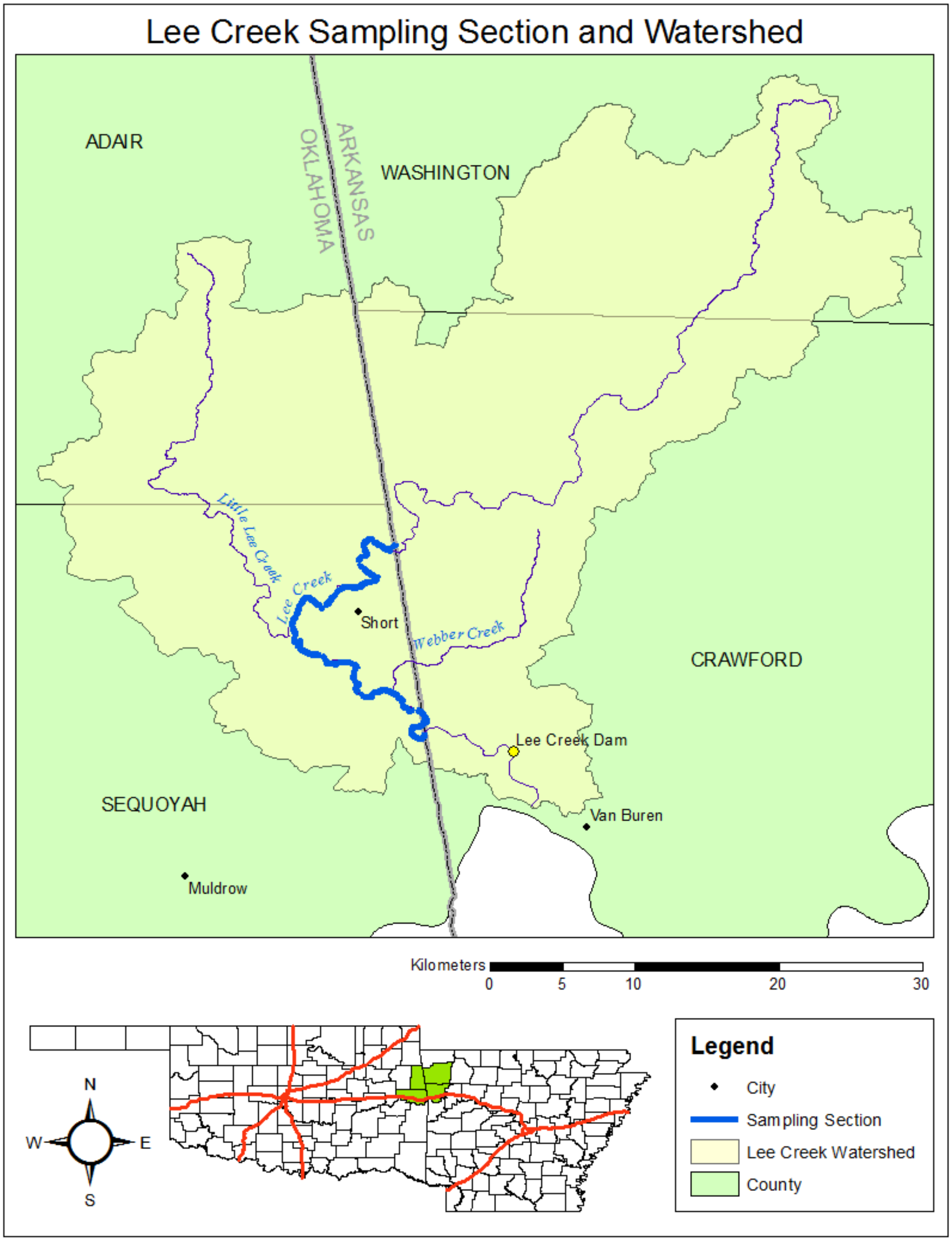

Figure 1. Map depicting the location and extent of Lee Creek and its watershed along the Oklahoma-Arkansas border. Samples collected during 2011-2012 occurred within the labeled sampling section.

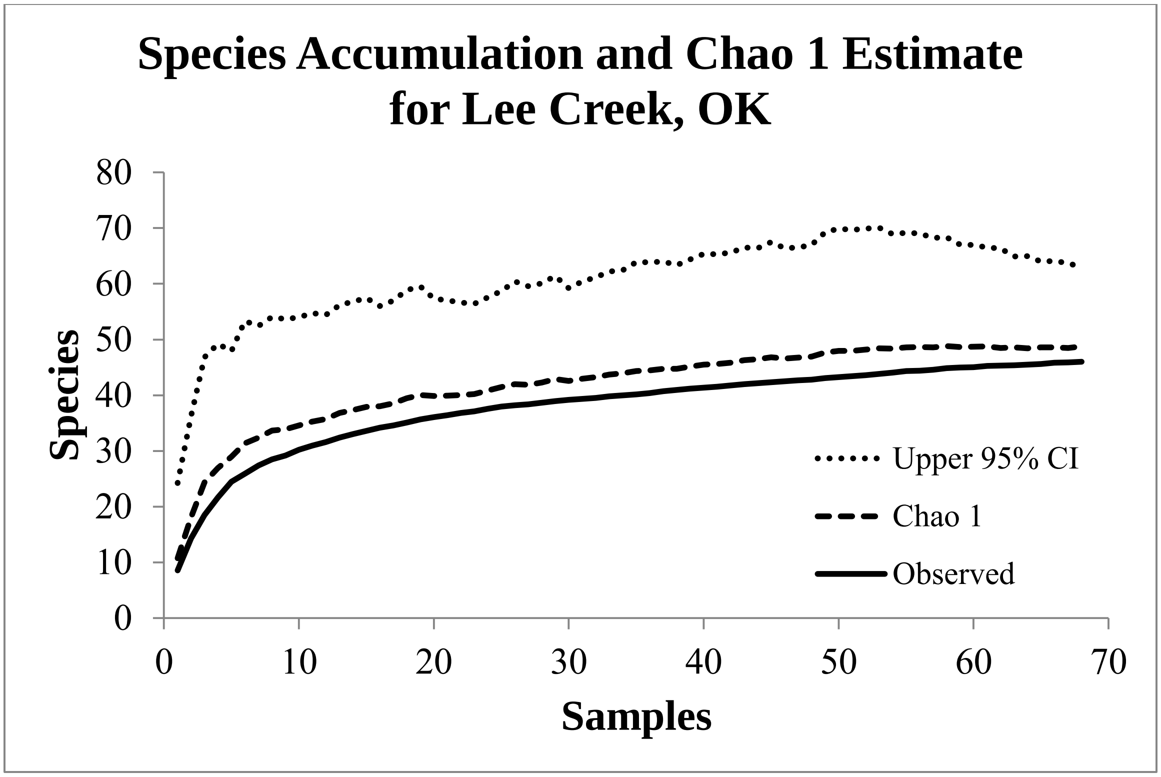

Figure 2. Species accumulation and Chao 1 species richness estimate curves calculated from all fish samples in Lee Creek, Oklahoma. Observed species represents the number of species captured from 2011 to 2012. Furthermore, observed species is interpreted as the lower 95% CI because Chao 1 will not generate a species estimate that is fewer than the number of species observed.

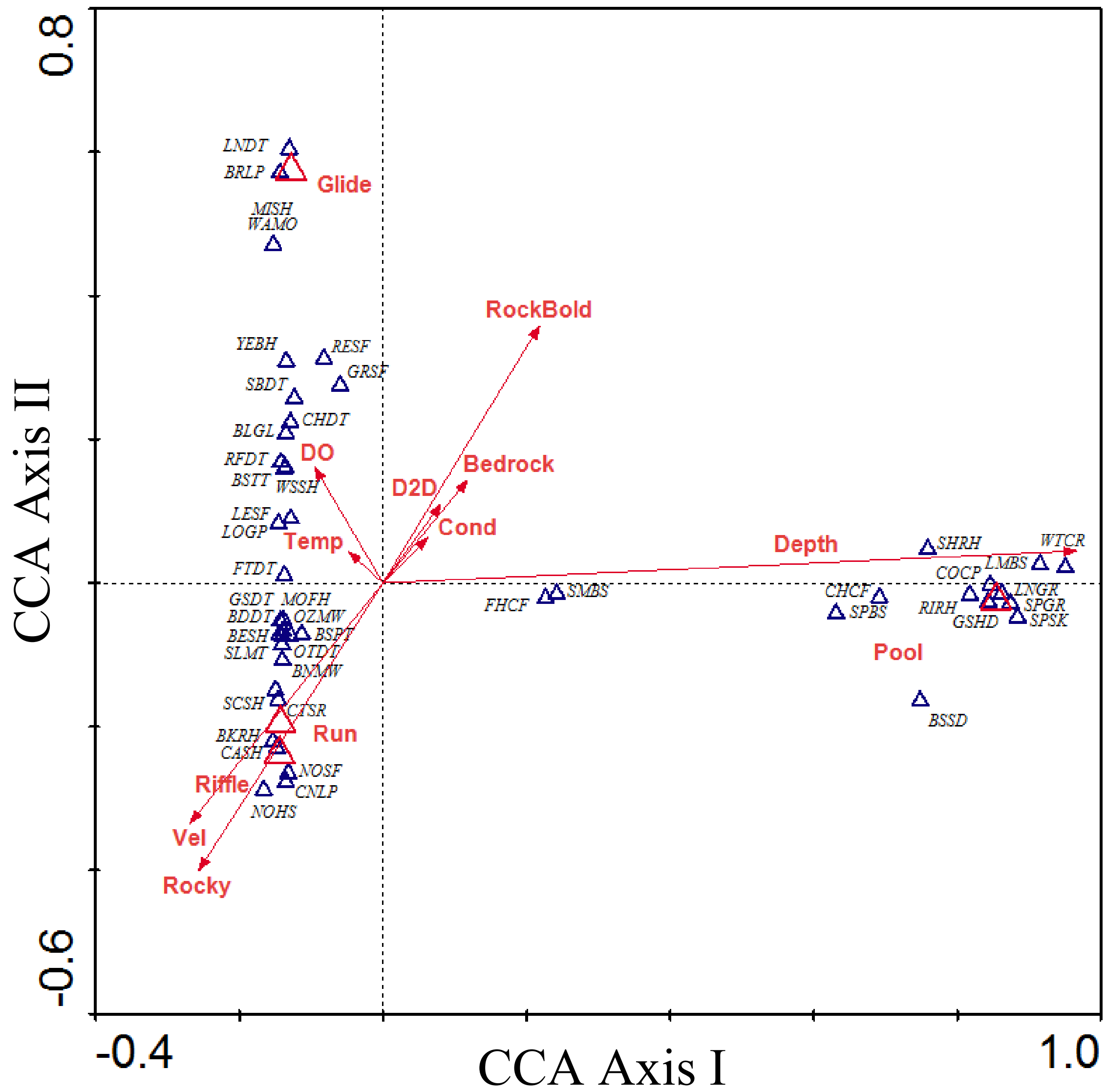

Figure 3. Biplot of species point and environmental vectors from canonical correspondence analysis (CCA). Analysis includes all channel units and species collected from Lee Creek, OK from 2011 to 2012. Please refer to Table 5 for species codes.

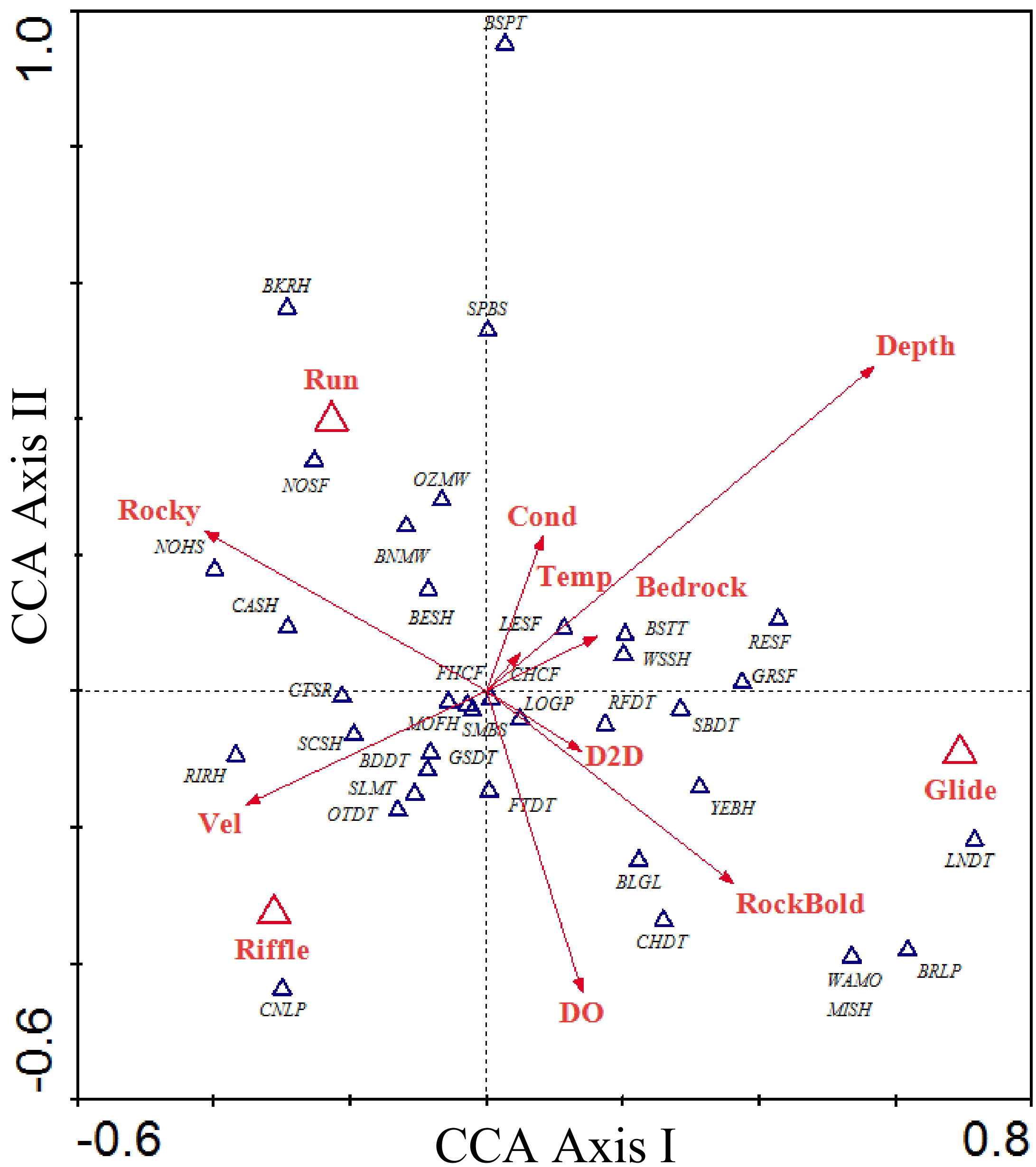

Figure 4. Biplot of species point and environmental vectors from canonical correspondence analysis (CCA). Analysis includes riffle, run, and glide channel unit samples from Lee Creek, OK from 2011 to 2012. Please refer to Table 5 for species codes.

