Final Report:
Tri-State Mining District Unionid Assessment, Missouri, Kansas, and Oklahoma, 2016 – 2018

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1.0 Introduction

The Tri-State Mining District (TSMD) is an area encompassing portions of Kansas, Missouri, and Oklahoma in which lead and zinc mining historically occurred (Figure 1-1, MacDonald et al., 2009). Due to over 100 years of mining (1850 – 1970), sand and gravel sized particles (chat; coarse tailings) and sand and silt sized particles (tailings) with high levels of lead and zinc have accumulated throughout the TSMD and have entered streams and rivers. With 3,337 mines recorded in the basin producing an estimated 21 million metric tons of zinc concentrates and 3.6 million tons of lead concentrates, these and other heavy metals have contaminated surface water, groundwater, sediments, and soils in the Spring River and Neosho River basins (Brosius and Sawin, 2001; MacDonald et al., 2009). Effects of mining have contributed to health and environmental problems, including probable declines in fish and macroinvertebrate populations (Wildhaber et al. 2000). As freshwater mussel (unionid) community declines within these basins may be attributed to this contamination, further investigation of the relationship between unionid community characteristics and metal contamination is required.

Previous studies within the Spring River and Neosho River basins have documented 41 unionid species, including several state and federally listed species (Table 1-1). The Spring River basin was most recently investigated from 2003 to 2006 to examine the relationship between unionid communities and metal contamination (Angelo et al., 2007). Angelo et al. (2007) surveyed 23 sites in Kansas, Missouri, and Oklahoma, including the Spring River, North Fork Spring River, Center Creek, Shoal Creek, Cow Creek, Brush Creek, Turkey Creek, and Willow Creek. Thirty (30) live species were encountered, including the federally endangered *Lampsilis rafinesqueana* and the federally threatened *Theliderma cylindrica*. An additional 3 species were collected as shell material. The number of live species was greatest upstream of the confluence of Spring River with Center Creek and Turkey Creek, with 27 species observed upstream and 16 observed downstream. Declines in unionid density and taxa richness corresponded geographically with elevated levels of lead, zinc, and cadmium (Angelo et al., 2007). Like Angelo et al. (2007), unionid communities in the lower Spring River (Oklahoma) were sparse and species-poor, with only 3 live unionid species found at 40% of sites (Vaughn, 1996).

Within the Neosho River basin 25 live unionid species have been recently found, with an additional 8 species collected as shells (Obermeyer et al., 1997). Recent surveys on the Neosho River proper have documented between 10 to 24 live species, including the federal endangered *L. rafinesqueana* and federal threatened *T. cylindrica* (Vaughn, 1996; Obermeyer et al., 1997; Bidwell et al., 2009), and between 47% and 65% of sites investigated harbored live unionids (Vaughn, 1996; Bidwell et al., 2009). A recent survey upstream of Miami, Oklahoma found 4 live species including *L. rafinesqueana* (Peoria Tribe of Indians of Oklahoma, 2014).

To further investigate the relationship between metal contamination and unionid communities, goals of this study were as follows;

1) Conduct a reconnaissance survey of the North Fork Spring River, Spring River, Center Creek, Shoal Creek, Tar Creek, Lost Creek, and Neosho River for areas containing live unionids and/or suitable unionid habitat with the goal of identifying approximately 25 sites that warrant further quantitative assessment,

2) Conduct quantitative unionid and habitat surveys at selected sites, and
3) Compare quantitative mussel data and preliminary sediment metal concentrations among sites.

Fieldwork was conducted from July 19th – July 26th, August 23rd – August 27th, October 3rd – October 6th, and October 14th – October 19th, 2016, from August 18th – August 21st and September 14th – September 29th, 2017, and from July 10th – July 11th, 2018.

2.0 Methods

2.1 Study Area

The Spring River flows 208 kilometers (km) from its headwaters in southwestern Missouri through southeastern Kansas and northeastern Oklahoma before joining the Neosho River at Grand Lake O' the Cherokees (Figure 1-1). The Spring River watershed encompasses 5,880 km^2 (Kiner et al., 1997), and its major tributaries include the North Fork Spring River, Center Creek, Turkey Creek, and Shoal Creek. Land use within the basin is generally rural, with 85% of the North Fork Spring River sub-basin, 70% of the Spring River sub-basin, and 52% of the Center Creek/Shoal Creek sub-basin categorized as agricultural, with much of the rest forested (Kiner et al., 1997). The Neosho River flows southeast 745 km from its headwaters in central Kansas and flows through Oklahoma to its confluence with the Spring River at Grand Lake O' the Cherokees. Major tributaries include Cottonwood River, Elk River, Elm Creek, Tar Creek, and Spring River.

2.2 Reconnaissance Site Selection

Reconnaissance sites were selected based on the following criteria:

- Accessibility,
- Published sediment chemistry and toxicity data,
- Available unionid community data, and
- Geographic Information System (GIS) data which:
    - Delineated historically stable stream reaches, and
    - Allowed a broad-scale geographic overview for
        - identification of habitat features generally associated with freshwater mussel communities such as gravel bars, riffles, and shoals, and
        - identification of access points.

As unionids generally require permanent, flowing water above stable, gravel-dominated substrates with a component of finer grained particles such as sand, sites were chosen with these criteria in mind and pool habitats were avoided. Areas where the overlay of 1963 topographic maps and current maps indicated shifts in the channel were also avoided, as unionid communities are generally found in stable river channels.

Reconnaissance sites were chosen to represent the range of potential contamination (i.e. reference, low contamination, medium contamination, and high contamination) and were distributed as evenly as possible across states, basins, and streams while meeting other site selection criteria. Sites were also placed upstream and downstream of mining input streams to document any change in sediment/water contamination and unionid community characteristics. As portions of the Spring River, Center Creek, Shoal Creek, and Neosho River were traversed, additional sites were investigated based on field observations such as the presence of shell material on the banks or in the shallows and/or seemingly suitable unionid habitat (stable but permeable substrate with some current velocity). As these conditions vary with river system, reference reaches were investigated first to facilitate understanding of mussel habitat within the Spring and Neosho River

systems.

An initial 56 sites were selected in 2016, with additional sites added during the 2016 reconnaissance survey. Additional reconnaissance surveys were conducted in 2017 and 2018 to fill in geographic 'gaps' and to further investigate river reaches of interest. A total of 102 sites were investigated; 2 on the North Fork Spring River, 34 on the Spring River, 27 on Center Creek, 30 on Shoal Creek, 1 on Lost Creek, 2 on Tar Creek, and 6 on the Neosho River (Table 2-1; Figure 2-1).

2.3 2016 – 2017 Reconnaissance Survey

Accessibility varied by site and by state and included stream-side, boat, and canoe access. Long stretches of river were accessible in Missouri, while only point access was available in much of Kansas and Oklahoma. In Missouri, most sites were accessed through bridge right of ways or other public lands, and sites upstream and downstream of the access were investigated while walking in the stream or from a canoe or boat. As Kansas and Oklahoma required landowner permission to access and sample sites, only sites with landowner access permission to the river were investigated. Permissions were coordinated prior to fieldwork when possible and in the field when needed.

A unionid habitat 'checklist' was developed by EcoAnalysts, Inc. (EA), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey – Columbia Environmental Research Center (USGS-CERC) to incorporate unionid habitat factors that might be qualitatively assessed. Unionid habitat requirements can vary by species and by stream, and efforts to describe suitable unionid habitat have ranged from simple variables such as substrate composition and current velocity to more complex hydraulic parameters such as shear stress, boundary Reynold's number, and relative substrate stability (ESI, 2014). For the reconnaissance survey, simple attributes that could be qualitatively assessed were used. Habitat attributes that allow unionids to persist include: current velocities slow enough to allow juveniles to settle to the substrate; substrate that is sufficiently stable that it is not scoured during high flow events; available food, dissolved oxygen and minerals; favorable water temperatures and water quality; and habitat for host fish (Strayer, 2008; Haag, 2012). As the Asian clam (*Corbicula fluminea*) has been used as a unionid surrogate in the past (Angelo et al., 2007), presence of *C. fluminea* was also documented, indicating that sediment and water quality was at least sufficient for *C. fluminea*. A map was created at each site and habitat observations recorded included:

- Geomorphic stream features (riffle, pool, run, etc.),
- Bank stability,
- Stream stability,
- Substrate composition (Wentworth Scale; Wentworth, 1922),
- Substrate stability/embeddedness/burrowing capacity,
- In-stream depositional features, and
- Distance to tributaries.

Each site was subjected to an initial reconnaissance search consisting of field team members dispersing throughout the

area searching for presence of unionids, *C. fluminea*, and/or suitable unionid habitat. Methods included a shoreline search for shell material, snorkeling throughout the area and fanning the substrate, and SCUBA diving in deeper areas. If a unionid community was discovered and/or field biologists agreed that the site harbored suitable unionid habitat, the area was delineated with a survey-grade Trimble GPS and was qualitatively sampled with timed searches to determine unionid distribution throughout the area, unionid community composition, and catch per unit effort (CPUE) (qualitative sites). Qualitative search effort per site ranged from 30 – 360-person minutes, and averaged 76 minutes.

All unionid data were recorded on standard EA data sheets, and habitat characterizations were logged within field notes and within the 'habitat checklist'. All data sheets were scanned upon return from the field, and data was entered into a database and underwent a line-by-line QA/QC procedure. All GPS points and features were downloaded and placed into an ArcGIS catalogue. Digital photographs taken in the field were stored on a project-specific SD card with a unique ID number, and photographs were compiled into an 'archive' set. This archive is un-edited and will not be opened. The project-specific memory card was tracked through a chain of custody form and is currently housed at EA.

2.4 Reconnaissance Sampling of Sediment and Water

Samples of bed sediment, surface water, and pore water were collected at most qualitative sites, at additional sites above and below suspected contamination inputs, and sites that helped define longitudinal gradients through the study area.

Each reconnaissance site was searched for the availability of fine-grained sediments suitable for toxicity testing. The collection of sediment samples was dependent on fine-grained sediment availability, proximity to potential contaminant inputs, and proximity to upstream and downstream qualitative sites. Sediment samples were collected by USGS-CERC to evaluate the presence of contaminants in these sediments. Sediment samples were collected with a polyvinyl chloride (PVC) scoop and were wet-sieved in the field to retain the sand, silt, and clay size fractions ("bulk sediments"; <2.0 millimeter [mm] particle diameter). Metal concentrations in these samples were characterized by X-ray fluorescence spectroscopy (XRF; Thermo Scientific Model XL2 980) following EPA method 6200 (USEPA, 2007). Sediment samples were dried in the USGS-CERC laboratory in a low temperature (<60^{o}C) oven, and dried samples were placed in a plastic bag and homogenized by hand before XRF analysis. Sediment samples were analyzed by XRF for 1 minute by placing the instrument window directly against a portion of the bag in full contact with the sediment. Three separate readings were taken for each sample, with the sample hand-kneaded between readings to ensure sample homogeneity. XRF analyses primarily provided useful information on concentrations of zinc and lead in sediments, as cadmium concentrations were less than the XRF detection limit (about 10.0 ug/g) in all but a few of the sediment samples. Results from these analyses were used to guide site selection for further quantitative unionid surveys.

Surface and pore water samples were collected by USGS-CERC at each site near where sediments were collected. These samples were collected from locations with flowing water over substrates similar to those sampled for mussels. Surface water was collected by subsurface grabs with a pre-cleaned 125- mL polyethylene sample bottle. Pore water was collected from about 4-6 cm below the sediment-water interface using push-point samplers (Zimmerman et al., 2005).

Aliquots of the push-point samples for analysis of metals, anions, and dissolved organic carbon (DOC) were filtered through 0.45 µm membranes in polypropylene syringe filter cartridges. Water samples were stored temporarily in a cooler and were then transported to USGS-CERC for sample processing, distribution, and analysis. Water samples were analyzed for metals, DOC, anions, and other water quality parameters. Results from surface and pore water analyses will be used to guide future long-term sediment and water toxicity testing with mussels and amphipods

Field duplicates were collected and analyzed for approximately 10% of water and sediment samples. Transfer of the samples from the field to the USGS-CERC Inorganics section was documented on a chain-of-custody form. Field operations associated with sample collection were recorded on field sampling sheets, and digital photographs of the sample sites were saved as part of the permanent project file.

Concentrations of lead, zinc, and cadmium within sediment samples were converted to Probable Effect Quotients (PEQ) by dividing the concentration of each metal by its Probable Effects Concentration (MacDonald et al., 2000). These PEQ values were then summed to create a "Sum-PEQ" index of toxicity hazards from the three-metal mixture. These values were categorized as Reference, Low, Medium, or High toxicity hazards using breakpoints modified from MacDonald et al., 2010. Sites with a Sum-PEQ less than 0.5 were categorized as 'Reference', sites with a Sum-PEQ between 0.5 and 4.0 were categorized as 'Low hazard', sites with a Sum-PEQ between 4.1 and 6.5 were categorized as 'Medium hazard', and sites with a Sum-PEQ greater than 6.5 were categorized as 'High hazard'.

2.5 2017 Quantitative Survey

After the reconnaissance survey, qualitative unionid data, habitat characteristics, and results of sediment and pore water sampling were analyzed for unionid community characteristics (number of live species, total number of species, CPUE), habitat suitability, and level of lead, zinc, and cadmium contamination. Using this information, 22 sites were selected for quantitative unionid sampling (Table 2-2; Figure 2-2). Sites were distributed over a range of contamination levels on the North Fork Spring River, Spring River, Center Creek, Shoal Creek, and Neosho River.

