Small Watershed Rotating Basin Monitoring Program

Basin Group 4: Washita River and Upper Red River Basins Final Report

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Project 3, Output 3.1

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1.0 PROJECT BACKGROUND AND DESCRIPTION

The Clean Water Act has charged each state's nonpoint source (NPS) pollution agency with two primary tasks: 1) identify all waters being impacted by NPS pollution, and 2) develop a management program describing implementation plans to correct identified problems. In addition, each state's NPS agency is tasked with the identification of all programs which are actively planning or enforcing NPS controls. Cooperation between local, regional, and interstate entities can magnify the impact of efforts to reduce NPS pollution. The state NPS agency can then report on total program status regarding efforts to address NPS impacts and improve water quality. The Oklahoma Conservation Commission (OCC) is assigned as the NPS Program technical lead by Oklahoma state statute and therefore must monitor to determine the occurrence, nature, and extent of NPS impacts to state waters. Robust and meaningful assessment of the state's water quality is the foundation for meeting the long-term goals of the Oklahoma NPS program and water quality management in general.

In 2000, the Oklahoma Conservation Commission (OCC) initiated a progressive ambient monitoring program to assess NPS issues on a larger spatial and temporal scale than previously done. Known as the *Small Watershed Rotating Basin Monitoring Program* ("Rotating Basin Program"), this effort entails fixed station sampling at or near the outlets of complete eleven-digit Hydrologic Unit Code watersheds (HUC-11). Oklahoma contains all or part of 414 U.S. Geological Survey (USGS) 11-digit HUC basins which have been collated into eleven larger planning basins for state water quality management purposes. The sampling units for the Rotating Basin Monitoring Program are based at the outlets of HUC 11 watersheds located entirely in the state. Secondary sites are located upstream in selected watersheds where isolation of a particular tributary influence is necessary. Fixed stations are segregated into five strategic basin groups, which are aggregations of several of the eleven planning basins. Stations are sampled every five weeks for a period of two years. Each year, sampling is initiated in a new basin group, resulting in a statewide coverage of all sites in five years (Figure 1).

To complement the fixed site monitoring, the OCC added a probabilistic component to the Rotating Basin Monitoring Program for Cycle 2 in 2008. This addition to the Rotating Basin Program provided a statistically qualified assessment of water quality conditions throughout the project basin. To accomplish this, sites were randomly selected from all waters of interest in a target area (i.e., basin unit), and the monitoring results were used to estimate water quality conditions in the larger area with known confidence (USGAO 2004). Analysis of the probabilistic component indicated that data collected from the fixed sites accurately represents the water quality of the basin. Therefore, probabilistic sites have not been monitored in Cycle 4. The fixed sites monitored in Cycle 4 are shown in Figure 1.

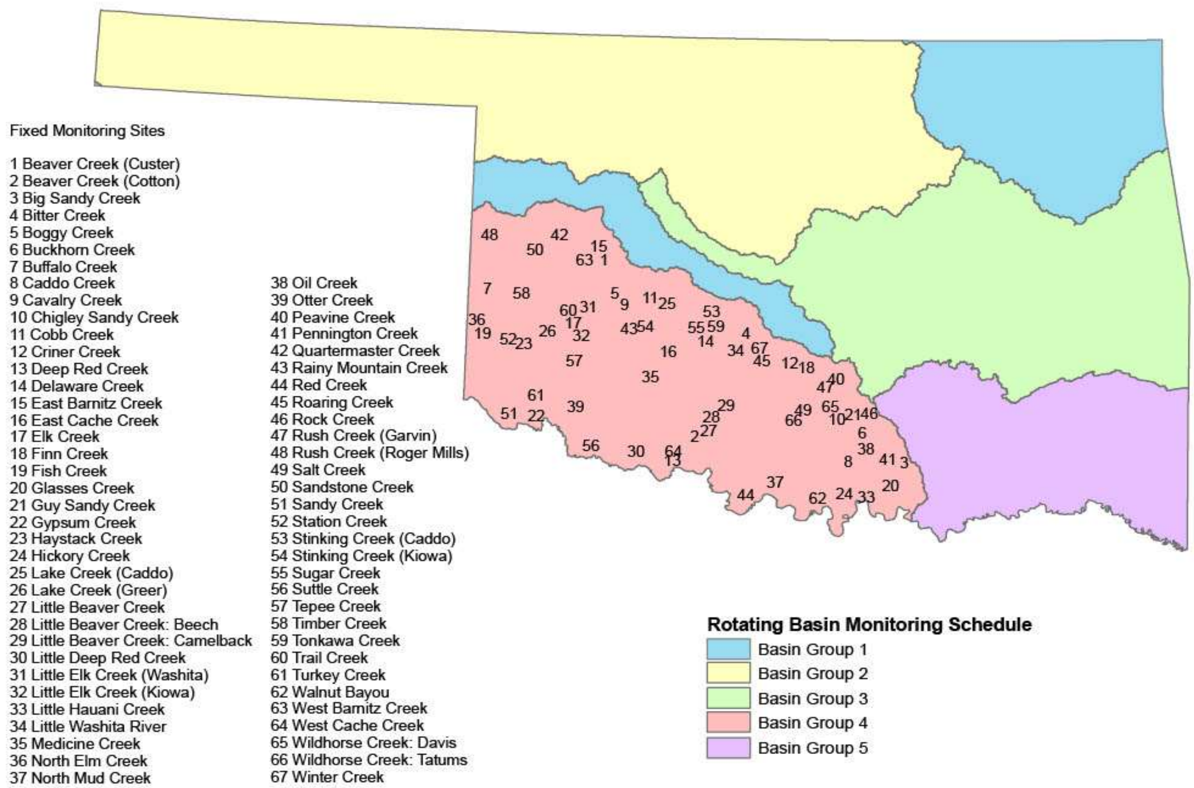

Figure 1. Monitoring sites in "Basin Group 4" for the fourth cycle of the Small Watershed Rotating Basin Monitoring Project.

Effectively coordinated with other state monitoring programs, the OCC's Rotating Basin program is designed to accomplish the state's NPS monitoring needs in four stages. The first stage includes a comprehensive, coordinated investigation and analysis of the causes and sources of NPS pollution throughout the state – *Ambient Monitoring*. The second stage involves more intensive, specialized monitoring designed to identify specific causes and sources of NPS pollution – *Diagnostic Monitoring.* The data from diagnostic monitoring can be used to formulate an implementation plan to specifically address the sources and types of identified NPS pollution. The third stage of monitoring is designed to initiate remedial and/or mitigation efforts to address the NPS problems – *Implementation Monitoring.* Finally, the fourth stage evaluates the effectiveness of the implementation through assessment and post-implementation monitoring – *Success Monitoring.* This assessment program provides a thorough and statistically sound evaluation of Oklahoma's waters every five years, which helps focus NPS program planning, education, and implementation efforts in areas where they can be most effective.

The Small Watershed Rotating Basin Monitoring Program considers the following specific questions in the context of Oklahoma Water Quality Standards and Use Support Assessment Protocols (USAPs) in addressing NPS pollution:

1. Which HUC 11 waterbodies are not supporting assigned beneficial uses due to NPS or NPS plus point source (PS) pollution?
2. Which waterbodies show elevated or increasing levels of NPS or NPS plus PS pollutants, which may threaten water quality?
3. What are the sources and magnitude of pollution loading within threatened or impaired waterbodies?
4. Which land uses or changes in land use are sources or potential sources for pollutants causing beneficial use impairment?

In its entirety, OCC's Rotating Basin Monitoring Program provides an assessment of water quality, watershed condition, and support status for selected streams statewide, which is necessary for planning, implementation, and eventual evaluation of mitigation efforts. The statewide ambient monitoring program has allowed a comprehensive approach for the identification of nonpoint source (NPS) affected waters, as well as the identification of high-quality streams. Results from this effort are used to assist the state in producing the 305(b) and 303(d) lists which are required by the EPA to assess beneficial use support for waterbodies biannually.

This report discusses the results of the *ambient* (routine physical, chemical, and biological sampling) and *diagnostic* (special parameter sampling) stages of the fourth cycle of the Rotating Basin program in the Washita River and Upper Red River Basins (see Figure 1). *Implementation* and *success* monitoring are typically accomplished through priority watershed projects and reported on separately in project-specific final reports.

This program will continue to provide a robust baseline dataset to assess the impact of NPS pollution throughout the state, identify the causes and sources of the pollution, and determine the success of measures to improve water conditions.

2.0 MATERIALS AND METHODS

2.1 GENERAL

Sampling stations were selected to effectively represent streams of the Washita River and Upper Red River basins. Candidate streams were selected from sub-watersheds within these basins located entirely within the state of Oklahoma having perennial water. Watersheds that did not have perennial water or were within a segment of a larger river being sampled by another agency were not chosen. Where a particular watershed was monitored by another entity, the stream was dropped from consideration as a Rotating Basin site, if the external monitoring met the project data quality objectives. For most sub-watersheds, the OCC monitoring site was located near the outflow of the primary stream but far enough upstream to limit backwater (surface and alluvial) effects of the waterbody to which it drained. For larger sub-watersheds, an additional site was sometimes located upstream to isolate a particularly strong tributary influence. In some cases, sites were specifically chosen to monitor a stream draining an area of land use different from most other streams being monitored in that region or sub-watershed.

Reconnaissance of all potential sites within the Washita River and Upper Red River basins was accomplished prior to the first round of monitoring in 2004, and sites which did not meet the sampling criteria were removed from the project. Sixty-one sites were monitored during the first rotating basin cycle, from 2004-2006. Sixty-four were monitored in the second cycle from June 2009-May 2011. Sixty-one sites were monitored during the third cycle from June 2014-May 2016. The fourth cycle of monitoring in these basins occurred from June 2019-May 2021. There were 67 fixed sites during this cycle of monitoring (Table 1).

The sites monitored in the Washita basin occur in two level-three ecoregions: The Central Great Plains (CGP) and the Cross Timbers (CT). In the Upper Red basin, sites were located in the Cross Timbers (CT), Central Great Plains (CGP), and Southwestern Tablelands (SWT) ecoregions. Seven sites had a heavy influence from a bordering ecoregion (i.e., the sites are very close to the ecoregion border and have water originating in the other ecoregions), so they were grouped with the influencing ecoregions when compared to reference conditions: Medicine Creek (located in CGP but influenced by the "Wichita Mountains"); Stinking Creek (located in CGP, influenced by CT); Big Sandy Creek, Buckhorn Creek, Caddo Creek, Oil Creek, and Pennington Creek (all located in CT but influenced by the "Arbuckle Uplift"). These changes are indicated by the "modified ecoregion" column in Table 1.

Table 1. Site list for Rotating Basin Monitoring Program: Basin Group 4 (Washita and Upper Red River Basins), Cycle 4. WBID is a unique waterbody identifier for each monitoring site. Ecoregions include Cross Timbers (CT), Central Great Plains (CGP), Southwest Tablelands (SWT). The modified ecoregion is a representation, not only of the location of the sampling point, but the entirety of the watershed that influences the stream.

Site Name	WBID	Latitude	Longitude	County	Ecoregion	Modified Ecoregion
Beaver Creek (Custer)	OK310830-03-0190C	35.533	-98.958	Custer	CGP	CGP
Beaver Creek (Cotton)	OK311210-00-0010D	34.3913	-98.1828	Cotton	CGP	CGP
Big Sandy Creek	OK310800-01-0090G	34.23133	-96.63492	Johnston	CT	Arbuckle
Bitter Creek	OK310820-01-0030D	35.0006	-97.8442	Grady	CGP	CGP
Boggy Creek	OK310830-03-0100C	35.306	-98.879	Washita	CGP	CGP
Buckhorn Creek	OK310800-02-0220C	34.42628	-96.9508	Murray	CT	Arbuckle
Buffalo Creek	OK311510-02-0090D	35.321	-99.867	Beckham	CGP	CGP

Site Name	WBID	Latitude	Longitude	County	Ecoregion	Modified Ecoregion
Caddo Creek	OK310800-03-0010F	34.24	-97.052	Carter	CT	Arbuckle
Cavalry Creek	OK310830-03-0070D	35.277	-98.853	Washita	CGP	CGP
Chigley Sandy Creek	OK310800-02-0190D	34.514	-97.122	Murray	CT	CT
Cobb Creek	OK310830-06-0050K	35.2908	-98.5941	Caddo	CGP	CGP
Criner Creek	OK310810-02-0050D	34.8552	-97.4962	McClain	CGP	CGP
Deep Red Creek	OK311310-03-0010D	34.218	-98.4	Cotton	CGP	CGP
Delaware Creek	OK310830-01-0030G	35.058	-98.176	Caddo	CT	CT
East Barnitz Creek	OK310830-03-0210C	35.595	-99.045	Custer	CGP	CGP
East Cache Creek	OK311300-03-0010M	34.9386	-98.4444	Caddo	CGP	CGP
Elk Creek	OK311500-03-0030C	35.1132	-99.1812	Washita	CGP	CGP
Finn Creek	OK310810-02-0020D	34.855	-97.424	McClain	CGP	CGP
Fish Creek	OK311800-00-0130G	35.0192	-99.8804	Greer	SWT	SWT
Glasses Creek	OK310800-01-0020M	34.0855	-96.7319	Marshall	CT	CT
Guy Sandy Creek	OK310800-02-0130D	34.519045	-97.025526	Murray	CT	CT
Gypsum Creek	OK311600-01-0020F	34.454	-99.412	Jackson	CGP	CGP
Haystack Creek	OK311800-00-0040D	34.958	-99.562	Greer	CGP	CGP
Hickory Creek	OK311100-02-0010M	34.014	-97.084	Love	CT	CT
Lake Creek (Caddo)	OK310830-06-0040J	35.2762	-98.5306	Caddo	CGP	CGP
Lake Creek (Greer)	OK311510-01-0040D	35.056	-99.378	Greer	CGP	CGP
Little Beaver Creek	OK311210-00-0050D	34.42	-98.142	Cotton	CGP	CGP
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	34.50712	-98.105866	Stephens	CGP	CGP
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	34.5506	-98.0551	Stephens	CGP	CGP
Little Deep Red Creek	OK311310-03-0040E	34.2772	-98.6793	Tillman	CGP	CGP
Little Elk Creek (Washita)	OK311500-03-0050A	35.21886	-99.08046	Washita	CGP	CGP
Little Elk Creek (Kiowa)	OK311500-03-0040E	35.0295	-99.1196	Kiowa	CGP	CGP
Little Hauani Creek	OK311100-01-0120B	33.99972	-96.91748	Marshall	CT	CT
Little Washita River	OK310820-02-0010A	34.9725	-97.8693	Grady	CGP	CGP
Medicine Creek	OK311300-04-0060H	34.772	-98.58	Comanche	CGP	Wichita
North Elm Creek	OK311800-00-0170G	35.0749	-99.96	Beckham	SWT	SWT
North Mud Creek	OK311100-04-0030C	34.0857	-97.615	Jefferson	CGP	CGP
Oil Creek	OK310800-01-0240P	34.3186	-96.9332	Johnston	CT	Arbuckle
Otter Creek	OK311500-01-0080F	34.56	-99.141	Tillman	CGP	CGP
Peavine Creek	OK310810-01-0120M	34.7676	-97.1607	Garvin	CT	CT
Pennington Creek	OK310800-01-0120G	34.241	-96.682	Johnston	CT	Arbuckle
Quartermaster Creek	OK310840-01-0060B	35.6823	-99.3207	Custer	CGP	CGP
Rainy Mountain Creek	OK310830-02-0060G	35.092	-98.744	Kiowa	CGP	CGP

Site Name	WBID	Latitude	Longitude	County	Ecoregion	Modified Ecoregion
Red Creek	OK311100-01-0290D	33.955	-97.77	Jefferson	CGP	CGP
Roaring Creek	OK310810-02-0170B	34.893	-97.7233	Grady	CT	CT
Rock Creek	OK310800-02-0122L	34.5447	-96.9591	Murray	CT	CT
Rush Creek (Garvin)	OK310810-01-0090H	34.73473	-97.21661	Garvin	CGP	CGP
Rush Creek (Roger Mills)	OK310840-02-0210H	35.6738	-99.8548	Roger Mills	CGP	CGP
Salt Creek	OK310810-03-0080G	34.543	-97.405	Garvin	CT	CT
Sandstone Creek	OK310840-02-0020C	35.593	-99.509	Roger Mills	CGP	CGP
Sandy Creek	OK311600-01-0040G	34.41	-99.621	Jackson	CGP	CGP
Station Creek	OK311800-00-0060G	34.9875	-99.667778	Greer	CGP	CGP
Stinking Creek (Caddo)	OK310830-04-0030K	35.18911	-98.1264	Caddo	CGP	CT
Stinking Creek (Kiowa)	OK310830-02-0020F	35.09464	-98.64553	Kiowa	CGP	CGP
Sugar Creek	OK310830-05-0010D	35.117	-98.197	Caddo	CT	CT
Suttle Creek	OK311310-01-0070H	34.235	-99.011	Tillman	CGP	CGP
Tepee Creek	OK311500-01-0110D	34.87	-99.167	Kiowa	CGP	CGP
Timber Creek	OK311510-01-0090G	35.291	-99.582	Beckham	CGP	CGP
Tonkawa Creek	OK310830-01-0050B	35.0868	-98.1862	Caddo	CT	CT
Trail Creek	OK311500-03-0070D	35.16	-99.228	Washita	CGP	CGP
Turkey Creek	OK311600-02-0060M	34.6255	-99.4567	Jackson	CGP	CGP
Walnut Bayou	OK311100-03-0010G	33.918	-97.281	Love	CT	CT
West Barnitz Creek	OK310830-03-0230C	35.595	-99.052	Custer	CGP	CGP
West Cache Creek	OK311310-02-0010M	34.275	-98.388	Cotton	CGP	CGP
Wildhorse Creek: near Davis	OK310810-01-0020G	34.5331	-97.1871	Garvin	CT	CT
Wildhorse Creek: near Tatums	OK310810-03-0010R	34.502	-97.457	Carter	CT	CT
Winter Creek	OK310810-02-0220G	34.9713	-97.7742	Grady	CGP	CGP

All sampling and analyses performed during this project were conducted under a Quality Assurance Project Plan (QAPP) approved by EPA Region VI and on file at the OCC Water Quality Division (OCC 2019), the Oklahoma Secretary of Energy & Environment (OSEE), and EPA Region VI in Dallas. All sampling and measurement activities of OCC Water Quality staff followed procedures outlined in the appropriate OCC Standard Operating Procedure (OCC 2021). Water quality chemical analyses were conducted by the Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) laboratory.

All data were compiled and entered into an Access database for later analysis. Upon retrieval, data were proofed and quality assured, and the descriptive statistics were generated for each parameter using the statistical software package *Minitab V. 17*.

2.2 WATER QUALITY MONITORING

Starting in June 2019 and completing in May 2021, 67 sites were monitored for physical and chemical parameters on five-week intervals (usually 20 total sampling events per site). This sampling frequency exceeds state data requirements for beneficial use assessment and meets a sample number necessary to provide a 90% level of confidence for principal water quality data (specifically phosphorus, a critical NPS concern) as determined from EPA's DEFT software (USEPA 2001). Samples were collected during both base flow and high flow conditions as they occurred on predetermined sampling dates. All sampling and measurement activities followed procedures outlined in the appropriate OCC SOP (OCC 2021).

One water sample was collected per site per 35-day interval in two, new, sample-rinsed HDPE bottles; one was preserved to a pH <2 with H_2SO_4, and both were stored and delivered on ice at 4° C or lower. Quality assurance/control samples were collected in accordance with Data Quality Objectives (DQOs) outlined in the project QAPP (OCC 2019). Samples were submitted to the ODAFF Laboratory for analysis of the following parameters: nitrate (NO_3), orthophosphate (PO_4), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia (NH_3; May 1 - September 30 only), chloride (Cl), sulfate (SO_4), total suspended solids (TSS), and total dissolved solids (TDS). An estimate of total nitrogen was calculated by summing the values of nitrate and TKN for each sample. Available nitrogen was calculated by summing the values of ammonia and nitrate. Due to high chloride levels in Basin 4 the reporting limits for nitrite (NO_2) were adjusted to levels that were orders of magnitude higher than those typically observed in stream samples, and therefore excluded from total nitrogen and available nitrogen calculations. Samples submitted to the lab mid-March 2020 through May 2020 were analyzed past holding times due to a state-mandated laboratory shut-down; these samples failed QA requirements (OCC 2019) and were therefore excluded from the statistical analyses presented in this report. In addition, *in-situ* water quality parameters were measured at each sampling location and included the following: water temperature, dissolved oxygen, pH, conductivity, alkalinity, hardness, turbidity, and instantaneous discharge.

Separate samples were collected and submitted concurrently for analysis of *E. coli* bacteria during the recreational season (May 1 – September 30), ensuring that a minimum of 10 samples were assessed per site over the two-year monitoring period. In addition, site observations of odor, excessive bottom deposits, surface scum, oil/grease, foam and other observations were recorded each time a site was visited.

2.3 BIOLOGICAL MONITORING

2.3.1 Habitat Assessment

In the summer of 2019, OCC staff began conducting instream and riparian habitat assessments at sites concurrent with fish collections (described in Section 2.3.2); any sites not sampled in 2019 were sampled in the summer of 2020. All assessments were conducted in accordance with procedures outlined in the OCC Habitat Assessment SOP (OCC 2021). The OCC's habitat assessment adheres to a modified version of the EPA Rapid Bioassessment Protocols (RBP) (Plafkin et al., 1989) and is designed to assess habitat quality in relation to its ability to support biological communities in the stream. The assessment is based on parameters grouped into three categories for a total of eleven components (Plafkin et al., 1989). The eleven components are discussed in more detail below. The three primary categories assessed include micro-scale habitat, macro-scale habitat, and riparian/bank structure. Micro-scale habitat includes substrate composition, stable cover, canopy, depth, and velocity. Macro-scale assesses the channel morphology, sediment deposits, and other parameters. The third category looks at the riparian zone quality, width, and structure (trees, shrubs, vines, and grasses) as well as bank features. Bank erosion and streamside vegetative cover are incorporated into this section.

Each stream segment was surveyed for 400 meters upstream or downstream of the starting point (usually a road crossing). Investigators recorded data for the described parameters for 20 stations at 20-meter intervals. Habitat data were entered, metrics were computed, and a "total habitat score" was rendered via calculations completed in Microsoft® *Access ®*. The total habitat score, which can reach a maximum of 180 points, was calculated based on quantitative weighting given to each of the habitat parameters in relation to their biological significance. Scores were computed for each of the eleven categories, summed, and assigned as an evaluation of that stream section and riparian zone. The habitat score was then obtained as the sum of habitat components, and then divided by the average habitat score of the reference sites from the same ecoregion to determine the percent of reference score.

OCC's habitat assessment components include:

(1) **Instream cover** is the component of habitat that organisms hide behind, within, or under. High quality cover consists of submerged logs, cobble and boulders, root wads, and beds of aquatic plants. Cover required by smaller members of the stream community will consist of gravel, cobbles, small woody debris, and dense beds of fine aquatic plants. At least 50% of the stream's area should be occupied by a mixture of stable cover types for this category to be considered optimal.

(2) **Pool bottom substrate** describes the type of stream bed found in pools. Pools are depositional areas of the stream, and as such, are easily damaged by materials that settle. A loose shifting pool bottom will not provide substrate for burrowing organisms and will not allow bottom-spawning fish to successfully spawn. It will not provide habitat to the smaller vertebrates and invertebrates that are necessary to

support many of the pool dwelling fish. At least 80% of all pool bottoms must have stable substrate for a reach to be considered optimal for the habitat component.

(3) **Pool variability** describes the depth of pools. A healthy, diverse community of aquatic organisms requires both deep and shallow pools. A fairly even mix of pool depths from a few centimeters to 0.5 meters or greater is optimal.

(4) **Canopy cover** assesses the shading of the stream section. Plants lie at the base of almost all food chains. Since plants require light for growth and survival, a stream that is functioning well needs some amount of light. Moderation is optimal, however, because light is associated with heat, and most aquatic organisms are stressed by the higher water temperature, lower oxygen solubility and higher metabolic rates that accompany the warming of water.

(5) The **percent of rocky runs and riffles** is calculated for the fifth component. Rocky runs and riffles offer a unique combination of highly oxygenated, turbulent water, flowing over high-quality cover and substrate. Turbulence prevents the formation of nutrient concentration gradients from cell membranes outward so that algae and other plants grow at a much higher rate than they would at the same concentration in pools. More food means more growth. Larger crops of algae are translated into larger invertebrate crops. It is these invertebrates, reared in riffle areas that feed many of the fish in the stream. Because turbulent water is well oxygenated, there has been no selection pressure for riffle dwelling organisms to develop tolerance to poorly oxygenated waters. These are often the first animals to disappear from the stream if oxygen becomes scarce. The presence of rocky runs and riffles offers habitat for many highly adapted animals that will increase diversity of samples collected from the streams they occupy.

(6) **Discharge** at representative low flow reflects stream size. Water is the most basic requirement of aquatic organisms. Larger streams tend to have more water, and thus, more varied high-quality habitat. Overall habitat quality should rise as streams increase in size and discharge, other factors being equal.

(7) **Channel alteration** is the seventh category. The presence of newly formed point bars and islands is very significant. Unstable streambeds support fewer types of animals than those that are stable. This is because unstable streambeds tend to have unstable pool bottom substrate, riffle areas whose cobbles are embedded in finer material and little cover because it is continually being buried. Few or no signs of channel alteration are considered optimal.

(8) **Channel sinuosity** measures how far a channel deviates from a straight line. More sinuous channels tend to have more undercut banks, root wads, submerged logs, etc. Index of Biotic Integrity (IBI) scores should be higher as channels become more sinuous. Sinuosity is calculated by dividing the length of the assessment (400 meters) by the distance between the GPS location of the start point and end point of the assessment.

(9) The **bank erosion** index assesses the stability of the stream bank. Stable stream banks tend to increase IBI scores for many reasons. Most importantly, they do not contribute sediment to the stream

channel. As a rule, channels with stable banks tend to be deeper and narrower than channels with unstable banks. Because of the increased depth and decreased width, they tend to be cooler, and they also tend to grow less algae for a given amount of nutrients than do shallow, wide channels. Overall habitat quality should increase as bank stability increases.

(10) The **vegetative stability** of the stream bank is an important component. Stream banks can be stabilized with a number of materials including rock, concrete, and fabric. Banks that are stabilized with vegetation benefit the aquatic community more than those stabilized with other materials. This is because the vegetation offers several extra advantages beyond that of bank stability. The riparian plants of the stream bank offer a high-quality source of food and shade to the aquatic community. Riparian vegetation stabilizes point bars and contributes greatly to structure in the form of root wads and woody debris. Overall habitat quality should improve as bank vegetative stability increases.

(11) The **streamside cover** category is representative of a large part of the energy and food input that comes from the terrestrial vegetation along the banks. A mixture of grasses, forbs, shrubs, vines, saplings, and large trees transfer these necessities to the stream more effectively than does any single type of vegetation. Habitat quality should increase as the form of bank vegetation increases in diversity.

2.3.2 Fish

Fish collections were completed in the summer of 2019 or 2020 for each site. Fish were collected from a 400-meter reach at all sites using a combination of seining and electroshocking according to procedures outlined in OCC SOP (2019). The collection of fish follows a modified version of the EPA Rapid Bioassessment Protocol V (Plafkin et al., 1989) supplemented by other documents. Specific techniques and relative advantages of seining and electrofishing vary considerably according to stream type and conductivity. Depending upon workable habitat, seining was performed first at all sites and was accomplished by use of either 6’ X 10’ or 6’ X 20’ seines of ¼ inch mesh equipped with 8’ brailes. Electroshocking was undertaken at all sites with suitable conductivities (usually < 1000 µS/cm) and involved the use of a Smith Root LR 24 backpack shocker. For sites possessing long pools too deep to seine or backpack shock, OCC field personnel employed a boat electrofishing unit consisting of a Smith-Root GPP 2.5 shocking unit powered by a Honda 5kw generator.

Except for those individuals readily identifiable, fish were placed in 10% formalin upon capture and identified to species by a professional taxonomist. Fish species identified and released in the field were photographed for reference. Threatened, endangered, rare and out of range samples were transferred to ethanol and retained for future reference.

Fish data were compiled and analyzed by site using state biocriteria and methods outlined in the state’s *Use Support Assessment Protocols* (OWRB 2016). In addition, each site was assessed using OCC's modified RBP method, which is a modified version of Karr’s Index of Biotic Integrity (IBI) (adapted from Plafkin et al., 1989). The condition of the fish community was based on indices of species richness, community quality, trophic structure, and by comparison to the average scores of high-quality streams in that ecoregion. High quality sites were determined by identifying the sites among all sampling locations that scored the highest for a composite scoring regime (OCC 2005). The modified IBI score was calculated using the following metrics:

(1) The **total number of fish species** decreases with decreasing water or habitat quality.

(2) The **number of sensitive benthic species (darters, madtoms, sculpins)** decreases with increasing siltation and increasing benthic oxygen demand. Many of these fish live within the cobble and gravel interstices and are very good indicators of conditions that make this environment inhospitable. These species are weak swimmers that do not readily travel up and down a stream, so their presence or absence at a site relates well to both past and present habitat and water quality conditions at that site.

(3) The **number of sunfish species** decreases with decreasing pool quality and with decreasing cover. Sunfish also require a fairly stable substrate on which to spawn, so their long-term success is also tied to conditions that affect the amount of sediment that enters and leaves the stream.

(4) The **number of intolerant species** is a characteristic of the fish community that separates high quality from moderate quality sites. A high-quality stream will have several members of the fish community that are intolerant to environmental stress. A stream of only moderate quality will have fish that are moderately and highly tolerant of environmental stress. The intolerant species will not be present in the moderate quality stream.

(5) The **proportion of tolerant individuals** is a characteristic that allows moderate quality streams to be separated from low quality streams. These are opportunistic, tolerant fish that dominate communities that have lost their competitors through loss of habitat or water quality.

(6) The **proportion of individuals as insectivorous cyprinids** increases as the quality and quantity of the invertebrate food base increases. These are the dominant minnows in North American streams but are replaced by either omnivorous or herbivorous minnows as the quality of the food base deteriorates. Often, as the density of aquatic invertebrates decreases, the standing crop of algae increases. This is because the aquatic invertebrates are the largest group of primary consumers. Fish that can switch their diet to algae or fish that eat only algae will replace fish that cannot adapt to the new conditions.

(7) The **proportion of individuals as lithophilic spawners** decreases as the quality of the stream decreases. Lithophilic spawners require cobble or gravel to spawn; hence, these fish are sensitive to siltation. This metric allows separation of excellent streams from moderate quality streams.

For each of these seven metrics, a score of 5, 3, or 1 was assigned (Table 2), and these scores were summed to get a total IBI score (35 point maximum) for each site. For all “proportion” metrics, the score was based on the actual metric. For all non–proportion metrics, the score was determined by dividing the monitoring site’s metric by the average high-quality site metric of the same ecoregion. Each monitoring site’s total score was then compared to average high-quality site total score in that ecoregion and given an integrity rating (as established and suggested by the EPA RBP; see Table 3, below.

Table 2. Index of Biotic Integrity (IBI) scoring criteria for fish.

Metrics	***5***	***3***	***1***
Number of species	>67%	33-67%	<33%
Number of sensitive benthic species	>67%	33-67%	<33%
Number of sunfish species	>67%	33-67%	<33%
Number of intolerant species	>67%	33-67%	<33%
Proportion tolerant individuals	<10%	10-25%	>25%
Proportion insectivorous cyprinid individuals	>45%	20-45%	<20%
Proportion individuals as lithophilic spawners	>36%	18-36%	<18%

Table 3. Index of Biotic Integrity (IBI) score interpretations for fish.

% Comparison to the Reference Score	Integrity Class	Characteristics
90 – 100 %	Excellent	Comparable to pristine conditions, exceptional species assemblage
78 – 89%	Good	Decreased species richness, especially intolerant species
62 – 77%	Fair	Intolerant and sensitive species rare or absent
42 – 61%	Poor	Top carnivores and many expected species absent or rare; omnivores and tolerant species dominant
0 – 41%	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

2.3.3 Macroinvertebrates (Bugs)

Collection of macroinvertebrates was attempted at all sites during both winter and summer index periods from June 2019 through March 2021 according to procedures outlined in the OCC SOP (2019). Index periods represent seasons of relative community stability that afford opportunity for meaningful site comparisons. For Oklahoma, the summer index occurs from June 1 to September 15; the winter index occurs from January 1 to March 15. Macroinvertebrate were only collected when flowing water was present. Sampling efforts included attempts to procure animals from all available habitats at a site; thus, total effort at a site may entail up to three total samples with one from each of the following habitats: rocky riffles, streamside vegetation, and woody debris.

Collection methods involved sampling each of the habitats similar to methods outlined in the EPA Rapid Bioassessment Protocols (Plafkin et at., 1989). Riffle sampling effort consisted of three, 1-m^2 kicknet samples in the areas of rocky substrate reflecting the breadth of the velocity regime at a site. Riffles with substrates of bedrock or tight clay were not sampled. Any streamside vegetation in the current that appeared to offer fine structure was sampled by agitation within a #30 mesh dip net for three minutes total agitation time. Any dead wood with or without bark which was in current fast enough to offer suitable habitat for organisms was sampled by agitation or by scraping/brushing upstream of a #30 mesh dip net for five minutes. Woody debris sampled generally ranged in size from ¼” to about 8” in diameter.

Each sample type was preserved independently in quart mason jars with ethanol, labeled, and sent to a professional taxonomist for picking and identification.

Macroinvertebrates were not accessed in this report due to time constraints and logistical problems that arose because of COVID. The samples were collected but many samples have not been sorted or identified. This data set will be included in the 2024 integrated report. An update to the site scores calculated for Basin 4 cycle 4 streams included in this report, will be completed and included as an addendum to the Basin 5 cycle 4 report completed next year, according to the following methods.

Data will be compiled, collated by year, season, and habitat type and entered into a spreadsheet for metric calculations. The six metrics used to assess the macroinvertebrate community include the following:

(1) The **number of taxa** refers to the total number of taxonomically different types of animals in the sample. As is the case with the fish, this number rises with increasing water and/or habitat quality (Plafkin et al., 1989).

(2) The **Modified Hilsenhoff Biotic Index (HBI)** is a measure of the invertebrate community's tolerance to organic pollution. It ranges between 0 and 10 with 0 being the most pollution sensitive. The index used in the RBP Manual is based on the pollution tolerance of invertebrates from the upper Midwest. The Index used here is calculated the same way but used tolerance values of North Carolina invertebrates (Plafkin et al., 1989).

(3) The **EPT Index** is the number of different taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera, the mayflies, stoneflies, and caddis flies respectively. With few exceptions, these insects are more sensitive to pollution than any other groups. As a stream deteriorates in quality, members of this group will be the first to disappear. This robust metric allows discrimination between all but the worst of streams (Plafkin et al., 1989).

(4) The **percent EPT** is a measure of how many individuals in the sample are members of the EPT group. This metric helps to separate high quality streams from those of moderately high quality. The highest quality streams will have many individuals of many different taxa of EPT. As conditions deteriorate, animals will begin to die or to drift downstream. At this point, the community will still have many taxa of EPT, but there will be fewer individuals (Plafkin et al., 1989).

(5) **Percent dominant two taxa** is the percentage of the collection composed of the most common two taxa. As more and more species are excluded by increasing pollution, the remaining species can increase in numbers due to the unused resources left by the excluded animals. This metric helps to separate the high-quality streams from those of moderate quality (Plafkin et al., 1989).

(6) The **Shannon-Weaver Species Diversity Index** measures the evenness of the species distribution. It increases as more taxa are found in the collection and as individual taxa become less dominant. The metric increases with increasing biotic quality (Plafkin et al., 1989).

In the Basin 5.4 report descriptive statistics of each season-specific sample type (e.g., summer riffle, winter vegetation, summer woody) for each site will be calculated in *Minitab V. 17* and compared to the average respective metric of high-quality streams in the ecoregion. High-quality sites were determined by identifying the sites among all sampling locations that scored the highest for a composite scoring regime (OCC 2005). A Bioassessment score will be calculated similarly to the IBI score for fish. For each site, scores of 6, 4, 2, or 0 will be assigned for each metric (according to the criteria in Table 4, below) and then summed to get a total Bioassessment score for each site, with a maximum of 36 points. For taxa richness and EPT taxa richness, the percentages used to assign scores is obtained by dividing each monitoring site metric by the average high-quality site metric in a particular ecoregion. For the HBI metric, the high-quality site value is divided by the monitoring site value (high-quality site metric / monitoring site metric). For the remaining metrics, the score is based on the actual values obtained instead of being relative to the high quality-site metric. Each monitoring site's total score is then compared to the average high-quality sites' total score (in that ecoregion) and classified according to the condition gradient outlined in Table 5 (adapted from Plafkin et al., 1989).

Table 4. Bioassessment scoring criteria for macroinvertebrates

Metrics	***6***	***4***	***2***	***0***
Taxa Richness**	>80%	60-80%	40-60%	<40%
Modified HBI* (**)	>85%	70-85%	50-70%	<50%
EPT/Total***	>30%	20-30%	10-20%	<10%
EPT Taxa**	>90%	80-90%	70-80%	<70%
% Dominant 2 Taxa**	<20%	20-30%	30-40%	>40%
Shannon-Weaver***	>3.5	2.5-3.5	1.5-2.5	<1.5

*Modified HBI Using North Carolina Tolerance Values
**RBP for Use in Streams and Rivers 1989
***Modified by OCC

Table 5. Bioassessment score interpretation for macroinvertebrates

% Comparison to the Reference Score	Biological Condition	Characteristics
>80%	Non-Impaired	Comparable to the best situation expected within the ecoregion. Balanced trophic and community structure for stream size.
52-79%	Slightly Impaired	Community structure less than expected. Species richness is less than expected due to loss of some intolerant forms. Percent contribution of tolerant forms is increased.
20-51%	Moderately Impaired	Fewer species due to the loss of most intolerant forms. Reduction in EPT index.
<19%	Severely Impaired	Few species present. If high densities of organisms occur, they are dominated by 1 or 2 taxa.

2.4 DATA ANALYSIS

2.4.1 Stream Scores

To assess current (cycle 4: 2017-2019) stream condition, streams were assigned a score ranging from 0 to 100% for water chemistry parameters, as well as habitat and biota. To avoid redundancy in site scores, a subset of water chemistry parameters were included in the analysis: three nutrient parameters (PO_4, Total Nitrogen (TN), NH_3, two salt parameters (Cl, SO_4), pH, DO% saturation and turbidity. Raw data results for other metrics are available in Appendix A.1, and descriptive statistics in appendix A.3.

For each site, each water quality parameter assessed was compared to the distribution of that parameter at high-quality reference sites (reference sites) from the same ecoregion (OCC 2005) using binomial models. We considered sample results from each water-quality parameter within each site independently. For most water-quality parameters, a sample result falling below the 75th percentile of reference site distribution for the same parameter was considered a success. First, we tested the null hypothesis that the success rate of a parameter within a site was $\geq$ 0.75, then we tested for a success rate of $\geq$ 0.50 using an $\alpha = 0.05$. Because optimal values for pH and DO% saturation are in the middle of their range, a success was considered a sample result falling above 25% and below 75% of reference. Therefore, two binomial tests were conducted in R Statistical Software (version 4.1.1, R Core Team, 2021). Because there were two thresholds to test for the pH and DO% saturation parameters, we conducted two binomial tests at each success threshold, combined the probabilities (i.e., $P(\geq 0.25) \cap P(\leq 0.75)$) and compared the resulting P-value to α=0.025 which was obtained via the Bonferroni correction. If we determined that the success rate of a parameter was at least 0.75, the stream was given a score of 1 for that parameter, and if the success rate was < 0.75 but $\geq$ 0.50, we assigned the stream a score of 0.5 for the parameter. If the success rate was <0.5 we assigned the stream a score of 0 for the parameter. The water-quality score of a stream was then based on the average score of all parameters, so that a score of 1 indicated a site exhibited no observed deviation from reference site condition across all parameters and a score of 0 indicated a site was most degraded compared to reference sites across all parameters.

Habitat assessment scores (original habitat scores) were calculated as percent of reference condition as outlined in sections 2.3.1. Additionally, to generate site scores for this analysis, the habitat score included one additional variable not utilized during our habitat assessment protocol. Percent fines (Fines%) has been demonstrated to have significant impacts on the quality of stream habitat (Waters, 1995). To attain the habitat score, the original habitat score was first divided by the average habitat score of the reference sites from the same ecoregion to determine the percent of reference score. To calculate the modified habitat score, we multiplied the percent reference score by 11 to weight it for the 11 components then added the additional habitat component (Fines%) and divided by 12 (11 original components + 1 new component).

The Fines% component was added to the assessment because excessive fine sediment is considered the top nonpoint source pollutant in stream ecosystems (Waters, 1995). The distribution of substrate composition samples attributed to the silt and unconsolidated clay category were compared to that of reference sites using a binomial test. The binomial test was conducted as described for water-quality parameters above, where a success rate ≥ 0.75 scored a 1 and a success rate < 0.75 and ≥ 0.5 scored 0.5. A success rate < 0.5 scored a 0.

Like habitat, fish scores are also calculated as percent of reference condition as outlined in section 2.3.2. Therefore, habitat and fish scores greater than 100% are possible. Habitat and fish scores that exceeded 100% were reduced to 100% to maintain a 0 to 100% distribution for all parameters (i.e., water chemistry, habitat, and fish). When macroinvertebrate data are processed, they will be scored using the same protocol.

Overall site score was then calculated by averaging water chemistry, fish and habitat scores. Sites with scores ≥ 0.9 were assigned an 'A', sites < 0.9 and ≥ 0.8 were assigned a 'B'. Sites < 0.8 and ≥ 0.7 were assigned a 'C', sites <0.7 and ≥ 0.6 were assigned a 'D', and all other sites were assigned an F. When macroinvertebrate data are finalized, site scores will be adjusted to reflect an average of all four metrics.

2.4.2 Trends Analysis

To assess long-term trends in water-quality parameter values in streams that have been monitored for at least 3 cycles since 2000, we used generalized linear mixed models (GLMM) built with the R package "lme4" (R Statistical Software version 1.1-27; Bates, et al., 2021). Model output was used to identify improvement or decline in stream condition. We included a random slope for monitoring cycle and a random intercept for each site, so that the trend could be evaluated independently at each stream with consideration for natural variability within streams in the monitored population. We further controlled variability associated with season and flow within sites by including two variables for month (i.e., using sine and cosine variables to accommodate the cyclical nature of month) and stream stage (e.g., low flow, base flow, elevated flow) respectively. We then evaluated the estimated random-slope coefficient of each site and determined coefficients that were 2 SE > 0 to be increasing, those with coefficient 2 SE < 0 deceasing, and all others stable. Decreasing nutrients, salts and turbidities were considered improving, whereas increases in those parameters was considered a degrading condition. Conversely, decreasing pH and DO% saturation was considered degrading.

Additionally, we assessed the long-term trends in the fish IBI scores for sites that have been assessed in at least 3 monitoring cycles. As with chemistry parameters, we used a GLMM to estimate a random intercept and slope for each site. Previous research has indicated that fish score may be heavily influenced by the cumulative rainfall from the year leading up to the sampling event. For that reason, we included recent annual precipitation (within 1 year prior to sampling event) at the HUC 8 level of each site as a covariate to correct for the influence of weather. Recent annual precipitation was estimated for each HUC

8 from the central most Mesonet (mesonet.org) station within the watershed when available. When a HUC 8 did not contain a Mesonet station we used the average of adjacent stations.

2.4.3 Watershed Assessment

To investigate potential sources of NPS pollution for streams showing beneficial use impairment, relevant data layers were explored using ArcMap 10.1 Geographic Information System (GIS) software. Data explored included the 2019 USGS National Land Cover Dataset (NLCD), oil and gas wells, confined animal feeding operations, national pollution discharge elimination system permit holders, total retention sites, biosolid land application sites and other data layers. The NLCD was explored to determine percent occurrence of particular land-use types such as bare rock/sand/clay, vegetation (separated into several categories, both natural and agricultural), open water, and residential/commercial/industrial uses (divided into several categories). Change in land-use was calculated between NLCD 2016 (end of the third rotation) and NLCD 2019 (end of the fourth rotation) for each watershed to inform a qualitative assessment of potential land-use impacts on stream trends. Change in permitted land-use from 2016 to 2019 was calculated and qualitatively reviewed to evaluate potential impacts to water chemistry warranting further evaluation. To examine the effects of point source versus non-point source pollution on the parameters at the monitoring sites, one-way ANOVAs were performed comparing sites with the permitted discharge to sites with no permitted discharge.

2.4.4 Beneficial Use Determination

Each fixed site's assigned beneficial uses were evaluated following the protocols outlined in the state's *Continuing Planning Process, Integrated Water Quality Report Listing Methodology* (Oklahoma Department of Environmental Quality, 2012) and per *Oklahoma Administrative Code 785, Chapter 46: Implementation of Oklahoma's Water Quality Standards, Subchapter 15: Use Support Assessment Protocols* (OWRB 2016). Streams were considered non-supporting when Oklahoma Water Quality Standards were violated as determined by criteria and rules listed in these documents. Parameters not addressed in OAC 785:46-15 were assessed using applicable state and federal rules and regulations to determine support status. Assessment results were submitted to the ODEQ for final assimilation in the state's 2022 Integrated Report submitted to EPA Region VI.

3.0 RESULTS

All chemical and physical water quality data collected for the project are included in Appendix A.1; Appendix A.2 contains bacteria data. Descriptive statistics for water quality parameters are presented by site in Appendix A.3. Fish data are presented in Appendix B. Macroinvertebrate data are usually presented in Appendix C. An appendix of Basin 4 rotation 4 macroinvertebrate data will be included in the Basin 5.4 rotating basin report.

Table 6 displays the geometric mean of *E. coli* bacteria samples for each site over the two-year monitoring period. Beaver Creek (Custer), Delaware Creek, Elk Creek, Rainy Mountain Creek, Sandy Creek, Sugar Creek, and Suttle Creek are highlighted in yellow and are designated Secondary Body Contact Recreation (SBRC), which allows for a higher bacteria concentration. All other sites are designated Primary Body Contract Recreation (PBCR). Buckhorn Creek, Cavalry Creek, Chigley Sandy Creek, Criner Creek, and Peavine Creek do not meet the *E. coli* standard. To be listed on the state's 303(d) list, the geometric mean must exceed the set criteria for at least one of the bacteria types (OWRB 2016).

3.1 SITE SCORES

3.1.1 Water Chemistry Scores and Trends

Water quality was assessed at 67 sites across 5 ecoregions. Approximately two-thirds of the sites monitored were in the Central Great Plains (43). The Cross Timbers ecoregion had the second greatest number of sites (16) and generally the poorest water quality. The Arbuckle (5), Southwest Tableland (2), and Wichita (1) ecoregions collectively represented fewer sites than either of the other ecoregions.

Water chemistry scores in the entire Basin ranged from 0.31 (Sugar Creek) to 1.0 at nine creeks (Table 7). Average water chemistry scores were generally the highest in the Wichita Mountains (1; only 1 site), Arbuckles (0.79) and Central Great Plains (0.79) and lowest in the Cross Timbers (0.63) and Southwest Tablelands (0.68; only 2 sites). Overall sulfate (0.63), orthophosphorous (0.67), chloride (0.67) and pH (0.7) deviated most from reference condition basin-wide.

Basin-wide there were 36 streams with 3 cycles of monitoring data, for which trends could be calculated. In general, TN saw the greatest decline (26 declining and 3 improving) followed by DO.sat (25 declining and 12 improving) and sulfate (17 declining and 2 improving). Contrarily, pH saw the greatest improvement (22 improving and 0 declining) followed by orthophosphorous (24 improving and 9 declining) and turbidity (19 improving and 8 declining).

With the exception of the one high quality site in the Wichita Mountains, average water chemistry scores were generally highest in the Arbuckle and Central Great Plains ecoregions. In the Arbuckles, pH and sulfate were the most likely to deviate from reference conditions, with average water chemistry scores of 0.2 and 0.6 respectively. Overall trends in the Arbuckles indicated stable conditions, with a few notable patterns. Three of the streams with degraded pH conditions (Caddo, Oil and Pennington) have improving trends. Orthophosphorous improved at all four sites with sufficient data. Caddo Creek with the poorest water chemistry and lowest overall site score, improved for six of the water chemistry parameters.

Overall water chemistry in the Central Great Plains was relatively good. Though, there were few consistent ecoregion wide trends in which specific water chemistry parameters drove poorer overall chemistry scores. Chloride, TN and Turbidity were the most likely variables to reduce overall water chemistry score with average scores of approximately 0.7 for all three parameters. Contrarily, Ammonia, pH and DO were generally most similar to reference conditions. In the CGP 23 sites had sufficient data to analyze water chemistry trends. Similar to the basin-wide trends, in the CGP, TN saw the greatest decline (20 declining and 1 improving), followed by DO.sat (16 declining and 7 improving), and sulfate (13 declining and 1 improving). Orthophosphorous (15 improving and 5 declining), pH (13 improving and 0 declining) and turbidity (11 improving and 3 declining) were most likely to improve. Six streams (Beaver (Custer), Buffalo, Tepee, Timber, Trail, and West Barnitz) indicated overall decline in water chemistry and warrant further investigation, while the remainder of sites generally showed improvement in some parameters and declines in others.

Overall water quality at the 16 creeks monitored in the Cross Timbers was poorest. Streams in CT commonly received suboptimal scores for SO_4 (average score = 0.28), PO_4 (average score = 0.34), and pH (average score = 0.34), but typically received good scores for NH_3 (average score = 1), TN (average score = 0.94) and turbidity (average score = 0.91). Of the eight sites with sufficient data to evaluate trends most were relatively stable overall. However, Chigley Sandy exhibited improvement, while Hickory Creek declined for six parameters. Sugar Creek, the lowest scoring site (0.31) in the Basin did show an improving trend for four parameters. Trends for specific parameters in the Cross Timbers followed trends in the entire basin and in the CGP with TN, sulfate, and DO.sat generally declining, and pH and Turbidity generally improving.

Table 6. Geometric mean of bacteria values for Basin 4 (Washita River and Upper Red River Basins) monitoring sites, 2019-2021. An asterisk (*) indicates that the stream does not meet state standards for E. coli. Those highlighted in yellow have secondary body contact recreation (SBCR) designation, allowing for higher bacteria concentrations.

Site Name	WBID	E. coli	
Beaver Creek (Custer)	OK310830-03-0190C	35.84	
Beaver Creek (Cotton)	OK311210-00-0010D	43.35	
Big Sandy Creek	OK310800-01-0090G	33.54	
Bitter Creek	OK310820-01-0030D	21.68	
Boggy Creek	OK310830-03-0100C	68.14	
Buckhorn Creek	OK310800-02-0220C	143.20	*
Buffalo Creek	OK311510-02-0090D	65.31	
Caddo Creek	OK310800-03-0010F	31.82	
Cavalry Creek	OK310830-03-0070D	129.91	*
Chigley Sandy Creek	OK310800-02-0190D	238.15	*
Cobb Creek	OK310830-06-0050K	99.20	
Criner Creek	OK310810-02-0050D	198.11	*
Deep Red Creek	OK311310-03-0010D	24.04	
Delaware Creek	OK310830-01-0030G	19.54	
East Barnitz Creek	OK310830-03-0210C	45.06	
East Cache Creek	OK311300-03-0010M	13.32	
Elk Creek	OK311500-03-0030C	58.74	
Finn Creek	OK310810-02-0020D	124.09	
Fish Creek	OK311800-00-0130G	16.29	
Glasses Creek	OK310800-01-0020M	15.71	
Guy Sandy Creek	OK310800-02-0130D	98.54	
Gypsum Creek	OK311600-01-0020F	42.21	
Haystack Creek	OK311800-00-0040D	31.27	
Hickory Creek	OK311100-02-0010M	7.05	
Lake Creek (Caddo)	OK310830-06-0040J	81.78	
Lake Creek (Greer)	OK311510-01-0040D	92.95	
Little Beaver Creek	OK311210-00-0050D	31.00	
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	35.07	
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	32.29	
Little Deep Red Creek	OK311310-03-0040E	20.96	
Little Elk Creek (Washita)	OK311500-03-0050A	116.23	
Little Elk Creek (Kiowa)	OK311500-03-0040E	68.56	
Little Hauani Creek	OK311100-01-0120B	50.73	
Little Washita River	OK310820-02-0010A	34.15	

Site Name	WBID	E. coli	
Medicine Creek	OK311300-04-0060H	17.83	
North Elm Creek	OK311800-00-0170G	5.30	
North Mud Creek	OK311100-04-0030C	29.43	
Oil Creek	OK310800-01-0240P	26.63	
Otter Creek	OK311500-01-0080F	29.57	
Peavine Creek	OK310810-01-0120M	142.68	*
Pennington Creek	OK310800-01-0120G	22.25	
Quartermaster Creek	OK310840-01-0060B	80.88	
Rainy Mountain Creek	OK310830-02-0060G	48.16	
Red Creek	OK311100-01-0290D	27.50	
Roaring Creek	OK310810-02-0170B	47.22	
Rock Creek	OK310800-02-0122L	80.10	
Rush Creek (Garvin)	OK310810-01-0090H	102.63	
Rush Creek (Roger Mills)	OK310840-02-0210H	19.58	
Salt Creek	OK310810-03-0080G	110.19	
Sandstone Creek	OK310840-02-0020C	28.91	
Sandy Creek	OK311600-01-0040G	50.85	
Station Creek	OK311800-00-0060G	49.95	
Stinking Creek (Caddo)	OK310830-04-0030K	55.66	
Stinking Creek (Kiowa)	OK310830-02-0020F	27.00	
Sugar Creek	OK310830-05-0010D	13.68	
Suttle Creek	OK311310-01-0070H	131.70	
Tepee Creek	OK311500-01-0110D	88.12	
Timber Creek	OK311510-01-0090G	36.18	
Tonkawa Creek	OK310830-01-0050B	83.82	
Trail Creek	OK311500-03-0070D	37.44	
Turkey Creek	OK311600-02-0060M	48.23	
Walnut Bayou	OK311100-03-0010G	20.39	
West Barnitz Creek	OK310830-03-0230C	37.71	
West Cache Creek	OK311310-02-0010M	7.64	
Wildhorse Creek: near Davis	OK310810-01-0020G	35.47	
Wildhorse Creek: near Tatums	OK310810-03-0010R	52.69	
Winter Creek	OK310810-02-0220G	14.54	

Table 7. Score for each site for each water quality parameter. A score of 1 indicated that 75% of measurements of the parameter were within the 75th percentile of the parameter values for high-quality reference sites within the same ecoregion. A score of 0.5 indicated that less than 75% but at least 50% of measurements were below the 75th percentile of reference, and a score of 0 was given when more than half of the measurements were outside the 75th percentile of reference. The score column in the far right is the average of the water quality scores. A score of 1 indicates that a site was identical to reference conditions.

Site Name	WBID	Modified Ecoregion	PO_4	TN	NH_3	Cl	SO_4	pH	DO%	Turbidity	Score
Big Sandy Creek	OK310800-01-0090G	Arbuckle	0.5	1	1	1	0.5	0.5	1	1	**0.81**
Buckhorn Creek	OK310800-02-0220C	Arbuckle	1	1	1	1	1	0	1	1	**0.88**
Caddo Creek	OK310800-03-0010F	Arbuckle	0	0.5	1	1	0	0	1	1	**0.56**
Oil Creek	OK310800-01-0240P	Arbuckle	1	1	1	1	0.5	0.5	1	1	**0.88**
Pennington Creek	OK310800-01-0120G	Arbuckle	1	1	1	1	1	0	0.5	1	**0.81**
Beaver Creek (Custer)	OK310830-03-0190C	CGP	0.5	1	1	1	0	1	1	1	**0.81**
Beaver Creek (Cotton)	OK311210-00-0010D	CGP	0.5	1	1	1	1	1	0.5	0.5	**0.81**
Bitter Creek	OK310820-01-0030D	CGP	1	1	1	1	1	1	1	1	**1**
Boggy Creek	OK310830-03-0100C	CGP	1	0	1	1	1	1	1	0.5	**0.81**
Buffalo Creek	OK311510-02-0090D	CGP	1	1	1	0	1	1	1	1	**0.88**
Cavalry Creek	OK310830-03-0070D	CGP	1	0	1	1	0	1	1	1	**0.75**
Cobb Creek	OK310830-06-0050K	CGP	0	0	1	1	1	1	1	1	**0.75**
Criner Creek	OK310810-02-0050D	CGP	0.5	1	1	1	1	1	1	1	**0.94**
Deep Red Creek	OK311310-03-0010D	CGP	1	1	1	0	1	1	0.5	0	**0.69**
East Barnitz Creek	OK310830-03-0210C	CGP	1	1	1	1	0	1	1	1	**0.88**
East Cache Creek	OK311300-03-0010M	CGP	1	1	1	1	1	1	1	1	**1**
Elk Creek	OK311500-03-0030C	CGP	1	0	0.5	1	1	1	1	0.5	**0.75**
Finn Creek	OK310810-02-0020D	CGP	0	1	1	1	1	1	1	1	**0.88**
Gypsum Creek	OK311600-01-0020F	CGP	1	0	1	0	0	1	0.5	1	**0.56**
Haystack Creek	OK311800-00-0040D	CGP	1	0	1	0	0.5	0.5	0.5	0	**0.44**
Lake Creek (Caddo)	OK310830-06-0040J	CGP	0	1	1	1	1	1	1	0.5	**0.81**
Lake Creek (Greer)	OK311510-01-0040D	CGP	1	0	0.5	1	1	0	0	1	**0.56**
Little Beaver Creek	OK311210-00-0050D	CGP	1	1	1	1	1	0.5	1	0.5	**0.88**
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	CGP	1	1	1	1	1	1	1	1	**1**
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	CGP	1	1	1	1	1	1	1	1	**1**
Little Deep Red Creek	OK311310-03-0040E	CGP	0.5	1	1	0	1	1	0.5	0	**0.63**
Little Elk Creek (Washita)	OK311500-03-0050A	CGP	1	0.5	0.5	1	1	1	1	1	**0.88**
Little Elk Creek (Hobart)	OK311500-03-0040E	CGP	1	0	0.5	1	1	1	1	0.5	**0.75**
Little Washita River	OK310820-02-0010A	CGP	0.5	1	1	1	1	1	1	1	**0.94**
North Mud Creek	OK311100-04-0030C	CGP	1	1	1	0.5	1	1	1	0	**0.81**

Site Name	WBID	Modified Ecoregion	PO_4	TN	NH_3	Cl	SO_4	pH	DO%	Turbidity	Score
Otter Creek	OK311500-01-0080F	CGP	0	0.5	1	0	1	1	0	0.5	**0.5**
Quartermaster Creek	OK310840-01-0060B	CGP	0.5	1	0.5	1	0	1	1	0.5	**0.69**
Rainy Mountain Creek	OK310830-02-0060G	CGP	0.5	1	1	0	1	1	1	1	**0.81**
Red Creek	OK311100-01-0290D	CGP	0.5	1	1	1	1	0.5	0	0	**0.63**
Rush Creek (Garvin)	OK310810-01-0090H	CGP	1	1	1	1	1	1	1	0	**0.88**
Rush Creek (Roger Mills)	OK310840-02-0210H	CGP	0	1	1	1	1	0.5	1	1	**0.81**
Sandstone Creek	OK310840-02-0020C	CGP	1	1	1	1	1	1	1	1	**1**
Sandy Creek	OK311600-01-0040G	CGP	1	0	1	0	0	1	0.5	1	**0.56**
Station Creek	OK311800-00-0060G	CGP	1	0.5	0.5	0	0	0.5	1	1	**0.56**
Stinking Creek (Kiowa)	OK310830-02-0020F	CGP	0.5	1	1	1	1	1	0.5	1	**0.88**
Suttle Creek	OK311310-01-0070H	CGP	1	1	1	0	1	1	0.5	0.5	**0.75**
Tepee Creek	OK311500-01-0110D	CGP	0.5	1	1	0	1	0	0.5	1	**0.63**
Timber Creek	OK311510-01-0090G	CGP	1	1	1	1	1	0.5	1	1	**0.94**
Trail Creek	OK311500-03-0070D	CGP	1	0	0	1	1	1	1	1	**0.75**
Turkey Creek	OK311600-02-0060M	CGP	1	0	1	0	0	0.5	1	0	**0.44**
West Barnitz Creek	OK310830-03-0230C	CGP	1	1	1	1	0	1	1	0.5	**0.81**
West Cache Creek	OK311310-02-0010M	CGP	1	1	1	1	1	1	1	1	**1**
Winter Creek	OK310810-02-0220G	CGP	1	1	1	1	1	1	1	1	**1**
Chigley Sandy Creek	OK310800-02-0190D	CT	0	1	1	1	1	0.5	1	1	**0.81**
Delaware Creek	OK310830-01-0030G	CT	0	1	1	0	0	1	0.5	1	**0.56**
Glasses Creek	OK310800-01-0020M	CT	0	1	1	1	0.5	0.5	0.5	1	**0.69**
Guy Sandy Creek	OK310800-02-0130D	CT	0	1	1	1	1	0.5	1	1	**0.81**
Hickory Creek	OK311100-02-0010M	CT	1	1	1	0	0	0	0.5	1	**0.56**
Little Hauani Creek	OK311100-01-0120B	CT	0.5	1	1	1	0	0	1	1	**0.69**
Peavine Creek	OK310810-01-0120M	CT	0	1	1	1	1	0.5	1	0.5	**0.75**
Roaring Creek	OK310810-02-0170B	CT	0	1	1	1	0	0	0.5	1	**0.56**
Rock Creek	OK310800-02-0122L	CT	1	1	1	1	1	1	1	1	**1**
Salt Creek	OK310810-03-0080G	CT	1	1	1	0	0	0	0.5	1	**0.56**
Stinking Creek (Caddo)	OK310830-04-0030K	CT	0	1	1	1	0	1	0.5	1	**0.69**
Sugar Creek	OK310830-05-0010D	CT	0	0	1	0	0	0	0.5	1	**0.31**
Tonkawa Creek	OK310830-01-0050B	CT	0	1	1	0.5	0	0.5	0.5	1	**0.56**
Walnut Bayou	OK311100-03-0010G	CT	0	1	1	0	0	0	1	0.5	**0.44**
Wildhorse Creek: near Davis	OK310810-01-0020G	CT	1	1	1	0	0	0	0.5	0.5	**0.5**
Wildhorse Creek: near Tatums	OK310810-03-0010R	CT	1	1	1	0	0	0	0.5	1	**0.56**
Fish Creek	OK311800-00-0130G	SWT	1	1	1	0	0	1	1	0	**0.62**

Site Name	WBID	Modified Ecoregion	PO_4	TN	NH_3	Cl	SO_4	pH	DO%	Turbidity	Score
North Elm Creek	OK311800-00-0170G	SWT	1	1	1	0	0	1	1	1	**0.75**
Medicine Creek	OK311300-04-0060H	Wichita	1	1	1	1	1	1	1	1	**1**

Table 8. Directional trend for sites that have been monitored for 3 or more cycles since the beginning of the Rotating Basin Monitoring Program. For nutrient (PO_4, TN, NH_3), salt (Cl, SO_4) and turbidity parameter; a score of 1 was given when a significant decreasing slope was detected indicating an 'improving' trend, whereas a score of -1 was assigned to significantly increasing slopes indicating a 'degrading' condition. For DO.sat and pH increasing values were considered improving and decreasing values were considered declining. The final column provides a ratio in improving to degrading parameters at a given site.

Site Name	WBID	Modified Ecoregion	PO_4	TN	NH_3	Cl	SO_4	pH	DO.Sat	Turb	I to D ratio
Big Sandy Creek	OK310800-01-0090G	Arbuckle	1	0	0	-1	-1	0	1	-1	2:3
Caddo Creek	OK310800-03-0010F	Arbuckle	1	0	1	1	1	1	-1	1	6:1
Oil Creek	OK310800-01-0240P	Arbuckle	1	-1	-1	0	0	1	1	0	3:2
Pennington Creek	OK310800-01-0120G	Arbuckle	1	0	-1	0	0	1	-1	-1	2:3
Cavalry Creek	OK310830-03-0070D	CGP	1	-1	1	-1	-1	1	1	1	5:3
Lake Creek (Greer)	OK311510-01-0040D	CGP	1	-1	0	1	1	1	-1	1	5:2
Sandy Creek	OK311600-01-0040G	CGP	1	-1	1	1	-1	1	-1	1	5:3
West Cache Creek	OK311310-02-0010M	CGP	1	1	1	-1	-1	1	-1	1	5:3
Little Beaver Creek	OK311210-00-0050D	CGP	1	-1	1	-1	-1	1	-1	1	4:4
Suttle Creek	OK311310-01-0070H	CGP	1	-1	-1	-1	-1	1	1	1	4:4
Deep Red Creek	OK311310-03-0010D	CGP	1	-1	1	-1	-1	1	-1	0	3:4
East Barnitz Creek	OK310830-03-0210C	CGP	1	-1	1	0	0	1	-1	0	3:2
Finn Creek	OK310810-02-0020D	CGP	1	-1	0	-1	-1	1	-1	1	3:4
Gypsum Creek	OK311600-01-0020F	CGP	1	-1	1	0	-1	0	-1	1	3:3
Rainy Mountain Creek	OK310830-02-0060G	CGP	1	-1	-1	-1	-1	1	-1	1	3:5
Sandstone Creek	OK310840-02-0020C	CGP	1	-1	-1	0	0	1	-1	1	3:3
Boggy Creek	OK310830-03-0100C	CGP	1	-1	-1	-1	-1	0	1	0	2:4
Haystack Creek	OK311800-00-0040D	CGP	1	-1	1	-1	0	0	-1	0	2:3
Otter Creek	OK311500-01-0080F	CGP	0	-1	0	-1	-1	1	-1	1	2:4
Red Creek	OK311100-01-0290D	CGP	-1	-1	-1	1	0	0	1	-1	2:4
Station Creek	OK311800-00-0060G	CGP	1	0	-1	0	0	0	1	0	2:1
Tepee Creek	OK311500-01-0110D	CGP	-1	-1	-1	0	0	1	-1	-1	1:5
Trail Creek	OK311500-03-0070D	CGP	0	-1	-1	0	-1	0	1	0	1:3
West Barnitz Creek	OK310830-03-0230C	CGP	-1	-1	-1	0	0	0	1	-1	1:4

Site Name	WBID	Modified Ecoregion	PO_4	TN	NH_3	Cl	SO_4	pH	DO.Sat	Turb	I to D ratio
Beaver Creek (Custer)	OK310830-03-0190C	CGP	-1	-1	-1	0	0	0	-1	0	0:4
Buffalo Creek	OK311510-02-0090D	CGP	0	0	-1	-1	0	0	-1	0	0:3
Timber Creek	OK311510-01-0090G	CGP	-1	-1	0	0	-1	0	-1	0	0:4
Chigley Sandy Creek	OK310800-02-0190D	CT	0	1	0	0	0	1	1	1	4:0
Delaware Creek	OK310830-01-0030G	CT	-1	-1	-1	-1	0	0	1	1	2:4
Hickory Creek	OK311100-02-0010M	CT	-1	-1	-1	-1	0	0	-1	-1	0:6
Salt Creek	OK310810-03-0080G	CT	1	0	1	-1	0	1	-1	1	4:2
Sugar Creek	OK310830-05-0010D	CT	0	-1	1	1	0	1	-1	1	4:2
Walnut Bayou	OK311100-03-0010G	CT	-1	-1	-1	0	-1	0	1	-1	1:5
Wildhorse Creek: near Davis	OK310810-01-0020G	CT	1	0	1	0	-1	0	-1	0	2:2
Wildhorse Creek: near Tatums	OK310810-03-0010R	CT	1	0	1	-1	-1	1	-1	1	4:3
Fish Creek	OK311800-00-0130G	SWT	-1	-1	1	-1	0	0	0	-1	1:4
North Elm Creek	OK311800-00-0170G	SWT	1	0	1	0	0	1	-1	1	4:1
Medicine Creek	OK311300-04-0060H	Wichita	1	1	-1	0	0	1	-1	1	4:2

3.1.2 Habitat Scores

The Arbuckle Ecoregion had the highest scoring reference sites and, as a result, the most stringent reference criteria (106.5 mean total points) of the ecoregions in Basin 4. Habitat scores in Arbuckle ranged from 62% to 97%, with Glasses and Buckhorn creeks scoring > 90% of reference condition. Caddo Creek scored the lowest and suffered from issues due to excessive fine sedimentation. Compared to the other ecoregions, streams in Arbuckle tended to benefit from more rocky habitats, stable vegetated banks, less fine sedimentation, and better instream flow and cover metrics. Arbuckle streams scored the worst for channel sinuosity, but this may be due to the ecoregion having rocky geology and steeper gradients than the other ecoregions.

With a mean reference habitat score of only 77.6 total points, the Central Great Plains had the lowest habitat criteria. Out of the 43 streams monitored, 36 of the sites scored $\geq$ 90% of reference or better. However, when habitat scores were adjusted to include Fines% only 26 sites received a score of 90% or better, indicating fine sediment may be an ecoregion scale impediment to high quality instream habitat; Fifty percent of CGP sites scored a 0 for Fines%. Only four creeks scored less than 80% (49% to 76%). Interestingly, the middle of the three Little Beaver Creek sites was the worst stream in CGP, whereas the upper-most Little Beaver Creek site was better than reference condition and the lower-most Little Beaver Creek site score was of moderate quality (86%). The middle Little Beaver Creek site suffered from bank instability that allowed excessive fine sediment into the stream creating a homogenous, shallow, sandy stream bed in contrast to the other two sites that benefited from rocky riprap, woody debris and, at the lower site, fine gravel riffles. Overall, streams in the CGP suffered from a lack of rocky habitats and bank stability, as well as increased fines sediments. CGP streams had better than average riparian condition, sinuosity, canopy shading and pool variability.

The mean habitat score for reference sites in the Cross Timbers was 84 points. Scores were evenly distributed across the 16 CT sites with the majority (56%) scoring between 70 – 90%. Streams in the CT ecoregion scored the worst for components related to fine sediment, including pool bottom variability, pool bottom substrate, and presence of rocky habitat, but were above average for flow, channel alterations and bank stability.

3.1.3 Fish Scores and trends

Overall, fish communities in six streams are improving and the remainder of streams with sufficient historic data (33) are stable. Indicating that even in streams where water chemistry has been declining, it has not led to a significant decline in fish communities to date.

All 7 streams in the Arbuckle and Southwest Tablelands Ecoregion had excellent fish communities. Three of the 5 streams in the Arbuckle, and both streams in the Southwest Tablelands had sufficient data to analyze trends. Four of the five sites were determined to be stable, and North Elm Creek's fish community is improving. Medicine Creek was the only stream in the Wichita ecoregion, and it was determined to have a good fish assemblage that has been stable over time.

Of stream fish communities in the Central Great Plains (CGP) 63% were excellent, 9% were good, 19% were fair and 2 streams were poor. Gypsum Creek was ranked as very poor, but it is the only stream from CGP that is exhibiting long-term improvements in the fish community. All other CGP streams were stable. In the Cross Timbers, 38% of fish communities were excellent, 19% were good, 13% fair, 25% poor and 6% very poor. Of the CT streams assessed for long-term trends, 4 were determined to be improving over time. One of the improving streams was categorized as very poor, and the other three were classified as poor. All other streams were determined to be stable.

3.1.4 Bug Scores

Macroinvertebrates were collected from each site according to SOPs (OCC 2021), but most samples have yet to be identified. The assessment will be completed once all samples are identified and counted and should be available in the 2024 Integrated Report. An update to the site scores calculated for Basin 4 cycle 4 streams included in this report, will be completed, and included as an addendum to the Basin 5 cycle 4 report completed next year.

Table 9. Habitat scores for Basin 4 (Washita River and Upper Red River Basins) sites. The score for each habitat component is listed and the 'Total Points' and 'Original Score' columns refer to the original habitat scoring metrics based on the 11 original components and subsequent comparison to ecoregion reference. The Fines% score is listed, and the 'Final Score' indicates the weighted average of all 12 habitat components.

Site Name	WBID	Modified Ecoregion	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover Shading	Rocky Runs or Riffles	Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetation Stability	Streamside Cover	Total Points	Original Score	Fines%	Final Score
Big Sandy Creek	OK310800-01-0090G	Arbuckle	3.3	5.8	0	13.6	4.1	11.7	0.4	0.6	9.6	8.4	9.9	67	63%	1	66%
Buckhorn Creek	OK310800-02-0220C	Arbuckle	15.2	11.8	13.3	19.8	16.1	0	4.2	1.5	7.2	5.1	9.3	104	97%	1	97%
Caddo Creek	OK310800-03-0010F	Arbuckle	4.4	4.3	14.6	4.6	2.2	20	0.4	0.8	7	5.2	9.1	73	68%	0	62%
Glasses Creek	OK310800-01-0020M	Arbuckle	9.9	8.6	17.2	14.2	10.3	15.1	0.4	1.3	8.1	6.2	9.6	101	95%	1	95%
Oil Creek	OK310800-01-0240P	Arbuckle	10.2	11.6	14.6	11.9	7.5	15.2	1.4	1.8	8.7	6.6	9.9	99	93%	1	94%
Pennington Creek	OK310800-01-0120G	Arbuckle	5.3	5	14.6	14	7.5	20	1	0.2	9.5	6.4	6.6	90	85%	1	86%
East Cache Creek	OK311300-03-0010M	CGP	14.9	6.8	20.2	18.7	5.9	10.6	8.7	2.3	9.2	7.3	9.9	115	148%	1	100%
Rush Creek (Roger Mills)	OK310840-02-0210H	CGP	16.7	3	19.2	18.8	0	16.6	5.8	1.5	10	8	4.8	104	135%	0	100%
Finn Creek	OK310810-02-0020D	CGP	3.1	3.9	17.2	18.1	4.1	15.8	3.5	0.7	6.7	4.8	9.7	88	113%	1	100%
Sandstone Creek	OK310840-02-0020C	CGP	7.9	0.8	17.2	19.9	0	17.1	1	1.2	7.2	7.3	10	90	115%	0.5	100%
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	CGP	4.1	8.1	14.6	6.9	2.2	19.8	12.3	0.9	6.6	4.3	9.1	89	115%	1	100%
Rainy Mountain Creek	OK310830-02-0060G	CGP	11.7	3.5	17.2	19.5	2.2	10.1	0.5	8.2	5.1	4.3	9.5	92	118%	0	100%

Site Name	WBID	Modified Ecoregion	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover Shading	Rocky Runs or Riffles	Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetation Stability	Streamside Cover	Total Points	Original Score	Fines%	Final Score
Haystack Creek	OK311800-00-0040D	CGP	8.8	3.8	17.2	17.4	2.2	9	3.5	3.8	6.2	5.7	10	88	113%	0.5	100%
Winter Creek	OK310810-02-0220G	CGP	10.6	2.7	19.3	8.9	4.1	18.3	0.4	1.4	6.3	5.2	9.5	87	112%	1	100%
Beaver Creek (Cotton)	OK311210-00-0010D	CGP	6.3	3.4	14.6	13.7	0	20	2.8	3	7.4	4.9	9.6	86	110%	0.5	100%
West Barnitz Creek	OK310830-03-0230C	CGP	5.7	0.4	0	19	0	20	16.5	5.4	7.3	3.4	10	88	113%	0.5	100%
Lake Creek (Caddo)	OK310830-06-0040J	CGP	6.8	0.4	17.2	16.8	0	12.1	0.4	0.2	8.8	8.2	9.67	81	104%	0.5	99%
Tepee Creek	OK311500-01-0110D	CGP	6.9	0.7	13	17.9	0	16.3	0.5	2.6	5.4	3.8	9.7	77	99%	1	99%
Otter Creek	OK311500-01-0080F	CGP	9.5	1.2	18.1	18.4	0	10.2	0.4	2.4	7.4	6.3	9.4	83	107%	0	98%
Cavalry Creek	OK310830-03-0070D	CGP	6.7	0.6	19.5	17.5	0	15.2	0.4	3.4	7.4	7	9	87	112%	0	100%
Stinking Creek (Kiowa)	OK310830-02-0020F	CGP	8.3	0.4	14.6	18	2.2	5.4	7.7	1.5	7	7.4	9.87	82	106%	0	97%
Station Creek	OK311800-00-0060G	CGP	16.8	6.3	16.1	17.6	4.1	0.6	0.7	4.5	5.3	6	4	82	106%	0	97%
Lake Creek (Greer)	OK311510-01-0040D	CGP	9.7	1.4	20.2	19.6	2.2	2.5	0.5	2.5	6.8	5.3	9.9	81	104%	0.5	99%
Bitter Creek	OK310820-01-0030D	CGP	3.4	1.3	14.6	5.8	2.2	20	2.3	1.4	8.3	7.4	9.9	77	99%	1	99%
Cobb Creek	OK310830-06-0050K	CGP	7.2	0.9	0	19.3	0	17.8	0.4	1.8	8.6	8.2	9.4	74	95%	1	95%
Suttle Creek	OK311310-01-0070H	CGP	7.6	2.4	19.7	17.3	4.1	10.2	1	4	3.5	2.6	6.2	79	101%	0.5	97%
Turkey Creek	OK311600-02-0060M	CGP	11.2	2.9	17.2	11.7	0	16.6	0.7	0.5	5.6	5.9	2.7	75	97%	0	89%

Site Name	WBID	Modified Ecoregion	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover Shading	Rocky Runs or Riffles	Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetation Stability	Streamside Cover	Total Points	Original Score	Fines%	Final Score
Boggy Creek	OK310830-03-0100C	CGP	9.2	0.9	19.3	17.9	0	15.9	0.4	1.5	6.6	7.5	2.67	82	106%	0	97%
Trail Creek	OK311500-03-0070D	CGP	8.9	1	20.2	16.3	0	4	0.4	2.4	6.4	6.2	9.67	75	97%	0	89%
Red Creek	OK311100-01-0290D	CGP	9.2	2.7	18.8	15.6	0	0.1	2.3	4.5	8.9	7.5	9.2	79	102%	0	93%
Little Elk Creek (Washita)	OK311500-03-0050A	CGP	8	1.7	20.2	17.2	0	10.3	1.4	2.1	7.3	7.4	3.1	79	101%	0	93%
North Mud Creek	OK311100-04-0030C	CGP	8.7	1.9	3	19.9	2.2	5.2	0.4	6.8	6.4	6.8	9.5	71	91%	0	84%
East Barnitz Creek	OK310830-03-0210C	CGP	4.7	0.4	13.2	18.8	0	20	0.5	9.5	4	3.4	3.2	78	100%	0	92%
Quartermaster Creek	OK310840-01-0060B	CGP	5.8	0.6	14	19.9	0	14	0.7	3.1	5.9	3.7	9.6	77	100%	0	91%
Criner Creek	OK310810-02-0050D	CGP	2.3	1.4	14.6	16.3	0	16.4	5.8	1.4	5.4	3.8	9.1	77	99%	1	99%
Little Beaver Creek	OK311210-00-0050D	CGP	6.3	0.8	19.3	6	0	15.4	0.4	3.1	5.8	6.5	9.2	73	94%	0	86%
Buffalo Creek	OK311510-02-0090D	CGP	7.1	0.4	0	19.8	0	8.4	0.4	1.5	7.5	8.1	9	62	80%	1	82%
Deep Red Creek	OK311310-03-0010D	CGP	6.7	5.1	14.6	10.7	2.2	0	11.1	2.1	6.3	0.7	9.3	69	89%	1	90%
Elk Creek	OK311500-03-0030C	CGP	7.3	1.3	13.3	8.9	0	11.1	0.5	4	7.2	6.1	8.7	68	88%	0	81%
Little Washita River	OK310820-02-0010A	CGP	2.5	1.5	15	3.5	0	19.9	0.4	4.8	6.6	5.5	3.2	63	81%	1	83%
Little Deep Red Creek	OK311310-03-0040E	CGP	4	1	16.3	7.6	2.2	11.2	2.8	0.2	7.6	7	9.6	70	90%	0	82%
Beaver Creek (Custer)	OK310830-03-0190C	CGP	2.1	0.4	0	18.9	0	18.1	15.1	3.5	4.6	0.7	9.5	73	94%	0	86%

Site Name	WBID	Modified Ecoregion	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover Shading	Rocky Runs or Riffles	Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetation Stability	Streamside Cover	Total Points	Original Score	Fines%	Final Score
Little Elk Creek (Kiowa)	OK311500-03-0040E	CGP	11.1	1.7	6.1	20	4.1	2.8	0.5	4.4	5.3	6.3	9.67	72	93%	0	85%
Gypsum Creek	OK311600-01-0020F	CGP	8.6	0.4	0	17	0	15	0.4	2.7	9.3	8.7	9.6	72	92%	0	85%
West Cache Creek	OK311310-02-0010M	CGP	2.4	2.5	20	7.4	2.2	0	0.4	1	7.3	3.6	9.9	57	73%	0.5	71%
Timber Creek	OK311510-01-0090G	CGP	13.2	2.6	0	20	0	0.4	0.4	3.4	4.5	6.4	9.4	60	78%	0	71%
Rush Creek (Garvin)	OK310810-01-0090H	CGP	2.9	2.4	13	3.8	2.2	16.5	0.7	0.2	7	2.2	9.6	61	78%	0.5	76%
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	CGP	3.6	0.4	0	7.2	0	0	0.7	4.8	6.1	2.7	9.2	35	45%	1	49%
Rock Creek	OK310800-02-0122L	CT	10.3	7.2	16.1	19.4	5.9	13.8	16.5	0.6	8.4	6.6	9.6	114	136%	1	100%
Tonkawa Creek	OK310830-01-0050B	CT	18.9	0.4	0	13.8	0	15.5	16.5	2.3	9.9	8.6	9.7	96	114%	0.5	100%
Guy Sandy Creek	OK310800-02-0130D	CT	3.5	2.9	9.9	19.4	0	18	0.4	0.9	9.6	7.6	9.9	82	98%	1	98%
Walnut Bayou	OK311100-03-0010G	CT	8.4	1.2	20.2	13.4	0	15.1	0.4	1.8	7.1	7.5	9.5	85	101%	0	92%
Hickory Creek	OK311100-02-0010M	CT	3.4	3	10.8	8.8	0	20	0.4	0.5	9.8	7.4	9.7	74	88%	1	89%
Little Hauani Creek	OK311100-01-0120B	CT	6.6	1.7	0	20	0	8	0.4	5	8.4	8.4	9.9	68	81%	1	83%
Chigley Sandy Creek	OK310800-02-0190D	CT	4.6	1.4	0	19.9	0	20	0.4	0	7.3	5.4	9.9	69	82%	1	84%

Site Name	WBID	Modified Ecoregion	Instream Cover	Pool Bottom Substrate	Pool Variability	Canopy Cover Shading	Rocky Runs or Riffles	Flow	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetation Stability	Streamside Cover	Total Points	Original Score	Fines%	Final Score
Wildhorse Creek: near Tatums	OK310810-03-0010R	CT	3.4	0.4	0	3.6	4.1	20	15.1	0.5	7.6	3.4	10	68	81%	1	83%
Roaring Creek	OK310810-02-0170B	CT	3.1	2.5	13.2	6.2	0	20	0.7	1.5	5.9	4.5	8.9	67	79%	1	81%
Sugar Creek	OK310830-05-0010D	CT	5.3	0.4	0	13.8	0	15.6	1.8	1	9.5	7.2	9.7	64	77%	0.5	74%
Stinking Creek (Caddo)	OK310830-04-0030K	CT	3.9	0.4	13.3	5.3	0	20	12.3	1.1	8.9	4.6	5	75	89%	0	82%
Wildhorse Creek: near Davis	OK310810-01-0020G	CT	5.1	4.1	20.2	7.5	0	0	0.4	0.2	6.7	4.5	3.6	52	62%	1	65%
Delaware Creek	OK310830-01-0030G	CT	6.9	2.6	14.6	4.6	2.2	15.1	11.1	0.9	0.9	3.8	4.4	67	80%	0	73%
Peavine Creek	OK310810-01-0120M	CT	3.8	2.8	0	19.8	0	1.8	0.5	0.8	5.3	4.7	9.3	49	58%	1	62%
Salt Creek	OK310810-03-0080G	CT	5.8	2.9	14	4.2	4.1	0	7.7	0.7	6	3.9	10	59	71%	1	73%
Fish Creek	OK311800-00-0130G	SWT	14.1	2.8	15	6.8	4.1	3.8	0.5	1.8	8.8	7.2	3.4	68	83%	0.5	80%
North Elm Creek	OK311800-00-0170G	SWT	16.6	6.9	3	13.3	4.1	0.6	0.5	3.4	6.1	5.6	9.7	70	85%	0	78%
Medicine Creek	OK311300-04-0060H	Wichita	18.2	8.5	6.8	11.3	9	13.7	0.4	2.4	10	7.9	10	98	127%	1	100%

Table 10. Results from fish assemblage assessments in Basin 4 (Washita and Upper Red River Basins) Cycle 4. Site information includes the name of the site, waterbody ID, Ecoregion and the aquatic community type (FWP: WWAC = warm water, CWAC = cool water, and HLAC = habitat limited). FWP with an '*' were assessed as WWAC due to missing reference criteria. The metrics used to determine the OK Conservation Commission scores are provided along with the resulting score (IBI (OCC)), the percentage of the score compared to high-quality reference sites (Percent Reference) and the interpretation of that score (Interpretation (OCC)). Additionally, the USAP score, and its interpretation are provided (IBI (USAP), Interpretation (OCC)). Finally, a value for the long-term trend is provided for sites that have been monitored for at least 3 cycles. A trend of 0 indicated the fish assemblage was stable, 1 indicates improvement and -1 indicates degradation, while NA indicates that the stream was not assessed for trend.

Site Name	WBID	Modified Ecoregion	FWP	Total Individuals	Total Species	Sensitive Benthic	Sunfish Species	Intolerant Species	Percent Tolerant	Percent Insectivore	Percent Lithophilic	IBI (OCC)	Percent Reference	Interpretation (OCC)	IBI (USAP)	Interpretation (OCC)	Trend
Big Sandy Creek	OK310800-01-0090G	Arbuckle	WWAC	929	22	5	9	1	33%	23%	43%	27	100%	Excellent	35	Attaining	0
Buckhorn Creek	OK310800-02-0220C	Arbuckle	WWAC	977	11	3	5	1	31%	21%	69%	27	100%	Excellent	35	Attaining	NA
Caddo Creek	OK310800-03-0010F	Arbuckle	WWAC	922	21	6	5	2	61%	31%	7%	25	100%	Excellent	27	Attaining	0
Oil Creek	OK310800-01-0240P	Arbuckle	WWAC	1215	14	3	6	1	30%	36%	68%	27	100%	Excellent	33	Attaining	0
Pennington Creek	OK310800-01-0120G	Arbuckle	CWAC*	3156	40	7	10	4	22%	58%	16%	29	100%	Excellent	33	Attaining	NA
Beaver Creek (Custer)	OK310830-03-0190C	CGP	WWAC	328	10	1	3	1	100%	0%	0%	21	94%	Excellent	19	Undetermined	0
Beaver Creek (Cotton)	OK311210-00-0010D	CGP	WWAC	148	15	0	5	0	100%	0%	0%	15	67%	Fair	25	Attaining	NA
Bitter Creek	OK310820-01-0030D	CGP	WWAC	476	18	2	4	2	92%	7%	0%	23	100%	Excellent	23	Attaining	NA
Boggy Creek	OK310830-03-0100C	CGP	WWAC	968	8	2	1	2	100%	0%	0%	17	76%	Fair	17	Not Attaining	0
Buffalo Creek	OK311510-02-0090D	CGP	WWAC	730	7	1	0	1	48%	48%	0%	19	85%	Good	21	Undetermined	0
Cavalry Creek	OK310830-03-0070D	CGP	WWAC	503	7	2	0	1	96%	3%	0%	17	76%	Fair	17	Not Attaining	0
Cobb Creek	OK310830-06-0050K	CGP	WWAC	655	16	0	5	0	100%	0%	0%	15	67%	Fair	27	Attaining	NA
Criner Creek	OK310810-02-0050D	CGP	WWAC	839	15	3	4	2	89%	5%	4%	23	100%	Excellent	23	Attaining	NA
Deep Red Creek	OK311310-03-0010D	CGP	WWAC	652	26	2	7	1	87%	12%	0%	23	100%	Excellent	33	Attaining	0
East Barnitz Creek	OK310830-03-0210C	CGP	WWAC	72	7	0	3	0	100%	0%	0%	13	58%	Poor	15	Not Attaining	0
East Cache Creek	OK311300-03-0010M	CGP	WWAC	1045	20	3	6	0	52%	18%	27%	21	94%	Excellent	29	Attaining	NA
Elk Creek	OK311500-03-0030C	CGP	HLAC*	359	15	1	6	1	87%	3%	0%	21	94%	Excellent	27	Attaining	NA
Finn Creek	OK310810-02-0020D	CGP	WWAC	1034	19	4	5	2	87%	3%	1%	23	100%	Excellent	27	Attaining	0
Gypsum Creek	OK311600-01-0020F	CGP	WWAC	143	6	0	1	0	100%	1%	0%	9	40%	Very Poor	15	Not Attaining	1

Site Name	WBID	Modified Ecoregion	FWP	Total Individuals	Total Species	Sensitive Benthic	Sunfish Species	Intolerant Species	Percent Tolerant	Percent Insectivore	Percent Lithophilic	IBI (OCC)	Percent Reference	Interpretation (OCC)	IBI (USAP)	Interpretation (OCC)	Trend
Haystack Creek	OK311800-00-0040D	CGP	WWAC	837	14	1	3	1	83%	17%	0%	21	94%	Excellent	23	Attaining	0
Lake Creek (Caddo)	OK310830-06-0040J	CGP	WWAC	730	15	0	5	0	96%	4%	0%	15	67%	Fair	23	Attaining	NA
Lake Creek (Greer)	OK311510-01-0040D	CGP	WWAC	744	17	1	5	1	87%	10%	3%	21	94%	Excellent	29	Attaining	0
Little Beaver Creek	OK311210-00-0050D	CGP	WWAC	1028	18	1	6	1	93%	7%	0%	21	94%	Excellent	29	Attaining	0
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	CGP	WWAC	106	8	0	4	0	100%	0%	0%	13	58%	Poor	23	Attaining	NA
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	CGP	WWAC	372	10	1	5	1	99%	1%	0%	21	94%	Excellent	21	Undetermined	NA
Little Deep Red Creek	OK311310-03-0040E	CGP	WWAC	641	11	1	4	1	99%	1%	0%	21	94%	Excellent	21	Undetermined	NA
Little Elk Creek (Washita)	OK311500-03-0050A	CGP	WWAC	779	16	2	6	1	88%	10%	1%	23	100%	Excellent	27	Attaining	NA
Little Elk Creek (Kiowa)	OK311500-03-0040E	CGP	WWAC	1792	13	1	2	1	96%	4%	0%	19	85%	Good	21	Undetermined	NA
Little Washita River	OK310820-02-0010A	CGP	WWAC	746	17	3	4	2	92%	3%	0%	23	100%	Excellent	27	Attaining	NA
North Mud Creek	OK311100-04-0030C	CGP	HLAC*	772	18	2	4	1	87%	11%	3%	23	100%	Excellent	27	Attaining	NA
Otter Creek	OK311500-01-0080F	CGP	WWAC	730	15	1	1	1	81%	19%	0%	17	76%	Fair	25	Attaining	0
Quartermaster Creek	OK310840-01-0060B	CGP	WWAC	163	11	1	3	0	98%	0%	2%	17	76%	Fair	21	No Criteria	NA
Rainy Mountain Creek	OK310830-02-0060G	CGP	WWAC	963	21	4	6	2	79%	14%	1%	23	100%	Excellent	27	Attaining	0
Red Creek	OK311100-01-0290D	CGP	WWAC	741	21	2	8	1	88%	9%	0%	23	100%	Excellent	29	Attaining	0
Rush Creek (Garvin)	OK310810-01-0090H	CGP	WWAC	330	17	3	5	2	91%	8%	0%	23	100%	Excellent	25	Undetermined	NA
Rush Creek (Roger Mills)	OK310840-02-0210H	CGP	WWAC	159	9	2	4	0	96%	0%	4%	19	85%	Good	23	Attaining	NA
Sandstone Creek	OK310840-02-0020C	CGP	WWAC	179	10	2	1	0	88%	0%	12%	15	67%	Fair	15	No Criteria	0
Sandy Creek	OK311600-01-0040G	CGP	HLAC*	785	12	1	2	1	84%	21%	0%	21	94%	Excellent	23	Attaining	0
Station Creek	OK311800-00-0060G	CGP	WWAC	402	14	1	5	1	93%	7%	0%	21	94%	Excellent	29	Attaining	0
Stinking Creek (Kiowa)	OK310830-02-0020F	CGP	WWAC	253	19	6	5	3	45%	18%	11%	23	100%	Excellent	29	Attaining	NA
Suttle Creek	OK311310-01-0070H	CGP	WWAC	1295	24	1	6	1	95%	6%	0%	21	94%	Excellent	25	Attaining	0

Site Name	WBID	Modified Ecoregion	FWP	Total Individuals	Total Species	Sensitive Benthic	Sunfish Species	Intolerant Species	Percent Tolerant	Percent Insectivore	Percent Lithophilic	IBI (OCC)	Percent Reference	Interpretation (OCC)	IBI (USAP)	Interpretation (OCC)	Trend
Tepee Creek	OK311500-01-0110D	CGP	WWAC	522	12	1	3	1	89%	11%	0%	21	94%	Excellent	21	Undetermined	0
Timber Creek	OK311510-01-0090G	CGP	WWAC	619	13	1	5	1	57%	43%	0%	23	100%	Excellent	29	Attaining	0
Trail Creek	OK311500-03-0070D	CGP	WWAC	899	12	1	5	1	89%	11%	0%	21	94%	Excellent	27	Attaining	0
Turkey Creek	OK311600-02-0060M	CGP	WWAC	357	10	1	2	1	92%	8%	0%	19	85%	Good	19	Undetermined	NA
West Barnitz Creek	OK310830-03-0230C	CGP	WWAC	177	4	0	0	0	100%	0%	0%	7	31%	Very Poor	15	Not Attaining	0
West Cache Creek	OK311310-02-0010M	CGP	WWAC	758	19	2	7	1	73%	27%	0%	25	100%	Excellent	29	Attaining	0
Winter Creek	OK310810-02-0220G	CGP	WWAC	1108	20	4	6	2	89%	8%	1%	23	100%	Excellent	27	Attaining	NA
Chigley Sandy Creek	OK310800-02-0190D	CT	WWAC	656	16	4	5	1	96%	2%	3%	21	92%	Excellent	23	Undetermined	0
Delaware Creek	OK310830-01-0030G	CT	WWAC	211	9	0	4	0	100%	0%	0%	11	48%	Poor	25	Attaining	1
Glasses Creek	OK310800-01-0020M	CT	WWAC	741	16	1	5	2	40%	8%	48%	23	100%	Excellent	31	Attaining	NA
Guy Sandy Creek	OK310800-02-0130D	CT	WWAC	365	15	3	7	1	49%	35%	10%	23	100%	Excellent	29	Attaining	0
Hickory Creek	OK311100-02-0010M	CT	WWAC	1316	29	2	10	0	75%	26%	1%	19	84%	Good	29	Attaining	0
Little Hauani Creek	OK311100-01-0120B	CT	WWAC	509	21	2	6	1	56%	29%	8%	21	92%	Excellent	31	Attaining	NA
Peavine Creek	OK310810-01-0120M	CT	WWAC	497	13	2	5	1	69%	31%	0%	19	84%	Good	27	Attaining	NA
Roaring Creek	OK310810-02-0170B	CT	WWAC	1552	19	3	5	2	82%	18%	0%	23	100%	Excellent	25	Undetermined	NA
Rock Creek	OK310800-02-0122L	CT	WWAC	325	11	2	5	0	60%	3%	27%	17	75%	Fair	31	Attaining	NA
Salt Creek	OK310810-03-0080G	CT	WWAC	189	12	0	5	0	100%	0%	0%	13	57%	Poor	21	Undetermined	0
Stinking Creek (Caddo)	OK310830-04-0030K	CT	WWAC	557	11	0	6	0	100%	0%	0%	13	57%	Poor	27	Attaining	1
Sugar Creek	OK310830-05-0010D	CT	WWAC	63	8	1	4	1	98%	0%	0%	13	57%	Poor	17	Not Attaining	1
Tonkawa Creek	OK310830-01-0050B	CT	WWAC	1890	14	1	6	0	100%	0%	0%	15	66%	Fair	23	Attaining	NA
Walnut Bayou	OK311100-03-0010G	CT	WWAC	1168	29	1	6	3	73%	11%	0%	19	84%	Good	33	Attaining	0
Wildhorse Creek: near Davis	OK310810-01-0020G	CT	WWAC	806	22	3	6	1	97%	1%	2%	21	92%	Excellent	23	Undetermined	0
Wildhorse Creek: near Tatums	OK310810-03-0010R	CT	WWAC	151	10	1	2	0	99%	1%	1%	9	40%	Very Poor	23	Undetermined	1

Site Name	WBID	Modified Ecoregion	FWP	Total Individuals	Total Species	Sensitive Benthic	Sunfish Species	Intolerant Species	Percent Tolerant	Percent Insectivore	Percent Lithophilic	IBI (OCC)	Percent Reference	Interpretation (OCC)	IBI (USAP)	Interpretation (OCC)	Trend
Fish Creek	OK311800-00-0130G	SWT	WWAC	848	17	1	5	2	97%	27%	0%	25	100%	Excellent	27	No Criteria	0
North Elm Creek	OK311800-00-0170G	SWT	WWAC	327	8	1	3	1	77%	4%	0%	23	96%	Excellent	23	No Criteria	1
Medicine Creek	OK311300-04-0060H	Wichita	WWAC	793	11	3	4	0	36%	15%	44%	23	88%	Good	31	Attaining	0

3.1.5 Overall Site Scores

Water-quality, habitat and fish scores were combined to generate a letter grade for each stream. Overall, 16 sites received an 'A', 28 received a 'B', 15 received a 'C', five received a 'D' and two received an 'F'.

The Arbuckle ecoregion generally had moderate WQ and habitat scores, but exceptional fish scores that all exceeded reference conditions. This indicates a resilient fish assemblage despite the presence of anthropogenic stressors. Land use in Arbuckle was commonly comprised of deciduous forests and grasslands with a low percentage of cultivated crops.

Most streams in the CGP received either an A (11) or B (21) with the remainder (11) receiving a C or D. The poorest scoring streams, receiving scores of a 'C' or 'D', were primarily impacted by low water quality scores and fish scores. Low fish scores appear primarily to be driven by water chemistry, with sites generally having consistent habitat scores throughout the ecoregion. Land use in the CGP was dominated by agriculture which is a potential cause of modest WQ scores for most sites.

Streams in the Cross Timbers appeared to be the most affected by anthropogenic stressors; six of the eight poorest scoring sites were in the CT. As in the CGP, streams in the CT with the lowest overall score tended to be most impacted by poor water chemistry and fish scores. Agricultural land use was common in CT, but the population and residential land use in the ecoregion was greater than that of CGP. The greater area of residential land-use may potentially impact WQ and habitat scores of the ecoregion.

The Wichita and SWT ecoregions provided the remaining 3 streams in the analysis. Medicine Creek was the only representative of the Wichita ecoregion and had exceptional WQ (100%) and habitat scores (121%). The fish score was good (88%) and may have suffered from reduced sampling efficiency related to the boulder substrate of the stream. Land use in the Wichita ecoregion is grasslands but may be becoming increasingly residential. Despite modest WQ scores (mean score = 69%) of SWT streams, habitat scores were good (mean score = 82%), and fish scores were excellent (mean score = 100%). Due to infrequent precipitation and high salinity waters of the streams in SWT, the fish inhabiting the ecoregion tend to be tolerant to stressors even at reference sites. This is the most likely explanation for the excellent fish scores despite poorer water quality scores. Land use in SWT is mostly comprised of shrub scrub.

Table 11. Scores from each assessment (WQ, fish and habitat) are averaged to provide an overall score (Final) for each stream. Final scores are converted to letter grades: ≥90= A, <90 B ≥80, <80 C ≥70, <70 D ≥60, <60=F. Detailed assessments for the water quality (WQ), fish, and habitat scores can be found in the previous tables.

Site Name	WBID	Modified Ecoregion	WQ Score	Fish Score	Habitat Score	Bug Score	Final	Letter Grade
Big Sandy Creek	OK310800-01-0090G	Arbuckle	81%	100%	66%		83%	B
Buckhorn Creek	OK310800-02-0220C	Arbuckle	88%	100%	97%		95%	A
Caddo Creek	OK310800-03-0010F	Arbuckle	56%	100%	62%		73%	C
Oil Creek	OK310800-01-0240P	Arbuckle	88%	100%	94%		94%	A
Pennington Creek	OK310800-01-0120G	Arbuckle	81%	100%	86%		89%	B
Beaver Creek (Custer)	OK310830-03-0190C	CGP	81%	94%	86%		87%	B
Beaver Creek (Cotton)	OK311210-00-0010D	CGP	81%	67%	100%		83%	B
Bitter Creek	OK310820-01-0030D	CGP	100%	100%	99%		100%	A
Boggy Creek	OK310830-03-0100C	CGP	81%	76%	97%		85%	B
Buffalo Creek	OK311510-02-0090D	CGP	88%	85%	82%		85%	B
Cavalry Creek	OK310830-03-0070D	CGP	75%	76%	100%		84%	B
Cobb Creek	OK310830-06-0050K	CGP	75%	67%	95%		79%	C
Criner Creek	OK310810-02-0050D	CGP	94%	100%	99%		97%	A
Deep Red Creek	OK311310-03-0010D	CGP	69%	100%	90%		86%	B
East Barnitz Creek	OK310830-03-0210C	CGP	88%	58%	92%		79%	C
East Cache Creek	OK311300-03-0010M	CGP	100%	94%	100%		98%	A
Elk Creek	OK311500-03-0030C	CGP	75%	94%	81%		83%	B
Finn Creek	OK310810-02-0020D	CGP	88%	100%	100%		96%	A
Gypsum Creek	OK311600-01-0020F	CGP	56%	40%	85%		60%	D
Haystack Creek	OK311800-00-0040D	CGP	44%	94%	100%		79%	C
Lake Creek (Caddo)	OK310830-06-0040J	CGP	81%	67%	99%		83%	B
Lake Creek (Greer)	OK311510-01-0040D	CGP	56%	94%	99%		83%	B
Little Beaver Creek	OK311210-00-0050D	CGP	88%	94%	86%		89%	B
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	CGP	100%	58%	49%		69%	D
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	CGP	100%	94%	100%		98%	A
Little Deep Red Creek	OK311310-03-0040E	CGP	63%	94%	82%		79%	C
Little Elk Creek (Washita)	OK311500-03-0050A	CGP	88%	100%	93%		93%	A
Little Elk Creek (Kiowa)	OK311500-03-0040E	CGP	75%	85%	85%		82%	B
Little Washita River	OK310820-02-0010A	CGP	94%	100%	83%		92%	A
North Mud Creek	OK311100-04-0030C	CGP	81%	100%	84%		88%	B
Otter Creek	OK311500-01-0080F	CGP	50%	76%	98%		75%	C

Site Name	WBID	Modified Ecoregion	WQ Score	Fish Score	Habitat Score	Bug Score	Final	Letter Grade
Quartermaster Creek	OK310840-01-0060B	CGP	69%	76%	91%		79%	C
Rainy Mountain Creek	OK310830-02-0060G	CGP	81%	100%	100%		94%	A
Red Creek	OK311100-01-0290D	CGP	63%	100%	93%		85%	B
Rush Creek (Roger Mills)	OK310840-02-0210H	CGP	81%	85%	100%		89%	B
Rush Creek (Garvin)	OK310810-01-0090H	CGP	88%	100%	76%		88%	B
Sandstone Creek	OK310840-02-0020C	CGP	100%	67%	100%		89%	B
Sandy Creek	OK311600-01-0040G	CGP	56%	94%	88%		79%	C
Station Creek	OK311800-00-0060G	CGP	56%	94%	97%		82%	B
Stinking Creek (Kiowa)	OK310830-02-0020F	CGP	88%	100%	97%		95%	A
Suttle Creek	OK311310-01-0070H	CGP	75%	94%	97%		89%	B
Tepee Creek	OK311500-01-0110D	CGP	63%	94%	99%		85%	B
Timber Creek	OK311510-01-0090G	CGP	94%	100%	71%		88%	B
Trail Creek	OK311500-03-0070D	CGP	75%	94%	89%		86%	B
Turkey Creek	OK311600-02-0060M	CGP	44%	85%	89%		72%	C
West Barnitz Creek	OK310830-03-0230C	CGP	81%	31%	100%		71%	C
West Cache Creek	OK311310-02-0010M	CGP	100%	100%	71%		90%	A
Winter Creek	OK310810-02-0220G	CGP	100%	100%	100%		100%	A
Chigley Sandy Creek	OK310800-02-0190D	CT	81%	92%	84%		86%	B
Delaware Creek	OK310830-01-0030G	CT	56%	48%	73%		59%	F
Glasses Creek	OK310800-01-0020M	CT	69%	100%	95%		88%	B
Guy Sandy Creek	OK310800-02-0130D	CT	81%	100%	98%		93%	A
Hickory Creek	OK311100-02-0010M	CT	56%	84%	89%		76%	C
Little Hauani Creek	OK311100-01-0120B	CT	69%	92%	83%		81%	B
Peavine Creek	OK310810-01-0120M	CT	75%	84%	62%		73%	C
Roaring Creek	OK310810-02-0170B	CT	56%	100%	81%		79%	C
Rock Creek	OK310800-02-0122L	CT	100%	75%	100%		92%	A
Salt Creek	OK310810-03-0080G	CT	56%	57%	73%		62%	D
Stinking Creek (Caddo)	OK310830-04-0030K	CT	69%	57%	82%		69%	D
Sugar Creek	OK310830-05-0010D	CT	31%	57%	74%		54%	F
Tonkawa Creek	OK310830-01-0050B	CT	56%	66%	100%		74%	C
Walnut Bayou	OK311100-03-0010G	CT	44%	84%	92%		73%	C
Wildhorse Creek: near Davis	OK310810-01-0020G	CT	50%	92%	65%		69%	D
Wildhorse Creek: near Tatums	OK310810-03-0010R	CT	56%	40%	83%		59%	F
Fish Creek	OK311800-00-0130G	SWT	63%	100%	80%		81%	B

Site Name	WBID	Modified Ecoregion	WQ Score	Fish Score	Habitat Score	Bug Score	Final	Letter Grade
North Elm Creek	OK311800-00-0170G	SWT	75%	96%	78%		83%	B
Medicine Creek	OK311300-04-0060H	Wichita	100%	88%	100%		96%	A

3.2 WATERSHED ASSESSMENT

Table 12 shows the land-use upstream of each monitoring site calculated from the 2019 NRCS National Land Cover Dataset in Geographic Information Systems (GIS). The watershed sizes and land uses vary widely, with Buckhorn Creek having the smallest watershed area, less than 1700 hectares, while the Wildhorse Creek: near Davis watershed includes more than 160,000 hectares. Grasslands/Herbaceous makes up the largest percentage of land use, on average, in this basin, followed by cultivated crops.

Table 13 presents the types and number of permitted activities (e.g., Concentrated Animal Feeding Operations [CAFOs], landfills, National Pollution Discharge Elimination System [NPDES] permits) that occur upstream of each site. Big Sandy Creek was the only stream with no permitted activity in the watershed in this basin.

It is uncertain if the 2016 list of permitted activities was complete, but there was a dramatic increase in the number of oil and gas wells in the basin since 2016, with an average increase of over 800 well sites in each watershed. Anecdotally, of the ten watersheds with the greatest increase in oil and gas well density (~400 - 8,000 new wells) and sufficient data to calculate trends, four declined for both chloride and sulfate, two declined for sulfate (stable chloride), three declined for chloride (stable sulfate) and one creek (Caddo) improved for both sulfate and chloride. These ten sites had a 70% greater frequency of declining salt concentrations when compared with the remaining 28 streams in the basin.

Twenty-two sites had NPDES in the watershed. To examine the effects of point source versus non-point source pollution on the parameters at the monitoring sites, one-way ANOVAs were performed comparing sites with the permitted discharge to sites with no permitted discharge. Table 14 shows the results: Most parameters showed no significant difference between sites with a NPDES vs. without. However, nutrients (orthophosphorous, TP, TN and TKN) were significantly lower in watersheds with no NPDES permits. Though, increases in NPDES permits in a watershed since 2016 did not reveal any consistent patterns in nutrient trends.

We found very little land-use change between 2016 and 2019. Only five watersheds exhibited more than a 0.25% increase in anthropogenically altered land-use. The Tonkawa creek watershed had the greatest change with a 4% conversion from grassland to cropland. Tonkawa creek had a poor water chemistry score (0.56), because of high nutrients (orthophosphorous), salts (chloride and sulfate), and poor DO and pH. Wildhorse near Tatums, Rush (Garvin), Elk Creek and Quartermaster had less than a 1% increase in land-use intensity with changes primarily an increase in development intensity (Rush, Elk and Quartermaster) or grassland to agriculture conversion (Wildhorse). The Stinking Creek (Caddo) watershed had about a 0.5% conversion from agriculture to grassland. Due to accuracy limitations inherent in NLCD, these small changes may simply be misclassification errors.

3.3 DESIGNATED USE SUPPORT ASSESSMENT

The designated uses assessed for the monitoring sites are presented in Table 15, along with the current draft attainment status of each use based on OCC data submitted to the 2022 Integrated Report (ODEQ). The 2022 Integrated Report is in a public comment period and these attainment statuses should not be considered final. The causes and potential source(s) (if known) of any impairments can be found in the Integrated Report when finalized. No stream monitored in Basin 4 is in full attainment of its designated uses. A list of parameters for which a stream is listed can be found in Appendix D, along with information regarding TMDL development status.

Table 12. Watershed land use (% of total watershed area) for Basin 4 (Washita River and Upper Red River Basins) monitoring sites based on the most recent Land Cover Dataset (NLCD; USGS 2019). Each site is given a unique waterbody identifier (WBID).

Site Name	WBID	Hectares	Water (%)	Developed, Open (%)	Developed, Low (%)	Developed, Medium (%)	Developed, High (%)	Bare Rock/Sand/Clay (%)	Deciduous Forest (%)	Evergreen Forest (%)	Mixed Forest (%)	Shrub/Scrub (%)	Grasslands/Herbaceous (%)	Pasture/Hay (%)	Cultivated Crops (%)	Woody Wetlands (%)	Emergent Wetlands (%)
Beaver Creek (Custer)	OK310830-03-0190C	20218.23	0.64	3.16	0.99	0.46	0.09	0.00	1.81	0.66	0.53	0.68	58.91	0.11	31.89	0.02	0.05
Beaver Creek (Cotton)	OK311210-00-0010D	68590.53	0.60	3.38	0.91	0.45	0.06	0.00	6.30	0.04	0.01	0.52	70.77	0.47	16.42	0.02	0.05
Big Sandy Creek	OK310800-01-0090G	6483.24	0.75	2.42	0.30	0.23	0.02	0.16	31.85	0.76	0.20	1.47	34.81	26.97	0.00	0.00	0.06
Bitter Creek	OK310820-01-0030D	26225.28	0.65	2.71	0.64	0.70	0.13	0.01	8.57	0.01	0.00	0.29	69.25	0.17	16.83	0.00	0.02
Boggy Creek	OK310830-03-0100C	30385.89	0.71	3.03	0.66	0.44	0.13	0.00	0.13	0.04	1.60	8.77	31.31	0.42	52.70	0.03	0.04
Buckhorn Creek	OK310800-02-0220C	1641.51	0.99	1.81	0.63	0.14	0.01	0.02	31.66	0.00	0.00	1.65	50.75	10.54	1.53	0.02	0.26
Buffalo Creek	OK311510-02-0090D	23522.49	0.10	3.37	0.63	0.63	0.21	0.12	0.15	0.00	1.93	21.13	56.29	0.05	15.13	0.20	0.04
Caddo Creek	OK310800-03-0010F	84068.55	1.14	2.72	1.52	1.19	0.30	0.05	23.15	0.02	0.04	1.94	53.84	11.80	2.13	0.03	0.13
Cavalry Creek	OK310830-03-0070D	26877.06	0.63	3.13	1.29	0.80	0.21	0.01	0.13	0.00	2.49	14.04	28.76	0.27	48.12	0.08	0.06
Chigley Sandy Creek	OK310800-02-0190D	11174.04	0.98	2.21	1.22	0.42	0.07	0.04	23.17	0.01	0.01	0.86	55.75	14.35	0.86	0.00	0.06
Cobb Creek	OK310830-06-0050K	34268.76	0.41	2.66	0.55	0.18	0.03	0.01	1.41	0.71	0.31	0.13	44.46	0.98	48.08	0.02	0.07
Criner Creek	OK310810-02-0050D	16342.47	1.01	2.73	0.56	0.30	0.03	0.00	16.23	0.00	0.00	0.71	61.43	7.57	9.35	0.01	0.07
Deep Red Creek	OK311310-03-0010D	159776.6	0.70	2.74	0.76	0.36	0.04	0.02	0.82	0.00	0.00	6.62	42.43	0.16	45.17	0.00	0.16
Delaware Creek	OK310830-01-0030G	10401.48	0.13	3.43	0.99	0.72	0.15	0.11	12.84	1.37	0.12	1.30	75.66	0.64	2.49	0.02	0.03
East Barnitz Creek	OK310830-03-0210C	30650.31	0.50	2.69	0.14	0.09	0.02	0.00	0.14	3.21	0.40	1.52	72.67	0.12	18.47	0.01	0.02
East Cache Creek	OK311300-03-0010M	17335.89	0.15	2.21	0.46	0.21	0.01	0.01	2.31	0.01	0.21	1.57	57.24	2.45	33.14	0.00	0.02
Elk Creek	OK311500-03-0030C	85671.18	0.57	4.10	1.35	0.98	0.46	0.01	0.00	0.02	1.86	21.56	22.35	2.24	44.43	0.04	0.03
Finn Creek	OK310810-02-0020D	16545.78	1.34	2.74	0.57	0.29	0.03	0.02	13.76	0.00	0.01	0.52	58.40	13.53	8.70	0.00	0.08
Fish Creek	OK311800-00-0130G	8111.61	0.04	0.93	0.14	0.07	0.00	0.02	0.01	0.03	0.53	72.27	25.54	0.00	0.41	0.00	0.00

Site Name	WBID	Hectares	Water (%)	Developed, Open (%)	Developed, Low (%)	Developed, Medium (%)	Developed, High (%)	Bare Rock/Sand/Clay (%)	Deciduous Forest (%)	Evergreen Forest (%)	Mixed Forest (%)	Shrub/Scrub (%)	Grasslands/Herbaceous (%)	Pasture/Hay (%)	Cultivated Crops (%)	Woody Wetlands (%)	Emergent Wetlands (%)
Glasses Creek	OK310800-01-0020M	4960.62	1.29	4.35	4.14	2.50	0.81	0.06	15.44	0.24	0.16	1.26	50.65	19.09	0.00	0.00	0.00
Guy Sandy Creek	OK310800-02-0130D	8226.36	0.70	2.27	1.55	0.36	0.04	0.00	22.13	0.00	0.03	1.71	55.93	15.07	0.21	0.00	0.01
Gypsum Creek	OK311600-01-0020F	26293.95	0.63	1.92	0.67	0.30	0.04	0.37	0.04	0.03	0.08	54.52	0.63	0.03	40.67	0.03	0.05
Haystack Creek	OK311800-00-0040D	34479.72	0.30	2.21	0.29	0.12	0.01	1.04	0.01	0.02	0.47	74.30	3.78	0.01	17.37	0.06	0.03
Hickory Creek	OK311100-02-0010M	29639.88	0.39	4.01	3.69	3.07	1.06	0.35	24.57	0.00	0.02	1.71	41.78	18.73	0.55	0.02	0.03
Lake Creek (Caddo)	OK310830-06-0040J	16491.33	0.11	2.79	0.45	0.25	0.06	0.00	2.32	1.46	0.21	0.17	41.03	1.95	49.11	0.03	0.06
Lake Creek (Greer)	OK311510-01-0040D	11115.27	0.04	3.80	0.43	0.13	0.02	0.00	0.01	0.00	3.74	35.46	0.18	0.05	56.03	0.09	0.02
Little Beaver Creek	OK311210-00-0050D	47620.8	0.53	3.67	1.03	0.70	0.16	0.02	10.51	0.00	0.01	0.92	68.40	0.50	13.47	0.03	0.05
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	33256.26	0.53	3.62	1.08	0.67	0.12	0.02	10.04	0.00	0.01	1.02	68.54	0.66	13.65	0.01	0.04
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	25283.07	0.46	3.71	1.22	0.78	0.14	0.03	11.25	0.00	0.00	1.03	67.05	0.79	13.49	0.01	0.04
Little Deep Red Creek	OK311310-03-0040E	33708.15	0.57	2.87	1.17	0.64	0.10	0.03	0.08	0.00	0.00	1.04	35.15	0.31	57.44	0.00	0.61
Little Elk Creek (Washita)	OK311500-03-0050A	11185.74	0.26	5.75	1.56	1.14	1.02	0.00	0.00	0.00	2.11	11.29	5.05	1.55	70.17	0.07	0.02
Little Elk Creek (Kiowa)	OK311500-03-0040E	26253.9	0.78	4.22	1.17	0.76	0.46	0.00	0.00	0.00	2.14	12.65	5.14	0.74	71.73	0.14	0.05
Little Hauani Creek	OK311100-01-0120B	6894.81	0.90	2.01	0.67	0.30	0.07	0.09	38.58	2.26	0.45	3.40	39.45	10.59	1.18	0.01	0.03
Little Washita River	OK310820-02-0010A	62384.49	0.54	3.35	1.07	0.94	0.20	0.16	14.07	0.33	0.06	1.13	66.51	0.71	10.87	0.01	0.05
Medicine Creek	OK311300-04-0060H	11221.38	0.07	1.05	0.17	0.08	0.01	0.00	7.70	0.88	5.64	8.76	73.85	0.00	1.77	0.00	0.03
North Elm Creek	OK311800-00-0170G	22716.36	0.10	0.81	0.32	0.46	0.05	0.16	0.26	0.01	0.57	53.28	38.12	0.01	5.84	0.01	0.00
North Mud Creek	OK311100-04-0030C	30604.32	0.42	2.02	1.17	0.64	0.08	0.03	11.56	0.00	0.00	0.87	66.99	7.62	8.49	0.04	0.07
Oil Creek	OK310800-01-0240P	5171.04	0.11	1.54	0.52	0.27	0.09	0.00	9.79	0.41	0.09	0.84	58.95	21.86	5.53	0.00	0.00
Otter Creek	OK311500-01-0080F	72396	3.83	2.22	1.22	0.65	0.07	0.01	0.85	0.04	2.47	21.93	18.19	0.51	47.65	0.24	0.12
Peavine Creek	OK310810-01-0120M	14657.31	1.53	1.88	0.81	0.23	0.01	0.05	20.45	0.00	0.01	0.60	55.88	16.49	1.96	0.03	0.08

Site Name	WBID	Hectares	Water (%)	Developed, Open (%)	Developed, Low (%)	Developed, Medium (%)	Developed, High (%)	Bare Rock/Sand/Clay (%)	Deciduous Forest (%)	Evergreen Forest (%)	Mixed Forest (%)	Shrub/Scrub (%)	Grasslands/Herbaceous (%)	Pasture/Hay (%)	Cultivated Crops (%)	Woody Wetlands (%)	Emergent Wetlands (%)
Pennington Creek	OK310800-01-0120G	24135.3	0.35	2.04	0.25	0.12	0.01	0.01	29.45	0.80	0.06	0.99	48.92	16.96	0.00	0.00	0.02
Quartermaster Creek	OK310840-01-0060B	44765.55	0.43	2.79	0.43	0.25	0.04	0.01	0.00	0.24	1.47	15.50	66.27	0.04	12.49	0.01	0.03
Rainy Mountain Creek	OK310830-02-0060G	80671.59	0.55	2.52	0.81	0.40	0.05	0.14	0.43	0.04	2.06	28.52	19.34	0.46	44.53	0.09	0.06
Red Creek	OK311100-01-0290D	15675.84	0.55	1.41	0.39	0.07	0.00	0.01	4.47	0.00	0.00	2.45	78.49	2.47	9.66	0.00	0.02
Roaring Creek	OK310810-02-0170B	17078.22	0.76	2.10	0.53	0.52	0.21	0.01	15.35	0.00	0.00	1.12	71.25	0.49	7.62	0.01	0.04
Rock Creek	OK310800-02-0122L	6866.73	0.67	2.04	1.15	0.45	0.03	0.00	24.61	0.02	0.13	1.45	56.26	13.16	0.00	0.00	0.02
Rush Creek (Roger Mills)	OK310840-02-0210H	15725.25	0.29	2.56	0.76	0.30	0.05	0.08	0.16	0.01	0.77	27.03	63.03	0.03	4.22	0.54	0.18
Rush Creek (Garvin)	OK310810-01-0090H	66080.97	0.81	3.17	1.23	0.91	0.26	0.03	21.21	0.02	0.01	1.06	60.05	3.45	7.73	0.02	0.04
Salt Creek	OK310810-03-0080G	18804.15	0.41	2.48	1.08	1.10	0.37	0.05	30.47	0.00	0.00	1.45	54.28	5.50	2.80	0.00	0.01
Sandstone Creek	OK310840-02-0020C	24697.44	0.56	2.16	0.29	0.18	0.04	0.09	0.01	0.10	4.05	21.73	63.61	0.07	7.08	0.02	0.01
Sandy Creek	OK311600-01-0040G	91995.48	0.07	3.43	0.58	0.24	0.04	0.01	0.02	0.01	1.03	31.26	0.78	0.03	62.39	0.07	0.02
Station Creek	OK311800-00-0060G	3893.94	0.15	2.24	0.33	0.14	0.00	0.03	0.00	0.00	0.32	50.42	2.67	0.00	43.67	0.02	0.00
Stinking Creek (Caddo)	OK310830-04-0030K	5466.33	0.02	2.65	0.23	0.07	0.02	0.00	10.33	7.08	0.14	0.66	68.58	0.67	9.49	0.00	0.05
Stinking Creek (Kiowa)	OK310830-02-0020F	26837.28	0.50	2.36	0.51	0.20	0.01	0.05	2.40	0.06	0.74	4.25	45.71	0.63	42.50	0.03	0.05
Sugar Creek	OK310830-05-0010D	59157.54	0.58	2.86	0.57	0.33	0.07	0.00	6.04	17.09	0.23	1.03	52.92	0.72	17.42	0.05	0.09
Suttle Creek	OK311310-01-0070H	15284.61	0.32	3.04	2.19	1.25	0.49	0.02	0.13	0.00	0.00	0.34	14.25	0.53	77.32	0.00	0.12
Tepee Creek	OK311500-01-0110D	16683.66	0.15	4.10	0.41	0.15	0.04	0.00	0.03	0.02	3.29	21.06	1.16	0.01	69.52	0.06	0.00
Timber Creek	OK311510-01-0090G	15684.93	0.50	3.60	0.79	0.37	0.10	0.05	0.00	0.01	2.06	18.03	59.09	0.06	15.33	0.02	0.01
Tonkawa Creek	OK310830-01-0050B	10465.83	0.55	3.69	3.11	2.19	1.03	0.04	6.74	5.12	0.19	0.53	63.00	1.19	12.54	0.01	0.05
Trail Creek	OK311500-03-0070D	22700.61	0.37	3.59	0.35	0.29	0.08	0.00	0.00	0.00	1.98	22.35	11.25	7.05	52.63	0.04	0.01
Turkey Creek	OK311600-02-0060M	73765.89	0.33	2.63	0.58	0.18	0.03	0.09	0.01	0.01	1.05	47.64	0.17	0.01	47.17	0.07	0.03

Site Name	WBID	Hectares	Water (%)	Developed, Open (%)	Developed, Low (%)	Developed, Medium (%)	Developed, High (%)	Bare Rock/Sand/Clay (%)	Deciduous Forest (%)	Evergreen Forest (%)	Mixed Forest (%)	Shrub/Scrub (%)	Grasslands/Herbaceous (%)	Pasture/Hay (%)	Cultivated Crops (%)	Woody Wetlands (%)	Emergent Wetlands (%)
Walnut Bayou	OK311100-03-0010G	84926.97	0.57	2.85	1.55	0.81	0.11	0.04	35.18	0.03	0.03	2.23	44.56	11.12	0.62	0.11	0.18
West Barnitz Creek	OK310830-03-0230C	34210.98	0.58	2.90	0.23	0.21	0.05	0.00	0.08	0.66	1.07	11.32	66.84	0.10	15.91	0.01	0.02
West Cache Creek	OK311310-02-0010M	117631.4	0.42	2.63	1.16	0.68	0.12	0.01	5.33	0.34	0.71	3.87	62.04	0.11	22.52	0.00	0.05
Wildhorse Creek: near Davis	OK310810-01-0020G	163328	1.42	2.67	1.02	0.70	0.17	0.09	23.25	0.62	0.05	1.32	58.96	4.76	4.85	0.03	0.10
Wildhorse Creek: near Tatums	OK310810-03-0010R	87926.49	2.20	2.85	1.09	0.85	0.20	0.03	23.12	0.02	0.01	1.15	58.34	3.67	6.31	0.03	0.13
Winter Creek	OK310810-02-0220G	10144.53	1.07	4.69	0.65	0.42	0.12	0.00	17.56	0.01	0.04	1.15	70.52	0.66	3.05	0.01	0.04

Table 13. Permitted land use for each Group 4 (Washita River and Upper Red River Basins) monitoring site watershed as of 2021 and change in permitted land use since the completion of Cycle 3 in 2016. Each site is given a unique identifier (WBID)

Site Name	WBID	# CAFO	CAFO change	# Landfill	Landfill Change	# Permitted Discharge	Discharge Change	# O & G Wells	OG Change	# Total Retention Lagoon	Lagoon Change	# Land Application	LandAp Change	# Public Water Intakes	Intakes Change	#Storage Disposal	Disposal Change
Beaver Creek (Custer)	OK310830-03-0190C		-1	1	1			226	78	6							
Beaver Creek (Cotton)	OK311210-00-0010D							3829	3829	7	-1	3					
Big Sandy Creek	OK310800-01-0090G																
Bitter Creek	OK310820-01-0030D	1						494	494								
Boggy Creek	OK310830-03-0100C							290	160	3							
Buckhorn Creek	OK310800-02-0220C		n/a		n/a		n/a	4	n/a		n/a		n/a		n/a		n/a
Buffalo Creek	OK311510-02-0090D					4	4	453	108								-1
Caddo Creek	OK310800-03-0010F		-1	1	1	59	51	9769	4171	2		4		13	13		
Cavalry Creek	OK310830-03-0070D					8	7	108	48								
Chigley Sandy Creek	OK310800-02-0190D							423	76	1							
Cobb Creek	OK310830-06-0050K	2						250	140								
Criner Creek	OK310810-02-0050D							747	747								
Deep Red Creek	OK311310-03-0010D			2		11	10	433	239	4		1		2	1		
Delaware Creek	OK310830-01-0030G					6	5	1544	594								
East Barnitz Creek	OK310830-03-0210C							9	-194								
East Cache Creek	OK311300-03-0010M							204	-438								
Elk Creek	OK311500-03-0030C		n/a	1	n/a	17	n/a	1335	n/a	7	n/a	5	n/a	1	n/a		n/a

Site Name	WBID	# CAFO	CAFO change	# Landfill	Landfill Change	# Permitted Discharge	Discharge Change	# O & G Wells	OG Change	# Total Retention Lagoon	Lagoon Change	# Land Application	LandAp Change	# Public Water Intakes	Intakes Change	#Storage Disposal	Disposal Change
Finn Creek	OK310810-02-0020D							723	256								
Fish Creek	OK311800-00-0130G							61	17								
Glasses Creek	OK310800-01-0020M		n/a		n/a	16	n/a	446	n/a		n/a		n/a	3	n/a		n/a
Guy Sandy Creek	OK310800-02-0130D	1	n/a		n/a		n/a	124	n/a		n/a		n/a		n/a		n/a
Gypsum Creek	OK311600-01-0020F							33	3								
Haystack Creek	OK311800-00-0040D							392	139								
Hickory Creek	OK311100-02-0010M					23	19	1524	481	1		3		1	1		
Lake Creek (Caddo)	OK310830-06-0040J	1		1				238	238								
Lake Creek (Greer)	OK311510-01-0040D							308	122	1							
Little Beaver Creek	OK311210-00-0050D			1				2962	1554	7		1					
Little Beaver Creek @ Beech Rd	OK311210-00-0050J		n/a		n/a		n/a	1452	n/a	6	n/a	1	n/a		n/a		n/a
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M							951	951	6		1					
Little Deep Red Creek	OK311310-03-0040E			1		6	5	126	-98	1							
Little Elk Creek (Washita)	OK311500-03-0050A							163	11	4	-2						-1
Little Elk Creek (Kiowa)	OK311500-03-0040E		n/a		n/a		n/a	288	n/a	6	n/a		n/a	1	n/a		n/a
Little Hauani Creek	OK311100-01-0120B		n/a		n/a		n/a	10	n/a		n/a		n/a		n/a		n/a
Little Washita River	OK310820-02-0010A			1		12	10	4359	4359	2							
Medicine Creek	OK311300-04-0060H							1									

Site Name	WBID	# CAFO	CAFO change	# Landfill	Landfill Change	# Permitted Discharge	Discharge Change	# O & G Wells	OG Change	# Total Retention Lagoon	Lagoon Change	# Land Application	LandAp Change	# Public Water Intakes	Intakes Change	#Storage Disposal	Disposal Change
North Elm Creek	OK311800-00-0170G							59	-4								
North Mud Creek	OK311100-04-0030C		-1			8	7	2051	2051								
Oil Creek	OK310800-01-0240P	1						6	-1								
Otter Creek	OK311500-01-0080F	1				10	8	65	2	5		1		6	4		
Peavine Creek	OK310810-01-0120M							316	311	5	5						
Pennington Creek	OK310800-01-0120G							2	1					2	1		
Quartermaster Creek	OK310840-01-0060B							650	415								
Rainy Mountain Creek	OK310830-02-0060G	2				5	4	3811	996	1		1					
Red Creek	OK311100-01-0290D							472	132								
Roaring Creek	OK310810-02-0170B							822	822								
Rock Creek	OK310800-02-0122L		n/a		n/a		n/a	109	n/a		n/a		n/a		n/a		n/a
Rush Creek (Garvin)	OK310810-01-0090H				-1	8	8	4182	4182	1		1		2	2		
Rush Creek (Roger Mills)	OK310840-02-0210H							156	156	1							
Salt Creek	OK310810-03-0080G					5	4	2384	1050								
Sandstone Creek	OK310840-02-0020C							388	116								
Sandy Creek	OK311600-01-0040G		n/a		n/a	6	n/a	185	n/a	1	n/a		n/a		n/a		n/a
Station Creek	OK311800-00-0060G							18	7								
Stinking Creek (Caddo)	OK310830-04-0030K							89	30								
Stinking Creek (Kiowa)	OK310830-02-0020F							321	37								
Sugar Creek	OK310830-05-0010D	1						862	271								

Site Name	WBID	# CAFO	CAFO change	# Landfill	Landfill Change	# Permitted Discharge	Discharge Change	# O & G Wells	OG Change	# Total Retention Lagoon	Lagoon Change	# Land Application	LandAp Change	# Public Water Intakes	Intakes Change	#Storage Disposal	Disposal Change
Suttle Creek	OK311310-01-0070H	5	2			19	16	185	-127	1		1					
Tepee Creek	OK311500-01-0110D							36	-2	2		1					
Timber Creek	OK311510-01-0090G							322	147								
Tonkawa Creek	OK310830-01-0050B		n/a		n/a		n/a	546	n/a		n/a		n/a		n/a		n/a
Trail Creek	OK311500-03-0070D							439	170								
Turkey Creek	OK311600-02-0060M			1		9	8	102	34								
Walnut Bayou	OK311100-03-0010G					36	32	9819	3846	1				10	9		
West Barnitz Creek	OK310830-03-0230C							464	215								
West Cache Creek	OK311310-02-0010M		n/a		n/a	30	n/a	563	n/a	14	n/a		n/a	2	n/a		n/a
Wildhorse Creek: near Davis	OK310810-01-0020G					29	24	18794	8400	10				4	2		
Wildhorse Creek: near Tatums	OK310810-03-0010R					14	12	12261	5234	7				4	2		
Winter Creek	OK310810-02-0220G		n/a		n/a		n/a	194	n/a		n/a		n/a		n/a		n/a

Table 14. Comparisons of site chemistry at rotating Basin 4 (Washita River and Upper Red River Basins) monitoring sites with and without National Pollution Discharge Elimination System (NPDES) permits based on one-way ANOVAs. Comparisons where p-values were less than 0.05 were considered significantly different.

Parameter	NPDES Permit	Sample Size (N)	Mean	Standard Deviation	p Value	Result
Alkalinity	NO	870	263.83	90.87	0.357	No significant difference
	YES	404	269.07	101.67		
Conductivity	NO	885	2647	6248	0.671	No significant difference
	YES	415	2511	2501		
DO	NO	849	9.343	2.969	0.238	No significant difference
	YES	399	9.132	2.899		
DO % Saturation	NO	847	96.621	27.287	0.407	No significant difference
	YES	396	95.28	25.2		
Flow	NO	753	8.744	13.964	0.013	Lower
	YES	350	11.15	16.721		
Hardness	NO	842	1138.1	1057.1	0.101	No significant difference
	YES	394	1038	863.6		
pH	NO	855	8.0415	0.3963	0.247	No significant difference
	YES	401	8.068	0.3327		
Water Temp	NO	862	16.312	7.86	0.017	Lower
	YES	403	17.471	8.359		
Turbidity	NO	859	26.54	71.55	0.009	Lower
	YES	406	38.8	88.8		
Ammonia	NO	252	0.0596	0.0809	0.886	No significant difference
	YES	103	0.0582	0.091		
Chloride	NO	757	523.5	2301.3	0.829	No significant difference
	YES	348	553	1600.1		
TDS	NO	758	2059	4414	0.631	No significant difference
	YES	348	1941	1947		
TKN	NO	758	0.5372	0.4557	0.01	Lower
	YES	350	0.6181	0.5354		
Nitrate	NO	759	0.6896	1.0514	0.13	No significant difference
	YES	350	0.8004	1.2914		
Ortho P	NO	758	0.0452	0.0543	<0.001	Lower
	YES	350	0.1222	0.3696		
Total P	NO	758	0.0727	0.0775	<0.001	Lower
	YES	350	0.1602	0.3715		
Sulfate	NO	758	642	782.3	0.783	No significant difference
	YES	348	625.1	1230		

Parameter	NPDES Permit	Sample Size (N)	Mean	Standard Deviation	p Value	Result
Alkalinity	NO	870	263.83	90.87	0.357	No significant difference
	YES	404	269.07	101.67		
Conductivity	NO	885	2647	6248	0.671	No significant difference
	YES	415	2511	2501		
DO	NO	849	9.343	2.969	0.238	No significant difference
	YES	399	9.132	2.899		
DO % Saturation	NO	847	96.621	27.287	0.407	No significant difference
	YES	396	95.28	25.2		
Flow	NO	753	8.744	13.964	0.013	Lower
	YES	350	11.15	16.721		
Hardness	NO	842	1138.1	1057.1	0.101	No significant difference
	YES	394	1038	863.6		
pH	NO	855	8.0415	0.3963	0.247	No significant difference
	YES	401	8.068	0.3327		
Water Temp	NO	862	16.312	7.86	0.017	Lower
	YES	403	17.471	8.359		
Turbidity	NO	859	26.54	71.55	0.009	Lower
	YES	406	38.8	88.8		
Ammonia	NO	252	0.0596	0.0809	0.886	No significant difference
	YES	103	0.0582	0.091		
Chloride	NO	757	523.5	2301.3	0.829	No significant difference
	YES	348	553	1600.1		
TDS	NO	758	2059	4414	0.631	No significant difference
	YES	348	1941	1947		
TKN	NO	758	0.5372	0.4557	0.01	Lower
	YES	350	0.6181	0.5354		
Nitrate	NO	759	0.6896	1.0514	0.13	No significant difference
	YES	350	0.8004	1.2914		
Ortho P	NO	758	0.0452	0.0543	<0.001	Lower
	YES	350	0.1222	0.3696		
Total P	NO	758	0.0727	0.0775	<0.001	Lower
TSS	NO	758	28.44	85.85	0.43	No significant difference
	YES	348	32.59	69.3		
Available N	NO	759	0.7094	1.0516	0.14	No significant difference
	YES	350	0.8175	1.2899		
Total N	NO	759	1.2261	1.1544	0.016	Lower
	YES	350	1.4185	1.3983		

Table 15. Designated use support assessment for rotating basin monitoring sites in Basin 4 (Washita River and Upper Red River Basins). Each site was assigned a unique waterbody identifier (WBID). Beneficial uses are listed along with the support status (F = fully supporting, N = not supporting, I = insufficient information, X = use not assessed, * = antidegredation designation). The category describes the different levels of beneficial use attainment (2 = attaining some uses and insufficient or no data to determine others, 3 = insufficient or no data to determine if any use is attaining, 4a = not attaining one or more use, but a TMDL has been completed, 5a = one or more use is not attaining due to pollutants, but a TMDL is underway or scheduled, and 5b = one or more use is not attaining due to pollutants, a TMDL is required.) Blanks indicate that a particular beneficial use was not designated for a waterbody.

Site Name	WBID	Size (Miles)	Category	Aesthetic	Agriculture	Emergency Water Supply	Cool Water Aquatic	Habitat Limited Aquatic	Warm Water Aquatic	Fish Consumption	High Quality Water	Primary Body Contact Rec	Public and Private Water Supply	Secondary Body Contact Rec	Sensitive Water Supply
Beaver Creek (Custer)	OK310830-03-0190C	22.54	5b	F	N				F	X				F	
Beaver Creek (Cotton)	OK311210-00-0010D	46.89	5a	F	N				N	X		F	I		*
Big Sandy Creek	OK310800-01-0090G	13.57	5a	F	F				N	X		F			
Bitter Creek	OK310820-01-0030D	6.02	2	F	F				F	X		F	I		
Boggy Creek	OK310830-03-0100C	24.89	5c	F	F				N	X		F			
Buckhorn Creek	OK310800-02-0220C	8.54	2	F	F				F	X		I			
Buffalo Creek	OK311510-02-0090D	20.32	5b	F	N				F	X		F	I		
Caddo Creek	OK310800-03-0010F	44.08	5c	F	F				N	X		F	I		
Cavalry Creek	OK310830-03-0070D	20.30	5a	F	N				N	X		N	I		
Chigley Sandy Creek	OK310800-02-0190D	14.31	5a	F	F				F	X		N	I		
Cobb Creek	OK310830-06-0050K	17.34	2	F	F				F	X		F	I		*
Criner Creek	OK310810-02-0050D	11.76	5a	F	F				F	X		N	I		
Deep Red Creek	OK311310-03-0010D	57.29	5a	F	N				N	F		F	I		
Delaware Creek	OK310830-01-0030G	11.68	5b	F	N				N	X				F	
East Barnitz Creek	OK310830-03-0210C	26.48	5b	F	N				N	X		F	I		
East Cache Creek	OK311300-03-0010M	28.40	5b	F	N				F	X		F	I		*
Elk Creek at HWY 44	OK311500-03-0030C	62.97	5a	F	N			N		X				F	
Finn Creek	OK310810-02-0020D	14.15	5a	F	F				F	X		N	I		
Fish Creek	OK311800-00-0130G	16.84	5a	F	N				N	X		F	I		
Glasses Creek	OK310800-01-0020M	10.56	2	F	F				I	X		F	I		
Guy Sandy Creek	OK310800-02-0130D	17.58	5c	F	F				N	X	*	I	I		
Gypsum Creek	OK311600-01-0020F	28.10	5b	F	N				N	X		F	I		
Haystack Creek	OK311800-00-0040D	43.06	5c	F	F				N	X		F	I		
Hickory Creek	OK311100-02-0010M	37.28	5c	F	F				N	I		F	I		
Lake Creek (Caddo)	OK310830-06-0040J	16.27	2	F	F				F	X		F	I		*
Lake Creek (Greer)	OK311510-01-0040D	13.33	2	F	F				F	X		F			
Little Beaver Creek	OK311210-00-0050D	39.49	5b	F	N				N	X		F	I		*
Little Beaver Creek @ Beech Rd	OK311210-00-0050J	39.49	5b	F	N				N	X		F	I		*
Little Beaver Creek @ Camelback Rd	OK311210-00-0050M	39.49	5b	F	N				N	X		F	I		*
Little Deep Red Creek	OK311310-03-0040E	33.57	5a	F	N				N	X		F	I		
Little Elk Creek (Washita)	OK311500-03-0050A	17.40	5a	F	F				N	X		F			
Little Elk Creek (Kiowa)	OK311500-03-0040E	15.40	5b	F	N				F	X		F	I		

Site Name	WBID	Size (Miles)	Category	Aesthetic	Agriculture	Emergency Water Supply	Cool Water Aquatic	Habitat Limited Aquatic	Warm Water Aquatic	Fish Consumption	High Quality Water	Primary Body Contact Rec	Public and Private Water Supply	Secondary Body Contact Rec	Sensitive Water Supply
Little Hauani Creek	OK311100-01-0120B	12.26	2	F	F				F	X		I			
Little Washita River	OK310820-02-0010A	36.98	5a	F	N				N	X		F	I		
Medicine Creek	OK311300-04-0060H	17.71	2	F	F				F	X		F	I		*
North Elm Creek	OK311800-00-0170G	12.77	5a	F	N				N	X		F	I		
North Mud Creek	OK311100-04-0030C	27.87	5a	F	F			N		X		F	I		
Oil Creek	OK310800-01-0240P	19.47	5a	F	F				N	X		F	I		
Otter Creek	OK311500-01-0080F	23.13	5a	F	N				N	X		F	I		
Peavine Creek	OK310810-01-0120M	3.81	5a	F	F				N	X		N	I		
Pennington Creek	OK310800-01-0120G	36.93	5c	F	F		N			X	*	F	I		
Quartermaster Creek	OK310840-01-0060B	32.98	5a	F	N				N	X		F	I		
Rainy Mountain Creek	OK310830-02-0060G	32.33	5b	F	N				N	X				F	
Red Creek	OK311100-01-0290D	17.42	5a	F	F				N	X		F	I		
Roaring Creek	OK310810-02-0170B	18.27	5a	F	F				N	X		F	I		
Rock Creek	OK310800-02-0122L	12.50	5c	F	F				N	X		I	I		*
Rush Creek (Garvin)	OK310810-01-0090H	10.30	5a	F	F				N	X		N			
Rush Creek (Roger Mills)	OK310840-02-0210H	16.33	2	F	F				F	X		F	I		
Salt Creek	OK310810-03-0080G	19.05	5a	F	F				N	X		N	I		
Sandstone Creek	OK310840-02-0020C	14.59	2	F	F				I	X		F	I		
Sandy Creek	OK311600-01-0040G	39.65	5a	F	N	F		N		F				F	
Station Creek	OK311800-00-0060G	10.58	5a	F	F				N	X		F			
Stinking Creek (Caddo)	OK310830-04-0030K	11.33	5b	F	N				N	X		F	I		
Stinking Creek (Kiowa)	OK310830-02-0020F	18.36	5a	F	F				N	X		F	I		
Sugar Creek	OK310830-05-0010D	32.40	5b	F	N				N	X				F	
Suttle Creek	OK311310-01-0070H	19.41	5a	F	N				N	X				F	
Tepee Creek	OK311500-01-0110D	19.44	5a	F	N				N	X		F			
Timber Creek	OK311510-01-0090G	12.01	2	F	F				I	X		F	I		
Tonkawa Creek	OK310830-01-0050B	13.71	2	F	F				I	X		I			
Trail Creek	OK311500-03-0070D	19.15	5a	F	N				N	X		F	I		
Turkey Creek	OK311600-02-0060M	51.64	5b	F	N				N	X		F	I		
Walnut Bayou	OK311100-03-0010G	10.82	5a	F	F				N	F		F	I		
West Barnitz Creek	OK310830-03-0230C	38.35	5b	F	N				N	X		F	I		
West Cache Creek	OK311310-02-0010M	19.17	5b	F	N				F	X		F	I		
Wildhorse Creek: near Davis	OK310810-01-0020G	8.97	5a	F	F				N	X		F	I		
Wildhorse Creek: near Tatums	OK310810-03-0010R	22.30	5b	F	N				N	X		F	I		
Winter Creek	OK310810-02-0220G	12.44	2	F	F				F	X		F	I		

4.0 SUMMARY

Overall, streams in the Washita and Upper Red River Basin are in good condition with more than half of the streams receiving a letter grade of A or B. However, several of the highest quality streams for which there was sufficient data to calculate trends, appear to be declining because of increased nitrogen inputs and salts. The cause of the decline is currently unknown, as land-use has not changed appreciably throughout the Basin since 2016, but these patterns follow basin-wide trends. So far fish trends have not followed changes to water chemistry; no streams in the basin have a declining fish IBI. However, changes to biotic community may lag behind changes to water quality, and additional focus may be warranted in specific watersheds with excellent fish communities and declining chemistry (Beaver Creek (Custer), Timber Creek, Trail Creek, Fish Creek, and Tepee Creek).

Only eight streams in the Basin received an overall score of a 'D' or 'F', and the low scores were primarily driven by poor water chemistry and fish scores. For those sites with sufficient data to calculate trends, water chemistry tended to decline for several parameters and improve for others. However, of the six creeks in the watershed with improving fish communities five scored a D or F (Delaware, Gypsum, Stinking (Caddo), Sugar and Wildhorse: Tatums), indicating that conditions may be improving in some of the watersheds with the poorest overall condition.

Other notable streams include Caddo Creek, which received a 'C' because of substandard water chemistry and habitat, has improved for 6 of the water chemistry parameters, despite the addition of over 4,000 oil and gas wells and 51 new NPDES permits. Buffalo (B), Beaver (Custer) (B), Timber (B) and Hickory Creek (C) have seen the greatest decline in water chemistry among creeks with intermediate overall scores.

In the last five years, the number of NPDES and Oil and Gas wells have increased. However, it is unclear if the 2016 list of oil and gas wells was complete, and if some of the 46,000 new wells recorded for this report were actually installed prior to 2016. Despite, the potential uncertainty in installation dates, the watersheds with the greatest change in wells still reflect areas of extensive oil and gas exploration. These same watersheds also tended to exhibit increasing salt concentrations. The streams in basin 4 have naturally high salt concentrations, so it is often difficult to isolate the impacts of anthropogenic alterations to chloride and sulfate. Additional landscape analyses may reveal relationships between permitted activities and salts.

Anecdotally, the watersheds with additional NPDES permits do not appear to have consistent increases in nutrient concentrations. However, basin-wide trends indicate a widespread increase in TN concentrations, as well as a decline in DO.sat. Additional work is needed to understand the trends in both TN and DO degradation. Because a reduction in DO.sat may indicate an improvement in some situations (supersaturation due to excessive eutrophication), new analytical approaches may be necessary to isolate streams where DO is degrading. While TN tended to increase in streams, orthophosphorous generally showed improvement, though additional work is needed to identify the causes. Finally, the basin-wide increase in pH warrants further investigation on sources and potential impacts.

5.0 LITERATURE CITED

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