CHAPTER III

CLIMATE-MEDIATED CHANGES TO THE NATURAL FLOW REGIME: IMPLICATIONS FOR FISHES OF GREATEST CONSERVATION NEED IN LEE CREEK, OKLAHOMA

Introduction

Although dams are arguably one of the greatest anthropogenic forces affecting streamflow (Graf 1999, 2006), they are not the sole source of perturbations in stream systems as other forces often act in concert with dams to alter stream hydrology. Accounting for these other forces is necessary to understand and predict the full scale of impacts of building dams on stream systems. For instance, land cover alterations can cause significant modifications to steam hydrology (Fohrer 2001, Grimm et al. 2008) and human-mediated climate change is predicted to cause dramatic shifts in precipitation patterns (IPCC 2007), both of which can affect stream biota (Schindler 1997, Xenopoulos et al. 2005, Weijters et al. 2009).

Land cover conversion, associated with expanding human populations, from native grasslands and forests into agriculture land and urban areas, has a large impact on the natural flow regime (Meyer and Turner 1992). Stream flow alteration occurs through decreased soil infiltration capacity and increased impervious surfaces (e.g., roofs and parking lots) within a watershed causing reduced baseflow but increased overland flow (Paul and Meyer 2001, Allen 2004, Wissmar et al. 2004). Typically, these areas display increased flood magnitudes, decreased lag-time between precipitation and peak stream flow, lower base flow, and increased non-point source pollution (Wang et al. 1997, Paul and Meyer 2001, Sutherland et al. 2002, White and Greer 2006).

Similarly, human-mediated climate change is predicted to affect the natural flow regime in much the same way as changing land cover primarily through altered precipitation patterns (IPCC 2007). Predictions indicate significant deviations in the timing and magnitude of precipitation events, which can dramatically affect stream hydrology (Poff et al. 1997, Groisman et al. 2001). The effects of climate change are expected to vary across regions (Whitfield 2010) although, some general trends are expected (IPCC 2007), such as increased intensity of rain storms coupled with decreased frequency of rain events (Karl and Knight 1998, Easterling et al. 2000).

Ultimately, these modifications to streamflow will impact fishes and other aquatic organisms. For instance, a shift in flood timing could affect fish reproduction by inadvertently triggering spawning cues or causing larval mortality (Bunn and Arthington 2002, Lytle and Poff 2004). Changes in the natural flow regime are of particular concern for fishes of conservation need, especially those that occur on the edge of their natural range and are highly adapted to flow.

With the wide-ranging availability of land use and precipitation data, it is possible to examine multiple anthropogenic forces acting on streams where dams have been built if sufficient temporal data exist on either side of the event. Lee Creek and its watershed in Oklahoma and Arkansas is a system where these criteria are mostly met and have implications for future decision makers to consider. Lee Creek is a 5th order stream and one of six scenic rivers in Oklahoma (OSRC 2010) with head-waters in the Boston Mountains of northwestern Arkansas, which flows through Oklahoma and confluences with Arkansas River near Van Buren, AR (Figure 1). In 1992, The Lee Creek Dam and Reservoir were constructed, threatening the continued existence of many fish species consider to be of "greatest conservation need" such as the wedgespot shiner *Notropis greenei*; Ozark minnow *Notropis nubilis*; sunburst darter *Etheostoma mihileze*; blackside darter *Percina maculate* and longnose darter *Percina nasuta* (ODWC 2005). Longnose darter in particular was of interest during the negotiations that led to the creation of the dam (FERC 1987) because Lee Creek was the last remaining river in Oklahoma that contained the longnose darter since becoming extirpated from the Poteau River after the system was dammed (Wagner 1985). As a result, the longnose darter is considered by the state of Oklahoma as "endangered"; the only fish species to be classified as such. Continuing to threaten the persistence of these species in Lee Creek was the proposal to create another dam (Pine Mountain Dam) in 2000 upstream of Lee Creek Dam (Federal Register 2010). Although consideration for the construction of Pine Mountain Dam was withdrawn in 2010, it remains authorized for construction and could be reconsidered in the future. As a result, understanding the role that additional factors such as land use and climate change have on hydrology of Lee Creek would be beneficial to these future decisions regarding dam construction. Therefore, I 1) quantified the extent of land cover change within the Lee Creek watershed since damming in 1992 and 2) investigated precipitation patterns that might have occurred concomitantly.

METHODS

Hydrological analysis

To determine alterations in streamflow coincident with impoundment, I obtained daily streamflow data from the USGS gaging station on Lee Creek near Short, OK (gage# 07249985; Figure 1), split the data into pre- (1970-1991) and post-impoundment (1992-2013) periods, and used Indicators of Hydrologic Alteration (IHA) software to determine differences (Richter et al. 1996, Mathews and Richter 2007). The IHA analysis calculates 32 ecologically significant parameters for each period, based on the water-year (Oct. 1-Sept. 31), and was used to determine how flow duration, magnitude, frequency, or timing might have changed (Richter et al. 1996). Because the data were not normally distributed I reported percentiles and medians (TNC 2009). High- and low-flow conditions were defined as median flow ± 25%. Streamflow that exceeded the two year return interval was considered a small flood; flow that exceeded the ten year return interval was a large flood. Extreme low-flows were defined as any flow that was in the lower 10% of the daily flows for the period. Range of variability analysis (RVA) bounds, which determine "natural" flow conditions based on the pre-impoundment period, were set to ± 17% of the median value for the period. I used significant count values (< 0.10) to determine statistical significance of IHA parameters (TNC 2009).

Land cover analysis

Because watershed factors can influence hydrology, I analyzed changes in watershed land cover since 1992, using 30 m resolution data available for 1992, 2001, and 2006 from the Multi-Resolution Land Characteristics Consortium (Vogelmann et al.

2001, Homer et al. 2007, Fry et al. 2011). No land cover data existed for the entire watershed before 1992, so pre-dam comparisons could not be made. Because of discrepancies in data collection and classification between 1992 and 2001, I used the 1992/2001 retrofit dataset (Fry et al. 2009), which corrected these issues and I converted the 2006 data to Anderson I land cover categories to correspond with the 1992 and 2001 retrofit data (Anderson et al. 1976). As a result, all three datasets contained comparable categories of land cover, which was summarized as percentages each year. Land cover change between 1992 and 2001 was contained within the retrofit dataset (Fry et al. 2009); changes between 2001 and 2006 were calculated using the "combine" feature in ArcGIS 10 (ESRI).

Precipitation Analysis

To consider any potential change in precipitation coincident with impoundment, I obtained precipitation data from the nearest station that had a long-term record (Sallisaw, OK, Oklahoma Climatological Survey). To examine the utility of using this site, which was located approximately 19 km southwest of the Lee Creek watershed, I correlated corresponding daily precipitation between Sallisaw and the short-term precipitation gage within the watershed located on Lee Creek, near Short, OK (Oklahoma Climatological Survey). Together, these two sites had comparable dates from 2003 to 2007. Long-term trends in precipitation were investigated for the period 1970-2010 and were analyzed with linear regression using total precipitation (mm), total number of rain-event days, and mean rain-event magnitude (total annual precipitation/total rain-event days) as dependent variables ($\log_{10}$ transformed for normality). I defined a rain event as any day with precipitation ≥ 0.025 mm and only used data for which the entire year was represented. I further investigated trends in precipitation by separately considering events < 25 mm, 25 – 50 mm, 50 – 76 mm, and > 76 mm. All regression analyses were performed using SAS (v 9.3, SAS Institute Inc. 2002).

Results

Hydrological analysis

Lee Creek's hydrology has experienced some changes since the construction of Lee Creek Reservoir. Fifteen of the 32 parameters had statistically significant differences (< 0.10; Table 1). For example, high-pulse count increased while high-pulse duration decreased (Figures 7 & 8). Similarly, high-flows were more frequent but with lower peaks (Figures 9 & 10) and the frequency of large flood events doubled post-impoundment (Figure 11). Also, stream flow tended to show increases post-impoundment, particularly with higher median discharge in July (Figure 12) and higher 90-day minimum flows (Figure 13). Furthermore, the timing of floods occur earlier in the year post-impoundment. Since impoundment, Lee Creek's hydrology has become increasingly variable as indicated by the coefficient of dispersion values for all significant parameters (Table 1).

Land cover analysis

Land cover remained fairly static in the Lee Creek watershed from 1992 to 2006 (Figure 2). The majority of the watershed was forested (76.8%), with only a 1.7

percentage point decrease since 1992. Grass/shrub land increased the most between 1992 and 2006 from 4.4% to 5.4%. Conversion into land cover types that would decrease soil infiltration, such as urban, was minor. Urban land cover was 3% in 1992, increased to 4% in 2001 and remained unchanged into 2006.

Precipitation Analysis

Rainfall characteristics at the Sallisaw, OK long-term gaging station were similar to those within the watershed at the near-Short, OK short-term station (Figure 3), suggesting that the Sallisaw station would adequately represent precipitation patterns within the Lee Creek watershed. From 1970-2010, no significant trend in total annual rainfall was evident (Table 2), although a significant negative trend in the number of rain-days ($P < 0.001$; Figure 4) along with a significant increase in average rain-event magnitude was apparent ($P < 0.001$; Figure 5). For example, in 1970, there were 129 days with rain having a mean event size of 9.6 mm, whereas in 2010 there were 89 days with rain and an average event size of 14 mm. Further suggesting declines in many, small event days, I found a significant negative trend for small rain events (< 25 mm; Figure 6), but not for any of the other rain-event size categories.

Discussion

Since impoundment in 1992, the timing and duration of high-flow events in Lee Creek have changed, creating a flashier system. The altered streamflow appears to be driven by long-term changes in precipitation (i.e., increased rain-event magnitude coupled with decreased rain-event frequency) rather than by land cover or direct effects of the impoundment. These findings are consistent with predictions of climate change (Easterling et al. 2000, Meehl et al. 2000, Dore 2005, IPCC 2007, Cheng et al. 2012), but because I only considered 40 years of record (20 pre- and post-impoundment), these changes may not reflect climate-change per se. Precipitation has oscillated in this part of Oklahoma since records began in 1895 (OCS 2013) and whether the changes I observed are indicative of long-term climate changes are unknown. Regardless, my results demonstrate how variation in precipitation can affect hydrology. Precipitation patterns are ultimately responsible for flow variability in streams (Hynes 1975, Changnon and Kunkel 1995, Poff et al. 1997) and stream flashiness has been shown to increase in concert with rain-event magnitude (Groisman et al. 2001, Kokkonen et al. 2004). If the pattern of decreased precipitation event frequency coupled with increased event magnitude patterns continue in the Lee Creek watershed, the resultant increased stream flashiness will likely have repercussions for the resident biota.

Beyond increased stream flashiness in Lee Creek, altered flood-event timing seems to also be evident. Effects of climate on flood timing are not well documented but seem to vary across regions and between scales (Whitfield 2010); ranging from delayed (Meyers et al. 2010) to accelerated timing (Simonovic and Li 2004, Boyer et al. 2010), or no pronounced impact at all (Loukas and Quick 1999, Cunderlik and Ouarda 2009). For example, modeled climate change scenarios in California predicted that flooding would be delayed from spring to winter (Meyers et al. 2010). In contrast, climate change projections for the Mid-Atlantic region USA indicated that seasonality of annual flooding would occur earlier in the year (Neff et al. 2000), while no changes have been expected throughout Canada (Cunderlik and Ouarda 2009). The results of my study provide evidence that floods in Lee Creek since 1992 have occurred considerably earlier in the year (i.e., April and May) instead of during fall (i.e., October and November) and this altered timing could have a profound effect on aquatic biota within stream ecosystems (Junk et al. 1989, Lytle and Poff 2004), particularly during reproduction and for early life stage development (Bunn and Arthington 2002).

Most studies that investigated the effects of flood timing and rate-of-change on aquatic ecology describe negative effects on spawning behavior, success, and overall recruitment (see Poff and Zimmerman 2010) because larval fishes experience high mortality and displacement during flood events (Harvey 1987, Filipek et al. 1991, Jellyman and McIntosh 2010). Species that require specific substrate types for ovipositing, or require nest building to complete spawning, may experience reproductive failure during flooding because of reconfiguration of substrate (Jager et al. 1997, Carline and McCullough 2003). The redistribution of bed-load materials during flooding can destroy fish eggs deposited in or on the substrate (Swanston 1991). For instance, rock bass (*Ambloplites rupestris*) in streams had to repeatedly rebuild nests that were destroyed during spring flooding events (Noltie and Keenleyside 1986), decreasing nest success. A shift in annual flood timing from fall to spring in Lee Creek would be of particular concern for fish species that reproduce in spring.

Several fish species in Lee Creek spawn during the spring, including many that are of greatest conservation need in Oklahoma (i.e., Ozark minnow *Notropis nubilus*, longnose darter *Percina nasuta,* and sunburst darter *Etheostoma mihileze*; Miller and Robison 2004) but data are lacking on how flooding will affect reproduction or recruitment for these species. Though it is unclear how climate-mediated changes in hydrology may affect population dynamics of Lee Creek's fishes, it may be substantial for imperiled species. For example, Lee Creek is the last remaining stream system within Oklahoma to contain the longnose darter (Gatlin and Long 2011), which has very low fecundity (i.e., females produce < 4 eggs per day) and spawns intermittently (Anderson et al. 1998). Information on the natural breeding behavior for longnose darter is lacking (Anderson et al. 1998), but similar species (*Percina spp*) depend on gravel and cobble substrate for spawning. For example, shield darter (*P. pellata*), dusky darter (*P. sciera*), and leopard darter (*P. pantherina*) require small gravel and cobble for burying eggs, which can be disturbed during flooding (New 1966, James and Maughan 1989, James et al. 1991, Labay et al. 2004). The advancement and increased flashiness of annual flood events could result in the extirpation of longnose darter from Oklahoma by limiting their spawning success due to flooding related nest failure.

Research investigating the effects of climate change on fishes and fisheries has primarily focused on temperature (Tonn 1990, Pörtner and Peck 2010), particularly for several salmonid species (Jonsson and Jonsson 2010, Wenger et al. 2011, Isaak et al. 2012); however, a paucity of information exists regarding warm-water fishes. It is imperative to consider how changing precipitation patterns as a predicted consequence of climate change will alter stream hydrology because it may determine a species ability to persist (Poff et al. 1997). My research provides evidence that climate-induced changes to the natural flow regime are currently underway and may negatively affect the fish community in an eastern Oklahoma scenic river, but more work is needed to reliably predict these effects across multiple systems.

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Tables and Figures

Table 1. Indicators of Hydrologic Alteration (IHA) scorecard generated from stream flow data collected at USGS gage #07249985 on Lee Creek near Short, OK investigating differences in hydrology before and after Lee Creek Dam was constructed in 1992. Significance counts can be interpreted similarly to a p-value where < 0.10 indicates significant deviation between pre- and post-impoundment values (bold).

	Medians		Coefficient of Dispersion (CD)		Deviation Factor		Significance Count	
	Streamflow (m^3)							
IHA Group	Pre-impact	Post-impact	Pre-impact	Post-impact	Medians	CD	Medians	CD
Group 1: Monthly								
October	0.623	1.203	7.281	1.903	0.932	0.739	0.153	0.177
November	3.589	4.212	6.085	2.827	0.174	0.535	0.771	0.426
December	6.853	8.226	2.538	1.760	0.200	0.307	0.749	0.572
January	5.536	6.499	2.224	2.774	0.174	0.247	0.732	0.582
February	11.780	13.830	0.885	0.822	0.174	0.071	0.483	0.894
March	24.820	12.980	0.789	1.429	0.477	0.811	0.333	0.120
April	17.290	16.120	0.998	1.161	0.068	0.163	0.891	0.654
May	11.670	9.826	**0.751**	**1.666**	0.158	**1.218**	0.305	**0.070**
June	3.617	3.157	1.568	2.692	0.127	0.717	0.762	0.315
July	**0.411**	**1.076**	2.229	2.943	**1.621**	0.320	**0.079**	0.535
August	0.197	0.231	3.442	3.690	0.173	0.072	0.897	0.895
September	0.166	0.248	2.917	7.550	0.489	1.588	0.295	0.230
Group 2: Magnitude and duration of annual extremes								
1-day minimum	0.015	0.007	**3.286**	**15.900**	0.524	**3.839**	0.560	**0.010**
3-day minimum	0.016	0.010	**3.210**	**12.750**	0.396	**2.970**	0.840	**0.062**
7-day minimum	0.017	0.015	3.313	8.838	0.108	1.667	0.948	0.106
30-day minimum	0.039	0.078	2.954	2.394	0.995	0.190	0.164	0.724
90-day minimum	**0.595**	**1.090**	1.754	2.247	**0.831**	0.281	**0.099**	0.493
1-day maximum	468.60	392.20	0.814	1.064	0.163	0.307	0.548	0.415
3-day maximum	288.70	234.60	0.689	0.774	0.188	0.123	0.483	0.760
7-day maximum	155.40	140.70	0.674	0.685	0.095	0.017	0.836	0.963
30-day maximum	63.680	68.60	0.520	0.687	0.077	0.322	0.608	0.299
90-day maximum	38.940	43.580	0.417	0.484	0.119	0.160	0.284	0.674
Base flow index	0.001	0.001	5.775	8.217	0.542	0.423	0.580	0.557

Table 1. continued

IHA Group	Medians: Streamflow (m^3) Pre-Impact	Medians: Streamflow (m^3) Post-impact	Coefficient of Dispersion (CD) Pre-impact	Coefficient of Dispersion (CD) Post-impact	Deviation Factor Medians	Deviation Factor CD	Significance Count Medians	Significance Count CD
Group 3: Timing of annual extremes								
Julian date of minimum	255	249.5	0.131	0.148	0.030	0.136	0.733	0.654
Julian date of maximum	123	114	0.389	0.253	0.049	0.351	0.718	0.572
Group 4: Frequency and duration of high and low pulses								
Low pulse count	3	3	0.667	0.417	0.00	0.375	0.288	0.404
Low pulse duration	18.00	22.00	1.569	2.165	0.222	0.379	0.628	0.431
High pulse count	**8.00**	**11.00**	0.625	0.546	**0.375**	0.127	**0.019**	0.515
High pulse duration	6.50	5.00	0.404	0.650	0.231	0.610	0.065	0.115
Low Pulse Threshold	0.570							
High Pulse Threshold	16.310							
Group 5: Rate and frequency of change in conditions								
Rise rate	1.104	0.998	1.470	2.205	0.096	0.500	0.831	0.289
Fall rate	-0.467	-0.531	-1.106	-1.260	0.136	0.139	0.754	0.726
Number of reversals	73.50	75.50	0.201	0.192	0.027	0.043	0.571	0.889
Environmental Flow Component (EFC) Results								
EFC Low flows								
October	0.793	1.161	3.625	1.820	0.464	0.498	0.323	0.249
November	2.294	3.469	3.568	2.140	0.512	0.400	0.390	0.403
December	6.173	6.683	1.095	1.230	0.083	0.123	0.803	0.717
January	4.863	5.097	1.596	1.397	0.048	0.125	0.768	0.642
February	8.814	10.260	0.560	0.563	0.165	0.004	0.135	0.992
March	10.730	9.741	0.546	0.688	0.092	0.259	0.712	0.586
April	10.730	8.169	**0.582**	**0.964**	0.239	**0.656**	0.542	**0.098**
May	7.030	6.180	0.713	1.079	0.121	0.515	0.550	0.127
June	2.945	2.534	1.238	1.781	0.139	0.438	0.719	0.180
July	**0.411**	**1.034**	2.134	2.451	**1.517**	0.149	**0.076**	0.776
August	0.368	0.312	1.907	2.607	0.154	0.367	0.867	0.403
September	0.249	0.312	3.341	8.491	0.250	1.541	0.818	0.116
EFC Parameters								
Extreme low peak	0.040	0.030	0.748	1.202	0.240	0.607	0.294	0.216
Extreme low duration	11.750	9.750	1.457	1.256	0.170	0.138	0.735	0.775
Extreme low timing	245.50	247.80	0.145	0.082	0.012	0.435	0.853	0.289
Extreme low freq.	1.500	2.00	1.333	1.500	0.333	0.125	0.465	0.953

Table 1. continued

	Medians		Coefficient of Dispersion		Deviation Factor		Significance count	
	Streamflow (m^3)							
EFC Parameters	Pre-impact	Post-impact	Pre-impact	Post-impact	Medians	CD	Medians	CD
High flow peak	**71.450**	**55.220**	0.585	0.708	**0.227**	0.211	**0.077**	0.548
High flow duration	5.750	5.00	0.457	0.650	0.130	0.424	0.340	0.264
High flow timing	65.750	64.50	0.210	0.258	0.007	0.226	0.997	0.312
High flow frequency	**8.00**	**10.50**	0.500	0.524	**0.313**	0.048	**0.044**	0.853
High flow rise rate	25.690	24.960	0.581	0.866	0.028	0.490	0.696	0.333
High flow fall rate	-10.690	-10.00	**-0.386**	**-0.744**	0.064	**0.928**	0.225	**0.033**
Small Flood peak	546.50	626.50	0.487	0.228	0.146	0.531	0.426	0.203
Small Flood duration	22.00	13.50	1.295	1.917	0.386	0.480	0.657	0.332
Small Flood timing	**301.00**	**122.00**	0.234	0.398	**0.978**	0.702	**0.092**	0.145
Small Flood rise rate	105.20	307.20	3.848	1.033	1.919	0.732	0.207	0.402
Small Flood fall rate	-46.390	-55.660	-0.778	-1.000	0.200	0.285	0.494	0.582
Large flood peak	1007.00	1079.00	0.250	0.173	0.072	0.311	0.515	0.500
Large flood duration	24.00	27.00	0.0	0.630	0.125		0.554	
Large flood timing	326.50	115.50	**0.014**	**0.148**	0.847	**9.850**	0.152	**0.057**
Large flood rise rate	201.00	109.90	**0.250**	**1.533**	0.453	**5.137**	0.460	**0.024**
Large flood fall rate	-49.570	-66.630	**-0.254**	**-0.568**	0.344	**1.234**	0.239	**0.067**

Table 2. Results of linear regression analyses investigating trends in precipitation within the Lee Creek watershed Oklahoma/Arkansas between 1970 and 2012. Data were obtained from the climate gaging station in Sallisaw, OK.

	Sallisaw		
	N	*P-value*	Trend
Annual Rainfall	37	0.53	None
Rain Days	37	< **0.001**	Negative
Event Magnitude	37	< **0.001**	Positive
Rain Event < 2.5 cm	37	< **0.001**	Negative
Rain Event 2.5 cm-5 cm	37	0.85	None
Rain Event 5 cm-7.6 cm	37	0.80	None
Rain Event > 7.6 cm	37	0.71	None

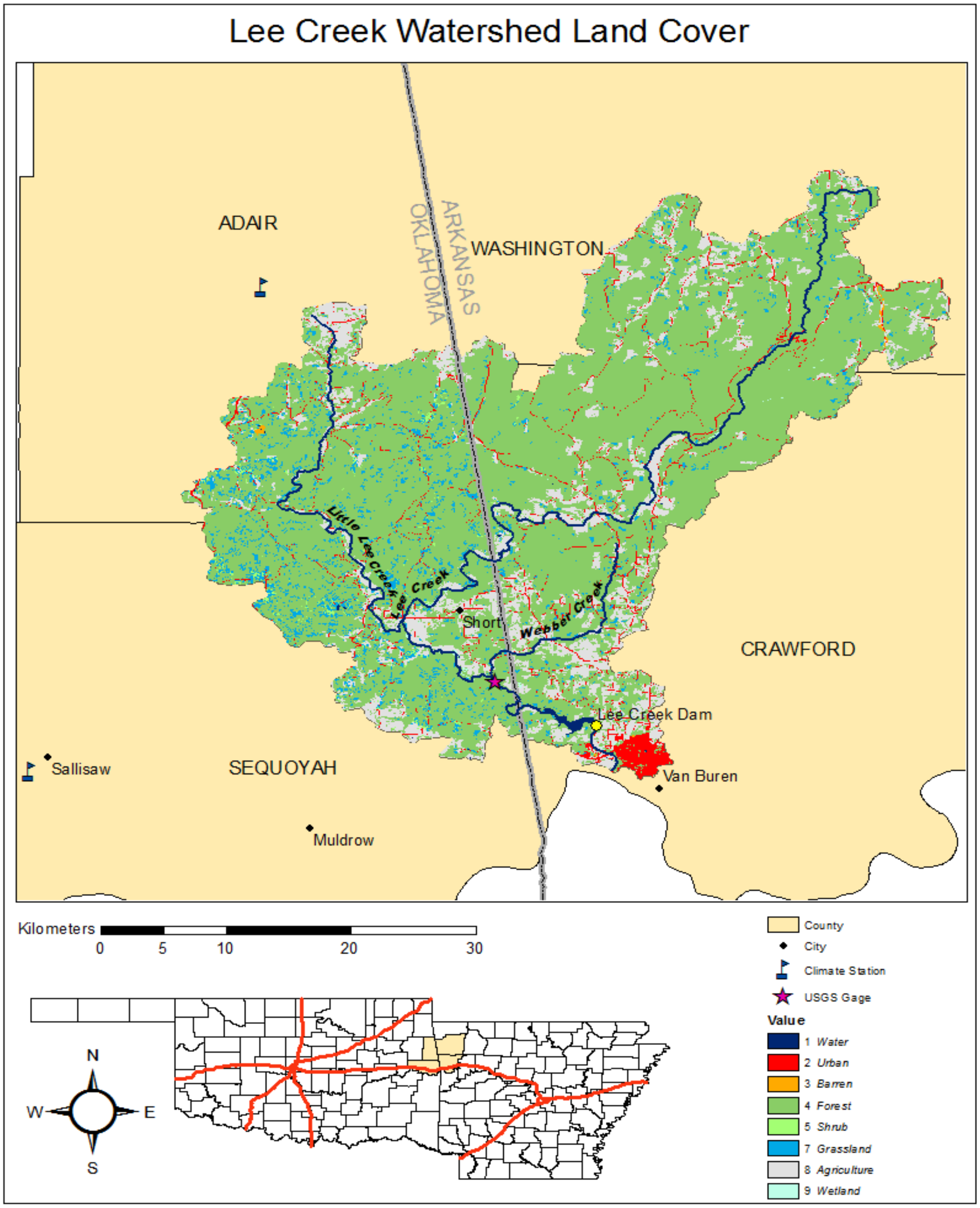


Figure 1. Map depicting the location, extent, and land cover types of the Lee Creek watershed in Oklahoma and Arkansas. Locations of climate stations and USGS stream flow gage station are provided.

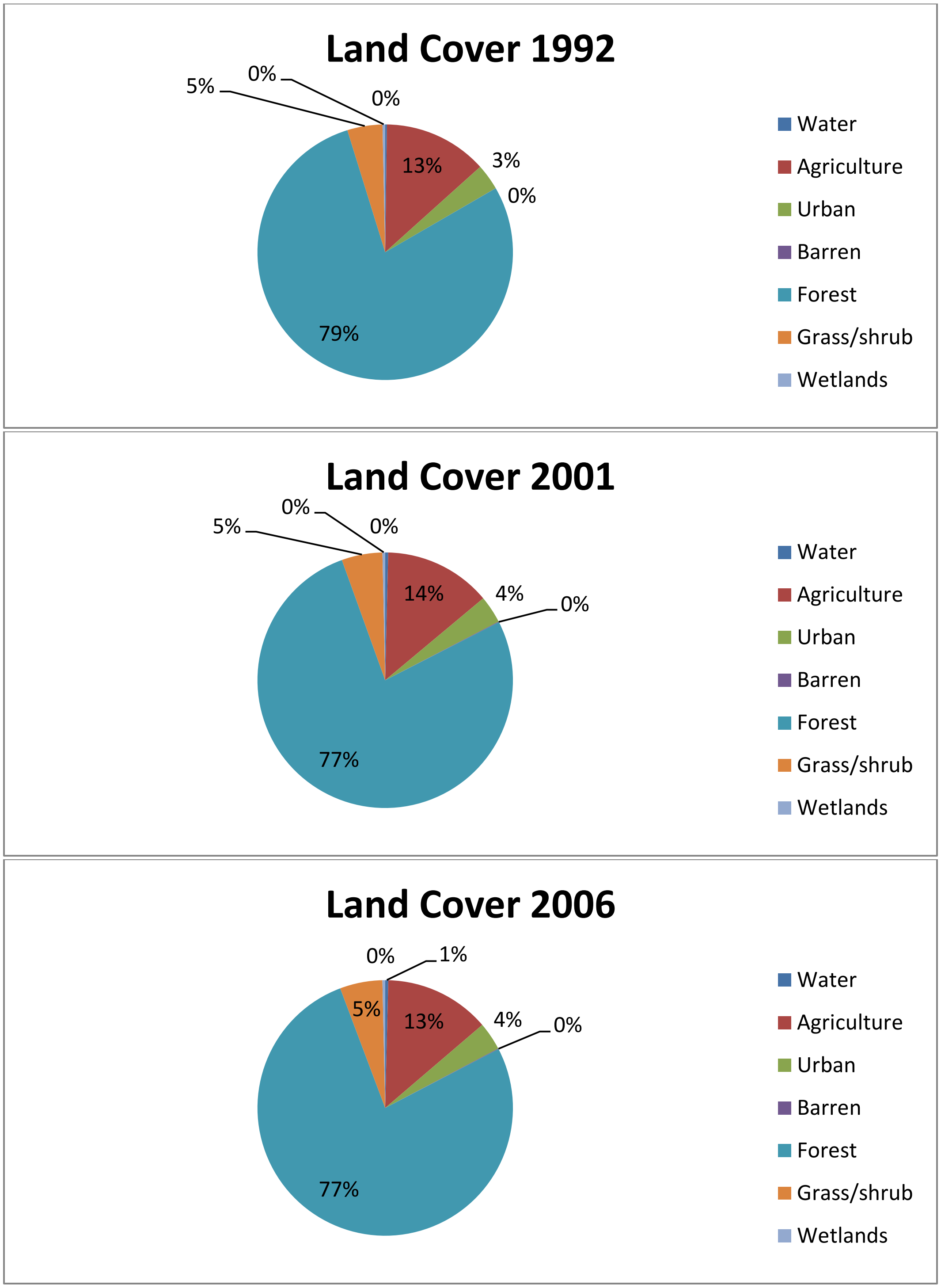


Figure 2. The proportion of land cover types present within Lee Creek's watershed for 1992, 2001, and 2006. Data collected during a survey investigating the effect of land cover change on hydrology.

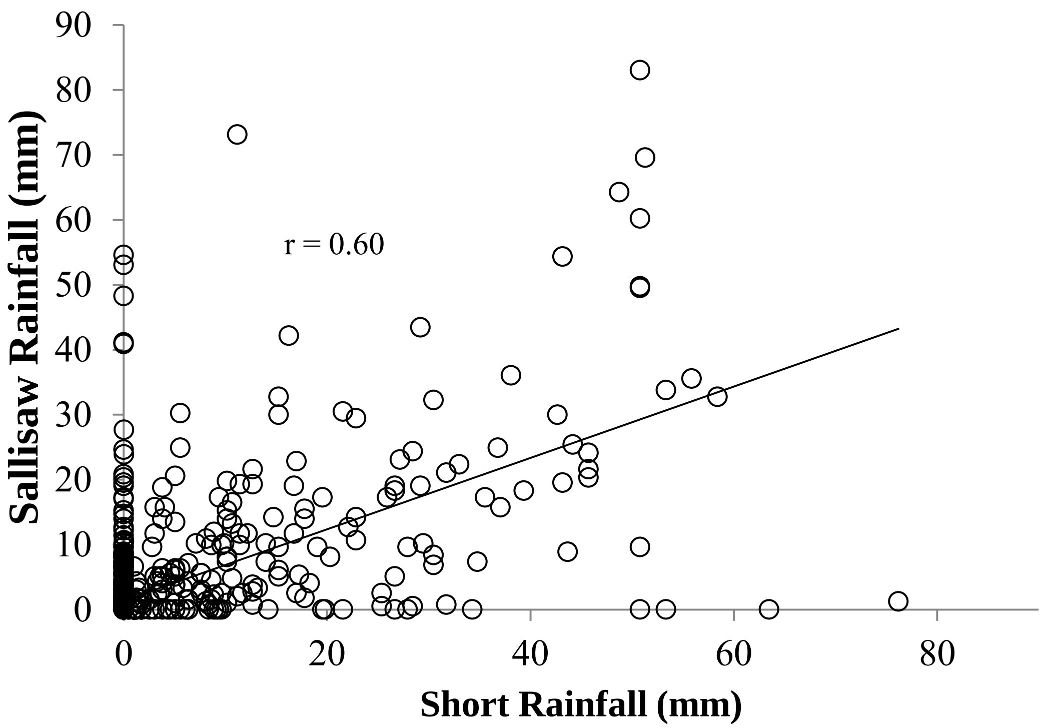


Figure 3. Scatterplot and correlation between rain events at the Sallisaw, OK gaging station and the Short, OK station. The Sallisaw, OK gage is located 19 km southwest of the Lee Creek watershed while the Short, OK gage is located within the watershed.

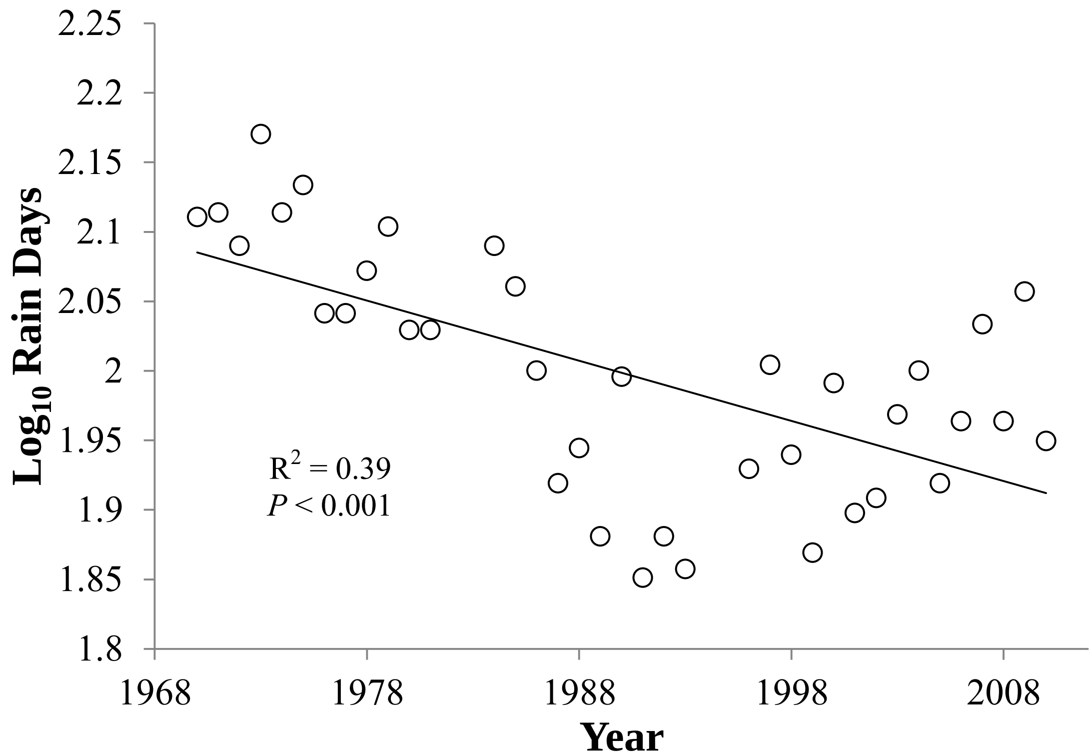


Figure 4. Scatterplot representing linear regression analysis investigating trends for the number of days that received rain in the Lee Creek watershed from 1970 to 2010. Data were obtained for the Sallisaw, OK climate station. Any day that recorded 0.001 inches of rain of more was considered a rain day.

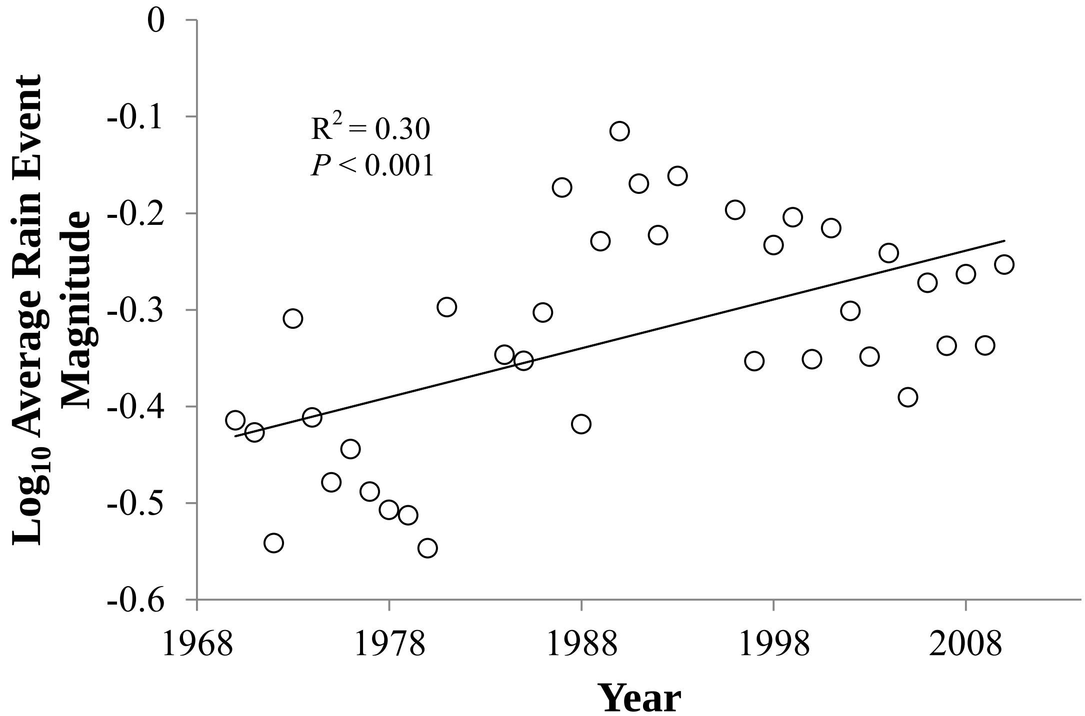


Figure 5. Scatterplot representing linear regression analysis for average rain event magnitude for the Lee Creek watershed from 1970 to 2010. Rain data was obtained from the Sallisaw, OK climate station. Magnitude was calculated as the quotient between total annual rainfall and total annual rain days.

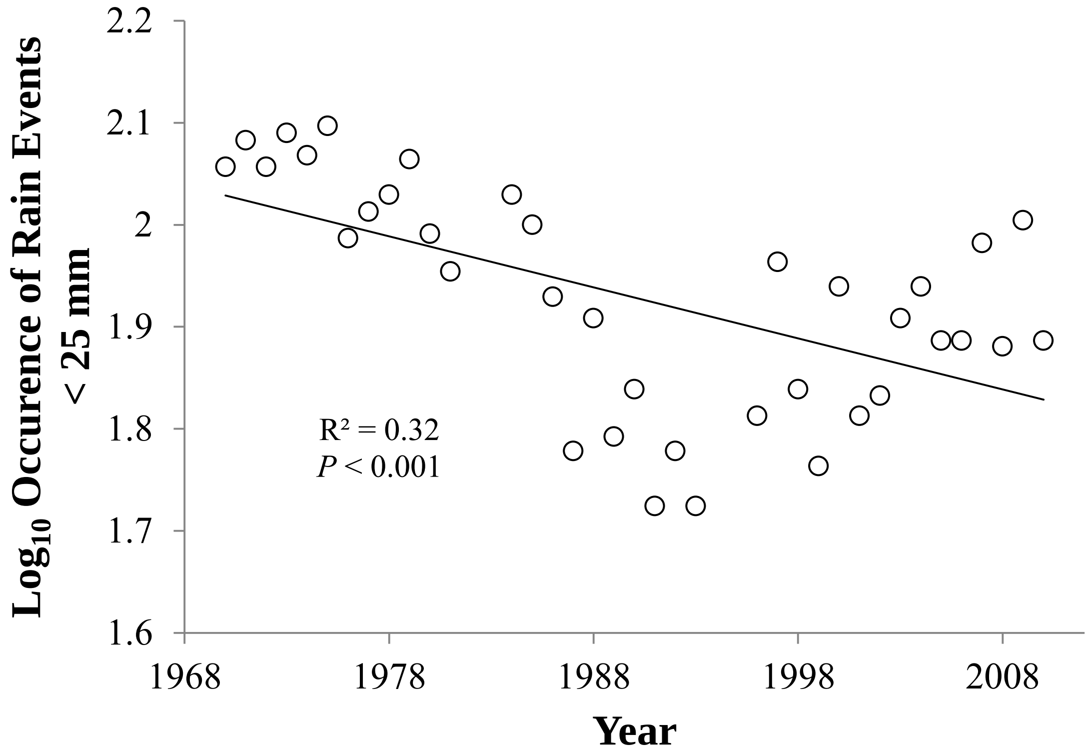


Figure 6. Scatterplot representing linear regression analysis investigating trends in the occurance of rain events that totaled less than 25 mm/day for the Lee Creek watershed from 1970 to 2010. Data were collected at the Sallisaw, OK climate station.

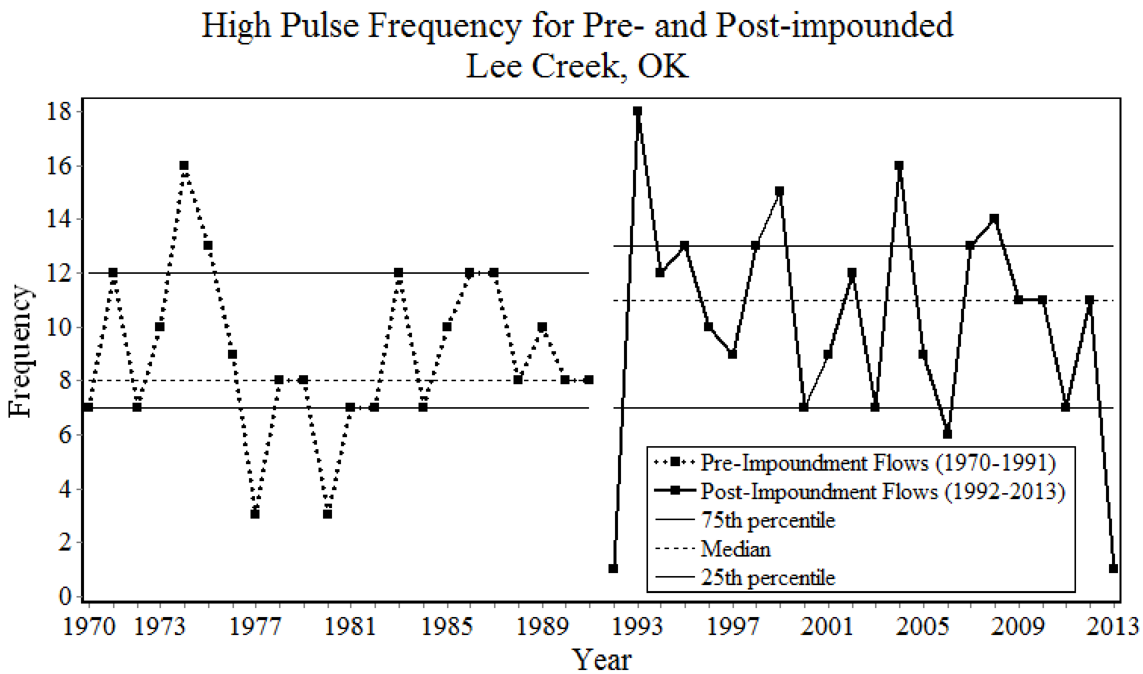


Figure 7. High-flow pulse frequency for pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

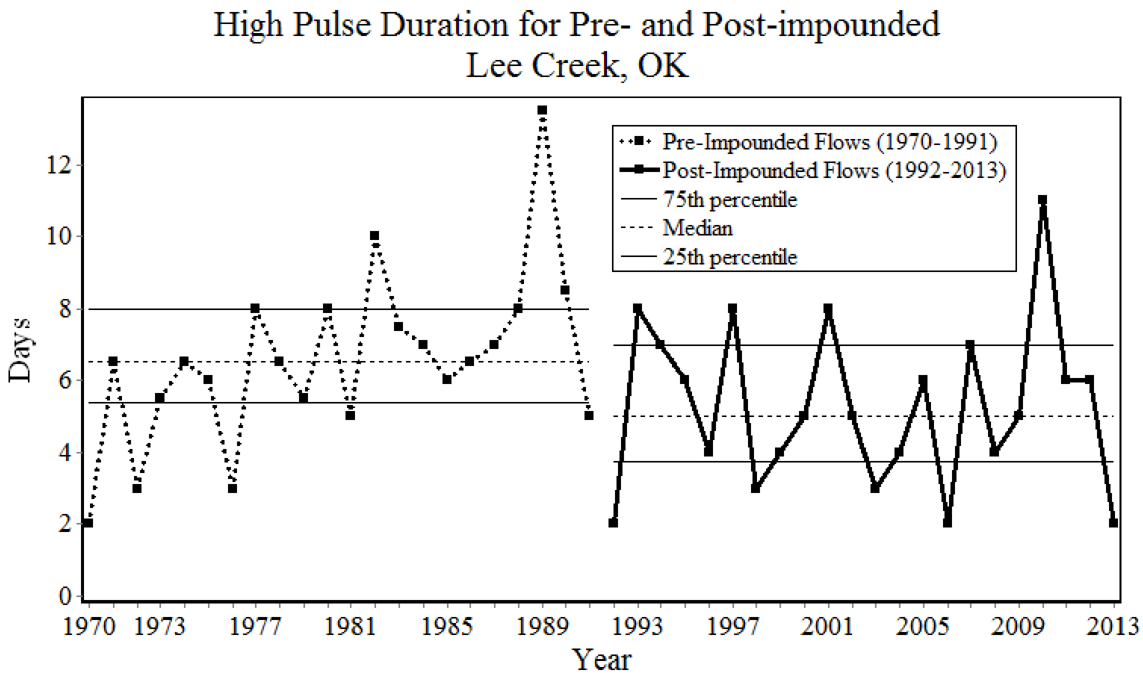


Figure 8. High-flow pulse duration for pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

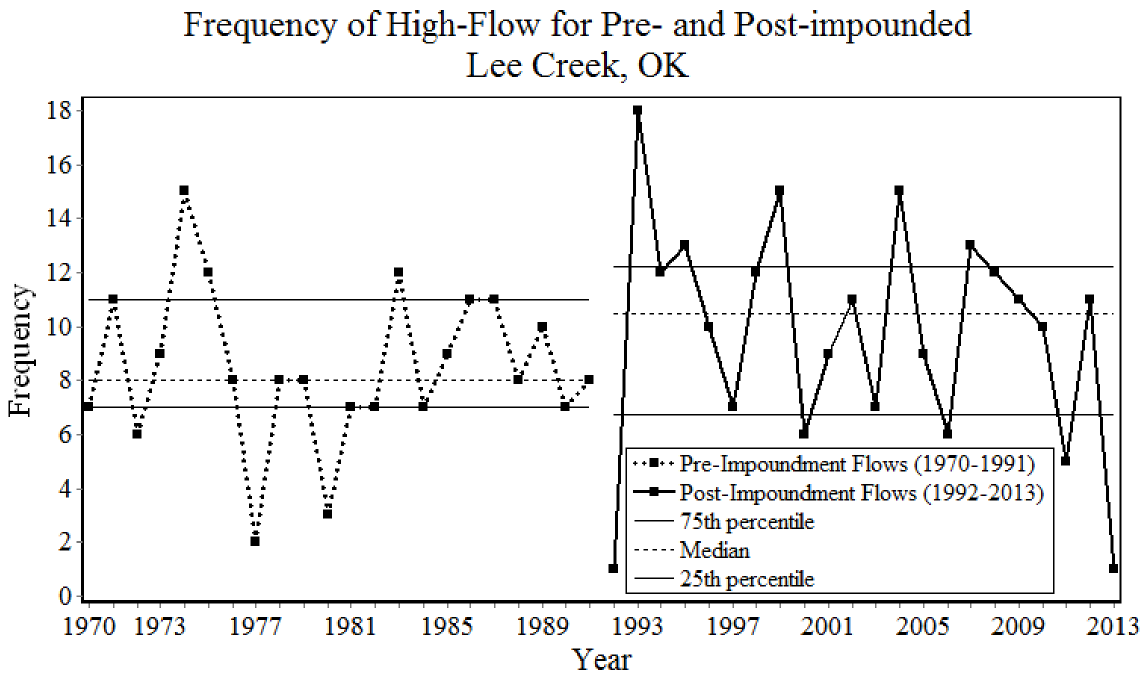


Figure 9. High-flow frequency for pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

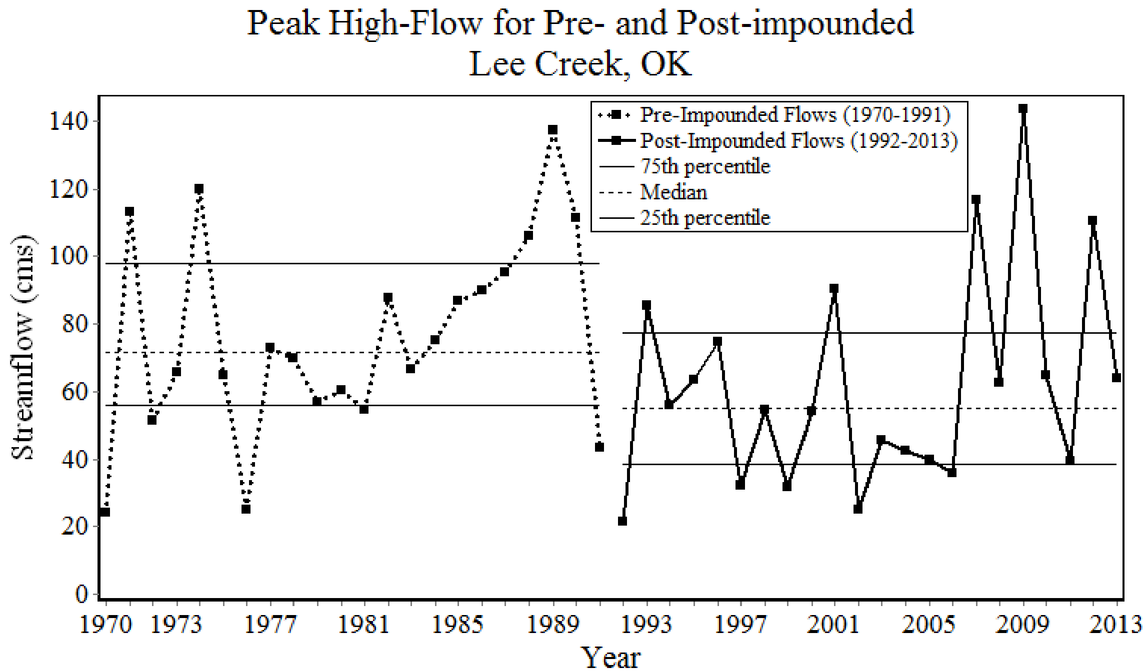


Figure 10. Peak high-flow events for pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

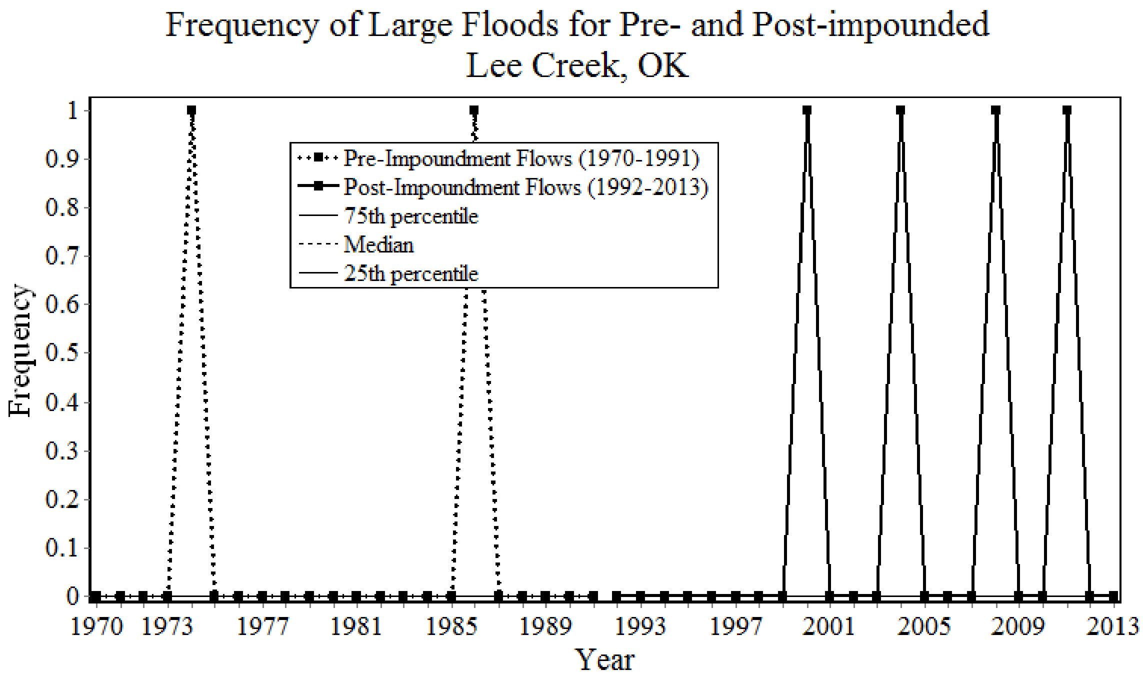


Figure 11. Frequency of large floods for Lee Creek, Oklahoma from 1970 to 2010. Data obtained from USGS gage #07249985 near Short, OK.

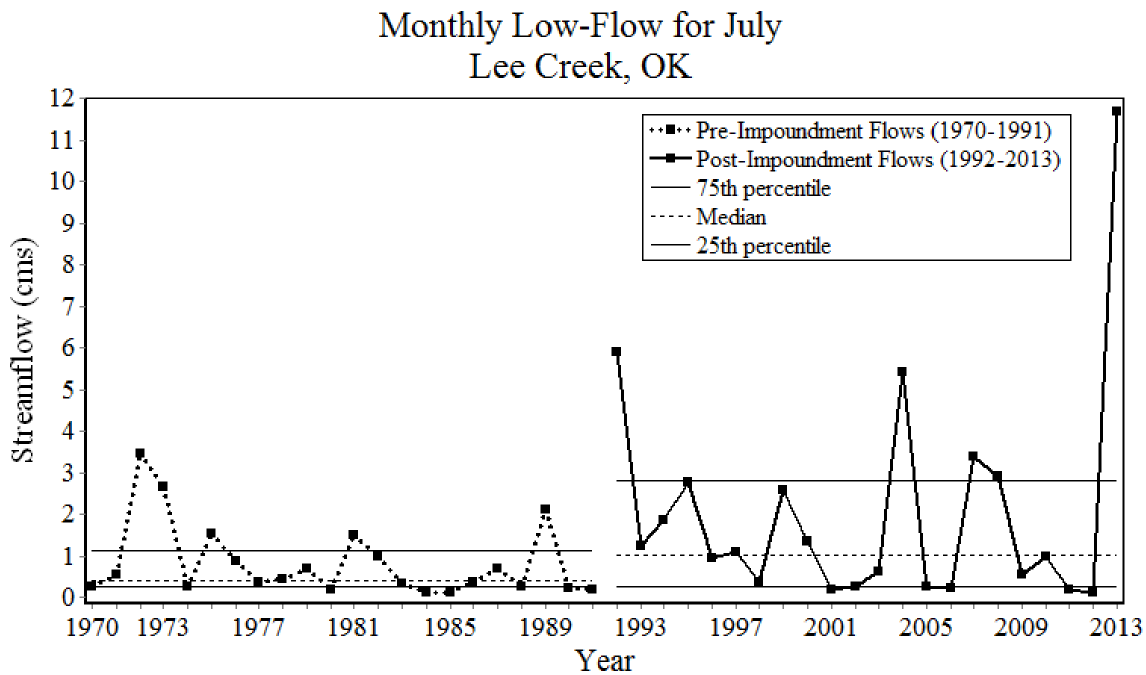


Figure 12. Monthly low flows for July between pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

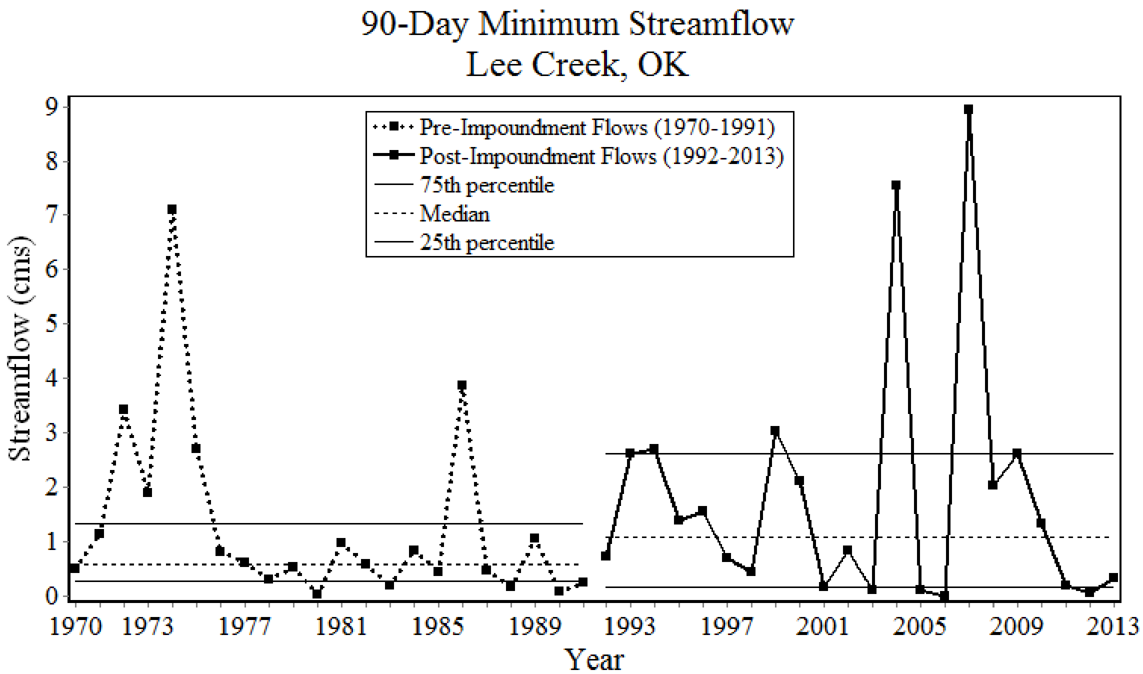
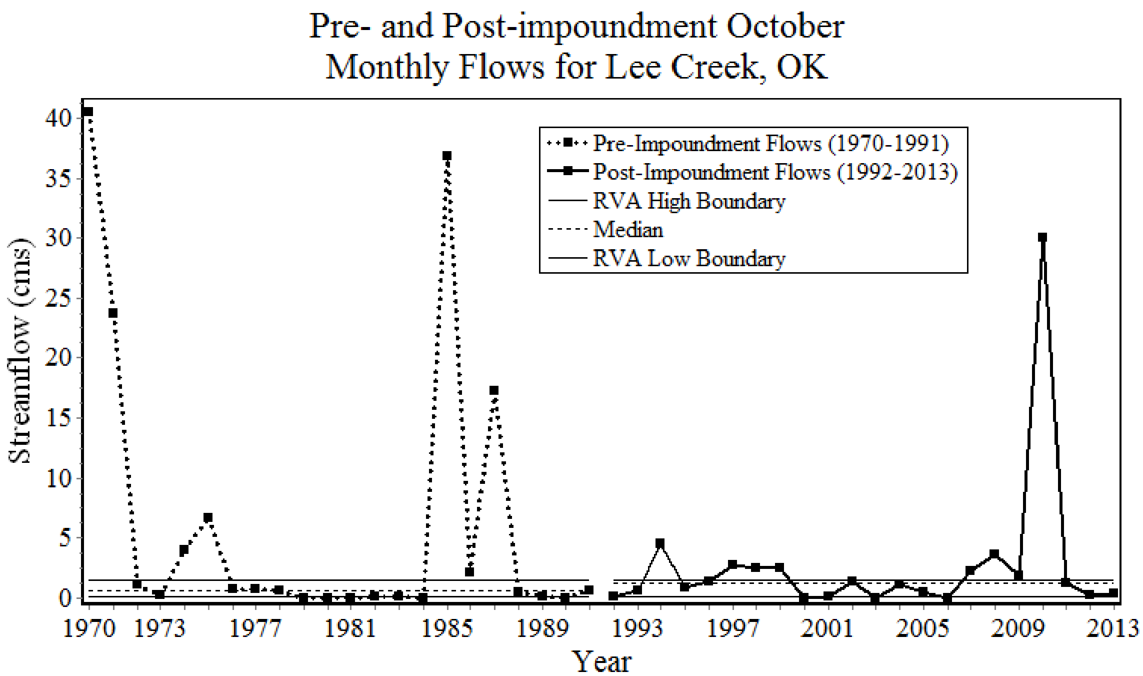
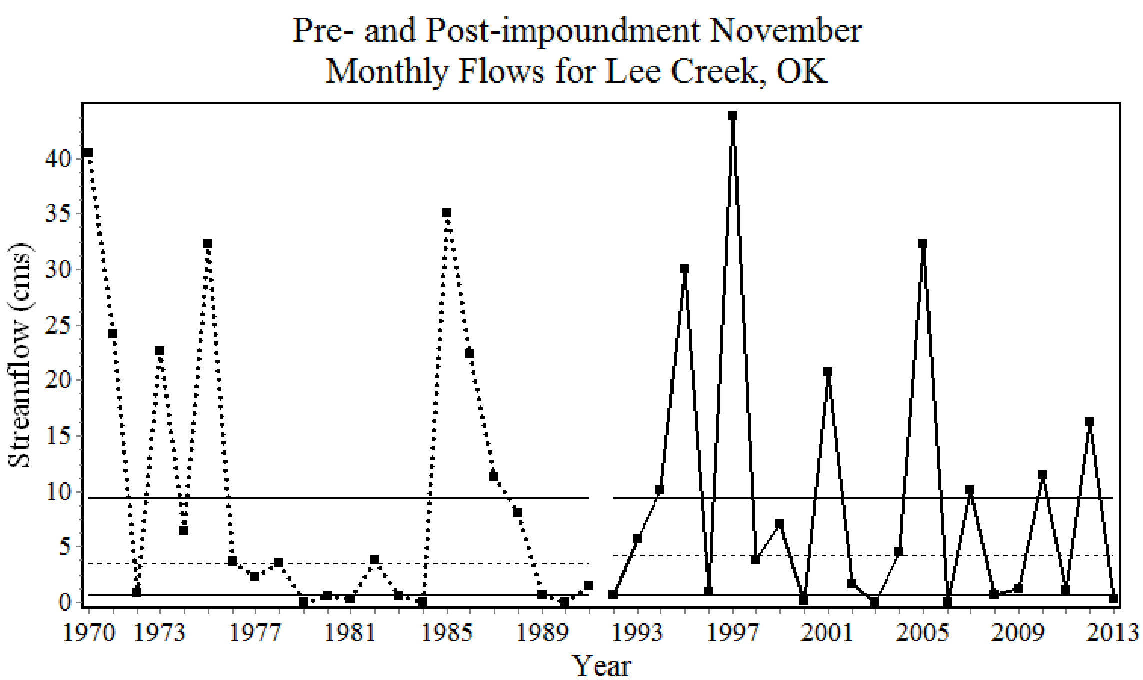


Figure 13. Average lowest flow for 90 consecutive days between pre- and post-impounded Lee Creek, OK. Stream flow data were collected from USGS gage #07249985 on Lee Creek near Short, OK.

CHAPTER III APPENDICES

Appendix A. Average monthly stream flow for pre- and post-impounded Lee Creek, OK. Data are presented in order of the water-year beginning in October. Data were collected from USGS gage #07249985 on Lee Creek near Short, OK.





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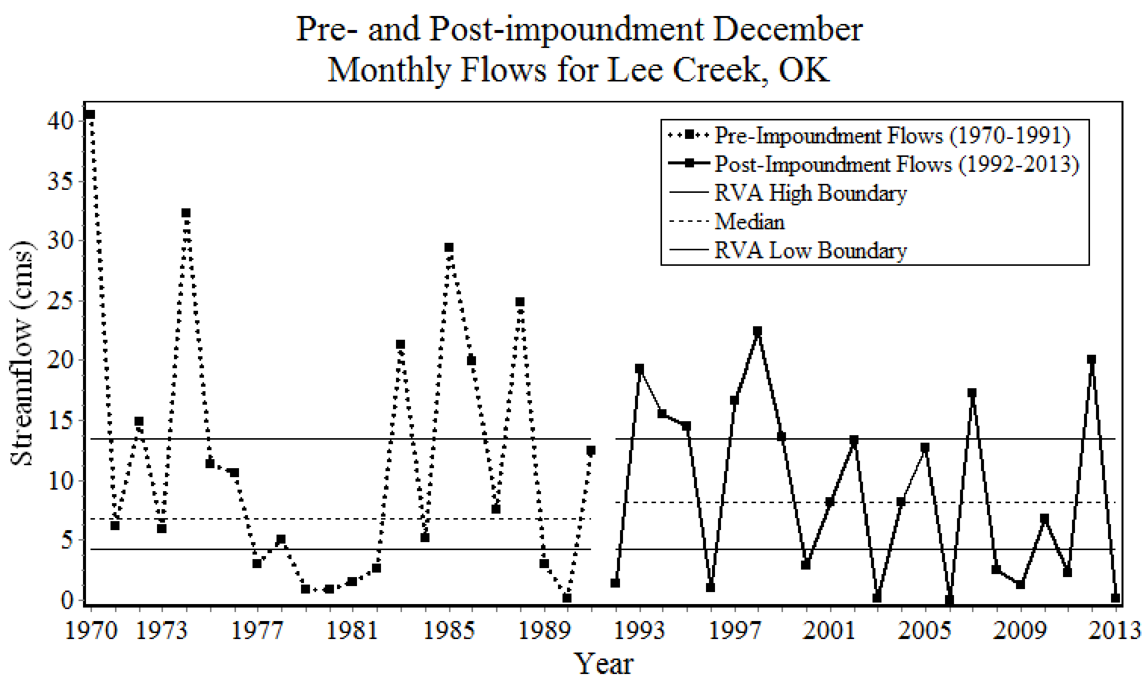

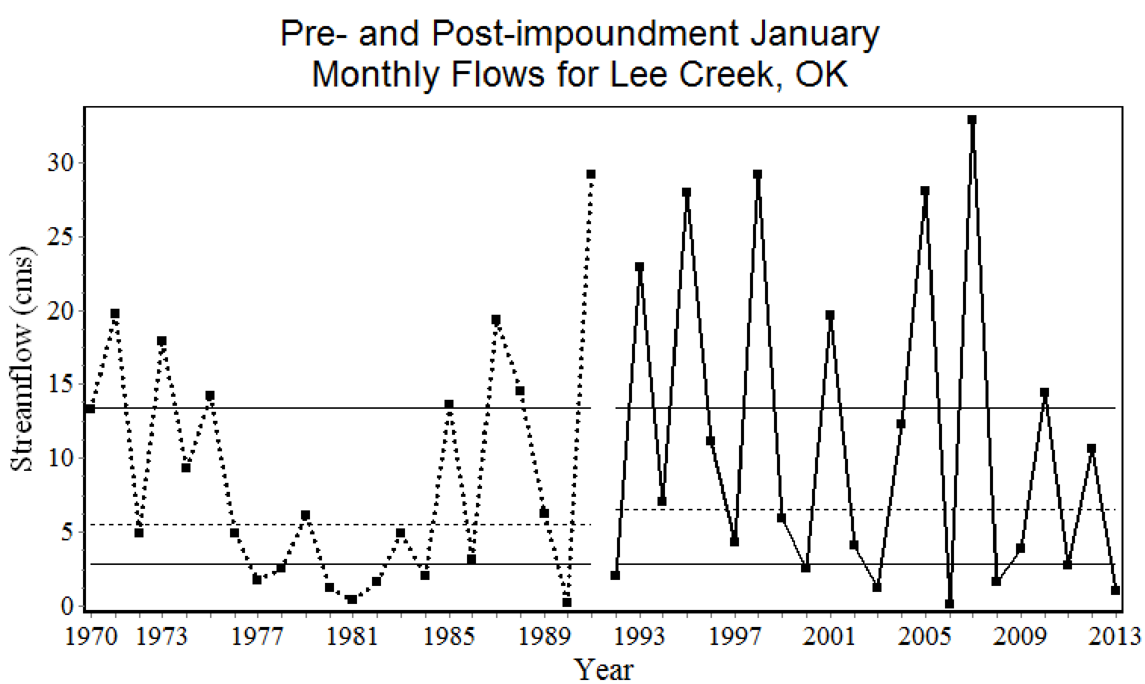

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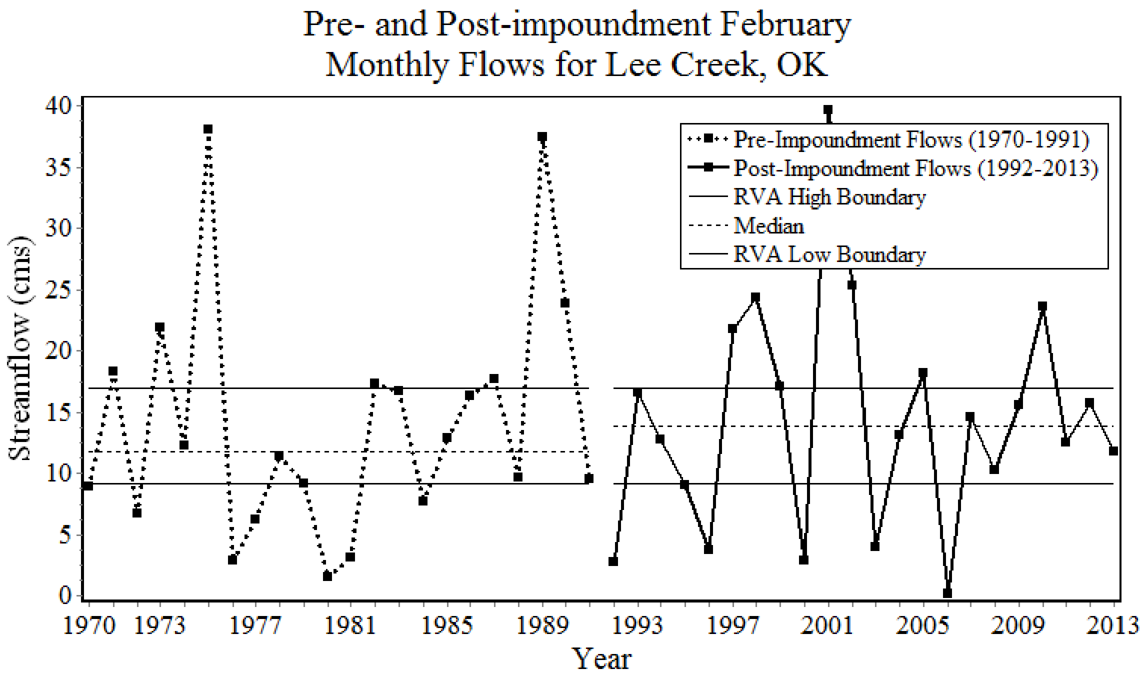

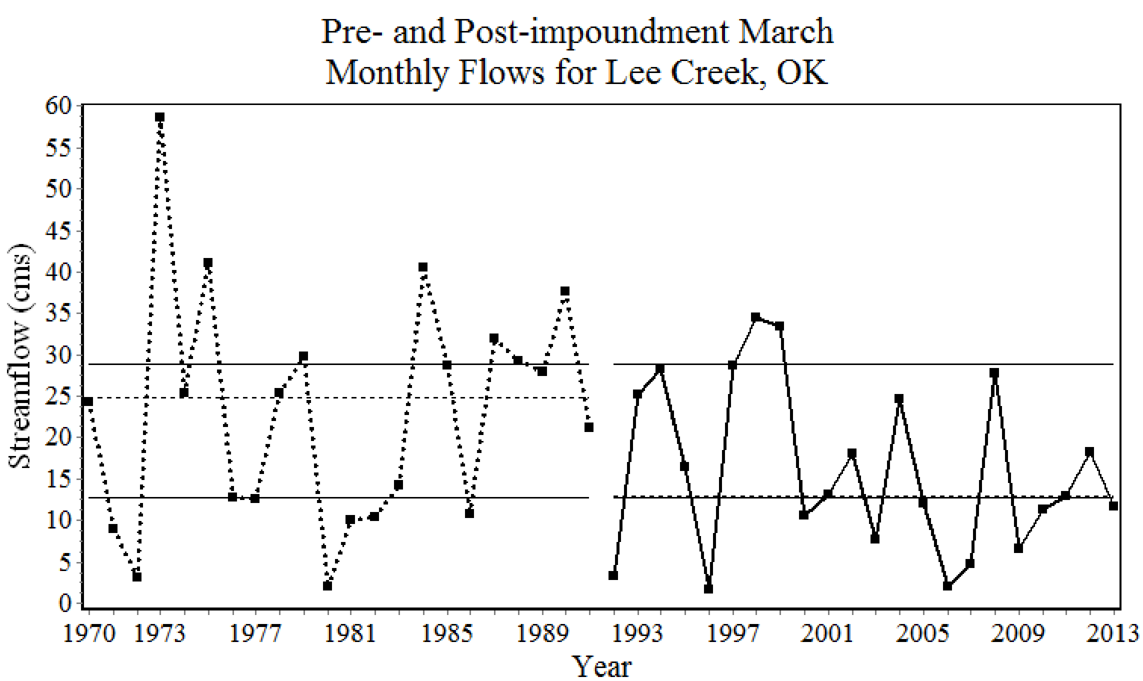

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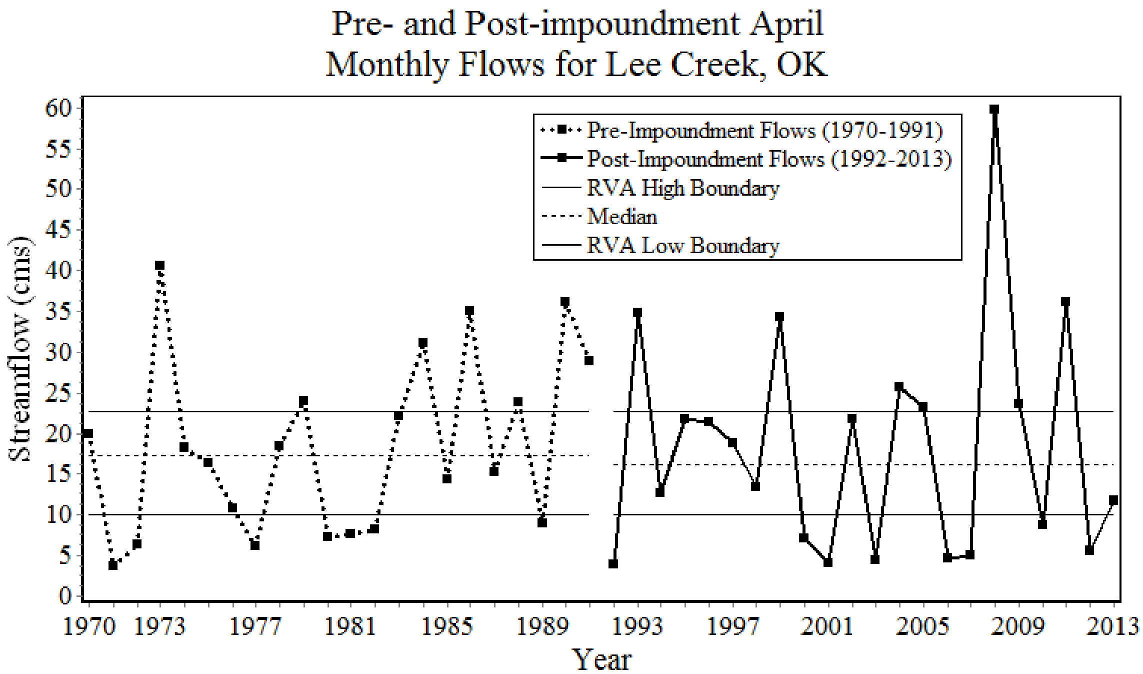

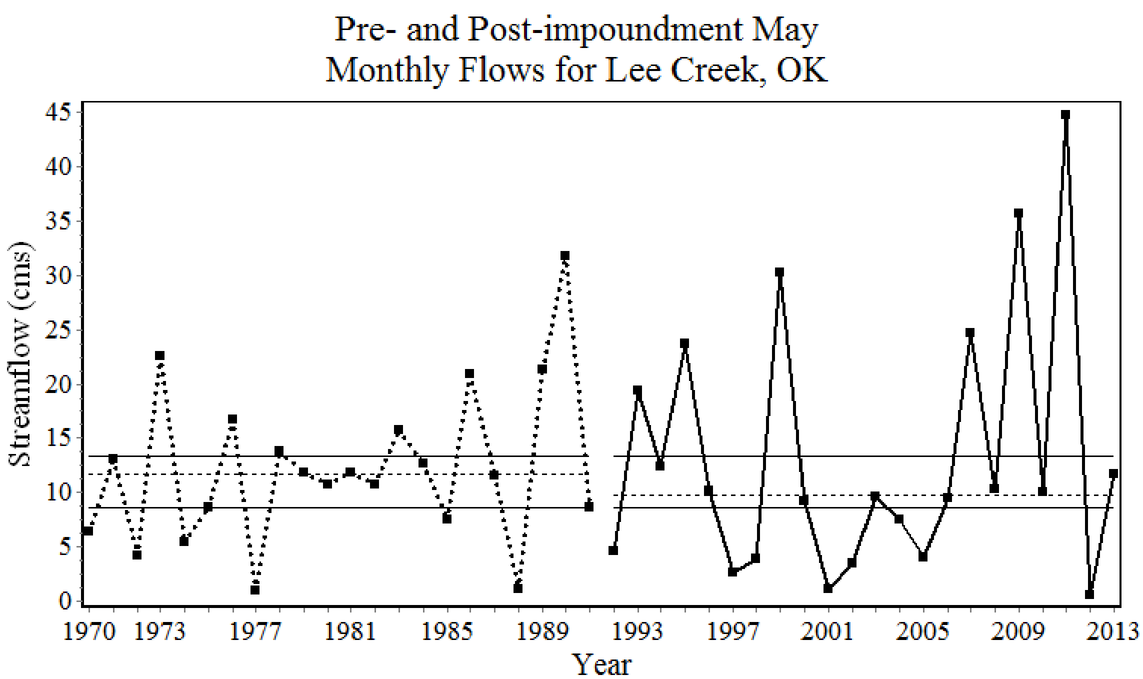

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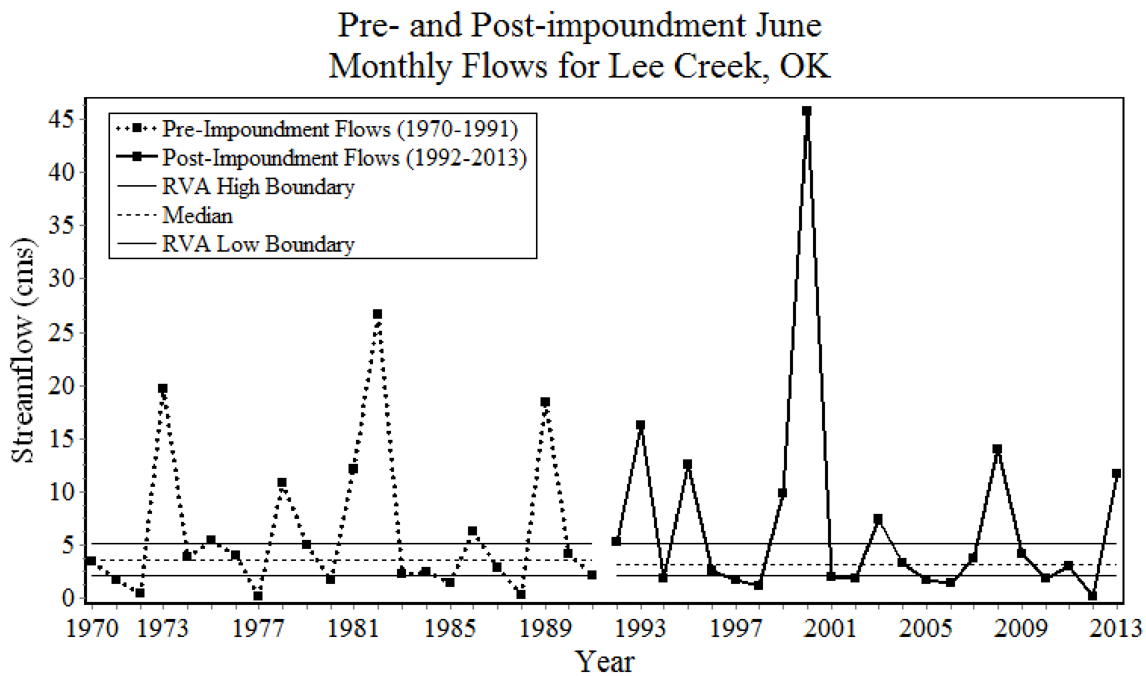

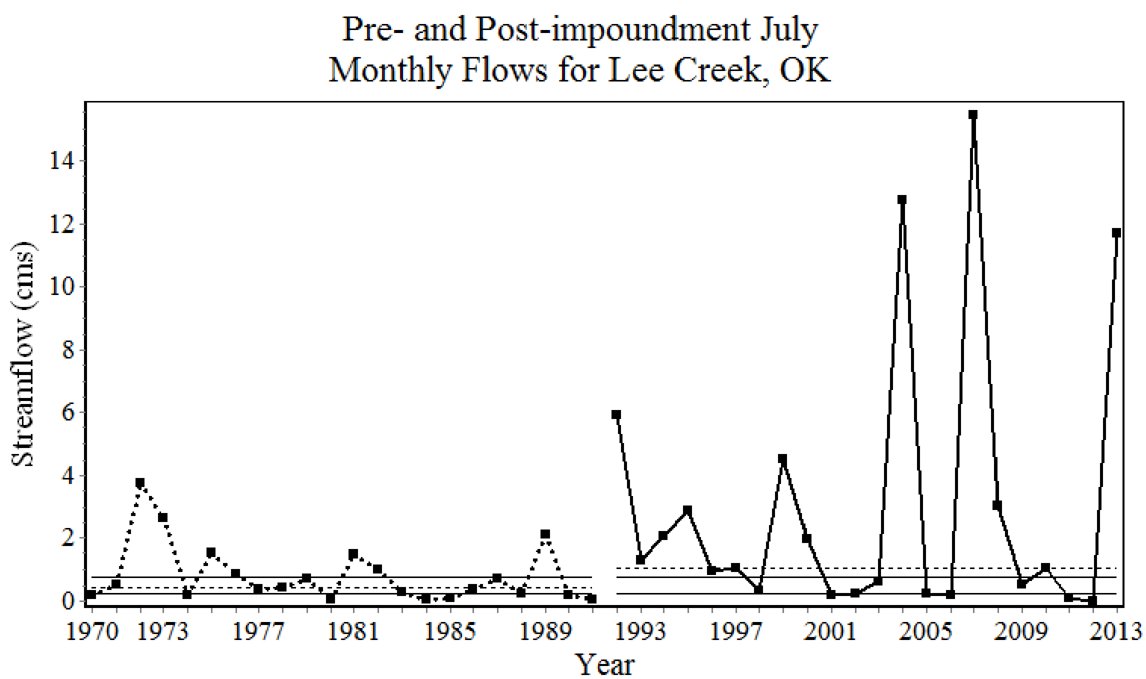

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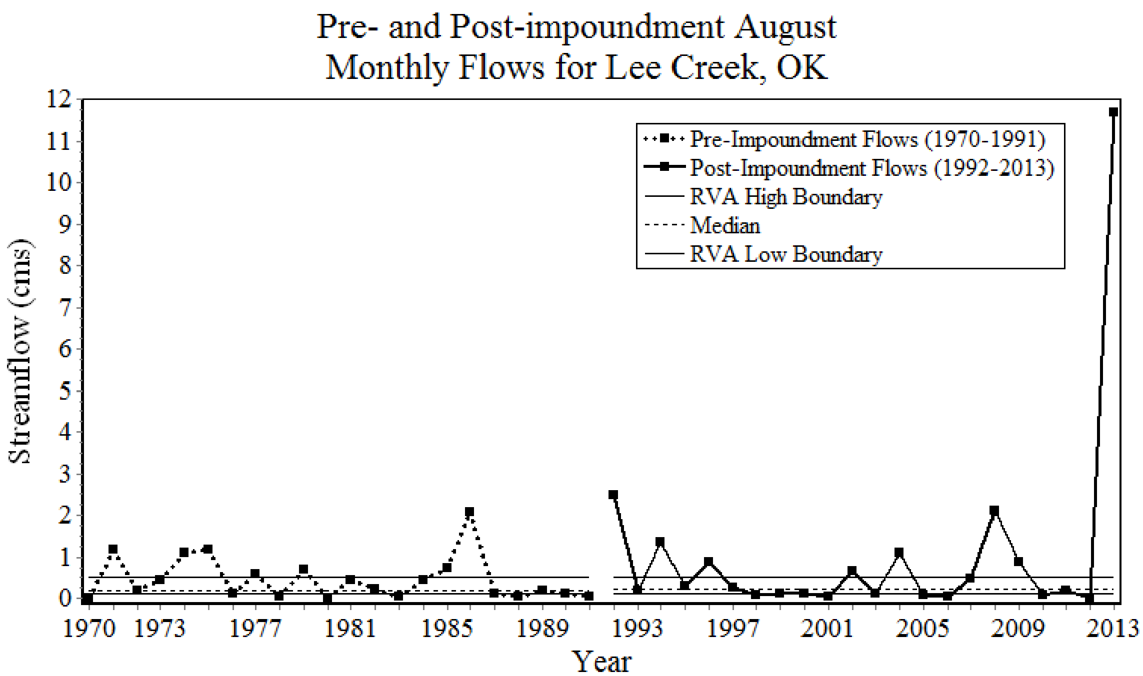
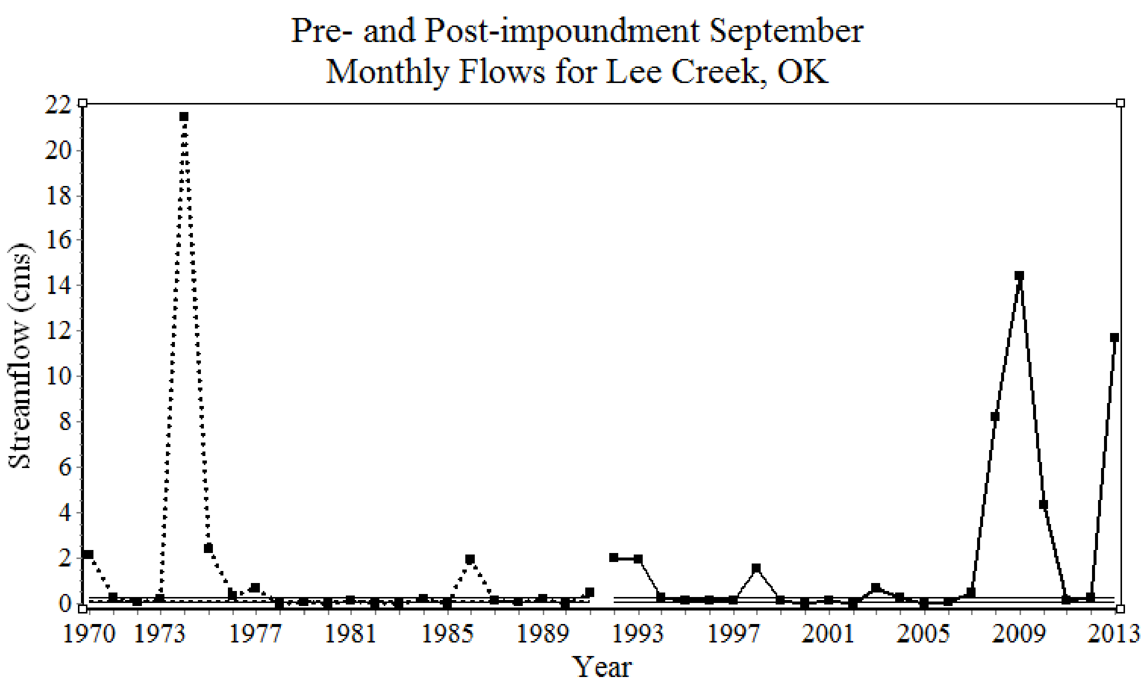
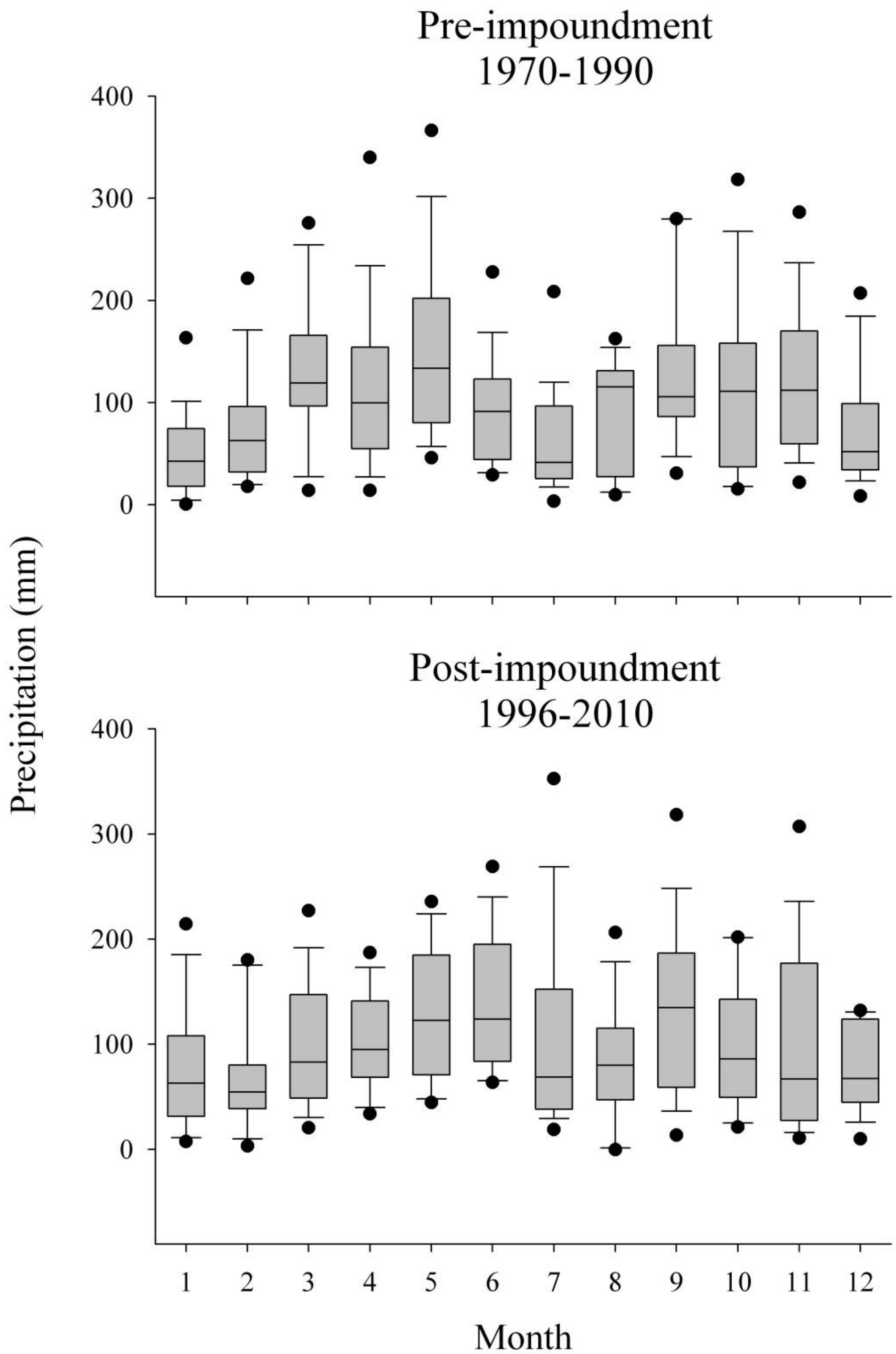




Appendix B. Total monthly precipitiation for the pre- and post-impounded Lee Creek Oklahoma-Arkansas watershed. Data were collected from the Sallisaw, Oklahoma climate station



VITA

Michael Ray Gatlin

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF HYDROLOGIC ALTERATION ON STREAM FISH COMMUNITY STRUCTURE IN LEE CREEK, OKLAHOMA

Major Field: Fisheries and Aquatic Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resources Ecology and Management; Fisheries and Aquatic Ecology at Oklahoma State University, Stillwater, Oklahoma in July, 2013.

Completed the requirements for the Bachelor of Science in Natural Resources Ecology and Management; Fisheries and Aquatic Ecology at Oklahoma State University, Stillwater, Oklahoma in December, 2010.

Experience:

June 2012-Present: Forest Fisheries Biologist, U.S. Forest Service, Carson National Forest, Taos, NM
January 2011-Present: Graduate Research Assistant, Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, OK
March 2010-December 2010: Fisheries Technician, Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, OK
2009-March 2010: Laboratory Technician, Oklahoma State University, Forest Hydrology Laboratory, Stillwater, OK
May 2009-August 2009: Biological Science Technician (Fisheries), U.S. Forest Service, Southern Research Station (CATT), Hector, AR
May 2008-August 2008: Stream Technician, Oklahoma Department of Wildlife Conservation, Higgins, OK
May 2007-August 2007: Forestry Intern, Sequoia Forest Keepers, Kernville, CA

Professional Memberships:

American Fisheries Society
North American Native Fishes Association
Southeastern Fishes Council