At each site, up to 100 randomly distributed 0.25 m^2 quantitative quadrat samples were collected within the previously delineated unionid habitat area/unionid community to characterize species richness, density, and age distribution. The number of quantitative samples depended on the size of the delineated area, and the number of quantitative samples ranged from 15 to 100 (Table 2-2). Each quantitative sample was excavated to a depth of approximately 15 cm, and material was placed into an attached mesh bag. Each sample was washed through a 6-mm sieve and searched for unionids and *Corbicula fluminea*. All live unionids were identified to species, measured (length in mm), and aged (external annuli count). Fresh dead shells were identified to species and counted. Weathered dead and sub-fossil shells were identified to species and noted as present. All live unionids were returned to the river near their collection point, and at least one individual of each species was photographed. Live *C. fluminea* encountered during quantitative sampling were enumerated and retained to obtain soft tissue as unionid surrogates for determination of tissue metals concentration. Live *C. fluminea* were placed in a plastic sample bag (one composite sample per site) filled with water and allowed to

expel gut contents over a 24-hour period, after which they were transferred to a clean plastic jar and placed in a cooler filled with dry ice and frozen. All *C. fluminea* samples were transferred to USGS-CERC after field sampling.

The following quantitative metrics were used to compare sites within each stream:

- Total number of live unionids,
- Total number of live species (species richness),
- Total number of species (live and dead),
- Total unionid density (no./m^2 [±2SE]),
- Adult unionid density (no./m^2 [±2SE]),
- Juvenile unionid density (no./m^2 [±2SE]),
- % Juvenile unionids,
- % Unionid mortality, and
- *Corbicula fluminea* density (no./m^2 [±2SE])

Quantitative micro-scale habitat features (depth [cm], current velocity [ft./second], and substrate constituents) were recorded at each quantitative sample point to compare physical habitat characteristics between sites in each stream. For each quantitative sample, a Gravelometer was used to characterize particle sizes (mm) in each of the four corners and the middle of the quadrat frame (modified pebble count). Pebble count data were entered into a program (The REFERENCE REACH Spreadsheet v4.2, Ohio Department of Natural Resources) to calculate D_{50} and D_{84} (size that 50% and 84% of particles are smaller than, respectively). Additionally, qualitative habitat characteristics were recorded, including:

- Dominant land use (forest/natural, agriculture, etc.),
- General site habitat (primary or secondary channel; run, riffle, and/or pool),
- Riparian corridor size (≤10 m or >10 m),
- Canopy cover (shaded, mostly shaded, mostly open, open),
- Substrate stability (loose, somewhat loose, somewhat stable, stable), and
- In-stream depositional features (gravel bars, detritus, etc.)

3.0 Results

3.1 2016 – 2017 Reconnaissance Survey

3.1.1 North Fork Spring River

North Fork Spring River was investigated with the objective of selecting a reference site for comparison of unionid communities with those in areas with higher levels of metals. Two (2) sites were investigated; North Fork 1 was approximately 100 m to 230 m upstream of the County Road (CR) 185 bridge in Jasper County, Missouri (Figure 3-1). This site was approximately 130 m long by 8 m wide and generally consisted of a shallow run with bedrock shelves extending from the right descending bank (RDB). North Fork 2 was approximately 8.5 km downstream of North Fork 1 and was approximately 300 m downstream of the Highway (HWY) 210 bridge in Jasper County, Missouri. This site was approximately 80 m long by 20 m wide and was a deep run downstream of a riffle.

North Fork 1

Habitat

North Fork 1 was upstream of CR 185. The area from the bridge upstream was searched for several hundred meters. Habitat within North Fork 1 was primarily shallow pools. Unionids were present from approximately 100 m to 230 m upstream of the CR 185 bridge, and unionid abundance was highest in the mid- to downstream portion of the mussel bed. In the area with unionids, a bedrock shelf along the RDB extended approximately 2 m into the stream and a gravel/cobble mix occurred along the left descending bank (LDB). Most live unionids were collected in this heterogenous mix of gravel, cobble, sand, and silt. Substrate within the mussel bed was stable and moderately consolidated (a few centimeters of gravel and sand covered a more stable base with available space for unionid burrowing). The foot of a small riffle marked the upstream extent of the unionid community. Upstream of the riffle, substrate was more consolidated, which may be preventing unionids from utilizing that area. Most of the mussel bed area was a smooth run that reached a maximum depth of approximately 1 m. The mussel bed area was delineated, and the total area was approximately 690 m^2.

Unionid Community

A total of 35 live individuals of 7 species were collected at North Fork 1 (Table 3-1). *Tritogonia verrucosa* (n=15) was the most commonly collected species, followed by *Amblema plicata* (n=6) and *Cyclonaias pustulosa* (n=6). Additional species collected include *Eurynia dilatata*, *Lasmigona complanata*, *Lasmigona costata*, and *Pleurobema sintoxia*. Species collected only as weathered dead shells include *Fusconaia flava*, *L. rafinesqueana*, *Ptychobranchus occidentalis*, and *Truncilla truncata*. A total of 50 minutes of qualitative effort was expended for a catch per unit effort (CPUE) of 7.0 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples were collected in the upstream portion of the site, where a suitable amount of fine sediments was located (USGS Site NF01). Metal concentrations were low, with lead and cadmium present in concentrations below the limit of detection and zinc present at a concentration of 22.9 microgram/gram (ug/g), for a Sum-PEQ of 0.0 (Table 3-2).

North Fork 2

Habitat

North Fork 2 was downstream of CR 201. The area from several hundred meters up to several hundred meters downstream of the bridge was searched for mussels. A mussel bed was located downstream of the riffle/chute complex downstream of the bridge. Mussel habitat at North Fork 2 occurred in a slow run, downstream of a narrow, swift chute. A gravel bar was present along the LDB; substrate riverward and downstream of the gravel bar was gravel and sand, with sand more prevalent along the LDB. Substrate was stable but easily excavated, and depths reached a maximum of approximately 1 m at the downstream end of the site. The mussel bed was delineated, and total area was 1,573 m^2.

Unionid community

A total of 122 live unionids of 11 species were collected within North Fork 2 (Table 3-1). Similar to North Fork 1, the unionid community was dominated by *A. plicata* (n=64), *T. verrucosa* (n=16), *C. pustulosa* (n=12), and *E. dilatata* (n=12). Additional live species included *F. flava*, *Lampsilis cardium*, *Leptodea fragilis*, *L. complanata*, *L. costata*, *P. sintoxia*, and *Strophitus undulatus*. *Quadrula quadrula* was collected only as a shell. Total search effort was 50 minutes, and CPUE (24.4/10 minutes) was higher than at North Fork 1. Unionids were more abundant in the downstream portion of the mussel bed in substrate of gravel, sand, and cobble.

Sediment metal concentrations

Sediment samples were collected at the upstream end of the site (USGS Site NF02). Similar to North Fork 1, metal concentrations were low, with lead and cadmium concentrations below the limit of detection and zinc present at a concentration of 294.2 ug/g for a Sum-PEQ of 0.6 (Table 3-2).

3.1.2 Spring River

Thirty-four (34) sites were investigated on the Spring River, extending from approximately 500 m downstream of the confluence with the North Fork Spring River in Missouri to approximately 12 km upstream of the confluence with the Neosho River in Oklahoma (Figure 3-2). Three (3) sites were in Missouri, 18 sites in Kansas, and 13 sites in Oklahoma. The goal for selecting quantitative study sites in the Spring River included selection of 2 reference sites upstream of Center Creek (Upper Spring River), at least 2 sites between Center Creek and Empire Reservoir (Middle Spring River), and 2 sites between Empire Reservoir and Grand Lake O' the Cherokees (Lower Spring River).

Spring 1A

Spring 1A consisted of a series of riffles and pools up and downstream of CR 270. Two unionid concentrations were found, one upstream (Spring 1A) and one downstream of the bridge (Spring 1B). Spring 1A was approximately 180 m upstream of the CR 270 bridge in Jasper County, Missouri. The delineated mussel concentration was approximately 230 m long by 40 m wide, for a total area of approximately 9,760 m^2. The upstream extent of this site was a riffle extending the width of the channel and the downstream end coincided with a constriction in the channel.

Habitat

Spring 1A consisted of a smooth run downstream of a large riffle that demarked the upstream extent of the unionid concentration. Banks were stable and vegetated throughout the site, and an island with emergent vegetation was present along the LDB at the downstream extent of the site. Substrate within the unionid concentration was an easily excavated yet stable mix of gravel, cobble, sand, and silt. Depths were greatest in the center upstream portion of the site and reached approximately 1.0 m.

Unionid community

A total of 199 live unionids of 12 species were collected within Spring 1A (Table 3-3). *Cyclonaias pustulosa* (n=44), *L. rafinesqueana* (n=41), and *P. sintoxia* (n=33) were the most abundant species. Additional species collected live included *Alasmidonta marginata*, *A. plicata*, *Cyprogenia aberti*, *E. dilatata*, *F. flava*, *L. costata*, *L. fragilis*, *P. occidentalis*, and *T. verrucosa*. Species represented by only dead shell included *Ligumia subrostrata*, *Q. quadrula*, and *Venustaconcha ellipsiformis*. A total of 50 minutes of qualitative searching was expended for a CPUE of 39.8 live individuals/10 minutes. Unionids were collected throughout the delineated unionid concentration, and abundance was greatest in the downstream portion along the LDB.

Sediment metal concentrations

As Spring 1A and Spring 1B were approximately 600 m apart, sediment and pore water samples were collected approximately midway between the sites (USGS Site SP01). Lead and cadmium were below the limit of detection, and zinc was present at a rate of 71.4 ug/g for a Sum-PEQ of 0.2 (Table 3-2).

Spring 1B

Spring 1B was approximately 400 m downstream of the CR 270 bridge in Jasper County, Missouri (Figure 3-2). A unionid concentration was located along the RDB and was approximately 180 m long by 20 m wide for a total area of approximately 2,690 m^2.

Habitat

Spring 1B was a shallow smooth run downstream of a riffle. Both banks were steeply cut, and the LDB upstream of the site was characterized by a large area of rip rap in gabion baskets that extended into the stream. Substrate consisted primarily of gravel with some silt, cobble, and sand, and was stable yet not highly consolidated. Depths generally did not exceed 1.0 m.

Unionid community

A total of 135 live unionids of 14 species were collected within Spring 1B (Table 3-3). One (1) live *T. cylindrica* was collected during site reconnaissance but was not encountered during qualitative searches (total of 15 species). Similar to Spring 1A, *L. rafinesqueana* (n=35), *C. pustulosa* (n=22), and *F. flava* (n=22) were the most commonly collected species. Additional species collected live included *A. plicata*, *C. aberti*, *E. dilatata*, *L. cardium*, *L. costata*, *L. fragilis*, *P.*

sintoxia, *P. occidentalis*, *Theliderma metanevra*, *S. undulatus*, and *T. verrucosa*. A total of 30 minutes of qualitative searches were conducted for a CPUE of 45.0 live unionids/10 minutes.

Spring 2

Spring 2 was approximately 7.5 km downstream of Spring 1B and south of Waco, Missouri at the southern end of CR 300 (Figure 3-2). The site consisted of a pool up and downstream of an old mill dam. Unionids were found at the downstream end of the pool as it transitioned to a riffle along the RDB. The unionid concentration was approximately 50 m long by 15 m wide for an approximate area of 550 m^2.

Habitat

Unionids occurred within smooth run upstream of a riffle along the RDB. Sand was more common within this area than in upstream areas, and substrate was gravel with sand and silt. Banks were stable and mostly covered by vegetation. Substrate surrounding the unionid concentration consisted of patches of bedrock and areas of more consolidated cobble and gravel. Depths within the area were shallow, occasionally approaching 1.0 m.

Unionid Community

A total of 216 live unionids of 14 species were collected at Spring 2, with *L. rafinesqueana* (n=73), *P. sintoxia* (n=32), and *T. verrucosa* (n=30) the most commonly collected species (Table 3-3). Additional species collected live included *A. plicata*, *C. aberti*, *E. dilatata*, *F. flava*, *L. cardium*, *L. complanata*, *L. costata*, *L. fragilis*, *P. occidentalis*, *T. metanevra*, and *C. pustulosa*. Fifty (50) minutes of qualitative search time was expended for a CPUE of 43.2 live unionids/10 minutes. Unionids were evenly distributed within Spring 2.

Sediment metal concentrations

Sediment and pore water samples were collected approximately 150 m upstream of Spring 2 along the RDB (USGS Site SP02). Lead and cadmium were below the limit of detection, and zinc was present at a rate of 99.2 ug/g for a Sum-PEQ of 0.2 (Table 3-2).

Spring 3

Spring 3 was approximately 5.0 km downstream of Spring 2 south of Lawton, Kansas near NE Center Star Road (Figure 3-2). The river was split by a large island. The north channel was searched for mussels. Habitat within the channel consisted of a series of riffles and pools. Mussels were found scattered throughout the site, but unionids were concentrated in a run area along the LDB upstream of a riffle. The area delineated was approximately 50 m long by 8 m wide, for a total area of approximately 330 m^2.

Habitat

Spring 3 was a flowing run between a pair of small riffles with a gravel, sand, and clay substrate along the LDB of a side channel. Banks were steep and comprised of stable clay with tree roots holding them in place. Areas outside of the

unionid concentration were more consolidated with cobble, and depths throughout the site reached a maximum of approximately 0.5 m.

Unionid community

A total of 59 live unionids of 9 species were collected at Spring 3, with *C. pustulosa* (n=16), *F. flava* (n=13), and *P. sintoxia* (n=12) the most commonly encountered species (Table 3-3). Additional species collected live included *E. dilatata*, *L. cardium*, *L. rafinesqueana*, *P. occidentalis*, *T. metanevra*, and *T. verrucosa*. *Amblema plicata* and *L. complanata* were found only as fresh dead shells. A total of 60 minutes of qualitative search time was spent for a CPUE of 9.8 live unionids/10 minutes. Unionids were not as dense as upstream sites, and were concentrated in substrate of gravel, sand, and clay.

Sediment metal concentrations

Sediment and pore water samples were collected approximately 70 m downstream of Spring 3 (USGS Site SP03). Lead, zinc, and cadmium were below the limit of detection for a Sum-PEQ of 0.0 (Table 3-2).

Spring 5

Spring 5 was approximately 9 km downstream of Spring 3 and approximately 1.4 km downstream of Center Creek (Figure 3-2). The area from several hundred meters upstream of a large island to downstream of the island were searched for mussels. Mussels were found along the RDB within a side channel of a small island upstream of the larger island. The mussel bed was approximately 35 m long by 12 m wide for an area of approximately 415 m^2.

Habitat

Spring 5 was located within a secondary channel around a small island along the RDB. Unionids were concentrated in a 0.3 to 1.0 m deep run in stable substrate of gravel, sand, and clay substrate. The RDB was stable with small, shrubby vegetation, whereas the bank along the LDB on the other side of the island was cut and heavily eroded. The secondary channel where unionids occurred may act as a flow refuge, as current velocities outside of Spring 5 were faster and substrate consisted of more consolidated gravel and cobble with less stabilizing clay.

Unionid community

A total of 43 live unionids of 8 species were collected at Spring 5, with *L. rafinesqueana* (n=13), *P. sintoxia* (n=11), and *C. pustulosa* (n=10) the most commonly collected species (Table 3-3). Additional species collected live included *L. cardium*, *P. occidentalis*, *T. cylindrica*, *T. verrucosa*, and *V. ellipsiformis*. A total of 60 minutes of qualitative searches were spent for a CPUE of 7.2 live unionids/10 minutes.

Sediment metal concentrations

Sediment and pore water samples were collected riverward of Spring 5 (USGS Site SP05) due to the lack of fine sediments found in the secondary channel. Both sediment and unionids were collected over a kilometer downstream of

Center Creek; ample distance for Center Creek and Spring River water to thoroughly mix. Water and sediment quality should be similar in the main and side channels. Cadmium was below the limit of detection, lead was present at a concentration of 36.4 ug/g, zinc was present at a concentration of 397.0 ug/g for a Sum-PEQ of 1.1 (Table 3-2).

Spring 6

Spring 6 was approximately 900 m downstream of Spring 5 along the RDB, immediately upstream of the SE 100th Street bridge (Figure 3-2). This site was approximately 2.2 km downstream of the confluence of Center Creek, and approximately 400 m upstream of the Turkey Creek confluence, which enters the Spring River within the left descending side channel of a large island downstream of the bridge. Turkey Creek flows upstream to the head of the large island during low water then down the right descending side of the Spring River channel. The area for several hundred meters upstream of the large island as well as both side channels within the Spring River were searched for mussels. Several weathered shells were found at the head of the large island and habitat seemed suitable, but no live unionids were found. Only one small pocket of mussels was found upstream of the bridge and influence of Turkey Creek (Spring 6). Spring 6 was located along the RDB, at the head and along the upstream edges of a small water willow bar. The unionid concentration measured approximately 13 m wide by 13 m long, for a total area of approximately 92 m^2.

Habitat

Spring 6 consisted of a small area around an island and was characterized by gravel over clay with some woody debris. The extent of unionids was restricted to approximately 3.3 m riverward of the island, where the gravel and clay substrate transitioned to a cobble and sand mixture. Clay banks bound by tree roots comprised the RDB, with cut banks upstream of the site. Depths within the unionid concentration ranged from 0.3 to 1.0 m. This small area may serve as a flow refugium.

Unionid community

A total of 44 live unionids of 9 species were collected at Spring 6, with the unionid assemblage dominated by *L. rafinesqueana* (n=29), *P. sintoxia* (n=4), and *P. occidentalis* (n=3; Table 3-3). Additional species collected included *A. plicata*, *F. flava*, *L. fragilis*, *Potamilus purpuratus*, *T. cylindrica*, and *T. verrucosa*. Sixty (60) minutes of qualitative effort was spent at Spring 6 for a CPUE of 7.3 live unionids/10 minutes. Unionids were restricted to the small area around the small island; no live individuals were observed further upstream or riverward of the island. A few shells were found at the head of the large island, but no live unionids were found.

Sediment metal concentrations

Sediment and pore water samples were collected approximately 100 m downstream of Spring 6, along the LDB of the right descending side channel of the Spring River due to lack of fine grained sediment closer to the mussel bed (USGS Site SP06). This sample location was within the flow from Turkey Creek. At this location, Turkey Creek water was much clearer than Spring River water. Water from the creek flowed upstream over the head of the gravel bar and down the left side of the right descending side channel. Cadmium was below the limit of detection, lead was present at a

concentration of 30.0 ug/g and zinc was present at a concentration of 387.5 ug/g for a Sum-PEQ of 1.1 (Table 3-2).

Spring 7

Spring 7 was an attempt to find a unionid community and/or suitable unionid habitat around a large island at the confluence of Turkey Creek, ranging from 150 m to 650 m downstream of Spring 6. No unionids nor suitable unionid habitat were identified and no qualitative searches were conducted in this area.

Habitat

Substrate along the secondary channel along the eastern side of the island consisted of loose gravel. Water from Turkey Creek flowed north around the island and then south in the channel along the RDB. The channel along the RDB consisted of a series of gravel bars and log jams forming faster runs and pockets of backwater, with some pockets of clay, gravel, and sand. In contrast, the LDB north of Turkey Creek had clear water with very loose gravel substrate, similar to the water and substrate within Turkey Creek. Downstream of Turkey Creek, the channel was primarily dry, and substrate was a mix of sand, gravel, and cobble.

Sediment metal concentrations

While no unionids nor unionid habitat was identified in this area, sediment and pore water samples were collected at the mouth of Turkey Creek to identify any influx of contaminants into the Spring River from Turkey Creek (USGS Site SP07). Cadmium was below the limit of detection, lead was present at a concentration of 122.3 ug/g, and zinc was present at a concentration of 1,659.3 ug/g for a Sum-PEQ of 4.6 (Table 3-2).

Spring 8A

Spring 8A was approximately 2.5 km downstream of Spring 6 and approximately 2.3 km downstream of the confluence with Turkey Creek, along the RDB (Figure 3-2). The area from the access point to approximately 300 m downstream was searched. Unionids were observed in a small strip of gravel, sand, and clay protected from flow by a water willow bar approximately 35 m long by 3 m wide, for an area of approximately 90 m^2.

Habitat

The dominant substrate type outside of the unionid habitat was bedrock within the main channel that transitioned to loose gravel and sand approximately 10 m from the RDB. The small patch of suitable habitat consisted of stable clay, gravel, and sand protected by a small water willow bar along the RDB, and reached a maximum depth of approximately 0.6 m. A back channel was also searched, but no unionids were found. The back channel consisted of multiple small pools (pockets) surrounded by piles of gravel. Spring 8A and its associated pocket of unionids and unionid habitat is likely a transient feature. The LDB consisted of a scoured, steep cut bank.

Unionid community

Three (3) live unionids of 3 species were collected; *L. cardium*, *L. fragilis*, and *P. grandis* (Table 3-3). Additional

species collected as weathered dead shells included *F. flava*, *L. rafinesqueana*, and *P. sintoxia*. A total of 60 minutes of qualitative sample effort were spent at Spring 8A for a CPUE of 0.5 live unionids/10 minutes.

Sediment metal concentrations

Sediment and pore water samples were collected approximately 240 m upstream of Spring 8A (USGS Site SP08) at the access point. Fine grained sediments were difficult to find in this site, as it was characterized by mostly bedrock and gravel. Cadmium was not detected, lead was present at a concentration of 61.0 ug/g, and zinc was present at a concentration of 772.7 ug/g for a Sum-PEQ of 2.2 (Table 3-2).

Spring 8B

Spring 8B was approximately 420 m downstream of Spring 8A along the LDB on an inside bend of the Spring River and 2.8 km downstream of Turkey Creek (Figure 3-2). This area was searched due to a known unionid community at this location (Angelo et al., 2007). Unionids were present in a narrow strip along the bank in a substrate of gravel, silt, clay, and sand out of the main channel. The area with mussels was approximately 8 m wide and 50 m long for a total area of approximately 400 m^2.

Habitat

Substrate adjacent to Spring 8B was dominated by loose gravel, while within the site, substrate was more stable and had fine sediments including silt, clay, and sand. A small gravel bar projected into the river at the upstream end of the site that may provide flow protection during high flow events.

Unionid community

Six (6) live unionids of 2 species were collected; *L. cardium* and *P. purpuratus* (Table 3-3). *Leptodea fragilis* was collected as a fresh dead shell. A total of 60 minutes of qualitative sample effort were spent at Spring 8B for a CPUE of 1.0 live unionids/10 minutes. Unionids were scattered throughout the site and appeared to be restricted to areas with fine sediments.

Sediment metal concentration

As sediment samples were collected nearby at Spring 8A, these sediment samples were considered representative of both Spring 8A and Spring 8B (USGS Site SP08).

Spring 9

Spring 9 was along the RDB approximately 1.3 km downstream of Spring 8B and 4.0 km downstream of Turkey Creek at the water plant (Figure 3-2). A series of reconnaissance dives at the site revealed no live unionids nor suitable unionid habitat, and no qualitative searches were conducted.

Habitat

Spring 9 was an approximately 4.0 m deep pool along the RDB with little flow. Substrate along the RDB was primarily cobble and boulder and the LDB was generally silt, woody debris and detritus. Scoured bedrock was common within the main channel.

Sediment metal concentrations

Pore water samples were collected along the RDB, which consisted of an area of large rocks, a rock slide, and a newly bulldozed road. Sediment was collected in areas of silt along the LDB to avoid these features (USGS Site SP09). Cadmium was below the limit of detection, lead was present at a concentration of 60.3 ug/g, and zinc was present at a concentration of 1,118.7 ug/g for a Sum-PEQ of 2.9 (Table 3-2).

Spring 10A, 10B, 10C, 10D, and 10E

Spring 10A, 10B, 10C 10D, and 10E were a group of closely clustered sites approximately 2.0 km downstream of Spring 9 and 6.1 km downstream of Turkey Creek (Figure 3-2). Spring 10A, Spring 10B, Spring 10D, and Spring 10E yielded no live unionids nor any suitable unionid habitat. These sites generally consisted of small strips of compact gravel near the banks with bedrock mid-channel. However, a small pocket of suitable habitat with live unionids was found at the upstream end of a side channel along the LDB at Spring 10C. Spring 10C was approximately 25 m long by 12 m wide for a total area of approximately 330 m^2.

Habitat

Spring 10C was at the head of a secondary channel along the LDB. Substrate was mostly stable gravel with some silt and sand. There was little flow, and a small gravel bar at the upstream end of the site may serve to protect the site from flow. Mussel habitat only extended 25 m into the side channel, after which the side channel was clogged with woody debris. Depths within Spring 10C ranged from 0.3 m to 1.0 m. Both banks along of the site were stable and vegetated with trees and grasses with some water willow present along the periphery of the site.

Unionid community

A total of 9 live unionids of 5 species were collected at Spring 10C (Table 3-3). *Cyclonaias. pustulosa* (n=3), *A. plicata* (n=2), and *L. cardium* (n=2) were collected and *L. rafinesqueana* and *Lampsilis siliquoidea* were both represented by a single live individual. *Fusconaia flava* was collected as a fresh dead individual, and *L. fragilis* and *Q. quadrula* were collected as weathered dead shells. A total of 80 minutes was spent qualitatively searching for a CPUE of 1.1 live unionids/10 minutes. Unionids were scattered throughout Spring 10C in areas of gravel, sand, and silt.

Sediment metal concentrations

Sediment and pore water samples were collected at the upstream end of Spring 10C near the head of the island and upstream of Short Creek. Cadmium was below the limit of detection, lead was present at a concentration of 46.8 ug/g, and zinc was present at a concentration of 1,091.4 ug/g for a Sum-PEQ of 2.7 (Table 3-2).

Spring 11A, 11B, and 11C

Spring 11A, Spring 11B, and Spring 11C were a cluster of sites approximately 4.0 km downstream of Spring 10E (Figure 3-2). These sites were at the upstream-most extent of Empire Reservoir and were characterized by deep water and low flows. No suitable unionid habitat nor live unionids were observed during reconnaissance dives.

Habitat

These sites contained woody debris along the banks with loose clay and silt before transitioning to loose clay, silt, and gravel in the center of the channel. This was a lentic environment with little to no discernable flow. Depths reached approximately 9.0 m in the center of the channel.

Sediment metal concentrations

While no suitable unionid habitat nor evidence of unionids was present, sediment and pore water samples were collected. This area was downstream of Short Creek, which may have had an influence on metals in water and sediment. Due to the deep water in the main channel, sediment was collected from the bank, which was very steep and "mucky" with lots of detritus (USGS Site SP11). Cadmium was below the limit of detection, lead was present at a concentration of 75.7 ug/g, and zinc was present at a concentration of 1,070.0 ug/g for a Sum-PEQ of 2.9 (Table 3-2).

Spring 12A

Spring 12A was immediately below the dam in Baxter Springs, Kansas and approximately 9 km downstream of Spring 11C (Figure 3-2). This area was investigated from approximately 20 m downstream of the dam to 500 m downstream of the dam and was characterized by a shallow (0.3 – 0.6 m) bedrock run that extended the width of the river. A large pocket of loose gravel and cobble was present along the RDB. Some weathered dead unionid shells were collected, but no live unionids or fresh shells were found. No suitable unionid habitat nor live unionids were collected during the initial reconnaissance survey.

Sediment metal concentrations

Because substrate consisted of bedrock below the dam, sediment samples and a duplicate sample were collected immediately upstream of the dam near a bridge pier (USGS Site SP12A and SP12A_DUP). Cadmium was below the limit of detection for both samples, while lead and zinc were present at concentrations of 44.8 ug/g and 44.3 ug/g and 910.0 ug/g and 951.8 ug/g for 12A and 12A_DUP, respectively (Table 3-2). The Sum-PEQ of USGS Site SP12A was 2.3 and 2.4 for SP12A_DUP.

Spring 12B

Spring 12B was approximately 1.6 km downstream of Spring 12A and was characterized by a large gravel bar/ island complex (Figure 3-2). Approximately 750 m of river within the complex was searched, including riverward of the islands and the back channels. Fresh dead *Obliquaria reflexa* shells were collected along an island during the initial

reconnaissance survey and a few scattered unionids were found in a pocket within the back channel. Two areas with unionids were found; one upstream of a riffle that extended downstream along a gravel bar (150 m long by 12 m wide for a total area of approximately 1,700 m^2) and one in a small pocket along the LDB (35 m long by 10 m wide for a total area of approximately 300 m^2). However, when the coordinates of the larger area along the edge of the gravel bar were plotted in ArcGIS, the delineated area appeared to fall on a gravel bar, suggesting this area is dewatered during low flow events.

Habitat

Substrate surrounding the areas of unionids was dominated by loose gravel. The two areas with unionids had differing substrate; the area at the head of the riffle extending through the riffle was generally gravel and cobble with swift currents and shallow (approximately 0.5 m) water. The pocket of unionids along the LDB had little flow with a substrate of gravel and sand overlying a layer of clay.

Unionid community

A total of 9 live unionids of 3 species were collected at Spring 12B; *Potamilus purpuratus* (n=5), *L. cardium* (n=2), and *T. verrucosa* (n=2; Table 3-3). Four additional species (*Lampsilis teres*, *L. fragilis*, *O. reflexa*, and *C. pustulosa*) were collected as fresh dead shell and *Ligumia subrostrata* was collected as a weathered dead shell. Despite collecting numerous fresh dead *O. reflexa* along the margins of a riffle, no live individuals of this species were observed. Live unionids were generally in substrate of gravel and sand. Due to the size of the island complex, a total of 360 minutes of qualitative searches were conducted in the area for a CPUE of 0.3 live unionids/10 minutes.

Sediment metal concentrations

Sediment and porewater samples were collected from the main channel approximately 230 m downstream of the unionid concentrations (USGS Site SP12B). Cadmium was below the limit of detection, lead was present at a concentration of 63.3 ug/g, and zinc was present at a concentration of 984.8 ug/g for a Sum-PEQ of 2.6 (Table 3-2).

Spring 12C

Spring 12C was approximately 750 m downstream of Spring 12C near the border of Kansas and Oklahoma, approximately 13.5 km downstream of Shoal Creek (Figure 3-2). This site was in a secondary channel along the right descending bank of the Spring River, and live unionids and fresh dead shells were observed throughout the secondary channel. Spring 12C was approximately 450 m long by 10 m wide for a total area of approximately 4,500 m^2.

Habitat

Spring 12C was within a secondary channel with various depths (0.2 – 2.0 m deep) and habitat types; the downstream section of the site consisted of a deeper run/pool, while the middle and upper sections of the site were dominated by shallow riffle and run complexes. A large deep pool was present in the middle of the site. Substrate was generally a stable gravel/cobble/sand mix, but was more embedded in the riffle complexes and very loose in the large pool.

Unionid Community

Seven (7) live unionids of 4 species were collected at Spring 12C; *L. cardium* (n=2), *O. reflexa* (n=2), and *T. verrucosa* (n=2; Table 3-3). While several fresh dead *L. fragilis* were collected throughout the site, live unionids were more abundant in the downstream and upstream areas where substrate was not highly embedded. A total of 60 minutes was spent qualitatively sampling for a CPUE of 1.2 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples collected were collected within the secondary channel along the RDB (USGS Site SP12C). Cadmium was below the limit of detection, lead was present at a concentration of 66.3 ug/g, and zinc was present at a concentration of 825.5 ug/g for a Sum-PEQ of 2.3 (Table 3-2).

Spring 13

Spring 13 was approximately 3.7 km downstream of Spring 12C, 2.3 km upstream of the old Blue Hole State Park, Oklahoma, and 17.2 km downstream of Shoal Creek (Figure 3-2). The site was U-shaped, with suitable unionid habitat and live unionids present along the banks. Spring 13 was approximately 200 m long by 40 m wide for a total area of approximately 8,300 m^2.

Habitat

This area was a shallow (0.1 m to 0.5 m deep), smooth run that extended from both banks. Substrate ranged from loose gravel in the middle of the channel to a stable mixture of gravel, cobble, and sand along the banks. Both banks were stable with well-developed riparian vegetation.

Unionid community

Ten (10) live unionids of 4 species were collected at Spring 13; *P. purpuratus* (n=5), *L. cardium* (n=3), *O. reflexa* (n=1), and *Truncilla donaciformis* (n=1; Table 3-3). Unionids were dispersed throughout the margins of the channel. A total of 60 minutes of qualitative sampling was conducted for a CPUE of 1.7 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples were collected within Spring 13 along the RDB (USGS Site SP13). Cadmium was below the limit of detection, lead was present at a concentration of 78.4 ug/g, and zinc was present at a concentration of 899.5 ug/g for a Sum-PEQ of 2.6 (Table 3-2).

Spring 13A

Spring 13A was approximately 900 m downstream of Spring 13 (Figure 3-2). This site was investigated due to a superficial resemblance to Spring 13. This site was upstream of a large riffle/rapid complex with house-sized boulders. A quick reconnaissance search found live unionids of 2 species (*L. cardium* and *O. reflexa*), but the area was not qualitatively searched as it was believed to be a continuation of Spring 13.

Spring 14 and Spring 15

Spring 14 and Spring 15 were upstream and downstream, respectively, of a large gravel bar at the old Blue Hole State Park and were approximately 1.4 km downstream of Spring 13A (Figure 3-2). Initial reconnaissance searches found a few live individuals of *L. cardium*, *L. rafinesqueana*, and *P. purpuratus*, but these individuals were randomly distributed and not indicative of a significant unionid community. Habitat within the area was dominated by loose gravel, cobble, and sand with a large riffle along the gravel bar. Most of the unionids were collected in small silt pockets along the LDB. Depths upstream and downstream of the riffle reached approximately 2 m.

Sediment metal concentrations

Sediment samples were collected along the RDB (USGS Site SP15), and just shoreward of the main channel due to depths. Cadmium was below the limit of detection, lead was present at a concentration of 61.9 ug/g, and zinc was present at a concentration of 966.6 ug/g for a Sum-PEQ of 2.6 (Table 3-2).

Spring 16

Spring 16 was approximately 4.1 km downstream of Spring 15, and this site was dominated by a large gravel bar along the LDB (Figure 3-2). A steady smooth run along the RDB appeared to provide suitable hydraulic conditions, however substrate was poor. Bedrock substrate was common mid-channel, and unstable gravel and cobble dominated near shore. As habitat was deemed unsuitable for unionids, no qualitative or sediment samples were collected.

Spring 17

Spring 17 was approximately 600 m downstream of Spring 16, upstream of the E 57 Road bridge (Devil's Promenade Bridge; Figure 3-2). This site harbored no unionid habitat nor contained evidence of unionids. Substrate was dominated by bedrock that extended from the RDB to approximately 75% of the stream width where substrate transitioned to loose gravel, silt, clay, and cobble along the LDB. Spring 17 was an approximately 7.0 m deep pool with rocky bluffs along the RDB (Devil's Promenade) and steep cut banks along the LDB. As this site did not contain suitable unionid habitat, it was not qualitatively searched, and no substrate samples were collected.

Spring 18

Spring 18 was approximately 1.7 km downstream of Spring 17, upstream of the Peoria Tribe of Indians Aquaculture Facility (Figure 3-2). Two (2) live individuals, *L. cardium* and *L. fragilis*, were observed during the initial reconnaissance survey, along with a handful of relict shell. This site was characterized by large gravel bars along both banks, a riffle at the downstream end of the site, and a large run upstream of the riffle. Substrate throughout the site consisted of unstable gravel and cobble, and depths reached approximately 2.0 m. As unionid habitat was poor, and the 2 live individuals were scattered throughout the area and not indicative of a present unionid community, Spring 18 was not qualitatively searched.

Sediment metal concentrations

While no unionid community nor suitable unionid habitat was observed at Spring 18, sediment samples were collected along the LDB within a backwater area, for a geographic continuum of sediment toxicity data (USGS Site SP18). Cadmium was below the limit of detection, lead was present at a concentration of 47.8 ug/g, and zinc was present at a concentration of 787.3 ug/g for a Sum-PEQ of 2.1 (Table 3-2).

Spring 19

Spring 19 was approximately 1.0 km downstream of Spring 18 along the LDB, and 27.3 km downstream of Shoal Creek (Figure 3-2). This site was a narrow strip of suitable habitat approximately 60 m long by 7 m wide for a total area of approximately 390 m^2.

Habitat

Habitat within Spring 19 consisted of a swift run over highly consolidated cobble, gravel, and sand. The LDB was cut and eroded with a fully vegetated riparian corridor. Areas surrounding the unionid concentration consisted of loose gravel and cobble.

Unionid community

A total of 36 live unionids of 6 species were collected at Spring 19 (Table 3-3). *Lampsilis cardium* (n=9), *P. purpuratus* (n=9), *L. rafinesqueana* (n=5), and *O. reflexa* (n=5) were the most commonly collected species. Additional species collected live included *L. fragilis* and *T. verrucosa*. A total of 40 minutes of qualitative searches were spent at this site for a CPUE of 9.0 live unionids/10 minutes. Unionids were evenly distributed throughout the strip of suitable habitat.

Sediment metal concentrations

Sediment samples were collected within Spring 19 (USGS Site SP19). Cadmium concentrations were below the limit of detection, lead was present at a concentration of 68.7 ug/g, and zinc was present at a concentration of 998.8 ug/g for a Sum-PEQ of 2.7 (Table 3-2).

Spring 20

Spring 20 was across the river from Spring 19 along the RDB in a side channel behind a large island (Figure 3-2). Suitable unionid habitat encompassed the entirety of the side channel and was approximately 250 m long by 12 m wide, for a total area of approximately 3,300 m^2.

Habitat

Spring 20 consisted of a riffle/run chute along the west side of a large gravel island. Banks appeared stable, with the LDB gently sloping up to the gravel bar and the RDB running along a moderately cut bank. Substrate consisted mostly of stable gravel, sand, and cobble. Depths were generally shallow, rarely exceeding 0.6 m.

Unionid community

Nineteen (19) live unionids of 7 species were collected within Spring 20 (Table 3-3). *Lampsilis cardium* (n=11) and *P. purpuratus* (n=3) were the most frequently collected species. *Lampsilis teres*, *L. fragilis*, *O. reflexa*, *T. verrucosa*, and *T. donaciformis* were all represented by a single live individual. *Ptychobranchus occidentalis* was represented by a single fresh dead individual. Forty (40) minutes of qualitative searches was spent for a CPUE of 4.8 live unionids/10 minutes. Unionids were collected along the channel margins of both banks throughout the side channel.

Sediment metal concentrations

Sediment samples were collected at the upstream end of the side channel, within the delineated unionid bed, and as Spring 20 and Spring 19 were near each other, the samples collected at Spring 20 were considered representative of both sites (USGS Site SP20). Cadmium concentration was below the limit of detection, lead was present at a concentration of 79.7 ug/g, and zinc was present at a concentration of 1,025.3 ug/g for a Sum-PEQ of 2.9 (Table 3-2).

Spring 21

Spring 21 was approximately 2.0 km downstream of Spring 19 and Spring 20, upstream of the confluence with Warren Branch (Figure 3-2). This site consisted of a 1.0 m deep pool with little flow. Banks were eroded and appeared to be unstable. Substrate consisted of loose gravel mid-channel, a loose gravel/cobble mix along the LDB and bedrock along the RDB. Initial reconnaissance searches observed 3 live *P. purpuratus* in a small silt pocket along the RDB. As this site generally contained unsuitable unionid habitat, and the small pocket of live unionids was not indicative of a significant unionid community, Spring 21 was not searched qualitatively.

Sediment metal concentrations

Sediment samples were collected upstream of Warren Branch to document sediment toxicity prior to this input (USGS Site SP21). Cadmium concentrations were below the limit of detection, lead was present at a concentration of 64.5 ug/g, and zinc was present at a concentration of 1,045.9 ug/g for a Sum-PEQ of 2.8 (Table 3-2).

Spring 22

Spring 22 was approximately 600 m downstream of Spring 21 and Warren Branch, and 30.2 km downstream of Shoal Creek (Figure 3-2). This area consisted of large gravel island with a small secondary channel along the LDB. Spring influence was evident in this secondary channel, as water temperatures were noticeably cooler. Qualitative searches were conducted within the main channel where suitable habitat was present and live unionids were observed during initial reconnaissance searches. This area of suitable habitat consisted of a shallow shoal at the head of a riffle towards the downstream end of the island and was approximately 40 m long by 17 m long for a total area of approximately 650 m^2.

Habitat

Substrate within the area of unionids was generally a stable mix of gravel, cobble, and sand. Surrounding substrate varied considerably; from loose gravel in the main channel to a sand-dominated substrate within the secondary channel.

Bedrock shelves were present along the LDB and the RDB consisted of a gravel bar.

Unionid community

One (1) live individual of both *L. cardium* and *O. reflexa* were collected during qualitative searches (Table 3-3). The number of live unionids collected during qualitative sampling was lower than expected, as approximately 12 live individuals (*P. purpuratus*, *L. cardium*, and *O. reflexa*) were collected within this area and 8 were collected within the secondary channel during initial reconnaissance searches. A total of 75 minutes of qualitative search time was spent for a CPUE of 0.3 live unionids/10 minutes. Unionids were collected from a 0.3 m run upstream of a gravel bar in a substrate of gravel, cobble, and sand.

Sediment metal concentrations

Sediment samples were collected from a side channel approximately 50 m from where pore water and surface water samples were collected within Spring 22 (USGS Site SP22). Cadmium concentration was below the limit of detection, lead was present at a concentration of 6.7 ug/g, and zinc was present at a concentration of 1,021.6 ug/g for a Sum-PEQ of 2.3 (Table 3-2).

Spring 23

Spring 23 was approximately 2.3 km downstream of Spring 22 (Figure 3-2). This area was characterized by a gravel bar along the LDB and steep cut banks along the RDB. Depths were greatest along the RDB and reached approximately 3.0 m. Substrate consisted of loose gravel and cobble, and no live unionids were observed. Due to the absence of suitable unionid habitat and live unionids, this site was not qualitatively searched, and no sediment samples were collected.

Spring 24

Spring 24 was approximately 1.9 km downstream of Spring 23, upstream of the East 100 Road bridge east of Miami, Oklahoma (Figure 3-2). This site was a pool with depths of approximately 7 m mid-channel. Substrate was not suitable for unionids, as substrate along the LDB consisted of loose gravel and bedrock that extended from the RDB to mid-channel. As habitat was poor and there was no evidence of unionids, this site was not qualitatively searched, and no sediment samples were collected.

3.1.3 Center Creek

A total of 27 sites were investigated on Center Creek from southeast of Carthage to Carl Junction, Missouri; approximately 3.1 km upstream of the confluence with the Spring River (Figure 3-3). The reconnaissance objective in Center Creek was to find at least 1 reference site and 2 sites with Sum-PEQ > 0.5. The majority of lead mining activity in the Center Creek watershed occurred downstream of HWY 171 and within Ben's Branch watershed (Figure 1-1, Figure 3-3).

Center 1

Center 1 was approximately 300 m downstream of County Road 90 in Jasper County, Missouri (Figure 3-3). This area was characterized by cool water and unsuitable unionid habitat. Substrate consisted of gravel with some silt, cobble, and sand but was either highly consolidated or loose. A few weathered shells were scattered over a large area (*E. dilatata*, *L. rafinesqueana*, and *V. ellipsiformis*), but no evidence of live unionids or suitable habitat was present, and no qualitative searches or sediment sampling was conducted.

Center 0

Center 0 was approximately 60 m downstream of the County Road 110 bridge in Jasper County, Missouri (Figure 3-3). This area was characterized by narrow stream width, shallow, cool water and multiple secondary channels. Qualitative searches were conducted upstream of a riffle where most live unionids were observed, and this unionid concentration was approximately 17 m long by 8 m wide for a total area of approximately 70 m^2. One (1) live unionid was collected in sediment samples, approximately 300 m downstream of this unionid concentration, suggesting unionids were scattered throughout the entire area.

Habitat

Substrate within the area of unionids consisted of gravel, cobble, and sand. The area was generally <1.0 m deep with smooth flow, and multiple secondary channels formed a small island complex. Banks were stable with a full riparian zone along the LDB and trees/mowed grass where residents had built a fire pit area on the RDB.

Unionid community

A total of 12 live unionids of 5 species were collected at Center 0 (Table 3-4). *Fusconaia flava* (n=5) and *E. dilatata* (n=4) were the most commonly encountered species. *Lampsilis rafinesqueana*, *L. siliquoidea*, and *P. occidentalis* were each represented by a single live individual. A total of 60 minutes was spent qualitatively searching this site for a CPUE of 2.0 live unionids/10 minutes. *Ligumia subrostrata* and *V. ellipsiformis* were collected only as weathered dead shells.

Sediment metal concentrations

Sediment, pore, and surface water samples were collected approximately 300 m downstream of Center 0, at the west end of a large island (USGS Site CC00). Both cadmium and lead levels were below the limit of detection, and zinc was present at a concentration of 315.8 ug/g for a Sum-PEQ of 0.7 (Table 3-2).

Center 1G1

Center 1G1 was located approximately 9 km downstream of Center 0 and approximately 230 m upstream of the South Chapel Road bridge (Figure 3-3). This area was characterized by a run/riffle/pool complex with a series of gravel bars and deep pools along the outside bends of the stream. Substrate was loose gravel, and the only evidence of unionids was a small fragment of shell. No live unionids were collected, no suitable habitat was observed, and no qualitative searches were conducted at this site.

Sediment metal concentrations

Sediment samples were collected upstream of the South Chapel Road approximately 60 m downstream of Center 1G1 and 280 m upstream of Center 1G2 (USGS Site CC01G). Cadmium was below the limit of detection, lead was present at a concentration of 10.7 ug/g, and zinc was present at a concentration of 114.2 ug/g for a Sum-PEQ of 0.3 (Table 3-2).

Center 1G2

Center 1G2 was approximately 340 m downstream of Center 1G1 and approximately 90 m downstream of the South Chapel Road bridge along the RDB (Figure 3-3). This site was a small backwater area almost completely isolated from Center Creek save for interstitial flow coming through a gravel bar. Center 1G2 was approximately 70 m long by 7 m wide for a total area of approximately 410 m^2.

Habitat

Center 1G2 was a small pocket within an otherwise dry side channel along the RDB. Little discernable flow was present, likely from seepage under gravel bars from the main channel. Substrate was a loose mix of gravel with some cobble, sand, silt, and detritus and depths reached a maximum of 1 m. The area surrounding Center 1G2 was a gravel island complex with loose substrate with runs and riffles.

Unionid community

A total of 6 live unionids of 3 species were collected at Center 1G2; *F. flava* (n=3), *L. siliquoidea* (n=2), and *L. subrostrata* (n=1; Table 3-4). Additional species collected as shell included *E. dilatata*, *L. rafinesqueana*, *P. sintoxia*, *P. occidentalis*, and *V. ellipsiformis*. A total of 60 minutes of qualitative searches were conducted for a CPUE of 1.0 live unionids/10 minutes. Unionids were randomly distributed throughout the site, and searches outside of this area yielded no unionids.

Sediment metal concentrations

Sediments were collected upstream of Center 1G2, approximately halfway between Center 1G1 and Center 1G2. Sediment toxicity results are presented in Center 1G1.

Center 1A1 and 1A2

Center 1A1 and Center 1A2 were upstream and downstream of the CR 175 bridge approximately 5.5 km downstream of Center 1G2 and approximately 1.2 km downstream of the confluence with Grove Creek (Figure 3-3). Center 1A1 was 150 m downstream of the bridge and was a deep run with a gravel bar along the RDB and bedrock shelves along the LDB. The downstream extent of the area was a large riffle, and substrate was loose gravel and bedrock and only a fragment of unionid shell was collected. Center 1A2 was approximately 200 m upstream of the bridge and was an island complex with substrate of bedrock, large cobble, and loose gravel. As no evidence of unionids nor suitable habitat was observed, these sites were not qualitatively searched, and no sediment samples were collected.

Center 1B1 and 1B2

Center 1B1 and Center 1B2 were approximately 2.1 km downstream of Center 1A1 near the Dyno explosives plant (Figure 3-3). Center 1B1 was approximately 550 m downstream of the Fir Road bridge and was characterized by fast runs and riffles with bedrock from the RDB to mid-channel and gravel bars and loose gravel along the LDB. Both banks were cut with significant bank erosion. One (1) *V. ellipsiformis* shell was collected during the initial reconnaissance survey, but no other signs of unionids nor unionid habitat were observed. Center 1B2 was approximately 400 m downstream of Center 1B1 and had similar habitat characteristics as Center 1B1; fast runs and riffles with loose gravel with some pockets of sand along the RDB. No evidence of unionids nor suitable unionid habitat were observed. No qualitative searches nor sediment sampling were conducted at either Center 1B1 or Center 1B2.

Center 1C

Center 1C was approximately 2.0 km downstream of Center 1B2 and 2.0 km upstream of the Highway 171 bridge (Figure 3-3). This area was a run/pool complex with log jams, tall cut banks, and loose, unstable gravel. One fragment of a unionid shell was found. Due to evidence of previous and ongoing erosion and shifting gravel bars, this area was not considered suitable unionid habitat. No qualitative searches were conducted, and no sediment samples were collected.

Center 1D

Center 1D was approximately 900 m downstream of Center 1C and 1 km upstream of the Highway 171 bridge (Figure 3-3). This area was comprised of a series of runs and riffles, with unstable gravel bars and cut banks. Substrate consisted of loose gravel, with small pockets of silt along ‘scalloped’ areas of the bank. No evidence of unionids nor unionid habitat were observed. No qualitative searches were conducted, and no sediment samples were collected.

Center 1E and 1F

Center 1E and Center 1F were approximately 650 m downstream of Center 1D and 400 m upstream of the Highway 171 bridge (Figure 3-3). Center 1E and Center 1F were upstream and downstream of a large riffle, respectively. Center 1E was an approximately 1.5 m deep pool upstream of a riffle. Substrate consisted of large boulder, cobble, and gravel over bedrock. Banks were eroded along the LDB, but the RDB was fully vegetated with a gravel bar on the inside bend of the river. No evidence of unionids was observed. Center 1F was below a riffle in a fast run. One (1) live *L. siliquoidea* was collected during the initial reconnaissance search in a silt pocket along the RDB (Table 3-4). A total of 45 minutes was spent qualitatively searching for a CPUE of 0.2 live unionids/10 minutes. This area appeared superficially to be suitable unionid habitat, but further examination found substrate consisting of loose sand, gravel, silt, and cobble. As habitat was poor and only one live individual was observed, no sediment samples were collected at this site.

Center 3

Center 3 was approximately 900 m downstream of Center 1F and was upstream of a bend in the river at the head of a riffle, in a 1.0 m deep pool (Figure 3-3). This area of suitable unionid habitat was approximately 6 m long by 10 m wide for a total area of approximately 70 m^2.

Habitat

Center 3 was upstream of a riffle with depths ranging from 0.6 m to 1.0 m, and substrate was comprised of gravel, sand, silt, and cobble. Current was gently flowing throughout the area, and velocities increased near the riffle along the LDB. Woody debris was present along the RDB where a large log had settled, and sand was more common in this area. Riparian vegetation was present along both banks, and banks appeared stable.

Unionid community

Two (2) live unionids of 2 species, *L. siliquoidea* and *P. sintoxia*, were collected (Table 3-4). *Ligumia subrostrata* was collected as a weathered dead shell. A total of 50 minutes of qualitative search time was expended at this site for a CPUE of 0.4 live unionids/10 minutes. Unionids were scattered throughout this site in areas of stable gravel, sand, silt, and cobble.

Sediment metal concentrations

Sediment samples were collected along the LDB approximately 120 m downstream of Center 3 (USGS Site CC03). Cadmium was below the limit of detection, lead was present at a concentration of 27.1 ug/g, and zinc was present at a concentration of 498.4 ug/g for a Sum-PEQ of 1.3 (Table 3-2).

Center 4

Center 4 was approximately 600 m downstream of Center 3 and 130 m downstream of the Route 66 bridge (Figure 3-3). This area was a shallow (0.3 m to 1.0 m) area upstream of a riffle with a gravel bar along the LDB. Substrate was generally rocky, with cobble overlying gravel. No shells were observed along the banks or within the stream, and no live unionids were found. No qualitative searches or sediment samples were collected.

Center 5

Center 5 was approximately 260 m downstream of Center 4 (Figure 3-3). This site was at the head of a large riffle and substrate was dominated by bedrock. No qualitative searches or sediment sampling was conducted.

Center 5A

Center 5A was approximately 240 m downstream of Center 5 (Figure 3-3). This area was a shallow run over bedrock along the RDB and loose gravel along the LDB. No evidence of live unionids was observed during the initial reconnaissance. No qualitative searches or sediment sampling was conducted.

Center 5B

Center 5B was approximately 400 m downstream of Center 5A (Figure 3-3). This site was downstream of a riffle, with a gravel bar along the LDB. During the initial reconnaissance search, 1 live *L. cardium* was collected in addition to a weathered dead *L. siliquoidea* and a sub-fossil *A. plicata*. The riffle/gravel bar complex was searched, and no additional

live unionids were found. Substrate was consolidated within the main channel and loose gravel along the channel margins. No qualitative searches or sediment sampling was conducted.

Center 5C and 5D

Center 5C and 5D were approximately 3 km downstream of Center 5B and approximately 600 m upstream of the Highway D bridge and the confluence of Bens Branch (Figure 3-3). Center 5C was a shallow run below a riffle with a gravel bar along the RDB and a small bar along the LDB. One (1) weathered dead *A. plicata* shell was found in this area, but substrate consisted of loose gravel. No live unionids were found in this area. Center 5D was approximately 75 m downstream of Center 5C. While these two sites were near each other, Center 5D had substrate consisting of a stable mix of gravel, sand, and cobble. Center 5D was located below a riffle along the LDB and an area of suitable habitat measured approximately 15 m long by 4 m wide for a total area of approximately 70 m^2. As live unionids and suitable habitat were observed during the initial reconnaissance, qualitative searches were conducted.

Habitat

Center 5D was a riffle/run complex with moderately swift current. The stream narrowed at this site, seldom exceeding 6 m wide. Substrate was dominated by gravel, sand, and cobble. Riparian zones along both banks were sparsely vegetated, but banks appeared to be stable.

Unionid community

A total of 12 live unionids of 4 species were collected at Center 5D (Table 3-4). *Fusconaia flava* (n=7) was the most commonly collected species followed by *L. rafinesqueana* (n=2), *P. occidentalis* (n=2), and *L. cardium* (n=1). *Amblema plicata* was collected as a subfossil shell. Fifty (50) minutes of qualitative searches were conducted for a CPUE of 2.4 live unionids/10 minutes. Unionids were concentrated in a stable gravel seam along the LDB from approximately 0.6 m from the bank to halfway into the channel. This site was below a small riffle and current was moderately swift.

Sediment metal concentrations

Sediment samples were collected approximately 15 m downstream of Center 5D (USGS Site CC05D). Cadmium was below the limit of detection, lead was present at a concentration of 206.5 ug/g, and zinc was present at a concentration of 860.7 ug/g for a Sum-PEQ of 3.5 (Table 3-2).

Center 6

Center 6 was approximately 550 m downstream of Center 5D, at the confluence with Bens Branch underneath the Highway D bridge (Figure 3-3). This area was a swift run/riffle complex with a substrate of consolidated cobble, gravel, and boulder. As no evidence of unionids nor suitable unionid habitat was observed, no qualitative searches were conducted, and no sediment samples were collected.

Center 7

Center 7 was approximately 600 m downstream of Center 6 and the confluence of Bens Branch (Figure 3-3). This area was characterized by a large, shallow (approximately 0.3 m deep) riffle/run complex with a substrate of gravel, cobble, sand, and silt. Substrate was stable where cobble was present, but loose in areas with pure gravel. Center 7 was in a small side channel and was approximately 2 m wide and 24 m long for a total area of 48 m^2. Numerous unionid species were collected as fresh or weathered dead shells during the initial reconnaissance survey, but no live unionids were collected despite suitable unionid habitat (Table 3-4). As Center 7 had unionid habitat and was downstream of the confluence with Bens Branch, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected approximately 120 m upstream of Center 7 along the RDB, just downstream from Ben's Branch (USGS Site CC07). Cadmium was present at a concentration of 24.7 ug/g, lead was present at a concentration of 337.6 ug/g, and zinc was present at a concentration of 5,269.9 ug/g for a Sum-PEQ of 19.1 (Table 3-2).

Center 8

Center 8 was approximately 1.2 km downstream of Center 7, 1.9 km downstream of Bens Branch, and 500 m upstream of Highway 230 bridge south of Oronogo, Missouri (Figure 3-3). The upstream extent of this area was a riffle complex with consolidated substrate mid-channel and loose gravel near the banks. The downstream portion was mostly bedrock, with loose gravel and sand along the banks. Two (2) fresh dead *L. cardium* were found during the initial site reconnaissance, but no live unionids nor suitable unionid habitat was observed. Sediment samples were collected to provide sediment toxicity data downstream of the Bens Branch confluence.

Sediment metal concentrations

Sediment samples were collected under the Highway 230 bridge, approximately 500 m downstream of Center 8 and 1.9 km downstream of Bens Branch (USGS Site CC08). Cadmium concentration was 10.9 ug/g, lead was present at a concentration of 321.0 ug/g, and zinc was present at a concentration of 2,872.5 ug/g for a Sum-PEQ of 11.0 (Table 3-2).

Center 9

Center 9 was approximately 1 km downstream of Center 8, 2.9 km downstream of Bens Branch, and 500 m downstream of the Highway 230 bridge (Figure 3-3). This area had eroded cut banks and loose gravel bars. Initial reconnaissance searches found no evidence of unionids nor suitable unionid habitat. No qualitative searches were conducted, and no sediment samples were collected.

Center 10A

Center 10A was approximately 1 km downstream of Center 9, 3.9 km downstream of Bens Branch, and 600 m upstream of the North Homestead Drive bridge (Figure 3-3). Like Center 9, this area was characterized by a complex of loose gravel bars and eroded banks. No evidence of unionids nor suitable habitat was observed.

Center 15A

Center 15A was approximately 7.5 km downstream of Center 10 at the upstream end of Center Creek Park in Carl Junction, Missouri and 11.5 km downstream of Bens Branch (Figure 3-3). This area was a riffle/run complex with rip rap along the RDB and gravel bars along the LDB. Most of the area was a 0.3 to 1 m deep, fast run, with a hard clay shelf along the RDB. Cut banks were present along the outside bends, and small pockets of sand in 'scallops' were present along the LDB gravel bar. One unionid fragment was found during the initial reconnaissance, and no suitable unionid habitat was observed.

Center 16

Center 16 was approximately 230 m downstream of Center 15 at the downstream end of Center Creek Park (Figure 3-3). This area was at the northern end of a bend in the river with riffles surrounding a small island. Substrate upstream of the riffles was loose cobble, gravel, and sand, and substrate within and downstream of the riffles was loose gravel. Small pockets of sand and silt were present along the LDB. Current was swift and the RDB was slightly undercut. No evidence of unionids was observed, and habitat was poor. Reconnaissance searches continued approximately 300 m downstream; substrate was similar and bedrock shelves were present along the RDB. As this was the furthest downstream site on Center Creek during the 2016 reconnaissance survey, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected at the downstream end of the area (USGS Site CC16). Cadmium was present at a concentration of 13.9 ug/g, lead was present at a concentration of 282.7 ug/g, and zinc was present at a concentration of 3,367.6 ug/g for a Sum-PEQ of 12.3 (Table 3-2).

Center 10B

Center 10B was approximately 5.2 km downstream of Center 16, 16.6 km downstream of Bens Branch, and 3.1 km upstream of the Spring River, between HWY JJ and HWY 303 (Figure 3-3). This site was a run along the LDB at an abrupt bend in the river downstream of a riffle complex with boulder, cobble, sand, and silt substrate. Center 10B was approximately 40 m long and 4 m wide for an area of approximately 160 m^2. While no live unionids were observed during initial reconnaissance searches, this area harbored better, stable, unionid habitat than surrounding areas and was qualitatively searched. No live unionids nor shell material were collected during qualitative searches (Table 3-4).

Habitat

Habitat within Center 10B was a stable mix of boulder and cobble with gravel and silt interspersed. This site contained the only stable substrate observed in the 2.6 km reach between Highway JJ and Highway 303; much of this reach was dominated by bedrock or loose gravel/sand. Depths were generally shallow (0.5 m) and current velocity decreased downstream with distance from an upstream riffle complex.

Sediment metal concentrations

Sediment samples were collected within Center 10 along the LDB (USGS Site CC10). Cadmium was below the limit of detection, lead was present at a concentration of 245.5 ug/g, and zinc was present at a concentration of 2,274.5 ug/g for a Sum-PEQ of 6.9 (Table 3-2).

3.1.4 Shoal Creek

A total of 30 sites were investigated on Shoal Creek, ranging from Ritchie, Missouri to downstream of Schermerhorn Park, Kansas (Figure 3-4). The objective in Shoal Creek was to find 1 reference site, and 2 sites with PEQ > 0.5

Shoal at Smack Out Access

This site was approximately 930 m upstream of the Highway 60 bridge and approximately 100 m upstream of the Missouri Department of Conservation's Smack Out access in Newton County, Missouri (Figure 3-4). This area was a shallow run/riffle complex with a stable gravel, sand, and cobble substrate. Banks were stable with fully vegetated riparian corridors. One (1) live *P. sintoxia* and a weathered dead shell of *Toxolasma lividum* was collected during initial site reconnaissance. No additional live unionids were observed and further qualitative searches were not conducted.

Shoal at Highway 60

This site was briefly investigated due to ease of access and was approximately 850 m downstream of the Smack Out access (Figure 3-4). This area was comprised of a deep pool with little flow. No evidence of unionids was observed and habitat was generally poor with substrate of loose cobble and gravel.

Shoal at House

This site was approximately 6.5 km downstream of Highway 60 at a private residence, and approximately 450 m upstream of the County Road W bridge (Figure 3-4). This area was characterized by a small dam and a gravel island complex with numerous shallow secondary channels. Substrate consisted of loose gravel and sand and was not suitable for unionids. No evidence of unionids was observed.

Shoal 1

Shoal 1 was approximately 450 m downstream of Shoal at House underneath the County Road W bridge (Figure 3-4). This area was comprised of a deep pool with little discernable flow. As no unionids nor suitable habitat was observed, no qualitative or sediment samples were collected. Subsequent conversations with B. Angelo (USEPA) and S. Faiman (MDC) indicated that a mussel concentration was previously documented upstream of the County Road W bridge along a side channel. This side channel was investigated in 2017, and no live unionids were found, suggesting that this area no longer supports unionids.

Shoal 1A

Shoal 1A was approximately 10.7 km downstream of Shoal 1 and approximately 60 m downstream of the Old Highway

E bridge (Figure 3-4). This area was a shallow run with a water willow bed along the RDB. Substrate was comprised of stable gravel, cobble, and sand. Shells of *Alasmidonta viridis*, *F. flava*, *L. rafinesqueana*, *L. cardium*, *P. occidentalis*, and *V. ellipsiformis* were collected, but no live unionids were observed. As this area contained suitable unionid habitat, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected within Shoal 1A along the LDB in a fast-flowing chute containing pockets of silt. Pore water was sampled within the adjacent stream channel (USGS Site SH01A). Cadmium was below the limit of detection, lead concentration was 42.6 ug/g, and zinc concentration was 543.1 ug/g for a Sum-PEQ of 1.5 (Table 3-2).

Shoal 2

Shoal 2 was approximately 4.7 km downstream of Shoal 1A and approximately 1.4 km upstream of the Missouri Department of Conservation's Cherry Corner Access south of Diamond, Missouri (Figure 3-4). This area consisted of a shallow shoal with a riffle/run complex downstream, and the area of suitable unionid habitat was approximately 40 m long by 15 m wide for a total area of approximately 545 m^2. Substrate consisted of gravel, cobble, silt, and sand with a loose top layer (approximately 5 cm) over stable substrate. Despite suitable unionid habitat, no live unionids and only a few weathered dead shells were observed (Table 3-5). No sediment samples were collected at this site.

Shoal 2A

Shoal 2A was approximately 220 m downstream of Shoal 2 (Figure 3-4). This was a shallow shoal with substrate similar to Shoal 2; gravel, cobble, silt, and sand. Qualitative sampling was conducted, but no sediment samples were collected as sediments were collected approximately 1.5 km downstream at Shoal 5A and no obvious stream inputs were observed between 2A and 5A.

Habitat

Substrate within this area was a stable mix of gravel, cobble, silt, and sand with pockets of silt along the RDB. Depths were shallow, and this area was a run with suitable unionid substrate.

Unionid community

One (1) live *F. flava* was collected in a pocket of silt, and shells of *L. cardium*, *L. rafinesqueana*, *L. subrostrata*, *P. sintoxia*, and *P. occidentalis* were collected throughout the area (Table 3-5). Thirty (30) minutes of qualitative searching was spent in this area for a CPUE of 0.3 live unionids/10 minutes.

Shoal 3A

Shoal 3A was 190 m downstream of Shoal 2A (Figure 3-4). This area was a shallow run and riffle with high current velocities. Substrate was loose gravel, with silt pockets along the RDB. Two (2) live unionids were collected, but no evidence of a stable unionid community was present, and this area contained poor unionid habitat. As few unionids and

no suitable habitat was observed, no qualitative searches nor sediment sampling was conducted.

Shoal 4A, 4B, and 4C

These sites were clustered around the Cherry Corner Access, ranging from 400 m upstream to 150 m downstream of the access, and approximately 800 m downstream of Shoal 3A (Figure 3-4). This area consisted of runs and riffles with high current velocities. Substrate consisted of gravel, cobble, sand, and silt and was generally loose along the channel margins and consolidated within the main channel. Scattered unionid shells were present, but no live unionids were collected during initial reconnaissance searches.

Shoal 5 and 5A

Shoal 5 and Shoal 5A were approximately 600 m downstream of Cherry Corner Access and approximately 450 m downstream of Shoal 4C (Figure 3-4). A unionid community was identified along the RDB along an eroded clay bank at Shoal 5A; this community was approximately 90 m long by 5 m wide for a total area of approximately 500 m^2.

Habitat

Shoal 5A was upstream of a large riffle along the edge of a smooth 1.0 m deep run. The RDB was eroded clay, and the LDB was a gravel bar and cut clay banks. Silt was more prevalent along the RDB and substrate was coarser mid-channel and along the LDB. Unionids were restricted to within 5.0 m of the RDB in substrate of gravel, sand and silt.

Unionid community

A total of 121 live unionids of 7 species were collected at Shoal 5A (Table 3-5). *Fusconaia flava* (n=46), *E. dilatata* (n=30), and *P. sintoxia* (n=24) were the most commonly collected species. Additional species collected live included *L. cardium, L. rafinesqueana*, *P. occidentalis*, and *V. ellipsiformis*. *Alasmidonta viridis* and *S. undulatus* were present as weathered dead shells. A total of 180 minutes was spent qualitatively searching this area for a CPUE of 6.7 live unionids/10 minutes. No live unionids were found mid-channel or along the LDB, where substrate shifted to a coarse mix of gravel, cobble, and sand.

Sediment metal concentrations

Substrate samples were collected approximately 80 m upstream of Shoal 5A along the RDB (USGS Site SH05A). Cadmium was below the limit of detection, lead was present at a concentration of 102.8 ug/g, and zinc was present at a concentration of 1,533.1 ug/g for a Sum-PEQ of 4.1 (Table 3-2).

Shoal 6A

Shoal 6A was approximately 2.8 km downstream of Shoal 5A, upstream of the Missouri Department of Conservation Allen Bridge Access near the Nighthawk Road bridge (Figure 3-4). A small unionid community was found upstream of a riffle. This unionid concentration was approximately 20 m long by 9 m wide for a total area of approximately 175 m^2.

Habitat

Shoal 6A was upstream of a riffle in a shallow glide along the RDB. Substrate was a fairly stable mix of gravel, silt, cobble, and sand. Riparian zones along both banks were vegetated, and a gravel bar was present along the LDB.

Unionid community

Eight (8) live unionids of three species were collected at Shoal 6A: *F. flava* (n=5), *P. occidentalis* (n=2), and *P. sintoxia* (n=1; Table 3-5). *Eurynia dilatata* and *L. rafinesqueana* were represented by weathered dead shells. A total of 220 minutes was spent qualitatively searching for a CPUE of 0.4 live unionids/10 minutes. Unionids were scattered throughout this area and were buried approximately 5.0 cm in gravel, silt, cobble, and sand substrate.

Sediment metal concentrations

Sediment samples were collected approximately 40 m downstream of Shoal 6A along the LDB (USGS Site SH06A). Cadmium was not present above the limit of detection, lead was present at a concentration of 90.6 ug/g, and zinc was present at a concentration of 996.2 ug/g for a Sum-PEQ of 2.9 (Table 3-2).

Shoal 6

Shoal 6 was approximately 1.7 km downstream of Shoal 6A and 950 m downstream of the Allen Bridge Access (Figure 3-4). This area was a complex of gravel islands and secondary channels with an unstable gravel, cobble, sand, and silt substrate. Several pockets along the channel margins harbored stable habitat that unionids may be able to utilize. An approximately 500 m section of river was searched in this area with no live unionids collected. Shell material was present on banks but was likely washed down from an upstream location. As no live unionids were collected and suitable habitat was limited to small pockets, this site was not qualitatively searched, and no sediment samples were collected.

Shoal 7

Shoal 7 was approximately 3.1 km downstream of Shoal 6 just downstream of the Lime Kiln Drive bridge (Figure 3-4). This site was approximately 200 m downstream of a low head dam at the head of a riffle on the LDB. The area of suitable unionid habitat measured approximately 19 m long by 18 m wide for a total area of approximately 350 m^2. As this site had a known unionid community (S. Faiman, MDC, pers. comm.) and live unionids were collected during initial reconnaissance searches, this site was qualitatively searched.

Habitat

Shoal 7 was a shallow run upstream of a riffle with depths of approximately 0.5 m. Substrate was mostly gravel with some cobble, sand, and silt with a few centimeters of loose gravel overlying stable substrate. The RDB had a narrow riparian corridor and was cut with exposed tree roots, while the LDB was fully vegetated and appeared stable. The river was shaded by the trees along the LDB and the mussel bed was primarily within this shaded area.

Unionid community

A total of 7 live unionids of 2 species were collected during Shoal 7 qualitative searches (Table 3-5). *Fusconaia flava* (n=5) and *P. sintoxia* were the only species collected during qualitative searches, but 2 live *P. occidentalis* and 1 live *L. rafinesqueana* were collected during initial reconnaissance searches. A total of 50 minutes was spent qualitatively searching this site for a CPUE of 1.4 live unionids/10 minutes. Unionids were scattered throughout the site, buried under a few centimeters of loose gravel.

Sediment metal concentrations

Sediment samples were collected within the site along the RDB (USGS Site SH07). Cadmium levels were below the limit of detection, lead was present at a concentration of 48.5 ug/g, and zinc was present at a concentration of 850.6 ug/g for a Sum-PEQ of 2.2 (Table 3-2).

Shoal 8

Shoal 8 was approximately 9.0 km downstream of Shoal 7 and approximately 5.7 km upstream of Tipton Ford (Figure 3-4). Shoal 8 was downstream of a shallow riffle/pool and extended 60 m along the RDB. Unionids and suitable habitat was limited to within 5 m of the bank for a total area of 300 m^2.

Habitat

This site was a shallow run with stable substrate comprised of gravel, cobble, sand, and silt. A strip of water willow was present along the RDB, and the site was limited riverward where substrate transitioned to a loose mix of gravel and cobble. Both banks were impacted by human activity; a railway supported by a rip rap apron was present along the RDB and pastures were present along the severely-eroded LDB.

Unionid community

Thirty-five (35) live individuals of 4 species were collected at Shoal 8 (Table 3-5). *Fusconaia flava* (n=16) and *L. rafinesqueana* (n=13) were the most commonly collected species, followed by *L. cardium* and *P. sintoxia*. *Eurynia dilatata* and *T. metanevra* were present as weathered dead shells. Unionids were scattered throughout the site and were generally more common near the edge of the water willow bed. A total of 80 minutes was spent qualitatively searching for a CPUE of 4.4 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples were collected at the upstream end of the site along the RDB (USGS Site SH08). Cadmium was below the limit of detection, lead was present at a concentration of 65.1 ug/g, and zinc was present at a concentration of 823.8 ug/g for a Sum-PEQ of 2.3 (Table 3-2).

Shoal 10B

Shoal 10B was approximately 5.7 km downstream of Shoal 7 at Tipton Ford (Figure 3-4). This site was a narrow,

shallow (0.2 m) run located in a secondary channel along the LDB. The area of unionid habitat was approximately 5 m wide and 35 m long for a total area of 175 m^2. Unionids had previously been found in the main channel, within the riffle and pool (R. Angelo, USEPA, pers. comm.), however the only evidence of unionids in 2017 was within the secondary channel.

Habitat

Substrate within Shoal 10B was a stable mix of gravel, sand, and silt. This site was in a small side channel protected from high current velocities observed within the primary channel by a large pile of woody debris at the upstream end of the secondary channel. Areas within the main channel surrounding Shoal 10B was dominated by loose gravel.

Unionid community

One (1) live *F. flava* was collected during qualitative searches (Table 3-5). A total of 60 minutes was spent qualitatively searching this site for a CPUE of 0.2 live unionids/10 minutes. This individual was collected near the upstream end of the site in a mix of sand and silt.

Sediment metal concentrations

Sediments were collected within the secondary channel (USGS Site SH10B). Cadmium was below the limit of detection, lead was present at a concentration of 65.0 ug/g, and zinc was present at a concentration of 646.4 ug/g for a Sum-PEQ of 1.9 (Table 3-2).

Shoal 9A

Shoal 9A was approximately 19.4 km downstream of Shoal 10B and downstream of the Coyote Drive bridge (Figure 3-4). The reach of Shoal Creek between Shoal 10B and Shoal 9A was not investigated due to channel instability identified during the initial site selection process. Shoal 9A was characterized by large gravel bars and loose gravel substrate. No evidence of unionids nor suitable unionid habitat was present.

Shoal 10A

Shoal 10A was 500 m downstream of Shoal 9A underneath the old Canary Drive bridge (Figure 3-4). This area was a deep pool upstream of a large, swift riffle. Substrate within the pool was gravel and cobble with silt along the periphery and was consolidated gravel and cobble within the riffle and loose gravel along the edges. While no live unionids nor shell fragments were found, and this site did not contain suitable unionid habitat, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected within Shoal 10A (USGS Site SH10A). Cadmium was below the limit of detection, lead was present at a concentration of 77.9 ug/g, and zinc was present at a concentration of 1,208.3 ug/g for a Sum-PEQ of 3.2 (Table 3-2).

Shoal 11

Shoal 11 was approximately 280 m downstream of Shoal 10A (Figure 3-4). This area was characterized by a run/pool complex with a large gravel bar along the RDB. Banks exhibited signs of erosion, as the LDB was an undercut clay bank and the RDB consisted of loose gravel. Substrate was generally poor and was comprised of unstable gravel, cobble, and clay. One (1) weathered dead *L. rafinesqueana* valve was found, but no evidence of a unionid community was observed.

Shoal 12

Shoal 12 was along the inside bend of the river approximately 1.0 km downstream of Shoal 11 (Figure 3-4). This area was a large run downstream of a riffle, with substrate of gravel, silt, cobble, boulder, and sand. The overlying layer of substrate was loose, but appeared stable approximately 8.0 cm below the loose layer. No signs of a unionid community were present.

Shoal 13, 14, and 15

These sites were a series of runs ranging from 300 m to 650 m downstream of Shoal 12 (Figure 3-4). These areas were characterized by shallow, swift runs along gravel bars and riffles at the downstream end of the gravel bars. Substrate was similar across sites, consisting of loose gravel with some cobble and sand. Some fragments of unionid shell were found, but no live unionids were observed. While these areas did not have suitable unionid habitat nor a unionid community, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected along the RDB at three points within a 30 m stretch upstream of the riffle at Shoal 14 (USGS Site SH14). Cadmium was below the limit of detection, lead was present at a concentration of 150.8 ug/g, and zinc was present at a concentration of 1,682.6 ug/g for a Sum-PEQ of 4.8 (Table 3-2).

Shoal 15A

Shoal 15A was approximately 420 m downstream of Shoal 15 near the wastewater treatment plant (Figure 3-4). This area was a shallow, wide run with bedrock shelves along the LDB. The RDB was comprised of gravel, sand, and silt substrate where 1 live *L. cardium* was collected (Table 3-5). Old subfossil valves of *F. flava* and *P. sintoxia* were also found. Areas riverward consisted of very loose gravel, cobble, and sand. Qualitative searches were conducted along the RDB in slower flowing areas near water willow beds where sand and silt were present. A total of 30 minutes was spent searching for a CPUE of 0.3 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples were collected along the RDB near where the live *L. cardium* was found (USGS Site SH15A). Cadmium was below the limit of detection, lead was present at a concentration of 164.7 ug/g, and zinc was present at a concentration of 2,160.1 ug/g for a Sum-PEQ of 6.0 (Table 3-2).

Shoal 16

Shoal 16 was approximately 6.0 km downstream of Spring 15A at Schermerhorn Park, Kansas (Figure 3-4). This area was a pool/riffle/run complex with a gravel bar along the RDB. The LDB consisted of eroded clay banks, and the RBD consisted of either cut clay banks with vegetation or gravel bars. Depths varied, ranging from 1.5 m in the upstream end of the site in the pooled area to 0.3 m within the riffle at the downstream end. Substrate throughout the area consisted of loose gravel and small cobble, with sand more common along the LDB and silt along the RDB. Substrate was 'sorted' and not a heterogenous mix of substrate types. While no live unionids nor shell fragments were observed and habitat was generally poor, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected at the upstream end of Shoal 16 along the LDB in a pocket of sand and silt (USGS Site SH16). Cadmium was below the limit of detection, lead was present at a concentration of 94.2 ug/g, and zinc was present at a concentration of 1,237.5 ug/g for a Sum-PEQ of 3.4 (Table 3-2).

Shoal 16A

Shoal 16A was approximately 900 m downstream of Shoal 16, and 550 m downstream of the Highway 26 bridge at Schermerhorn Park (Figure 3-4). Despite seemingly suitable unionid habitat, no live unionids nor evidence of unionids was observed (Table 3-5). The area of suitable unionid habitat was approximately 55 m long by 22 m wide for a total area of approximately 1,240 m^2. As sediment samples were collected approximately 900 m upstream at Shoal 16, no sediment samples were collected at Shoal 16A.

Habitat

This site was a shallow run upstream of a riffle, with substrate comprised of a stable mix of cobble, gravel, and sand. Both banks were stable with a vegetated riparian corridor, although there was a small segment of fence extending into the stream along the RDB to allow livestock water access. Substrate at this site appeared more stable than other sites within this reach of Shoal Creek.

Unionid community

Although no unionids were observed during reconnaissance, this area contained the most stable habitat in this reach of Shoal Creek. A 60-minute qualitative search was conducted, but no unionids were found, and CPUE was 0 unionids/10 minutes (Table 3-5).

Shoal 17

Shoal 17 was 350 m downstream of Shoal 16A (Figure 3-4). This area was dominated by a large bluff along the LDB with bedrock extending into the stream. The RDB was a large gravel bar and substrate along the RDB to mid-channel was comprised of loose gravel and sand. Shells of *L. siliquoidea* and *L. cardium* were found along the gravel bar, but no live unionids and no suitable unionid habitat was observed.

Shoal 18

Shoal 18 was approximately 715 m downstream of Shoal 17 (Figure 3-4). This area was downstream of a deep pool at a bend of Shoal Creek and was characterized by a 250-m long riffle/run complex, with a high-velocity riffle along the LDB. Some bedrock was present at the head of the riffle along the RDB, and substrate throughout this area was mostly loose gravel and cobble. While no evidence of unionids was observed, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected along the LDB (USGS Site SH18). The concentration of cadmium was below the limit of detection, lead was present at a concentration of 103.3 ug/g, and zinc was present at a concentration of 1,515.3 ug/g for a Sum-PEQ of 4.1 (Table 3-2).

3.1.5 Neosho River

Six (6) sites were investigated on the Neosho River, ranging from approximately 19.5 km upstream to 2.5 km downstream of Miami, Oklahoma at the Interstate 44 bridge (Figure 3-5). Two streams that drain much of the TSMD mining area in Oklahoma and Kansas, Elm Creek and Tar Creek, enter the Neosho River within the study area. The objective of the reconnaissance in the Neosho River was to find 1 reference site and 1 site with a PEQ > 0.5.

Neosho 2

Neosho 2 was approximately 4.2 km upstream of the East 60 Road bridge (Stepps Ford Bridge) and approximately 10.5 km upstream of the confluence of Elm Creek (Figure 3-5). This area was dominated by a gravel bar along the RDB on the inside bend of the river and clay cut banks along the LDB. Substrate varied across the river; the RDB was dominated by loose gravel and silt, and shifted to bedrock mid-channel to the LDB. Flows increased towards the LDB, and water was much more turbid in the Neosho River than the Spring River or its tributaries. One (1) live *L. fragilis* was collected on the gravel bar, but no additional live unionids were found during the initial reconnaissance search, suggesting that this live individual was not part of a larger unionid community. Additional weathered dead shells were scattered along the bank and were likely washed down from an upstream source. As no unionid community was observed, no qualitative searches were conducted, but sediment samples were collected to document sediment toxicity in this reach of the Neosho River.

Sediment metal concentrations

Sediments were collected along the RDB within the site (USGS Site NR02). Both cadmium and lead were below the limit of detection and zinc was present at a concentration of 43.3 ug/g for a Sum-PEQ of 0.1 (Table 3-2).

Neosho 3

Neosho 3 was approximately 2.5 km downstream of Neosho 2, 1.5 km upstream of the Stepps Ford bridge, and 7.9 km upstream of Elm Creek (Figure 3-5). A large gravel bar was present along the inside bend of the river with steep clay cut banks along the outside (RDB) bend.

Habitat

Substrate was generally loose gravel along the gravel bar that transitioned to bedrock mid-channel with a small strip of clay along the RDB. The gravel substrate was more stable at this site than at Neosho 2, and clay was present with the gravel approximately 2.5 to 5.0 cm under the substrate. Both banks exhibited signs of instability, with the bank along the RDB a high (5.0 m) steep cut clay bank and the LDB a loose gravel bar.

Unionid community

Three (3) live unionids of two species, *Potamilus ohiensis* and *P. purpuratus*, were collected at Neosho 3 (Table 3-6). All three individuals were collected along the LDB on the periphery of the gravel bar in substrate of loose gravel. A total of 240 minutes was spent qualitatively searching this area for a CPUE of 0.1 live unionids/10 minutes.

Sediment metal concentrations

Sediment samples were collected at the upstream end of the site along the LDB, downstream of a gravel bar in a small pocket against an eroded bank (USGS Site NR03). Cadmium and lead were below the limit of detection, and zinc was present at a concentration of 43.3 ug/g for a Sum-PEQ of 0.1 (Table 3-2).

Neosho at Stepps Ford

Neosho at Stepps Ford was along the RDB approximately 1.9 km downstream of Neosho 3, 160 m downstream of the Stepps Ford bridge, and 5.9 km upstream of the confluence with Elm Creek (Figure 3-5). Live unionids were observed throughout this area on top of the substrate within pockets of gravel surrounded by patches of bedrock. Additionally, piles of live unionids were present on a small gravel bar extending through the site, suggesting that these individuals were gathered by a predator. This site was approximately 130 m long and 25 m wide for a total area of approximately 3,250 m^2.

Habitat

Substrate throughout this site was consistent with the reach of river downstream of the Stepps Ford bridge; bedrock shelves interspersed with gravel and cobble. Depths were shallow (up to 0.5 m) and current velocities were swift. A narrow gravel bar was riverward of the RDB and extended through the upstream section of the site.

Unionid community

A total of 141 live unionids of 7 species were collected at Neosho at Stepps Ford (Table 3-6). *Theliderma metanevra* (n=94), *C. pustulosa* (n=26), and *T. verrucosa* (n=17) were the most commonly collected species. Other species collected live included *L. cardium*, *O. reflexa*, *P. sintoxia,* and *P. purpuratus*. Several fresh dead *T. donaciformis* were collected on a gravel bar. A total of 40 minutes was spent qualitatively searching this site for a CPUE of 35.3 live unionids/10 minutes.

Sediment metal concentrations

Sediments were collected within the site along the RDB (USGS Site NRSF). Cadmium was below the limit of detection, lead was present at a concentration of 9.7 ug/g, and zinc was present at a concentration of 69.2 ug/g for a Sum-PEQ of 0.2 (Table 3-2).

Neosho 4

Neosho 4 was approximately 5.2 km downstream of the Stepps Ford bridge and 700 m upstream of Elm Creek (Figure 3-5). This site was within a deep run/pool along the LDB downstream of a gravel bar. Live unionids were observed in a strip of silt/clay along the bank downstream of the gravel bar. This strip of unionids was approximately 80 m long by 7 m wide for a total area of approximately 480 m^2.

Habitat

Habitat within the site varied from loose gravel along the gravel bar to clay and silt downstream of the gravel bar along the bank. Suitable unionid habitat was limited to this narrow strip along the LDB within approximately 7 m of the bank. Riverward substrate shifted to bedrock. Upstream substrate was loose sand and downstream the bank was full of woody debris. Substrate in the strip with unionids was generally compacted clay and silt, and unionids were found interspersed throughout this area. Woody debris and downed trees were common and little flow was present.

Unionid community

A total of 18 live unionids of 4 species were collected at Neosho 4; *P. purpuratus* (n=10), *L. fragilis* (n=5), *L. complanata* (n=2), and *T. verrucosa* (n=1; Table 3-6). A total of 60 minutes was spent qualitatively searching this site for a CPUE of 3.0 live unionids/10 minutes. All individuals were collected within the face of the clay bank and at the 'toe' of the bank in clay and silt substrate.

Sediment metal concentrations

Sediment samples were collected upstream of this unionid concentration along the gravel bar (USGS Site NR04). Cadmium and lead were present below the limit of detection and zinc was present at a concentration of 72.0 ug/g for a Sum-PEQ of 0.2 (Table 3-2).

Neosho 5

Neosho 5 was approximately 500 m downstream of Neosho 4, immediately downstream of the confluence with mining-impacted Elm Creek along the LDB and approximately 12 km upstream of the confluence with Tar Creek (Figure 3-5). This site was characterized by a steep compacted clay bank. Three (3) live *P. purpuratus* were collected during the initial reconnaissance search.

Habitat

This area was comprised of a deep pool with little current. Substrate was mostly compacted clay and silt along the banks,

with substrate of loose gravel and cobble riverward. Unionids were restricted to a strip of compacted clay and silt along the LDB. The Elm Creek confluence was at the upstream end of the site, but no obvious flow was coming from this input. Both banks were clay and were eroded, but not incised. Woody debris and dead trees were common.

Unionid community

Two (2) live *P. purpuratus* were collected during qualitative searches (Table 3-6). These individuals were scattered within the strip of suitable habitat. A total of 60 minutes was spent qualitatively searching this area for a CPUE of 0.3 live unionids/10 minutes.

Sediment metal concentrations

Sediments were collected below the Elm Creek confluence, within a small inlet with heavy silt deposits (USGS Site NR05). Cadmium and lead were below the limit of detection and zinc was present at a concentration of 65.0 ug/g for a Sum-PEQ of 0.1 (Table 3-2).

Neosho 6

Neosho 6 was along the LDB approximately 2.1 km downstream of Riverview Park in Miami, Oklahoma, 300 m downstream of the confluence of mining-impacted Tar Creek, and immediately downstream of the Interstate 44 bridge (Figure 3-5). This area was characterized by soft clay and silt banks, with a protected pocket of suitable unionid habitat and live unionids riverward of the bank. The area of unionids was approximately 20 m long by 10 m wide for a total area of 210 m^2.

Habitat

Habitat within the unionid concentration was unique compared to upstream sites investigated in the Neosho River. While the LDB was similar to upstream sites (clay cut banks), unionids were located riverward of the bank in substrate of silt and clay overlying stable gravel. Unionids were within a pocket downstream of the bridge that was protected from flow. Depths within this unionid concentration ranged from 0.6 m to approximately 2 m, and current velocity was low.

Unionid community

A total of 32 live unionids of 5 species were collected at Neosho 6 (Table 3-6). *Potamilus purpuratus* (n=18), *O. reflexa* (n=9), and *L. fragilis* (n=3) were the most commonly collected species. Additional species collected included *P. ohiensis* and *T. donaciformis*. A total of 60 minutes was spent qualitatively searching this area for a CPUE of 5.3 live unionids/10 minutes. Unionids were evenly distributed within the patch of suitable substrate.

Sediment metal concentrations

Sediment samples were collected 35 m upstream of Neosho 6, under an Oklahoma Trailway Bridge, and at a shallow area downstream along the LDB (USGS Site NR06). Cadmium was below the limit of detection, lead was present at a concentration of 42.9 ug/g, and zinc was present at a concentration of 229.6 ug/g for a Sum-PEQ of 0.8 (Table 3-2).

3.1.6 Tar Creek

Two (2) sites were investigated in Tar Creek (Figure 3-5). Tar Creek 1 was near Northeastern Oklahoma A&M College in Miami, Oklahoma, and Tar Creek 2 was located near the confluence with the Neosho River.

Tar Creek 1

Tar Creek 1 was an approximately 600 m reach of Tar Creek ranging from the East Central Avenue bridge to a pipeline crossing downstream of the Rockdale Boulevard bridge (Figure 3-5). This reach was included runs and riffles with bedrock substrate, narrow stream width, and shallow water depth. Small pockets of loose gravel and sand occurred throughout the reach, but unionid habitat was poor. No evidence of unionids was observed. As contamination is known within Tar Creek, sediment samples were collected.

Sediment metal concentrations

Sediment samples were collected approximately 180 m upstream of the East Central Avenue bridge and from eroded bank material mixed with organic detritus on top of bedrock (USGS Site TC01). Cadmium was below detection, lead concentration was 203.6 ug/g, and zinc concentration was 4,794.3 ug/g for a Sum-PEQ of 12.0 (Table 3-2).

Tar Creek 2

Tar Creek 2 was approximately 2.1 km downstream of Tar Creek 1 and approximately 900 m upstream of the confluence with the Neosho River (Figure 3-5). Habitat within this area differed from Tar Creek 1; this area was a deep pool with no discernable flow and had substrate of silt, clay, and woody debris. A bedrock shelf was present along the RDB with an abrupt drop off into fine sediments. No evidence of unionids was observed.

Sediment metal concentrations

Sediment samples were collected at the downstream end of the site along the RDB where bedrock was covered by a clay bank (USGS Site TC02). Cadmium was below the limit of detection, lead was present at a concentration of 280.5 ug/g, and zinc was present at a concentration of 2,217.5 ug/g for a Sum-PEQ of 7.0 (Table 3-2).

3.1.7 Lost Creek

One (1) site was investigated on Lost Creek due to reports of a known historic unionid population. This site was approximately 5.5 km upstream of Wyandotte, Oklahoma and is impacted by the Newton County, Missouri Designated Waste Area (Figure 3-6).

Lost Creek 1

Lost Creek was a small stream with a run/riffle/pool complex and clear water. Substrate was loose gravel with some cobble and sand, and compact clay shelves along the LDB. The stream was shallow (<0.5 m) with some deeper (1.5 m) pools. Banks were cut along the outside bends and showed signs of instability. The landowner indicated that unionids

were present before 2015 flooding, and substrate had been siltier prior to the floods. Some fragments of shell were observed but no live unionids were observed.

3.2 Quantitative Site Selection

3.2.1 North Fork Spring River

One (1) reference site was needed in the Nork Fork Spring River. Of the 2 sites sampled on the North Fork, North Fork 2 was selected for the quantitative study due to the larger size of the bed and the higher abundance of unionids (Figure 2-2, Table 3-1, Table 3-7).

3.2.2 Spring River

The objective in the Spring River was to select 2 reference sites upstream of Center Creek, 2 sites between Center Creek and Empire Reservoir, and 2 sites downstream of Empire Reservoir. