Species Status Assessment Report for the Arkansas River Shiner (*Notropis girardi*) and Peppered Chub (*Macrhybopsis tetranema*)

Arkansas River shiner (bottom left) and peppered chub (top right - two fish)
(Photo credit U.S. Fish and Wildlife Service)

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION (CHAPTER 1)

The Arkansas River shiner (*Notropis girardi*) and peppered chub (*Macrhybopsis tetranema*) are restricted primarily to the contiguous river segments of the South Canadian River basin spanning eastern New Mexico downstream to eastern Oklahoma (although the peppered chub is less widespread). Both species have experienced substantial declines in distribution and abundance due to habitat destruction and modification from stream dewatering or depletion from diversion of surface water and groundwater pumping, construction of impoundments, and water quality degradation. This report summarizes the U.S. Fish and Wildlife Service's (Service) Species Status Assessment (SSA) for the Arkansas River shiner and peppered chub. The purpose of the SSA is to summarize the most relevant information regarding Arkansas River shiner and peppered chub life history and ecology, document the current condition of both species and their habitat, and forecast the future condition of both species and their habitat, taking into account the environmental factors that are most influencing these species and their habitats.

ES.2 SPECIES BIOLOGY AND RESOURCE NEEDS (CHAPTER 2)

The Arkansas River shiner and peppered chub are small cyprinid minnows once widespread and common in the western portion of the Arkansas River basin in Kansas, New Mexico, Oklahoma, Arkansas, and Texas. The Arkansas River shiner was first described in 1929, while the peppered chub has had a complex taxonomic history before being described under its current species nomenclature in 1999.

Habitat for both species are near identical, consisting historically of the main channels of wide, shallow, sandy bottomed rivers and larger streams of the Arkansas River basin, with peppered chubs appearing more adapted for headwater areas. Adults of both species prefer shallow channels where currents flow over clean fine sand, and generally avoid calm waters and silted stream bottoms. Both species have adaptations to tolerate the adverse conditions of the drought-prone prairie streams they inhabit, including a high capacity to endure elevated temperatures and low dissolved oxygen concentrations. Peppered chubs appear more associated with turbid water compared to Arkansas River shiner.

Arkansas River shiner and peppered chub are members of a reproductive guild that broadcast spawns semibuoyant eggs, which are kept suspended until hatching in flowing water. This reproductive strategy appears to be an adaptation to highly variable environments where stream flows are unpredictable and suspended sediments and shifting sand can cover eggs laid in nests or crevices. Without stream flow, eggs sink to the bottom where they may be covered with silt and die. After hatching, adequate stream length likewise provides the extended flow time needed by larval fish which may require strong currents to keep them suspended in the water column until they are capable of horizontal movement and strong enough to leave the main channel.

Channel complexity is also correlated with stream length resulting in slower transport rates in streams with wider and more braided channel morphology which allow more time for developing eggs and larva to reach their free swimming stage.

ES.3 INFLUENCES ON VIABILITY (CHAPTER 3)

We evaluated the past, current, and future influences that affect the resource needs necessary for long term viability of the Arkansas River shiner and peppered chub. We organized these influences around the stressors (i.e., changes in the resources needed by the Arkansas River shiner and peppered chub) and discussed the sources of those stressors. Stressors affecting the viability of the Arkansas River shiner and peppered chub discussed in this section include altered flow regimes, impoundments and other stream fragmentation, modified geomorphology, decreased water quality, physical removal of fish/direct mortality, and the introduction of invasive species. The source of many of these stressors is related to the construction of dams and impoundments (a body of water confined within an enclosure) which alter streamflows and fragments streams. Additional sources of stressors include groundwater withdrawals, development, invasive vegetation, weather conditions including climate change, commercial bait fish harvesting, and off road vehicle use within habitat.

Arkansas River shiners and peppered chubs need flowing water in order to maintain viable populations. Low flow events (including isolated pooling) and inundation can impair or eliminate appropriate habitat for both species, and while adults of each species are adapted and can typically survive these events for a short time, populations that experience these events regularly face compromised reproduction and may not persist. Impoundments negatively affect Arkansas River shiners and peppered chubs by changing flow regimes, temperature regimes, substrates, sedimentation rates, water quality, channel morphology, nutrient availability, and by acting as barriers to fish passage. Inundation (formation of lakes and smaller lentic (still water) habitats occurring upstream of dams) causes an increase in sediment deposition; deep, colder water often devoid of oxygen and necessary nutrients; and proliferation of predator species which prefer deep water habitats.

Reduced stream flow resulting from impoundments contributes to the loss of wide, shallow sand bed river channels characteristic of Arkansas River shiner and peppered chub habitat. Impoundments often reduce the magnitude and frequency of high flows leading to channel stabilization and narrowing downstream, alter bank plant communities, restrict downstream transport of nutrients that support ecosystem development, and alter river substrate. Impoundments also trap streamflow, reducing the availability of water downstream leading to more frequent lack of flow, channel drying, pool isolation, and vegetative encroachment. The reduction in flows of occupied habitat reduces reproductive success in both of these species and decreases their viability.

Although drought is a naturally occurring phenomenon in Great Plains streams, exploitation of groundwater resources has contributed to a permanent decline in streamflow and the subsequent loss of pelagic broadcast spawning fishes where streams are decoupled from aquifers because of groundwater depletion. Groundwater pumping has caused declines of stream length, reduced critical surface flows during the spring reproductive season, and increased river drying. within the Great Plains.

Within the Great Plains, average temperatures have increased and projections indicate this trend will continue over this century. Precipitation within the southern portion of the Great Plains is expected to decline, with extreme events such as heat waves, sustained droughts, and heavy rainfall becoming more frequent. These components negatively affect Arkansas River shiner and peppered chub due to their small species population size (and likely compromised genetic diversity as a species), virtually non-existent dispersal ability, and probable difficulty in behavioral changes which also accommodate their specialized life cycles.

Adequate water quality is necessary to maintain suitable conditions for Arkansas River shiner and peppered chub, and may be impaired through contamination or alteration of water chemistry. Dissolved oxygen levels may be reduced from increased nutrients in the water column from runoff or wastewater effluent. Increased water temperature from climate change and from low flows during drought can exacerbate low dissolved oxygen levels, especially when reduced flows strand fish in isolated pools. Similarly, fish stranded in isolated pools can be subjected to increased salinity. Land use activities that may result in poor water quality include irrigated cropland, concentrated animal feeding operations, municipal solid waste sites, and stormwater runoff from urban areas from.

Additional stressors to Arkansas River shiner and peppered chub discussed in Chapter 3 (to a lesser extent) include the introduction of invasive species, in-stream gravel mining and dredging, recreational off-road vehicle use within habitat, and commercial bait harvest. Also discussed are ongoing and potential management actions targeted to improve Arkansas River shiner and peppered chub populations.

ES.4 CURRENT CONDITION (CHAPTER 4)

We described the current condition of the Arkansas River shiner and peppered chub through analysis of demographic and habitat based analytical factors. Demographic factors include capture ratio (collections with species presence to collection where the species was not collected) and relative abundance. Habitat include stream fragmentation, channel narrowing, flood frequency and low flow analysis.

The Arkansas River shiner and peppered chub historically inhabited numerous rivers across the Arkansas River drainage (see historical distribution maps in Chapter 2). We conclude that dispersion between major rivers occurred historically, but each of the major rivers supported 'local populations.'

ES.4.1 CURRENT RANGE AND DISTRIBUTION

Arkansas River shiner

Fish collection records in the Arkansas River basin span from the pre-1930s until the present. Data show that survey efforts and positive findings for the Arkansas River shiner increased across all Resiliency Units pre-1930 through 1959. Between 1960 and 1989 survey efforts and positive findings increased although the percentage of positive surveys slightly declined with time (30 percent pre-1930, 26 percent 1930-1959, and 20 percent 1960-1989). Collection efforts from 1990 to present were significantly greater as compared to previous time periods and collections containing the Arkansas River shiner increased. However, the percentage of collections where Arkansas River shiners were captured declined to only 15 percent.

Regarding current distribution of the Arkansas River shiner, we considered the last 17 years (2000 to present) as current condition for our assessment. In examining presence/absence capture data only, records indicate that the species occurs only in the South Canadian River, in 5 subunits (of the historical 23 occupied subunits).

Peppered chub

Our analysis of current condition of the peppered chub is based numerous scientific publications from species experts who concluded that by the year 2000, the peppered chub had significantly declined and was now isolated to the Ninnescah River in Kansas and the South Canadian River between Ute Reservoir in New Mexico and Lake Meredith in the Texas panhandle. In assessing the current condition (2013-2017), survey efforts yielded a total of 1,826 collections with only 38 of those (2 percent) containing the peppered chubs. The peppered chub distribution is limited to the South Canadian River between Ute Reservoir in New Mexico and Lake Meredith in the Texas panhandle represents only 6 percent of its historical range. The ratio of positive to negative peppered chub surveys in the Upper South Canadian River dropped to 45 percent and peppered chubs were not collected in the Ninnescah River during this time period.

ES.4.2 RELATIVE ABUNDANCE

Arkansas River Shiner

The relative abundance of Arkansas River shiner has significantly declined in 4 analytical subunits. Though none of the models show relative abundance to have reached zero, relative abundance in these four analysis subunits have declined to less than 5 percent and are asymptotically approaching zero. However, there was no significant trend in Southern Canadian River subunit 5, suggesting that the relative abundance is stable at 30 percent. The lack of a significant directional trend and the large number of samples in the subunit indicate a stable Arkansas River Shiner population.

Peppered Chub

Relative abundance in the Upper South Canadian River subunit 5 has declined from 13.9 to 1.7 percent is currently categorized to be in poor condition. Peppered chub are no longer found in surveys of the Ninnescah River.

4.2.1 Community Analysis

We analyzed all available data for fish communities in the South Canadian River to reveal correlations between the presence of Arkansas River shiner and peppered chub and other fish species. We found that fishes associated with Arkansas River shiner and peppered chub are smaller minnows or minnow-like fishes that can excel in shallow, fast moving environments. We compared pre- and post-impoundment fish data to reveal the resulting changes in fish communities. Our results suggest that the Upper South Canadian River community is one most closely associated with Arkansas River shiner and peppered chub, as compared to the Lower South Canadian River. Additionally, a comparison of upper to lower stretches of the Lower South Canadian River suggests that the communities are becoming more similar to one another, although it appears that since the 1980s these communities are trending slightly away from the Arkansas Rivers shiner.

ES.4.3 HABITAT FACTORS

ES.4.3.1 System Hydrology

In order to evaluate the effect of the impoundments on the aggregate hydrology of these systems and compare these effects with the population dynamics of the Arkansas River shiner and peppered chub, we conducted analysis on the hydrological habitat factors detailed below.

<u>ES.4.3.1.1 Hydroperiod</u>

Termed here as the hydroperiod, this interval provides some collective insight into the period of time most relevant to fish spawning and recruitment (spring and summer) as well as the effects the annual hydrograph has upon geomorphology and channel planform. Hydroperiod contrasts the effects of dams on the natural flow regime.

We categorized a Good condition for the hydroperiod metric to be when there is any gain in post-impoundment discharge to a loss of up to 10 percent. A Fair condition is a 10-20 percent decrease in post-impoundment discharge and Poor condition is represented by a 25-75 percent decrease. A Null condition exists where there is greater than a 75 percent decrease in post-impoundment mean stream discharge during the hydroperiod. A summary of results across USGS gauges within each Resiliency subunit for hydroperiod analysis (and other hydrologic measures) is represented in Table ES-1 and ES-2 at the end of this section.

ES.4.3.1.2 Flood Frequency Analysis

Flood flows are a natural process but occur at longer return intervals (5-100 years). Such events engage and inundate high-flow side channels, oxbows, or other features within the floodplain and maintain or create new habitat through avulsive, scour, and depositional river dynamics. When flood flows are eliminated or attenuated by impoundments, the floodplain becomes increasingly isolated thereby affecting both aquatic and riparian ecosystems. To gain specific insight into how dams and flood flows have changed from the pre- and post-impoundment periods, we performed a flood frequency analysis at the same USGS stream gages previously identified. Categorically, we defined a Good condition for the FFA metric to be when the weighted sum of the proportional differences of the 2, 5, and 10-year return intervals is greater than 75 percent. A Fair condition is between 50-75 percent and a Poor condition is between 10-50 percent. A Null condition is less than 10 percent. A summary of results across USGS gauges within each Resiliency subunit for flood frequency analysis (and other hydrologic measures) is represented in Table ES-1 and ES-2 at the end of this section.

ES.4.3.1.3 Low Flows

A summary of results across USGS gauges within each Resiliency subunit for flow conditions is represented in Table ES-1 and ES-2 at the end of this section. We noted that decreasing low-flow conditions does not always indicate a favorable situation. Peak flows have been drastically attenuated thereby eliminating or greatly limiting the floodplain inundation and the hydraulic forces necessary to destabilize stream banks and create new habitat. As a result, the channel has been greatly narrowed and vegetation (often exotics) has been allowed to armor the banks. If low-flows are then decreased through, for example, steady irrigation deliveries, vegetation communities become even more ensconced and the floodplain further isolated.

In summary, all resiliency units are hydrologically degraded. The natural hydrographs have been, for the most part, fundamentally altered for an extended period of time. The magnitude, timing, and duration of essential hydrograph elements (e.g., spring runoff) have often been eliminated in favor of agricultural or municipal demands.

ES.4.3.2 River Fragmentation

Both the Arkansas River shiner and peppered chub need a minimum length (135 miles) of unimpounded and connected river for long-term successful reproduction. Therefore, we identified river fragments within the Arkansas River Basin by locating instream barriers (large and small impoundments, locks and diversion) and river channels known to be dry for significant portions of the year. We assigned categorical values to those fragments based on river distances important for pelagic broadcast spawning fishes. We identified six river fragments providing adequate length for Arkansas River shiner and peppered chub. Note that our reference to species needs in this section is only in terms of river fragment length and the extirpation of Arkansas

River shiner and/or peppered chub from some of these fragments is likely driven by a combination of other stressors. A summary of the current condition for the river fragmentation habitat factor is shown within Table ES-1 and ES-2.

ES.4.3.3 Channel Narrowing

All river stretches analyzed in this SSA had a decrease in unvegetated riverbed acreages between the 1950s and 2010s, with the exception of the Arkansas River near Ralston, OK which had an increase of 9.0 percent. Unvegetated riverbed acreage decrease averaged 60 percent, ranging from a low of 4.5 percent change (Ninnescah River near Clearwater, KS) to over 96 percent loss (South Canadian River near Canadian, TX). The decrease in riverbed change was often in areas located downriver from impoundments, although some areas other factors, such as water withdrawals from irrigation or oil & gas development, may have played a role in the decrease. Typically, as distance downriver from impoundment increased, the percent of unvegetated riverbed lost decreased. A summary of the current condition of unvegetated river channel segments between 1950s and 2010s are summarized in Table ES-1 and ES-2 at the end of this section.

ES.4.4 RESILIENCY, REPRESENTATION, AND REDUNDANCY

ES.4.4.1 Species Resiliency

Within this analysis, resiliency is classified as high, moderate, low, or null for each resiliency unit. The null rating is used for Resiliency Units when Arkansas River shiner or peppered chub have been extirpated. Based on the demographic and habitat factors used to describe resiliency in this SSA, we described an overall level of resiliency by Resiliency Unit in Table ES-1 for the Arkansas River shiner and Table ES-2 for the peppered chub. Our analysis found that in the two resiliency units currently occupied by the Arkansas river shiner, both units have an overall moderate level or resiliency. The one resiliency unit currently occupied by the peppered chub has poor resiliency.

Table ES-1. Current resiliency for the Arkansas River shiner.

CURRENT RESILIENCY *Arkansas River shiner*										
	Demographic Factors				Habitat/Flow Factors					*CURRENT RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Relative Abundance Trend	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Lower Arkansas	Ø	na	Ø	Ø	Ø	na	na	na	na	Ø
Upper Arkansas	Ø	na	Ø	Ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	Ø
Cimarron	Ø	na	Ø	Ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	Ø
North Canadian	Ø	na	Ø	Ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	Ø
Lower S. Canadian	Poor & Good	Poor & Good	Poor to Fair	Poor	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	MODERATE
Upper S. Canadian	Good	Good	Good	Good	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	MODERATE

Table ES-22. Current resiliency of the peppered chub.

CURRENT RESILIENCY *Peppered Chub*									
	Demographic Factors			Habitat/Flow Factors					*CURRENT RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Upper Arkansas (includes Ninnescah and Salt Fork)	Ø	na	Ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	Ø
Cimarron	Ø	na	Ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	Ø
North Canadian	Ø	na	Ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	Ø
Lower South Canadian	Ø	Ø	Ø	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	Ø
Upper South Canadian	Fair	Good	Poor	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	LOW

ES4.4.2 Species Representation

Arkansas River shiners and peppered chubs have likely lost genetic and ecological diversity, as some populations have been extirpated. As such, maintaining the remaining representation in the form of genetic diversity may be important to the capacity of the Arkansas River shiner and peppered chub to adapt to future environmental change.

Arkansas River shiner

Our best-available information suggested that the Arkansas River shiner has representation in the form of genetic diversity in three areas: (1) The South Canadian River upstream of Lake Meredith, Texas (from samples in the headwaters of the South Canadian River in New Mexico and its tributary Reveulto Creek), (2) The South Canadian River downstream of Lake Meredith, Texas (in Oklahoma) and (3) the introduced population in the Pecos River, New Mexico. We expect additional genetic variation was present in extirpated Arkansas River shiner populations elsewhere across its former range that has now been lost.

Representation in the form of ecological diversity across the extant populations of Arkansas River shiners is unknown. We expect that ecological diversity was lost in the now extirpated Arkansas River shiner populations across the wide-spread and varying habitat conditions of the Arkansas River basin.

Peppered chub

We consider the peppered chub to have limited representation in the form of genetic and ecological diversity due to fact that only a single functioning population exists between the Ute Dam, New Mexico and Lake Meredith, Texas. Research indicates that the peppered chub has "considerable stocks of genetic diversity" within this single population; however, the species lacks the representation of species with multiple populations occurring across varying landscapes. At least one study reported that peppered chubs displayed variation in multiple physical characteristics between populations within the South Canadian and extirpated Ninnescah Rivers, and suggested that these differences were adaptive responses to differing local environmental conditions. These morphological differences between the remaining South Canadian River population and the presumed extirpated Ninnescah River population suggest a loss of unique representation in the form of adaptive ecological diversity. We expect that additional genetic diversity was also present in the extirpated peppered chub populations across varying ecological settings within the wide-ranging Arkansas River basin which has now been lost. In summary, both the Arkansas River shiner and peppered chub currently have limited representation. Despite restrictions of their range due to impoundments and other habitat alterations and decline in abundance, it is possible that their genetic variation is sufficient to survive the naturally occurring conditions of the arid prairie stream environments in which they evolved.

However, it is unknown if these species have the genetic variability or the ability to adapt to continuing habitat and flow alterations because it is not expected that their basic life history strategies for broadcast-spawning for reproduction would change.

ES4.4.3 Species Redundancy

Redundancy is defined as the ability of a species to withstand catastrophic events (a rare destructive natural event or episode involving many populations and occurring suddenly). Species redundancy is about spreading the risk and can be measured through the duplication and distribution of resilient populations across the range of the species. The greater the number of resilient populations (or resiliency units, in the case of our analysis) a species has distributed over a larger landscape; the better able it can withstand catastrophic events.

Arkansas River Shiner

Historically, the Arkansas River shiner occurred in six resiliency units distributed across six states. However, it is now extirpated from all but two (Upper and Lower South Canadian River) of resiliency units across three states. We presume that one or both of the remaining resiliency units could be extirpated due to a catastrophic event. Given the current level of redundancy across the range, the species as a whole has a higher risk of extirpation due to an unusually rare and destructive drought, or other catastrophic event.

Peppered Chub

The peppered chub once occupied five resiliency units and ranged across six states; however, all but one resiliency unit has been extirpated. With one resiliency unit remaining it is difficult to determine if there is any remaining redundancy at the species-level, and we are unable to determine the adequate level of redundancy to ensure this species' viability. Regardless, we conclude that the species is at higher risk of extirpation due to a potential catastrophic event when compared to historical conditions. Given the current low level of redundancy across the range, without active management the species as a whole has a higher risk of extirpation compared to historical conditions.

ES.5 FUTURE CONDITON (CHAPTER 5)

In this chapter we identified a range of plausible future scenarios, based on differing influences (stressors and conservation) to the Arkansas River shiner and peppered chub. We applied future scenarios in the context of resiliency, representation, and redundancy to describe the potential future viability of the Arkansas River shiner and peppered chub.

ES.5.1 FUTURE CLIMATE

We considered the projected changes in annual maximum temperature, precipitation, and potential evapotranspiration for the early and middle twenty-first century 2010-2069 and the implications on Arkansas River shiner and peppered chub resiliency. If current emissions continue without abatement (RCP 8.5) then annual maximum temperatures will increase by over 6°F by mid-century. Increased air temperatures will lead to increased water temperatures which will in turn reduce the water's oxygen carrying capacity and simultaneously increase oxygen demand by increasing metabolic rates. Variations in annual precipitation are expected to be minor (less than 0.1 inch/year loss to gains up to 0.5 inch/year in the eastern reaches). However, due to the increased temperatures and other factors, potential evapotranspiration across most of the study area will increase, leading to an effective water loss of over 7.5 inches/year.

ES.5.2 FUTURE SCENARIOS

Overview:

We identified four future scenarios that best represent the potential range of outcomes, based on differing stressors and conservation actions that affect both species. An overview outline of those scenarios is provided below.

1) Continuation of Existing Trends
    - Water demands continue at the existing rate
    - Current rate of emissions continues (Representative Concentration Pathway [RCP] 8.5)
    - No additional conservation implemented
2) Water Conservation with Flow Trends Stabilizing
    - Water demands stabilize, resulting in no changes to future flows
    - Current rate of emissions is mitigated – assuming no future effect to flows
    - Water conservation is implemented
3) Species Conservation and Continuation of Existing Trends
    - Water demands continue at the existing rate
    - Current rate of emissions continues (RCP 8.5)
    - Species targeted conservation action are implemented
4) Species and Water Conservation with Flow Trends Stabilizing
    - Water demands stabilize, resulting in no changes to future flows
    - Current rate of emissions is mitigated – assuming no future effect to flows
    - Water conservation is implemented
    - Species targeted conservation actions are implemented

We applied each of these scenarios independently to the Arkansas River shiner and peppered chub to characterize future species resiliency, representation, and redundancy. A brief summary of the results of our analysis is provided in the sections below.

ES.5.2.1 Scenario 1 – Continuation of Existing Trends

Arkansas River shiner

Because only the Upper and Lower South Canadian River are currently known to be occupied by the Arkansas River shiner, those were the only resiliency units evaluated in our analysis of future scenarios. Under the Continuation of Existing Trends Under the Continuation of Existing Trends Scenario, we expect resiliency of both occupied Resiliency Unis to decline from Moderate to

Low by 2039 and would expect the resiliency to continue to be low at 2069 and that the species will be more vulnerable to demographic and environmental stochasticity.

Under the Continuation of Existing Trends scenario, the current level of representation may be maintained through 2039, although overall population size in the Upper and Lower South Canadian River units could decline, potentially affecting genetic diversity. By 2069 it is possible that the Lower South Canadian River could be functionally extirpated, leaving only the Upper South Canadian River and non-listed Pecos River population to provide species representation.

Under the Continuation of Existing Trends scenario current redundancy of only two populations (Upper and Lower South Canadian River) would be generally maintained by 2039, although with a low resiliency in both units, these populations will be relatively vulnerable to extirpation. By 2069, it is possible that the lower South Canadian River could become functionally extirpated, leaving only the Upper South Canadian River population, with low resiliency.

Peppered chub

The one occupied resiliency unit for peppered chub currently has low resiliency. We don't expect a change in resiliency at 2039 or 2069 in a Continuation of Existing Trends scenario. The peppered chub is already vulnerable to disturbances such as random fluctuation in birth rates or variations in annual rainfall and would continue to be in a Continuation of Existing Trends scenario.Under the Continuation of Existing Trends scenario, the current level of representation may be maintained through 2039, although overall population size in the Upper South Canadian River could decline, potentially affecting genetic diversity. By 2069 it is possible that the only remaining population of the peppered chub could be functionally extirpated from the South Canadian River.

Under the Continuation of Existing Trends scenario, the peppered chub will continue to exhibit no redundancy, as only one population would be maintained by 2039. Too, with a **LOW** resiliency (even lower resiliency as compared to current condition) this population will be more vulnerable to extirpation. By 2069, it is possible, with the loss of this single remaining population of the species, that the peppered chub could become functionally extinct.

ES.5.2.2 Scenario 2 – Water Conservation with Flow Trends Stabilizing

Arkansas River shiner

We expect that both occupied Resiliency Units would maintain a moderate level of resiliency into the future under a Water Conservation with Flow Trends Stabilizing future scenario. The current level of representation may be maintained through 2069 for the Arkansas River shiner. We presume that one or both of the remaining resiliency units could be functionally extirpated due to a catastrophic event. As such, we anticipate a lower level of redundancy in the future. Given the current level of redundancy across the range, the species as a whole has a higher risk of extirpation due to an unusually rare and destructive drought, regardless of water conservation efforts in the future.

Peppered chub

Under future scenario two, we expect the one remaining peppered chub Resiliency Unit to continue to be low through 2069. The peppered chub has limited representation in the form of genetic and ecological diversity due to fact that only a single functioning population exists between the Ute Dam, New Mexico and Lake Meredith, Texas. The peppered chub has a higher risk of extirpation form a catastrophic event, due to smaller range and single resiliency unit within the range. Given the current level of redundancy across the range, the species as a whole has a higher risk of extirpation due to an unusually rare and destructive drought, regardless of water conservation efforts.

ES.5.2.3 Scenario 3 – Species Conservation and Continuation of Existing Trends

Under the Species Conservation and Continuation of Existing Trends scenario, we make two assumptions:

1. All species conservation actions (described in Chapter 5) are implemented and are successful
2. Flow and habitat trends continue at current rates, as water demands continue to rise at current rates, and climate emissions scenario RCP 8.5 continues

Arkansas River shiner

Currently, there are two occupied resiliency units in the range of Arkansas River shiner. In scenario 3, with introductions and other conservation efforts, we expect that there may be up four occupied Resiliency Units. We expect that by 2039, the resiliency units in the South Canadian River will have low to moderate resiliency and that any reestablished populations in the Salt Fork or Cimarron Resiliency Units will have low resiliency. By 2069 we expect one resiliency unit to have low to moderate resiliency and the other three units to have low levels of resiliency with one unit being low to extirpated. Under Scenario 3, the Arkansas River shiner would have representation in the form of genetic diversity in five areas (four in the historic range and one introduced Pecos River population). Because fish for reintroductions will come from either the South Canadian River or Pecos River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established it could potentially provide for increased ecological adaptability in the future. Under Scenario 3, redundancy of four populations of Arkansas River shiner would be maintained: Upper and Lower South Canadian River, Cimarron River and Arkansas River. With all four units possibly exhibiting low resiliency, these populations would be vulnerable to catastrophic events, reducing redundancy in the future.

Peppered chub

Under the conditions outlined in Scenario 3 (which includes reintroductions of peppered chub into two currently extirpated Resiliency Units), we expect two Resiliency Units to have a resiliency of low to moderate and one Resiliency Units to have a low level of resiliency by 2039. By 2069 we would anticipate two Resiliency Units to have low resiliency and one to have low to moderate resiliency. Under Scenario 3, the peppered chub has representation in the form of genetic diversity in three areas. Because broodstock for fish reintroductions will come from the South Canadian River, genetic variation is not necessary improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future. Increasing to three Resiliency Units being populated, would increase the overall redundancy of peppered chub. However, all units exhibiting low (or low to moderate) resiliency, these units would be vulnerable to catastrophic events, possibly reducing redundancy in the future.

ES.5.2.4 Scenario 4 – Species and Water Conservation with Flow Trends Stabilizing

Under this scenario the following assumptions were made:

1. All species and water conservation actions (described in Chapter 5) implemented and are successful
2. Flow trends stabilize as water demands stabilize and climate emissions are mitigated

Arkansas River shiner

With the reintroduction of Arkansas River shiner into two resiliency units and the conservation efforts considered in future Scenario 4, we would expect two Resiliency Units to have low resiliency, one unit to maintain moderate resiliency, and one unit to increase from moderate to high resiliency by 2039 and to maintain this level of resiliency in each unit through 2069. Under Scenario 4, the Arkansas River shiner has representation in the form of genetic diversity in five areas (the four units in its historical range and the introduced Pecos River population). Because broodstock for fish reintroductions will come from the either South Canadian River or Pecos River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future. Redundancy increases by 2039 by establishing Arkansas River shiner in two additional Resiliency Units compared to current condition. We would anticipate redundancy of four populations of Arkansas River shiner would be maintained after 2039. However, with two of the four units exhibiting low resiliency, these units would be vulnerable to catastrophic events, possibly reducing redundancy in the future.*Peppered chub*

With the reintroduction of peppered chub into two resiliency units and the conservation efforts considered in future Scenario 4, we would anticipate one Resiliency Unit to have a low level of resiliency, one unit to have a low to moderate level of resiliency and the currently occupied unit to increase form low to moderate resiliency by 2039. We would expect that all units would maintain the same level of resiliency through 2069. Under Scenario 4, the peppered chub has representation in the form of genetic diversity in three areas. Because broodstock for fish reintroductions will come from the South Canadian River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future. Redundancy is expected to increase with the reintroduction of peppered chub into two Resiliency Units by 2039. We expect that redundancy of three populations of peppered chub would be maintained in the Upper South Canadian River, Cimarron River and South Ninnescah River through 2069. However, with two of the three populations potentially exhibiting low resiliency, these populations would be vulnerable to catastrophic events, possibly reducing redundancy in the future.

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CHAPTER 1 – INTRODUCTION

The Arkansas River shiner (*Notropis girardi*) and peppered chub (*Macrhybopsis tetranema*) are small minnows currently restricted primarily to the contiguous river segments of the South Canadian River basin spanning eastern New Mexico downstream to the Texas panhandle for peppered chub and into Oklahoma for Arkansas River shiner. The Arkansas River shiner had been considered for listing since 1989 (54 FR 554) and was listed as threatened under the Endangered Species Act of 1973, as amended (Act) on November 23, 1998 (63 FR 64772). Critical habitat was designated for the Arkansas River shiner on October 13, 2005 (70 FR 59808). The peppered chub was petitioned for listing under the Act in 2007 (Forest Guardians 2007, p. 28), and the U.S. Fish and Wildlife Service (Service) published a 90-day finding determining that the petition had substantial information to indicate listing may be warranted on December 16, 2009 (74 FR 66866).

This Species Status Assessment (SSA) was undertaken by the Service to inform an Arkansas River shiner recovery plan and to provide support for a decision on whether or not to propose listing and designation of critical habitat for the peppered chub. The document may also be used to support other Endangered Species Act actions in the future. The SSA does not result in or predetermine any decisions by the Service under the Act. Those decisions will be made by the Service after reviewing this document, along with supporting analysis, any other relevant scientific information and all applicable laws, regulations and policies. The SSA framework is intended to foster an in-depth, all-inclusive review of these species' biology, resource requirements, and stressors to evaluate their current biological status and whether they have the resources and conditions needed to maintain long-term viability (Service 2016, entire; Smith et al. 2018, entire). The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from listing, to consultations, and recovery. As such, the SSA Report will be a living document upon which many other documents such as listing rules, recovery plans, and 5-year reviews will be based. Both the Arkansas River shiner and peppered chub are included within this document because they share much of the same historical and current ranges, resource needs, and stressors.

The objective of this SSA is to thoroughly characterize the viability of the Arkansas River shiner and the peppered chub based on the best scientific and commercial information available. In this description, we will define what these species need to support self-sustaining populations, describe their current conditions in terms of those needs, and provide a forecasted future condition under plausible future scenarios. In conducting this analysis, we will take into consideration the likely changes—past, present and future—that are occurring within the range of these species to help us understand what factors drive the viability of the species.

For the purpose of this assessment, we define **viability** as the ability of these species to sustain populations in the wild over time. Using the SSA framework (Figure 1-1), we describe these species' viability in terms of their **resiliency**, **representation, and redundancy** (collectively, the 3Rs)

- **Resiliency** is defined as the ability of a population to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, for example, birth versus death rates, and population size. Healthy populations are more resilient and better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

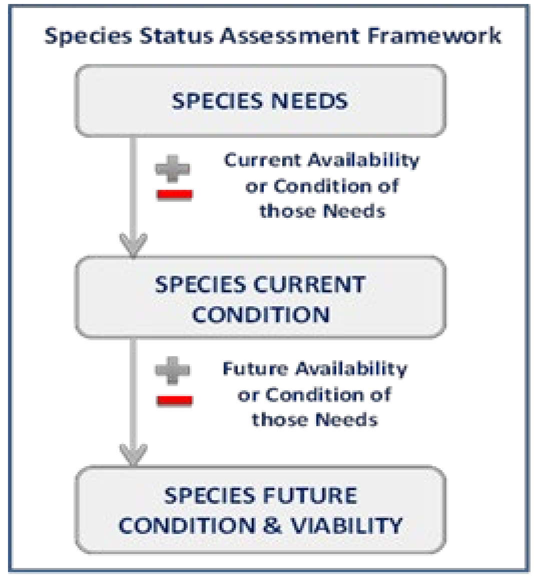


Figure 1-1. Species Status Assessment Framework

- **Representation** is defined as the ability of a species to adapt to changing environmental conditions over time. Representation can be measured through the breadth of adaptive diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent of, and variability of habitat characteristics within, their geographical range.

- **Redundancy** is defined as the ability of a species to withstand catastrophic events (a rare destructive natural event or episode involving many populations and occurring suddenly). Redundancy is about spreading the risk and can be measured through the duplication and distribution of resilient populations across the range of the species. The greater the number of resilient populations a species has distributed over a larger landscape, the better able it can withstand catastrophic events.

To characterize the viability of the Arkansas River shiner and peppered chub in the future, we assessed a range of plausible future conditions to allow us to consider the species' future resiliency, redundancy, and representation. This SSA provides a thorough assessment of biology and resource needs of these species and assesses demographic risks, stressors, and limiting factors in the context of determining the viability. The format for this SSA Report includes descriptions of the species' biology and the resource needs of individuals, populations, and species (Chapter 2); analysis of current stressors on the species or their resources and their influence on long term species' viability (Chapter 3); assessment of the historical and current range and distribution, and areas of known and/or presumed extirpation, along with current condition in terms of resiliency, redundancy, and representation (Chapter 4); an assessment of future conditions based on scenarios in which we vary stressors and availability of resources, and subsequent impacts on species' resiliency, redundancy, and representation in the future (Chapter 5).

CHAPTER 2 – SPECIES BIOLOGY AND RESOURCE NEEDS

In this chapter we provide biological information about the Arkansas River shiner (*Notropis girardi*) and peppered chub *(Macrhybopsis tetranema*), including their physical environments, the taxonomic history and population genetics, morphological descriptions, reproductive and other life history traits. We then outline the resource needs of individuals, populations, and species. These resources (water quantity and quality, stream reach lengths that provide suitable habitat conditions, flow regime, channel morphology, food resources, etc.) are key factors that determine the resiliency of Arkansas River shiners and peppered chubs. Finally, we consider the population and species level needs for each species in the context of their historical ranges.

2.1. BIOLOGY AND LIFE HISTORY

2.1.1. Physical Environment

Arkansas River shiner

The Arkansas River shiner is a cyprinid minnow once widespread and common in the western portion of the Arkansas River basin in Kansas, New Mexico, Oklahoma, Arkansas, and Texas. This species is no longer found in over 83 percent of its historical range (3,896 river miles) and now appears to be entirely restricted to portions of the South Canadian River (or identified as Canadian River on USGS topographic maps) in eastern New Mexico, the Texas panhandle, and Oklahoma (673 river miles) (63 FR 64772; as analyzed in Chapter 4 of this report). A non-native, introduced population of the Arkansas River shiner occurs in the Pecos River in New Mexico, just outside of the species' historical range (Bestgen et al. 1989, p. 228).

Peppered chub

The peppered chub is also a cyprinid minnow which historically occurred in the upper Arkansas River basin in Oklahoma, Kansas, Texas, New Mexico, and Colorado but is now functionally extirpated from 94 percent of its former range (2,601 river miles) (Luttrell et al 1999, p. 981; as analyzed in Chapter 4 of this report) and is restricted to portions of the South Canadian River (or identified as Canadian River on USGS topographic maps) in eastern New Mexico and the Texas panhandle (170 river miles). Up until 2012, the species was thought to also persist in the Ninnescah River in Kansas; however, new information based on a substantial number of surveys targeting the peppered chub suggests the species is functionally extirpated from the Ninnescah River (Pennock et al. 2017, p. 57, Vernon Tabor, Kansas ESFO, pers. comm., October 20, 2017 and as analyzed in Chapter 4 of this report).

Because both species are primarily restricted to the South Canadian River basin, this basin serves as the focal point of the current physical environment with which these species are associated. The historical and potential current range of the Arkansas River shiner is illustrated in Figure 2-1 and the associated range for the peppered chub in Figure 2-2.

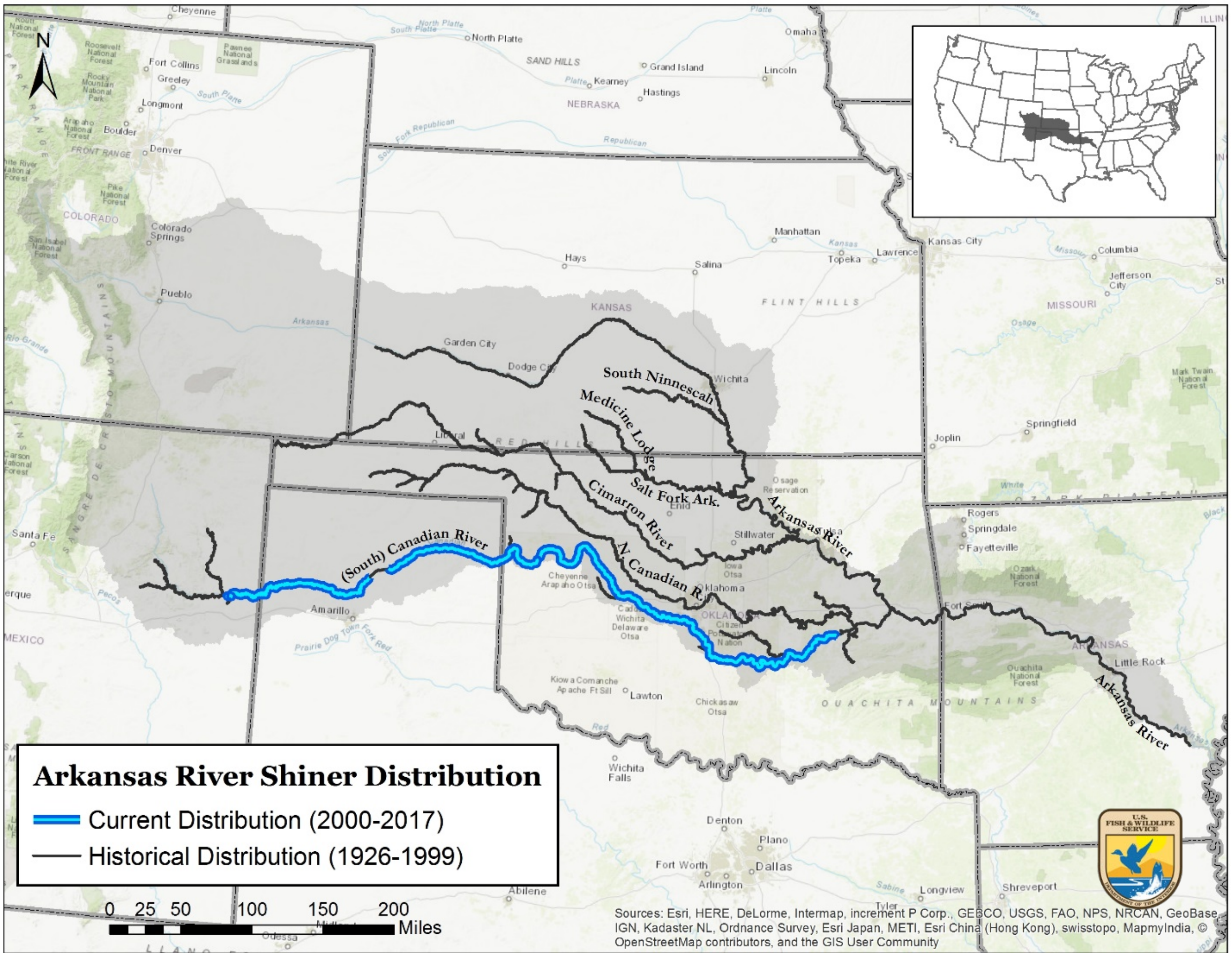


Figure 2-1. Arkansas River shiner historical and current distribution map.

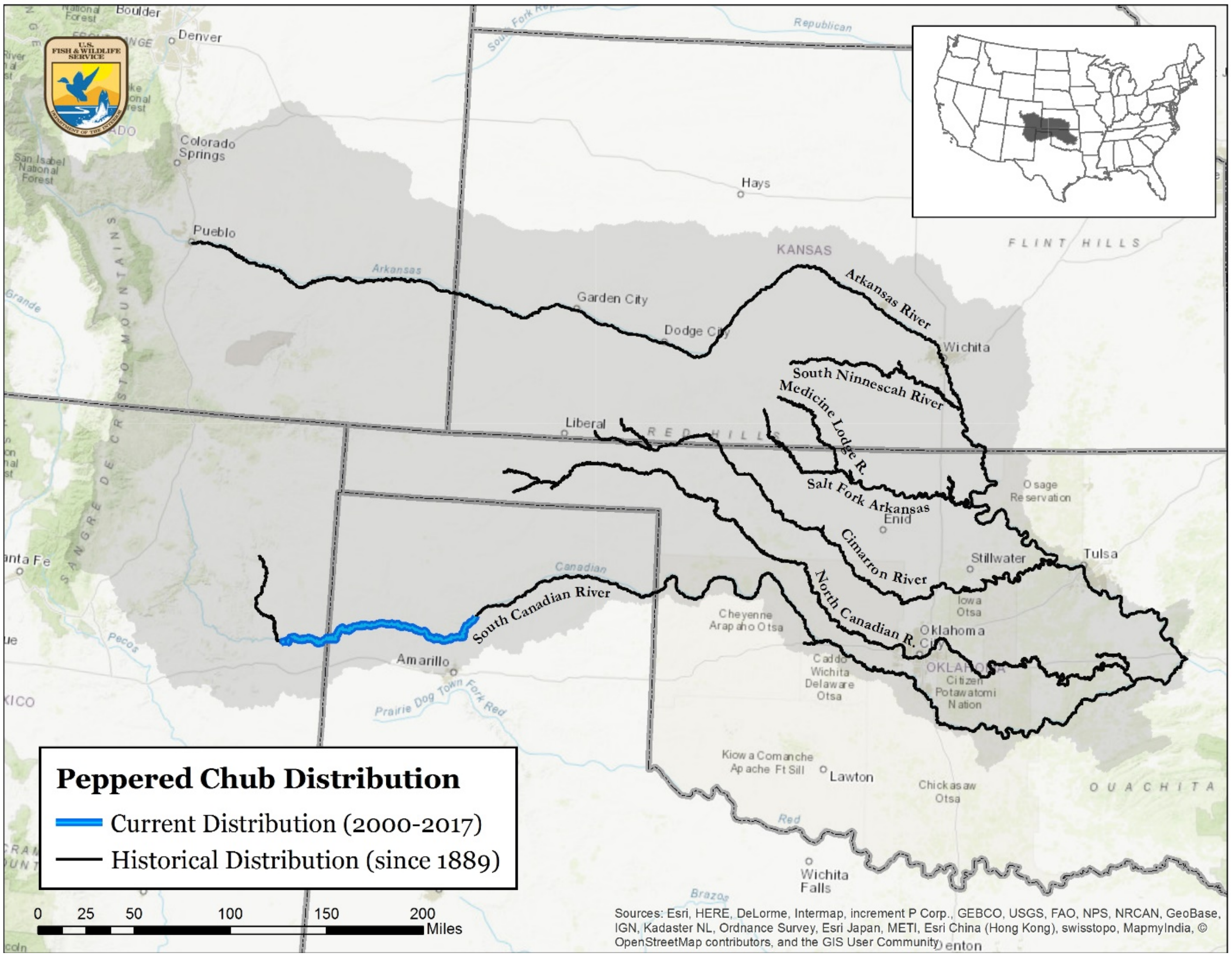


Figure 2-2. Peppered chub historical and current distribution map.

2.1.2. Taxonomy and Genetics

<u>Arkansas River shiner</u>

The Arkansas River shiner was collected in the South Canadian, Arkansas, and Cimarron Rivers, Oklahoma in 1926 by Ortenburger and was first described in 1929 (Hubbs and Ortenburger 1929, pp. 32-33), although fish collection records from the basin as early as 1884 exist (63 FR 64773). Hubbs and Ortenburger (1929, p. 33) speculated that *N. girardi* was closely related to the Red River shiner (*N. bairdi*), finding collection specimens difficult to distinguish.

The American Fisheries Society classification for the Arkansas River shiner (Page et al. 2013, p. 30) is as follows. The Service recognizes this taxonomic classification.

Phylum: Chordata
Class: Teleostei
Order: Cypriniformes
Family: Cyprinidae
Genus: Notropis
Species: Girardi

A 2010 assessment examined the genetic status of the Arkansas River shiner as well as potential hybridization with the Arkansas River shiner and other fish species (Osborne et al. 2010, entire). A portion of this assessment screened for variation at six microsatellite loci, finding moderate to high polymorphism (occurring in several different forms). Mitochondrial analysis likewise indicated that Arkansas River shiner genetic diversity is high across populations sampled in the South Canadian River in New Mexico and Oklahoma; Revuelto Creek, New Mexico; and the Pecos River, New Mexico (Osborne et al. 2010, p. 8). Using both microsatellite and mitochondrial data, Osborne et al. (2010, p. 8) found little to no genetic diversity within populations. These results suggest that genetic diversity is high between populations, but not within individual populations of Arkansas River shiner.

<u>Peppered chub</u>

The peppered chub (initially named *Hybopsis tetranemus*, and formerly referred to as the Arkansas River speckled chub) was first described by Gilbert in 1886 (pp. 208–209), and has been reclassified under several names throughout its taxonomic history. These include:

- *Hybopsis tetranemus* Gilbert 1886, pp. 208-209
- *Hybopsis aestivalis tetranemus* Bottrell et al. (1964); Davis and Miller (1967); Robison and Buchanan (1988); Williams et al. (1989)
- *Extrarius aestivalis tetranemus* Sublette et al. (1990); Cross and Collins (1995, pp. 15,62)
- *Macrhybopsis aestivalis tetranemus* Propst (1999)
- *Macrhybopsis tetranema* Eisenhour (1999, 2004); Hubbs et al. (2008, p. 21)

Prior to Eisenhour's 1999 dissertation (published 2004), the peppered chub was classified as one of six subspecies within the *Macrhybopsis aestivalis* (commonly: speckled chub) complex, the systematics of which had been unclear due to confusing morphological variation across the range of the complex (Eisenhour 2004, p. 9). Eisenhour examined morphometrics (measurements of external shape), meristics (counts of features of fish), pigmentation, and tuberculation across the range of the complex and concluded that results support the recognition of five individual species, including *Macrhybopsis tetranema*, or peppered chub. The former complex name *M. aestivalis* is now applied to one of the newly recognized individual species, the speckled chub, occurring within the Rio Grande River and some of its tributaries within New Mexico, Texas, and Mexico.

The American Fisheries Society classification for the peppered chub (Page et al. 2013, p. 28) is as follows:

Phylum: Chordata
Class: Teleostei
Order: Cypriniformes
Family: Cyprinidae
Genus: Macrhybopsis
Species: tetranema

The Service recognizes this taxonomic classification.

Genetic studies directed at examining relationships between *M. tetranema* and others of the (former) *Macrhybopsis aestivalis* complex reveal monophyly (shared common ancestry) as well as high genetic similarity with *M. australis* of the Red River basin, and the more wide-ranging *M. hyostoma* (Underwood et al. 2003, p. 493). The results of these genetic studies were consistent with indications from morphology that *M. tetranema* and *M. australis* are sister species, and assumed that both had indications of hybridization with *M. hyostoma*. Based on allozyme comparisons alone, Underwood et al. (2003, p. 497) speculated that *M. tetranema*, *M. australis*, and *M. hyostoma* could possibly comprise a single species, but also stated that patterns of morphological variation in both river basins imply distinct species. Genetic similarity and implied relation was higher between these three species inhabiting the Red and Arkansas River basins, while markedly divergent from *Macrhybopsis* species inhabiting the Rio Grande and San Marcos River basins (Underwood et al. 2003, p. 493).

More recently, Echelle et al. (in press) used the mitochondrial gene and a nuclear sequence (S7 intron 1) to assess the molecular systematics of the genus *Macrhybopsis*. Echelle et al. (in press) found that the current species level taxonomy of *Macrhybopsis* is generally supported, as is the species status for the morphologically distinct *M. tetranema* and *M. australis*. Both *M. tetranema* and *M. australis* are "ecologically and morphologically similar forms occurring in the upstream reaches of the mainstem and associated larger tributaries of their respective drainages." Historically, *M. tetranema* occurred with *M. cf. hyostoma* in downstream portions of the Arkansas River system occupied by *M. tetranema* in Oklahoma and southern Kansas, but there was "little evidence of ongoing hybridization," based on previous morphological analyses. Currently, the two species are considered occur in separate non-overlapping geographic areas because of apparent extirpation of *M. tetranema* in portions of its historical range. Analysis of

ND2 haplotypes in *M. tetranema* and *M. cf. hyostoma* indicated shallow past genetic introgression between *M. tetranema* and *M. cf. hyostoma.* For the nuclear S7 gene, *M. tetranema* and *M. cf. hyostoma* share a number of alleles that are widespread in the latter. However, *M. tetranema* carries a subclade of alleles demonstrating an ancient, shared ancestor with *M. australis* that apparently was not shared with *M. cf. hyostoma*. Echelle et al. (2018) point out that the high level of allelic homogeneity between *M. tetranema* and *M. cf. hyostoma* does not preclude the possibility that *M. tetranema* is a separate species. It has persisted through evolutionary time as a morphologically and ecologically different form and thus qualifies as a distinct species under two separate species concept definitions. In addition, the phylogenetic species concept (Eldredge and Cracraft 1980, entire) and the evolutionary species concept (Wiley 1978, entire; Mayden 1997, entire). The subclade of S7 alleles shared between *M. tetranema* and *M. australis* is markedly divergent, suggesting that the morphological and ecological distinctiveness between *M. tetranema* and *M.* cf. *hyostoma* has persisted through a long interval of evolutionary time (Echelle et al., 2018).

2.1.3 Morphological Descriptions

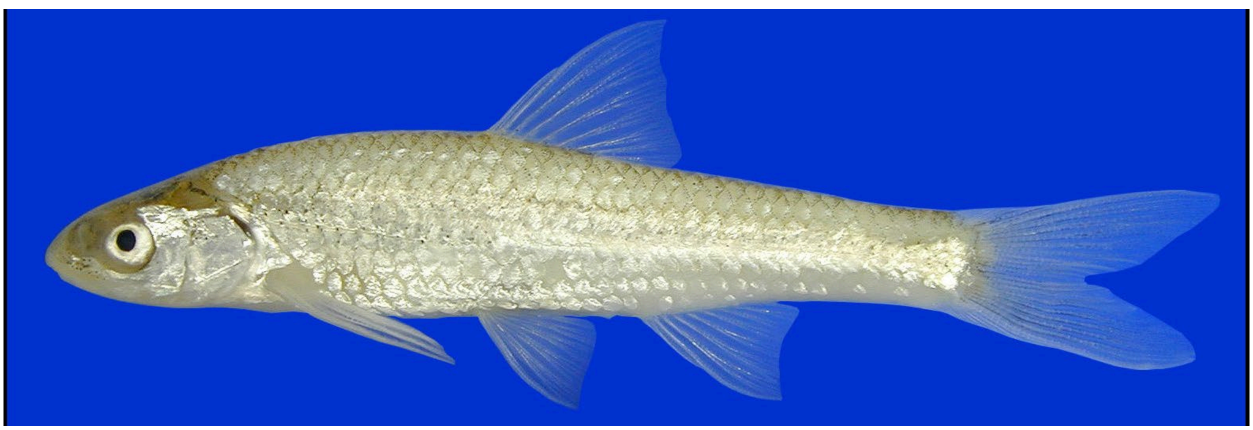


Photo of Arkansas River shiner: Chad Thomas, Texas State University-San Marcos

<u>Arkansas River shiner</u>

The Arkansas River shiner is a small, robust shiner with a small, dorsally flattened head, rounded snout, and small subterminal mouth (Miller and Robison 2004, p. 146-147; Robison and Buchanan 1988p. 212). Adults attain a maximum length of 51 mm (2 in.). Dorsal, anal, and pelvic fins all have eight rays, and there is usually a small, black chevron present at the base of the caudal fin. Dorsal coloration tends to be light tan, with silvery sides gradually grading to white on the belly. Breeding males have two to four rows of tubercles on their pectoral fins, and the sexes are otherwise indistinguishable.

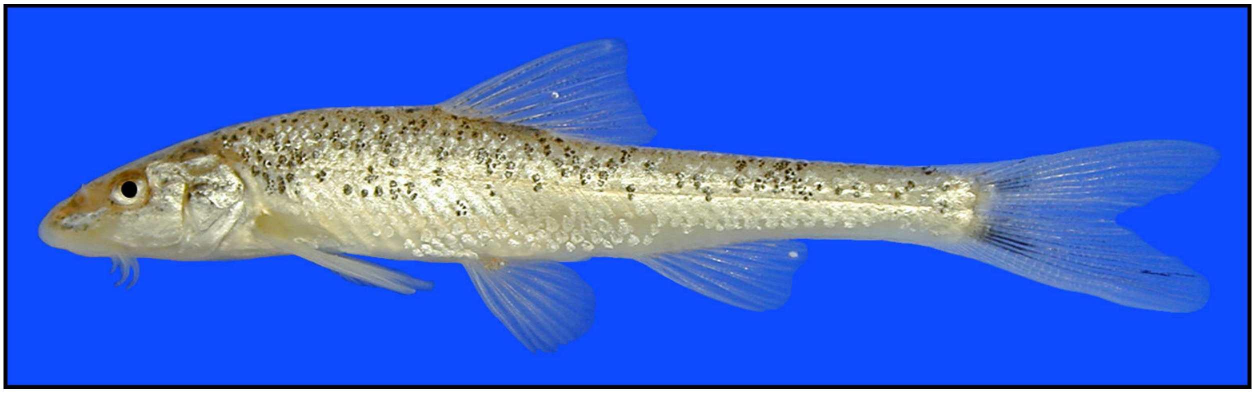


Photo of peppered chub: Chad Thomas, Texas State University-San Marcos

Peppered chub

The peppered chub is a small minnow with a fusiform (tapering at both ends) body shape rapidly tapering to a conical head. Mouth position is inferior and horizontal, with two distinct pairs of barbels present. Taste buds are present over most of the body. Pigment is nearly confined to the dorsal half of the body with dark spots scattered across this area. The lateral stripe is poorly defined and centered one scale row above lateral line. Small pale areas are often present at the posterior and anterior base of the dorsal fin. The head has pigment over the brain; a preorbital bar is present, but often indistinct. Dorsal fin rays are weakly pigmented and darker at the bases. Pigmentation is lacking on pectoral, pelvic, and anal fins. The caudal fin has a white ventral border; the rays are poorly pigmented, and coloration is darker at the base of each caudal lobe (Eisenhour 1999, p. 975). Adults attain a maximum length of 3 inches (in) (77 millimeters (mm)). Eight fin rays are typically present in the dorsal, anal, and pelvic fin, although this is somewhat variable. Anal and dorsal fins are slightly falcate (curved or hooked); pelvic fins are rounded; pectoral fins are long, falcate, and just reaching the bases of the pelvic fins in adult males. Adult females have shorter and pointed pectoral fins, usually not reaching the pelvic fin bases (Eisenhour 2004, pp. 13, 24, 29). Pectoral rays (2-10) are greatly thickened in large nuptial males, bearing rows of small, conical, antrorse (pointing forward) tubercles. Basal parts of rays bear 1-2 rows of tubercles. Females are without tubercles (Eisenhour 1999, p. 974).

2.2 INDIVIDUAL REQUIREMENTS

2.2.1 Microhabitat

Arkansas River shiner

Early studies indicated that the habitat of the Arkansas River shiner consisted of the main channels of wide, shallow, sandy bottomed rivers and larger streams of the Arkansas River basin (Moore 1944, p. 209). Adult Arkansas River shiners were uncommon in quiet pools or backwaters, and were almost never found in tributaries having deep water and bottoms of mud or stone (Lewis and Dalquest, 1955, p. 10; Cross 1967, p. 136). Cross (1967, p. 136) determined that adults typically oriented themselves into the current on the "lee" sides of transverse sand ridges and feed upon organisms that are washed downstream. Polivka and Matthews (1997, entire) found the environmental variables related to adult Arkansas River shiner presence in the South Canadian River in Oklahoma were the presence of sand ridges and mid-channel habitats, water depths of 0-20 in (0-50 centimeters (cm)), dissolved oxygen of 10-13 milligrams (mg)/liter (l), and relatively slow current speeds of 0-39 in/second (s) (0-39 in/s) (Polivka and Matthews 1997, entire). Microhabitat selection by Arkansas River shiners in the Canadian River of New Mexico and Texas included mean water depths between 6.6 and 8.3 in (17-21 cm) and relatively slow current velocities between 11.7 and 16.4 in/s (29.7-41.6 cm/s) (Wilde et al. 2000, pp. 5-15). Polivka and Matthews (1997, entire) found that juvenile Arkansas River shiners associated most strongly with the presence of backwater and island habitat types, slower currents, and lower conductivity (total dissolved solids).

Polivka and Matthews (1997, p. 7) found that the Arkansas River shiner in the South Canadian River of central Oklahoma, like most fishes occurring in the highly variable environments of plains streams, used a broad range of microhabitat features. Wilde et al. (2000) found no obvious selection for, or avoidance of, specific habitat types, including main channel, side channels, backwaters, and pools by Arkansas River shiners in the Canadian River of New Mexico and Texas. Arkansas River shiners did tend to select side channels and backwaters slightly more than expected based on the availability of these habitat types (Wilde et al. 2000, p. 39). Substrates in the Canadian River were predominantly sand; however, the Arkansas River shiner was observed to occur over silt slightly more than expected based on the availability of this substrate (Wilde et al. 2000, pp. 39-42). Marsh-Matthews and Matthews (2013) likewise failed to detect any habitat affinities within seine hauls made by the Service (in 2012-13) that contained Arkansas River shiners. These collections were made within a wide range of current, depth, and mesohabitat types, and the number of individuals within a given seine haul did not appear to be related to any specific feature of the habitat (Marsh-Matthews and Matthews 2013, p. 153). Results of their analysis from multiple collection data suggested that habitats available to Arkansas River shiners and other Canadian River fishes are highly related to river discharge. These results indicated that at times of seasonal high flow, Arkansas River shiners take advantage of a much wider variety of available microhabitat types. Conversely during seasonal low flows, their presence is positively associated with deeper shaded habitats, typically near shore, and in winter is positively associated with habitats with complex substrates and higher oxygen concentrations (Marsh-Matthews and Matthews 2013, pp. 154-155).

Edie Marsh-Matthews and William Matthews (pers. comm. July 15, 2018) suggest that Creek mouths where they connect with the observed variability in microhabitat selection is also related to historical Arkansas River shiner abundance as well as seasonality. In August 1976, Matthews collected 11,351 Arkansas River shiners (counted and released) in fewer than 100 seine hauls in the South Canadian River near Norman, Oklahoma. At that time the species was broadly distributed in flowing microhabitats or in larger rivers and shaded backwaters. In October 1976, he collected more than 4,000 Arkansas River shiners in similar sampling where the species was highly concentrated in backwater pools. Marsh-Matthews and Matthews suggests that conditions likely serve as refugia during sampling need to be taken into consideration and infers from their observations that when Arkansas River shiners were still very abundant they used a wide variety of habitats in summer but local habitat use was more restricted in winter. Thus, the drastic differences in abundance of Arkansas River shiners from study to study and seasonal variation need to be taken into account when assessing microhabitat preference shot, low flow periods.

Peppered chub

Habitat of the peppered chub also consists of the main channels of wide, shallow, sandy bottomed rivers and larger streams of the Arkansas River basin. In the Canadian River of New Mexico and Texas, peppered chubs were found to use main channel habitats above sandy substrate slightly more than expected based on availability of those habitat types (Wilde et al. 2000, p. 39). Adult peppered chubs prefer shallow channels where currents flow over clean fine sand (Cross & Collins 1995, p. 62; Collins et al. 1995, p. 45), avoid calm waters and silted stream bottoms, and appear more adapted for headwaters of streams than do other members of the (former) *M. aestivalis* complex (Layher and Brinkman 2005, p. 5). They typically select swifter currents than the Arkansas River shiner during winter, spring, and summer (Bonner 2000, p. 8), and tend to select a slightly greater proportion of habitats with cobble substrate during the spring and with gravel substrate during the summer (Bonner 2000, p. 17). In the Canadian River of New Mexico and Texas, peppered chubs generally occurred in deeper waters. However, peppered chub presence was not associated with specific water temperatures, dissolved oxygen concentration, conductivity, pH, or current velocity (Wilde et al. 2000, pp. 15-21). Layher and Brinkman (2005, p. 9) summarized information received from the Kansas Department of Wildlife and Parks, Environmental Services Division which revealed relationships between water chemistry and peppered chub densities. Differing somewhat from the findings of Bonner (2000), Layer and Brinkman found that peppered chubs appeared to prefer water temperatures around 20 °C (68 °F), and 5 mg/L dissolved oxygen appeared to be their minimum requirement. Peppered chubs were most often found in sites with pHs between 7.8 and 8.7, and appeared to prefer water with nitrate levels less than 4.0 mg/L. Peppered chub juvenile-specific habitat information is lacking, but they are assumed to share similar preferences shown by juvenile Arkansas River shiners.

2.2.2 Physiological Tolerances

Arkansas River shiner

Matthews (1987) classified several species of fishes, including the Arkansas River shiner, based on their tolerance for adverse conditions and selectivity for physicochemical gradients. The Arkansas River shiner was described as having a high thermal and oxygen tolerance, indicating a high capacity to tolerate elevated temperatures and low dissolved oxygen concentrations (Matthews 1987, p. 116). Observations from the Canadian River in New Mexico and Texas revealed that dissolved oxygen concentrations, conductivity, and pH rarely influenced habitat selection by the Arkansas River shiner (Wilde et al. 2000, pp. 5, 9). Arkansas River shiner specimens were collected over a wide range of conditions, including water temperatures from 0.39 to 36.78° Celsius (C) (32.7 to 98.2° Fahrenheit [F]), dissolved oxygen from 3.4 to 16.3 parts per million, conductivity (total dissolved solids) from 0.7 to 14.4 millisiemens (mS)/cm, and pH from 5.6 to 9.0 (Wilde et al. 2000, pp. 5, 9). Mueller (2013, p. 39) indicated that early life stages of the Arkansas River shiner were sensitive to total dissolved solids of greater than 1000 ppm (50 percent mortality in under 40h, usually under 10h). However, Marsh-Matthews and Matthews (2013, p. 46) reported collecting high relative abundances of adult shiners in samples with specific conductances of over 2000 µS/cm (approximately 1000 to 1400 ppm TDS). Within seine hauls made by USFWS (in 2012-13) that contained Arkansas River shiners, Marsh-Matthews and Matthews (2013) found that physiochemical measurements (temperature, oxygen concentration, pH, conductivity, depth, and current speed) made at approximately 50 transect points each month of survey showed a wide range of conditions, but none represented conditions directly harmful to fishes. Within and among transects in any given month, physical variables such as oxygen concentration, pH, or conductivity varied little, and heterogeneity in those traits was low at any given time (Marsh-Matthews and Matthews 2013, pp. 156).

Peppered chub

In the Canadian River of New Mexico and Texas, peppered chubs were found within a wide range of water temperatures, from 0.1-36.8° C (32.2-98.2° F), and in waters with dissolved oxygen from 3.7-16.3 ppm. Conductivity in locations with peppered chubs ranged from 0.7-14.2 mS/cm, and pH ranged from 5.6-9.0. Current velocities ranged from 0-189.0 cm/s, and depth ranged from 1.5-94 cm (Wilde et al. 2000, pp. 15-21). Research by Bonner and Wilde (2002) indicated a preference by peppered chubs for turbid water. They suggested that this is due to the peppered chub's ability to outcompete other fishes less adapted to foraging in turbid waters, as well as an advantage of predator avoidance (Bonner and Wilde 2002, p. 1206).

2.2.3 Feeding

Arkansas River shiner

The Arkansas River shiner is a generalized forager and feeds upon both items suspended in the water column and items lying on the substrate (Jimenez 1999, pp. 14-28; Bonner et al. 1997, p. 7). In the South Canadian River of central Oklahoma, Polivka and Matthews (1997, p. 7) found that gut contents were dominated by sand/sediment and detritus (decaying organic material). Invertebrate prey, although important, were an incidental component of the diet. In the South Canadian River of New Mexico and Texas, the diet of Arkansas River shiners was dominated by detritus, invertebrates, grass seeds, and sand and silt (Jimenez 1999, pp. 14-28). Invertebrates were the most important food item, followed by detrital material, when available. Terrestrial and semiaquatic invertebrates were consumed at higher levels than were aquatic invertebrates (Jimenez 1999, p. 17). With the exception of the winter season, when larval flies were consumed much more frequently than other aquatic invertebrates, no particular invertebrate taxa dominated the diet (Bonner et al. 1997, p. 7). In the nonnative population of the Arkansas River shiner inhabiting the Pecos River in New Mexico, fly larvae, copepods, immature mayflies, insect eggs, and seeds were the dominant items observed in the diet (Keith Gido, University of Oklahoma, *in litt.* 1997).

Peppered chub

Peppered chubs are generalist feeders that feed aggressively to fuel rapid growth (Bottrell et al. 1964, p. 398). Peppered chubs have evolved for feeding in highly turbid streams. Bonner and Wilde (2002) found that prey consumption by peppered chubs only decreased 21 percent over increasing turbidity (from 0 to 4000 nephelometric turbidity units (NTUs)). Comparatively, Arkansas River shiner (also tolerant of high turbidity) prey consumption decreased by 59 percent over the same gradient (Bonner and Wilde 2002, p. 1203). Peppered chubs have barbels, large olfactory lamellae, and taste buds covering their bodies, including their eyes (Bonner and Wilde 2002, p. 1206). These adaptations help them find prey in turbid waters where sight feeding is difficult. They feed primarily on larval insects, small crustaceans, immature aquatic insects, and plant material (Pflieger 1975 p. 138; Robison and Buchanan, 1988 p. 183; Wilde et al. 2001, p. 406-407). At about 10 days old, they begin to forage among sediments on the river bottom. They also sometimes rise to the top and hit the surface to dislodge food (held by surface tension) (Bottrell et al. 1964, p. 398). Wilde et al. (2001, p. 407) describes peppered chubs as feeding “at or near the substrate.” Pflieger (1975 p. 138) described their feeding as follows: they “swim slowly about with the pectoral fins widespread and the rather long barbels in contact with the bottom. Large quantities of sand are taken into the mouth, sorted for any food it may contain, and then ejected from the mouth and gill openings.”

2.3 POPULATION LEVEL REQUIREMENTS

The Arkansas River shiner was listed as a threatened species on November 23, 1998, based on reductions in the species' range and numbers due to habitat destruction and modification, stream dewatering, diversion of surface water, groundwater pumping, construction of impoundments, and water quality degradation (63 FR 64772). A final designation of critical habitat for this species was published on October 13, 2005. Within the critical habitat rule, the primary constituent elements required to provide for the physiological, behavioral, and ecological requirements of the Arkansas River shiner were found by the Service to include adequate spawning flows over sufficient distances, habitat for food organisms, appropriate water quality, a natural flow regime, rearing and juvenile habitat appropriate for growth and development to adulthood, and suitable habitat (e.g., sufficient flows and absence of barriers) to allow Arkansas River shiners to recolonize upstream habitats (69 FR 59863-59865). All of these factors involve water availability which, likewise with the peppered chub, is essential for all life functions. Both species' water needs for survival and reproduction are detailed within this and the following section.

2.3.1 Reproduction

Prairie stream fish such as the Arkansas River shiner and peppered chub are members of a reproductive guild that broadcast spawns semibuoyant eggs, which are kept suspended until hatching in flowing water. This reproductive strategy appears to be an adaptation to highly variable environments where stream flows are unpredictable and suspended sediments and shifting sand can cover eggs laid in nests or crevices (Bonner 2000, p. 35). Once saturated with water after spawning, semibuoyant eggs remain suspended in the water column as long as current is present. For peppered chub, fertilized eggs develop as they drift in the current and hatch 25-28 hours after fertilization. (Bottrell et al. 1964, p. 398; Robison and Buchanan 1988 p. 183). Bottrell et al. (1964, pp. 395, 397) found that captive raised peppered chub eggs hatched on average 25.5 hours after fertilization and "on the third day the young fish begins to swim with purposeful movements and to take food" (Bottrell et al. 1964, p. 397). For Arkansas River shiner, approximately 3 days elapse between the time of spawning and the time that the larvae are capable of horizontal movement. Therefore, under flowing water conditions, eggs and developing young are swept downstream from their parent locality (Moore 1944, pp. 211-212). Without stream flow, eggs sink to the bottom where they may be covered with silt and die (Platania and Altenbach 1998, p. 565). The duration of the drift stage (eggs and fry incapable of deliberate movement) is dependent on developmental rate, which is correlated with water temperature. However, the distance eggs and larvae are transported during the drift phase is dependent not only on rate of development but also on river morphology and water velocity during the 3-5 day period immediately after spawning (Platania and Altenbach 1998, p. 566). Specifics related to the reproductive strategies of the pelagic broadcast spawning Arkansas River shiner and peppered chub and their physical population requirements related to reproduction (stream flow, stream length and connectivity, channel complexity, etc.) are discussed further within this section.

2.3.1.1 Natural Flow Regime

Periodic high flows are essential for successful reproduction and recruitment for pelagic broadcast spawning fish such as the Arkansas River shiner and peppered chub. These natural pulses in flow also help maintain the natural wide, braided channel morphology representing the preferred habitat of both species. Main channel impoundments, tributary impoundments, and off-channel reservoirs alter the natural flow regime upon which entire river ecosystems are adapted (Poff et al. 1997, p. 772; Bunn and Arthington 2002, p. 492; Richter et al. 2003, p. 207). The components of the flow regime include the magnitude, frequency, duration, predictability, and rate of change of hydrologic conditions (Poff et al. 1997, p. 770). Impoundments often reduce the magnitude and frequency of high flows leading to channel stabilization and narrowing downstream, alter bank plant communities, restrict downstream transport of nutrients that support ecosystem development, and alter river substrate (Poff et al. 1997, pp. 773–777; Mammoliti 2002, pp. 223–224). Impoundments also trap streamflow, reducing the availability of water downstream and leading to more frequent lack of flow, channel drying, and pool isolation.

Arkansas River shiner

Cross (1970, p. 136) observed that adult Arkansas River shiners are uncommon in quiet pools or backwaters which lack streamflow and also observed that they typically orient themselves into the current on the "lee" sides of transverse sand ridges and feed upon organisms that are washed downstream, all of which require streamflow. Arkansas River shiners spawn multiple times during the spawning season, under a variety of flow regimes, from no flow to high flow (Bonner 2000, p. 34), but periods of flowing water are generally necessary for reproductive success. It is not known whether eggs spawned and hatched in isolated pools (without flow) survive (Wilde et al. 2000, p. 107). Therefore, minimal low flows may be important for maintaining population numbers as they allow for reproduction throughout the summer. Moore (1944 pp. 210-211) suggested that fast flow and reduced visibility (brought about by the increase in turbidity) help hide eggs from predators, and these environmental cues incite pregnant females to release their eggs. Platania and Altenbach (1999, p. 565) found that if discharge is insufficient to keep eggs afloat, they quickly sink where they are susceptible to being suffocated by shifting sediments. Polivka and Matthews (1997, p. 3) found that juvenile Arkansas River shiners associated most strongly with current and backwater and island habitat types and suggested that these preferences were correlated with predator avoidance.

Peppered chub

Peppered chubs deposit semi-buoyant eggs broadcast into strong currents when water temperatures reach 21°C, usually between May and August (Cross and Collins 1995, Robison and Buchanan 1988 p. 183; Bottrell et al 1964, p. 393). This provides sufficient oxygen for developing eggs in highly turbid streams. Fertilized eggs develop as they drift in the current, and hatch 25-28 hours after fertilization (Bottrell et al 1964, p. 398; Robison and Buchanan 1988 p. 183). Larval fish may require strong currents to keep them suspended in the water column until they are strong enough to leave the main channel (Wilde et al. 2000, p. 107). Little is known about the streamflow requirements of juvenile peppered chubs, but it is assumed to be similar to adult fish. Adult peppered chubs prefer shallow channels where currents flow over clean fine sand (Cross and Collins 1995 p. 62; Collins et al. 1995 p. 45), avoid calm waters and silted stream bottoms and are more adapted for headwaters of streams than other members of the *M. aestivalis* complex (Layher and Brinkman 2005, p. 5). Peppered chubs typically select swifter currents than the Arkansas River shiner during winter, spring, and summer (Bonner 2000, p. 8). Like the Arkansas River shiner, the peppered chub has been observed to spawn multiple times during the spawning season, under a variety of flow regimes, from no flow to high flow (Bonner 2000, p. 34), but periods of flowing water are essential for reproductive success. It is not known whether eggs spawned and hatched in isolated pools (without flow) survive (Wilde et al. 2000, p. 107). Therefore, minimal low flows may be important for maintaining population numbers as they allow for reproduction throughout the summer.

2.3.1.2 Stream Length

Platania and Altenbach (1998) estimated that for the broadcast-spawning cyprinid guild which includes the Arkansas River shiner and peppered chub, eggs could be transported 72-144 km (45-90 mi) before hatching and, depending on fry developmental rates, could be transported total distances as great as 216 km (134 mi) before becoming free-swimming juveniles. These estimates suggest that a substantial length of unimpounded river may be required for successful reproduction. They also speculated that the duration of the drift stage (egg and larvae) of broadcast-spawning cyprinids is dependent not only on the rate of development but also on river morphology and water velocity during the 3-5 day period immediately after spawning (Platania and Altenbach 1998 p. 566). Adequate stream length, as well as flow, is necessary to suspend eggs in the water column for a period of time until hatching to prevent them from quickly sinking where they are susceptible to being suffocated by shifting sediments (Platania and Altenbach 1999, p. 565). After hatching, adequate stream length likewise provides the extended flow time needed by larval fish, which may require strong currents to keep them suspended in the water column until they are capable of horizontal movement and strong enough to leave the main channel (Wilde et al. 2000, p. 107).

Perkin and Gido (2011, p 371) analyzed 60 river fragment lengths within the Great Plains and literature accounts of population status for eight pelagic spawning cyprinids (including Arkansas River shiner and peppered chub) within these fragments to derive thresholds in stream length associated with extirpations. For Arkansas River shiner, Perkin and Gido (2011 p. 374) found the estimated minimum threshold in stream fragment length associated with population persistence for Arkansas River shiner to be 217 km (~135 mi). Perkin and Gido (2011 p. 374) found the estimated minimum threshold in stream fragment length associated with population persistence for peppered chub to be 205 km (~127 mi).

2.3.1.3 Channel Complexity

The geomorphology of Great Plains streams was historically characterized by wide, braided channels with sand-dominated or clay beds (Matthews, 1988 p. 391; Worthington et al. (2014, entire). Today, various anthropogenic and natural factors have resulted in many smaller tributaries being dry for a large portion of the year and main river channels often restricted to a simple, narrow thalweg (channel centerline) (Woods et al., 2005, poster). Moore (1944, p. 213) first described the downstream drift of Arkansas River shiner eggs and proposed a relationship existed between elevated stream flow and the onset of spawning. In addition to flow, Worthington et al. (2014 entire) suggested downstream semi-buoyant egg drift is also related to habitat complexity and interspersion of habitat patches within the landscape. Bond et al. (2000, entire) illustrated that by adding fragmentation to the landscape and modifying flow and sediment behavior in a stochastic grid-based model, the potential movement distances of dispersing organisms were significantly altered. Too, the addition of obstacles and dead water zones into streams decreased the distances organisms drifted downstream, principally by causing them to move laterally more often, and also by creating crevices that could trap organisms. Changes in the natural flow regime and reduced complexity of rivers have potentially increased the length of channel required for ichthyoplankton to successfully reach the free swimming stage (Worthington et al. 2014, p. 6-7).

In the Great Plains, fragmentation linked to water supply reservoir construction has resulted in channel narrowing of braided downstream reaches, creating potential for increased particle transport rates (Worthington et al. 2014, p. 6). However, the effect of reduced discharge related to the presence of dams may somewhat offset the increased egg transport associated with this reduced habitat complexity (Worthington et al. 2014, p. 6). Slower transport rates in streams with wider and more braided channel morphology would allow more time for developing eggs and larva to reach their free swimming stage (Dudley and Platania 1999, p. 428). Using gellan beads as a semi-buoyant egg surrogate, Worthington et al. (2014 entire) highlighted the interaction between hydrology and geomorphology in influencing the distribution of downstream drifting gellan beads, and by extension, the eggs of pelagic broadcast spawning cyprinids. The study highlights how disturbance in the natural functioning of river systems, such as the balance between flow rates and channel morphology, is likely to have contributed to the decline of prairie fish species like the Arkansas River shiner and peppered chub.

2.3.2 Abundance

Secure populations require a minimum number of individuals to assure stability and persistence. This is often referred to as the minimum viable population and is generally calculated through a population viability analysis that estimates extinction risk given a number of input variables.

There are no published minimum viable population estimates for Arkansas River shiners or peppered chubs; therefore, it is unknown how many fish are required to sustain populations of these fish. Population estimates are difficult to assess for these wide ranging and mobile species. Numbers of individuals vary widely across river segment, season and year which is affected by ecological conditions and reproductive success of these short lived species. Therefore, measuring changes in long-term trends of abundance of these species or shifts in community structures (relative abundance) can serve as an indicator of population condition, particularly when comparing to historical estimates.

2.4 SPECIES LEVEL REQUIREMENTS

As discussed in Chapter 1, for the purpose of this assessment, we define **viability** as the ability of the species to sustain populations in the wild over time. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its **resiliency**, **representation, redundancy**, and (the 3Rs). Using various time frames and the current and projected levels of the 3Rs, we thereby describe the species' level of viability over time.

2.4.1 Resiliency

For the Arkansas River shiner and peppered chub to maintain viability, its populations or some portion thereof must be resilient. Resiliency is the ability of a population to respond to and recover from stochastic environmental disturbances and perturbations and stochastic demographic conditions. Environmental disturbances include events such as drying, flooding, and storms; perturbations include typical year-to-year variation in rainfall and temperatures. Demographic stochasticity includes random fluctuations in fertilization rates, egg development, or other processes. In short, resiliency is the ability of a population to recover from harsh years and stochastic events. To be resilient, the Arkansas River shiner and peppered chub must have self-sustaining populations; that is, populations that are able to sustain themselves through good and bad years. We detailed the requirements for a self-sustaining population above, in the *Population Level Requirements* section.

2.4.2 Representation

Representation is the ability of a species to adapt to long-term changes in its environment; in short, it is the evolutionary potential of a species. To maintain the evolutionary potential of the Arkansas River shiner and peppered chub, the adaptive genetic or ecological diversity and the evolutionary processes that drive adaptation need to be maintained. Generally speaking, this means the maintenance or creation of multiple populations within the species' historical ranges, and the maintenance or creation of historical patterns of gene flow. In order to maintain genetic diversity over time, both the Arkansas River shiner and the peppered chub require multiple populations and some level of connectivity between these populations to allow for the flow of genetic material.

Given the above, the breadth of adaptive diversity can be captured by a wide distribution of geographically diverse regions (termed resiliency units) identified and described further in the *Current Conditions* section.

2.4.3. Redundancy

Redundancy is the ability of a species to withstand and recover from catastrophic events; it is about spreading risk of a catastrophic event, such as a major drying event or flood, among multiple populations. Spreading the risk entails having multiple populations with a sufficient spatial distribution to minimize the overlap between populations and catastrophic events. The greater the number of resilient populations of a species, the more likely the species can withstand catastrophic events. The Arkansas River shiner and peppered chub require multiple self-sustaining populations distributed across their respective ranges to maintain or create redundancy.

2.4.4. Summary

The species-level needs for long-term viability of the Arkansas River shiner and peppered chub require multiple (redundancy), genetically or ecologically diverse (representation), self-sustaining populations (resiliency) within the historical ranges of these species.

CHAPTER 3 – INFLUENCES ON VIABILITY

In this chapter we evaluate the past, current, and future influences that are currently affecting or may affect in the future the resource needs necessary for long term viability of the Arkansas River shiner (*Notropis girardi*) and peppered chub (*Macrhybopsis tetranema*). We analyzed these influences in terms of causes and effects to the species by assessing the pathways by which each influence affects the species, and each of the causes is examined for its historical, current, and potential future effects on the species' status. We organized these influences around the stressors (i.e., changes in the resources needed by the Arkansas River shiner and peppered chub) and discuss the sources of those stressors. In general, stressors will be discussed as affecting both species similarly, unless otherwise noted. The most important stressors are related to loss of the specific water resources that individuals and populations need to complete their life history.

Stressors affecting the viability of the Arkansas River shiner and peppered chub discussed in this section include altered flow regimes, including discussion of impoundments, groundwater losses, and impacts of climate; stream fragmentation; modified geomorphology; decreased water quality; introduction of invasive species; and the physical removal of fish or direct mortality. The source of many of these stressors is primarily related to the construction of dams and impoundments (a body of water confined within an enclosure) which alter streamflows and fragment streams. Additional sources of stressors include groundwater withdrawals, development, invasive vegetation, weather conditions affected by large-scale climate, commercial bait fish harvesting, and off road vehicle use within habitat. Many of these stressors and their sources discussed in the following sections are highly interrelated as illustrated in the Influence Diagram depicted in Figure 3-1.

The analysis summarized in this SSA report concentrates on current stressors and their sources affecting the biological status of the Arkansas River shiner and peppered chub. Because the range of both species has contracted, we focused on and summarize the stressors documented in the South Canadian River basin, where these species have been most recently and thoroughly observed. Although the effects of the stressors on the Arkansas River shiner and peppered chub are considered primarily from the South Canadian River basin (except where specifically stated otherwise), we expect that nearly all of the stressors have occurred within the other historically occupied river basins and stream reaches, given the terrain and land use practices in those areas. We also expect that the response of the Arkansas River shiner and peppered chub in those other areas would be and has been similar to those discussed below.

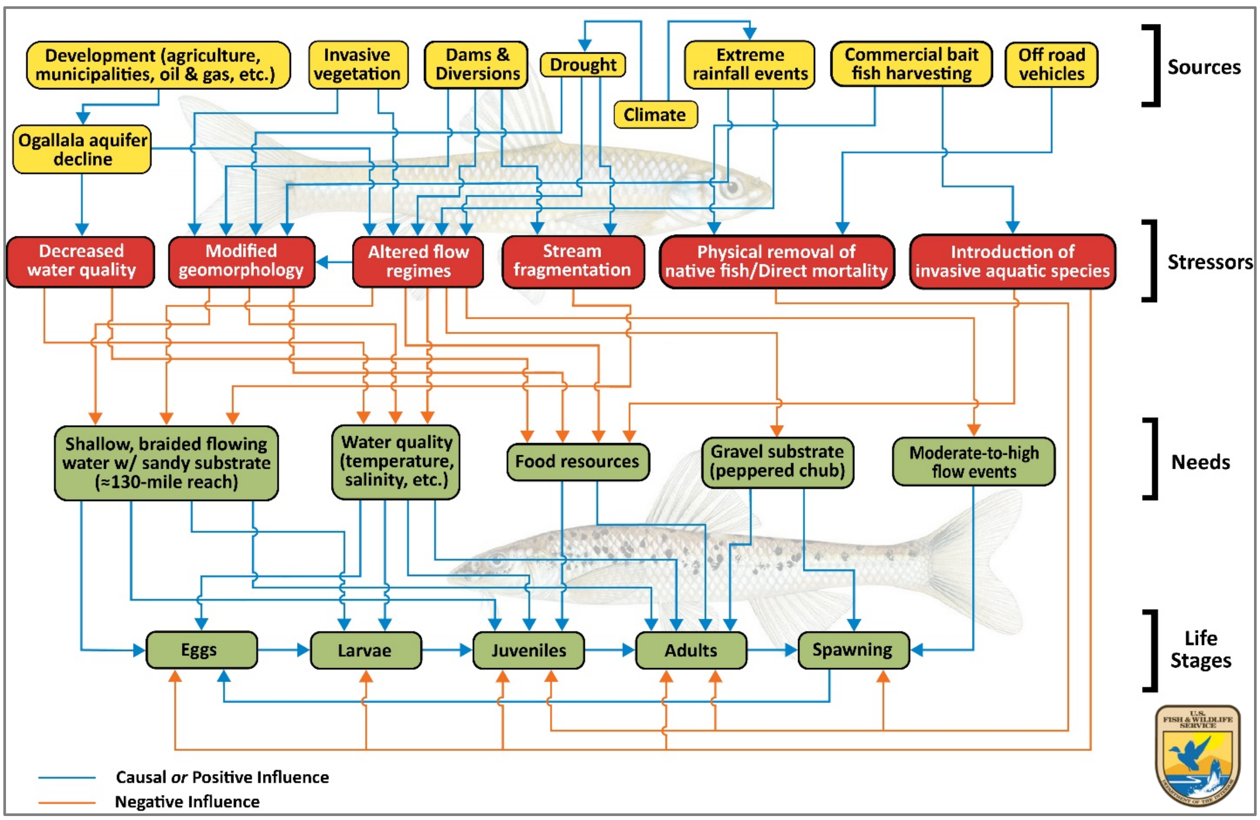


Figure 3-1. Arkansas River shiner/peppered chub influence diagram

3.1. ALTERED FLOW REGIMES

Arkansas River shiners and peppered chubs need flowing water in order to maintain viable populations. Low flow events (including isolated pooling) and inundation can impair or eliminate appropriate habitat for both species, and while adults of each species are adapted and can typically survive these events for a short time, populations that experience these events regularly face compromised reproduction and may not persist (See Chapter 2 - Species Biology and Resource Needs).

3.1.1 Water Impoundments

Demand for water in the Arkansas River drainage has led to the construction of at least 50 major reservoirs in Arkansas, Colorado, Kansas, New Mexico, Oklahoma, and Texas (Bonner & Wilde 2000, p. 189). Impoundments and fragmentation of streams have altered the timing, duration and magnitude of flows throughout the Arkansas River basin. Barriers to fish movement have acted as a ratcheting mechanism (irreversible by natural process) contributing to local extirpations (Perkin et al. 2017, p. 7374). Arkansas River shiner and peppered chub have been functionally extirpated from 83 percent and 94 percent of their respective range (63 FR 64772; Luttrell et al. 1999, p. 981; as analyzed in Chapter 4 of this report). The decline in distribution of both species in the past is the result of stream fragmentation, stream dewatering, habitat degradation and altered stream flow and dynamics. Inundation (formation of lakes and smaller lentic habitats) has primarily occurred upstream of dams, both large (such as Ute, Sanford, and Eufaula Dams on the South Canadian River) and small (watershed dams for flood control, low water crossings, diversion dams, etc.). Inundation causes an increase in sediment deposition; deep, colder water often devoid of oxygen and necessary nutrients; and proliferation of predator species which prefer deep water habitats. The negative effects of impoundments on riverine systems, including changed temperature regimes, flow regimes, substrates, sedimentation, water quality, channel morphology, and nutrient availability, and their action as barriers to fish passage, are well documented (Bonner and Wilde 2000, p. 189; Schrank et al. 2001, p. 419; Bunn and Arthington 2002, p. 495; Eberle et al. 2002, p. 186; Mammoliti 2002, pp. 223–226; Quist et al. 2005, p. 53; Dudley and Platania 2007, p. 2081; Suttkus and Mettee 2009, p. 3; Perkin et al. 2010, p. 2; Perkin and Gido 2011, pp. 379–380).

Main channel impoundments, tributary impoundments, and off-channel reservoirs alter the natural flow regime upon which the entire river ecosystem is adapted (Poff et al. 1997, p. 772; Bunn and Arthington 2002, p. 492; Richter et al. 2003, p. 207). The components of the flow regime include the magnitude, frequency, duration, predictability, and rate of change of hydrologic conditions (Poff et al. 1997, p. 770). The consequences of impoundments on both upstream and downstream fish assemblages are well documented in many river systems. In the Solomon River basin of Kansas, Eberle et al. (2002, p. 188) discovered that the plains minnow (*Hybognathus placitus*) has been extirpated due to conversion of sandy, braided channels to non-sandy, narrow channels following impoundment. The authors also found that 18 fish species were introduced or immigrated into the altered system, where increased competition from non-native species may have contributed to the decline of native fish species (Eberle et al. 2002, p. 182). In the South Canadian River in Texas, the plains minnow and Arkansas River shiner comprised approximately 96 percent of the fish assemblage prior to impoundment of Lake Meredith and less than 1 percent downstream of the dam after impoundment (Bonner and Wilde 2000, pp. 192–193). At least two other cyprinid species, including the peppered chub, have disappeared downstream of Lake Meredith, while two other species have become much more common and now dominate the assemblage (Bonner and Wilde 2000, p. 193). These examples illustrate the effects impoundments can have on fish species assemblages, including broadcast-spawning minnows native to prairie streams and their potential replacement by other species.

Reduced water velocities upstream from impoundments increase the likelihood of the establishment of new species or increased abundance of existing species more adapted to the lentic (no flow or still waters) environment (Poff et al. 1997, p. 776). Lentic fish species are often top predators and can have negative impacts on smaller, riverine species (Poff et al. 1997, p. 777; Mammoliti 2002, p. 223). Downstream flood frequencies are also altered by impoundments. Prior to the completion of Ute Dam in 1963, the flow at the downstream gage (USGS Station Number 07227000) having a 10-year recurrence interval was 2,461 cubic meter per second (cms) (86,920 cubic feet per second (cfs)). After completion of the dam, the flow with this recurrence interval was only 73 cms (2,584 cfs), a 97.0 percent reduction. Mean flow at this gage prior to impoundment was 8.5 cms (299 cfs); after impoundment mean flow dropped to 0.9 cms (32.7 cfs), an 89.1 percent decrease.

Similarly, before Sanford Dam formed Lake Meredith in 1965, the flow at the downstream gage near Canadian, Texas (USGS Station Number 07228000) having a 10-year recurrence interval was 2,371 cms (83,730 cfs). Following completion of the dam, the flow with the same recurrence interval fell to only 427.6 cms (15,100 cfs), an 82 percent reduction. Mean flow at this gage before impoundment was 15.5 cms (548 cfs). Subsequent to impoundment, mean flow was reduced to 2.2 cms (77.1 cfs), an 85.9 percent decline. The shifts in flood frequencies and annual mean discharges appear to favor fish adapted to less variable flows over obligate riverine broadcast-spawners, such as the Arkansas River shiner and peppered chub.

The loss of seasonal peak flows disrupts spawning and larval development (Poff et al. 1997, p. 776), which is of concern for broadcast spawning fish such as the Arkansas River shiner and peppered chub. Virtually every broadcast spawning fish endemic to the Great Plains has been affected by habitat fragmentation and stream dewatering. Arkansas River shiners and peppered chubs suffer direct mortality to all life stages when rivers dry. No flow conditions may result in the disruption of spawning when adults are trapped in isolated pools within intermittent reaches, and poor recruitment of juveniles when habitat required for larvae and juveniles is limited or lacking.

3.1.2 Groundwater Losses

Groundwater underlies much of the earth's surface, and in many places it is in direct contact with surface-water bodies (Winter 2007, p. 23). Most streams require some contribution from groundwater to provide reliable habitat for aquatic organisms (Winter 2007, p. 15). Although drought is a naturally occurring phenomenon in Great Plains streams, overexploitation of groundwater resources has contributed to a permanent decline in streamflow and the subsequent loss of pelagic broadcast spawning fishes in streams that are decoupled from aquifers because of groundwater depletion (Perkin et al. 2017, p. 7374). Modeling by Perkin et al. (2017) provided evidence that ground water pumping over the past half-century has caused declines of stream length within the Great Plains. This decline in prevalence of lengthy steams, confounded by the concurrent increase in impoundments, coincided with a decline in fish species that require longer stream lengths, and has greatly altered fish assemblages (Perkin et al. 2017, p. 7375-7376).

In the United States, the biggest uses of water from aquifers include agricultural irrigation and oil and coal extraction (Zabarenko May 20, 2013). Where not governed by a groundwater conservation district, Texas is the only western state that generally allows landowners to remove as much groundwater from beneath their land as is possible without liability (TWDB 2017, p. 122). In the South Canadian River basin/area, groundwater extraction for oil and gas activities in combination with drought is likely to result in reduced stream flow in the future. Future water withdrawals from aquifers that support spring flows in the range of the Arkansas River shiner and peppered chub will likely result in further reduction of critical surface flows and river drying.

The High Plains/Ogallala Aquifer underlies 111.8 million acres (about 175,000 square miles) in parts of eight States, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Heavy use of this aquifer for cropland irrigation began in the 1950s and continues today (Figure 3-2). Throughout much of the aquifer, groundwater withdrawals exceed the amount of recharge, and water levels have declined fairly consistently through time. Although water level declines in excess of 300 feet have occurred in several areas over the last 50 to 60 years, the rate of decline has slowed, and water levels have risen in a few areas (TWDB 2018).

Since 1987, the U.S. Geological Survey, in collaboration with numerous State, local, and Federal water-resources entities, has compiled water levels from wells completed in the High Plains aquifer. Water levels were measured in 8,327 wells for 2013 and in 8,307 wells for 2015. McGuire (2017) report present water-level changes in the High Plains aquifer from predevelopment (about 1950 to 2015). The water levels used for the analysis generally were measured in winter or early spring, when irrigation wells typically were not pumping, and after water levels generally had recovered from pumping during the previous irrigation season. The map of water-level changes in the High Plains aquifer, predevelopment to 2015 (Figure 1), is based on water levels from 3,164 wells (McGuire 2017).

Future groundwater depletion may further reduce surface flows of the South Canadian River basin by reducing groundwater contribution to surface flows. A reduction in surface flows also has implications for water quality, since less water is available to dilute potentially harmful pollutants (discussed further in Section 3.4). Under more extreme cases of groundwater withdrawal, groundwater levels may be lowered to the point where South Canadian River surface water may infiltrate the river bed and recharge groundwater supplies, further reducing surface water flows. Although groundwater conservation districts manage groundwater resources within their jurisdictional boundaries to ensure that groundwater will be available for future users, the 2017 Texas State Water Plan indicates statewide groundwater supplies are projected to decrease up to 24 percent by 2070, primarily due to depletion of the Ogallala Aquifer (TWDB 2017, p. 71).

Another source of groundwater depletion within the species range is the U.S. Bureau of Reclamation's Lake Meredith Salinity Control Project. Soon after its completion and water use from Lake Meredith began, a generally increasing trend of chloride (salt) concentration was observed, with drought cycles producing chloride contents up to 1500 mg/L in Lake Meredith. Federal Drinking Water Standards recommend maximum chloride contents in drinking water of 250 mg/L and State standards are 300 mg/L. The change in water supply from less saline groundwater was extremely objectionable to some citizens. Beginning in 1969, the Canadian River Municipal Water Authority and other agencies sought to identify the source of the salt water and to determine whether or not water quality in Lake Meredith could be improved. An area in New Mexico just downstream from Ute Dam near Logan was early identified as being a major contributor of salt water to the Canadian River System. Studies by the Bureau of Reclamation and consultants indicated that about 70 percent of the chlorides reaching Lake Meredith originate in this localized area, filtering into the river channel from a shallow brine aquifer which is under artesian pressure. Water in the brine aquifer is roughly as salty as seawater. As a solution, the Lake Meredith Salinity Control Project funded by the State of Texas, Federal Government, and the Canadian River Municipal Water Authority installed wells to pump water from the brine aquifer to reduce the artesian pressure and reduce the introduction of salt into the Canadian River. An injection well then disposes of the saline water approximately 3,000 feet below ground surface. Operation began in September 2001 (CRMWA, 2018).

Chloride control projects such as this may lead to changes in flow regime and water quality. These highly saline flows are natural in the region. Native prairie stream fishes have evolved under these conditions and are uniquely adapted for life in these harsh aquatic ecosystems. Changes in salinity levels can promote colonization (invasion) by generalist species, which may compete with the specialist prairie stream fishes for limited resources (TPWD 2005, p. 275-276). The interception of brine flows can also significantly reduce the base flows of the Canadian River. A pre-construction Environmental Assessment conducted for the project estimated that it would reduce the assumed base flow of 4 cfs below Ute Reservoir by an average of 1.4 cfs (35 percent). This would equate to a 12 to 14 percent reduction in base flow below the confluence of the Canadian River with Revuelto Creek (Bureau of Reclamation 1995, p. 19). This reduction in flow affects nearly all habitat currently occupied by the peppered chub, as well as the portion of occupied habitat in which Arkansas River shiners are most abundant.

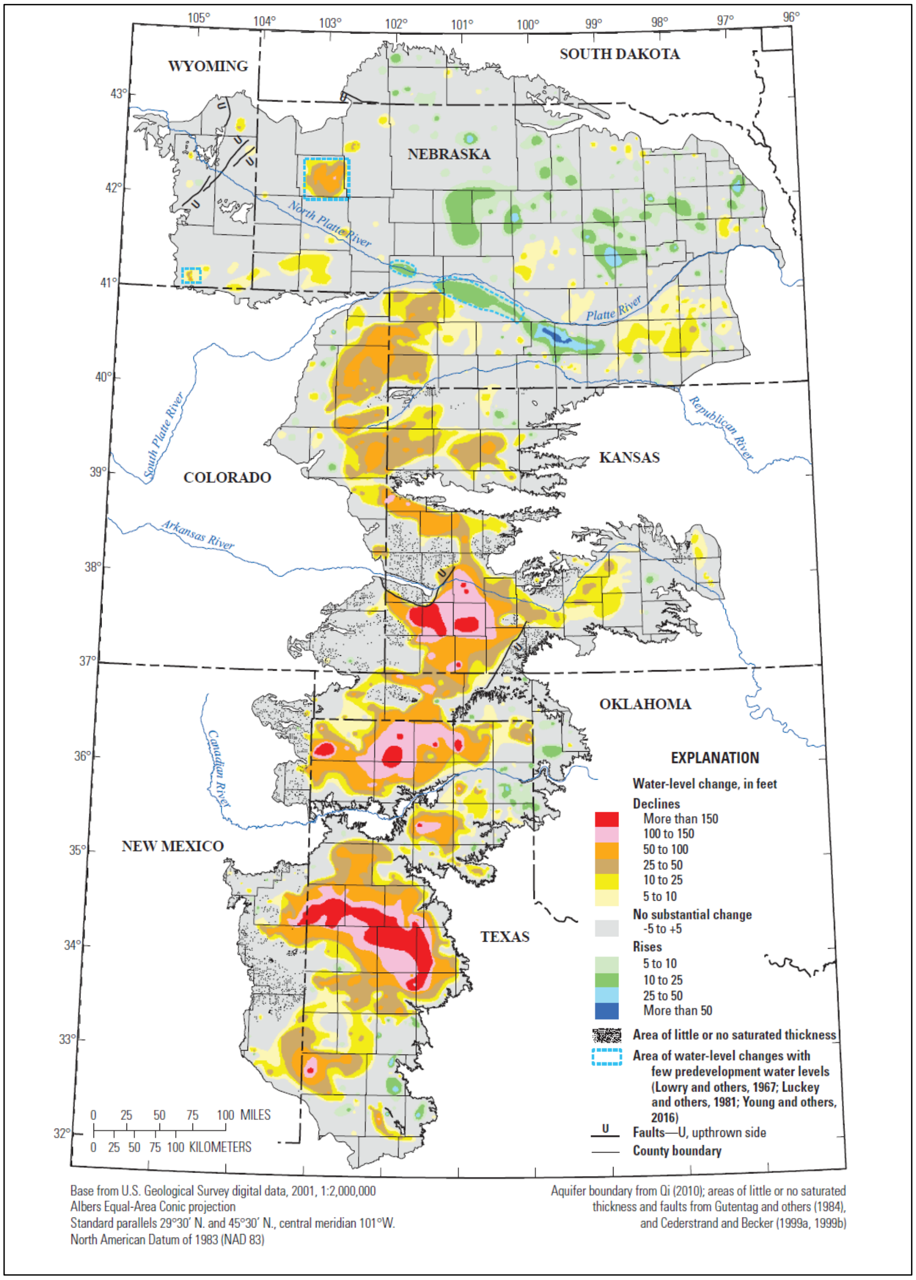


Figure 3-2. Water level changes in the High Plains aquifer, predevelopment (about 1950) to 2015.

Increasing withdrawals from aquifers may have significant effects to the availability of surface water across the range of the Arkansas River shiner and peppered chub. Groundwater withdrawal is anticipated to continue to decrease surface water flow and volume at levels that will likely further impair the reproductive output of Arkansas River shiners and peppered chubs at the individual, population, and species level. In Great Plains streams, the extinction probability of fishes at a given site increases significantly from drought when that site is not fed by groundwater (Falke et al. 2012, p. 865, Perkin et al. 2017, p. 4).

3.1.3 Climate Effects on Precipitation and Drought

Scientific measurements spanning several decades demonstrate that changes in climate are occurring and that the rate of change has been faster since the 1950s. Examples include warming of the global climate system overall and substantial changes in precipitation in some regions of the world, including increases in extreme drought and flood events. (For these and other examples, see IPCC 2014, pp. 7, 40-54). The main scientific measure of climate change, the earth's average annual temperature (the surface air temperature above land and oceans), shows clear evidence of the change since modern recordkeeping began in 1880 (Figure 3-3).

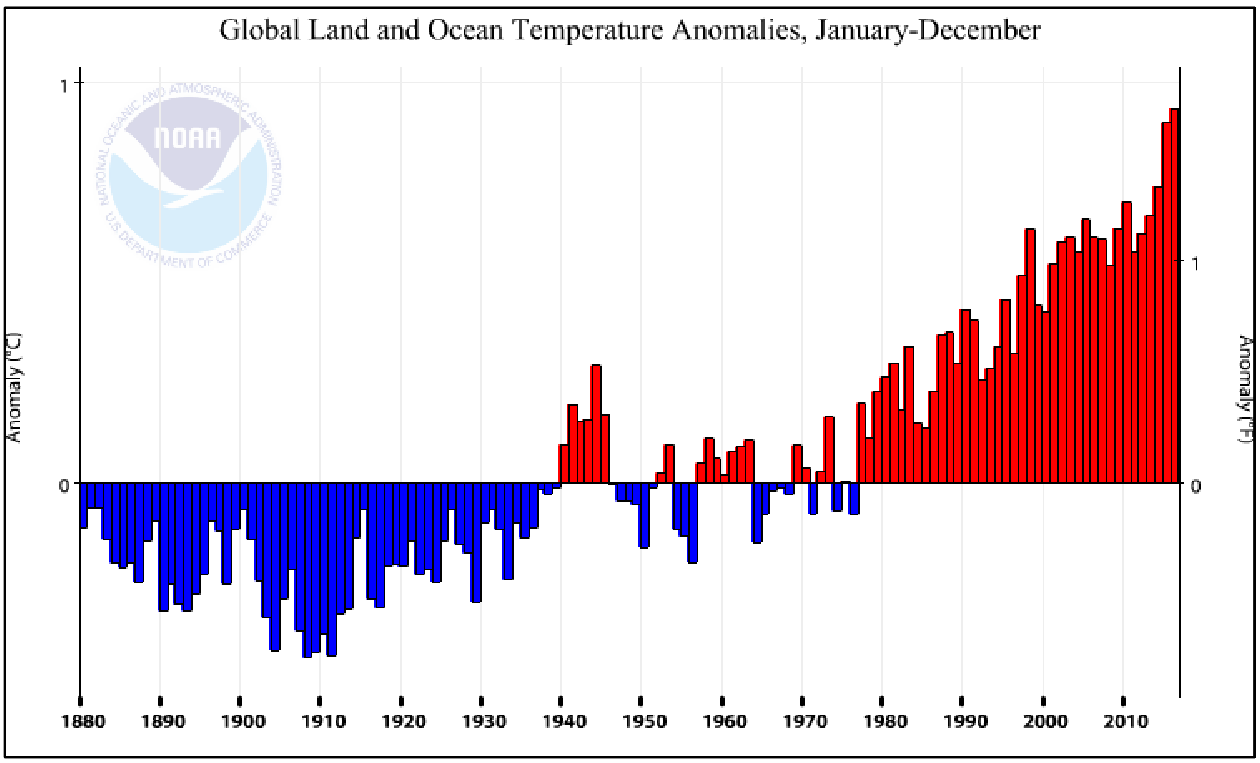


Figure 3-3. Change ("anomaly") in average annual global mean temperature (°C left axis, °F right axis), 1880 – 2016, relative to average for the 20th century. Source: NOAA https://www.ncdc.noaa.gov/cag/time-series/global

Two key points of evident in Figure 3-3 are: (1) the average annual temperature varies, i.e., each year is not necessarily warmer than the last; and (2) despite the variability, a clear warming trend is evident. Building on scientific data and analyses provided by the Intergovernmental Panel on

Climate Change (IPCC), the most recent (2014) assessment by the IPCC concluded: "*Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.*" (IPCC 2014, p. 2). A similar conclusion was stated in the Third National Climate Assessment: "*Global climate is changing and this is apparent across a wide range of observations*." (Melillo et al. 2014, p. 18)

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of greenhouse gas emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (e.g., Meehl et al. 2007, entire; Ganguly et al. 2009, pp. 11555, 15558; Prinn et al. 2011, pp. 527, 529; Flato et al. 2013, entire). All combinations of models and emissions scenarios yield very similar projections of increases in the most common measure of climate change, average global surface temperature, over the near term (2016 – 2035), until about 2030 – 2040 (Kirtman et al. 2013, pp. 955-956, 978-982,1009-1012 including Fig. 11.25). Although projections of the intensity and rate of warming begin to differ under different scenarios after about 2030, the overall trajectory of all the projections is one of an increased warming trend through the end of this century, even for the projections based on scenarios that assume that the rate of greenhouse gas emissions will decline and their concentrations in the atmosphere will stabilize (RCP 4.5 and RCP 6.0) or decline (RCP 2.6) (Collins et al. 2013, pp. 1054-1058, including Tables 12.2 and 12.3).

Within the Great Plains, average temperatures have increased, and projections indicate this trend will continue over this century (Shafer et al. 2014, pp. 442-445). Future precipitation is much more challenging to model, and therefore projections of it have more uncertainty as compared to temperature. Precipitation within the southern portion of the Great Plains is expected to decline, with extreme events such as heat waves, sustained droughts, and heavy rainfall becoming more frequent (Shafer et al. 2014, p. 445, Fig. 19.4; Walsh et al. 2014, pp. 28-40). Seager et al. (2007, pp. 1181, 1183–1184) suggests that 'dust bowl' conditions of the 1930s could be the new climatology of the American Southwest, with future droughts being much more extreme than most droughts on record. More recently, Cook et al. (2015, entire) described the past history of repeated drought in the absence of changing climate, and projected a substantial increase in the risk of drought in the southwest and central plains under both moderate and high future emissions scenarios used for current climate change modeling, exceeding droughts observed during the last millennium. Other modeling also projects changes in precipitation in North American through the end of this century, including an increase in dry conditions throughout the central Great Plains (Swain and Hayhoe 2015, entire). Future droughts will increase competition for water between ecological needs and consumptive uses such as agriculture and industry. Döll et al. (2009, entire) projects that the combination of reservoirs and water withdrawals will have a disproportionately negative effect on annual river discharges in several locations across the globe, including the central and western United States. Already, drought and decreased reservoir releases have caused the once continuously flowing Kiamichi River in South Oklahoma to shift to a series of shallow, isolated pools with water temperatures exceeding 40°C (104°F) (Galbraith et al. 2010, p. 1175).

Climate may have direct or indirect effects on species. These effects may be positive, neutral, or negative, and may change over time, depending on the species and other relevant considerations, such as interactions of climate with other variables. Examples of possible results include habitat fragmentation, alterations in key vegetation in response to temperature or other climate-related changes such as expansion of invasive species, or changes in types or abundance of competing species, predators, or prey (Settele et al. 2014, pp. 274–275, 278–19). The life history characteristics of many species are closely connected with climate conditions, e.g., thermal tolerances during certain stages of the life cycle. Accordingly, many climate scientists have expected that numerous species will shift their geographical distributions in response to warming of the climate (e.g., McLaughlin et al. 2002, p. 6070). Populations occurring in fragmented habitats can be more vulnerable to effects of climate change and other threats, particularly for species with limited dispersal abilities (McLaughlin et al. 2002, p. 6074). Fish species occurring in fragmented habitats such as the Arkansas River shiner and peppered chub are especially vulnerable to this stressor due to their virtual inability to shift their ranges in response to changing conditions in habitat quality and availability.

If species are unable to shift their ranges in response to changing conditions, they must adapt to those new conditions in order to persist. The adaptive capacity of species is considered to have three main components (Beever et al. 2016, p. 132): (1) evolutionary adaptive capacity (i.e., the ability to evolve, via genetic changes); (2) dispersal ability, which may involve highly localized to long-distance movements to locations where conditions are within the range of what the species can tolerate; and (3) and phenotypic plasticity, a term that generally refers to behavior adjustments. Each of these components would appear to be challenging to the Arkansas River shiner and peppered chub due to their small numbers of populations (and likely compromised genetic diversity as a species), virtually non-existent dispersal ability, and probable difficulty in behavioral changes which also accommodate their specialized life cycles.

As flows decline due to impoundments, drought, or groundwater lowering from pumping, habitat for the Arkansas River shiner and peppered chub is altered, reduced, and could eventually cease to exist. While Arkansas River shiners and peppered chubs may survive periods of low flow, as low flows persist, they face oxygen deprivation, increased water temperature, and, ultimately, stranding, reducing survivorship, reproduction, and recruitment in the population.

3.2. STREAM FRAGMENTATION

3.2.1 Physical Structures Affecting Stream Connectivity

Dams fragment habitat and create physical barriers to the movement of fish. Although free-swimming fish and early life-history stages would likely be capable of passing downstream through small fish barriers such as weirs (low dams built to raise the level of water upstream), low-water crossings, and natural or manmade falls, adults and larval stages of Arkansas River shiners and peppered chubs are not likely capable of passing downstream through most reservoirs large enough to act as water supply or hydroelectric sources. Likewise, due to the small size and limited swimming ability of these species, upstream movement of adults would likely be prohibited by nearly any fish barrier including impoundments (regardless of type or function), weirs, falls, pipeline reinforcements structures, and some low-water crossings. Even in the event ichthyoplanktonic stages of either species are capable of passing over a fish barrier, existing adult fish typically remain isolated below the barrier, unable to return to spawning areas upstream and prohibiting successive reproductive efforts. Because of their reproductive need for unimpounded flowing water, both species have been eliminated from short fragments and typically persist only in river segments that are at a minimum of 217 river kilometers (km) (135 miles (mi)) in length for Arkansas River shiner, and 205 river km (127 mi) in length for peppered chub (Perkin and Gido 2011, p. 374). The blocking of movement of adult fish also limits their ability to seek suitable habitat during drought conditions.

Alo and Turner (2005, pp. 1144–1146) attribute river fragmentation and associated loss of reproductive effort to downstream fish migration barriers (either through mortality or emigration) as a key factor reducing effective population size in the Rio Grande silvery minnow (*Hybognathus amarus,* another pelagic broadcast spawning fish), potentially leading to loss of genetic diversity and increased potential for extirpation. Bestgen and Platania (1991, pp. 227–228) found that Rio Grande silvery minnows were restricted to a 186-km (116 mi) reach of the Rio Grande River between 1986 and 1989 and that fish were most abundant downstream of diversion dams in this stretch of river. Rio Grande silvery minnows were less abundant in upstream portions of this reach, indicating reproductive output passed over diversion dams (Bestgen and Platania 1991, pp. 228), and adults were later unable to migrate back upstream, thereby increasing in abundance just below diversion dams. Bestgen and Platania argue (1991, p. 230) that habitat below diversion dams is an important refugium for fish during periods of low flow, but the impediment to upstream migration caused by these diversion dams has a negative impact on population persistence that likely outweighs any positive aspect of refugium creation. The lifespan of Arkansas River shiners and peppered chubs are short enough that two or more successive years of isolation (especially during peak reproductive season) in segments substantially shorter than the estimated 217 and 205 (respectively) river km (135 and 127 mi) required for population sustainment would likely lead to extirpation of that population (Perkin and Gido 2011, p. 374).

3.3. MODIFIED GEOMORPHOLOGY

3.3.1. Effects from Impoundments

Decreases in stream flows in the South Canadian River contribute to the loss of wide, shallow sand bed river channels characteristic of Arkansas River shiner and peppered chub habitat. Impoundments often reduce the magnitude and frequency of high flows leading to channel stabilization and narrowing downstream, alter bank plant communities, restrict downstream transport of nutrients that support ecosystem development, and alter river substrate (Poff et al. 1997, pp. 773–777; Mammoliti 2002, pp. 223–224). Impoundments also trap streamflow, reducing the availability of water downstream leading to more frequent lack of flow, channel drying, pool isolation, and vegetative encroachment. Reduction in flows of occupied habitat reduces reproductive success in both of these species and decreases their viability. As mentioned in Section 3.1., Eberle et al. (2002, p. 188) discovered that the plains minnow in the Solomon River basin of Kansas has been extirpated due to conversion of sandy, braided channels to non-sandy, narrow channels following impoundment.

Another alteration of the normal hydrologic regime occurs when dams release sediment-free water downstream that alters the composition of the river substrate. River and stream water velocity slows rapidly where water enters the standing water of reservoirs, resulting in the settlement of suspended sediment within the reservoir (Poff et al. 1997, p. 773). The resulting release of lower turbidity, high-velocity water from dams may scour the substrate downstream, causing the channel to incise and become further removed from its natural floodplain while removing sand, and to a lesser extent gravel substrate preferred by Arkansas River shiner and peppered chub. Additionally, decreased turbidity provides a competitive advantage to fishes that are not as well adapted to the naturally turbid water. Bonner and Wilde (2002, p. 1205) found that fish adapted to the naturally turbid conditions of the Canadian River are displaced by less-adapted fish that have a competitive advantage in less turbid water released from a main channel reservoir.

Reservoirs that are created upstream of dams also drastically alter the riverine habitat. The conversion of shallow lotic (flowing) habitat to deeper lentic habitat negatively affects species adapted to flowing riverine systems. Arkansas River shiners and peppered chubs, like other fish poorly adapted to lentic conditions, would likely experience increased mortality from large piscivorous (fish-eating predators) fish in reservoirs (Winston et al. 1991, p. 103). Also, as previously discussed, these species spawn via semi-buoyant eggs and experience free-floating developmental stages that will settle to the bottom of lentic habitats and be smothered by sediment or predated upon by bottom-dwelling organisms. As such, reservoirs likely act as a sink and reproductive trap for upstream populations (Pringle 1997, pp. 427–428), and no populations of either Arkansas River shiner or peppered chub are known to be capable of sustaining population growth through successful reproduction in reservoirs.

3.4. WATER QUALITY

Water quality suitability is necessary for a healthy aquatic community, and may be impaired through contamination or alteration of water chemistry. Chemicals enter the environment through both point and nonpoint discharges including spills, industrial sources, municipal effluents, and agricultural runoff. These sources may contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. An additional type of water quality impairment is alteration of water quality parameters such as dissolved oxygen, temperature, and salinity levels. Dissolved oxygen levels may be reduced from increased nutrients in the water column from runoff or wastewater effluent. Increased water temperature from climate change and from low flows during drought can exacerbate low dissolved oxygen levels, especially when reduced flows strand fish in isolated pools. Similarly, fish stranded in isolated pools can be subjected to concentrated salinity. As the saline water emerges from the ground, it is diluted by surface flow. As surface flow decreases, however, the concentration of salinity in the river increases. Additionally, aquifers have become increasingly saline due to salinized water recharge (Hoagstrom 2009, p. 35). Irrigation return flows exacerbate salinity levels as salts build up on irrigated land and then are washed into the watershed.

Multiple land use practices and resulting sources of pollution can potentially impact surface water quality. These may include runoff from irrigated cropland, concentrated animal feeding operations (CAFOs), leaching from municipal solid waste sites, and stormwater runoff from urban areas from either point or non-point pollution sources. Point sources include discharges such as municipal or industrial wastewater, while nonpoint source pollution results from varying sources such as stormwater runoff, atmospheric deposition of mercury from coal-fired power plants, or pesticide drift from croplands. Nonpoint source pollution resulting in nutrient loading of receiving waters has been suggested to be one of the leading threats to freshwater aquatic ecosystems in the United States (Richter et al. 1997, p. 1090).

3.5. INTRODUCTION OF INVASIVE SPECIES

The alteration of the hydrologic regime and geomorphology of rivers resulting from impoundments can cause the proliferation of larger, piscivorous fish not normally associated with unimpounded prairie streams. This fish community conversion is exacerbated by the transfer or stocking of game species in these areas. These species may include smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides salmoides*), Florida largemouth bass (*Micropterus salmoides floridanus*), striped bass (*Morone saxatilis*), and channel catfish (*Ictalurus punctatus*) (Howell and Mauk 2011, pp. 11–12) which may predate upon Arkansas River shiners or peppered chubs as they come into contact with lentic environments within and upstream of impoundments. As mentioned previously, Eberle et al. (2002, p. 188) found that 18 fish species were introduced or immigrated into the Solomon River basin system following impoundment, where increased competition from non-native species may have contributed to the decline of native fish species (Eberle et al. 2002, p. 182).)

Anthropogenic activities have resulted in altered flow regimes, including reductions in stream discharge and high-flow events; high levels of fragmentation; modified geomorphology and loss of channel complexity; decreased water quality; and introductions of non-native species. These actions have resulted in new system conditions, different from the prevailing extremes that formerly characterized prairie rivers and streams (Matthews 1988, p. 387; Perkin and Gido 2011, p. 371).

3.6. ADDITIONAL STRESSORS

Numerous other human activities may influence the viability of the Arkansas River shiner and peppered chub but are not well understood, not currently quantified, or are not certain to directly impact these species. These activities have the potential to physically remove Arkansas River shiners and peppered chubs, leading to their mortality, to kill individuals through direct contact, or to alter preferred habitats in ways detrimental to the species' viability.

3.6.1. In-stream Gravel Mining and Dredging

In-stream mining involves the excavation of sand and gravel deposits from streambeds by various methods and the processing of those materials. A single commercial dredging operation can occupy several thousand linear feet of river and remove tens of thousands of cubic yards of river substrate per month. Processing includes screening and grading the deposits using streamwater, and discharging the water back into the stream (Meador and Layher 1998, p. 7). In-stream mining alters channel morphology, often creating deeper areas with lower flows (Meador and Layher 1998, p. 8). Deeper areas resulting from in-stream dredging provide support for fish adapted to lentic conditions and may shift fish assemblages from riverine fish to lake-adapted fish (Paukert et al. 2008, p. 630).

Forshage and Carter (1974, pp. 698–699) observed a decrease in minnow species and abundance in the Brazos River at a dredging site downstream of Possum Kingdom Lake. The reduction of minnows was associated with the loss of gravel substrate, increased turbidity, and a decrease in benthic organisms resulting from the dredging of gravel within the channel (Forshage and Carter 1974, p. 699). In-stream dredging is most likely to impact Arkansas River shiners and peppered chubs when it occurs directly within occupied channels and results in alterations of channel depth and flow regime, and thereby reduces the quality of the stream habitat for use in foraging and reproduction by these species. In-stream dredging may impact individual Arkansas River shiners and peppered chubs directly by localized dewatering or contact with machinery. Large in-stream mining and dredging operations could cause widespread and delayed effects to these species due to substantial changes in flow regime and channel depth.

Dependent upon the scope of a project, in-stream mining operations within Texas and Oklahoma may be required to obtain a Section 404 and/or 402 permit from the U.S. Army Corps of Engineers. In-stream dredging operations within Oklahoma must obtain a state mining permit or waiver of permit from the Oklahoma Department of Mines. In-stream dredging operations within Texas are required to obtain a dredge permit from the Texas Parks and Wildlife Department. Although smaller, unpermitted activities do occasionally occur, it is unlikely that they substantially impact Arkansas River shiners and peppered chubs at the individual, population, or species level. Given the information available, it appears that permitted and non-permitted in-stream dredging and mining could potentially affect Arkansas River shiners and peppered chubs. However, these affects are not well documented, or expected to occur at levels approaching other threats such as impoundment and drought.

3.6.2. Off-Road Vehicle Use

Recreational off-road vehicle use occurs within the South Canadian river basin, and is known to occur specifically at the Lake Meredith National Recreation Area, Texas which is maintained by the National Park Service. Off road vehicle use has been authorized at the Lake Meredith National Recreation Area since the 1970s (under CFR 7.57) and has changed drastically since that time, both in intensity and in the types of off road vehicles used, and has led to detrimental effects to natural and cultural resources (USFWS 2014, p. 2). Beginning January 1, 2004, the State of Texas passed Senate Bill 155 which included language prohibiting motor vehicles from entering navigable riverbeds statewide; however, the South Canadian River and the Prairie Dog Town Fork of the Red River were exempted by statute. At the Lake Meredith National Recreation Area, it is common for the South Canadian River and inflow streams to dry up during summer conditions, leaving fish congregated in isolated pools. Off-road vehicle users are known to routinely drive through these pools and shallow portions of the South Canadian River, posing a threat to congregated fish including Arkansas River shiner and peppered chub (Arlene Wimer, Paul Jones, and Jeremy Stevens, National Park Service 2014 personal communications). Arkansas River shiner specimens sampled from the South Canadian River in isolated pools during summer drought showed higher levels of stress indicators, such as parasites and poor nutrition, than those sampled in more favorable habitat conditions (Gene Wilde, pers. comm., March 24, 2014). These stranded individuals therefore may be more likely to be harmed or killed by added disturbances such as being trampled or splashed out of the pools by repeated off-road vehicle traffic, and/or by the resulting degradation of habitat quality from changes in turbidity, loss of vegetation along the stream margins, and accelerated water loss (Gene Wilde, pers. comm., March 24, 2014).

Regularly occurring events such as the annual Sand Drags held at the Lake Meredith National Recreation Area draw thousands of motorized participants. Although recreational off-road vehicle use along the South Canadian River at the Lake Meredith National Recreation Area and elsewhere on private lands is known to occur, it is unknown whether or not these actions are affecting the resiliency of Arkansas River shiners and peppered chubs at population levels.

3.6.3. Commercial bait harvest

Minnows of the genus *Notropis* are used as bait fishes and are harvested in the commercial bait industry in Texas. Commercial bait harvesters are required to obtain an annual non-game Permit to Possess or Sell Nongame Fish Taken from Public Fresh Waters from the Texas Parks and Wildlife Department that identifies the water bodies from which collections may be made, and reports the contents of their collections (Texas Parks and Wildlife Department 2018). There are currently no active Permits to Possess or Sell Nongame Fish Taken From Public Fresh Waters that authorize harvest in the Canadian River (C.J. Martinez, pers. comm., March 20, 2018). Texas Parks and Wildlife Department has developed recommendations to prohibit new permits in the South Canadian River upstream of Lake Meredith; however, no such recommendations exist to prohibit new bait harvest permits downstream of Lake Meredith. In Oklahoma, is unlawful to take or possess more than 25 nongame bait fish in rivers or streams, except for shad, of which 200 may be taken or possessed.

Additional information may be required to fully understand the historical and potential and future impacts that commercial bait harvests have on Arkansas River shiners and peppered chubs, but the best available information indicates that these collections are a source of concern when collection efforts occur in occupied habitat and are either extensive or occur during periods of drought and range restriction. However, it is currently unknown whether or not these actions are affecting the resiliency of Arkansas River shiners and peppered chubs at population levels.

3.7 MANAGEMENT ACTIONS

Effective management actions for Arkansas River shiner and peppered chub should target those stressors that most affect population resiliency and species viability. Actions that could affect stressors include 1) Implementation of water conservation strategies with reservoir operations and other water users (ground and surface water) to secure existing flows and provide for additional reservoir releases, where feasible, to stop or reverse channel narrowing, enhance channel complexity, and promote successful reproduction; 2) Removal of existing fish movement and flow barriers on main stem and larger tributaries to improve flows and connectivity, increase sediment transport, and enhance channel complexity; 3) Riparian and floodplain restoration to minimize impacts from salt cedar encroachment and other invasive and opportunistic species such as common reed and the newly documented ravenna grass (Robertson et al. 2017, p. 21) to maintain wider, braided channels more suitable for successful reproduction; 4) Development of captive propagation techniques for both species, to be used for refugia populations as well as for re-introductions; 5) Re-establishment or augmentation of Arkansas River shiner and peppered chub populations at appropriate locations within their historical ranges, with adequate monitoring to determine their success, and 6) Development and implementation of a drought/spill salvage response plan for both species. A more detailed assessment of past and current management action is included in Chapter 4 – Current Conditions, with potential future management efforts discussed in Chapter 5 – Future Conditions.

CHAPTER 4 - CURRENT CONDITION

4.1 INTRODUCTION

In this chapter we describe the current condition of the Arkansas River shiner (*Notropis girardi*) and peppered chub (*Macrhybopsis tetranema*) through analysis of demographic, habitat and flow factors. Demographic factors include capture ratio (collections with species presence to collection where the species was not collected), relative abundance, whereas habitat and flow factors include stream fragmentation, channel narrowing, flood frequency and low flow analysis.

4.2 DEFINING POPULATIONS

In context of ecology, populations are defined as a group of organisms of one species that interbreed and live in the same place at the same time. The Arkansas River shiner and peppered chub historically inhabited numerous rivers of the Arkansas River basin (see historical distribution maps in Chapter 2) and without the presence of dams it is likely that each of these species exhibited some level of genetic exchange between these large rivers. Eggs and larvae drifted downstream and once able to swim, fish may have begun to make their way up a different river from where they were spawned. This mixed dispersion view would consider each species as having only one (relatively large) population. Our view in this SSA is that dispersion between major rivers did occur, but each of the major rivers supported ‘local populations’ with independently fluctuating abundances, driven by differing factors at different times. To provide a stepped-down ‘population’ analysis for this SSA, we combined the concept of historical ‘local populations’ (including currently functionally extirpated areas) with what we currently view as local populations to designate SSA Resiliency Units (Figure 4-1).

For analytical purposes, we divided the Arkansas River into two Resiliency Units (Upper and Lower), based on the expansive length of the river, significant alterations such as dams and channelization separating the two units, and the significant change in river size (from 4th to 7th order) as it transitions between the two units. We identified the Cimarron and North Canadian Rivers as individual Resiliency Units because the entire stretches of both rivers historically were occupied by local populations of both species (63 FR 64773). We designated two units (Upper and Lower) in the South Canadian River, based on the presence of Lake Meredith and Sanford dam, which geographically isolates populations of Arkansas River shiner (and historically peppered chub).

As mentioned above, Resiliency Units are the scale at which we will describe population resiliency for both species and assess representation and redundancy among these Units. However, to assess conditions within each Resiliency Unit at a somewhat finer scale, we subdivided each Resiliency Unit into multiple subunits (Figure 4-2). This downscaling allows us to better describe potentially differing conditions within a Resiliency Unit to better understand the drivers affecting current condition.

Subunits were classified based on three factors: 1) river lengths within each subunit were targeted to range from 100-200 miles; 2) where major impoundments occurred, that location served as a boundary between subunits; and 3) where no major impoundment occurred, we utilized the 10-digit hydrologic unit code boundary.

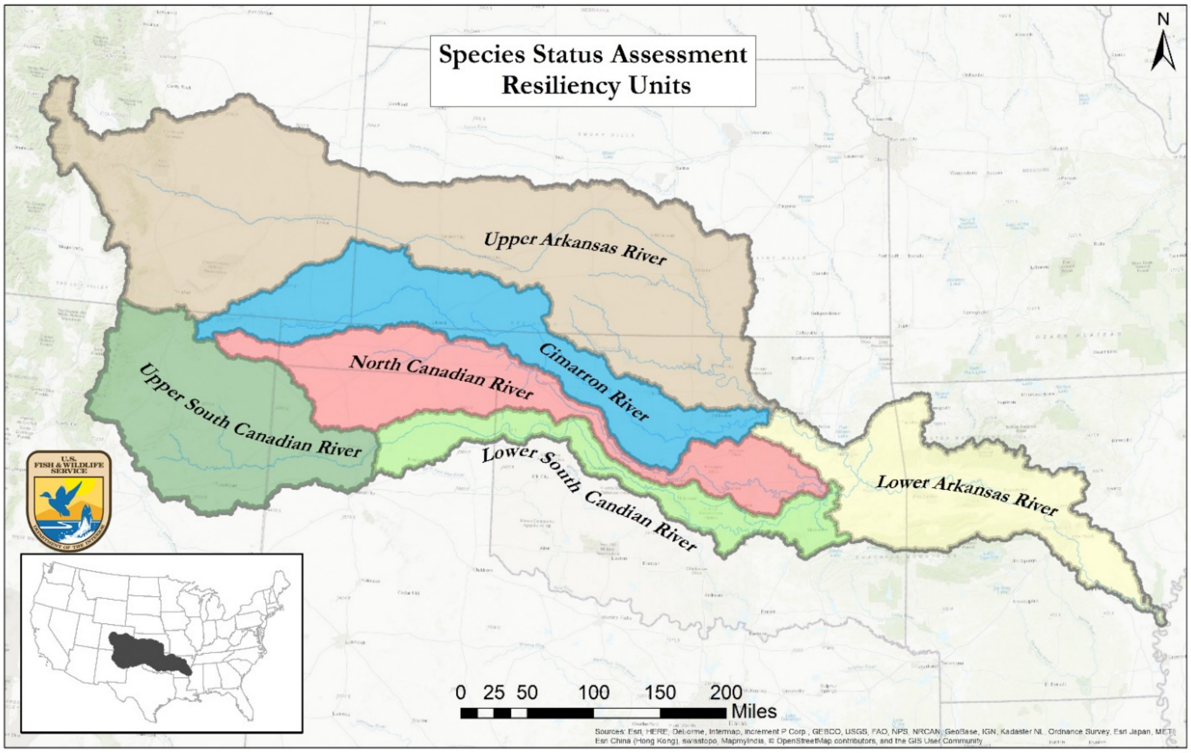


Figure 4-1. Resiliency Units for the Arkansas River Shiner and Peppered Chub (excluding Lower Arkansas River) Species Status Assessment.

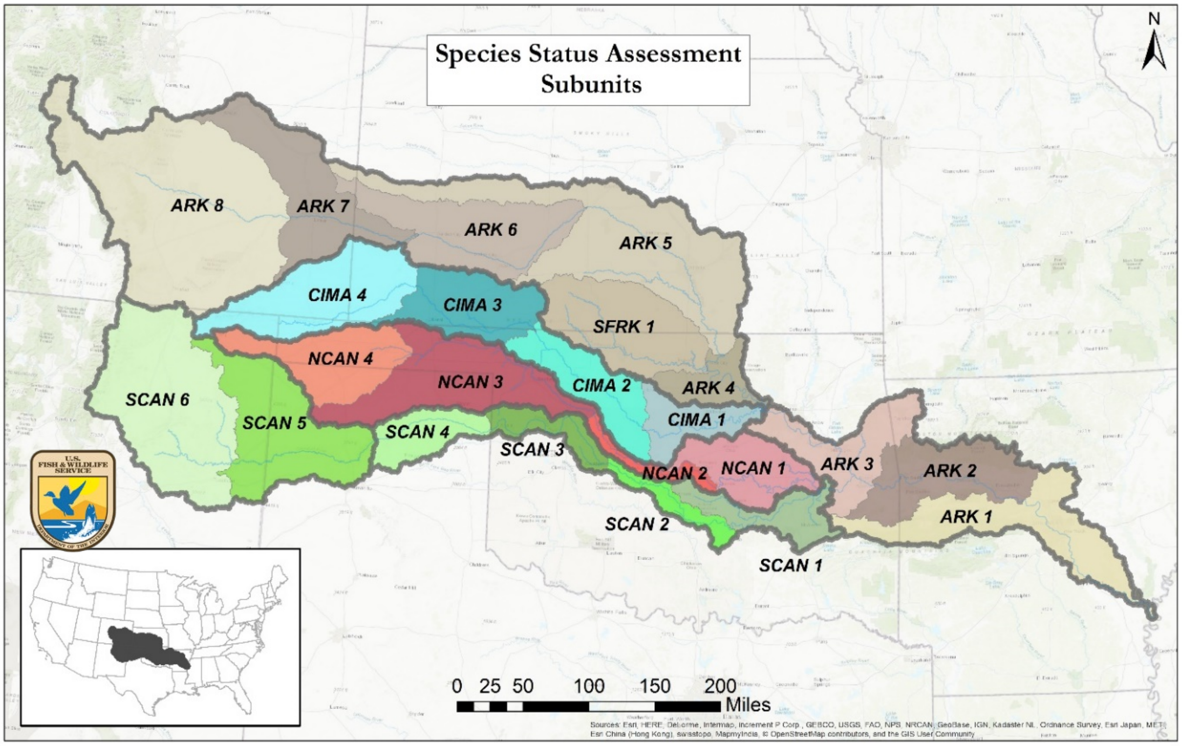


Figure 4-2. Analytical subunits for the Arkansas River Shiner and Peppered Chub Species Status Assessment.

4.3 DEMOGRAPHIC FACTORS

Presence/absence and relative abundance of the Arkansas River shiner and peppered chub were assessed by consolidated fish collection records from numerous state, federal, and academic sources. Those sources are identified in Table 4-1 below and more detailed information on data sources, consolidation methods, and use for specific analyses are included in *Appendix A – Fish Data Records.* Because of the significant number of collections (8,192) over more than 100 years, it should be noted that survey methodology likely varied, which could influence overall catch and species composition. Only a limited number of the datasets we obtained provide methodology information to the level we could determine potential gear bias towards one species or another, therefore we were not able to separate out our analysis by gear type. However, the use of sein for collection in these relatively shallow but wide Great Plains streams has been used for over 100 years and is still considered today the most effective way to survey. Another limitation of the dataset is the measurement of overall effort (typically measured in time and/or area surveyed), which was only included in a small proportion of the data. Based on the recognition of these data limitation, we limited our analysis to presence/absence and relative abundance.

Table 4-1. Fish collection data sources used for this SSA.

Type	Source	# Collections	# Lots	Data Use
Literature	1891 Jordan, D.S.	2	11	Presence/Absence
Museum Collection	Burke Museum - University of Kansas	303	1,580	Presence/Absence
Museum Collection	Museum of Southwest Biology	5	5	Presence/Absence
Museum Collection	Museum of Zoology - University of Michgan	210	639	Presence/Absence
Museum Collection	Natural History Museum - Eastern New Mexico University	47	133	Presence/Absence
Museum Collection	Oklahoma State University Museum Ichthyology Collection	1,292	4,074	Presence/Absence
Museum Collection	Sam Noble Museum of Natural History - University of Oklahoma	905	7,654	Presence/Absence
Online Database	Fishnet2	420	3,286	Presence/Absence
State Agency Collections	Arkansas Game and Fish Comission	24	28	Presence/Absence
	TOTAL Presence/Absence	3,208	17,410	
Federal Agency Collections	U.S. Fish and Wildlife Serv. - New Mexico- Fisheries	102	499	Abundance
Federal Agency Collections	U.S. Fish and Wildlife Serv. - OK- Ecological Services and Fisheries	293	2,156	Abundance
Literature	1955 Lewis and Dalquest	34	108	Abundance
Literature	1997 Pittenger and Schiffmiller	5	23	Abundance
Literature	1997 Polivka and Matthews	8	58	Abundance
Literature	2002 Giggleman et al.	11	65	Abundance
Literature	2002 Wilde	31	230	Abundance
Literature	2005 Wilde	258	1,704	Abundance
Literature	2009 GEI Report	15	71	Abundance
Literature	2010 Wilde	26	97	Abundance
Online Database	Fishes of Texas	37	109	Abundance
State Agency Collections	Colorado Parks and Wildlife Department	272	1,902	Abundance
State Agency Collections	Kansas Department of Wildlife, Parks, and Tourism	2,932	17,180	Abundance
State Agency Collections	OK Dep. of Env. Qual. - Jimmy Pigg (partial confirmed data)	917	9,308	Abundance
State Agency Collections	Texas Parks and Wildlife Department	3	32	Abundance
University Collections	Oklahoma State University - Dr. Shannon Brewer	40	418	Abundance
	TOTAL Abundance	4,984	33,960	
	OVERALL TOTAL	**8,192**	**51,370**	

4.3.1 Current Range and Distribution

4.3.1.1 Arkansas River shiner

Distribution Overview

Available records indicate that fish collections in the Arkansas River basin were scattered and somewhat limited before the 1930s (104 collections total); however, Arkansas River shiners were captured in 31 of those 104 collections (30 percent) and were found in all Resiliency Units where survey effort occurred (Figure 4-3). Survey efforts and positive findings of Arkansas River shiner increased through the 1930-1959 (739 collections, 189 collections with Arkansas River shiner) and 1960-1989 (2,036 collections, 408 with Arkansas River shiners) time periods; however, the percentage of positive surveys slightly declined with time (26 percent and 20 percent, respectively). Available records indicate that the Arkansas River shiner was last captured from the Arkansas River in Kansas in 1967 (near Oxford, KS) and from the Ninnescah River in 1975. Collection efforts from 1990 to present were significantly greater (5,203 collections) as compared to previous time periods and collections containing the Arkansas River shiner increased to 782. However, the percentage of collections where Arkansas River shiners were captured declined to only 15 percent.

By 1990, Arkansas River shiners in the Arkansas River were likely functionally extirpated from all but the Arkansas River subunit in Oklahoma (ARK 4) (Figure 4-3, Table 4-2). The last Arkansas River shiner in subunit ARK-4 was captured in 1998. By 1999, the fish is now likely functionally extirpated from the entire Arkansas River, with 17 collections in ARK-4 since 1998, none of which reported capture of the Arkansas River shiner (Figure 4-3, Table 4-2). Last confirmed reports of Arkansas River shiners from the Cimarron and North Canadian River both occurred in 1993, with 396 survey efforts in the Cimarron and 344 in the North Canadian River since the fish was last found (Table 4-2), leading us to conclude that the fish is likely functionally extirpated from those rivers, as well.

Regarding current distribution of the Arkansas River shiner, we consider the last 17 years (2000 to present) for our assessment. In examining presence/absence capture data only, records indicate that the species occurs only in the South Canadian River, SCAN 1-5 subunits (Figure 4-4). The Arkansas River shiner was last captured in SCAN 6, which is upstream of Ute Reservoir, in 1977, with at least 30 collections since that time.

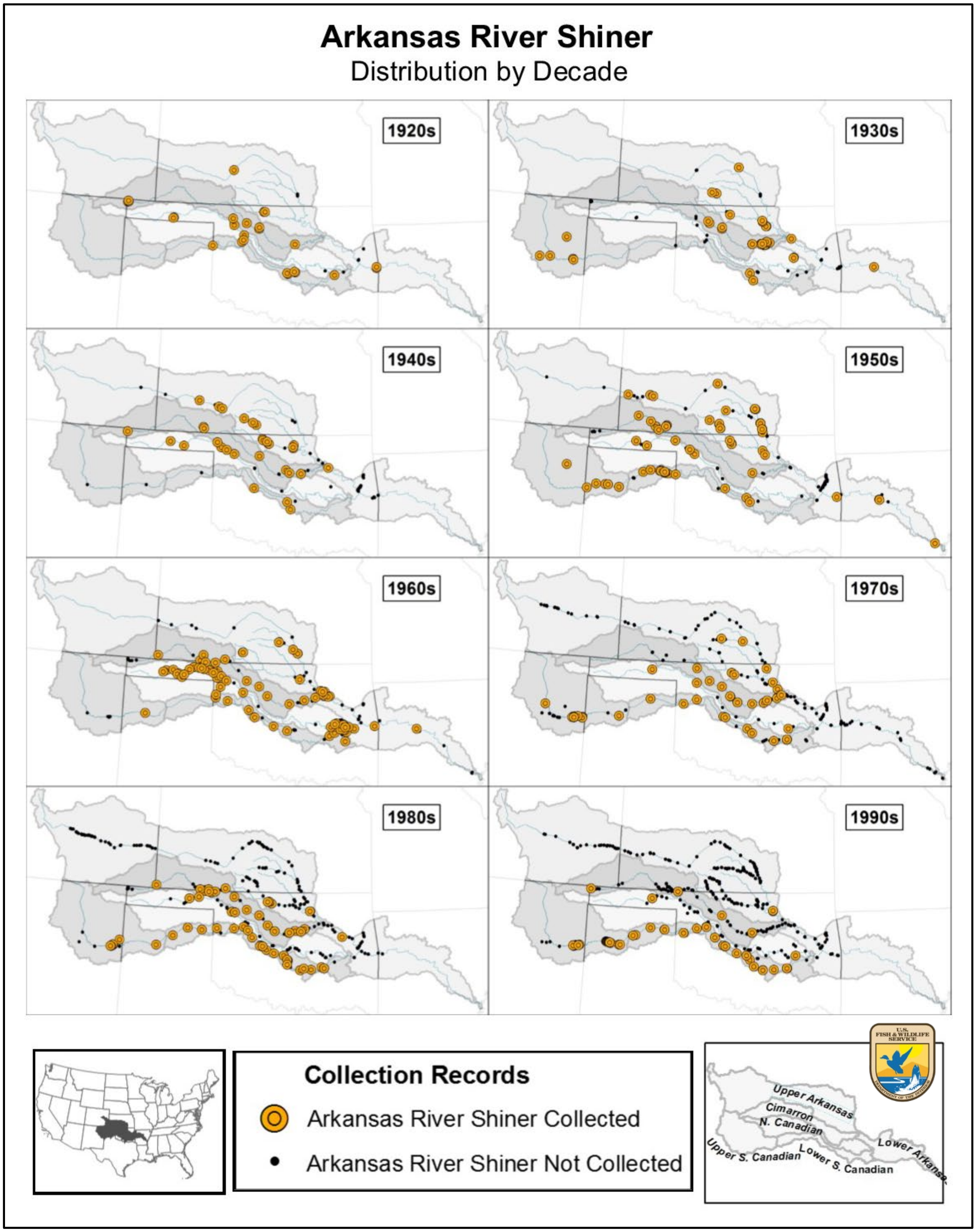


Figure 4-3. Distribution of Arkansas River shiner by decade. Orange points indicate presence of Arkansas River shiner and black points indicate additional collection efforts during the specified 10-year time period where Arkansas River shiner was not captured.

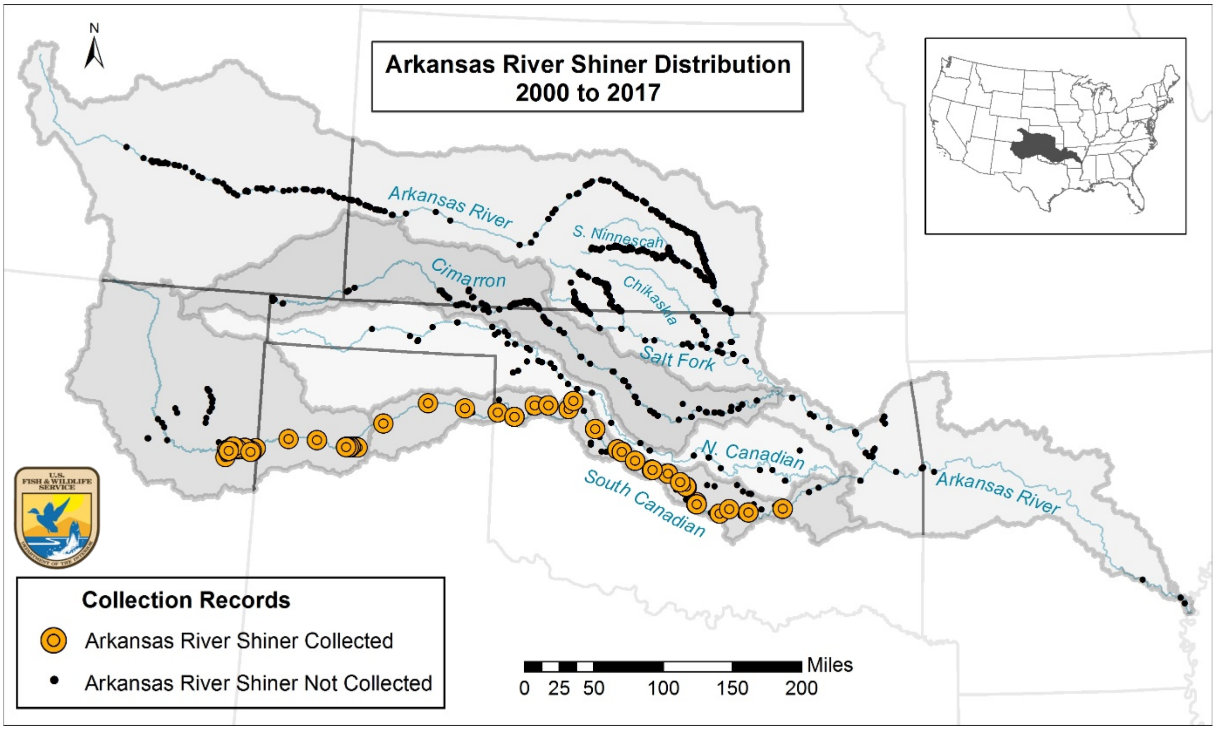


Figure 4-4. Distribution of the Arkansas River shiner - 2000 to present. Orange points indicate presence of Arkansas River shiner and black points indicate collection efforts where Arkansas River shiner was not captured.

Table 4-2. Historical records of Arkansas River shiner collections. First report is the first year that the shiner was reported captured within the respective watershed and analysis subunit. Last Report is the last year that a sample containing the shiner was recorded. Proportion Positive is the proportion of collections that collected Arkansas River shiners. Total Samples are the number of samples collected by all collectors during the Period of Record. Samples after Record are the number of samples by all collectors recorded after the last shiner collection.

		Arkansas River Shiner Period of Record				
Resiliency Unit	Subunit	First Report	Last Report	Proportion Positive	Total Samples	Samples After Record
Lower Arkansas	ARK 1	1959	1959	100.0%	1	17
	ARK 2	1927	1963	19.6%	51	58
	ARK 3	1936	1981	2.5%	315	372
Upper Arkansas	ARK 4	1934	1998	7.2%	222	9
	SFRK 1	1926	1987	29.8%	188	600
	ARK 5	1939	1978	33.3%	90	1360
	ARK 6	1926	1952	33.3%	21	110
	ARK 7	1950	1950	2.9%	34	189
	ARK 8	None	None	N/A	N/A	166
Cimarron	CIMA 1	1929	1993	23.0%	369	113
	CIMA 2	1926	1991	29.9%	137	141
	CIMA 3	1941	1992	31.8%	107	98
	CIMA 4	1926	1992	9.4%	96	44
North Canadian	NCAN 1	1932	1993	13.0%	92	22
	NCAN 2	None	None	N/A	N/A	195
	NCAN 3	1928	1993	20.7%	246	125
	NCAN 4	1926	1963	50.0%	28	2
Lower South Canadian	SCAN 1	1926	2016	53.7%	229	0
	SCAN 2	1920	2016	77.9%	353	0
	SCAN 3	1928	2016	63.3%	166	0
	SCAN 4	1926	2011	39.4%	104	15
Upper South Canadian	SCAN 5	1939	2016	88.3%	549	0
	SCAN 6	1939	1977	16.1%	31	30

Presence/Absence Analysis

<u>Capture Ratios</u>

All available fish collection data was converted to presence/absence (binary) for the Arkansas River shiner. We then divided the number of collections capturing Arkansas River shiner by the total number of collections by decade and subunit to assess what we refer to as capture ratio. There were numerous decades where the number of collections within a subunit was less than 10 collections (and in many just 2-5 collections). To minimize error due to a small number of collections, we chose to not include subunits where the number of collections in a given decade was less than 10. We also calculated capture ratios for each subunit for the last 17 years (2000-2017) (Table 4-3), which is the time period we used in this assessment to represent current condition for the Arkansas River shiner. Single collections without detection of the Arkansas River shiner do not confirm absence of the species at those sites, as detections may be influenced by sample size or low species abundance. However, our analysis can provide an indication of changing species abundance and allows us to assess change over time.

As discussed in the *Distribution Overview* section above, Arkansas River shiners have not been captured in the Arkansas, Cimarron, or North Canadian Rivers in the last 17 years (2000-2017), where we now consider the species functionally extirpated. We provide historical capture ratios for those rivers, but our analysis of current condition only includes the Upper and Lower South Canadian River, where the fish still persists.

We evaluated capture ratio results by subunit and decade to determine an 'optimal' ratio to serve as our baseline condition for assigning descriptive rankings used in our resiliency analysis at the end of this chapter. Our assessment is limited to approximately 120 years of survey data and optimal (highest) decadal capture ratio during that time period is likely different than centuries before. However, we do consider that optimal conditions (over the span of a decade) within the last 120 years represented adequate conditions for viable self-sustaining populations and can serve as an indicator for resiliency today.

Our analysis indicates the highest mean capture ratio by decade was 0.92 (92 percent of collections captured Arkansas River shiner), which occurred in SCAN-5 in the 1990s (171 of 195 surveys collected Arkansas River shiner) and 2000s (174 of 189). Using this value as our baseline optimal reference condition, we assigned a score of ***Good*** as those within 20 percent of baseline (calculated as 0.92-0.74), ***Fair*** with a decline between 20 and 80 percent (0.73-0.18), and ***Poor*** if the decline was at or greater than 80 percent (0.17 or less).

Our results for the Lower South Canadian River indicate that the current mean ratio (2000-2017) of 0.63, which is the fourth highest ratio within the Lower South Canadian River collections, but well below the optimal range of 92-74 percent discussed above. In breaking down capture ratios in the Lower South Canadian River by subunit, we find that SCAN 2 maintains a ***Good*** capture ratio (0.78), SCAN 1 and 3 have ***Fair*** capture ratios (0.52 and 0.61, respectively), where SCAN 4 (0.04) is near the lowest on record, considered ***Poor***. In the 1950s, the SCAN 4 capture ratio was 0.50, indicating a decline in capture over time.

The current (2000-2017) mean capture ratio for the Upper South Canadian (SCAN 5 only) is 0.92 percent, which is the highest on record. Arkansas River shiners were last collected from SCAN 6 (upstream of Ute Reservoir) in 1977.

Table 4-3. **(A)** Ratio of positive to negative surveys of Arkansas River shiner by decade and current condition (2000-2017). Decades and subunits with less than 10 collections are not included in this analysis and are indicated with an asterisk (*). For additional visual comparison, colors in the red spectrum indicate a capture ratio of less than 0.50, whereas colors in the blue spectrum are greater than 0.50. **(B)** – Corresponding resiliency scores. ***Good*** as those within 20 percent of baseline (calculated as 0.92-0.74), ***Fair*** with a decline between 20 and 80 percent (0.73-0.18), and ***Poor*** if the decline was at or greater than 80 percent (0.17 or less).

Arkansas River Shiner (A)											
Resiliency Unit and Subunits	**1920s**	**1930s**	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**	**2000-2017**
Lower Arkansas River											
ARK-Sec1				*	*	*			*		
ARK-Sec2	*	*		0.19	0.17	0	0	0	*		
ARK-Sec3	*	*	0.02		0.17	0	0.01	0	0	*	0
Upper Arkansas River											
ARK-Sec4		0.20	*	*	0.13	0.06	0.06	0.04	*		
SFRK-Sec1	*	0.33	0.32	0.50	0.36	0.17	0.14	0	0	0	0
ARK-Sec5	*	*	*	0.49	0.22	0.09	0	0	0	0	0
ARK-Sec6	*	*	0.23	0.19	*	0	0	0	0	0	0
ARK-Sec7			*	*	*	0	0	0	0	0	0
ARK-Sec8				*		0	0	0	0	0	0
Cimarron River											
CIMA-Sec1	*	0.25	0.18	*	0.23	0.42	0.22	0.03	0	0	0
CIMA-Sec2	0.67	*	*		*	0.31	0.21	0.01	0	0	0
CIMA-Sec3		*	*	0.42	0.33	0	0.26	0.03	0	0	0
CIMA-Sec4	0.27		*	*	0.10		0.02	0.02	0	*	0
North Canadian River											
NCAN-Sec1	*	*	*	*	0.33	*	0.00	0.03	*	*	
NCAN-Sec2		*	*	*	*	0	0	0	0	*	0
NCAN-Sec3	*		0.50	0.29	0.69	0.27	0.11	0.02	0	*	0
NCAN-Sec4	*		*	*	0.54		*		*		
Lower South Canadian River											
SCAN-Sec1	*	*	*	*	0.22	0.47	0.85	0.72	0.42	0.67	0.52
SCAN-Sec2	0.23	0.23	*	*	*	0.38	0.90	0.88	0.75	0.82	0.78
SCAN-Sec3	*		*	*	*	*	*	0.62	0.79	0.43	0.61
SCAN-Sec4	*		*	0.50		*	*	0.28	0.11	0.04	0.07
Upper South Canadian River											
SCAN-Sec5		*	*	0.78	*	0.55	0.61	0.92	0.92	0.91	0.92
SCAN-Sec6		*	*	*	*	0.04	*	*	0	*	0

Arkansas River Shiner (B)											
Resiliency Unit and Subunits	**1920s**	**1930s**	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**	**2000-2017**
Lower Arkansas River											
ARK-Sec1				*	*	*			*		
ARK-Sec2	*	*		Fair	Poor	Null	Null	Null	*		
ARK-Sec3	*	*	Poor		Poor	Null	Poor	Null	Null	*	Null
Upper Arkansas River											
ARK-Sec4		Fair	*	*	Poor	Poor	Poor	Poor	*		
SFRK-Sec1	*	Fair	Fair	Fair	Fair	Poor	Poor	Null	Null	Null	Null
ARK-Sec5	*	*	*	Fair	Fair	Poor	Null	Null	Null	Null	Null
ARK-Sec6	*	*	Fair	Fair	*	Null	Null	Null	Null	Null	Null
ARK-Sec7			*	*	*	Null	Null	Null	Null	Null	Null
ARK-Sec8				*		Null	Null	Null	Null	Null	Null
Cimarron River											
CIMA-Sec1	*	Fair	Fair	*	Fair	Fair	Fair	Poor	Null	Null	Null
CIMA-Sec2	Fair	*	*		*	Fair	Fair	Poor	Null	Null	Null
CIMA-Sec3		*	*	Fair	Fair	Null	Fair	Poor	Null	Null	Null
CIMA-Sec4	Fair		*	*	Poor		Poor	Poor	Null	*	Null
North Canadian River											
NCAN-Sec1	*	*	*	*	Fair	*	Null	Poor	*	*	
NCAN-Sec2		*	*	*	*	Null	Null	Null	Null	*	Null
NCAN-Sec3	*		Fair	Fair	Fair	Fair	Poor	Poor	Null	*	Null
NCAN-Sec4	*		*	*	Fair		*		*		
Lower South Canadian River											
SCAN-Sec1	*	*	*	*	Fair	Fair	Good	Fair	Fair	Fair	Fair
SCAN-Sec2	Fair	Fair	*	*	*	Fair	Good	Good	Good	Good	Good
SCAN-Sec3	*		*	*	*	*	*	Fair	Good	Fair	Fair
SCAN-Sec4	*		*	Fair		*	*	Fair	Poor	Poor	Poor
Upper South Canadian River											
SCAN-Sec5		*	*	Good	*	Fair	Fair	Good	Good	Good	Good
SCAN-Sec6		*	*	*	*	Poor	*	*	Null	*	Null

<u>Probability of Capture Analysis</u>

Presence/absence (binary) data were analyzed for trends using logistic regression (R Core Team 2017, GLM package). Parameter estimates and fit statistics for the logistic regressions of both the Arkansas River shiner and peppered chub can be found in Table 4-4.

Table 4-4. Parameter estimates and fit statistics for logistic regressions of presence/absence data.

	Intercept		Slope			
Analysis Sub-Unit	Estimate	*P*-value	Estimate	*P*-value	N	AIC
Arkansas River Shiner						
SCAN1	-56.6463	0.0001	0.0287	0.0001	215	280.46
SCAN2	-54.9822	0.0000	0.0283	0.0000	347	352.99
SCAN3	38.9234	0.0965	-0.0192	0.1013	164	215.12
SCAN4	80.2901	0.0000	-0.0409	0.0000	114	129.04
SCAN5	-83.1880	0.0000	0.0428	0.0000	541	337.65
SCAN6	216.7095	0.0030	-0.1113	0.0028	59	21.60
Peppered Chub						
SCAN1	54.7548	0.0220	-0.0291	0.0165	215	96.66
SCAN2	116.4552	0.0024	-0.0614	0.0019	347	35.00
SCAN3	216.7595	0.0601	-0.1125	0.0588	164	12.19
SCAN4	131.3013	0.0124	-0.0679	0.0114	114	57.93
SCAN5	-61.6517	0.0000	0.0313	0.0000	541	631.22
SCAN6	3838.7200	0.9980	-1.9800	0.9980	59	8.50

Modeled trends (Figure 4-5 indicate a high and increasing probability of Arkansas River shiners in samples collected in SCAN 2 and 5. These probabilities exceed 90 percent for SCAN 5 and 80 percent for SCAN 2 during the most recent 20 years of sampling. We did consider the increase as possibly an artifact of increased targeting of Arkansas River shiner and peppered chub in later surveys. Although this is possible, our evaluation of survey efforts in the Upper South Canadian River suggest that survey methods were not significantly different among the years and targeting of certain species does not appear to be a factor that significantly influenced our results.

The probability of ARS in SCAN 1 has also increased, but the odds of a shiner in a sample never exceed 20 percent. The probability of shiner collection in SCAN 4 and 6 declined significantly during the sample period. By the most recent two decades those probabilities had reached 10 to 20 percent in SCAN 4 and were virtually zero in SCAN 6.

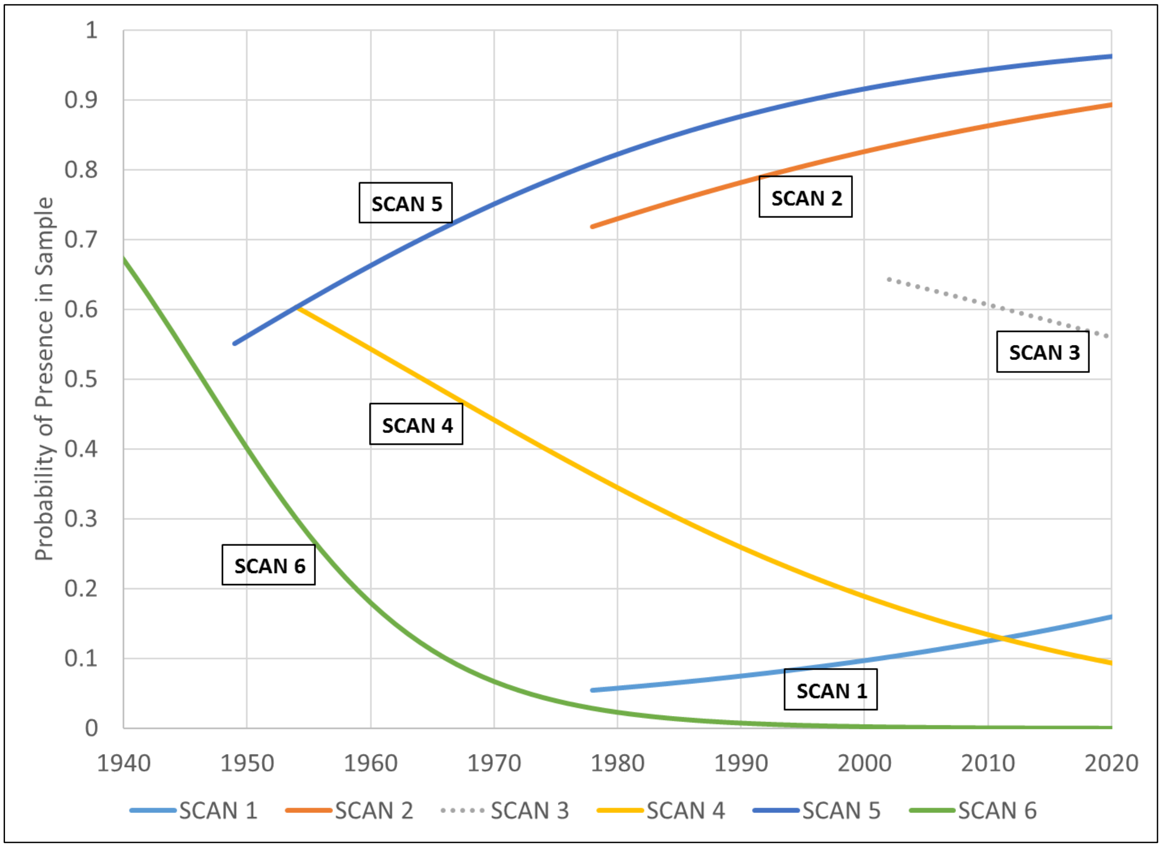


Figure 4-5. Logistic regression estimate lines for the Arkansas River shiner in each analysis subunit of the South Canadian River. Dotted lines (SCAN 3) are not significant and should not be interpreted. Each line represents the probability that an Arkansas River shiner will be found in a sample using sampling methods consistent with the methods used to collect the source samples over time.

4.3.1.2 Peppered chub

Distribution Overview

Macrhybopsis complex

As discussed in Chapter 2, taxonomy of chub species within the Arkansas River basin is complex. For the purposes of this SSA analysis, we have grouped chub species within the Arkansas River basin that belong to the genus *Macrhybopsis* into a single complex (*Macrhybopsis* complex) for our historical (before the year 2000) presence/absence analysis. The decision to combine species within this complex came after compiling fish collection records and observing the complexity of name changes throughout the years. It is possible that species identifications assigned to various chubs within this complex may have not always kept up with the latest accepted species name, as identified in the scientific literature. Therefore, if only fish identified as '*tetramena'* were utilized in the analysis, the dataset would ignore a potentially significant number of additional records (such as *Hybopsis aestivalis*) that, if keyed out today, some would likely be identified as a *Macrhybopsis tetranema*. Conversely, to assume all *Hybopsis aestivalis* (Girard) should be included as *M. tetranema* would overestimate the dataset for the same reason.

Fish identified in the Arkansas River Basin as one of the species outlined below are what Cross and Moss (1987) and Eisenhower (1999 and 2004) referred to as the speckled chub complex, which is characterized by black spots randomly scattered over the dorsum of the body and 2-4 prominent maxillary barbels. These characteristics make them unique from other chubs (*Hybopsis amblops. H. amnis* and *Hybopsis/Macrhybopsis storeriana*) in the Arkansas River drainage. Therefore, we combined fishes outlined below to assess historical distribution and abundance of the Arkansas River Basin *Macrhybopsis*. See Chapter 2, Section 2.1.2 Taxonomy and Genetics for additional discussion regarding peppered chub taxonomy.

- *Extrarius aestivalis* (21 collections)
- *Extrarius aestivalis tetranemus* (1 collection)
- *Extrarius tetranemus* (1 collection)
- *Hybopsis aestivalis* (3 collections)
- *Hybopsis tetranemus* (4 collections)
- *Macrhybopsis aestivalis* (140 collections)
- *Macrhybopsis aestivalis tetranemus* (40 collections)
- *Macrhybopsis hyostoma* (217 collections)
- *Macrhybopsis tetranema* (477 collections)

As described for Arkansas River shiner above, fish collections in the Arkansas River Basin before the year 1930 were limited and scattered throughout most Resiliency Units within the Arkansas River Basin, with 104 total collections made (Figure 4-6) and 20 of which (19 percent) contained fish belonging to the *Macrhybopsis* complex. Similar to Arkansas River shiner in the 1930-1959 time period, collection efforts (739) and positive findings of fishes within the *Macrhybopsis* complex (103) increased, and the percent of collections containing fishes from the *Macrhybopsis* complex slightly declined to 14 percent. We observed a somewhat different trend (as compared to Arkansas River shiner) by the 1960-1989 time period, when collection effort increased to 2,036 samples; however, the number of collections containing the *Macrhybopsis* complex only slightly increased to 117 and the percentage of collection containing the *Macrhybopsis* complex decreased to less than one percent. During this 1960-1989-time period we also observed extirpation of the *Macrhybopsis* complex from three upper subunits (ARK-6, 7, and 8) of the Upper Arkansas River Resiliency Unit, the upper Cimarron River subunit (CIMA 3), and the upper North Canadian subunit NCAN-4 (Figure 4-6, Table 4-5).

During the 1970s and 1980s, as first noted by Luttrell et al. (1999, p. 984) the *Macrhybopsis* complex was not collected from the Cimarron River and was presumed extirpated. However, in the 1990s fish from the *Macrhybopsis* complex were once again collected from numerous sites in the Cimarron River. Luttrell et al. (1999, entire) examined museum specimens from earlier collections and conducted their own surveys from 1991 to 1997 from the Salt Fork, Chikaskia, and Cimarron Rivers and concluded that the peppered chub was extirpated from these three rivers and replaced by the shoal chub (*Macrhybopsis hyostoma*). They suggested that the shoal chub re-appearance in the Cimarron River was likely reintroduced via bait bucket release.

Survey efforts from 1990 to present yielded a total of 5,391 collections, with 669 (12 percent) of those containing the *Macrhybopsis* complex. During this time period, the *Macrhybopsis* complex is present in 10 of the 20 historically occupied subunits.

<u>*Peppered chub*</u>

Our review of current condition of the peppered chub is based on the conclusions of numerous species experts who concluded that by the year 2000, the peppered chub had significantly declined and was isolated to the Ninnescah River in Kansas and the South Canadian River between Ute Reservoir in New Mexico and Lake Meredith in the Texas panhandle (Luttrell et al. 1999, Eisenhour 1999, Eisenhour 2004).). Therefore, our remaining analyses in this report of chub collections from the Upper South Canadian and South Ninnescah Rivers are of what we consider peppered chub, and not the *Macrhybopsis* complex.

In assessing current condition for the peppered chub, we examined two recent time periods; 2000 to present and 2013 to present, to provide differing perspectives on what one may consider the current condition of the peppered chub. We provide the current condition spanning back to 2000 to 2017 and more of a conservative view by inclusions of 17 years of collection data. The much shorter view of current condition based on 5 years of collection data (2013-2017) is typically too short of a window to draw conclusions from. However, using this shorter timeframe in this case for the peppered chub is justified based on significant survey effort by Kansas Department of Wildlife, Parks and Tourism in portions of the Arkansas River basin (including the Ninnescah River), which provides a large sample size within a relatively short time period and is supported by Pennock et at. 2017.

Our analysis of the year 2000 to 2017 yields 3,662 collections in the historical distribution of the *Macrhybopsis* complex, with 363 of those (10 percent) containing the peppered chub (Figure 4-7) in the South Ninnescah River and South Canadian between Ute Reservoir in New Mexico and Lake Meredith in the Texas panhandle. The peppered chub distribution (based on river miles considered occupied) in the South Ninnescah and Upper South Canadian River represents only 11 percent of the species historical range.

In assessing the past 5 years of collections (2013-2017), survey efforts yielded a total of 1,826 collections with only 38 of those (2 percent) containing the peppered chubs (Figure 4-8). The peppered chub distribution, now only in the South Canadian River between Ute Reservoir in

New Mexico and Lake Meredith in the Texas panhandle, represents only 6 percent of its historical range. Although we provide both time periods to provide differing views of current condition, we adopt the shorter time span of 2013-2017 to represent the species' current condition based on significant survey effort conducted within those five years.

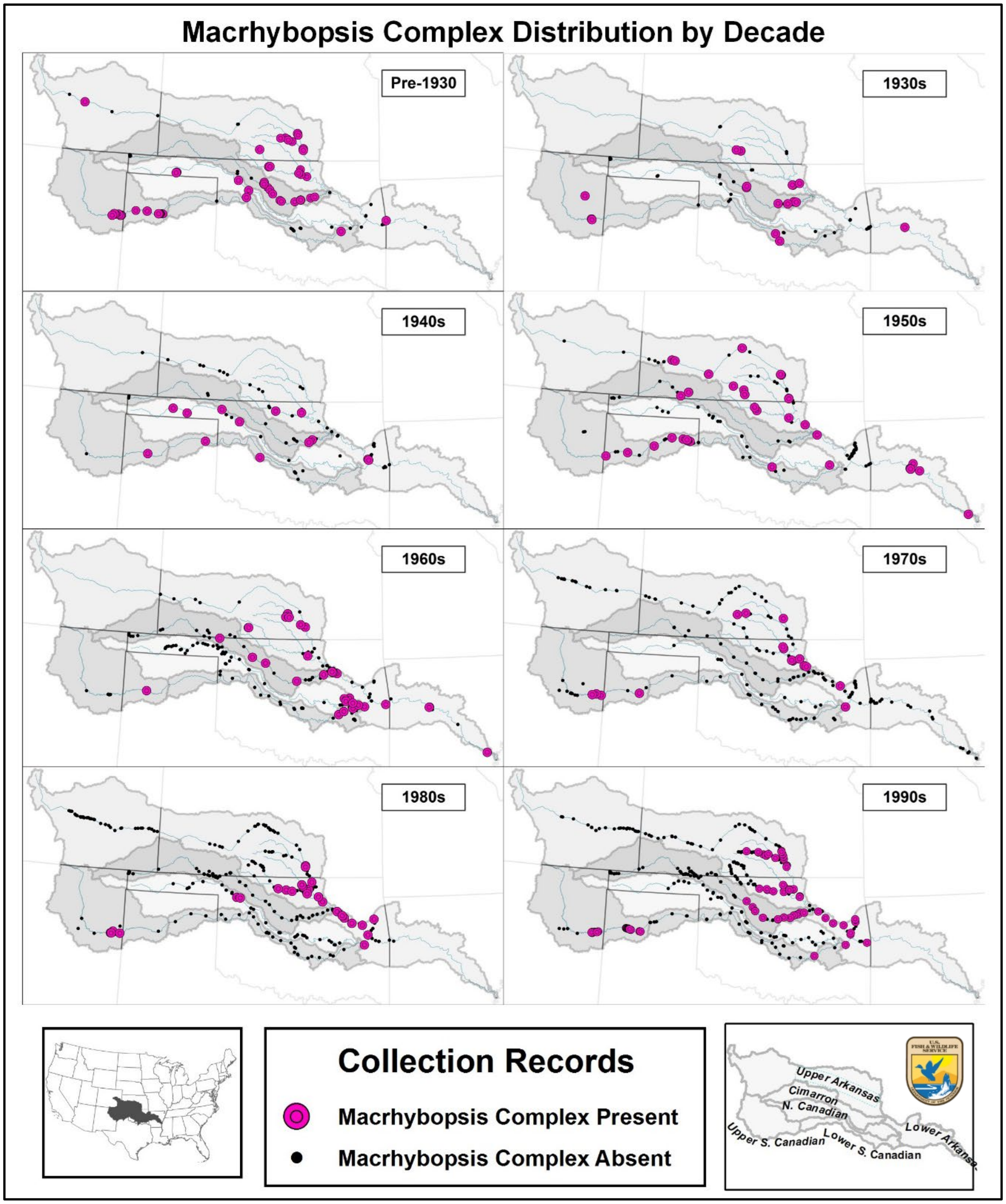


Figure 4-6. Distribution of *Macrhybopsis* complex by decade, 1889-1999. Pink points indicate collection of *Macrhybopsis* complex and black points indicate collection efforts (during the specified decade) where *Macrhybopsis* complex was not captured.

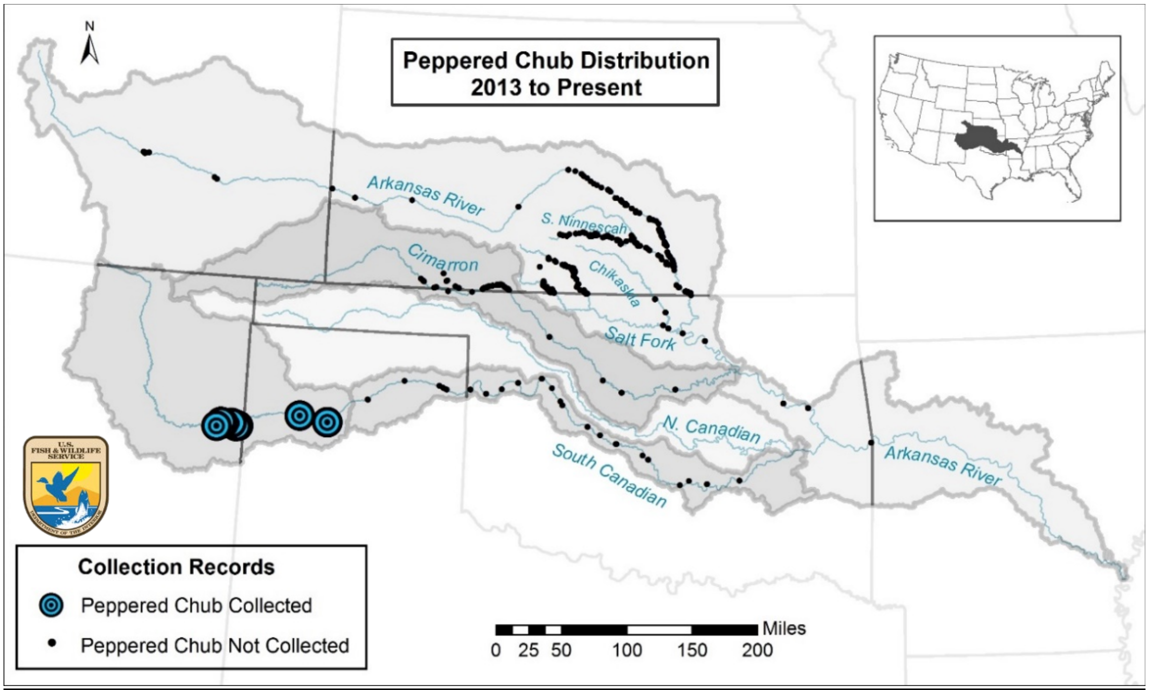


Figure 4-7. Distribution of the peppered chub - 2000 to 2017. Blue points indicate presence of peppered chub since 2000 and black points indicate collection efforts where peppered chub was not captured.

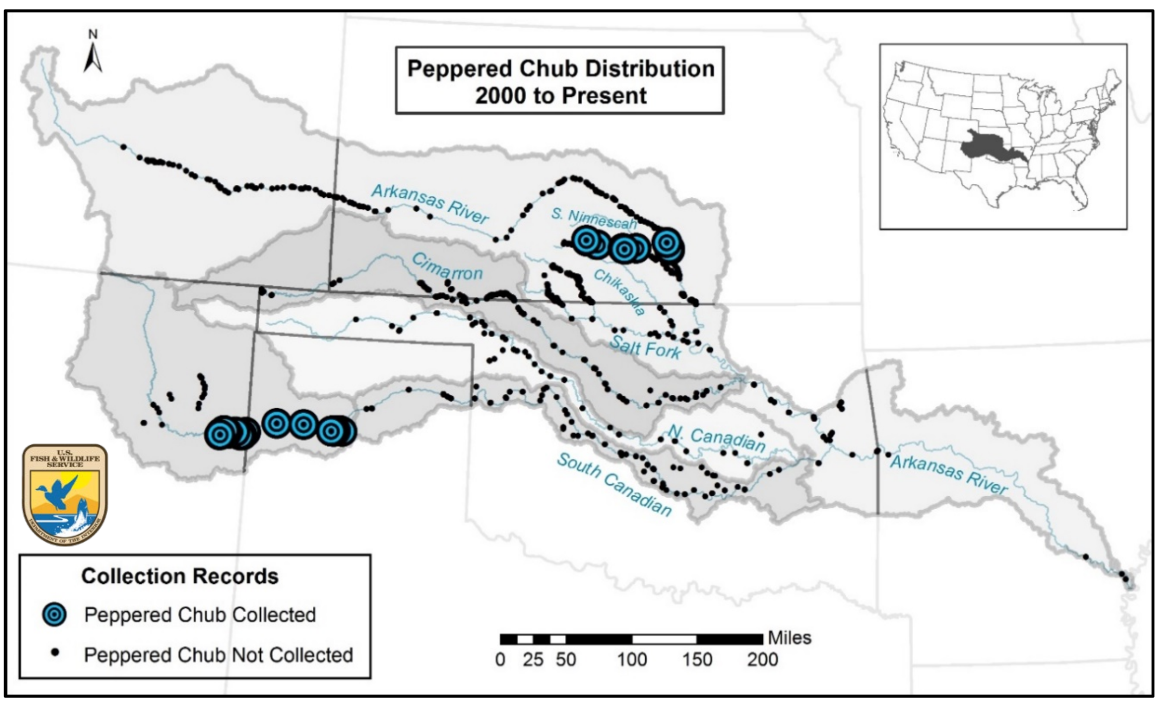


Figure 4-8. Distribution of the peppered chub in the last 5 years - 2013 to 2017. Blue points indicate presence of peppered chub since 2013 and black points indicate collection efforts where peppered chub was not captured.

Table 4-5. Historical records of *Macrhybopsis* complex collections. First report is the first year that the complex was reported within the respective watershed and analysis subunit. Last Report is the last year that a sample containing the complex was recorded. Proportion Positive is the proportion of collections that collected individuals in the *Macrhybopsis* complex. Total Samples are the number of samples collected by all collectors during the Period of Record. Samples after Record are the number of samples by all collectors recorded after the last complex collection.

		Macrhybopsis complex period of record				
Resiliency Unit	Subunit	First Report	Last Report	Proportion Positive	Total Samples	Samples After Record
Lower Arkansas	ARK 1	1959	2003	23.5%	17	1
	ARK 2	1939	1993	19.6%	92	9
	ARK 3	1946	2008	6.8%	664	5
Upper Arkansas	ARK 4	1934	2009	18.6%	231	0
	SFRK 1	1926	2010	13.8%	398	390
	ARK 5	1889	2012	17.6%	792	668
	ARK 6	1950	1958	63.6%	11	105
	ARK 7	None	None	N/A	N/A	194
	ARK 8	1889	1889	33.3%	6	158
Cimarron	CIMA 1	1929	2011	18.7%	487	0
	CIMA 2	1928	2010	16.1%	273	6
	CIMA 3	1950	1963	20.8%	24	522
	CIMA 4	None	None	N/A	N/A	152
North Canadian	NCAN 1	1959	1962	21.7%	23	81
	NCAN 2	None	None	N/A	N/A	195
	NCAN 3	1928	1982	8.9%	90	281
	NCAN 4	1926	1949	69.2%	13	17
Lower South Canadian	SCAN 1	1929	1999	7.3%	178	47
	SCAN 2	1932	1952	21.1%	19	321
	SCAN 3	1928	1940	33.3%	6	160
	SCAN 4	1949	1959	17.6%	51	67
Upper South Canadian	SCAN 5	1939	2016	70.1%	549	0
	SCAN 6	1939	1939	25.0%	4	57

Presence/Absence Analysis

All available fish collection data was converted to presence/absence (binary) for the *Macrhybopsis* complex. We then divided the number of collections capturing the *Macrhybopsis* complex by the total number of collections (by decade and subunit) to assess what we refer to as capture ratio. There were two decades (1960s and 1980s) where the number of collections within a subunit was less than 10 collections). Similar to our Arkansas River shiner analysis, to minimize error due to a small number of collections, we chose to not include subunits where the number of collections in a given decade was less than 10. Capture ratios by decade were calculated only for Resiliency Units where the species recently or currently occurs; SCAN 5 of the Upper South Canadian River (SCAN-5) and ARK-5 of the Upper Arkansas River, which includes the South Ninnescah River (Table 4-6). We also calculated capture ratios for the two subunits for the last 17 years (2000-2017) and five years (2013-2017) (Table 4-6 A), which are the time periods we used in this assessment to represent current condition for the peppered chub. Single collections without detection of the peppered chub do not confirm absence of the species at those sites, as detections may be influenced by sample size or low species abundance. However, our analysis can provide an indication of changing species abundance and allows us to assess change over time.

Table 4-6 (A). Ratio of positive to negative peppered chub surveys by decade and current condition (2000-2017 and 2013-2017). Decades and subunits with less than 10 collections are not included in this analysis and are indicated with an asterisk (*). For additional visual comparison, colors in the red spectrum indicate a capture ration of less than 0.50, whereas colors in the blue spectrum are greater than 0.50. **(B) *Good -*** within 20 percent of baseline (calculated as 0.95-0.76), ***Fair -*** with a decline between 20 and 80 percent (0.75-0.19), and ***Poor*** - decline at or greater than 80 percent (0.18 or less).

Macrhybopsis complex (A)									
	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2000-2017	2013-2017
Upper Arkansas River									
ARK 5				0.06	0.14	0.17	0.01	0.06	0
Upper South Canadian River									
SCAN 5	0.09	*	0.21	*	0.95	0.75	0.48	0.66	0.45

Macrhybopsis complex (B)									
	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2000-2017	2013-2017
Upper Arkansas River									
ARK 5				Poor	Poor	Poor	Poor	Poor	Null
Upper South Canadian River									
SCAN 5	Poor	*	Fair	*	Good	Fair	Fair	Fair	Fair

We evaluated capture ratio results by subunit and decade to determine an 'optimal' ratio to serve as our baseline condition for assigning descriptive rankings used in our resiliency analysis at the end of this chapter. Our assessment is limited to 67 years of survey data; optimal decadal conditions during that time period is likely much different than previous centuries. However, we do consider that optimal conditions (over the span of a decade) within the last 67 years represented suitable conditions for viable self-sustaining populations and can serve as an indicator for resiliency today.

Our results indicate the 'optimal' highest mean capture ratio by decade was 0.95 (176 of 185 survey collections captured *Macrhybopsis* complex), which occurred in SCAN 5 in the 1990s. Using this value as our baseline, we assigned '***Good***' as those within 20 percent of baseline (calculated as 0.95-0.76), '***Fair***' with a decline between 20 and 80 percent (0.75-0.19), and '***Poor***' if the decline was at or greater than 80 percent (0.18 or less).

In determining current condition for the peppered chub we assessed two different time periods; 2000-2017 and 2013-2017, as discussed above. Our 2000-2017 results indicate that the Upper South Canadian River presence to absence ratio was highest at 66 percent with the Ninnescah River (ARK-5) at only 4 percent. With our more recent current condition assessment (2013-2017) our results indicate that the ratio in the Upper South Canadian River dropped to 45 percent (considered Fair) and peppered chubs were not collected (considered null) in the Ninnescah River (ARK-5) during this time period (Table 4-6 B).

Probability of Capture Analysis

Modeled trends for the peppered chub were significantly declining and the probability of capture was approaching zero in SCAN 1, SCAN 2, and SCAN 4 (Figure 4-9, Table 4-4 above). The probability of capture has significantly increased during the sample period exceeding 80 percent in recent years in SCAN 5. Insufficient samples and a preponderance of zero captures in SCAN 3 and SCAN 6 resulted in insignificant regressions.

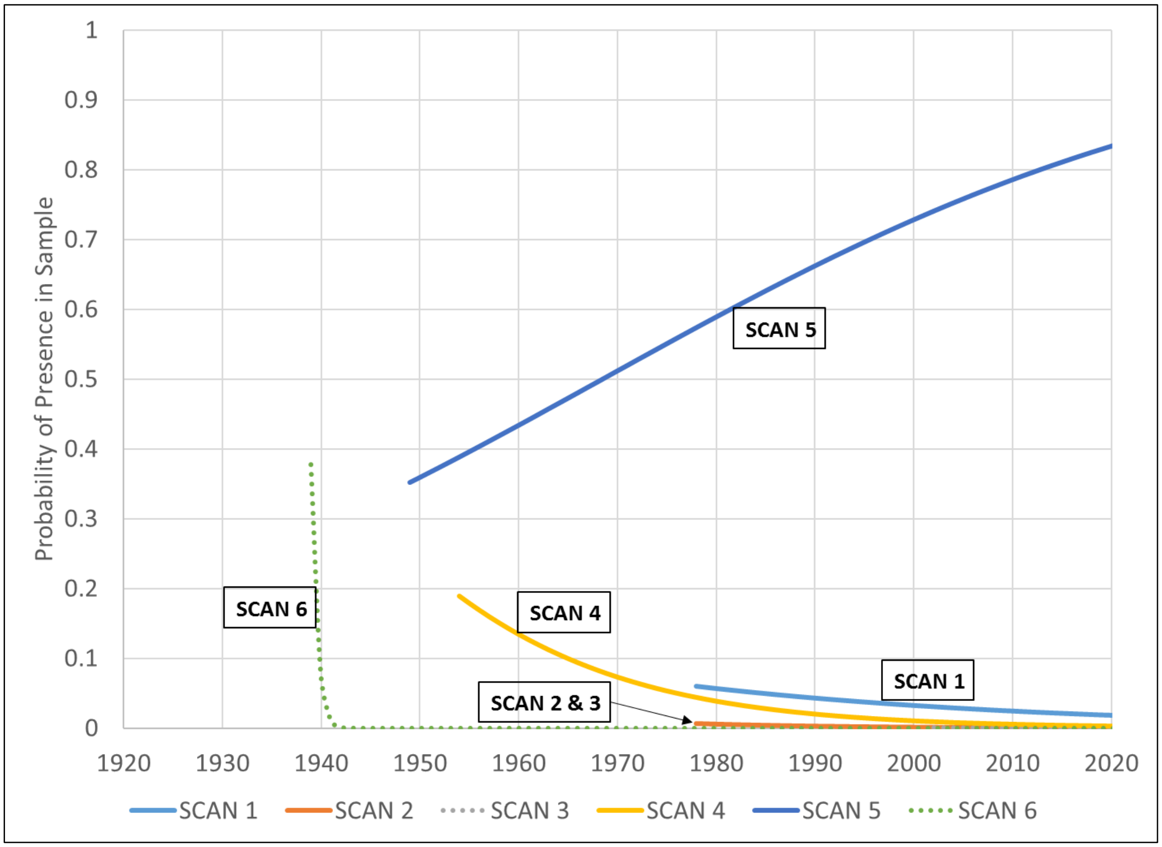


Figure 4-9 Logistic regression estimate lines for the peppered chub in each analysis subunit of the South Canadian River. Dotted lines (SCAN 3 and 6) are not significant and should not be interpreted. Each line represents the probability that a peppered chub will be found in a sample using sampling methods consistent with the methods used to collect the source samples over time.

4.3.2 Relative Abundance

Although evaluation of presence/absence data can provide useful distribution information for both species, it does not shed light on potential shifts in fish community structure where the species still occurs. Therefore, we also assessed the relative abundance of Arkansas River shiner and peppered chub in relation to other species collected, as one means to evaluate potential temporal shifts in fish community structure. A sub-set of our fish collection database used for relative abundance analysis (Table 4-1, above), which is a calculation of Arkansas River shiner or peppered chub to the total number of fishes captured. We removed all collection records where a value for total catch of each species could not be confirmed. Numbers for total catch of each species may not be available in certain museum collections that have been culled due to the large number of individuals that represented that collection. The number of fish collected, as cataloged for those culled collections, likely represents the number of fishes in the museum collection and not the total number of fish collected. Therefore, all museum records (unless otherwise confirmed) were removed from our relative abundance analysis, resulting in an analysis of 3,937 collections, as compared to 8,210 for our presence/absence analysis.

4.3.2.1 Arkansas River shiner

Relative Abundance – Baseline Condition Analysis

The current (2000-2017) relative abundance of Arkansas River shiner in the Upper South Canadian River (SCAN 5) at 32.3 percent, is greater than the historical mean (1900-1999) (Table 4-7). Using this value as our baseline condition for resiliency factors, we assigned ***Good*** to relative abundance within 20 percent of the baseline condition (26 percent-32 percent), ***Fair*** between 20 and 80 percent of the baseline (7 percent-25 percent) and ***Poor*** if less than 20 percent of baseline (<7 percent).

Given these rankings, our analysis indicates that only subunit, SCAN 5, is at the reference optimal condition and considered ***Good***. SCAN 3 with a current relative abundance of 8.0 is considered ***Fair***, with SCAN 1, 2, and 4 all considered ***Poor*** in terms of relative abundance as it compares to baseline conditions.

Table 4-7. Current and historical relative abundance of Arkansas River shiner in the South Canadian River, by subunit, with current condition ranking score.

Arkansas River Shiner		
	1900-1999	2000-Present
SCAN 1	8.0	1.0 (Poor)
SCAN 2	13.0	5.3 (Poor)
SCAN 3	no data	8.0 (Fair)
SCAN 4	20.7	2.5 (Poor)
SCAN 5	28.1	32.3 (Good)

Relative Abundance - Trend Analysis

The relative abundance of Arkansas River shiners has decreased with time in the four analysis subunits of the South Canadian River downstream of Lake Meredith (SCAN-1,2, 3, & 4) (Figure 4-10). There was no significant relationship in the analysis of the South Canadian River upstream of Lake Meredith (SCAN 5 where; were available (Figure 4-10). Three of four significantly declining Quasi-Poisson regression intersect the x-axis (0 percent relative abundance) before the end of sampling. The other declining Quasi-Poisson regression (SCAN 2) intersects the x-axis within the next 5 years. Unlike the Lower South Canadian River (SCAN 1-4), the relative abundance of shiners in the Upper South Canadian River (SCAN 5) have not significantly changed during the sample period. Based on relative abundance alone, our results suggest that the Arkansas River shiner population on the South Canadian River between Ute

Reservoir and Lake Meredith may be the only stable population remaining.

Relative abundance of Arkansas River shiner in samples was calculated by dividing the total number of Arkansas River shiner by the total number of fishes captured in a given sample and converting to percent. Relative abundance was regressed against year using a quasi-Poisson regression in R (GLM package). While a Poisson distribution for regression residuals is ideal for count data, a quasi-Poisson is modified to account for numerous zeros in the dataset. Parameter estimates and fit statistics for both the Arkansas River shiner and peppered chub in the South Canadian River are found in Table 4-8.

Table 4-8. Parameter estimates and fit statistics for the relative abundance quasi-Poisson regressions. Deviance and the change in deviance from null deviance (ΔD) is a measure of goodness of fit.

	Intercept		Slope			
Analysis Sub-Unit	Estimate	*P*-value	Estimate	*P*-value	N	Deviance (ΔD)
Arkansas River Shiner						
SCAN1	156.6847	0.0000	-0.0802	0.0000	89	7.27 (-2.84)
SCAN2	91.0128	0.0000	-0.0469	0.0000	146	13.61 (-3.58)
SCAN3	429.3764	0.0000	-0.2151	0.0000	81	8.74 (-5.21)
SCAN4	71.0727	0.0051	-0.0371	0.0042	86	84.00 (-1.00)
SCAN5	-1.2970	0.8180	0.0001	0.9850	466	91.19 (-0.00)
Peppered Chub						
SCAN1	-101.7260	0.3910	0.0468	0.4290	89	0.19 (-0.01)
SCAN2	-27.3000	0.0555	0.0000	1.0000	146	0.00 (0.00)
SCAN3	-27.3000	0.6230	0.0000	1.0000	81	0.00 (0.00)
SCAN4	84.4882	0.3120	-0.0459	0.2820	86	1.59 (-0.17)
SCAN5	9.3348	0.4010	-0.0059	0.2910	466	81.08 (-0.27)

The relative abundance of Arkansas River shiners has significantly declined in the SCAN 1, 2, 3, and 4 analysis subunits (Figure 4-10, Table 4-8). Though none of the models show relative abundance to have reached zero, relative abundance in these four analysis subunits have declined to less than 5 percent and are asymptotically approaching zero. There was no significant trend in SCAN 5. Throughout the sampled period (1954 to 2016) the modeled relative abundance has remained stable at 30 percent. The lack of a significant directional trend and the large number of samples in the SCAN 5 analysis subunit indicate a stable Arkansas River shiner population.

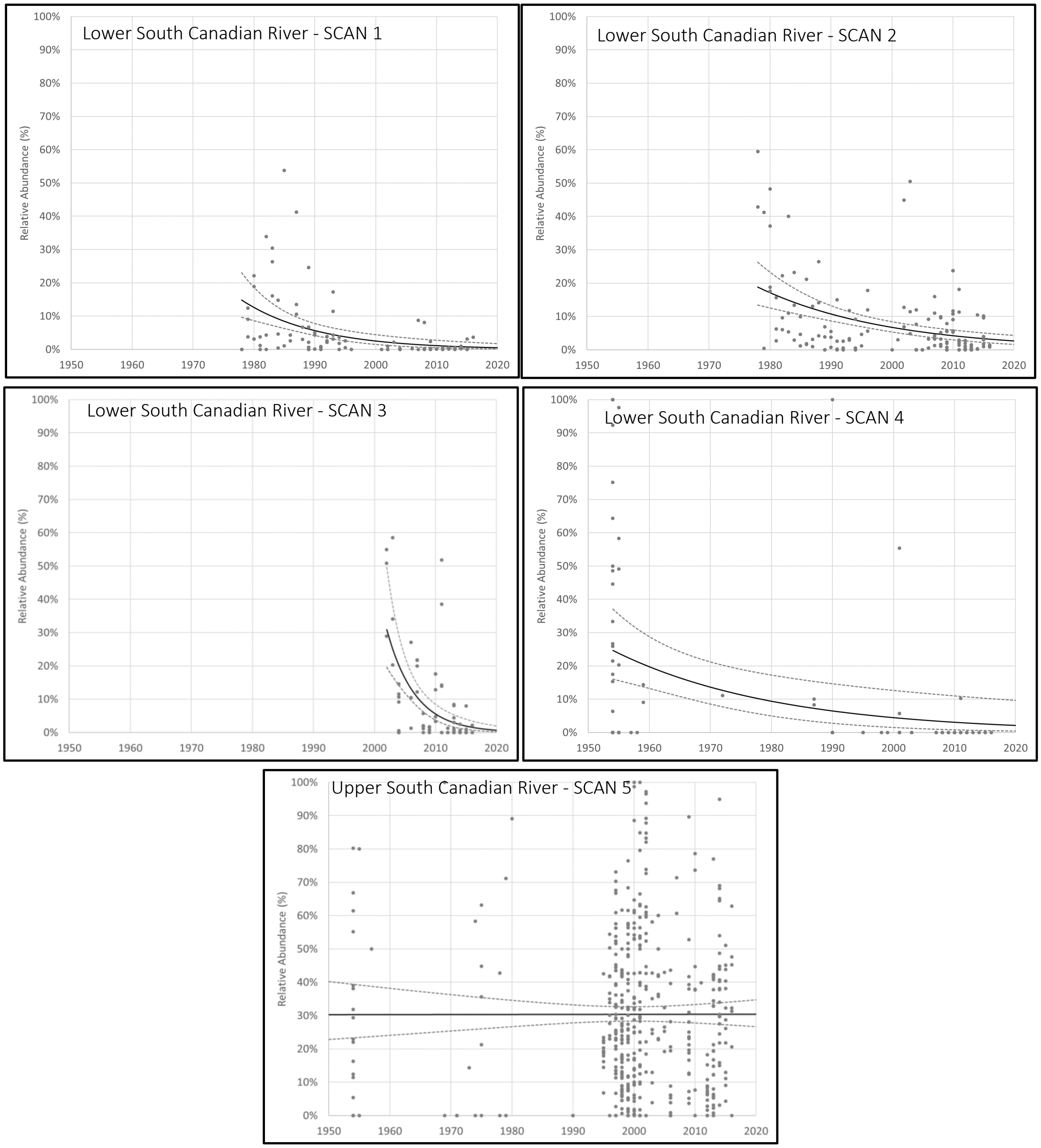


Figure 4-10. Relative abundance of Arkansas River shiner in the South Canadian River, subunits 1-5. Each dot represents relative abundance of Arkansas River shiner in a single collection. Quasi-Poisson regression (solid black lines) with 95 percent regression confidence intervals (gray dashed lines).

4.3.2.2 Peppered Chub

Relative Abundance – Baseline Condition Analysis

The mean relative abundance of peppered chub, from 1900-1999, in SCAN 5 at 13.9 percent is the highest value (Table 4-7). Using this value as our baseline condition for resiliency factors, we assigned ***Good*** to relative abundance within 20 percent of the baseline condition (11 percent-13.9 percent), ***Fair*** between 20 and 80 percent of the baseline (3-10 percent) and ***Poor*** if less than 20 percent of baseline (<3 percent). Given these rankings, our analysis indicates that peppered chub relative abundance in the Upper South Canadian River (SCAN 5) is considered ***Poor*** for both 2000-2017 and 2013-2017 time periods. Peppered chub relative abundance in the Ninnescah River (ARK 5) is considered ***Poor*** in the 2000-2017-time period and null (not collected) in the 2013-2017 period.

Table 4-9. Current and historical relative abundance of peppered chub in SCAN 5 of the Upper South Canadian River and ARK 5 of the Upper Arkansas River, which includes the South Ninnescah River, with current condition ranking score.

Peppered chub			
	1900-1999	2000-2017	2013-2017
ARK 5	0.1	0.2	0
SCAN 5	**13.9**	2.0	1.7

4.3.3 Community Analysis

The following fish community analysis is provided to better describe changes in fish community structure, it relates to Arkansas River shiner and peppered chub. Results from this analysis are not used quantitatively in our resiliency results at the end of this chapter, however they do provide additional insight on community changes that have taken place.

All available data (1926 to 2017) for fish communities in the Upper and Lower South Canadian River were converted to presence/absence data to maximize the number of samples included in the multivariate analysis. Only fishes reported as a species (no genus level or uncertain identifications) were included, with two exceptions: the *Macrhybopsis* complex (see section 4.3.1.2, above for further explanation) and what we refer to at the *Fundulus* complex, which included *Fundulus kansae* and *Fudulus zebrinus*. Similar to species of the *Macrhybopsis* complex, both of these *Fundulus* species went through a name change during the time of our collection records and after examining collection results, it was apparent that many specimens were incorrectly named. Therefore, for this analysis we combined *F. kansae* and *F. zebrinus*, which we refer to as the Plains killifish complex (Placom). Finally, only species that occurred in at least 10 percent of samples were examined in these analyses (see Table 4-10 for a list of species). A detrended correspondence analysis (DCA) explored gradients in the species presence at sample sites (R, R Core Team 2017; Vegan package, Oksanen et al. 2018.

Table 4-10. A list of all species included in the multivariate analysis of South Canadian River fish communities. Species codes are truncations of the scientific names and are used to identify species in the analysis visualization.

Code	Scientific Name	Common Name
Notgir	*Notropis girardi*	Arkansas River Shiner
MacCom	*Macrhybopsis complex*	Chub Complex
Carcar	*Carpiodes carpio*	River Carpsucker
Cypcar	*Cyprinus carpio*	Common Carp
Cyplut	*Cyprinella lutrensis*	Red Shiner
Cyprub	*Cyprinodon rubrofluviatilis*	Red River pupfish
Dorcep	*Dorosoma cepedianum*	Gizzard Shad
Placom	*Fundulus kansae*	Northern Plains Killifish
Placom	*Fundulus zebrinus*	Plains killifish
Gamaff	*Gambusia affinis*	Western Mosquitofish
Hybpla	*Hybognathus placitus*	Plains Minnow
Ictpun	*Ictalurus punctatus*	Channel Catfish
Lepcya	*Lepomis cyanellus*	Green Sunfish
Lephum	*Lepomis humilis*	Orangespotted Sunfish
Lepmac	*Lepomis macrochirus*	Bluegill
Lepmeg	*Lepomis megalotis*	Longear Sunfish
Micsal	*Micropterus salmoides*	Largemouth Bass
Notath	*Notropis atherinoides*	Emerald Shiner
Notstr	*Notropis stramineus*	Sand Shiner
Phemir	*Phenacobius mirabilis*	Suckermouth Minnow
Plagra	*Platygobio gracilis*	Fathead chub
Pimpro	*Pimephales promelas*	Fathead Minnow
Pimvig	*Pimephales vigilax*	Bullhead Minnow

Generally, the two species of interest (Arkansas River shiner and peppered chub) separated from most other species along the first axis of the DCA (Figure 4-11). The two species of interest were most closely correlated with each other, the plains killifish complex, and other plains associated minnows (blue grouping, Figure 4-11). Suckermouth minnows, largemouth bass, and most sunfish presences were negatively correlated to the presence of the species of interest (red grouping, Figure 4-11). A group of fishes was plotted intermediate to the red and blue groups. The intermediate group (orange grouping, Figure 4-11) were not correlated with either the Plains minnow group or the sunfish group indicating that those intermediate fishes could co-occur or not occur with either group. Several fishes contained within the intermediate group (e.g., mosquitofish, carp, shad, fathead and bullhead minnows) are cosmopolitan and frequently occur in widely varied and distributed habitats. The Euclidean distance in the first four DCA dimensions of the analyzed fishes from the species of interest were calculated and plotted to better show the community gradient relative to the Arkansas River shiner and peppered chub. Again, there is a clear gradient in the South Canadian River fish community (Figure 4-12). Fishes associated with the Arkansas River shiner and peppered chub are smaller minnows or minnow-like fishes that can excel in shallow, fast moving environments. This community transitions to fishes more commonly associated with larger systems with more open runs (suckermouth minnow, carp, and sunfishes) and structure (sunfishes).

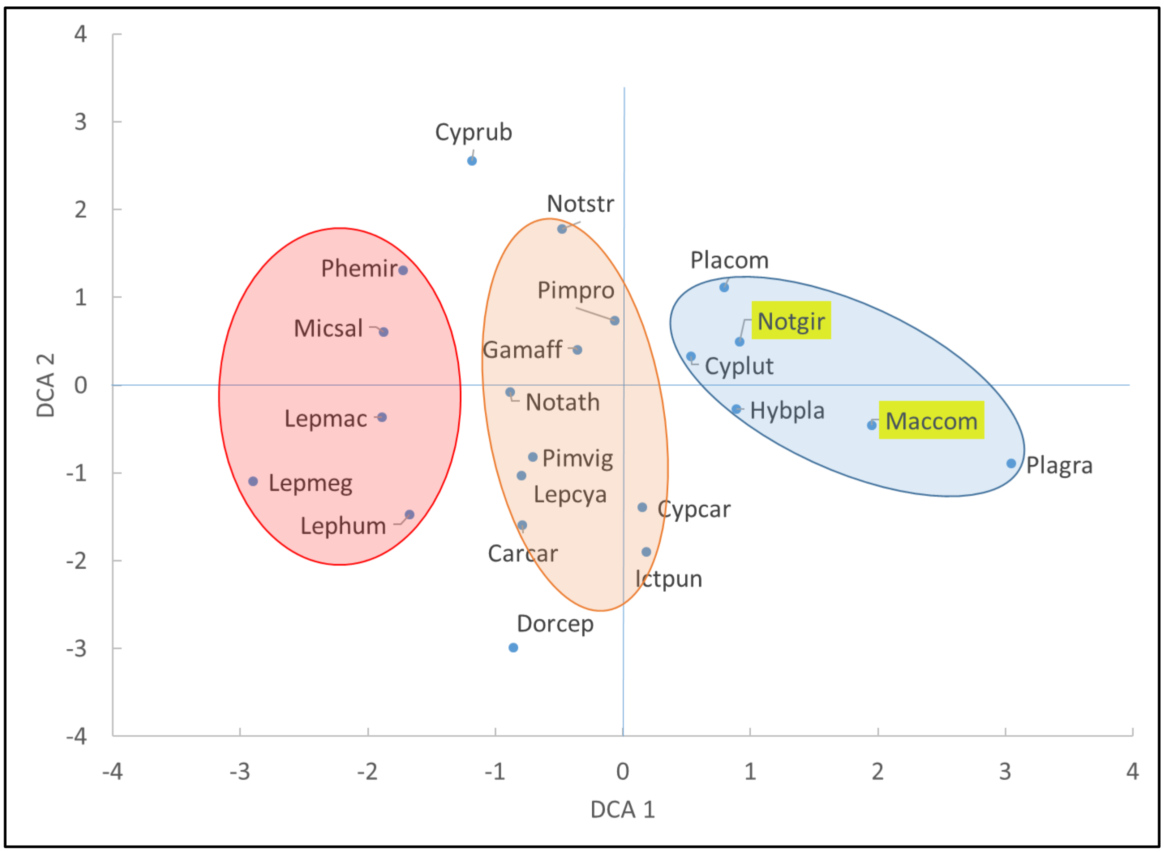


Figure 4-11. Species occurring in samples taken from the Upper and Lower South Canadian River plotted on the first two detrended correspondence analysis axes. The species of interest, Arkansas River shiner (Notgir) and peppered chub (MacCom), are highlighted in yellow. Apparent community gradient groupings are circled in red (left), orange (middle), and blue (right).

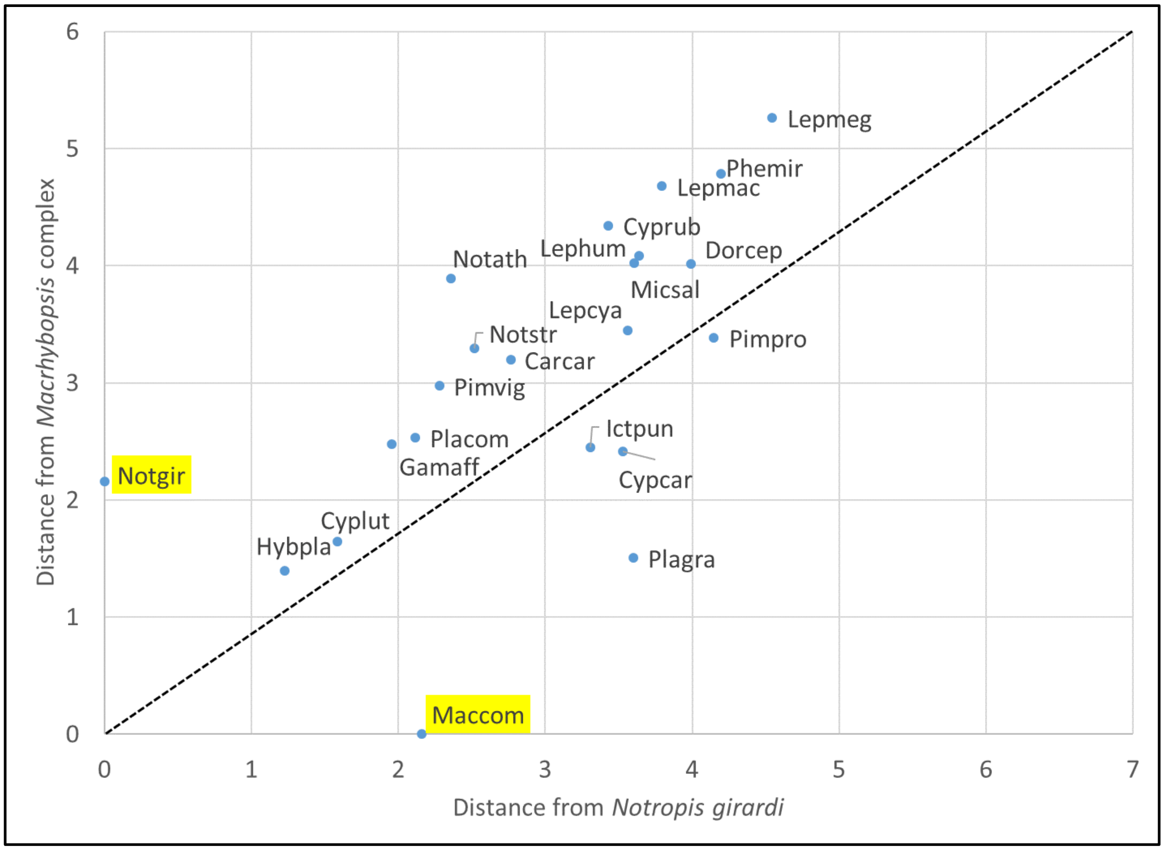


Figure 4-12. Euclidean distance in four dimensional space between each fish species score (from DCA) and the two species of interest, Arkansas River shiner (Notgir, horizontal axis) and peppered chub (MacCom, vertical axis). A black, dashed line indicates the location where species would be equidistant from the two species of interest.

Sample sites along the South Canadian River were blocked by sample decade and analysis subunit. In the early decades of sampling, analysis subunit communities separated primarily along the first DCA axis as an upstream to downstream gradient from left (negative) to right (positive, Figure 4-13). During the ensuing decades, those subunits have shifted in community composition towards communities more similar to those only found in the downstream subunits and away from the two species of interest. Re-plotting those subunit scores by decade using the Euclidean distance of those subunits from the species of interest results in Figure 4-14. Before 1940, Figure 4-14 shows the differences in communities between upstream (SCAN 3 and SCAN 5) and downstream (SCAN 1 and SCAN 2) with conflicting results in SCAN 4. After the construction of Conchas Dam in 1939, which is upstream of all samples, all subunits began to exhibit similar communities to the downstream subunits. After the construction of Ute Dam (upstream of SCAN 5) and Sanford Dam (between SCAN 4 and SCAN 5), SCAN 1 thorough SCAN 4 eventually grouped together, resembling the historic downstream community. During that same period, SCAN 5 became distinct from the other analysis subunits, most closely resembling the historic upstream community by being intermediate to the historic upstream and downstream communities.

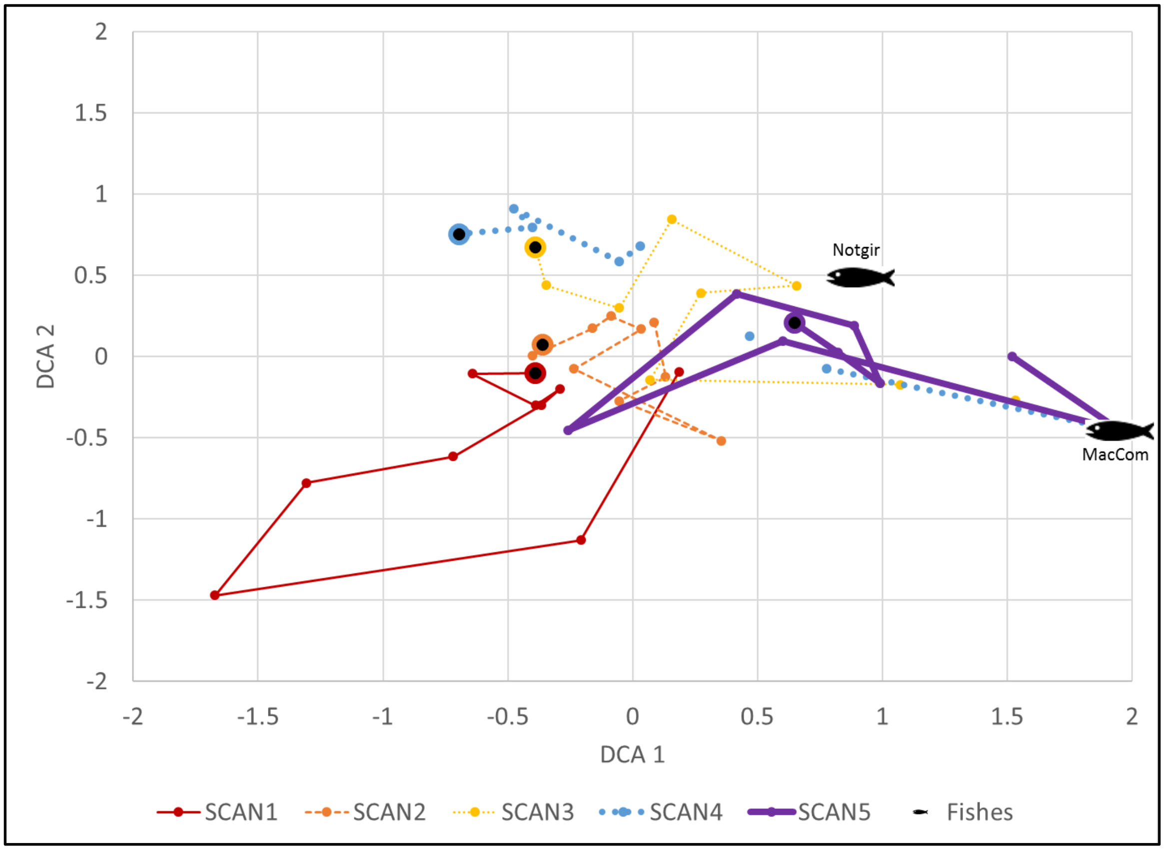


Figure 4-13. Mean analysis subunit scores by decade plotted against the first two DCA axes. The final decade of samples (2010) is indicated by enlarged points with black fill. Lines connect decadal sample means in chronological order. No connection indicates a gap in sampling occurring over more than one decade. For reference to the species of interest, the locations of the Arkansas River shiner (Notgir) and peppered chub (MacCom) are also plotted.

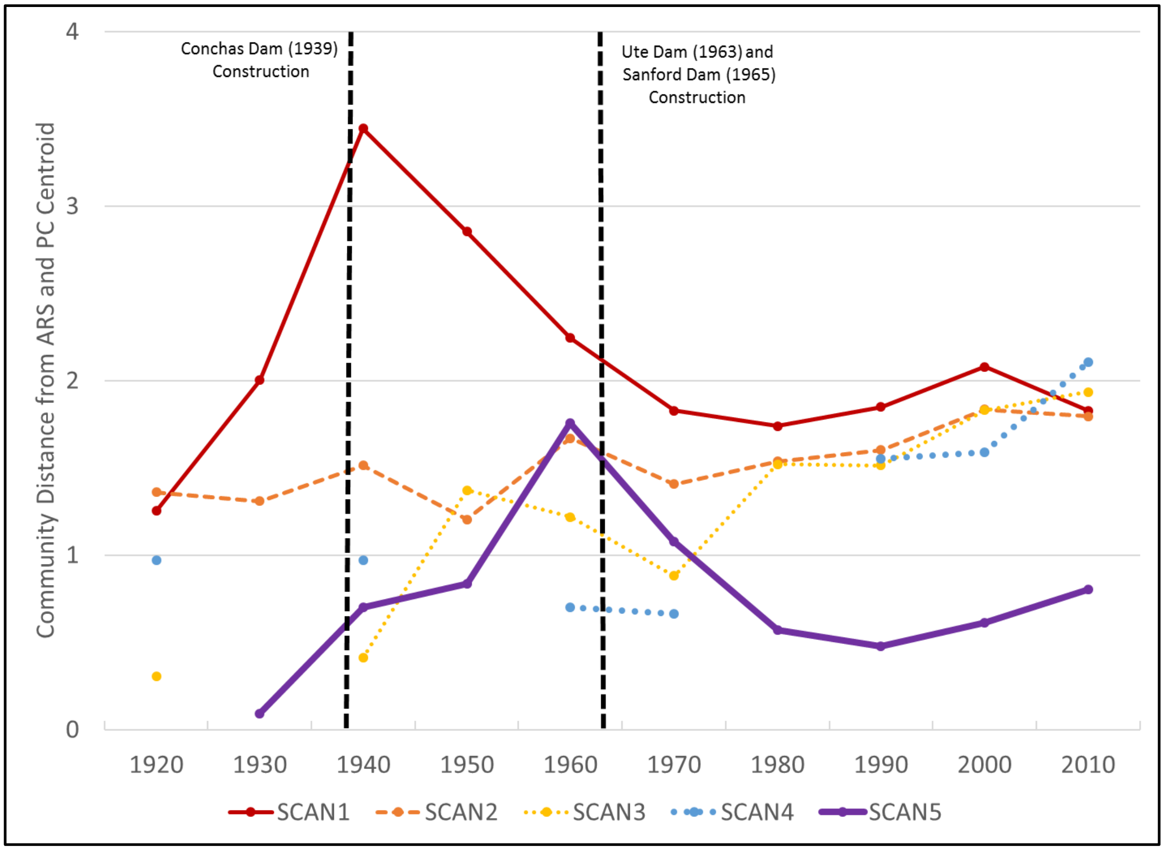


Figure 4-14. The Euclidean distance between mean South Canadian River analysis subunit DCA scores (first two dimensions) and the average of Arkansas River shiner and peppered chub scores (centroid) by decade. The approximate temporal location of dam constructions on the South Canadian River are indicated by vertical dashed lines.

Both populations of fishes have significantly declined in all analyzed reaches, except for SCAN 5 where populations have remained relatively stable. The likely functional extirpations and declines of both Arkansas River shiner and peppered chub across the basins studied in this report cannot be fully explained by these population and community analyses alone. However, these analyses do provide strong coincidental evidence that upstream and downstream fish communities are becoming more similar. This qualitative trend matches a trend reported by Luttrell et al. (1999) that there was a relationship between the extirpation of chubs (*Macrhybopsis tetranema* and *M. hyostoma*) from significant reaches of the Arkansas River Basin and the construction of large, flood-control reservoirs.

4.4 HABITAT FACTORS

4.4.1 System Hydrology

Ecohydrology is a merger of the fields of ecology and hydrology that explores the interactions between biological communities and the water cycle. We selected a total of 17 U.S. Geological

Survey (USGS) stream gages within the South Canadian, North Canadian, Beaver, Cimarron, and Arkansas River systems in order to characterize the historical and contemporary hydrology. Gages with long-term data records spanning all Resiliency Units (with the exception of the Lower Arkansas River) were the target of our selection. In addition, there are a number of impoundments which have a strong influence on the natural flow regime. Our intent is to use an ecohydrological approach to: 1) evaluate the effect of the impoundments on the aggregate hydrology of these systems and 2) compare these effects with the population dynamics of the Arkansas River shiner and peppered chub. Figure 4-15 shows the location of the stream gages and impoundments we considered in our analysis.

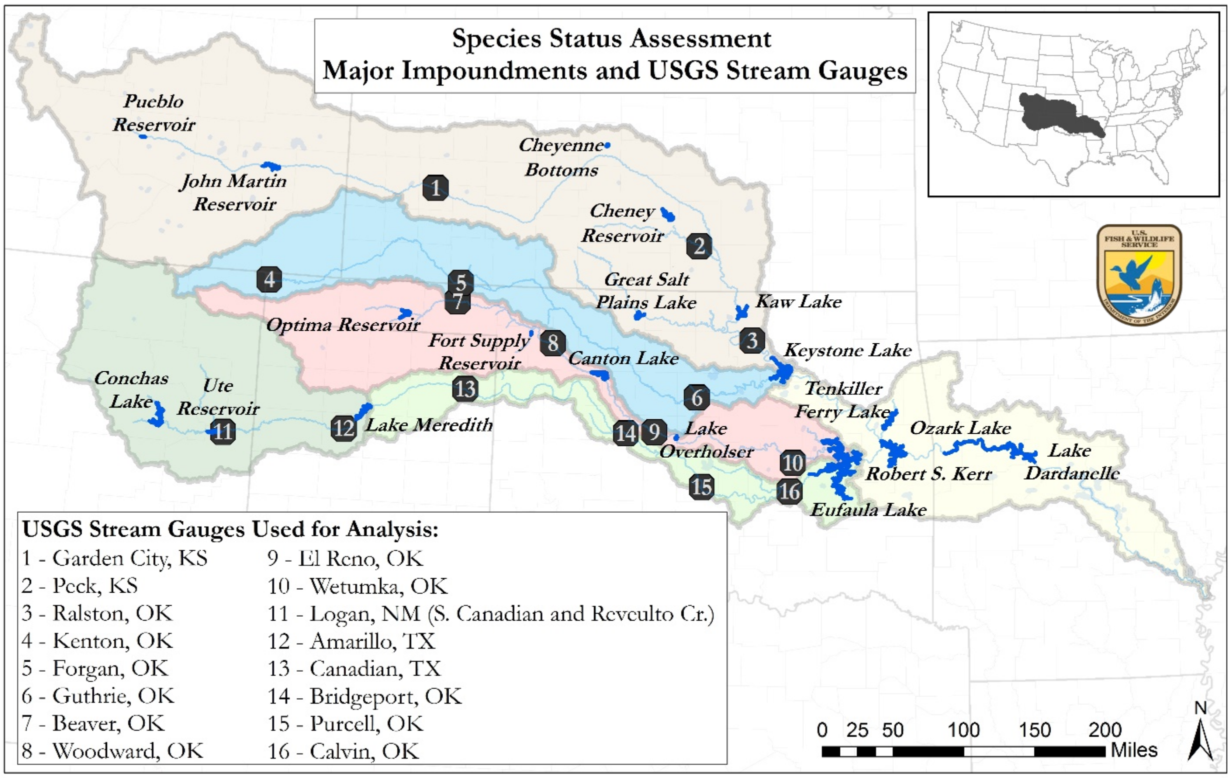


Figure 4-15. Major impoundments and USGS stream gages used for hydrologic analyses.

The alteration of the natural flow regime is regarded by many to be the single greatest and persistent threat to the ecological integrity of freshwater ecosystems (Poff et al. 1997, p. 769; Bunn and Arthington 2002, p. 492). Dams, groundwater pumping, and other surface water diversions can dramatically alter a hydrograph and transform the structure and function of both aquatic and riparian ecosystems (Poff et al. 1997, p. 773; Bunn and Arthington 2002, p. 492; Tockner and Stanford 2002, p. 312). Important facets of flow alterations include impacts on the magnitude, duration, frequency, and timing, of the annual hydrograph.

First, we focus our analysis on the magnitude of a seasonally defined, mean daily discharge that is then pooled decadaly as an indicator of systemic change in response to the installation of dams and their impoundments (e.g., Baxter 1977, p. 256). Second, we examine the magnitude and shifts in return intervals from a flood frequency analysis as a high-flow metric intended to capture the collective effect of dams on peak discharge values.

Lastly, we turn to a low-flow metric as a means to characterize how the installation of dams and their impoundments may have altered low-flow conditions and how frequent these conditions occur through time. We follow the convention established previously of grouping our analyses by Resiliency Unit as discussed in Section 4.2 and shown in Figure 4-2. Table 4-11 provides the definitions of the hydrology metrics.

4.4.1.1. Hydroperiod and Mean Daily Discharge

We examined mean daily discharge data for the period of record (POR) for each stream gage and determined the start and end date for the spring runoff, summer, and fall hydrographs. Termed here as the hydroperiod, this interval provides some collective insight into the period of time most relevant to fish spawning and recruitment (spring and summer) as well as the effects the annual hydrograph has upon geomorphology and channel planform. After inspecting all stream gages within a given Resiliency Unit, we then assigned a single, comprehensive time interval (e.g., March-November) that best captures the relevant portions of the annual hydrograph. After specifying the hydroperiod, we then pooled the mean daily discharge values by decade for each stream gage and compared the pre- and post-impoundment (decades following completion of impoundment) periods.

We scored the hydroperiod metric, for each stream gage, as the percent difference between the mean post-impoundment and pre-impoundment discharge for the appropriate hydroperiod, which determines the overall proportion of gains or losses in average stream discharge from pre- and post-impoundment during the period of time most important for the fishes and the maintenance of their habitat. That is:

$$\text{Percent difference} = \frac{\text{Mean post-impoundment discharge - Mean pre-impoundment discharge}}{\text{Mean pre-impoundment discharge}} \times 100$$

In short, the metric contrasts the effects of dams on the natural flow regime.

Table 4-11. Hydrology metric definitions.

Condition Rating	Hydroperiod	Flood Frequency Analysis	Low-flow Conditions
Null	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **greater than a 90% decrease**.	**The weighted sum of the proportional differences for the 2, 5, and 10 year events** between pre- and post-impoundment is less **than 10%.**	_
Poor	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **between a 25-90% decrease**.	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **between 10-50%**.	**An increasing pattern or high frequency** in the number of days of less than 0.57 m^3/s (20 ft^3/s).
Fair	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **between a 10-25% decrease**.	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **between 50-75%**.	**A cyclical pattern** (**or in a headwater/intermittent tributary location**) in the number of days of less than 0.57 m^3/s (20 ft^3/s).
Good	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **from a positive gain to a 10% decrease**.	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **greater than 75%.**	**A decreasing pattern or low frequency** in the number of days of less than 0.57 m^3/s (20 ft^3/s).

Categorically, a ***Good*** condition for the hydroperiod metric is when there is any gain in post-impoundment discharge to a loss of up to 10 percent. A ***Fair*** condition is a 10-20 percent decrease in post-impoundment discharge and ***Poor*** condition is represented by a 25-90 percent decrease. A ***Null*** condition exists where there is greater than a 90 percent decrease in post-impoundment mean stream discharge during the hydroperiod (Table 4.1).

Again, dams represent the single greatest factor to both aquatic habitat fragmentation and effects to the natural flow regime. With an estimated average density of one dam every 42 km (26.1 mi) in third through seventh order rivers in the United States (Poff et al. 2007, p. 5732) and only 42 rivers greater than 200 km (124.3 mi) free from regulated flows (Poff et al. 2007, p. 5733), dams have greatly altered aquatic ecosystems on a continental scale. We therefore chose to predicate both the hydroperiod and flood frequency (see Section 4.3.1.2) metrics on a comparison of pre- and post-impoundment periods.

Alternative scoring criteria – There are, however, six stream gages that either do not have an upstream dam that we identified or the POR does not include the pre-impoundment period. These include the following:

All stream gages in the Cimarron River Resiliency Unit (no upstream dams)

- USGS 07154500; Cimarron River near Kenton, OK (CIMA 4)
- USGS 07156900; Cimarron River near Forgan, OK (CIMA 3)
- USGS 07160000; Cimarron River near Guthrie, OK (CIMA 1)

North Canadian River Resiliency Unit

- USGS 07242000 North Canadian River near Wetumka, OK (NCAN 1; no stream gage data prior to Lake Overholser constructed in 1918)

Upper South Canadian River Resiliency Unit

- USGS 07227100; Revuelto Creek near Logan, NM (SCAN 5; Revuelto Creek is an unregulated tributary to the South Canadian River)

Lower South Canadian Resiliency Unit

- USGS 07229200; Canadian River at Purcell, OK (SCAN 2; no data prior to Lake Meredith, 1965)

Scoring these gages in a way that is generally congruent with those that do have an upstream impoundment or POR that spans an impoundment date is problematic. Nonetheless, we needed to provide some context in terms of a current condition that reflects past patterns and any change therein. We therefore asked if there is a notable trend in the decadal averages during the hydroperiod since 1980 relative to the past. This approach gives us some ability to assess current conditions and reasonably project that into the future. This is, in part, a qualitative metric as the categorical ratings are not numerically based but represent an increasing or stable trend (***Good***), a cyclical pattern where the future direction is not clear (***Fair***), or a decreasing trend (***Poor***). In the case of the ***Fair*** rating, there are several states where the cyclical pattern may be on the increase, decrease, or at the top/bottom of a given cycle. In any case, we simply cannot confidently predict, given the array of potential perturbations, the near-term direction of the cycle. Thus, we rated these cases as ***Fair*** even though the future could be increasing or decreasing.

The Upper Arkansas River Resiliency Unit – The stream gages in the Upper Arkansas River Resiliency Unit evaluated include the following:

- USGS 07139000; Arkansas River at Garden City, KS (subunit ARK 6);
- USGS 07145500; Ninnescah River near Peck, KS (subunit ARK 5); and
- USGS 07152500; Arkansas River at Ralston, OK (subunit ARK 4).

We determined the hydroperiod for the Upper Arkansas River Resiliency Unit as lasting from April-November (Figure 4.16). Although the Ninnescah River near Peck, KS and the Arkansas River at Ralston, OK gages (Appendix B - Hydrology) have a spring ascending limb beginning as early as January, we deemed April as more appropriate based on the needs and life history characteristics of the fishes.

The Garden City gage is located approximately 177 km (110 mi) downstream of John Martin Reservoir. Constructed and managed by the U.S. Army Corps of Engineers, John Martin Reservoir is located in eastern Colorado and was completed in 1948. It is used for flood control, irrigation storage, and as a recreational facility (USACE 2017, entire). John Martin is located toward the headwaters of the Upper Arkansas River Resiliency Analysis Unit, and thus an important and influential position in the system.

The Garden City gage is the most upstream gage we evaluated in the Upper Arkansas River Resiliency Unit. Current condition results for the hydroperiod metric at this gage are rated as ***Poor*** as the percent difference between pre- and post-impoundment is -57.8 percent; a decline in average stream discharge during the hydroperiod of nearly 60 percent.

The influence of John Martin Reservoir has dramatically altered the pre-impoundment hydrograph (Figure 4-16a). In particular, the first spring runoff pulse (≈ Julian Day [JD] 111) has been virtually eliminated in the post-impoundment era, which Kelly et al. (2005, p. 1-3) maintains that, among other attributes, is a key biotic and abiotic characteristic of the annual hydrograph.

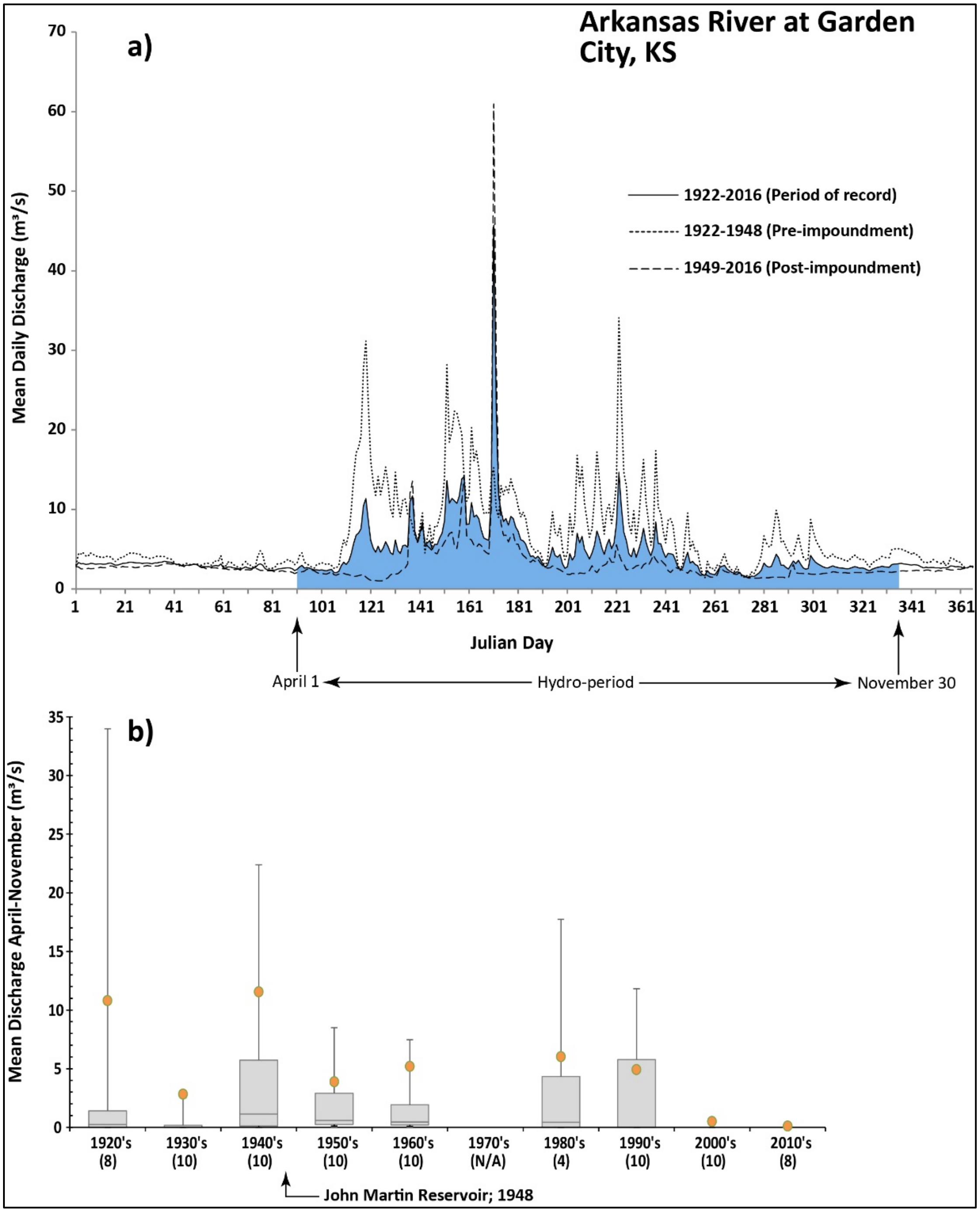


Figure 4-16. Stream gage data at USGS 07139000; Arkansas River at Garden City, Kansas. Upper panel (a) shows the mean daily discharge for the period of record (6/21/1922-12/31/2016) and the pre- and post-impoundment periods. Also shown is the hydroperiod for the Upper Arkansas River Resiliency Unit. Lower panel (b) is the mean discharge for the hydroperiod by decade. The bottom of the boxes represents the 25th percentile and the top of the boxes represents the 75th percentile. The line through the box represents the median value and the colored dot indicates the mean. Bars above and below the boxes represent the 90th and 10th percentiles, respectively. Sample size (in years) is shown in parentheses.

While the Arkansas River shiner will spawn in response to lessor spring runoff events and summer spates, population maintenance over time is likely linked to spring and early summer spawn. In addition to the alteration in magnitude and timing of the spring spawning period, there is a considerable reduction in discharge throughout the majority of the hydroperiod with the notable exception of the almost instantaneous peak around JD 171, or June 20th. This peak (rising quickly to approximately 10-fold over the preceding values) bears little resemblance to the pre-impoundment (natural) flow regime and is likely tied to reservoir operations and irrigation or interstate compact deliveries. Not only are reproduction cues affected by this reduction in discharge, but with lower flows the species' ability to move upstream (after its downstream egg and larval dispersal) becomes more limited.

The decadal distribution of flows at the Garden City gage shows a somewhat muted signal of post-impoundment stream discharge. This is likely a function of the considerable distance downstream from John Martin and the various sources of local inflow in the reach between John Martin and the Garden City gage. Nonetheless, there is an altered flow regime as both variability and high flow events have decreased since dam completion in 1948. Notable departures from this pattern include droughts of the 1930s and the wet period of the 1980s and 1990s. Taken together, however, the overall pattern suggests a degree of homogenization of the system (e.g., Poff et al. 2007, p. 5732) where both high and moderate flows deviate from the unregulated state. Most salient, and of greatest concern in this reach (ARK 6 subunit), is the trend in the 2000s and 2010s where flows are severely diminished from regional drought.

Conversely, the Peck, KS gage on the Ninnescah River (ARK 5 subunit) and Ralston, OK gage on the Arkansas River (ARK 4 subunit) show a different dynamic. Although both gages have upstream impoundments (Cheney Reservoir on the north fork of the Ninnescah River and Great Salt Plains Reservoir and Kaw Reservoir affecting the Arkansas River), there appears to be a somewhat natural flow pattern during the hydroperiod. Cheney Reservoir was built and managed by the Bureau of Reclamation for water supply and was completed in 1964. Great Salt Plains Reservoir was built by the U.S. Army Corps of Engineers as a flood control facility and was completed in 1941; however, the lake has never filled to capacity and currently suffers from high salt concentrations. Kaw Lake was built and completed by the U.S. Army Corps of Engineers as a flood control facility and completed in 1976. A hydroelectric plant with an annual capacity of 104 gigawatt hours was added subsequently in 1981. Again, despite these facilities, the pre- and post-impoundment hydrographs are comparable in most respects. Notable exceptions are diminished peak flows on the Ninnescah River and a fairly consistent pattern of increased mean daily discharge during the post-impoundment period on the Arkansas River, which are presumably due to demands of the hydroelectric power plant at Kaw Lake. Current condition rankings for both the Peck, KS and Ralston, OK gages are both ***Good***, with the Peck, KS gage showing -5.5 percent loss and the Ralston, OK gage showing a 24.2 percent gain in hydroperiod mean daily discharge.

The Cimarron River Resiliency Unit – The stream gages in the Cimarron River Resiliency Unit we evaluated include the following:

- USGS 07154500; Cimarron River near Kenton, OK (CIMA 4)
- USGS 07156900; Cimarron River near Forgan, OK (CIMA 3)
- USGS 07160000; Cimarron River near Guthrie, OK (CIMA 1)

Again, none of the Cimarron River Resiliency Unit gages have an upstream dam and were therefore subject to the alternative scoring criteria presented previously. Here, we determined the hydroperiod spanning from March-November (Figure 4-17). In terms of the mean daily hydrograph, the Kenton, OK and Forgan, OK gages are quite different from the Guthrie, OK gage (Forgan, OK and Guthrie, OK are shown in *Appendix B – Hydrology*). Both the Kenton, OK and Forgan, OK gages abruptly increase from winter base flows with no apparent spring runoff signal whereas the Guthrie, OK gage has a discernable ascending limb. Mean flows do gradually increase at the Kenton gage, but they peak in mid-August which would tend to preclude a characteristic spring runoff pattern especially given its headwater location near the New Mexico border (Figure 4.17a). The Kenton, OK gage shows a high degree of flashiness that ostensibly arise from storm events that can be attributed, at least in part, to its headwater positon in the system. Again, however, the absence of a spring runoff signal is fairly atypical. More telling, however, is the steadily decreasing pattern in decadal mean flows during the hydroperiod (Figure 4.17b). Here, irrigation withdrawals are likely not a key factor given the overall low volume of water available in the headwaters reach. The decadal plots also illustrate the extreme, flashy nature of the river in this reach as the mean discharge values during the hydroperiod are well beyond the 90^{th} percentile. The 2010s do, however, show an encouraging upward trend and mean flows are approaching historical levels. Nonetheless, in lieu of the overall decreasing pattern, we rated the Kenton, OK gage as ***Poor*** as there is no readily discernable cyclic pattern and declines in discharge variability, mean, and median values have steadily decreased since the 1960s (with the exception of the 2010s). Even when considering the 2010s, the pattern at the Kenton, OK gage suggests a system in hydrologic decline with an uncertain future.

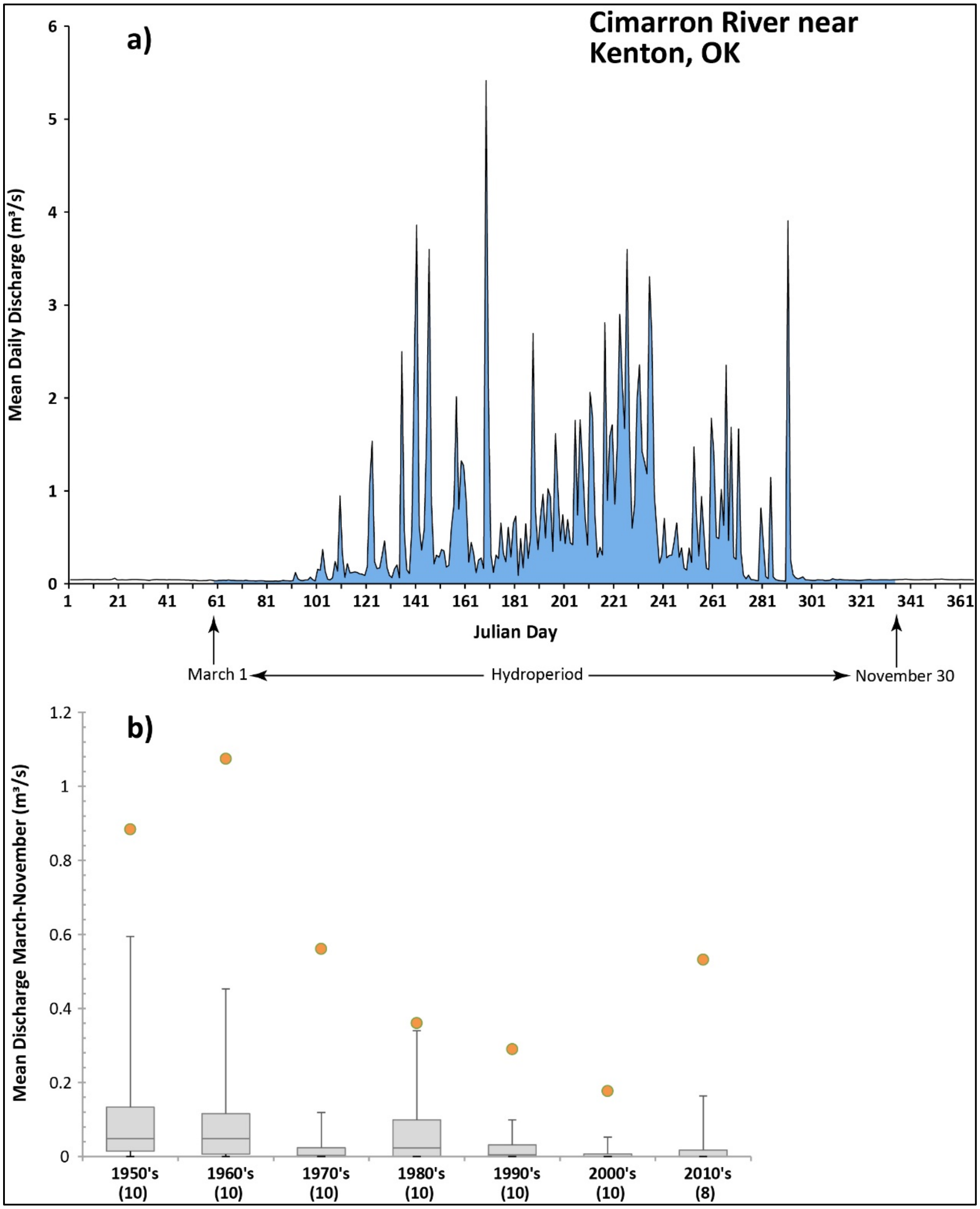


Figure 4-17. Stream gage data at USGS 07154500; Cimarron River near Kenton, OK. Upper panel (a) shows the mean daily discharge for the period of record (10/1/1950-12/31/2016). Also shown is the hydroperiod for the Cimarron River Resiliency Unit. Lower panel (b) is the mean discharge for the hydroperiod by decade. The bottom of the boxes represents the 25th percentile and the top of the boxes represents the 75th percentile. The line through the box represents the median value and the colored dot indicates the mean. Bars above and below the boxes represent the 90th and 10th percentiles, respectively. Sample size (in years) is shown in parentheses.

The gage near Forgan, OK is situated approximately 256 km (159 mi) downstream from the Kenton, OK gage, roughly one-third of the Cimarron's overall length. The gage itself is located in Kansas just across the border. The Forgan, OK gage shows a more stable pattern with year-round flows of between 1 and 1.5 m^3/s (35 to 53 ft^3/s). The Forgan, OK gage also displays some pronounced flow variability but to a lesser degree than the Kenton, OK gage. The Forgan, OK gage exhibits a slight summer low-flow signal which could suggest some local irrigation or other consumptive withdrawal in the reach between the Kenton, OK and Forgan, OK gages. Here again, the decadal pattern during the hydroperiod demonstrates a progressive decline since the 1960s, with the current decade (2010s) being less than half of those in the 1960s. Flow variability has also decreased dramatically. We therefore rated the Forgan, OK gage as ***Poor***.

Being the farthest downstream, the Guthrie, OK gage displays a more seasonally characteristic pattern. That is, there is a defined spring ascending limb, a summer low-flow period, a period of increase flows arising from summer/fall convective thunderstorms, and a winter base flow interval. The decadal distribution of the hydroperiod shows a clear cyclical pattern that reflects a wet period of the 1980s and 1990s as well as the recent drought of the 2000s and 2010s. The 2010s are the driest decade of the period of record. Given the cyclical pattern and the uncertainty surrounding future trends, we therefore rated the Guthrie, OK gage as ***Fair***.

The North Canadian River Resiliency Unit – The stream gages in the North Canadian River Resiliency Unit we evaluated include the following:

- USGS 07234000 Beaver River at Beaver, OK (subunit NCAN 3)
- USGS 07237500 North Canadian River at Woodward, OK (subunit NCAN3)
- USGS 07239500 North Canadian River near El Reno, OK (NCAN 2)
- USGS 07242000 North Canadian River near Wetumka, OK (NCAN 1)

We determined the hydroperiod for the North Canadian River Resiliency Unit as lasting from March-November (Figure 4-18). The Beaver River merges with the North Canadian River near Fort Supply Lake and is therefore the farthest upstream gage we examined in this system. The remainder of the gages in the North Canadian Resiliency Unit are shown in *Appendix B - Hydrology*.

The Beaver River at Beaver, OK gage (henceforth the Beaver, OK gage) is located in the Oklahoma panhandle approximately 63 km (39 mi) downstream of Optima Lake. Optima Lake was completed in 1978 by the U.S. Army Corps of Engineers but has never reached capacity due to decreasing streamflow caused by extensive groundwater pumping (Wahl and Tortorelli 1997, p. 3). Both groundwater extraction and the completion of the Optima Lake impoundment have dramatically altered the hydrograph (Figure 4-18a); peak discharge values (spawning cues, habitat maintenance and expansion, etc.) are greatly attenuated in the post-impoundment era. Figure 4-18b also demonstrates the continual decline in hydroperiod flow where both magnitude and variability are merely a fraction of their historical values. The rating for the Beaver, OK gage is therefore ***Null*** as the percent decline between pre- and post-impoundment is 90.2 percent. Again, that's not to imply that Optima Lake is the sole factor influencing this decline as widespread groundwater extraction has certainly taken a toll on the system over time.

The Woodward, OK gage is located approximately 40.5 km (25 mi) downstream of the Wolf Creek and North Canadian confluence. Fort Supply Lake was completed in 1942 by the U.S. Army Corps of Engineers as a flood control and conservation storage facility on Wolf Creek, a tributary of the North Canadian River. Optima Lake is approximately 137 km (85 mi) upstream of the Woodward, OK gage. Although the timing of the post-impoundment hydrograph is similar to the pre-impoundment period (*Appendix B - Hydrology*), the streamflow magnitude and variability are markedly reduced. Steady declines have occurred since the 1950s with modest improvements in the 1980s and 1990s and to a certain extent the 2000s. The current decade, however, shows further declines in stream discharge magnitude and variability. The Woodward, OK gage is rated as a ***Poor*** with a pre- and post-impoundment decline of 59.1 percent.

The El Reno, OK gage is located, approximately 93 km (57 mi) downstream of Canton Lake in central Oklahoma. Canton Lake was completed in 1948 by the U.S. Army Corps of Engineers as a flood control facility and a municipal water supply. Although peak flows are largely attenuated, the El Reno, OK gage is somewhat closer to a natural flow regime in that the timing of the annual hydrograph is generally intact and some of the smaller spates appear to be basically unaltered (*Appendix B - Hydrology*). This is broadly reflected in the pre- and post-impoundment decline of only 18 percent, which accords it a ***Fair*** rating. The decadal distribution shows a cyclical pattern alternating dry and wet periods; however, the 2010s continue to show the effects of regional drought.

The Wetumka, OK gage is located approximately 189 km (117 mi) east of Oklahoma City in east-central Oklahoma. Lake Overholser, located within Oklahoma City limits, was constructed in 1918 along the North Canadian River. The Wetumka, OK gage has no records prior to the construction of Lake Overholser and is therefore rated according to the alternative scoring criteria presented earlier. The Wetumka, OK gage shows an ostensibly natural hydrograph with a cyclical decadal distribution that tends to reflect normal fluctuations of dry and wet periods. The mean annual hydrograph shows a gradual increase in flows during the spring, a summer low-flow period, and a winter base flow condition. The current cycle (2000s and 2010s) is in a dry period but not to the degree observed in western portions of this and other Resiliency Units and not necessarily out of phase with the historical pattern. We therefore rate the Wetumka, OK gage as ***Fair***.

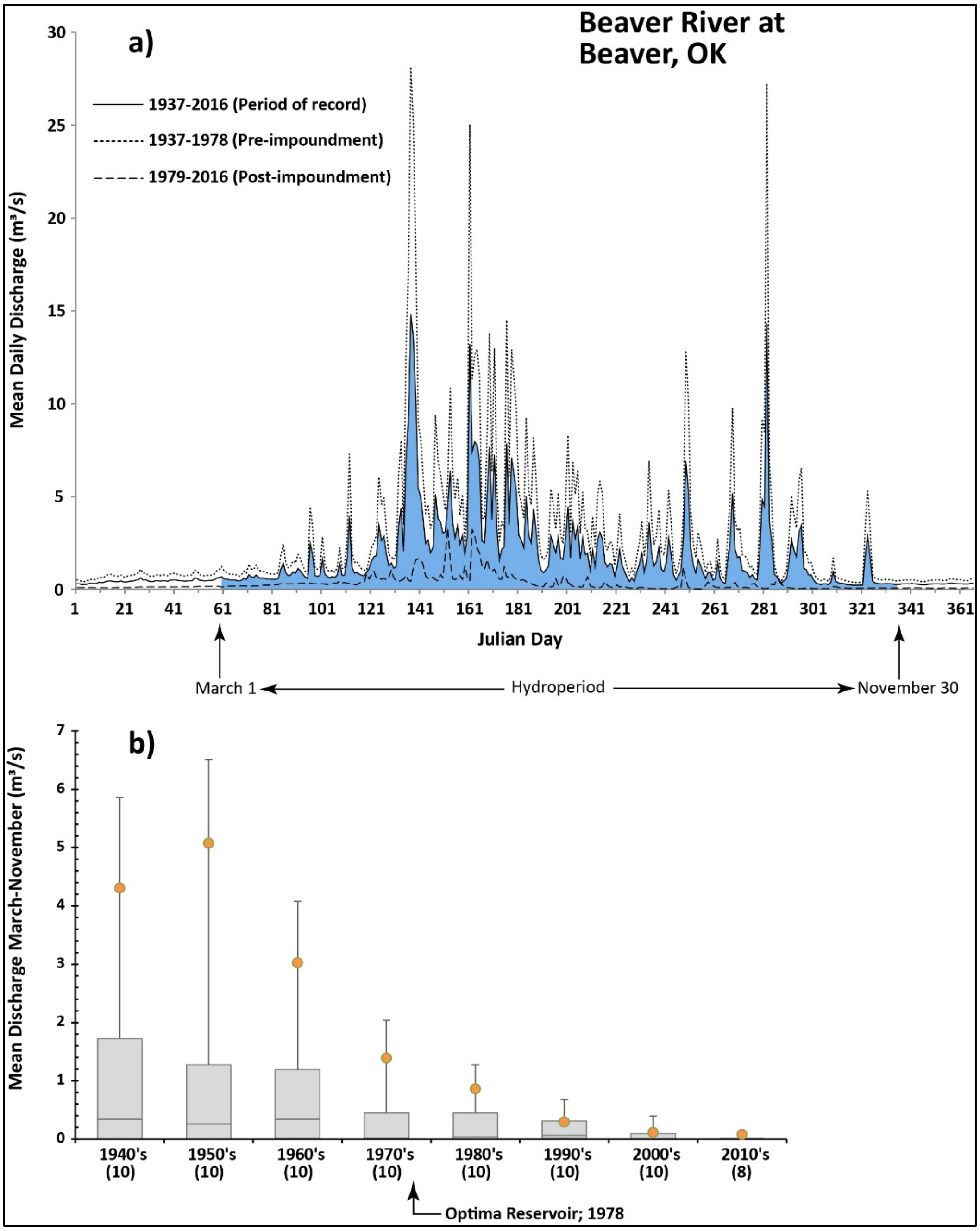


Figure 4.-18 Stream gage data at USGS 07234000 Beaver River at Beaver, OK. Upper panel (a) shows the mean daily discharge for the period of record (10/1/1937-12/31/2016) and the pre- and post-impoundment periods. Also shown is the hydroperiod for the North Canadian River Resiliency Unit. Lower panel (b) is the mean discharge for the hydroperiod by decade. The bottom of the boxes represents the 25th percentile and the top of the boxes represents the 75th percentile. The line through the box represents the median value and the colored dot indicates the mean. Bars above and below the boxes represent the 90th and 10th percentiles, respectively. Sample size (in years) is shown in parentheses.

Upper South Canadian River Resiliency Unit – The stream gages in the Upper South Canadian River Resiliency Unit we evaluated include the following:

- USGS 07227000; Canadian River at Logan, NM (SCAN 5);
- USGS 07227100; Revuelto Creek near Logan, NM (SCAN 5); and
- USGS 07227500; Canadian River near Amarillo, TX (SCAN 5).

We determined the hydroperiod for the Upper South Canadian River Resiliency Unit as lasting from April-November (Figure 4-19). Plots for Revuelto Creek, NM and the Canadian, TX gages are shown in *Appendix B - Hydrology*. Ute Reservoir in New Mexico is the most upstream feature in this Resiliency Unit and thus plays a key role in its regulation.

The Logan, NM gage is located approximately 36 km (22 mi) from the New Mexico-Texas border in northeastern New Mexico and is situated approximately 6 km (3.7 mi) downstream of Ute Lake. Completed in 1963, Ute Lake is owned and operated by the New Mexico Interstate Stream Commission (NMISC) as a water storage facility. As per Article IV of the Canadian River Compact (Canadian River Compact 1951, p. 1), New Mexico has free and unrestricted use of all waters originating in the drainage basin of the Canadian River (which we have termed the South Canadian River) above Conchas Dam provided that all impoundments created below Conchas Dam are limited to a total storage volume of 246.7 million m^3 (200,000 acre-feet). Thus, the only in-stream flow out of Ute Lake supplying the headwaters portion of the Upper South Canadian River Resiliency Unit is seepage from the dam itself (up to 0.14 m^3/s or 5 ft^3/s). Adding to the seepage flows are tributary flows from Revuelto Creek (see below). The NMISC has applied to appropriate the water rights of the dam seepage for instream flow use; however, the application is pending approval by the Office of the State Engineer (Bannerman 2017).

The Logan, NM gage shows substantial effects of upstream regulation. As shown in Figure 4-19, the timing, duration, variability, and magnitude of the annual hydrograph have all been greatly affected by impoundments (Conchas Dam in 1939 and Ute in 1963) and the post-impoundment decadal distribution of hydroperiod mean discharge is a fraction of the pre-impoundment period. In the post impoundment era, the spring runoff is virtually absent and flows rarely achieve a daily mean of 5 m^3/s (177 ft^3/s). On occasion, storage at Ute Lake can exceed the maximum level allowed under the Canadian River Compact thus necessitating a release. This occurred in 2017 from heavy monsoon rainfall and resulted in a release of approximately 9.9 m^3/s (350 ft^3/s) for several weeks. In addition, the NMISC has also provided additional water for instream use through the Arkansas River shiner management plan. Nonetheless, the rating for the Logan, NM gage is ***Null*** as the pre- and post-impoundment mean hydroperiod decline is 90 percent.

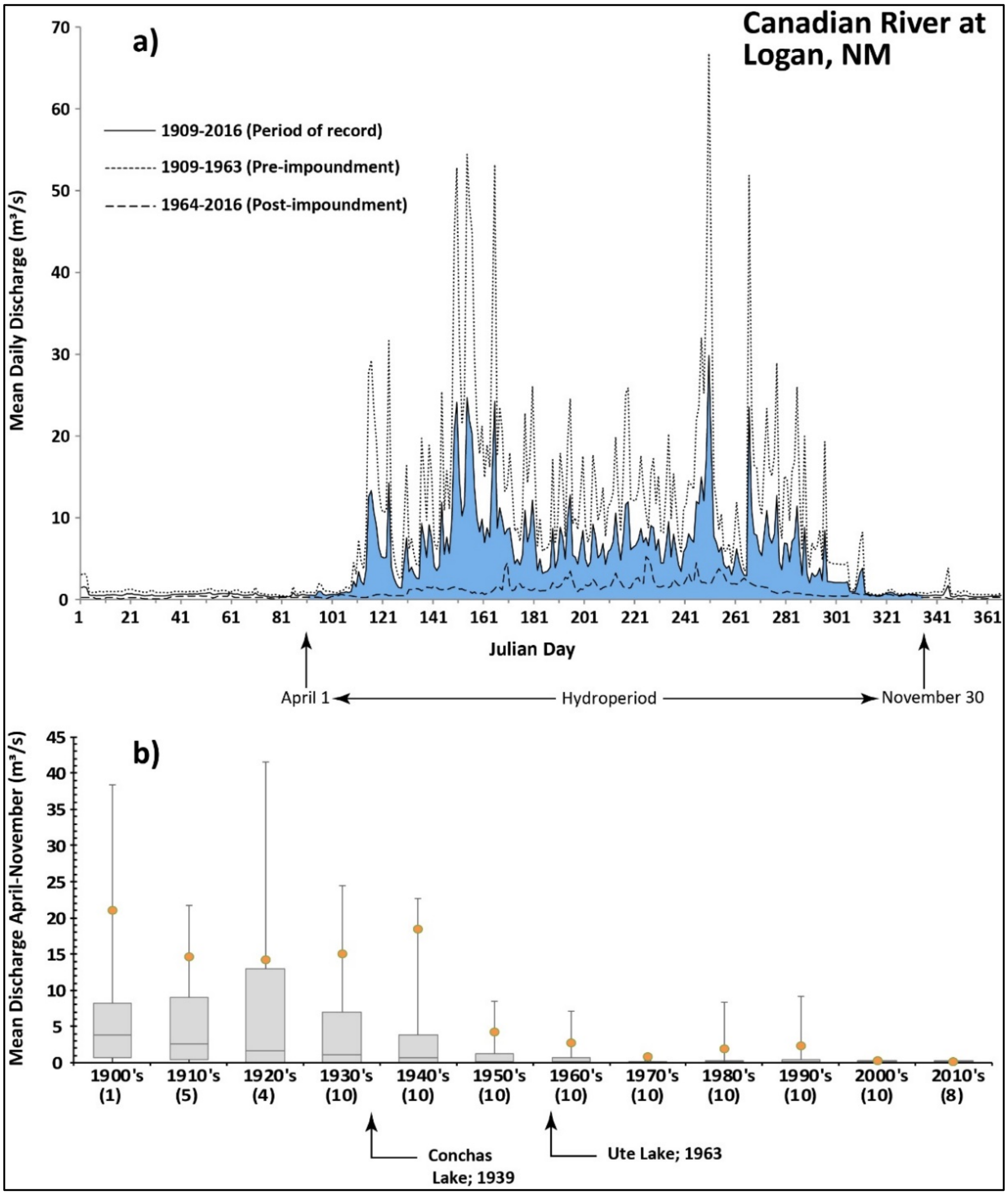


Figure 4-19. Stream gage data at USGS 07227000; Canadian River at Logan, NM. Upper panel (a) shows the mean daily discharge for the period of record (discontinuous between 1/1/1909-7/31/1925 and continuous between 1/2/1927-12/31/2016) and the pre- and post-impoundment periods. Also shown is the hydroperiod for the Upper South Canadian River Resiliency Unit. Lower panel (b) is the mean discharge for the hydroperiod by decade. The bottom of the boxes represents the 25th percentile and the top of the boxes represents the 75th percentile. The line through the box represents the median value and the colored dot indicates the mean. Bars above and below the boxes represent the 90th and 10th percentiles, respectively. Sample size (in years) is shown in parentheses.

Revuelto Creek is an unregulated tributary to the South Canadian River. The confluence is approximately 10 km (6.2 mi) downstream of Ute Lake and the Revuelto, NM gage is approximately 3.3 km (2.1 mi) upstream of the confluence. Revuelto Creek is often intermittent but can contribute significant flows rates and volumes to the South Canadian River. These events are typically of short duration but can serve to maintain and enhance aquatic habitat. For example, in October 2017, there was a spate of nearly 226 m^3/s (8,000 ft^3/s). Similar discharge rates typically arise from the summer monsoons and can, again, play a key role in habitat structuring further downstream on the South Canadian River.

Since there are no impoundments on Revuelto Creek, it was rated according to the alternative scoring criteria presented previously. Revuelto Creek displays a cyclical pattern and the duration of each dry/wet cycle appears to be roughly 20 years. Since 2000, there has been a decreasing trend in mean hydroperiod discharge with the 2010s being the lowest during the period of record (since 1960). By definition, we therefore rate the Revuelto Creek, NM gage as ***Fair***.

The Amarillo, TX gage is located approximately 130 km (85 mi) downstream of the New Mexico-Texas state line and is last stream gage before the South Canadian River enters Lake Meredith. It is well downstream of Ute Lake but still exhibits an altered flow regime as peak flows are notably muted and flow variability has been greatly reduced (Appendix B - Hydrology). Following the 1950’s drought and the completion of Ute Lake in 1963, mean discharge during the hydroperiod have been relatively stable but at a markedly lower level than the pre-impoundment era. Since 2000, all aspects of the flow regime (mean and median discharge, flow variation, etc.) have decreased further. As a result, we have rated the Amarillo, TX gage a ***Poor*** as the pre- and post-impoundment mean hydroperiod decline is 69.3 percent.

Lower South Canadian River Resiliency Unit – The stream gages in the Lower South Canadian River Resiliency Unit we evaluated include the following:

- USGS 07228000; Canadian River near Canadian, TX (SCAN 4);
- USGS 07228500; Canadian River at Bridgeport, OK (SCAN 2);
- USGS 07229200; Canadian River at Purcell, OK (SCAN 2); and
- USGS 07231500; Canadian River at Calvin, OK (SCAN 1).

We determined the hydroperiod for the Lower South Canadian River Resiliency Unit as lasting from April-November (Figure 4-20). Plots for the Bridgeport, Purcell, and Calvin, OK gages are shown in *Appendix B - Hydrology*. Lake Meredith in Texas is the most upstream feature in this Resiliency Unit and lies on the border with the Upper Canadian River Resiliency Unit.

The Canadian, TX gage is located approximately 116 km (72 mi) downstream of Lake Meredith and about 39 km (24 mi) from the Texas-Oklahoma state line. Historically, Lake Meredith was a municipal water source. Although being a considerable distance downstream from Lake Meredith, the Canadian, TX gage also shows a high degree of departure from the pre- and

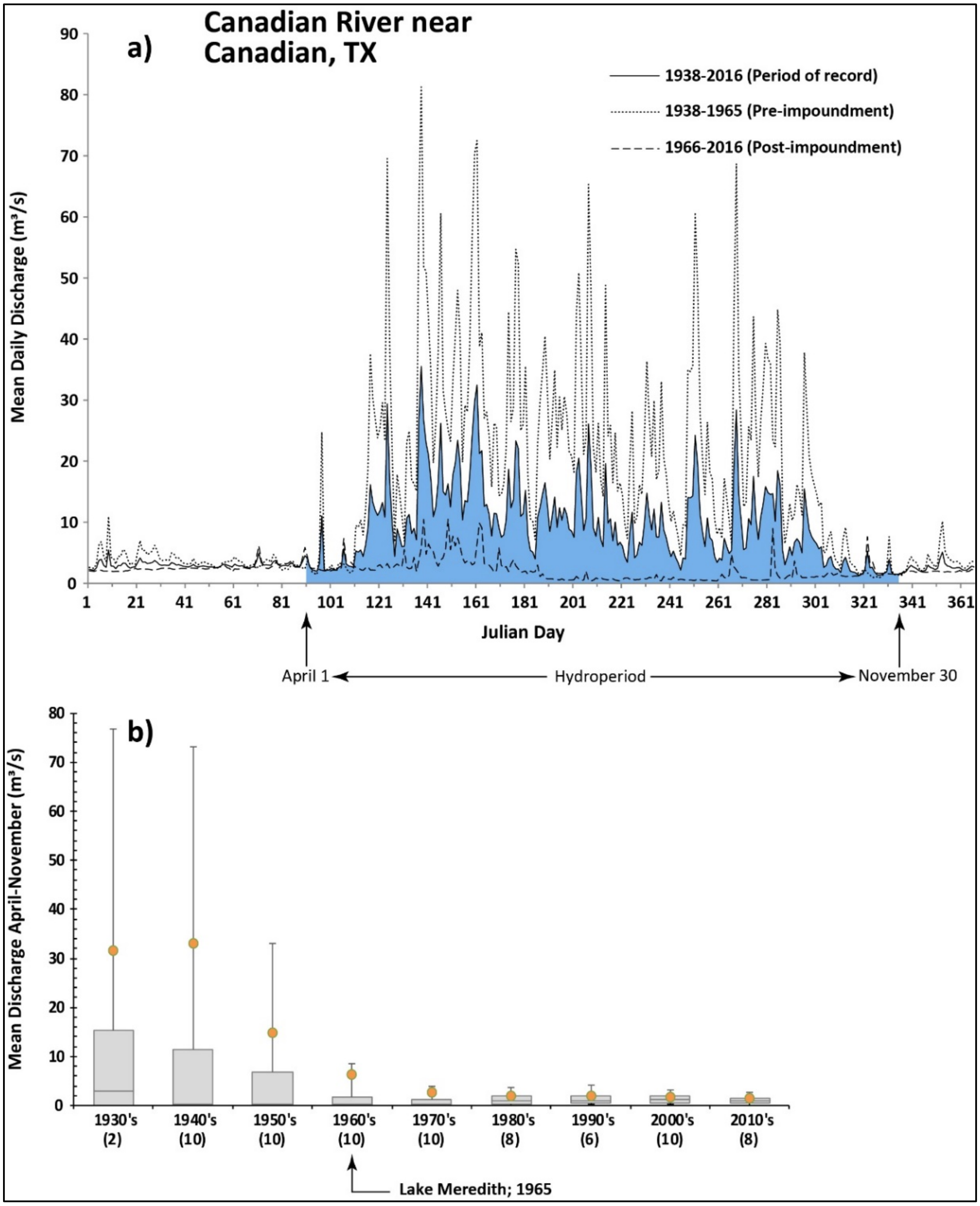


Figure 4-20. Stream gage data at USGS 07228000; Canadian River near Canadian, TX. Upper panel (a) shows the mean daily discharge for the period of record (4/1/1938-12/31/2016) and the pre- and post-impoundment periods. Also shown is the hydroperiod for the Lower South Canadian River Resiliency Unit. Lower panel (b) is the mean discharge for the hydroperiod by decade. The bottom of the boxes represents the 25th percentile and the top of the boxes represents the 75th percentile. The line through the box represents the median value and the colored dot indicates the mean. Bars above and below the boxes represent the 90th and 10th percentiles, respectively. Sample size (in years) is shown in parentheses.

post- impoundment hydrology (Figure 4-20). Peak flows are highly attenuated or completely absent.

There is little seasonal variability aside from an extended summer low-flow interval. Spring pulses are present but at drastically lower levels than the pre-impoundment era. Figure 4-20b illustrates the dramatic alteration to the natural flow regime since the completion of Lake Meredith. The rating for Canadian, TX gage is ***Null*** as the pre- and post-impoundment mean hydroperiod decline is 90.3 percent.

The Bridgeport, OK gage is located approximately 270 km (168 mi) downstream of the Canadian, TX gage in west-central Oklahoma. Lake Meredith remains the only substantial impoundment influencing the reach upstream from the Bridgeport, OK gage. Here, peak flows are also attenuated and there is some degree of juxtaposition between pre- and post-impoundment hydrology in the winter where post-impoundment discharge is slightly greater than pre-impoundment. Timing of the annual hydrograph is essentially intact. The decadal distribution of the hydroperiod shows the reduction in flow variation and mean discharge but an upward trend since the 1980s in median discharge; however, the 2010s indicate a decrease in both mean and median discharge from the preceding decades. The rating for the Bridgeport, TX gage is, however, ***Poor*** as the pre- and post-impound mean hydroperiod decline is 49.3 percent.

The Purcell, OK gage is located approximately 124 km (77 mi) downstream of the Bridgeport, OK gage. Although still influenced by Lake Meredith, its downstream distance (approximately 510 km [317 mi]) tends to buffer its effects. In addition, there is a short pre-impoundment gage record (1959-1961). Given the limited pre-impoundment data, we chose to rate this gage under the alternative scoring criteria. As such, the limited decadal distribution shows what we interpreted as a declining pattern. We therefore rate Purcell, OK gage as ***Fair***. Note that the mean hydroperiod discharge is trending downward and flow variability is also decreasing since the completion of Lake Meredith.

The final gage we evaluated in the Lower South Canadian Resiliency Unit is at Calvin, OK, which is located approximately 145 km (90.1 mi) downstream of the Purcell, OK gage. This places it approximately 655 km (407 mi) downstream of Lake Meredith. While the Calvin, OK gage is even further downstream, we do have a much longer pre-impoundment gage record (1905-1965). Here, peak flows are often attenuated but not to the same degree as the upstream gages. There is also the same winter juxtaposition noted with the Purcell, OK gage and the timing of the hydrograph is essentially unchanged between pre- and post-impoundment. The decadal distribution of mean hydroperiod discharge shows a cyclical pattern with a current dry phase beginning in the 2000s. We rated the Calvin, OK gages as ***Fair*** with a pre- and post-impound mean hydroperiod decline of 21.6 percent.

4.4.1.2. Flood Frequency Analysis

The frequency of a given flow event is an important facet of ecohydrology. Within most lotic systems, numerous habitat features are created, maintained, and modified by a range of flow events that occur over a variety of time scales. For example, bankfull discharges (i.e., a 2-3 year return interval) produce and maintain river bars and riffle-pool sequences through their ability to sort bed substrates (Poff et al. 1997, p. 772). Flood flows are a natural process but occur at longer return intervals (5-100 years). Such events engage and inundate high-flow side channels, oxbows, or other features within the floodplain and maintain or create new habitat through avulsive, scour, and depositional river dynamics (Hill et al. 1991, p. 200). When flood flows are eliminated or attenuated by impoundments, the floodplain becomes increasingly isolated thereby affecting both aquatic and riparian ecosystems (Tockner and Stanford 2002, p. 308; Poff et al. 2007, p. 5732).

To gain specific insight into how dams and flood flows have changed from the pre- and post-impoundment periods, we performed a flood frequency analysis at the same USGS stream gages previously identified. We employed the USGS's PeakFQ, Release 7.1 (Flynn et al. 2006, entire). This tool implements procedures for flood frequency analysis recommended in Bulletin 17B from the Hydrology Subcommittee, Interagency Advisory Committee on Water Data (1982, entire). Although we opted to exclude historical peaks (outliers), we included peaks known to have been influenced by water regulation, urbanization, and other watershed changes.

We defined a Flood Frequency Analysis (FFA) metric that captures the most relevant return intervals for the Arkansas River shiner and peppered chub. We therefore included the 2, 5, and10-year return intervals in the metric. Further, we weighted the metric more heavily toward the 2-year return interval to account for the more immediate needs of reproduction/recruitment and existing habitat maintenance. This factors in the most relevant flows for short-lived species in these degraded systems. The 5 and 10-year events represent inundation of off-channel/floodplain habitat and new channel-forming flows. Longer return intervals are basically extensions of the 10-year event but more function to fully reset the system.

The FFA metric is therefore represented as the proportional difference between the pre- and post-impoundment period of the weighted sum of the 2, 5, and 10-year events. This provides a single value that represents the weighted percentage of post-impoundment flows, at the three return intervals, remaining from (or in excess of) the pre-impoundment period. That is:

0.5(ratio of the 2-yr events) + 0.25(ratio of the 5-yr events) + 0.25(ratio of the 10-yr events)

Since this metric is also predicated on an upstream impoundment, we formulated an alternative scoring criteria for those stream gages that do not have an upstream impoundment detailed earlier. In order to best capture current conditions, we used the above equation and parsed the peak discharge gage records at the year 2000. This at least enables us to contrast the last two decades (2000-2017) with the previous era (beginning of the period of record through 1999).

Categorically, a ***Good*** condition for the FFA metric is when the weighted sum of the proportional differences of the 2, 5, and 10-year return intervals is greater than 75 percent. A ***Fair*** condition is between 50-75 percent and a ***Poor*** condition is between 10-50 percent. A ***Null*** condition is less than 10 percent.

The differences in discharge magnitude at the three return intervals at many of the gages that follow is striking and illustrates the effects of dams on high flow events. This has significant implications on the ability to maintain in-stream habitat and access new areas through avulsive and new channel-forming processes. The aggregate effect of this is typically channel narrowing and incision (see also Section 4.4.3 *Channel Narrowing*, below). Once this process begins, and flood flows continue to be attenuated, vegetative armoring of the channel margins and floodplain exacerbates the problem. In addition, dams tend to starve the system of sediment which also affects mesohabitat dynamics and armors the stream bed as existing sediment is progressively flushed from the system. Taken together, the sediment sequestration caused by dams and the attenuation of flood-flows tend to homogenize the system and dramatically limit the types and extent of available aquatic habitat.

The Upper Arkansas River Resiliency Unit — The stream gages in the Upper Arkansas River Resiliency Unit we examined are: Arkansas River at Garden City, KS; Ninnescah River near Peck, KS; and Arkansas River at Ralston, OK.

The Garden City, KS gage receives a rating of ***Poor*** as the proportion of pre-impoundment 2, 5, and 10-year return intervals remaining in the post-impoundment era is 11.7 percent. The values for each return interval are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	166.3 (5,874)	502.9 (17,760)	833.1 (29,420)
Post-impoundment	12.2 (430.6)	64.1 (2,265)	161.4 (5,700)

The Peck, KS gage (on the Ninnescah River) receives a rating of ***Good*** as the FFA score is 102.8 percent; post-impoundment annual peak flows for the 5 and 10-year events are slightly larger than pre-impoundment values and the 2-year events are comparable. Longer return intervals are also slightly larger for the post-impoundment era except for 100-year event which is slightly smaller. In general, despite Cheney Lake being completed in 1964, flood flows appear to be basically intact and are comparable to the natural flow regime. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	324.8 (11,470)	536.6 (18,950)	691.8 (24,430)
Post-impoundment	307 (10,840)	585.9 (20,690)	782.7 (27,640)

The Ralston, OK gage also receives a ***Good*** rating as the FFA score is 79.5 percent; reductions are seen across all return intervals but are as dramatically different as many of the other gages. Recall that Kaw Lake (completed in 1976) is a hydroelectric facility which may explain the similarity of the pre- and post-impoundment values. That is, reservoir operations may require keeping a certain storage level for consistent output of the hydroelectric plant and thus leave little flexibility in flood storage capacity. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	1,588.3 (56,090)	3,063.9 (108,200)	4,241.9 (149,800)
Post-impoundment	1,362.3 (48,110)	2,325.4 (82,120)	2,993.1 (105,700)

The Cimarron River Resiliency Unit – The stream gages in the Cimarron River Resiliency Unit we examined are: the Cimarron River near Kenton, OK; Cimarron River near Forgan, OK; and the Cimarron River near Guthrie, OK stream gages. None of these gage have an upstream impoundment so we employ the alternative scoring criteria presented above.

The Kenton, OK gage receives a rating of ***Fair*** with a FFA score of 50.2 percent; note, however the ***Fair*** rating threshold is 50 percent. Reductions are seen in the post-2000 values for all three return intervals in the metric as well as the 25- and 50-year events. The 100-year event is slightly larger in the post-2000 era. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	132.7 (4,687)	340.4 (12,020)	535.8 (18,920)
Post-2000	58.2 (2,056)	177 (6,252)	326.5 (11,530)

The Forgan, OK gage receives a rating of ***Null*** with a FFA score of 8.8 percent. Post-2000 values are an order of magnitude less than the POR-1999 values for all return intervals. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	65.3 (2,306)	256.8 (9,068)	510 (18,010)
Post-2000	6.5 (229)	20.2 (714)	38.1 (1,345)

The Guthrie, OK gage receives a rating of ***Fair*** with a FFA score of 72.5 percent with modest reductions in the 2, 5, and 10-year return intervals. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	849.8 (30,010)	1,636.7 (57,800)	2,227.1 (78,650)
Post-2000	656.4 (23,180)	1,126.7 (39,790)	1,485.5 (52,460)

The North Canadian River Resiliency Unit – The stream gages in the North Canadian River Resiliency Unit we examined are: Beaver River at Beaver, OK; North Canadian River at Woodward, OK; North Canadian River near El Reno, OK; and the North Canadian River near Wetumka, OK. Again, the Wetumka, OK gage is rated using the alternative scoring criteria as there are no gage records prior to the completion of Lake Overholser in 1918.

The Beaver, OK gage receives a rating of ***Null*** with a FFA score of 6.0 percent. All three return intervals considered in the metric show an order of magnitude reduction. The 50 and 100-year events are only slightly better. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	210.8 (7,443)	488.5 (17,250)	741.9 (26,200)
Post-impoundment	5.1 (182)	35.9 (1,269)	87.4 (3,085)

The Woodward, OK gage receives a ***Poor*** rating with a FFA score of 12.1 percent. Here also, reductions of an order of magnitude are seen throughout all return intervals. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	122.8 (4,335)	302.7 (10,690)	487 (17,200)
Post-impoundment	17.1 (605)	33.1 (1,170)	46.1 (1,628)

The El Reno, OK gage receives a rating of ***Fair*** with a FFA score of 68.9 percent. Although located downstream of Canton Lake, values for all three metric return intervals are decreased but are comparable. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	143.3 (5,062)	224.1 (7,915)	286.9 (10,130)
Post-impoundment	88.5 (3,124)	163.9 (5,788)	226.6 (8,004)

The Wetumka, OK gage receives a rating of ***Good*** under the alternative FFA scoring criteria with a FFA score of 110.1 percent. Reasons for this are not entirely clear but may stem from the gage being located a considerable distance downstream (189 km [117 mi]) of Lake Overholser, which is located within the Oklahoma City limits. Further, Lake Overholser has a modest storage capacity of 20.97 million m^3 (17,000 acre-feet). In any case, the post-2000 values are all slightly more than the POR-1999 values for all return intervals. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	340.7 (12,030)	568 (20,060)	746.4 (26,360)
Post-2000	360.5 (12,730)	651 (22,990)	852.3 (30,100)

Upper South Canadian River Resiliency Unit – The stream gages in the Upper South Canadian River Resiliency Unit we examined are: Canadian River at Logan, NM; Revuelto Creek near Logan, NM; and the Canadian River near Amarillo, TX.

The Logan, NM gage receives a ***Null*** rating with a FFA analysis score of 1.9 percent. Again, the Logan, NM gage is located a short distance below Ute Lake and New Mexico has free use of all water in the catchment so long as the storage below Conchas Dam is less than 246.7 million m^3 (200,000 acre-feet). Thus, flood flows of virtually any return interval are almost entirely attenuated except for when storage at Ute Lake exceed the maximum allowable volume. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	710.8 (25,100)	1,578.4 (55,740)	2,461.3 (86,920)
Post-impoundment	8.3 (293)	36.2 (1,277)	73.2 (2,584)

The Revuelto Creek, NM gage receives a ***Fair*** rating under the alternative scoring criteria as there is no upstream impoundment. The FFA score is 65.6 percent which, again, represents the current conditions (since 2000) relative to the past. The decrease discharge magnitude reflects regional drought conditions since 2000. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	163.1 (5,761)	296.2 (10,460)	410.6 (14,500)
Post-2000	118.8 (4,195)	182.9 (6,458)	225.8 (7,973)

The Amarillo, TX gage receives a ***Poor*** rating with a FFA score of 38.7 percent. Although a considerable distance downstream from Ute Lake, all return intervals show substantial declines. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	928.8 (32,800)	1,543 (54,490)	2,026.6 (71,570)
Post-impoundment	312.6 (11,040)	642.2 (22,680)	925.4 (32,680)

Lower South Canadian River Resiliency Unit

The Canadian, TX gage received a ***Poor*** rating with a FFA score of 12.8 percent. Being a relatively short distance downstream of Lake Meredith, all return intervals showed a substantial decrease in discharge magnitude, particularly the 2, 5, and 10-year values included in the FFA metric. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	751.8 (26,550)	1,621.1 (57,250)	2,371 (83,730)
Post-impoundment	70.3 (2,481)	231.6 (8,180)	427.9 (15,110)

The Bridgeport, OK gage received a ***Fair*** rating with a FFA score of 53.6 percent; note, however, the ***Fair*** rating threshold is 50 percent. While effects of peak discharge attenuation from Lake Meredith are still apparent, the magnitude of declines are somewhat mediated by the increased distance from the reservoir. Further, the attenuation of peak flows declines with an increase in return interval. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	774.5 (27,350)	1,430.9 (50,530)	1,978.2 (69,860)
Post-impoundment	347.7 (12,820)	833.6 (29,440)	1,234.3 (43,590)

The Purcell, OK gage received ***Poor*** rating with FFA score of 42.1 percent. Again, the Purcell, OK gage was rated under the alternative scoring criteria. Results show a fairly uniform reduction across all return intervals since 2000; however, the effects of Lake Meredith are still present. The values for each return interval in the FFA metric are:

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
POR-1999	616.2 (21,760)	1,230.4 (43,450)	1,755.9 (62,010)
Post-2000	257.9 (9,109)	515.6 (18,210)	751.8 (26,550)

The Calvin, OK gage received ***Fair*** rating with a FFW score of 70.5 percent. Clearly, the effects of Lake Meredith have diminished but are still influencing the flood flow frequencies. Still, this portion of the Lower South Canadian appears to be the most hydrologically intact.

	Return Interval		
	2-year; m^3/s (ft^3/s)	**5-year; m^3/s (ft^3/s)**	**10-year; m^3/s (ft^3/s)**
Pre-impoundment	1,868.6 (65,990)	3,041.2 (107,400)	3,919.1 (138,400)
Post-impoundment	1,185.1 (41,850)	2,300.5 (81,240)	3,112 (109,900)

4.4.1.3. Low Flows

For each of the seventeen stream gages, we examined USGS's mean daily discharge data for the period of record to determine how regularly low-flow conditions occurred. For the purposes of this analysis, low-flow conditions were defined as those less than 0.57 m^3/s (20 ft^3/s). While this discharge rate is still a lotic condition, and thus viable habitat, the value represents a rough threshold where intermittency, channel drying, and water quality impacts become a concern in these degraded systems. We then summed the number of days per year the mean daily flow met this criterion and also plotted the five-year moving average of the number of low-flow days. (Appendix B - Hydrology).

Although this metric is highly variable between USGS gaged sites and flows naturally become lower moving upstream towards the headwaters of these rivers, we utilized this metric as a means to assess temporal change within each site (no comparison between gaged sites). While the other two metrics above (Hydroperiod and Flood Frequency) include higher flow conditions that are critical for reproductive success and channel maintenance, we chose this lower flow analysis to assess those periods when important resources such as habitat, river connectivity, food, and water quality may be limited.

We generally treated the low-flow metric qualitatively. That is, categorically, a ***Good*** condition is when there is a decreasing pattern or low frequency of occurrence in the annual number of days of low-flow conditions. A ***Fair*** condition is characterized by a cyclical pattern or when the stream gage is located in a headwater/intermittent tributary of a given river thus rendering the value of 0.57 m^3/s (20 ft^3/s) a more natural or common state. The latter is a special case applicable for the Kenton, OK and Revuelto Creek, NM gages. A ***Poor*** condition is when there is an increasing pattern or high frequency in the number of low-flow days. We did not include a ***Null*** condition for the low-flow metric.

The Upper Arkansas River Resiliency Unit – The low-flow conditions in this Resiliency Unit are generally favorable; however, the Garden City, KS gage received a ***Poor*** rating as there have may many consecutive years since 2000 where low-flow conditions have existed for more than 350 days per year. Further downstream, both the Peck, KS and Ralston, OK gages receive a ***Good*** rating with very few years where low-flow conditions exist, particularly in recent times.

The Cimarron River Resiliency Unit – The low-flow conditions are variable in this Resiliency Unit and appear to follow the upstream-to-downstream (west-to-east) pattern present in other metrics. The Kenton, OK gage received a ***Fair*** rating by virtue of its headwater location. The frequency distribution shows a steady pattern of low-flow conditions of approximately 350 days per year since the early 1950s but this likely a result of its position in the system and a natural state. The Forgan, OK gage received a ***Poor*** rating for its increasing trend of low-flow conditions, which has been increasing since the late 1990s. Further downstream, the Guthrie, OK gage received a ***Good*** rating for virtually no low-flow conditions since the 1950s.

The North Canadian River Resiliency Unit – In general, low-flow conditions in this Resiliency Unit also follow an upstream-to-downstream pattern. The Beaver, OK gage received a ***Poor*** rating as there has been an increasing trend since the early 1970s. In more recent times, there have been approximately 350 days per year of low-flow conditions whereas prior to the 1970s, there was roughly 250 days per year on average of low-flow conditions. The Woodward, OK gage, although cyclical and not as pronounced as the Beaver, OK gage, also received a ***Poor*** rating for a sharp increase in the number of low-flow days since 2006 that has exceeded any other time in the gage record. El Reno, OK received a ***Fair*** rating as the pattern appears, in general, cyclical. While recent years show an increase in the number of low-flow days, the 5-year moving average is not out of the range of historical records. Lastly, the Wetumka, OK gage received a ***Good*** rating as low-flow conditions have not occurred since the late 1960s.

Upper South Canadian River Resiliency Unit – The low-flow conditions in this Resiliency Unit are also variable and again follow an upstream-to-downstream pattern. The Revuelto Creek, NM gage received a ***Fair*** rating for its location in an intermittent tributary. The Logan, NM gage received a ***Poor*** rating for the high frequency of low-flow years that are in excess of 350 days per year. The influence of both Conchas Lake and Ute Lake on the frequency of low-flow conditions can clearly be seen. The Amarillo, TX gage shows a clear cyclical pattern, with a 10-year interval, and therefore a received a ***Fair*** rating. The influence of Ute Lake is not apparent on low-flow conditions.

Lower South Canadian River Resiliency Unit – From a low-flows perspective, the Lower South Canadian River Resiliency Unit is in a comparatively ***Good*** condition. The Canadian, TX and Bridgeport, TX gages received a ***Fair*** rating for generally decreasing trend, although some recent years show slight increases in the number of low-flow days. The Purcell, TX gage received a ***Good*** rating for a clearly decreasing trend and low frequency of occurrence and the Calvin, TX gage displayed a somewhat cyclical pattern also with a low frequency of occurrence and therefore a ***Fair*** rating.

Low Flow Summary

It should be noted that decreasing low-flow conditions does not always indicate a favorable situation. Consider a pattern we have identified in most of these systems. Peak flows have been drastically attenuated thereby drastically limiting or eliminating floodplain inundation and thus the hydraulic forces necessary access new habitat. As a result, the channel has been greatly narrowed and vegetation (often exotics) has been allowed to armor the banks. If low-flows are then decreased through, for example, steady irrigation deliveries, vegetation communities become even more ensconced and the floodplain further isolated.

4.4.1.4. Current Conditions Hydrology Summary

Hydrologically, all Resiliency Units are degraded. The natural hydrographs have been, for the most part, fundamentally altered for an extended period of time. The magnitude, timing, and duration of essential hydrograph elements (e.g., spring runoff) have often been eliminated in favor of agricultural or municipal demands. Table 4-12 provides a summary of the hydrology metrics for the Current Conditions.

Table 4-12. Current condition ratings for hydrology metrics.

CURRENT CONDITIONS HYDROLOGIC RESILIENCY RANKINGS					
Resiliency Unit	**Subunit**	**USGS Gauge Name**	**Hydroperiod**	**Flood Frequency Analysis**	**Low Flow Conditions**
Upper Arkansas	ARK 1		.	.	.
	ARK 2		.	.	.
	ARK 3		.	.	.
	ARK 4	Arkansas River at Ralston, OK	Good	Good	Good
	ARK 5	Ninnescah River near Peck, KS	Good	Good	Good
	ARK 6	Arkansas River at Garden City, KS	Poor	Poor	Poor
	ARK 7		.	.	.
	ARK 8		.	.	.
Cimarron	CIMA 1	Cimarron near Guthrie, OK	Fair*	Fair*	Good
	CIMA 2		.	.	.
	CIMA 3	Cimarron near Forgan, OK	Poor*	Null*	Poor
	CIMA 4	Cimarron near Kenton, OK	Poor*	Fair*	Fair
North Canadian	NCAN 1	North Canadian near Wetumka, OK	Fair*	Good*	Good
	NCAN 2	North Canadian near El Reno, OK	Fair	Fair	Fair
	NCAN 3	North Canadian at Woodward, OK	Poor	Poor	Poor
	NCAN 3	North Canadian at Beaver, OK	Null	Null	Poor
	NCAN 4		.	.	.
Upper South Canadian	SCAN 5	Revuelto Creek near Logan, NM	Fair*	Fair*	Fair
	SCAN 5	South Canadian at Logan, NM	Poor	Null	Poor
	SCAN 5	South Canadian near Amarillo, TX	Poor	Poor	Fair
Lower South Canadian	SCAN 1	South Canadian at Calvin, OK	Fair	Fair	Fair
	SCAN 2	South Canadian at Purcell, OK	Poor*	Poor*	Good
	SCAN 3	South Canadian at Bridgeport, OK	Poor	Fair	Fair
	SCAN 4	South Canadian near Canadian, TX	Null	Poor	Fair

*no impoundments identified or data previous to impoundment date for comparison; special scoring criteria

4.4.2 River Fragmentation

As discussed in Chapter 2, Section 2.3.1.2 *Stream Length*, both the Arkansas River shiner and peppered chub need a substantial length (135 miles) of unimpounded and connected river for long-term successful reproduction and viability. Therefore, we identified river fragments within the Arkansas River Basin by locating instream barriers (large and small impoundments, locks and diversion) and channels known to be dry for significant portions of the year (Perkin and Gido 2011, pp. 374-375) (Figure 4-21). Rivers and tributaries chosen for analysis were only those that are currently, or once were, occupied by either the Arkansas River shiner or peppered chub.

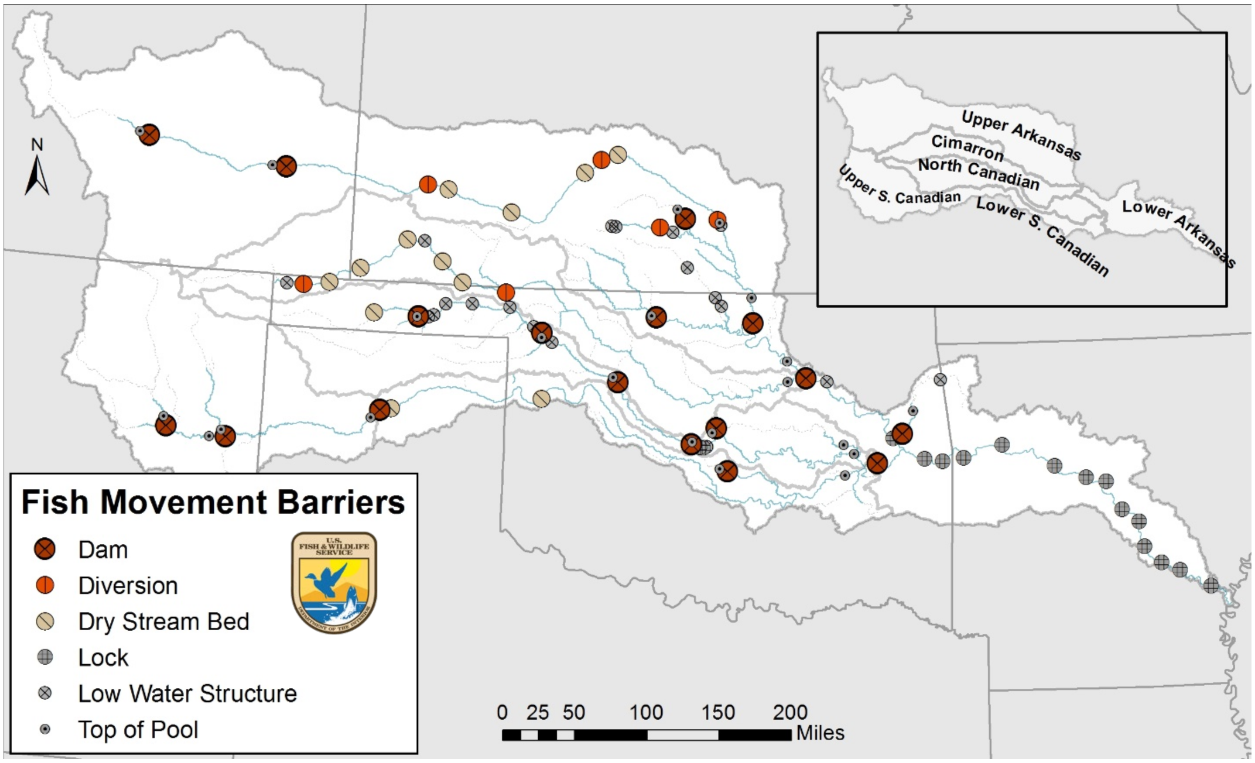


Figure 4-21. Location of known instream barriers, upstream extent of reservoir pools, and river channels known to be dry for a significant portion of year within the Arkansas River basin.

After identifying instream barriers, we measured distance between and assigned values to those fragments based on river distances important for pelagic broadcast spawning fishes (Platania and Altenbach 1999, p. 565-566; Wild et al. 2000, p. 112; Perkin and Gido 2011, pp. 375) (Table 4-13).

After assigning values to each fragment, we identified six river fragments providing adequate length for Arkansas River shiner and peppered chub (Figure 4-22):

1) Arkansas and Salt Fork River - Great Salt Plains Lake downstream to Keystone Reservoir (186 miles);
2) Cimarron River - Old Settlers Irrigation Ditch downstream to Keystone Reservoir (334 miles);
3) North Canadian River – Oklahoma City low water dam downstream to Lake Eufaula (237 miles);
4) South Canadian River – dry river bed near Camargo, OK downstream to Lake Eufaula (326 miles);

5) South Canadian River – Lake Meredith/Sanford Dam downstream to dry riverbed near Camargo, OK (158 miles); and
6) South Canadian River – Ute Reservoir/Dam downstream to Lake Meredith (179 miles). Note that our reference to species needs in this section is only in terms of river fragment length and the extirpation of Arkansas River shiner and/or peppered chub from some of these fragments is likely driven by a combination of other stressors.

Table 4-13. River fragment lengths and description of pelagic broadcast spawning fishes success (based on river length alone), with emphasis on Arkansas River shiner and peppered chub.

River Fragment Length	**Description** (as identified in Perkin and Gido 2011)
0-63 miles	Complete extirpation of pelagic broadcast spawning fishes.
64-134 miles	Partial extirpation of some pelagic broadcast spawning fishes, but below the length threshold for Arkansas River shiner (peppered chub threshold = 127 miles).
135-184 miles	Above the Arkansas River shiner and peppered chub length thresholds, but below the combined pelagic broadcast spawning threshold.
Greater than 184 miles	No extirpation of pelagic broadcast spawning fishes anticipated

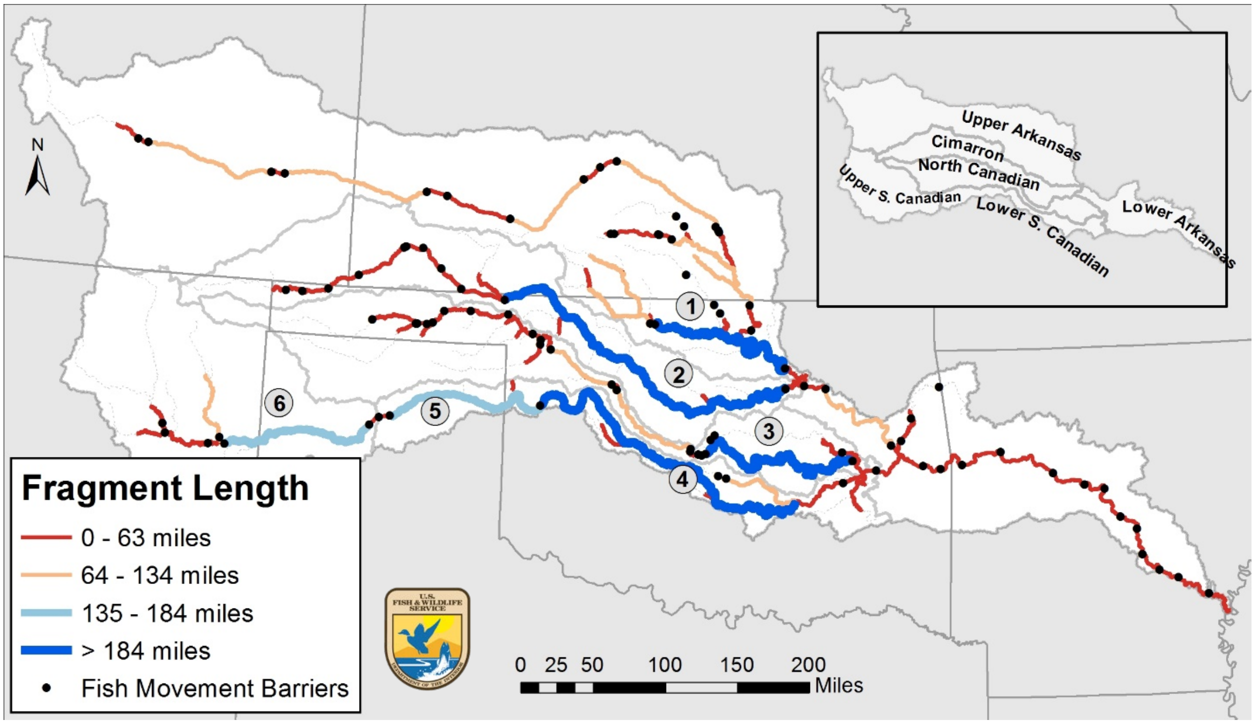


Figure 4-22. River fragments affecting Arkansas River shiner and peppered chub within the Arkansas River basin.

4.4.3 Channel Narrowing

4.4.3.1 Methods

Temporal changes in channel area were determined by comparing unvegetated channel area from the1950s-1960s (earliest aerial imagery available) to 2010s. Sites for analyses were selected based primarily upon locations with fish survey history and in close proximity to a USGS stream gage. Over 870 river miles were digitized as part of this analysis (Figure 4-23).

Once sites were selected, the earliest aerial photographs available (1950s-1960) were downloaded from USGS Earth Explorer (2018). Individual aerial photographs were first batch cropped to remove film frames and then were 'stitched' together using the Microsoft program Image Composition Editor. The resulting stitched aerial photograph was imported into ArcGIS 10.4.1 and then georeferenced. Once georeferenced, a shapefile polygon of the unvegetated river channel was created by tracing the unvegetated river channel at a scale of 1:24,000 for all sites. Length of unvegetated river channel digitized varied by location and was determined by the amount of imagery available from the 1950s.

Once the 1950s unvegetated river channel polygon was created, a second polygon, which traced the current (2010s; post-impoundment) unvegetated river channel was created (Figure 4-24). We used default world imagery from the ArcGIS online server to map the 2010s unvegetated river channel. The 2010s unvegetated river channel was also mapped at a scale of 1:24,000 unless the river had narrowed to the extent that the individual banks could not be distinguished at that scale, in which case either 1:12,000 (one site) or 1:6,000 (one site) was utilized.

The 1950s and 2010s unvegetated river channel polygons both began and ended at the same points to help ensure that reaches were comparable. Distance mapped varied by site, ranging from 20 to 40 river miles, and was determined by the availability of historic aerial photography coverage. Once mapped, area was calculated using XTools Pro 16.1. Area of unvegetated river channel was then divided by river miles mapped to determine average area for comparison between years and sites.

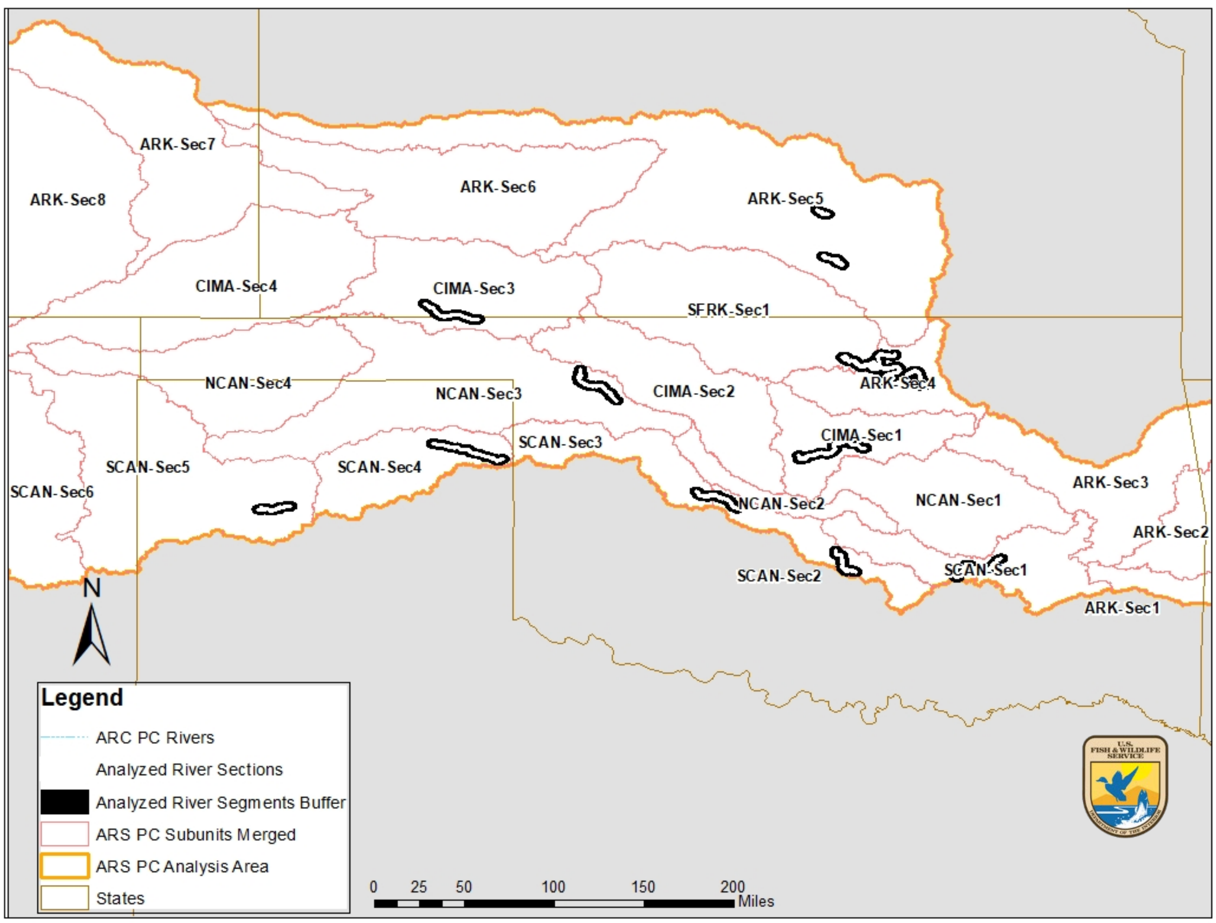


Figure 4-23. Location of Segments for River Channel Narrowing Analysis.

At six sites where significant change occurred from 1950s to 2010s, a 10-mile stretch was then analyzed for incremental change between the 1950s and 2010s. The additional years of analysis were typically the late 1960s or early 1970s, and the 1990s, based on availability. For the site near Tonkawa, OK on the Salt Fork of the Arkansas River, a 1937 aerial photograph was digitized and mapped in order to get pre-impoundment data. Historic aerial photography for the selected years was georeferenced then digitized. These additional unvegetated rived channel polygons were used to determine if the change in the same 10-mile stretches from the 1950s to the 2010s was consistent through time (*i.e.* linear) or changed at a non-uniform rate (i.e., stepped).

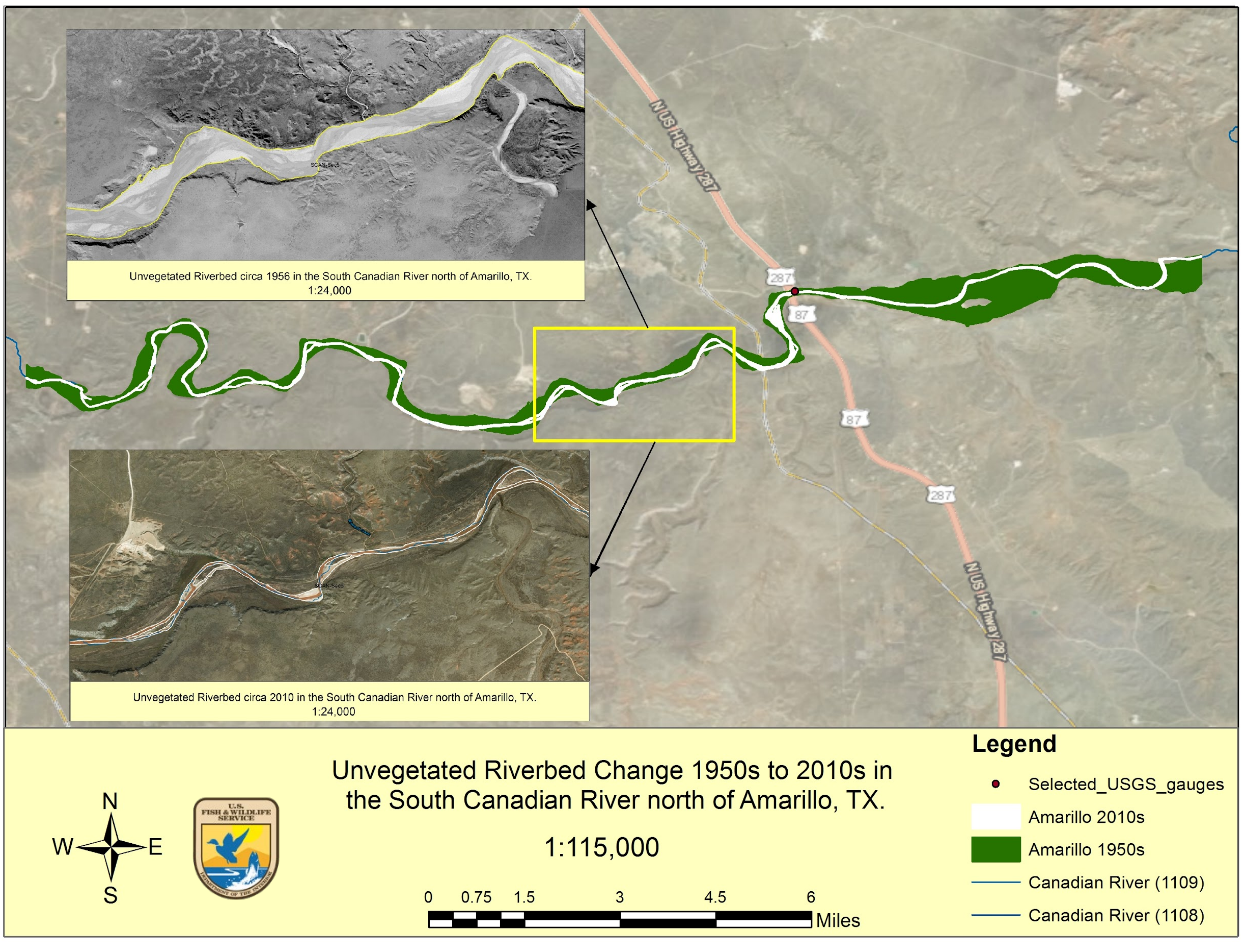


Figure 4-24. Unvegetated riverbed change from 1950s to 2010s in the South Canadian River north of Amarillo, TX. Additional maps in Appendix C – Riverbed Change.

4.4.3.2 Results

South Canadian River

SCAN1 - We compared a 30-mile stretch of the South Canadian River near Calvin, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 5,789.4 acres (2,342.9 hectares) with an average of 193.0 acres/mile (Figure 4-25 below). In the 2010s the same stretch of river occupied 3,014.0 acres (1,219.7 hectares) with an average of 100.5 acres/mile. Therefore, only 52.1 percent of the unvegetated river channel from the 1950s remained in the 2010s.

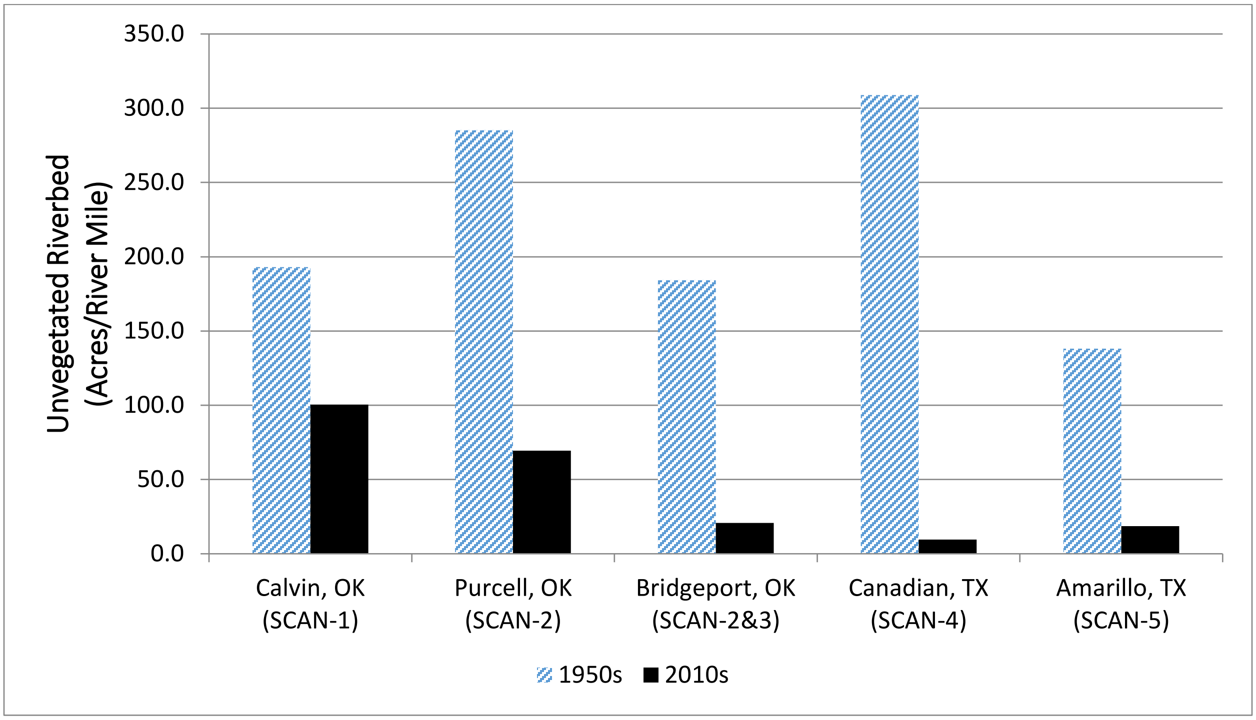


Figure 4-25. Change in Unvegetated Riverbed from 1950s to 2010s for five sites on the South Canadian River.

SCAN-2 - We compared a 20-mile stretch of the South Canadian River near Purcell, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 5,705.0 acres (2,308.7 hectares) with an average of 285.3 acres/mile. In the 2010s the same stretch of river occupied 1,388.3 acres (561.8 hectares) with an average of 69.4 acres/mile. Therefore, 24.3 percent of the unvegetated river channel from the 1950s remained in the 2010s.

SCAN-2/3 - We compared a 30-mile stretch of the South Canadian River near Bridgeport, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 5,524.9 acres (2,235.9 hectares) with an average of 184.2 acres/mile. In the 2010s the same stretch of river occupied 620.2 acres (251.0 hectares) with an average of 20.7 acres/mile. Therefore, 11.2 percent of the unvegetated river channel from the 1950s remained in the 2010s.

We also compared a 10-mile stretch which included the stream gage of the South Canadian River near Bridgeport, OK to see how the unvegetated riverbed changed every approximately 20 years, rather than just from 1950s to 2010s (Figure 4-26). In the 1954, the 10-mile stretch of unvegetated riverbed was 2,356.2 acres (935.5 hectares), with an average acres/mile of 235.6. In 1974, the same 10-mile stretch of unvegetated riverbed was 548.6 acres (222.0 hectares), with an average of 54.9 acres/mile, a 76.7 percent decline from 1954. In 1995, the same 10-mile stretch of unvegetated riverbed was 412.2 acres (166.8 hectares), with an average of 41.2 acres/mile, a 24.9 percent decline from 1974. In 2015, the same 10-mile stretch of unvegetated riverbed was 246.1 acres (99.6 hectares), with an average of 24.6 acres/mile, a 40.3 percent decline from 1995 and an 89.6 percent decrease from 1954.

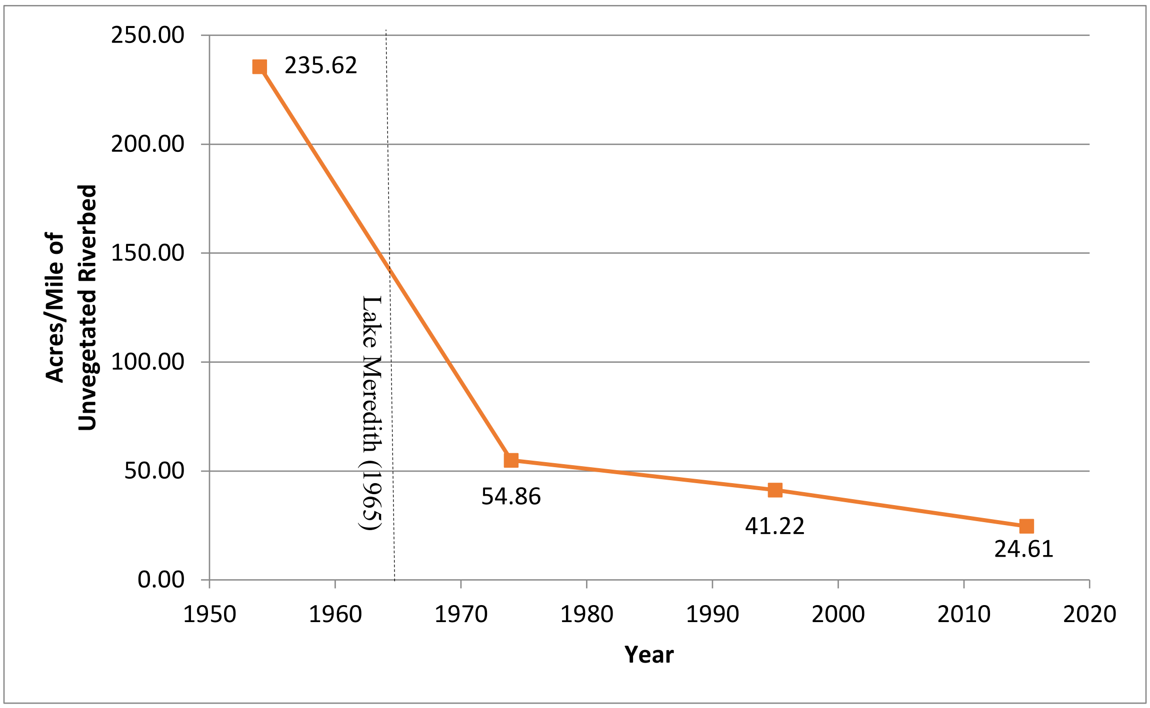


Figure 4-26. Unvegetated riverbed change in the South Canadian River at Bridgeport, OK during years 1954, 1974, 1995, and 2015.

SCAN-4 - We compared a 40-mile stretch of the South Canadian River near Canadian, Texas for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, this river segment had an unvegetated river bed area of 12,356.0 acres (5,000.3 hectares) with an average of 308.9 acres/mile. In the 2010s the same stretch of river occupied 384.9 acres (155.5 hectares) with an average of 9.6 acres/mile. Therefore, 3.1 percent of the unvegetated river channel from the 1950s remained in the 2010s.

SCAN-5 - We compared a 22-mile stretch of the South Canadian River near Amarillo, Texas for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 3,037.9 acres (1,229.4 hectares) with an average of 138.1 acres/mile. In the 2010s the same stretch of river occupied 408.5 acres (165.3

hectares) with an average of 18.6 acres/mile. Therefore, 13.4 percent of the unvegetated river channel from the 1950s remained in the 2010s.

We also compared a 10-mile stretch which included the stream gage of the South Canadian River near Amarillo, TX to see how the unvegetated riverbed changed every approximately 20 years, rather than just from 1950s to 2010s (Figure 4-27). In the 1954, the 10-mile stretch of unvegetated riverbed was 1,498.3 acres (606.4 hectares), with an average acres/mile of 149.8. In 1969, the same 10-mile stretch of unvegetated riverbed was 655.3 acres (265.2 hectares), with an average of 65.5 acres/mile, a 56.3 percent decline from 1954. In 1991, the same 10-mile stretch of unvegetated riverbed was 526.0 acres (212.9 hectares), with an average of 52.6 acres/mile, a 19.7 percent decline from 1969. In 2015, the same 10-mile stretch of unvegetated riverbed was 194.2 acres (78.6 hectares), with an average of 19.4 acres/mile, a 63.1 percent decline from 1991 and a 67.1 percent decrease from 1954.

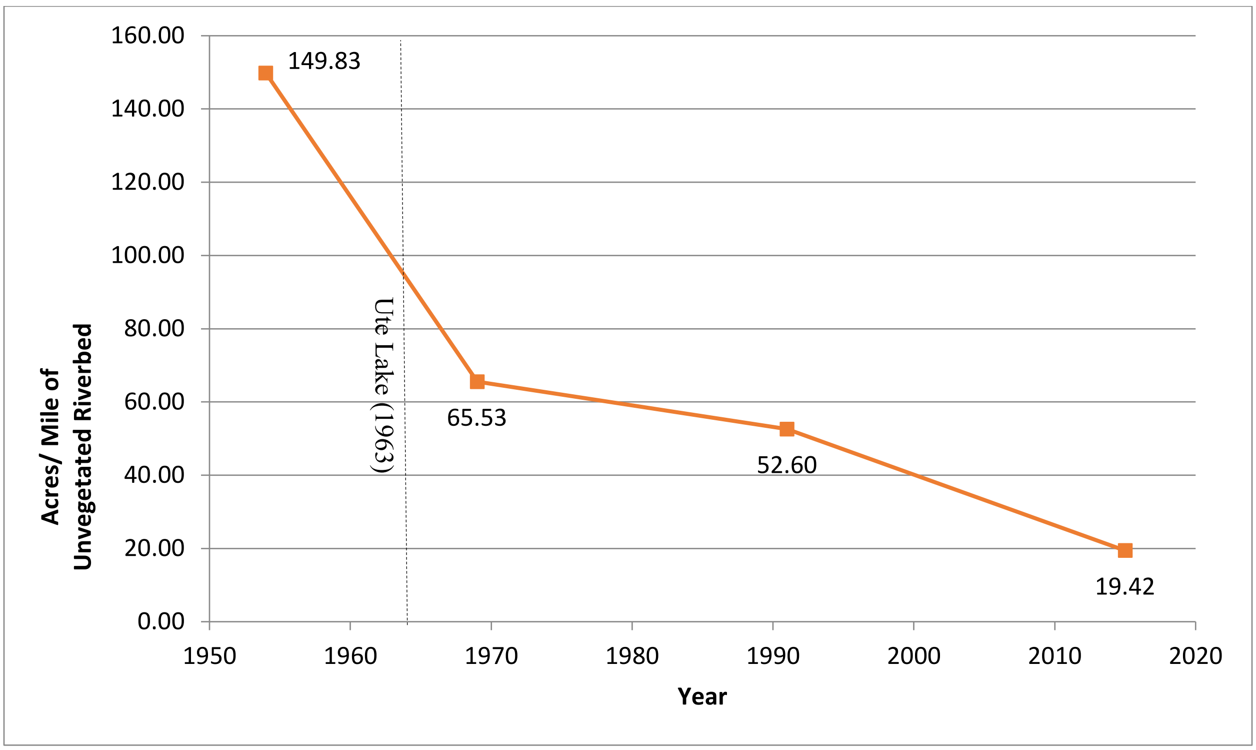


Figure 4-27. Unvegetated riverbed change in the South Canadian River near Amarillo, TX during years 1954, 1969, 1991, and 2015.

North Canadian River

NCAN-3 - We compared a 36-mile stretch of the North Canadian River near Woodward, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 2,144.7 acres (867.9 hectares) with an average of 59.6 acres/mile (Figure 4-28). In the 2010s the same stretch of river occupied 130.7 acres (85.9 hectares) with an average of 3.6 acres/mile. Therefore, 6.1 percent of the unvegetated river channel from the 1950s remained in the 2010s.

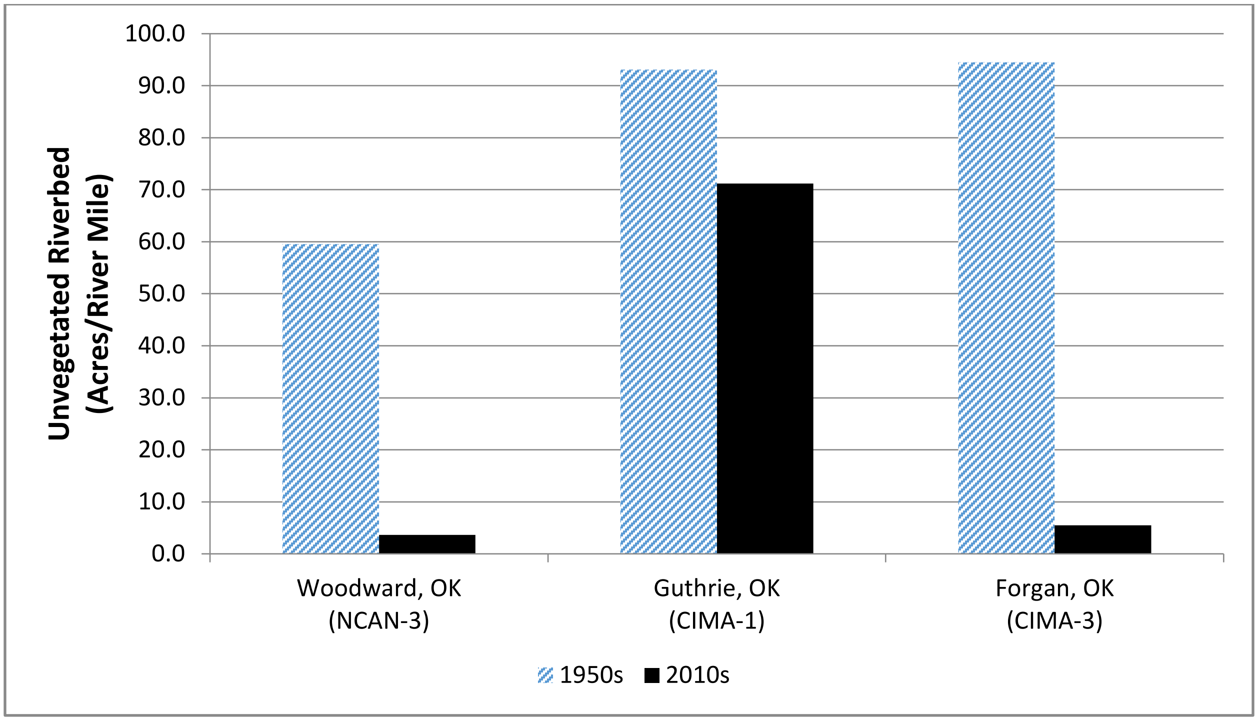


Figure 4-28. Change in Unvegetated Riverbed from 1950s to 2010s for three sites on the Cimarron and North Canadian Rivers.

We also compared a 10-mile stretch which included the stream gage of the North Canadian River near Woodward, OK to see how the unvegetated riverbed changed every approximately 20 years, rather than just from 1950s to 2010s (Figure 4-29). In the 1955, the 10-mile stretch of unvegetated riverbed was 509.3 acres (206.1 hectares), with an average acres/mile of 50.9. In 1973, the same 10-mile stretch of unvegetated riverbed was 148.5 acres (60.1 hectares), with an average of 14.9 acres/mile, a 71 percent decline from 1955. In 1995, the same 10-mile stretch of unvegetated riverbed was 57.2 acres (23.1 hectares), with an average of 2.7 acres/mile, a 61.5 percent increase from 1973 and an 80.8 percent decrease from 1955. In 2015, the same 10-mile stretch of unvegetated riverbed was 28.9 acres (11.7 hectares), with an average of 2.9 acres/mile, a 49.5 percent decline from 1995 and a 94.3 percent decrease from 1955.

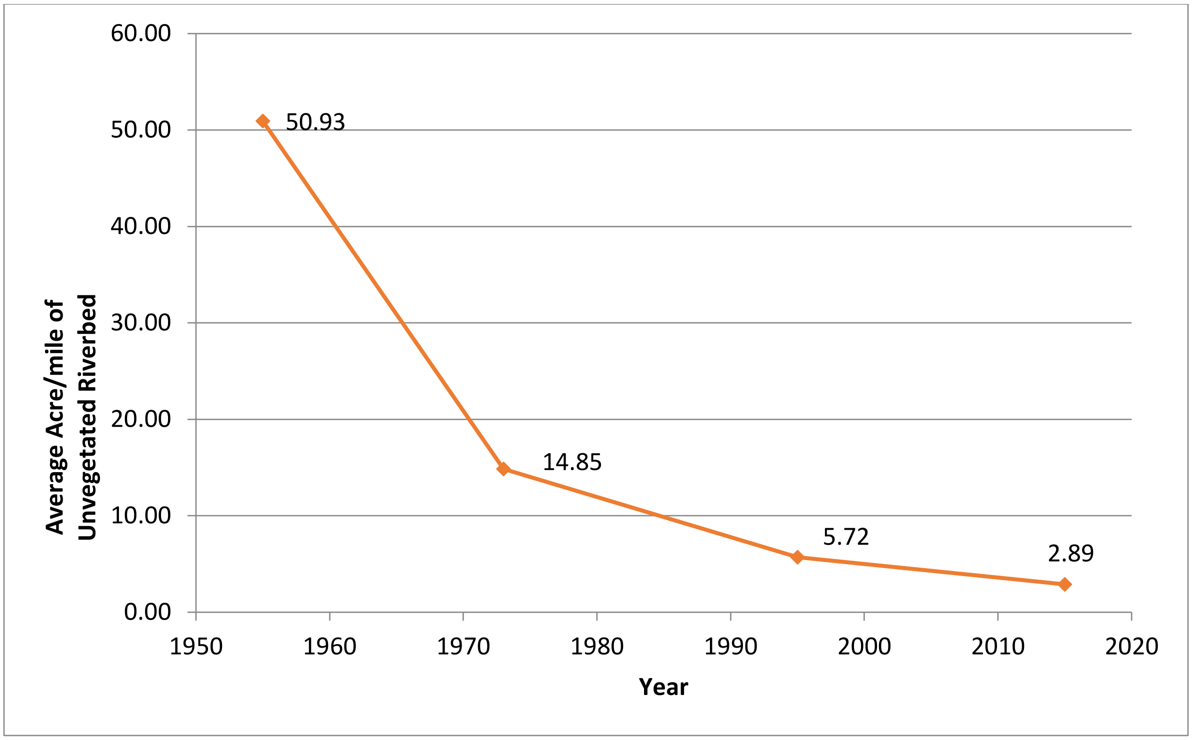


Figure 4-29. Unvegetated riverbed change in the North Canadian River near Woodward, OK during years 1955, 1973, 1995, and 2015.

Cimarron River

CIMA-1 - We compared a 44-mile stretch of the Cimarron River near Guthrie, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 4,097.1 acres (1,658.0 hectares) with an average of 93.1 acres/mile (Figure 4-89). In the 2010s the same stretch of river occupied 3,133.4 acres (1,268.1 hectares) with an average of 71.2 acres/mile. Therefore, 71.2 percent the unvegetated river channel from the 1950s remained in the 2010s.

We also compared a 10-mile stretch which included the stream gage of the Cimarron River near Guthrie, OK to see how the unvegetated riverbed changed every approximately 20 years, rather than just from 1950s to 2010s (Figure 4-30). In the 1955, the 10-mile stretch of unvegetated riverbed was 1,114.0 acres (450.8 hectares), with an average acres/mile of 111.4. In 1968, the same 10-mile stretch of unvegetated riverbed was 863.0 acres (349.3 hectares), with an average of 86.3 acres/mile, a 22.5 percent decline from 1955. In 1995, the same 10-mile stretch of unvegetated riverbed was 1,038.4 acres (420.2 hectares), with an average of 120.3 acres/mile, a 20.3 percent increase from 1968. In 2015, the same 10-mile stretch of unvegetated riverbed was 736.4 acres (298.0 hectares), with an average of 73.6 acres/mile, a 29.1 percent decline from 1991 and a 44.9 percent decrease from 1955.

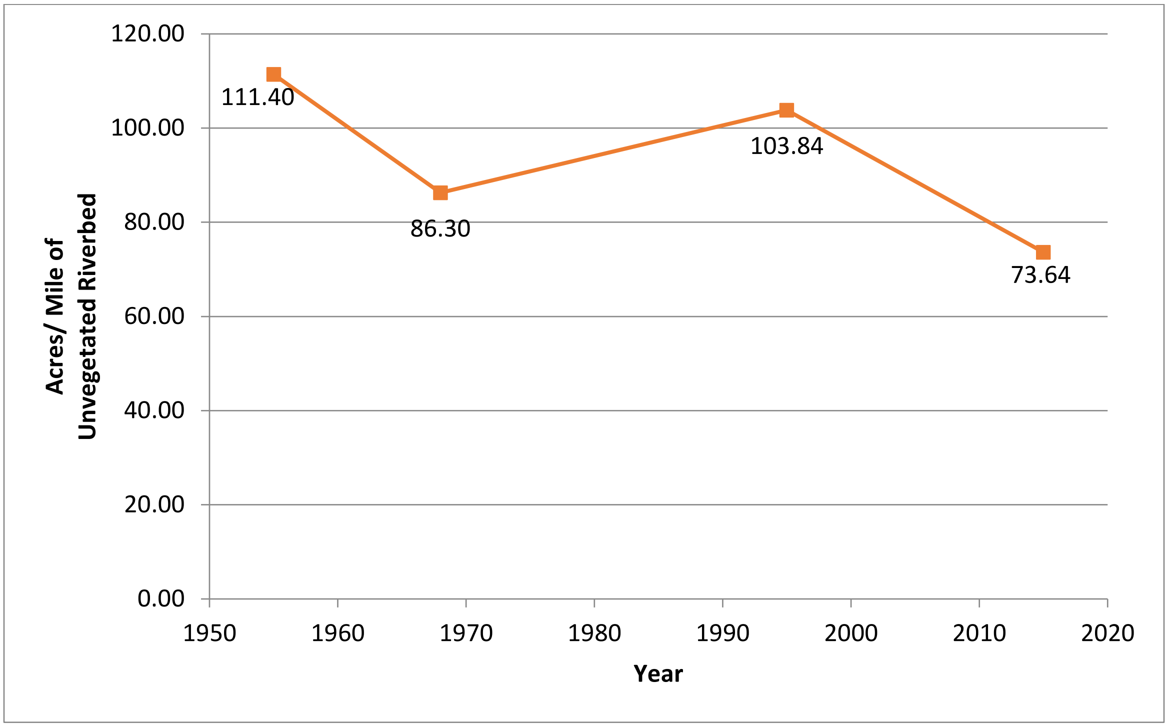


Figure 4-30. Unvegetated riverbed change in the Cimarron River near Guthrie, OK during years 1955, 1968, 1995, and 2015.

CIMA-3 - We compared a 34-mile stretch of the Cimarron River near Forgan, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 3,213.3 acres (1,300.4 hectares) with an average of 94.5 acres/mile (Figure 4-28, above). In the 2010s the same stretch of river occupied 186.6 acres (75.5 hectares) with an average of 5.5 acres/mile. Therefore, 5.8 percent of the unvegetated river channel from the 1950s remained in the 2010s.

Ninnescah River

ARK-5 - We compared a 16.5-mile stretch of the Ninnescah River near Clearwater, Kansas for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 353.6 acres (143.1 hectares) with an average of 21.4 acres/mile (Figure 4-31). In the 2010s the same stretch of river occupied 341.1 acres (138.0 hectares) with an average of 20.7 acres/mile. Therefore, 96.5 percent of the unvegetated river channel from the 1950s remained in the 2010s.

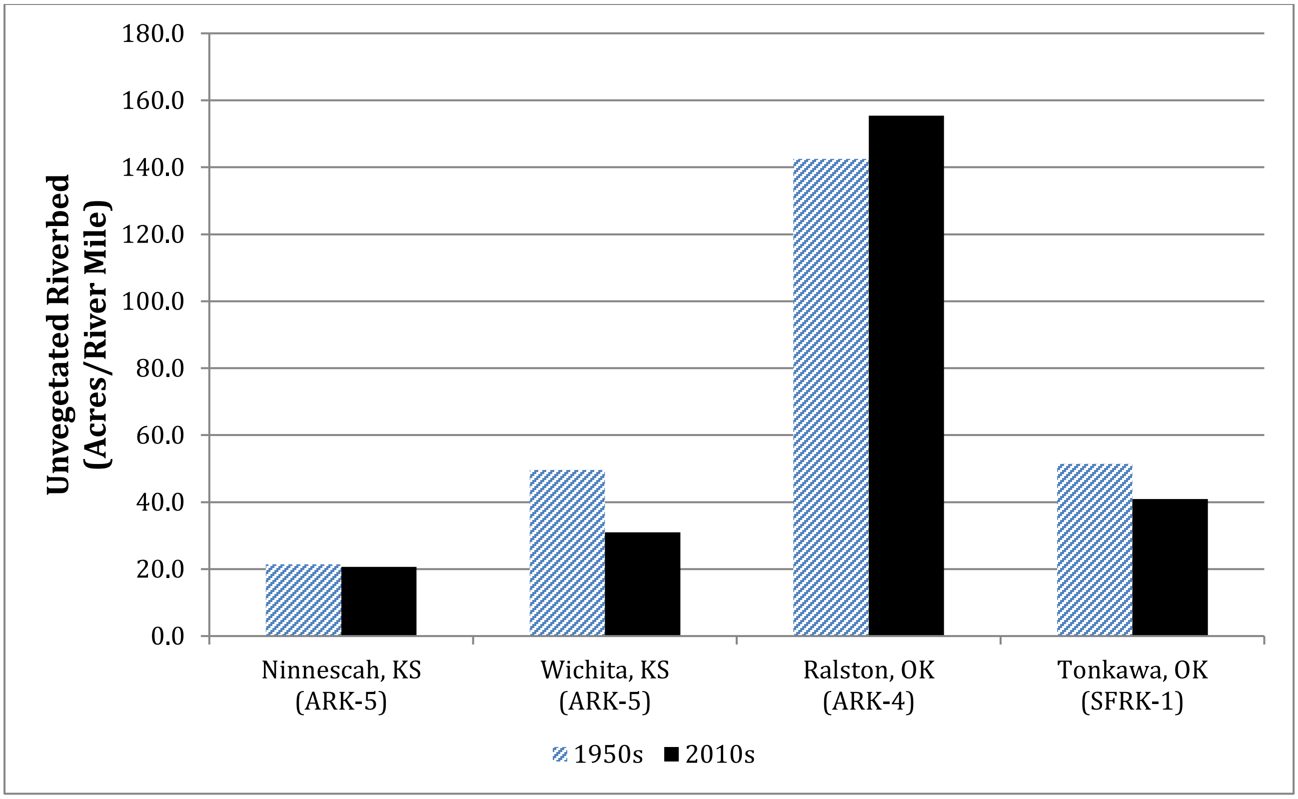


Figure 4-31. Change in Unvegetated Riverbed from 1950s to 2010s for four sites on the Arkansas River and Salt Fork of the Arkansas River.

Upper Arkansas River

ARK-5 - We compared a 6.5-mile stretch of the Arkansas River northwest of Wichita, Kansas for temporal change in unvegetated river channel between the 1950s and 2010s (Figure 4-31, above). In the 1960s, the stretch analyzed had an unvegetated river bed area of 322.7 acres (130.6 hectares) with an average of 49.6 acres/mile (Figure 4-31, above). In the 2010s the same stretch of river occupied 201.4 acres (81.5 hectares) with an average of 31.0 acres/mile. Therefore, 62.4 percent of the unvegetated river channel from the 1960s remained in the 2010s.

ARK-4 - We compared a 63-mile stretch of the Arkansas River from the Kaw Reservoir Dam downstream to Ralston, Oklahoma for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 8,980.6 acres (3,634.3 hectares) with an average of 142.5 acres/mile (Figure 4-31, above). In the 2010s the same stretch of river occupied 9,789.3 acres (3,961.6 hectares) with an average of 155.4 acres/mile. Therefore, the unvegetated river channel increased to 109.0 percent from the 1950s remained in the 2010s.

We also compared a 10-mile stretch of the Arkansas River near Ralston, OK to see how the unvegetated riverbed changed for four time periods, rather than just from 1950s to 2010s (Figure 4-30). In the 1955, the 10-mile stretch of unvegetated riverbed was 1,508.99 acres (610.4 hectares), with an average acres/mile of 150.8. In 1966, the same 10-mile stretch of unvegetated riverbed was 1,546.6 acres (625.9 hectares), with an average acres/mile of 154.7, a 2.5 percent increase from 1955 (Figure 4-32). In 1995, the same 10-mile stretch of unvegetated riverbed was 1,553.6 acres (628.77 hectares), with an average of 155.44 acres/mile, a 0.5 percent increase from 1966 and a 3.0 percent increase from 1955. In 2015, the same 10-mile stretch of unvegetated riverbed was 1,691.4 acres (684.5 hectares), with an average of 169.1 acres/mile, an 8.9 percent increase from 1995 and a 12.1 percent increase from 1955.

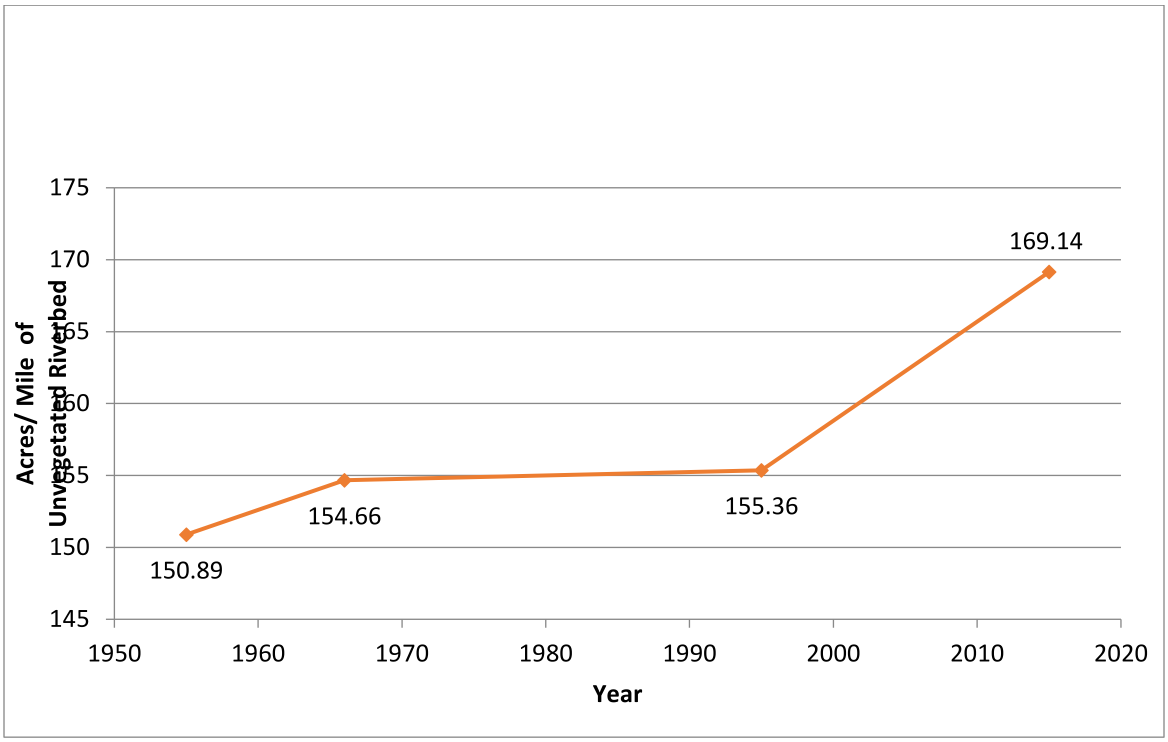


Figure 4-32. Unvegetated riverbed change in the Arkansas River near Ralston, OK during years 1955, 1966, 1995, and 2015.

Salt Fork of the Arkansas River

SFRK-1 - We compared a 34.5-mile stretch of the Salt Fork of the Arkansas River from the just above Tonkawa, Oklahoma down to the junction with the Arkansas River for temporal change in unvegetated river channel between the 1950s and 2010s. In the 1950s, the stretch analyzed had an unvegetated river bed area of 1,773.9 acres (717.9 hectares) with an average of 51.4 acres/mile (Figure 4-31, above). In the 2010s the same stretch of river occupied 1,412.4 acres

(571.6 hectares) with an average of 40.9 acres/mile. Therefore, 79.6 percent of the unvegetated river channel from the 1950s remained in the 2010s.

We also compared a 10-mile stretch of the Salt Fork of the Arkansas River near Tonkawa, OK to see how the unvegetated riverbed changed for five time periods, rather than just from 1950s to 2010s (Figure 4-33). In 1937 (pre-impoundment), the 8-mile stretch of unvegetated riverbed was 393.2 acres (159.1 hectares), with an average acres/mile of 45.2. In 1995, the same 8-mile stretch of unvegetated riverbed was 335.0 acres (135.6 hectares), with an average acres/mile of 141.9, a 14.8 percent decrease from 1937. In 1966, the same 8-mile stretch of unvegetated riverbed was 252.5 acres (102.2 hectares), with an average of 31.6 acres/mile, a 24.6 percent decrease from 1955 and a 35.8 percent decrease from 1937. In 1995, the same 8-mile stretch of unvegetated riverbed was 257.3 acres (104.1 hectares), with an average of 32.2 acres/mile, a 1.9 percent increase from 1966 and a 34.6 percent decrease from 1937. In 2015, the same 8-mile stretch of unvegetated riverbed was 231.9 acres (93.8 hectares), with an average of 29.0 acres/mile, a 9.8 percent decrease from 1995 and a 41.0 percent decrease from 1937.

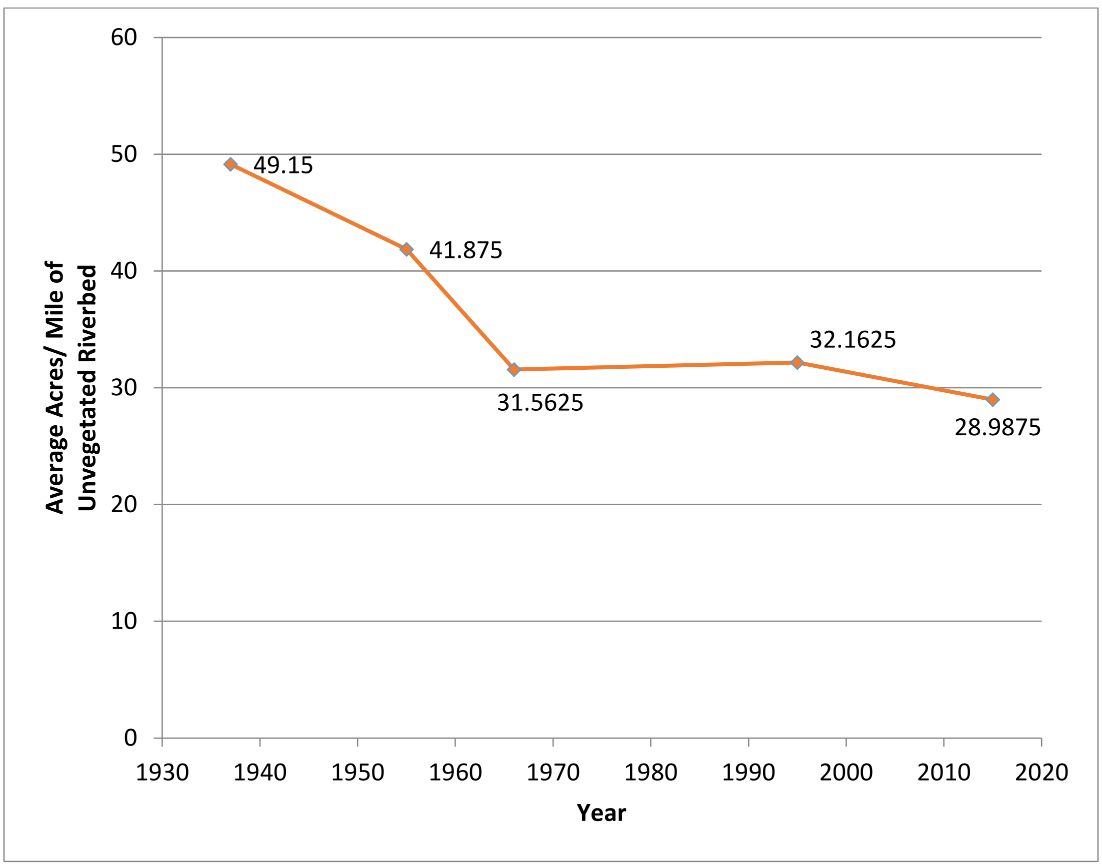


Figure 4-33. Unvegetated riverbed change in the Salt Fork of the Arkansas River near Tonkawa, OK during years 1937, 1955, 1966, 1995, and 2015.

4.4.3.3 Summary

All rivers had a decrease in unvegetated riverbed acreages between the 1950s and 2010s, with the exception of the Arkansas River near Ralston, OK which had an increase of 9.0 percent. Unvegetated riverbed acreage decrease averaged 60 percent, ranging from a low of 4.5 percent change (Ninnescah River near Clearwater, KS) to over 96 percent loss (South Canadian River near Canadian, TX). The decrease in riverbed change was often in areas located downriver from impoundments, although some areas other factors, such as water withdrawals from irrigation or oil & gas development, may have played a role in the decrease. Typically, as distance downriver from impoundment increased, the percent of unvegetated riverbed lost decreased (Table 4-14).

Table 4-14. Summary table of channel narrowing results.

Subunit	Site	River Miles Analyzed	1950s Ac/mi	2010s Ac/mi	% of 1950s	Water Diversion	Dam year	Resiliency Rank
ARK 4	Ralston, OK	63	142.5	155.4	109.0	Kaw Lake	1976	*Good*
SFRK 1	Tonkawa, OK	34.5	51.4	40.9	79.6	Salt Plains Lake	1941	*Good-Fair*
ARK 5	Ninnescah, KS	16.5	21.4	20.7	96.5	Cheney Reservior	1964	*Good-Fair*
ARK 5	Wichita, KS	6.5	49.6	31.0	62.4	John Martin Reservoir	1948	*Fair*
CIMA 1	Guthrie, OK	44	93.1	71.2	76.5	Center Pivot Irrigation	1950s +	*Good-Fair*
CIMA 3	Forgan, OK	34	94.5	5.5	5.8	Center Pivot Irrigation	1950s +	*Null*
NCAN 3	Woodward, OK	36	59.6	3.6	6.1	Optima Lake	1978	*Null*
SCAN 1	Calvin, OK	30	193.0	100.5	52.1	Lake Meredith	1965	*Fair-Good*
SCAN 2	Purcell, OK	20	285.3	69.4	24.3	Lake Meredith	1965	*Poor-Fair*
SCAN 2&3	Bridgeport, OK	30	184.2	20.7	11.2	Lake Meredith	1965	*Poor*
SCAN 4	Canadian, TX	40	308.9	9.6	3.1	Lake Meredith	1965	*Null*
SCAN 5	Amarillo, TX	22	138.1	18.6	13.4	Conchas / Ute	1939 / 1963	*Poor*

Using the percent change in unvegetated riverbed from the 1950s to the 2010s as a basis for comparison, areas that had declined less than 25 percent were assigned a score of ***Good*,** areas with a decline between 26 and 50 percent were assigned a score of ***Fair***, areas with a decline between 51 and 89 percent were assigned a score of ***Poor***, and areas with a decline more than 90 percent were assigned a score of ***Null***.

In addition to scoring based upon percent loss of unvegetated riverbed since the 1950s, a second score was determined based upon average acres/mile of unvegetated riverbed. Using unvegetated riverbed size in the 1950s as a baseline, we found that 50 percent (6 of 12) of the site analyzed were greater than 100 acres in size and that 42 percent (5 of 12) were between 50 and 99 acres in size. Therefore, we scored areas in 2010s at least 100 acres in size as ***Good***, areas between 50 and 99 acres in size as ***Fair***, areas between 10 and 49 acres in size as ***Poor***, and areas less than 10 acres in size as ***Null***.

We then combined the percent loss score and area score to determine a final channel narrowing score. If both scores were the same, then the score was listed once. If the two scores were different, then the scoring reflected both score, with the first score being the percent change score and the second score being the area score (i.e. if percent change was ***Fair*** and area was ***Good***, then final score is ***Fair-Good***). Final scores are provided in section 4.5 below.

4.4.4 Current Water Quality

4.4.4.1 Methods

Historic water quality data were obtained through data requests sent to relevant state water resource agencies. The Oklahoma Water Resources Board provided (via email) water quality data for the Salt Fork of the Arkansas River at US 77 near Tonkawa, the Cimarron River at US 81 near Dover, and the South Canadian River at US 66 near Bridgeport for the years 1999 through 2017. Data for the South Canadian River at US 87-287 near Amarillo were downloaded using the Surface Water Quality Viewer Information System, a product of the Texas Commission on Environmental Quality for the years 1968 to 2017. Water quality data for the Arkansas River and North Canadian River during time periods relevant to population of Arkansas River shiner (before 1998 for the Arkansas River or 1993 for the North Canadian) or the *Macrhybopsis* complex (before 1958 or in Kansas for the Arkansas River, or before 1982 for the North Canadian River) were not available. Information regarding fish kills on the Salt Fork of the Arkansas River was also solicited from the Oklahoma Kill Management Response Team, administered by the Oklahoma Department of Environmental Quality.

4.4.4.2 Results

In general, the Cimarron River was the saltiest river of those measured as evidenced by chloride concentrations exceeding those in the Salt Fork of the Arkansas River by 2 to 10 times and concentrations in the South Canadian River by 5 to over 30 times (Figure 4-34). U.S. Fish and Wildlife Service water quality records from 2002-2010 fish surveys shows mean conductivity in the Cimarron River in Kanas averaging 4,703 µmhos/cm, with a significant increase moving downstream to near Freedom, OK of 34,566 µmhos/cm. Mean conductivity declined moving downstream from Freedom, OK, with the lowermost 50 miles (Ripley, OK to Keystone Reservoir) of the Cimarron River measuring 6,648 µmhos/cm and 8,680 µmhos within the lowermost 150 miles (Okeene, OK to Keystone Reservoir) of the Cimarron River. Corresponding measurements (2002-2010 fish surveys) within the South Canadian River, where the Arkansas River shiner currently occurs, averaged 1,684 µmhos/cm in the Lower South Canadian River and 2,577 µmhos/cm in the Upper South Canadian River. Although conductivity in the lower Cimarron River measures 3-5 times greater than the South Canadian River, historical fish collections in the Cimarron River near Buffalo, OK captured Arkansas Rivers shiner near Englewood Kansas where conductivity averaged 10,879 µmhos/cm (Pigg 1987). Pigg (1987) also collected Arkansas River shiner in the Cimarron River east of Buffalo, OK, where conductivity was likely much higher than at Englewood, KS. It should also be noted that chloride concentrations have been increasing in occurrence in the upper South Canadian near Amarillo, TX since the 1990s (Figure 4-34). Dissolved oxygen concentrations were never measured at levels potentially harmful to the ARS or PC based on warm water aquatic life criteria (Figure 4-35).

Though numerous contaminants were measured in the obtained datasets, most of those measurements were not reliably repeated overtime, were below quantification limits, or were not at biologically relevant levels. Arsenic in the Cimarron River was the only exception. Arsenic concentrations between 1999 and 2010 in the Cimarron, South Canadian, and Salt Fork of the Arkansas River were almost uniformly 10 or 11 µg/L and there were no notes to indicate why the 38 reported values for that decade were almost uniform. However, from 2011 to 2017 arsenic concentrations averaged 49.10 µg/L in the Cimarron River (N=4, range 38.00 to 74.90 µg/L) while the South Canadian River averaged 3.31 µg/L Arsenic (N-9, range 2.36 to 4.43 µg/L). Those arsenic concentrations in the Cimarron River are above levels (28 µg/L) that caused golden shiners *Notemigonus crysoleucas* to exhibit avoidance behaviors, but well below acutely toxic concentrations (12.5 mg/L; Hartwell et al. 1989, p.452). Arsenic levels in all measured rivers exceed EPA established levels for human health for the consumption of organisms, but none exceed EPA established levels designed to protect freshwater aquatic life (EPA National Recommended Water Quality Criteria, https://www.epa.gov/wqc/national-recommended-water-quality-criteria).

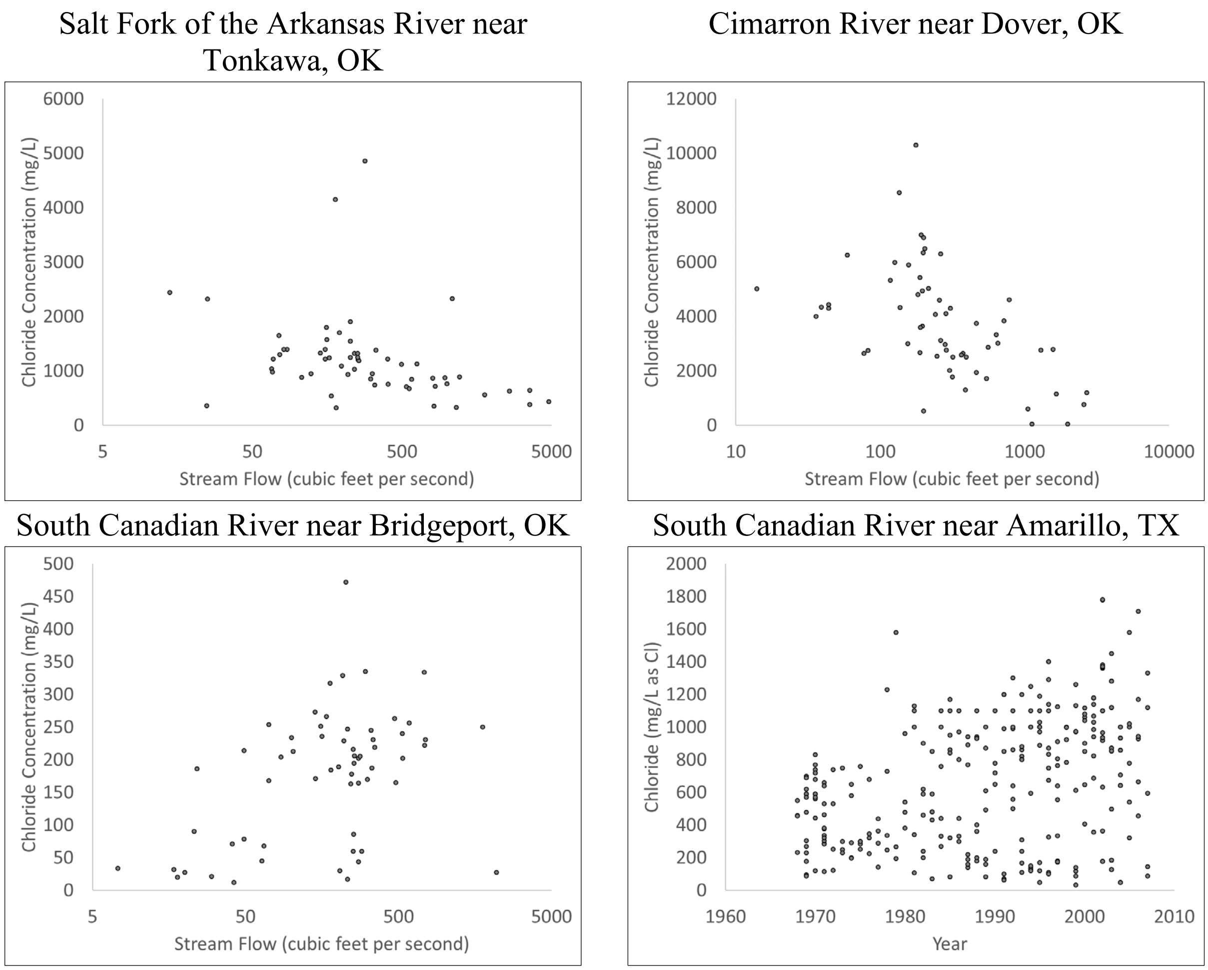


Figure 4-34. Chloride concentrations in rivers with current or recent populations of Arkansas River shine or peppered chub. River concentrations are graphed against stream flow to illustrate the potential dilution effect of rains. Reliable streamflow data was not present in the dataset for the South Canadian River near Amarillo, TX.

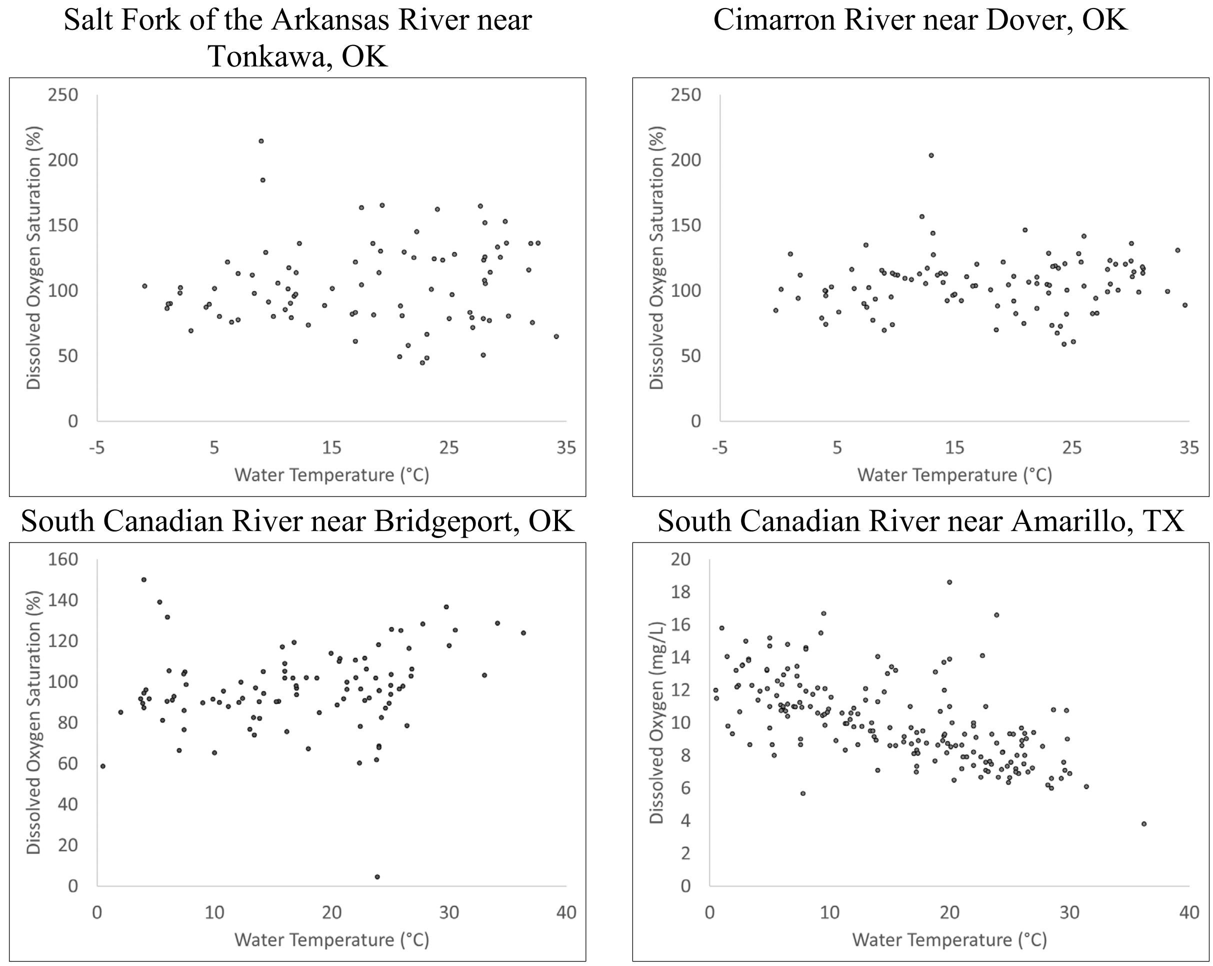


Figure 4-35. Dissolved oxygen concentrations corrected for temperature and salinity (expressed as percent saturation). Correction factors were not reliably available for the South Canadian River near Amarillo, TX and that data is presented as raw concentrations.

4.5 RESILIENCY, REPRESENTATION, AND REDUNDANCY

4.5.1 Resiliency

Resiliency describes the ability of a population to withstand either periodic or stochastic disturbance events, not rising to the level of catastrophic. Resiliency is positively related to population size and health and may be influenced by habitat factors such as flow, connectivity, and geomorphology. Generally speaking, populations need abundant individuals within habitats of adequate area and quality to maintain survival and reproduction in spite of disturbance. For the purposes of this SSA report, the term resiliency is applied to Resiliency Unit (or populations).

We summarized the overall current condition of the Arkansas River shiner and peppered chub within each Resiliency Unit by designating three relative categories (***Good, Fair,*** and ***Poor***) as discussed in the corresponding demographic and habitat sections 4.3 and 4.4 above and summarized in Tables 4-15, 4-16, and 4-17 below. The current condition category is a qualitative estimate based on the analysis of the four measurable population factors: capture ratio, probability of presence trend, relative abundance, and relative abundance trend; and five habitat/flow factors: stream fragment length, channel narrowing, flood frequency analysis, hydroperiod, and low flow conditions. Analysis methods and results for each of these factors are described in sections 4.3 and 4.4 above.

Table 4-15. Demographic factors and criteria definitions for the Arkansas River shiner.

	Demographic Factors for Arkansas River Shiner (ARS)			
Condition Category	**Capture Ratio**	**Probability of Capture Trend**	**Relative Abundance**	**Relative Abundance Trend**
NULL (Ø) *Factor No Longer Measureable*	No ARS captured	No ARS Captured	No ARS Captured	No ARS captured
POOR *Siginificant Departure from Baseline Condition*	Capture ratio of **0.17 or less**	Probability of Presence Trend **Declining**	Relative abundance of ARS less than 7**%**	Long-term trend of ARS relative to other species captured is **Declining**
FAIR *Fair to Moderate Departure from Baseline Condition*	Capture ratio of **0.18-0.73**	n/a	Relative abundance of ARS **7-25%**	n/a
GOOD *Near Baseline Condition*	Capture ratio **0.74 or greater**	Probability of Presence Trend **Stable or Increasing**	Relative abundance of ARS greater than **26%**	Long-term trend of ARS relative to other species captured is **Stable or Increasing**

Table 4-16. Demographic factors and criteria definitions for the peppered chub.

	Demographic Factors for Peppered Chub (PC)		
Condition Category	**Capture Ratio**	**Probability of Capture Trend**	**Relative Abundance**
NULL (Ø) *Factor No Longer Measureable*	No PC captured	No ARS Captured	No PC Captured
POOR *Siginificant Departure from Baseline Condition*	Capture ratio of **0.18 or less**	Probability of Presence Trend **Declining**	Relative abundance of PC less than **3%**
FAIR *Fair to Moderate Departure from Baseline Condition*	Capture ratio of **0.19-0.75**	n/a	Relative abundance of ARS **3-10%**
GOOD *Near Baseline Condition*	Capture ratio **0.75 or greater**	Probability of Presence Trend **Stable or Increasing**	Relative abundance of ARS greater than **11%**

Table 4-17. Habitat and flow factors for the Arkansas River shiner and peppered chub.

Habitat and Flow Factor Definitions					
	Stream Fragment Length	**Channel Narrowing**	**Flood Frequency Analysis**	**Hydroperiod**	**Low Flow Conditions**
Null	**Less than 64 river miles** (pelagic extirpation)	**Greater than 90% loss** of area (acres/mile) since 1950s **<10 acres/mile**	**The weighted sum of the proportional differences for the 2, 5, and 10 year events** between pre- and post-impoundment is less **than 10%.**	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **greater than a 90% decrease**.	–
Poor	**64-135 river miles** - between pelagic extirpation and species threshold	**50%-89% loss** of area (acres/mile) since 1950s **10-49 acres/mile**	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **between 10-50%**.	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **between a 25-90% decrease**.	**An increasing pattern or high frequency** in the number of days of less than 0.57 m^3/s (20 ft^3/s).
Fair	**136-185 river miles** - Above the Arkansas River shiner and peppered chub needs thresholds, but below the combined pelagic broadcast spawning threshold.	**24%-50% loss** of channel area (acres/mile) since 1950s **50-99 acres/mile**	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **between 50-75%**.	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **between a 10-25% decrease**.	**A cyclical pattern** in the number of days of less than 0.57 m^3/s (20 ft^3/s).
Good	**Greater than 185 river miles** - No extirpation of pelagic broadcast spawning fishes anticipated (based on fragment length alone).	**25% or less loss** of channel area (acres/mile) since 1950s **100+ acres/mile**	The weighted sum of the proportional differences for the **2, 5, and 10 year events** between pre- and post-impoundment is **greater than 75%.**	The percent difference in stream discharge of the hydroperiod between pre- and post-impoundment is **from a positive gain to a 10% decrease**.	**A decreasing pattern or low frequency** in the number of days of less than 0.57 m^3/s (20 ft^3/s).

For this report, resiliency is classified as **High**, **Moderate**, or **Low** for each analysis area. **High** resiliency represents a combination of population and habitat factors that are '***Good***' to ***Fair*** and would support a high probability of maintaining existing populations capable of withstanding periodic or stochastic disturbances under current conditions. **Moderate** represents a combination of population and habitat factors that are mostly ***Good*** to ***Fair***, but may have some reduced resiliency due to factors classified as ***Poor***, and would support a moderate probability of maintaining populations (and withstanding periodic or stochastic disturbances) under current conditions. **Low** resiliency represents a combination of population and habitat factors that are mostly ***Fair*** to ***Poor*** (but may have some factors classified as ***Good***) and would only support a low probability of maintaining populations and withstanding periodic or stochastic disturbances under current conditions.

4.5.1.1 Resiliency Results

Arkansas River shiner

Arkansas (Upper and Lower), Cimarron, and North Canadian Rivers

The Arkansas River shiner is considered functionally extirpated from the Arkansas, Cimarron and North Canadian Rivers, therefore resiliency no longer exists in these rivers (Table 4-18). It should be noted that some habitat factors in these now unoccupied rivers do Some of these rivers do potentially have favorable flow and stream width conditions, which we further assess in Chapter 5 – Future Condition.

Table 4-18. Current resiliency summary table for the Arkansas River shiner.

CURRENT RESILIENCY *Arkansas River shiner*										
	Demographic Factors				Habitat/Flow Factors					*CURRENT RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Relative Abundance Trend	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Lower Arkansas	ø	na	ø	ø	ø	na	na	na	na	ø
Upper Arkansas	ø	na	ø	ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	ø
Cimarron	ø	na	ø	ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	ø
North Canadian	ø	na	ø	ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	ø
Lower S. Canadian	Poor & Good	Poor & Good	Poor to Fair	Poor	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	MODERATE
Upper S. Canadian	Good	Good	Good	Good	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	MODERATE

Upper South Canadian River

Current resiliency of the Arkansas River shiner in the Upper South Canadian River is considered ***Moderate***. All demographic factors represent ***Good*** conditions; however, our analysis of habitat and flows suggest that this stretch of the river is in moderate to significant decline. And although relative abundance and capture ratio analysis indicates a stable population, it should be noted that community composition may be shifting away from Arkansas Rivers shiner (Figure 4-14), which could serve as the first indicator of demographic decline. Stream fragment length is adequate (although not optimal) for the species threshold (ranked as ***Fair***), but our channel narrowing, flood frequency, and hydroperiod analyses all indicate significant decline to channel morphology and river flows. Additionally, our low flow analyses indicates that two of the three gages analyzed (Revuelto Creek and South Canadian River near Logan, NM) show ***Poor*** low-flow conditions, with the Amarillo, TX USGS gage indicating ***Fair*** low-flow conditions.

All demographic factors represent ***Good*** conditions; however, our analysis of habitat and flows suggest that this stretch of the river is in moderate to significant decline. Stream fragment length is adequate for the species threshold, but our channel narrowing, flood frequency, and hydroperiod analyses all indicate significant decline due to channel morphology and river flows. Additionally, our low flow analyses indicates that two of the three gages analyzed (Revuelto Creek and South Canadian River near Logan, NM) show ***Poor*** low-flow conditions, with the Amarillo, TX USGS gage indicating ***Fair*** low-flow conditions.

Lower South Canadian River - Current Resiliency of the Arkansas River shiner in the Lower South Canadian River is considered **Moderate** due to a combination of ***Fair*** to ***Poor*** demographic and habitat factors (Table 4-18). SCAN 2 maintains a ***Good*** capture ratio (0.78), SCAN 1 and 3 still have ***Fair*** capture ratios (0.52 and 0.61, respectively), where SCAN 4 (0.04) is near the lowest on record. Probability of detection analysis indicates SCAN 4 significantly declined (***Poor***), where SCAN 1 & 2 significantly increased (***Good***). SCAN 3 appears to be declining, but results were not significant. Relative abundance for SCAN 3 of 8.0 is considered ***Fair***, with SCAN 1, 2, and 4 all considered ***Poor*** (1.0, 5.3, and 2.5, respectively) as compared to optimal baseline conditions. The relative abundance trend significantly declined in all subunits of the Lower South Canadian River.

In terms of habitat and flow factors, stream fragment length is ***Good*** for the Lower South Canadian River, with one stretch of river above the species needed threshold and the other above the pelagic spawning threshold. However, our channel narrowing analysis indicates the Lower South Canadian River has significantly narrowed since the 1950s, with all subunits in significant decline. Flood frequency and hydroperiod also indicate ***Poor*** to ***Fair*** flow/habitat conditions for the species, whereas our low flow metric indicating that the number of low flow days indicates a ***Good*** condition.

Peppered chub

<u>*Arkansas (Upper and Lower), Cimarron, North Canadian, and Lower South Canadian Rivers*</u>

The peppered chub is considered functionally extirpated from the Arkansas, Cimarron, North Canadian and South Canadian Rivers, therefore resiliency no longer exists in these rivers (Table 4-19). Some of these rivers do potentially have favorable conditions in terms of flow and stream width, which we further assess in Chapter 5 – Future Condition.

<u>*Upper South Canadian River*</u>

Current Resiliency of the peppered chub in the Upper South Canadian River is considered low. Capture ratios, as compared to baseline conditions, are considered ***Fair*** and relative abundance is considered ***Poor***. Probability of presence is the only demographic factor considered ***Good***. It should be noted community composition may be shifting away from peppered chub (Figure 4-14), which could serve another indicator of demographic decline. Additionally, our analysis of habitat and flows suggest that this stretch of the river is in moderate to significant decline. Stream fragment length is adequate (although not optimal), for the species threshold (ranked as ***Fair***) but our channel narrowing, flood frequency, and hydroperiod analyses all indicate significant decline to channel morphology and river flows. Additionally, our low flow analyses indicate that two of the three gages analyzed (Revuelto Creek and South Canadian River near Logan, NM) show ***Poor*** low flow conditions, with the Amarillo, TX USGS gage indicating ***Fair*** low flow conditions.

Table 4-19. Current resiliency of the peppered chub.

CURRENT RESILIENCY *Peppered Chub*									
	Demographic Factors			Habitat/Flow Factors					*CURRENT RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Upper Arkansas (includes Ninnescah and Salt Fork)	Ø	na	Ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	Ø
Cimarron	Ø	na	Ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	Ø
North Canadian	Ø	na	Ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	Ø
Lower South Canadian	Ø	Ø	Ø	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	Ø
Upper South Canadian	Fair	Good	Poor	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	LOW

4.5.2 Species Representation

Maintaining representation in the form of genetic or ecological diversity is important to maintain the Arkansas River shiner and peppered chub's capacity to adapt to future environmental changes. Arkansas River shiner and peppered chub must retain populations throughout their range to maintain the overall potential genetic and life history attributes that can buffer the species' response to environmental changes over time. Both species have likely lost genetic and ecological diversity, as some populations have been functionally extirpated. As such, maintaining the remaining representation in the form of genetic diversity may be important to the capacity of the Arkansas River shiner and peppered chub to adapt to future environmental change.

<u>Arkansas River shiner</u>

As discussed in Chapter 2, mitochondrial analysis indicates that Arkansas River shiner genetic diversity is high across populations sampled in the South Canadian River and Reveulto Creek (a tributary of) in New Mexico; the South Canadian River in Oklahoma; and the Pecos River in New Mexico (Osborne *et al*. 2010, p. 8, 15). Considering that genetic diversity was observed to be high across these sampled populations, our best-available information suggests that the Arkansas River shiner has representation in the form of genetic diversity in three areas: (1) The South Canadian River upstream of Lake Meredith, Texas (as evidenced by Osborne's samples in the headwaters of the South Canadian River in New Mexico and its tributary Reveulto Creek); (2) The South Canadian River downstream of Lake Meredith, Texas (Osborne's samples in the South Canadian River in Oklahoma); and (3) the introduced population in the Pecos River, New Mexico (non-listed entity – outside of historical range). We expect additional genetic variation was present in now-functionally extirpated Arkansas River shiner populations elsewhere across its former range that has now been lost. Representation in the form of ecological diversity across the extant populations of Arkansas River shiners is unknown. We expect that ecological diversity was likely present in now-functionally extirpated Arkansas River shiner populations across the wide-ranging and varying Arkansas River basin, which has also now been lost.

Contrary to expectations for a somewhat recently introduced (~1978) species, Arkansas River shiners within the non-native Pecos River population display high levels of within-population genetic diversity. Preliminary genetic studies suggest that the Pecos River population may make a valuable contribution to captive breeding and reintroduction efforts (Osborne et al. 2010, p. 2-3). In the Final Rule for the designation of critical habitat for Arkansas River shiner, transplantation of individuals from the Pecos River population is raised as a possible management action (Service 2005).

<u>Peppered chub</u>

Eisenhour (1999, p. 973) reported that peppered chubs (identified specifically as *Macrhybopsis tetranema*) displayed variation in multiple physical characteristics between populations within the South Canadian and presumably now-functionally extirpated Ninnescah Rivers, and suggested that these differences were adaptive responses to differing local environmental conditions. Eisenhour pointed out that although the upper South Canadian River is an extremely turbid stream, the Ninnescah River is "very clear" at low flows (Matthews, 1988, p. 390). Suspended sediment data from 1969-1970 support these observations. The mean suspended sediment from the Ninnescah River (two stations) was 118 mg/1, whereas the mean suspended sediment at a South Canadian River station at the New Mexico-Texas state line was 639 mg/l (U.S. Geological Survey 1975). Eisenhour suggested that the larger eyes and smaller barbels of northeastern peppered chubs may be adaptive to the less turbid streams of that area. The more sharply sloping head and smaller and more embedded scales of southwestern peppered chubs may be adaptive to the strong currents and shifting beds of sand characteristic of the upper South Canadian, North Canadian, and Cimarron Rivers (Eisenhour 1999, p. 973). These morphological differences between the remaining South Canadian River population and the functionally extirpated Ninnescah River population observed by Eisenhour suggest a loss of unique representation in the form of adaptive ecological diversity. We expect that additional ecological diversity was also likely present in now-functionally extirpated peppered chub populations across varying ecological settings within the wide-ranging Arkansas River basin which has now been lost.

Dr. Osborne used both mitochondrial (mtDNA) and neutral genetic (microsatellites) markers to track changes in gene diversity, heterozygosity, allelic richness, and genetic effective size over a time series for both Arkansas River shiner (2009, 2012-2015, 2017) and peppered chub (2015-2017). Samples were collected from the South Canadian River in New Mexico and Texas. Results indicate that the sampled populations of both species "harbor considerable genetic diversity at the microsatellite DNA loci and mitochondrial gene (Osborne 2017, p. 8)." There was a decline in genetic diversity metrics between samples (2012-2015 to 2017); this may be indicative of a decline in genetic effective population size during this period. Peppered chub had high and stable genetic diversity between sampling periods despite a lower relative abundance. There was no evidence of population genetic structure among sampling sites for either species, consistent with other pelagic broadcast spawning cyprinids (e.g., speckled chub, Rio Grande shiner, plains minnow)(Osborne 2017, p. 6). Both species have “considerable stocks of genetic diversity,” but continue to face substantial extinction risk, because of small population size and geographic range, the threat of long term regional drought, and habitat desiccation (Osborne 2017, p. 9).

We consider the peppered chub to have limited representation in the form of genetic and ecological diversity due to fact that only a single functioning population exists between the Ute Dam, New Mexico and Lake Meredith, Texas. As described in Osborne (2017, p. 9), the peppered chub has “considerable stocks of genetic diversity” within this single population; however, the species lacks the representation of species with multiple populations occurring across varying landscapes.

In summary, both the Arkansas River shiner and peppered chub currently have limited representation. Despite restrictions of their range due to impoundments and other habitat alterations and decline in abundance, it is possible that their genetic variation is sufficient to survive the naturally occurring conditions of the arid prairie stream environments in which they evolved. However, it is unknown if these species have the genetic variability or the time required to adapt to continuing habitat and flow alterations because it is not expected that their basic life history strategies for broadcast-spawning for reproduction would change.

4.5.3 Species Redundancy

As we stated in Chapter 2, redundancy is defined as the ability of a species to withstand catastrophic events (a rare destructive natural event or episode involving many populations and occurring suddenly). Species redundancy is about spreading the risk and can be measured through the duplication and distribution of resilient populations across the range of the species. To provide a slightly stepped-down ‘population’ analysis for this SSA, we combined the concept of historical local populations (including functionally extirpated areas) with what we currently view as local populations to designate Resiliency Units. The greater the number of resilient populations (or Resiliency Units, in the case of our analysis) a species has distributed over a larger landscape; the better its ability to withstand catastrophic events.

Arkansas River Shiner

Historically, the Arkansas River shiner occurred in six Resiliency Units distributed across six states. However, it is now functionally extirpated from all but two (Upper and Lower South Canadian River) of the Resiliency Units. Within the Lower South Canadian River, the species is thought to be distributed from the Texas panhandle (downstream of Meredith) downstream to Lake Eufaula. However, more recent but limited surveys (therefore not included in our analysis above) within the last 5-10 years have failed to capture Arkansas River shiner within some of the most upstream sites in Texas and far western Oklahoma, suggesting this population's distribution may be contracting. Additional surveys in the upper stretch of this unit are needed. Based on a smaller range and fewer Resiliency Units (populations), the species has a higher risk of extirpation from a catastrophic event. Therefore, Arkansas River shiner species-level redundancy has declined since historical conditions and may be at risk for further loss.

Peppered Chub

The peppered chub once occupied five Resiliency Units and six states across its range. However, all but one Resiliency Unit (Upper South Canadian River) has been functionally extirpated. Similar to the Arkansas River shiner, the peppered chub has a higher risk of extirpation form a catastrophic event, due to smaller range and only one remaining Resiliency Unit (population). Therefore, the peppered chub has experienced a decline in species-level redundancy since historical conditions and may be at risk for further loss.

CHAPTER 5 - FUTURE CONDITIONS

5.1 INTRODUCTION

We assessed the needs of the Arkansas River shiner and peppered chub in Chapter 2 and influences on their viability (stressors and conservation) in Chapter 3 to determine the current condition of both species in Chapter 4. In this chapter we identify a range of plausible future scenarios, based on differing influences (stressors and conservation) to the Arkansas River shiner and peppered chub. We apply future scenarios in the context of resiliency, representation, and redundancy to describe the potential future viability of the Arkansas River shiner and peppered chub.

5.2 UNIT SELECTION FOR CURRENT CONDITION ANALYSIS

Our analysis of current condition of the Arkansas River shiner and peppered chub yields only one river where these two species remain within their historical distribution, the South Canadian River. Both species continue to occupy the Upper South Canadian River resiliency unit, whereas the Arkansas River shiner also occupies the Lower South Canadian River resiliency unit.

There are other resiliency units, or sub-units, in which the species no longer occur but where multiple habitat factors met our ***Fair*** to ***Good*** score (Tables 4-18, 4-19). We view these areas as potential for future recovery, and our assessment of these units are summarized below:

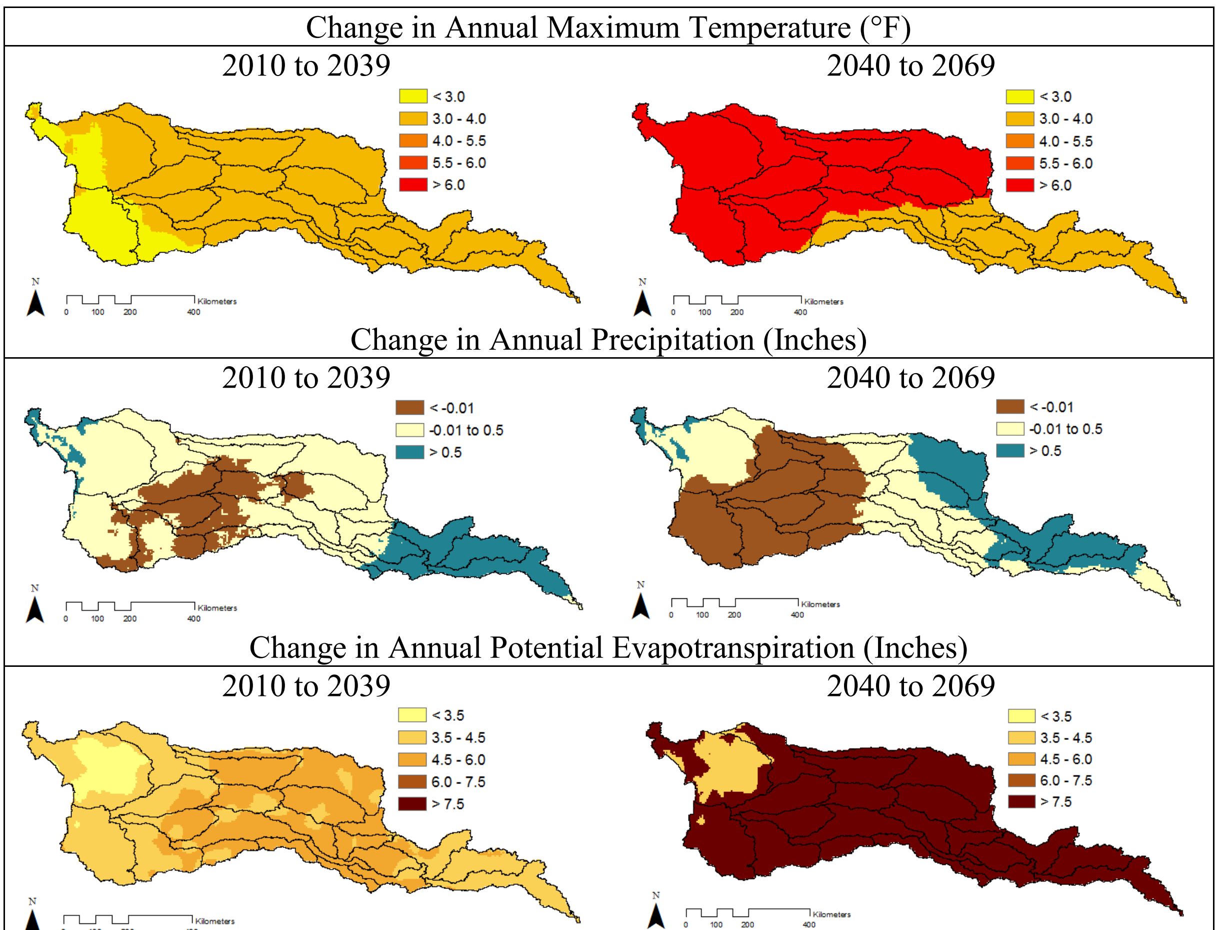
South Ninnescah River – Located in the upper Arkansas River in subunit 5, the South Ninnescah River maintains ***Good*** flow patterns (hydroperiod, flood frequency and low flow conditions) within 20 percent of baseline (pre-impoundment) conditions (Table 4.12). Stream narrowing has also been negligible and is scored as ***Good***, with only a 3.5 percent loss. Fragment length was scored as ***Poor*** (121 river miles), but only 15 river miles below what would be considered a ***Fair*** score.

Arkansas and Salt Fork River – Located upstream of Keystone Reservoir, this stretch of the Arkansas River combined with the Salt Fork of the Arkansas maintains ***Good*** flow patterns within 20 percent of baseline conditions (Table 4.12). The river has increased 9 percent in width since the 1950s and river distance is scored ***Good***, and with over 185 miles of non-fragmented river allowing for fish movement.

Cimarron River – The Cimarron River from the Oklahoma/Kansas border downstream to Keystone Reservoir has over 330 river miles of non-fragmented river (***Good***), and stream width in this lower section of the Cimarron (as compared to the upper section in Kansas) is still adequate (71.2 acres/mile) and has narrowed much less (23 percent versus 94 percent decline, respectively), resulting in a ***Good-Fair*** score. Low flow conditions are scored as ***Good***, whereas hydroperiod and flood frequency are scored as ***Fair***.

5.3 FUTURE CLIMATE

The dominant effects of climate change into the mid-twenty-first century in the analysis areas are related to temperature increases (Figure 5-1). If current emissions continue without abatement (Representative Concentration Pathway; RCP 8.5) then annual maximum temperatures will increase by over 6°F by mid-century. Increased air temperatures will lead to increased water temperatures, which will in turn reduce the water's oxygen carrying capacity and simultaneously increase oxygen demand by increasing metabolic rates. Variations in annual precipitation are expected to be minor (less than 0.1 inch/year loss to gains up to 0.5 inch/year in the eastern reaches). However, due to the increased temperatures and other factors, potential evapotranspiration across most of the study area will increase, leading to an effective water loss of over 7.5 inches/year.



Source: Derived from MACAv2-Metdata datasets.

Figure 5-1. Projected change in annual maximum temperature (top), precipitation (middle), and potential evapotranspiration (bottom) for the early and middle twenty-first century (2010-2069 vs 1971-2000, RCP 8.5).

5.4 FUTURE SCENARIOS OVERVIEW

We identified four future scenarios that best represent the potential range of outcomes, based on differing stressors and conservation actions that affect both species. An overview outline of those scenarios is provided below, with additional details and analyses in sections following.

1) Continuation of Existing Trends
    - Water demands continue at the existing rate
    - Current rate of emissions continues (Representative Concentration Pathway [RCP] 8.5)
    - No additional conservation implemented
2) Water Conservation with Flow Trends Stabilizing
    - Water demands stabilize, resulting in no changes to future flows
    - Current rate of emissions is mitigated – assuming no future effect to flows
    - Water conservation is implemented
3) Species Conservation and Continuation of Existing Trends
    - Water demands continue at the existing rate
    - Current rate of emissions continues (RCP 8.5)
    - Species targeted conservation action are implemented
4) Species and Water Conservation with Flow Trends Stabilizing
    - Water demands stabilize, resulting in no changes to future flows
    - Current rate of emissions is mitigated – assuming no future effect to flows
    - Water conservation is implemented
    - Species targeted conservation actions are implemented

5.5 SCENARIO 1 – CONTINUATION OF EXISTING TRENDS

Under the Continuation of Existing Trends scenario, we continued current rates of flow factors (hydroperiod, flood frequency, and low flows) and applied a future change to the hydroperiod rate at 20 years (to 2039) and 50 years (to 2069), based on RCP 8.5 climate projections and related pour point analysis (see Appendix B for methodology). Under this scenario, stream narrowing continues at current rates and stream fragmentation is analyzed qualitatively, based on changes to flow factors and stream narrowing. To assess fish demographics (presence/absence and relative abundance) we used habitat and flow projections based on methods above to qualitatively project future fish demographic conditions.5.5.1 Arkansas River Shiner

5.5.1.1 Resiliency

Upper South Canadian River

Flow Factors

Hydroperiod – Although the Upper South Canadian River Resiliency Unit contains additional stream gages (see Chapter 4), we chose to limit evaluations of the future conditions to the USGS 07227500; Canadian River near Amarillo, TX. This is largely due to the New Mexico gages being located just downstream of Ute Lake, and thus greatly influenced by the dam and its operations. The Amarillo, TX gage is the only other stream gage within this resiliency unit (see also Chapter 4 for a discussion of the other physical features). The hydroperiod in the Upper South Canadian River Resiliency Unit remains unchanged (April-November). See Appendix D for future Hydrology results.

It is important to understand the time periods in which our comparisons apply. For the current conditions in Chapter 4, we evaluated the pre- and post-impoundment periods during the hydroperiod. Again, the hydroperiod is the interval of the annual hydrograph which captures the most important period of time for the fish (reproduction and recruitment) as well as the influence the annual hydrograph has on physical habitat (creation of new habitat in the floodplain, maintenance of existing habitat, etc.). For the future conditions, our comparisons are also drawn between the pre-impoundment era and the future. While a return to the pre-impoundment hydrology is not feasible, the pre-impoundment future scenario comparisons do provide a common frame of reference to that of the current conditions analysis and is also more consistent with the comparisons used in the fish response/demographic analyses. The scale in Table 4-11, Chapter 4 still applies.

The future time horizons we considered are: 1) 20 years; 2020-2039 and 2) 50 years; 2020-2069. To construct the future hydrographs, we took the last 20-year sequence of the gage record (1997-2016, excluding provisional data) and transposed it into the future. That is, for the time horizon of 2020-2039, we transposed one 20-year sequence and for the 2020-2069 we transposed 2.5, 20-year sequences. We then adjusted the values of the future hydrographs by the average time-rate-of-change (cumulative) during the 1997-2016 interval and a transformation of future precipitation estimates into effective runoff (the portion of runoff that reaches a stream). The latter was derived from an ensemble of 29 downsampled Global Circulation Models under the RCP8.5 (U.S. Climate Resilience Toolkit). Termed here as the climate factor, the transformation can be either an increase or decrease in effective runoff and is summarized as a percent change from the reference period (1986-2015). Our rationale for selecting this reference period is that it captures, in general, both a wet interval (1980s and 1990s) and a dry period since the early 2000s. Lastly, this reference period also represents more recent climate trajectories.

Future conditions at the Amarillo, TX stream gage are anticipated to degrade further (see also Hydrology Appendix D). When comparing the pre-impoundment era to the 20-year future time horizon (2020-2039), the hydroperiod rating remains in a categorically ***Poor*** condition with an 85.1 percent decline from pre-impoundment conditions. The mean daily hydrograph shows drastic reductions in peak flows from the pre-impoundment period and an overall reduction in mean daily discharge in all but winter base flows. In addition, the mean discharge for the hydroperiod shows a reduction in all flow statistics including reductions in annual discharge variability.

Similarly, for the 2069-time horizon, the categorical condition remains ***Poor*** with a decline from the post-impoundment era of 85.8 percent, a slight decrease from the 2039 score. Although the climate factor was slightly less than the 2039-time horizon (a decrease in effective runoff of 7.14 percent in 2039 vs. a decrease of 5.9 percent in 2069), the projected reduction in surface flow (cumulatively continued from the reference period of 1997-2016) has further impacted stream discharge.

Flood Frequency Analysis – The issue of forecasting flood magnitude and frequency in the future time steps is difficult. It is a broadly held view that floods are increasing worldwide (Hirsch and Archfiled 2015, p. 198) in response to warming climate conditions and thus increased levels of precipitation (Kunkel et al. 2013, p. 499). That is, an increasingly warmer atmosphere can hold more moisture via the Clausius-Clapeyron relationship. Projections by the U.S. Global Research Program (2017, p. 207) maintain a medium level of confidence for increased frequency and intensity of precipitation in the central United States mainly through convective, warm-season events. Despite these projections, most studies on flooding trends do not indicate that the magnitude of floods are increasing (Hirsch and Archfiled 2015, p. 198) and the International Panel on Climate Change (IPCC) Fifth Assessment Report concludes that:

"… there continues to be a lack of evidence and thus a low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale" (IPCC 2013, p. 2104).

Mallakpour and Villarini (2015, p. 250) employed a flood threshold approach (which eliminates outliers in drought years) in an examination of 774 stream gages in the central United States and concluded that there is limited evidence of significant changes in the magnitude of peak flood events but strong evidence in the increased frequency of such events, and that these changes stem from alterations in both seasonal rainfall and temperature patterns throughout the region. Further, Peterson et al. (2013, p. 825) also acknowledges the trend of increasing precipitation but also points out the absence of a strong relationship this pattern has to river flooding. One contributory explanation for this are seasonal shifts (from rain-on-snow events to summer convective storms) where heavy precipitation does not necessarily lead to large runoff volumes and thus not a strong streamflow response. Additional factors include large catchment sizes.

Conversely, Qin and Lu (2014, p. 1205) employed an intensive methodology whereby a number of General Circulation Models were coupled with a spatially explicit hydrologic model (SLURP) to predict the magnitude of the future 200-year return interval at three discrete time steps (T_1 = 2011-2030, T_2 = 2046-2065, and T_3 = 2080-2099). Ensemble model results indicate modest increases of 5.23, 4.08, and 12.92 percent, respectively. Worst case scenario results were 25.18, 31, and 44.46 percent, respectively, indicating considerable variation and uncertainty for what amounts to be an extreme flood event with a low return interval.

Given the inherent difficulties and substantiated low confidence in forecasting future flood frequency and magnitude (IPCC 2013, p. 2104, Kundzewicz et al. 2013, p. 2), we are reluctant to employ any predictions beyond some qualitative statements as they may apply to aquatic habitat. As a result, we do not change the numerical score or categorical rating from those of our pre- and post-impoundment evaluation (see Chapter 4). In addition, the impoundments in the vast majority of these systems are by far the largest driver in the alteration of the natural flow regime and, as such, fully capable of muting or completely eliminating the influence of climate change variation at the return interval floods (2, 5, and 10-year events) we have included in the evaluation of the Arkansas River shiner and the peppered chub.

Qualitatively, then, there is some support for the increase in flood frequencies but not necessarily the magnitude of stream discharge associated with a given return interval. Nonetheless, if we examine a hypothetical case where the following exists:

1) The 10-year, post-impoundment event at the Amarillo, TX gage is 925.4 m^3/s (32,680 ft^3/s) and
2) The worst case scenario from Qin and Lu (2014, p. 1205) in T3 (2046-2065), which is roughly equivalent to our end-member year of 2069, shows an increase in the 200-year event of 31 percent.

When applying this worst case scenario, the Amarillo, TX 10-year event increases to 1,212.3 m^3/s (42,810.8 ft^3/s) whereas the pre-impoundment 10-year event is 2,026.6 m^3/s (71,570 ft^3/s). If we then apply the same factor to the 2- and 5-year events, we arrive at a 50.63 Flood Frequency Analysis score which barely attains a ***Fair*** rating by 0.63 percent. Current conditions rate the Amarillo, TX gage at ***Poor*** with a score of 38.7 percent. This hypothetical scenario is merely intended to illustrate that, given an extreme case, even when the post-impoundment discharge is maximized to a potential boundary value under an aggressive climate change scenario, the weighted Flood Frequency Analysis score it is still only half of the pre-impoundment value.

While an increase in magnitude would likely benefit the Arkansas River shiner and peppered chub through floodplain inundation and habitat creation/maintenance, large gains are not realistic and smaller gains will likely be offset by increases in municipal and agricultural water demands. Again, what can be said with some degree of confidence is that the frequency of a given return interval may increase in the future. This should be generally viewed as a positive ecological aspect in these highly altered systems; again, however, some gains in flood event discharge may be offset by future water demands. We therefore retain the current condition scores and ratings as we cannot, with any degree of confidence, derive the values necessary for a numerical comparison.

With respect to the Amarillo, TX gage, we anticipate that there would at least be a similar attenuation of peak flood flows by Ute Lake and thus, by extension, similar impacts to the flood frequencies as seen in the pre- and post-impoundment eras. The pre- and post-impoundment score is 38.7 percent. That is, of the weighted 2, 5, and 10-year events there is 38.7 percent of the pre-impoundment flooding regime in place at these return intervals. This resulted in a ***Poor*** rating for the current conditions and we do not see this condition changing in the future at either time horizon. Therefore, we rated both future conditions as ***Poor*** for the future Flood Frequency Analysis.

Low Flow Conditions – The Low Flow conditions, days per year of less than 0.57 m^3/s (20 ft^3/s), are expected to remain as a ***Fair*** rating. We anticipate the cyclic pattern to continue but there is a possibility that increased water demands may influence the pattern to some degree. Nonetheless, the low flow condition should generally follow an approximate 20-year period of increases and decreases in the number of days of low flow conditions.

Habitat Factors

With stream narrowing rates continuing (Figure 5-2 and Riverbed Change Appendix C), the South Canadian River near Amarillo likely resembles the Cimarron River at Forgan (5.5 acres/mile) or North Canadian River at Woodward (3.6 acres/mile) current condition (Chapter 4, Figure 4-28), where the Arkansas River shiner and peppered chub are functionally extirpated. Similar narrowing has already occurred within the South Canadian River near Canadian, Texas (9.6 acres/mile), where the Arkansas River shiner has not been collected since 2011 (USFWS collections). Based on these results, we consider a maximum of 10 acres/mile or less a critical threshold for both the Arkansas River shiner and peppered chub. Timing of such narrowing near Amarillo is uncertain, but given current rates this change is possible by as early as 2039 and likely by 2069, without improvements to the existing flow regime, leading to a ***Poor*** to ***Null*** condition.

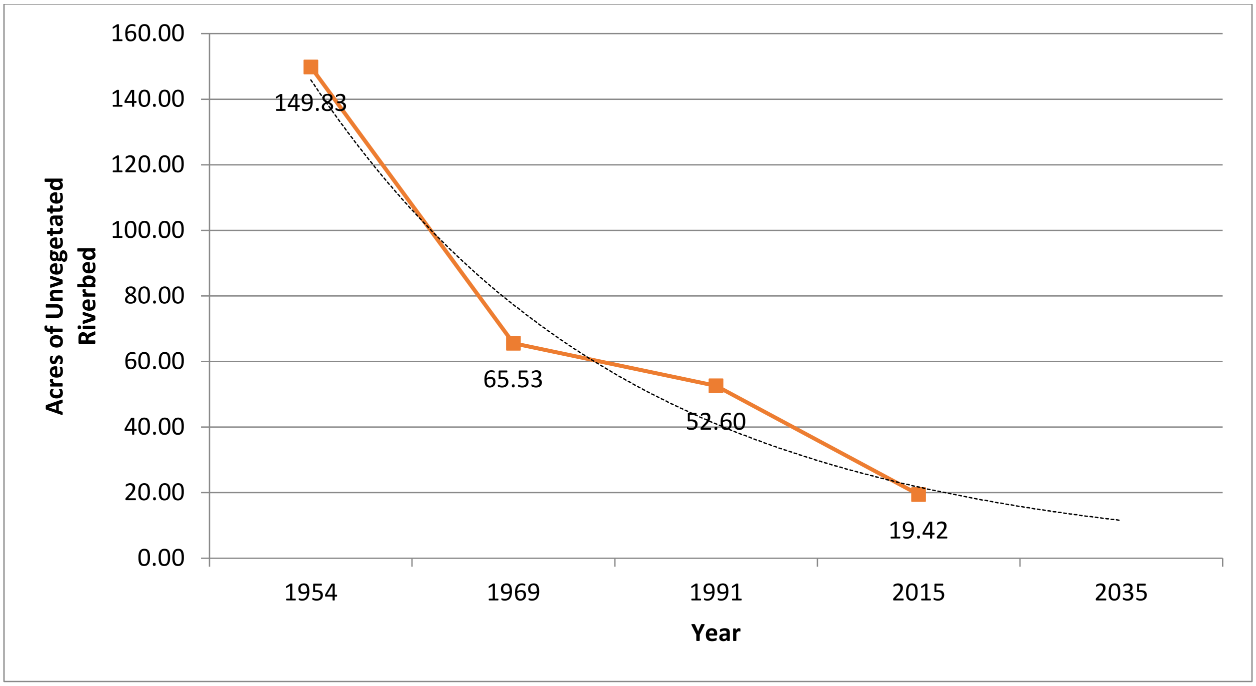


Figure 5-2: Unvegetated riverbed change in the South Canadian River at Amarillo, TX during years 1954, 1969, 1991, and 2015.

With a decrease in the mean annual discharge, increased temperatures and evapotranspiration, river fragmentation increases in the future. Fragmentation could be offset by stream narrowing, which could result in a smaller, more incised channel with capacity to maintain lower flows, but this interaction and outcome is unknown. Groundwater availability, which provides base flows and maintains connectivity when levels are adequate, will continue to be affected as the Ogallala Aquifer in the Southern High Plains continues to decline. With these increased pressures to base flow, the Canadian River length declines from current condition (179 miles) but will maintain at least the 135 miles needed for successful reproduction another 20 years, considered ***Fair***. By 50 years under this continuation scenario, with the Ogallala continuing to decline and water demands continuing, and with temperatures and evapotranspiration continuing to increase, river length will continue to decrease, resulting in a lowering of the ranking to ***Poor*** (less than 135 miles).

Fish Response

All demographic factors for Arkansas River shiner current condition in chapter 4 were considered ***Good*** (Table 4-18) with trends stable to increasing, while habitat and flow factors ranged from ***Null*** to ***Fair***. This combination of ***Good*** fish demographics with ***Poor to Fair*** habitat and flow factors suggests that current flow and habitat factors in the Upper South Canadian River may currently sustain Arkansas River shiner populations; however, with flow and habitat conditions continuing to worsen, we expect the Arkansas River shiner population demographics to be negatively affected. Stream narrowing is expected to reach the critical threshold of 10 acres/mile or less in some areas, and this will be combined with additional fragmentation and decline of existing flow patterns. We expect that these conditions will force the population further downstream to more suitable habitat and flow conditions, but with Lake Meredith at the downstream stretch of this Upper South Canadian River, the population has only a limited distance to move. Given these additional stressors and additional limits to overall habitat availability, we expect that capture rates and relative abundance will change to a ***Fair*** condition by 2039 and to a ***Poor*** condition by 2069.

Under this continuation scenario and based on the changes to fish, flow, and habitat factors described above, we expect that future resiliency of the Arkansas River shiner in the Upper South Canadian River will drop from **MODERATE** to **LOW** by 2039 and will continue as **LOW** into 2069.

Lower South Canadian River

<u>*Flow Factors*</u>

Hydroperiod – We chose to limit our future considerations in the Lower South Canadian River Resiliency Unit to the USGS 07228500; Canadian River at Bridgeport, OK gage as the Arkansas River shiner is currently extant at this location and it is centrally located within the resiliency unit.

As with the Amarillo, TX gage, future hydroperiod conditions at the Bridgeport, OK gage are compared against the pre-impoundment era. Similar to the Amarillo, TX gage, the Bridgeport, OK gage remains at a ***Poor*** categorical rating for both the 20 and 50-year horizons with a 57.7 and 58.8 percent reduction from the pre-impoundment period.

Flood Frequency Analysis – As discussed for the Upper South Canadian River Resiliency Unit, a Flood Frequency Analysis based on a prediction of future peak flood values is not practical. Similar to the Amarillo, TX gage, we would expect a continued attenuation of peak flows at all return intervals; Lake Meredith would remain in place and operations would be comparable to the current conditions. The current condition score is 53.6 percent meaning that the weighted sum of the 2, 5, and 10-year events is 53.6 percent of the pre-impoundment regime. This is rated as categorically ***Fair***. Given no reliable means to predict future change, we therefore rate the Flood Frequency Analysis for the 20 and 50-year future periods as ***Fair***.

Low Flow Conditions – Low Flow conditions are also thought to rate as ***Fair*** for both the 20 and 50-year future time horizons. Although the period from 2008-2012 saw additional days in low flow conditions, more recent years (2013-2015) show a decreasing trend, hence a generally cyclical pattern.

Habitat Factors

All three stretches of the Lower South Canadian River analyzed for current condition show that the river channel is becoming more narrow (Figure 4-25, Chapter 4), which continues under this scenario (Figure 5-3 and Riverbed Change Appendix C). We expect the upper reaches to reach critically low thresholds (10 acres/mile or less critical – see Upper South Canadian River discussion above) sooner than lower reaches. For example, Bridgeport or stretches above (SCAN 3), could possibly narrow to 20 acres/mile by 2039 and to 10 acres/mile by 2069.

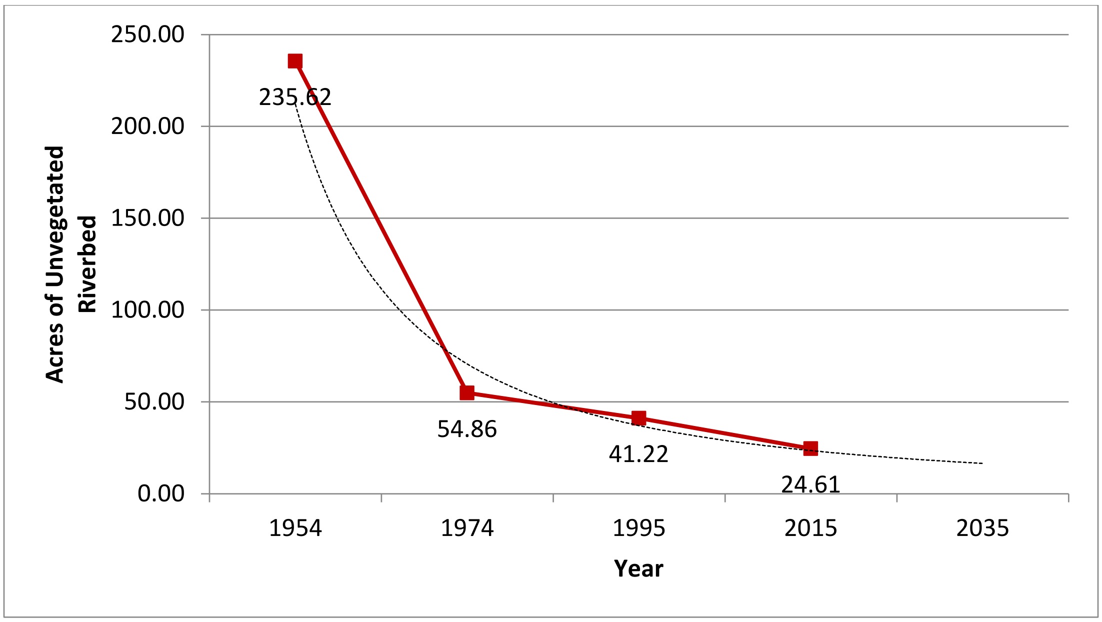


Figure 5-3. Unvegetated riverbed change in the South Canadian River at Bridgeport, OK during years 1954, 1974, 1995, and 2015.

Similar to the Upper South Canadian River, this scenario results in a decrease in the mean annual discharge, increased temperatures and evapotranspiration, and increased river fragmentation in the future. Fragmentation could be offset by stream narrowing, which could result in a smaller, more incised channel with capacity to maintain lower flows, but this interaction and outcome is unknown. Groundwater availability, which provides base flows and maintains connectivity when levels are adequate, will continue to be affected as the Ogallala Aquifer in the Southern High Plains continues to decline. Upper stretches of the Lower South Canadian River (SCAN 3 & 4) currently exhibit fragmentation through river drying (Figure 4-22) and we expect additional stretches of river to dry, or existing stretches will be dry for a longer period of time. Additionally, stream drying could move downstream resulting in a shorter fragment length. Given that the Lower South Canadian River in SCAN 1-3 currently provides a more than adequate length of river for the Arkansas River shiner, we expect the fragment distance of greater than 185 miles to be maintained by 2069.

Fish Response

Current demographic factors for the Arkansas River shiner in the Lower South Canadian River range from ***Poor*** to ***Good.*** Demographic factors are ***Poor*** in SCAN 4, which we expect to decline to ***Null*** (no fish captured) by 2039 under this continuing scenario (Table 5-1 below). SCAN 3 currently ranges from ***Fair*** to ***Poor*****,** and with effects to habitat and flow continuing as described above, we expect the condition to worsen. By 2039 SCAN 3 scores under this scenario drop to ***Poor***, with a ***Poor*** to ***Null*** score by 2069, indicating that the Arkansas River shiner may no longer be captured in this stretch of river. With continuing trends, we expect fish demographics in lower stretches (SCAN 1 & 2) to possibly improve in the short term (20 years) as the population shifts downstream and habitat remains suitable. By 2069, given declining habitat factors (particularly stream narrowing) it is possible that SCAN 2 may not be suitable habitat for Arkansas River shiner, changing to a ***Poor to Null***. Under this scenario, only SCAN 1 could possibly provide suitable habitat for the species by 2069, although it would be in a lesser condition than 30 years prior, considered ***Poor*** for all demographic factors. There is high uncertainty as to the 50 year condition of this stretch of river, but as suitable habitat exists only in this stretch of river, fragment length will likely not be long enough (84 miles in SCAN 1) to allow for successful reproduction. Suitable habitat would need to occur in both SCAN 1 and 2 (248 miles combined) to allow for successful reproduction and population viability.

Under this continuation scenario and based on the changes to fish, flow, and habitat factors described above, we expect that future resiliency of the Arkansas River shiner in the Lower South Canadian River will drop from **MODERATE** to **LOW** by 2039, and the species could possibly become functionally extirpated (**LOW/ Ø**) by 2069.

Table 5-1. Arkansas River shiner future demographics, by subunit. Bold arrow before score indicates a change in score from current condition. Smaller arrow in parenthesis after score indicates a change in that condition, but not rising to the level of a score change.

Scenario 1 - Continuation of Existing Trends ***Arkansas River Shiner Demographics***				
South Canadian River	**Demographic Factors**			
	Capture Ratio	**Probability of Capture Trend**	**Relative Abundance**	**Relative Abundance Trend**
	20 Years (to 2039)			
SCAN 5	**↓ Fair**	**↓ Fair**	**↓ Fair**	**↓ Fair**
SCAN 4	**Ø**	**Ø**	**Ø**	**Ø**
SCAN 3	**↓ Poor**	**Poor (↓)**	**↓ Poor**	**Poor (↓)**
SCAN 2	**Good (↑)**	**Good (↑)**	**Poor (↑)**	**Poor (↑)**
SCAN 1	**Fair (↑)**	**Good (↑)**	**Poor (↑)**	**Poor (↑)**
	50 Years (to 2069)			
SCAN 5	**↓ Poor**	**↓ Poor**	**↓ Poor**	**↓ Poor**
SCAN 4	**Ø**	**Ø**	**Ø**	**Ø**
SCAN 3	**↓ Poor to Ø**	**↓ Poor to Ø**	**↓ Poor to Ø**	**↓ Poor to Ø**
SCAN 2	**↓ Poor to Ø**	**↓ Poor to Ø**	**↓ Poor to Ø**	**↓ Poor to Ø**
SCAN 1	**↓ Poor**	**↓ Poor**	**Poor**	**Poor**

Resiliency Summary

Table 5-2 below provides a summary of our future (to 2039 and 2069) demographic and habitat flow factors under Scenario 1 – Continuation of Existing Trends for the Arkansas River shiner. Because only the Upper and Lower South Canadian River are currently known to be occupied by the Arkansas River shiner, those were the only resiliency units evaluated in our analysis. Other resiliency units are provided in the table to provide a larger context of the future condition of Arkansas River shiner as compared to its historical distribution.

Table 5-2. Summary results of habitat, flow and demographic factors and future resiliency under Scenario 1 - Continuation of Existing Trends. Bold arrow before score indicates a change in score from current condition. Smaller arrow in parenthesis after score indicates a change in that condition, but not rising to the level of a score change. Question mark after a score indicates the trend was not significant.

SCENARIO 1 - Continuation of Existing Trends *Arkansas River Shiner*											
		Demographic Factors				Habitat/Flow Factors					
	CURRENT RESILIENCY	Capture Ratio	Probability of Capture Trend	Relative Abundance	Relative Abundance Trend	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	*FUTURE RESILIENCY*
		20 Years (to 2039)									
Lower Arkansas	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Upper Arkansas	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Cimarron	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
North Canadian	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Lower South Canadian	MODERATE	↓Good to Ø	↓Good to Ø	↓Poor to Ø	↓Poor to Ø	Good	↓Poor to Null	Fair	Poor (↓)	Fair	LOW
Upper South Canadian	MODERATE	↓Fair	↓Fair	↓Fair	↓Fair	Fair (↓)	↓Poor to Null	Poor	Poor (↓)	Fair	LOW
		50 Years (to 2069)									
South Ninnescah	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Arkansas/Salt Fork	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Cimarron	Ø	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Lower South Canadian	MODERATE	Poor to Ø	Poor to Ø	Poor to Ø	Poor to Ø	Fair to Poor	Poor to Nul (↓)	Fair	Poor (↓)	Fair	LOW/Ø
Upper South Canadian	MODERATE	↓Poor	↓Poor	↓Poor	↓Poor	↓Poor	↓Poor to Null	Poor	Poor (↓)	Fair	LOW

5.5.1.2 Representation

As identified in Chapter 4 – Current Condition, we consider the Arkansas River shiner to have representation in the form of genetic diversity in three areas: the Upper and Lower South Canadian River, which are geographically isolated from one another by Lake Meredith and the Pecos River population, which is outside of the species historical range. Under the Continuation of Existing Trends scenario, the current level of representation may be maintained through 2039, although overall population size in the Upper and Lower South Canadian River units could decline, potentially affecting genetic diversity. By 2069 it is possible that the Lower South Canadian River could be functionally extirpated, leaving only the Upper South Canadian River and non-listed Pecos River population to provide species representation.

5.5.1.3 Redundancy

Under the Continuation of Existing Trends scenario current redundancy of only two populations (Upper and Lower South Canadian River) would be generally maintained by 2039, although with a **LOW** resiliency in both units, these populations will be relatively vulnerable to extirpation. By 2069, it is possible that the lower South Canadian River could become functionally extirpated, leaving only the Upper South Canadian River population, with low resiliency.

5.5.2 Peppered Chub

The only known current population of peppered chub is in the Upper South Canadian River. Therefore, under the Continuation of Existing Trends scenario, no other resiliency units were included for peppered chub.

5.5.2.1 Resiliency

Upper South Canadian River

Flow and habitat factors

To minimize duplication, see the Upper South Canadian River *Flow Factors* and *Habitat Factors* discussion above (5.5.1 Arkansas River Shiner – 5.5.1.1 Resiliency).

Fish Response

Current demographic factors for the peppered chub in the Upper South Canadian River range from ***Good to Poor.*** With flow and habitat conditions continuing to worsen (as described above) under this scenario, we expect the peppered chub population to be negatively affected. Stream narrowing is expected to reach the critical threshold of 10 acres/mile or less in some areas, and this will be combined with additional fragmentation and decline of existing hydrology. We expect that these conditions will force the population further downstream, but with Lake Meredith at the downstream stretch of this Upper South Canadian River, the population (currently occupying 179 miles) is limited in how much it can be constricted before stream distance falls below the species threshold of 135 miles. Given these additional stressors and additional limits to overall habitat availability, we expect that capture rates and relative abundance will at best be a ***Fair*** condition by 2039 and all factors a ***Poor*** condition by 2069.

Under this continuation scenario and based on the changes to fish, flow, and habitat factors described above, we expect that future resiliency of the peppered chub in the Upper South Canadian River will continue as **LOW by 2039,** and the species could possibly become functionally extirpated (**LOW/ Ø**) **by 2069**.

Resiliency Summary

Table 5-3 below provides a summary of our future (to 2039 and 2069) demographic and habitat flow factors under Scenario 1 – Continuation of Existing Trends for the peppered chub. Because only the Upper South Canadian River is currently known to be occupied by the peppered chub, that is the only resiliency unit evaluated in our analysis. Other resiliency units or subunits are provided in the table to provide a larger context of the future condition of peppered chub as compared to its historical distribution.

Table 5-3. Summary results of habitat, flow and demographic factors of 20 and 50 year-future resiliency under the Continuation of Existing Trends scenario for Peppered Chub. Bold arrow before score indicates a change in score from current condition. Smaller arrow in parenthesis after score indicates a change in that condition, but not rising to the level of a score change.

SCENARIO 1 - Continuation of Existing Trends *Peppered Chub*										
	CURRENT RESILIENCY	Demographic Factors			Habitat/Flow Factors					*FUTURE RESILIENCY*
		Capture Ratio	Probability of Capture Trend	Relative Abundance	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
		20 Years (to 2039)								
South Ninnescah	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Arkansas/Salt Fork	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Cimarron	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Lower South Canadian	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Upper South Canadian	LOW	Fair (↓)	**↓**Fair	Poor (↓)	Fair (↓)	Poor	**↓**Poor to Null	Poor (↓)	Fair	LOW
		50 Years (to 2069)								
South Ninnescah	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Arkansas/Salt Fork	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Cimarron	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Lower South Canadian	Ø	Ø	Ø	Ø	.	.	.	.	.	Ø
Upper South Canadian	LOW	**↓**Poor	**↓**Poor	Poor (↓)	**↓**Poor	Poor (↓)	**↓**Poor to Null	Poor	Fair	LOW/Ø

5.5.2.2 Representation

As identified in Chapter 4 – Current Condition, we consider the peppered chub to have limited representation in the form of genetic and ecological diversity due to the fact that only a single functioning population exists between the Ute Dam, New Mexico and Lake Meredith, Texas. Under the Continuation of Existing Trends scenario, the current level of representation may be maintained through 2039, although overall population size in the Upper South Canadian River could decline, potentially affecting genetic diversity. By 2069 it is possible that the peppered chub could be functionally extirpated from the South Canadian River.

5.5.2.3 Redundancy

Under the Continuation of Existing Trends scenario, the peppered chub will continue to exhibit no redundancy, as only one population would be maintained by 2039. Too, with a **LOW** resiliency (even lower resiliency as compared to current condition) this population will be more vulnerable to extirpation. By 2069, it is possible, with the loss of this single remaining population of the species, that the peppered chub could become functionally extinct.

5.6 SCENARIO 2 – WATER CONSERVATION WITH FLOW TRENDS STABILIZING

Under the Water Conservation with Flow Trends Stabilizing scenario, we assume that current flow and habitat factors are maintained through 2069. This scenario would require that water demands stabilize, resulting in no changes to future flows. Current climate emissions rates would be mitigated and water conservation actions would also be implemented. This scenario would reflect the Current Condition, as described in Chapter 4; for this reason, only final conclusions are provided below.

5.6.1 Arkansas River shiner

5.6.1.1 Resiliency

Arkansas (Upper and Lower), Cimarron, and North Canadian Rivers

The Arkansas River shiner is considered functionally extirpated from the Arkansas, Cimarron and North Canadian River; therefore resiliency no longer exists in these rivers (Table 5-4). Some of these rivers do potentially have favorable conditions in terms of flow and stream width, which we further assess Scenario 3 and 4.

Table 5-4. Summary of future resiliency of Arkansas River shiner under the Water Conservation and Flow Trends Stabilizing scenario.

SCENARIO 2 - Water Conservation with Flow Trends Stabilizing *Arkansas River shiner*										
	Demographic Factors				Habitat/Flow Factors					*FUTURE RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Relative Abundance Trend	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Lower Arkansas	Ø	na	Ø	Ø	Ø	na	na	na	na	Ø
Upper Arkansas	Ø	na	Ø	Ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	Ø
Cimarron	Ø	na	Ø	Ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	Ø
North Canadian	Ø	na	Ø	Ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	Ø
Lower S. Canadian	Poor & Good	Poor & Good	Poor to Fair	Poor	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	MODERATE
Upper S. Canadian	Good	Good	Good	Good	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	MODERATE

Upper South Canadian River

Resiliency of the Arkansas River shiner in the Upper South Canadian River is considered. **MODERATE**. All demographic factors represent ***Good*** conditions; however, our analysis of habitat and flows suggest that this stretch of the river is in moderate to significant decline. Stream fragment length is adequate for the species threshold, but our channel narrowing, flood frequency, and hydroperiod analyses all indicate significant decline to channel morphology and river flows. Additionally, our low flow analyses indicate that two of the three gauges analyzed (Revuelto Creek and South Canadian River near Logan, NM) show ***Poor*** low flow conditions, with the Amarillo, TX USGS gauge indicating ***Fair*** low flow conditions.

Lower South Canadian River

Resiliency of the Arkansas River shiner in the Lower South Canadian River is considered **MODERATE**, due to a combination of ***Fair*** to ***Poor*** demographic and habitat factors (Table 4-11). SCAN 2 maintains a ***Good*** capture ratio (0.78), SCAN 1 and 3 still have ***Fair*** capture ratios (0.52 and 0.61, respectively), where SCAN 4 (0.04) is near the lowest on record. Probability of detection analysis indicates SCAN 4 has significantly declined (***Poor***), where SCAN 1 & 2 have significantly increased (***Good***). SCAN 3 appears to be declining, but results were not significant. Relative abundance for SCAN 3 of 8.0 is considered ***Fair***, with SCAN 1, 2, and 4 all considered ***Poor*** (1.0, 5.3, and 2.5, respectively) as compared to baseline conditions. The relative abundance trend has significantly declined in all subunits of the Lower South Canadian River.

In terms of habitat and flow factors, stream fragment length is ***Good*** for the Lower South Canadian River, with one stretch of river above the species needed threshold and the other above the pelagic spawning threshold. However, our channel narrowing analysis indicates the Lower South Canadian River has significantly narrowed since the 1950s, with all subunits in significant decline. Flood frequency and hydroperiod also indicate ***Poor*** to ***Fair*** flow/habitat conditions for the species, whereas our low flow metric (number of low flow days) indicates a ***Good*** condition.

5.6.1.1 Representation

As identified in Chapter 4 – Current Condition, we consider the Arkansas River shiner to have representation in the form of genetic diversity in three areas: the Upper and Lower South Canadian River, which are geographically isolated from one another by Lake Meredith and the Pecos River population, which is outside of the species historical range. Under the Water Conservation with Flow Trends Stabilizing scenario, the current level of representation may be maintained through 2069.

5.6.1.3 Redundancy

Historically, the Arkansas River shiner occurred in six resiliency units distributed across six states. However, it is now functionally extirpated from all but two (Upper and Lower South Canadian River) of resiliency units. Within the Lower South Canadian River, the species is thought to be distributed from the Texas panhandle (downstream of Meredith) downstream to Lake Eufaula. However, more recent but limited surveys (therefore not included in our analysis in Chapter 4) within the last 5-10 years have failed to capture Arkansas River shiner within some of the most upstream sites in Texas and far western Oklahoma, suggesting this population's distribution may be contracting. Additional surveys in the upper stretch of this unit are needed. Based on a smaller range and fewer resiliency units (populations), the species has a higher risk of extirpation from a catastrophic event. Therefore, Arkansas River shiner species-level redundancy has declined since historical conditions and may be at risk for further loss.

Drought is a potential catastrophic event that could impact the Arkansas River shiner in the future. We presume that one or both of the remaining resiliency units could be functionally extirpated due to a catastrophic event. Given the current level of redundancy across the range, the species as a whole has a higher risk of extirpation due to an unusually rare and destructive drought.

5.6.2 Peppered Chub

5.6.2.1 Resiliency

Arkansas (Upper and Lower), Cimarron, North Canadian, and Lower South Canadian Rivers

The peppered chub is considered functionally extirpated from the Arkansas, Cimarron North Canadian River and Lower South Canadian River, therefore resiliency no longer exists in these rivers (Table 5-5). Some of these rivers do potentially have favorable conditions in terms of flow and stream width, which we further assess in Chapter 5 – Future Condition.

Table 5-5. Summary of future resiliency of peppered chub under the Water Conservation and Flow Trends Stabilizing scenario.

SCENARIO 2- Water Conservation with Flow Trends Stabilizing *Peppered Chub*									
	Demographic Factors			Habitat/Flow Factors					*FUTURE RESILIENCY*
	Capture Ratio	Probability of Capture Trend	Relative Abundance	Stream Fragment Length	Channel Narrowing	Flood Frequency	Hydroperiod	Low Flow	
Upper Arkansas (includes Ninnescah and Salt Fork)	ø	na	ø	Fair	Fair to Good	Poor & Good	Poor & Good	Poor & Good	ø
Cimarron	ø	na	ø	Good	Null to Good	Null & Fair	Poor & Fair	Poor & Good	ø
North Canadian	ø	na	ø	Fair	Null	Null to Good	Poor to Fair	Poor to Good	ø
Lower South Canadian	ø	ø	ø	Good	Null to Good	Poor to Fair	Poor to Fair	Fair & Good	ø
Upper South Canadian	Fair	Good	Poor	Fair	Poor	Null to Fair	Null to Fair	Poor to Fair	LOW

Upper South Canadian River

Resiliency of the peppered chub in the Upper South Canadian River is considered **LOW**. Capture ratios, as compare to baseline conditions are considered ***Fair*** and relative abundance is considered ***Poor***. Probability of presence is the only demographic factor considered ***Good***. Additionally, our analysis of habitat and flows suggest that this stretch of the river is in moderate to significant decline. Stream fragment length is adequate for the species threshold, but our channel narrowing, flood frequency, and hydroperiod analyses all indicate significant decline to channel morphology and river flows. Additionally, our low flow analyses indicate that two of the three gauges analyzed (Revuelto Creek and South Canadian River near Logan, NM) show ***Poor*** low flow conditions, with the Amarillo, TX USGS gauge indicating ***Fair*** low flow conditions.

5.6.2.2 Representation

As identified in Chapter 4 – Current Condition, we consider the peppered chub have limited representation in the form of genetic and ecological diversity due to fact that only a single functioning population exists between the Ute Dam, New Mexico and Lake Meredith, Texas.

5.6.2.3 Redundancy

The *Macrhybopsis* complex, which included the peppered chub, once occupied five resiliency units and six states across its range. Currently, the peppered chub is believed to occur in one resiliency unit, (Upper South Canadian River), and has only recently been collected from two states (Texas and New Mexico). Similar to the Arkansas River shiner, the peppered chub has a higher risk of extirpation form a catastrophic event, due to smaller range and fewer resiliency units spread across the range. Therefore, the peppered chub has experienced a decline in species-level redundancy since historical conditions.

5.7 SCENARIO 3 – SPECIES CONSERVATION AND CONTINUATION OF EXISTING TRENDS

Under the Species Conservation and Continuation of Existing Trends scenario, we make two overarching assumptions:

1. All species conservation actions described below are implemented and are successful
2. Flow and habitat trends continue at current rates, as water demands continue to rise at current rates, and a climate emissions scenario of RCP 8.5 is reached

An outline of conservation actions included in this scenario is provided below:

All Occupied Segments (Arkansas River Shiner and Peppered Chub)

- Riparian Restoration - invasive species control – primarily salt cedar and common reed (phragmites) to slow down the rate of stream narrowing in areas where considerable narrowing has occurred.
- Floodplain restoration - Creation of riparian floodplain wetlands/oxbows to create egg and fry development areas and enhance reproduction. This could be particularly important for areas where stream distance may not be adequate for spawning or in upstream areas where the species is no longer able to repopulate due to stream drying.

Upper Canadian River (Arkansas River Shiner and Peppered Chub)

- Releases from Ute Reservoir
  - Releases in accordance with the Arkansas River Shiner Management Plan – to benefit ARS when water is above conservation pool
  - Additional releases where needed to stop or reverse channel narrowing, enhance channel complexity, and promote successful reproduction – 375 cfs capability

Lower South Canadian River

- Re-establish ARS in Canadian, TX (SCAN 4) – with appropriate monitoring

Ninnescah River (Peppered Chub)

- Re-establish peppered chub
- Enhance fish movement to promote successful reproduction – two approaches
  - Remove or modify existing structures
  - Assisted migration through collection and movement of peppered chubs

Arkansas River and Salt Fork

- Re-establish Arkansas River shiner
- Work with Kaw Reservoir to promote releases beneficial to one or both species

5.7.1 Arkansas River Shiner

5.7.1.1 Resiliency

Upper South Canadian River

Flow Factors

See *Flow Factors* for the Upper South Canadian River under the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Habitat Factors

See *Habitat Factors* for the Upper South Canadian River under the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Species Conservation and Fish Response

In this section we describe how the Arkansas River shiner will respond to future habitat and flow factors in combination with specific species conservation actions. For the discussion on how the species will respond to habitat and flow factors alone (before species conservation is implemented) see *Fish Response* for the Upper South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.4.1 Resiliency).

Under the Continuation of Existing Trends scenario, resiliency of the Upper South Canadian River is considered **LOW** (Table 5-2 above). Under this Species Conservation with Continuation of Existing Trends scenario, resiliency is improved through species specific conservation. Reproduction is enhanced through more appropriate timing of releases from Ute Reservoir and through higher releases to maintain channel complexity and minimize stream narrowing. Riparian restoration also slows or reverses stream narrowing in areas where significant narrowing has occurred. Although this level of conservation may not be able to maintain flow and habitat at current conditions in the Upper South Canadian River, specific actions such as flood plain restoration could enhance reproductive success and recruitment to make up for some losses to flows and habitat. Under this scenario, resiliency in the Upper South Canadian River could improve from **LOW to LOW/MODERATE through year 2069.**

Lower South Canadian River

Flow Factors

See *Flow Factors* for the Lower South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Habitat Factors

See *Habitat Factors* for the Lower South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Species Conservation and Fish Response

In this section we describe how the Arkansas River shiner will respond to Continuation of Existing Trend in terms of flows and habitat change in combination with species specific conservation actions. For the discussion on how the species will respond to changing habitat and flow factors alone (before species conservation is implemented) see *Fish Response* for the Lower South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.14.1 Resiliency).

Under the Continuation of Existing Trends scenario, resiliency of the Lower South Canadian River is considered **LOW** (Table 5-6). Under this Species Conservation with Continuation of Existing Trends scenario, resiliency is improved through species specific conservation. Although Lake Meredith does not provide additional releases under this scenario (reservoir has never reached elevation to allow for releases in accordance with the Canadian River Compact) floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Adult Arkansas River shiner are re-established in the upper stretches of the Lower South Canadian River (near Canadian, TX), possibly every three to five years, which would repopulate a significant stretch of the river downstream into Oklahoma, given spawning is successful. Riparian restoration would be targeted at stretches of river showing considerable channel narrowing, adding to channel complexity and slowing downstream movement of the population (if done at a large enough scale). Given that Arkansas River shiner repopulates upper stretches of the Lower South Canadian River, resiliency could slightly improve from **LOW to LOW/MODERATE by 2039**. However, with the significant rate of change in the Lower South Canadian River (see *Habitat Factors* and *Flow Factors* for the Lower South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)), and without releases similar to what Ute Reservoir can provide for the Upper South Canadian River, it is unlikely the upper stretches of the Lower South Canadian River could sustain a reproducing population of Arkansas River shiner into **2069, thus resiliency would remain LOW/ Ø.**

Cimarron River

Flow Factors

For the Cimarron River Resiliency Unit, we limit our future scenario evaluation to the USGS 07160000; Cimarron River near Guthrie, OK. This is due to its location near the bottom of the catchment and thus a suitable index for the system on the whole. Other than Eagle Nest

Dam (New Mexico) near the headwaters, there are no large-scale dams on the Cimarron River that could have a systemic impact on the flow regime. As such, for the current condition (Chapter 4), we evaluated the Guthrie, OK gage using an alternative criterion. That is, instead of a pre- and post-impoundment comparison, we contrasted the hydroperiod since 2000 with previous decades. An increasing discharge trend equated to a ***Good*** rating, a decreasing trend represented a ***Poor*** rating, and cyclical pattern, that tends to follow natural drought and pluvial periods, was given a ***Fair*** rating. We extend that methodology here but compare the current conditions (1980-2016) with the future projections (2020-2029 and 2020-2069) under the RCP 8.5 climate scenarios.

Hydroperiod – Current conditions at the Guthrie, OK gage were rated as ***Fair*** for both the hydroperiod and Flood Frequency Analysis. Since 2000, mean daily discharge during the hydroperiod has declined and in the 2010s has reached lows comparable to the 1950s. However, this stretch of the Cimarron River has historically exhibited a cyclical pattern where the 1980s and 1990s exhibited a wet period, suggesting that improvements to hydroperiod are possible. The hydrograph for both future time steps shows notable decreases in discharge rates, and comparisons of the hydroperiod between 1980-2016 and the future time intervals show a decreasing trend. This is likely a result of ongoing groundwater extraction exacerbated by drier conditions under the RCP 8.5 climate regime (a reduction in effective runoff of 8.9 percent for the 2020-2039 interval and a reduction of 4.3 percent for the 2020-2069 interval). Given the uncertainty surrounding the cyclical pattern of the hydroperiod in this section of the Cimarron River, we maintain a rating of ***Fair*** both future time horizons, with the possibility of a ***Poor*** rating if the rate of decline becomes more pronounced.

Flood Frequency Analysis – For the Flood Frequency Analysis, we again retain a ***Fair*** rating (72.5 percent of the pre-2000 flooding regime still in place) as there are no dependable means to forecast flood magnitudes in the future.

Low Flow Conditions – Low flow conditions remain as a ***Good*** rating, as we do not foresee significant changes in the number of low flow days.

Habitat Factors

With stream narrowing rates continuing (Appendix C), flows in the Cimarron River near Guthrie will continue to decline, although at a much lower rate compared to upstream at Forgan or currently occupied habitat on the South Canadian River (Bridgeport and Amarillo). Although the rate of decline is low compared to historical conditions and there is a relatively wide existing channel (74 acres/mile), which is slightly wider than the South Canadian River at Purcell (69 acres/mile), the Cimarron River stretch near Guthrie will be will provide adequate (not optimal) channel width (considered ***Fair***) through 2069.

This scenario results in a decrease in the mean annual discharge, increased temperatures and evapotranspiration, and increased river fragmentation as a result of drying, in the future. Groundwater availability, which provides base flows and maintains connectivity when levels are adequate, will continue to be affected as the Ogallala Aquifer in the Southern High Plains continues to decline. Given that the Cimarron River currently provides a more than adequate length of river for the Arkansas River shiner (over 330 river miles), we expect the fragment distance of greater than 185 miles to be maintained by 2069.

Species Conservation and Fish Response

The Arkansas River shiner is considered functionally extirpated under current condition. We cannot say with certainty that the fish is extirpated from the Cimarron River; however, despite numerous surveys, it is undetectable at this time and does not support a resilient population. Under this Species Conservation and Continuation of Trends scenario, we assume that fish re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation of the species has been lessened. There is support in the literature for this assumption, based on the re-establishment of the shoal chub in the Cimarron River, after being undetected for over 20 years (Luttrell et al. 1999, pp. 984-985). It is possible that significant drought conditions in the late 1980s and early 1990s led to the species decline, but that current conditions may support populations once again. Shoal chub continues to persist in the Cimarron River.

In addition to re-establishment of the Arkansas River shiner in the Cimarron River, floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Too, riparian restoration focusing on narrowing stretches of river could add to channel complexity and slowing downstream movement of the population (if done at a large enough scale). With uncertainty regarding the exact stressor leading to the species being functionally extirpated and if that stressor still exists, we assume under this scenario that a reintroduced population with riparian and floodplain management could maintain **LOW resiliency through 2069.**

Arkansas and Salt Fork River

Flow Factors

The Ralston, OK gage has one primary upstream impoundment (Kaw Lake) and one on a major tributary (Salt Fork Arkansas River; Great Salt Plains Lake). Again, Kaw Lake is a hydroelectric facility completed in 1976.

Hydroperiod – Current conditions at the Ralston, OK gage show a 24.2 percent increase from pre-impoundment mean daily discharge during the hydroperiod, which is likely due to hydroelectric operations and power demands. As such, current conditions at the Ralston, OK gage were rated as ***Good***. For the 2020-2039 future time period, there is a 17.1 percent increase over pre-impoundment conditions and therefore also a ***Good*** rating. For the 2020-2069 interval, there is a 24.7 percent increase in hydroperiod mean daily discharge which is also a ***Good*** rating.

Flood Frequency Analysis – Although decreased, the current condition Flood Frequency Analysis shows that 79.5 percent of the 2, 5, and 10-year events remain intact, which equates to a ***Good*** rating. Again, we cannot predict how the magnitudes of these return intervals will change in the future, so we retain the ***Good*** rating for the FFA in both future time intervals.

Low Flow Conditions – The low flow metric is also rated ***Good*** for the current conditions, and we do not foresee any significant changes. Therefore, we rate the low flow conditions as ***Good*** for both future time intervals.

<u>Habitat Factors</u>

Because all flow factors are considered ***Good*** through 2069 and the channel has slightly widened as compared to 1950s, channel width in this scenario is considered ***Good*** through 2069. Additionally, river drying is not expected to occur under this scenario, therefore stream distance will remain over 185 miles (considered ***Good***) through 2069.

<u>Species Conservation and Fish Response</u>

The Arkansas River near Ralston last supported the Arkansas River shiner in 1998. Under this Species Conservation and Continuation of Trends scenario, we assume that Arkansas River shiner re-introductions (every three to five years) are successful. For the re-establishment to be successful, Kaw Reservoir releases would be timed to benefit species reproduction and minimize egg and larval drift into Keystone Reservoir at the downstream end of this section of river. Given a self-sustaining population with proper releases and reintroductions only intermittently (three to five years as compared to every year), species resiliency within this section of the Arkansas River and Salt Fork of the Arkansas River could change from functionally extirpated to **LOW**.

Table 5-6. Summary of Arkansas River shiner resiliency under the Species Conservation and Continuation of Existing Trends scenario.

SCENARIO 3 - Species Conservation with Continuation of Existing Trends *Arkansas River Shiner*				
	CURRENT RESILIENCY	Demographic Factors	Habitat/Flow Factors	*FUTURE RESILIENCY*
		20 Years (to 2039)		
South Ninnescah	Ø	No Arkansas River shiner management	N/A	Ø
Arkansas/Salt Fork	Ø	Re-establishment of Arkansas River shiner	Kaw Releases	LOW
Cimarron	Ø	Re-establishment of Arkansas River shiner	Riparian & floodplain restoration	LOW
Lower South Canadian	MODERATE	Improved reproduction	Riparian & floodplain restoration	LOW / MODERATE
Upper South Canadian	MODERATE	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration	LOW / MODERATE
		50 Years (to 2069)		
South Ninnescah	Ø	No Arkansas River shiner management	N/A	Ø
Arkansas/Salt Fork	Ø	Re-establishment of Arkansas River shiner	Kaw Releases	LOW
Cimarron	Ø	Re-establishment of Arkansas River shiner	Riparian & floodplain restoration	LOW
Lower South Canadian	MODERATE	Improved reproduction	Riparian & floodplain restoration	LOW / Ø
Upper South Canadian	MODERATE	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration	LOW / MODERATE

5.7.1.2 Representation

Under the Species Conservation with Continuation of Existing Trends scenario, the Arkansas River shiner would have representation in the form of genetic diversity in five areas: the Upper and Lower South Canadian River, which are geographically isolated from one another by Lake Meredith, the Pecos River population, which is outside of the species historical range, the Cimarron River in Oklahoma, and the Arkansas and Salt Fork River in Oklahoma. Because fish for reintroductions will come from either the South Canadian River or Pecos River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established it could potentially provide for increased ecological adaptability in the future.

5.7.1.3 Redundancy

Under the Species Conservation with Continuation of Existing Trends scenario, redundancy of four populations of Arkansas River shiner would be maintained: Upper and Lower South Canadian River, Cimarron River and Arkansas River. With all four units possibly exhibiting low resiliency, these populations would be vulnerable to catastrophic events, reducing redundancy in the future.

5.7.2 Peppered Chub

5.7.2.1 Resiliency

Upper South Canadian River

Flow Factors

See *Flow Factors* for the Upper South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Habitat Factors

See *Habitat Factors* for the Upper South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.1.1 Resiliency)

Species Conservation and Fish Response

In this section we describe how the peppered chub will respond to future habitat and flow factors in combination with specific species conservation actions. For the discussion on how the species will respond to habitat and flow factors alone (before species conservation is implemented) see *Fish Response* for the Upper South Canadian River under for the Continuation of Existing Trends scenario above (under 5.5.4.1 Resiliency).

Under the Continuation of Existing Trends scenario, resiliency of the Upper South Canadian River is considered **LOW by 2039 and LOW/ Ø by 2069** (Table 5-2); however, resiliency is improved through species specific conservation. Reproduction is enhanced through more appropriate timing of releases from Ute Reservoir and through higher releases to maintain channel complexity and minimize stream narrowing. Riparian restoration also slows or reverses stream narrowing in areas where significant narrowing has occurred. Although this level of conservation may not be able to maintain flow and habitat at current conditions in the Upper South Canadian River, specific actions such as flood plain restoration could enhance reproductive success and recruitment to make up for some losses to flows and habitat. Under this scenario, resiliency in the Upper South Canadian River could improve from **LOW to LOW/MODERATE by 2039 and from LOW/ Ø to LOW by year 2069.**

Cimarron River

Flow Factors

See *Flow Factors* for the Cimarron River under the Species Conservation and continuation of Existing Trends scenario above (under 5.7.1.1 Resiliency)

Habitat Factors

See *Habitat Factors* for the Cimarron River under the Species Conservation and Continuation of Existing Trends scenario above (under 5.7.1.1 Resiliency)

Species Conservation and Fish Response

The peppered chub is considered functionally extirpated from the Cimarron River under current condition. We cannot say with certainty that the fish is extirpated from the Cimarron River; however, if it does exist within the system it is undetectable at this time and does not support a resilient population. Under this Species Conservation and Continuation of Trends scenario, we assume that peppered chub re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation of the species has been lessened. There is support in the literature for this assumption, based on the re-establishment of the shoal chub in the Cimarron River, after being undetected for over 20 years (Luttrell et al. 1999, p. 984-985). It is possible that significant drought conditions in the late 1980s and early 1990s led to the species decline, but that current conditions may support populations once again. Shoal chub continues to persist in the Cimarron River.

In addition to re-establishment of the peppered chub in the Cimarron River, floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Too, riparian restoration focusing on narrowing stretches of river could add to channel complexity and slowing downstream movement of the population (if done at a large enough scale). With uncertainty regarding the exact stressor leading to the species being functionally extirpated and if that stressor still exists, we assume under this scenario that a reintroduced population with riparian and floodplain management could maintain **LOW resiliency through 2069.**

Ninnescah River

Flow Factors

Hydroperiod – Although having an upstream impoundment (Cheney Lake, completed 1964), current conditions at the Peck, KS gage show a generally intact natural flow regime. In fact, flow conditions have generally improved since the 1970s. The exception to this is the 2010s drought, in which almost all flow metrics have fallen to historic lows. Nonetheless, the hydroperiod rating for the current conditions is ***Good***, with only a 5.5 percent reduction in mean daily discharge from pre- and post-impoundment periods. For the future interval of 2020-2039, the hydroperiod rating falls slightly to a 20.6 percent reduction from pre-impoundment conditions and thus a ***Fair*** rating. For the 2020-2069 interval the rating improves to only a 10.5 percent reduction, which also equates to a ***Fair*** rating, albeit by 0.5 percent.

Flood Frequency Analysis – Flood frequencies (2, 5, and 10-year return intervals) are essentially unchanged at 103 percent of pre-impoundment levels. We therefore rate the Flood Frequency Analysis as ***Good*** for both future time horizons.

Low Flow Conditions – Low flows are also rated as ***Good*** in the current conditions, and we do not anticipate significant changes to this metric. Therefore, we rate low flow conditions as ***Good*** for both future intervals.

Habitat Factors

Channel width of the Ninnescah River near Peck, KS has not changed from the 1950s. With projections of future flows slightly declining at 2039, but with nearing current condition by 2069, the channel may see only a slight decrease in the next 20-50 years.

Because parameters are expected to be ***Fair*** to ***Good*** through 2069, no additional stream drying or additional fragmentation is assumed under this scenario.

Species Conservation and Fish Response

The South Ninnescah River supported the peppered chub as late as 2012; however, significant survey effort since that time has not yielded any peppered chubs, and we now consider the species in the South Ninnescah River functionally extirpated. Under this Species Conservation and Continuation of Trends scenario, we assume that peppered chub re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation of the species has been lessened.

In addition to re-establishment of the peppered chub in the Ninnescah River, this scenario includes management to remove the effects of fragmentation on the species. Currently the fragment length of South Ninnescah combined with the Arkansas River downstream to Kaw Reservoir is 121 miles, just under what may be needed for successful egg and larval development and upstream fish movement. To remove this stressor, one of two options is implemented: 1) work with the City of Kingston and Camp Mennoscah in Kansas (temporary spring/summer dam) to improve fish passage through modification of existing low water dam and temporary dam structures, or 2) implement an assisted migration plan where adult fish would be collected and moved upstream during certain times of the year and eggs/larvae would be collected and moved downstream during the spawn. Under either option we assume under this scenario that it results in a reproducing population within the South Ninnescah River. With the assumption that river fragmentation is the main stressor affecting the resiliency of this peppered chub population, the reintroduction and management of this population could result in a population with **LOW to MODERATE resiliency through 2069.**

Table 5-7. Summary of peppered chub resiliency under the Species Conservation and Continuation of Existing Trends scenario.

SCENARIO 3 - Species Conservation with Continuation of Existing Trends *Peppered Chub*				
	CURRENT RESILIENCY	Demographic Factors	Habitat/Flow Factors	*FUTURE RESILIENCY*
		20 Years (to 2039)		
South Ninnescah	Ø	Re-establishment of peppered chub	Minimize stream fragmentation	LOW / MODERATE
Arkansas/Salt Fork	Ø	No peppered chub management	N/A	Ø
Cimarron	Ø	Re-establishment of peppered chub	Riparian & floodplain restoration	LOW
Lower South Canadian	Ø	No peppered chub management	N/A	Ø
Upper South Canadian	LOW	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration	LOW / MODERATE
		50 Years (to 2069)		
South Ninnescah	Ø	Re-establishment of peppered chub	Minimize stream fragmentation	LOW / MODERATE
Arkansas/Salt Fork	Ø	No peppered chub management	N/A	Ø
Cimarron	Ø	Re-establishment of peppered chub	Riparian & floodplain restoration	LOW
Lower South Canadian	Ø	No peppered chub management	N/A	Ø
Upper South Canadian	LOW	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration	LOW

5.7.2.2 Representation

Under the Species Conservation with Continuation of Existing Trends scenario, the peppered chub has representation in the form of genetic diversity in three areas: the Upper South Canadian River, Cimarron River in Oklahoma, and the South Ninnescah River in Kansas. Because broodstock for fish reintroductions will come from the South Canadian River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future.

5.7.2.3 Redundancy

Under the Species Conservation with Continuation of Existing Trends scenario, redundancy of three populations of peppered chub would be maintained: the Upper South Canadian River, Cimarron River and South Ninnescah River. With all units potentially exhibiting low resiliency, these populations would be vulnerable to catastrophic events, possibly reducing redundancy in the future.

5.8 SCENARIO 4 – SPECIES AND WATER CONSERVATION WITH FLOW TRENDS STABILIZING

Assumptions under this scenario:

1. All species and water conservation actions described are implemented and are successful
2. Flow trends stabilize as water demands stabilize and climate emissions are mitigated, similar to RCP 4.5

5.8.1 Arkansas River Shiner

5.8.1.1 Resiliency

Upper South Canadian River

Under this scenario, significant water conservation is implemented to the level that current condition flows and habitat is maintained. In addition, species specific conservation for the Arkansas River shiner provides additional enhancements to reproduction and recruitment that does not exist under the current condition. With additional releases from Ute Reservoir targeting spawning flows and channel maintenance, reproduction would be enhanced. Under this scenario, water conservation results in an instream flow protection maintaining baseflows and allowing for fish movement upstream to improve repopulation all stretches of the Upper South Canadian River. Riparian restoration will aid in maintaining existing channels and improve areas where channels have narrowed. Floodplain restoration could provide additional egg and larval development in the Upper South Canadian beyond what currently exists. Resiliency of the Arkansas River shiner at current condition within the Upper South Canadian River is **MODERATE**, but if existing flow and habitat conditions are maintained and additional species specific conservation is implemented, resiliency in this unit could be **HIGH** through year 2069 (Table 5-8).

Lower South Canadian River

Under this Species Conservation with Stabilizing Flows scenario, resiliency is improved through species specific conservation and maintain by protections of stream flow through 2069. Although Lake Meredith does not provide additional releases under this scenario (reservoir has never reached elevation to allow for releases in accordance with the Canadian River Compact), floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Adult Arkansas River shiner are re-established in the upper stretches of the Lower South Canadian River (near Canadian, TX), possibly every three to five years, which would repopulate a significant stretch of the river downstream into Oklahoma, given spawning is successful. Riparian restoration would be targeted at stretches of river showing considerable channel narrowing, adding to channel complexity and slowing downstream movement of the population (if done at a large enough scale). Given that the Arkansas River shiner repopulates upper stretches of the Lower South Canadian River and that current flows patterns are maintained to protect fish in the lower portions of the Lower South Canadian River, resiliency could be maintained at **MODERATE** through 2069**.**

Cimarron River

The Arkansas River shiner is considered functionally extirpated under current condition. We cannot say with certainty that the fish is extirpated from the Cimarron River; however, if it does exist within the system, it is undetectable at this time and does not support a resilient population. Under this scenario, significant water conservation is implemented to the level that current condition flows and habitat is maintained. In addition, we assume that fish re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation of the species has been lessened. There is support in the literature for this assumption, based on the re-establishment of the shoal chub in the Cimarron River, after being undetected for over 20 years (Luttrell et al. 1999, pp. 984-985). It is possible that significant drought conditions in the late 1980s and early 1990s led to the species decline, but that current conditions may support populations once again. Shoal chub continues to persist in the Cimarron River.

In addition to re-establishment of the Arkansas River shiner in the Cimarron River, floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Too, riparian restoration focusing on narrowing stretches of river could add to channel complexity and slowing downstream movement of the population (if done at a large enough scale). With uncertainty regarding the exact stressor leading to the species being functionally extirpated and if that stressor still exists, we assume under this scenario that a reintroduced population with water conservation and riparian and floodplain management could maintain **LOW resiliency through 2069.**

Arkansas and Salt Fork River

The Arkansas River near Ralston last supported the Arkansas River shiner in 1998. Under this Species Conservation and Flow Trends Stabilize scenario, we assume that Arkansas River shiner re-introductions (every three to five years) are successful. For the re-establishment to be successful, Kaw Reservoir releases would be timed to benefit species reproduction and minimize egg and larval drift into Keystone Reservoir at the downstream end of this section of River. Given a self-sustaining population with proper releases and reintroductions only intermittently (three to five years as compared to every year), species within this section of the Arkansas River and Salt Fork of the Arkansas River could change from functionally extirpated to **LOW resiliency through 2069**.

Table 5-8. Resiliency summary for the Arkansas River shiner under the Species Conservation with Flow Trends Stabilizing scenario.

SCENARIO 4 - Species Conservation with Flow Trends Stabilizing *Arkansas River Shiner*				
	CURRENT RESILIENCY	Demographic Factors	Habitat/Flow Factors	*FUTURE RESILIENCY*
		20 Years (to 2039)		
South Ninnescah	ø	No Arkansas River shiner management	N/A	ø
Arkansas/Salt Fork	ø	Re-establishment of Arkansas River shiner	Kaw Releases; maintain existing flows	LOW
Cimarron	ø	Re-establishment of Arkansas River shiner	Riparian & floodplain restoration; maintain existing flows	LOW
Lower South Canadian	MODERATE	Improved reproduction	Riparian & floodplain restoration; maintain existing flows	MODERATE
Upper South Canadian	MODERATE	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration; maintain existing flows	HIGH
		50 Years (to 2069)		
South Ninnescah	ø	No Arkansas River shiner management	N/A	ø
Arkansas/Salt Fork	ø	Re-establishment of Arkansas River shiner	Kaw Releases; maintain existing flows	LOW
Cimarron	ø	Re-establishment of Arkansas River shiner	Riparian & floodplain restoration; maintain existing flows	LOW
Lower South Canadian	MODERATE	Improved reproduction	Riparian & floodplain restoration; maintain existing flows	MODERATE
Upper South Canadian	MODERATE	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration; maintain existing flows	HIGH

5.8.1.2 Representation

Under the Species Conservation with Flow Trends Stabilizing scenario, the Arkansas River shiner has representation in the form of genetic diversity in five areas: the Upper South Canadian River, Cimarron River in Oklahoma, Arkansas and Salt Fork River in Oklahoma, and the Pecos River in New Mexico (non-listed entity outside of the species historical range). Because broodstock for fish reintroductions will come from the either South Canadian River or Pecos River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future.

5.8.1.3 Redundancy

Under the Species Conservation with Continuation of Existing Trends scenario, redundancy of four populations of Arkansas River shiner would be maintained: Upper and Lower South Canadian River, Cimarron River and Arkansas River. With two of the four units exhibiting low resiliency, these populations would be vulnerable to catastrophic events, possibly reducing redundancy in the future.

5.8.2 Peppered Chub

5.8.2.1 Resiliency

Upper South Canadian River

Under this scenario, significant water conservation is implemented to the level that current condition flows and habitat is maintained. In addition, species specific conservation for the peppered chub provides additional enhancements to reproduction and recruitment that do not exist under the current condition. With additional releases from Ute Reservoir targeting spawning flows and channel maintenance, reproduction would be enhanced. Under this scenario, water conservation results in an instream flow protection maintaining baseflows and allowing for fish movement upstream to improve all stretches of the Upper South Canadian River. Riparian restoration will aid in maintaining existing channels and improve areas where channels have narrowed. Floodplain restoration could provide additional egg and larval development in the Upper South Canadian beyond what currently exists. Resiliency of the peppered chub within the Upper South Canadian River is currently **LOW**, but if existing flow and habitat conditions are maintained or improved and additional species specific conservation is implemented, resiliency in this unit could be **MODERATE** through year 2069.

Cimarron River

The peppered chub is considered functionally extirpated under current condition. Under this scenario, significant water conservation is implemented to the level that current condition flows and habitat are maintained. In addition, we assume that fish re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation of the species has been lessened.

In addition to re-establishment of the peppered chub in the Cimarron River, floodplain restoration could provide enhancement of egg and larval development if done on a large enough scale. Too, riparian restoration focusing on narrowing stretches of river could add to channel complexity and slowing downstream movement of the population (if done at a large enough scale). Although uncertainty exists regarding the exact stressor leading to the species being functionally extirpated, there is evidence from reestablishment of the shoal chub in the Cimarron River, that it is possible. We assume under this scenario that a reintroduced population with water conservation and riparian and floodplain management could maintain **LOW** resiliency through 2069.

Ninnescah River

The South Ninnescah River supported the peppered chub as late as 2012; however, significant survey effort since that time has not yielded any peppered chubs, and we now consider the species in the South Ninnescah River functionally extirpated. Under this Species Conservation and Flow Stabilization scenario, we assume that peppered chub re-introductions (every three to five years) are successful and the stressor that caused the functional extirpation is reduced or managed for.

In addition to re-establishment of the peppered chub in the Ninnescah River, this scenario includes management to remove the effects of fragmentation on the species. Currently the South Ninnescah fragment combined with the Arkansas River downstream to Kaw Reservoir is 121 river miles, just under the 135 miles needed for successful egg and larval development and upstream fish movement. To remove this stressor, one of two options is implemented: 1) work with the City of Kingston, KS and scout camp to improve fish passage through modification of existing low water dam and temporary dam structures, or 2) implement of an assisted migration plan to collect and move adult fish upstream during certain times of the year; eggs/larvae collected from the translocated fish would move downstream during the spawn. Under this scenario we assume that either of the two actions result in a reproducing population within the South Ninnescah River. With the assumption that river fragmentation is the main stressor affecting the resiliency of this peppered chub population and existing flows are maintained or improved, the reintroduction and management of this population could result in a population with **LOW to MODERATE resiliency.**

Table 5-9. Resiliency summary for the Peppered chub under the Species Conservation with Flow Trends Stabilizing scenario.

SCENARIO 4 - Species Conservation with Flow Trends Stabilizing *Peppered Chub*				
	CURRENT RESILIENCY	Demographic Factors	Habitat/Flow Factors	*FUTURE RESILIENCY*
		20 Years (to 2039)		
South Ninnescah	Ø	Re-establishment of peppered chub	Minimize stream fragmentation; maintain existing flows	LOW / MODERATE
Arkansas/Salt Fork	Ø	No peppered chub management	N/A	Ø
Cimarron	Ø	Re-establishment of peppered chub	Riparian & floodplain restoration; maintain existing flows	LOW
Lower South Canadian	Ø	No peppered chub management	N/A	Ø
Upper South Canadian	LOW	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration; maintain existing flows	MODERATE
		50 Years (to 2069)		
South Ninnescah	Ø	Re-establishment of peppered chub	Minimize stream fragmentation; maintain existing flows	LOW / MODERATE
Arkansas/Salt Fork	Ø	No peppered chub management	N/A	Ø
Cimarron	Ø	Re-establishment of peppered chub	Riparian & floodplain restoration; maintain existing flows	LOW
Lower South Canadian	Ø	No peppered chub management	N/A	Ø
Upper South Canadian	LOW	Improved reproduction and fish movement	Ute Releases; Riparian and floodplain restoration; maintain existing flows	MODERATE

5.8.2.2 Representation

Under the Species Conservation with Stabilization of Flows scenario, the peppered chub has representation in the form of genetic diversity in three areas: the Upper South Canadian River, Cimarron River in Oklahoma, and the South Ninnescah River in Kansas. Because broodstock for fish reintroductions will come from the South Canadian River, genetic variation is not necessarily improved for the species. But over time, if one or more new populations becomes established they could potentially provide for increased ecological adaptability in the future.

5.8.2.3 Redundancy

Under the Species Conservation with Continuation of Existing Trends scenario, redundancy of three populations of peppered chub would be maintained: the Upper South Canadian River, Cimarron River and South Ninnescah River. With two of the three populations potentially exhibiting low resiliency, these populations would be vulnerable to catastrophic events, possibly reducing redundancy in the future.

5.9 OTHER CONSIDERATIONS

5.9.1 Future Water Demands

Although the Continuation of Existing Trends scenario likely captures many water demands into the future, our analysis did not include additional significant, unforeseen demands that could occur in the future. We provide a summary of those below, but because of the high uncertainty of what demands could look like 20 and 50 years from now and how those could affect flows and river habitats, we did not include additional water demands as a specific scenario. It is reasonable to assume that significant additional demands could affect future resiliency and change our resiliency scores (i.e. **MODERATE** to **LOW or LOW to Ø**). One potential future demand, as discussed in the 2014 Oklahoma Water Plan, is the development of a new reservoir on the South Canadian River, near Hydro, OK (OWRB 2012, p. 55). A change to the South Canadian River as large as this could significantly affect flows and habitats (as demonstrated by analyses in the report) and stress an already **LOW** resilient population to the point of extirpation **(Ø)** of the Arkansas River shiner from the Lower South Canadian River. A summary of this reservoir proposal and other potential future demands, by Resiliency Unit, is provided in Appendix E - Water Demands.

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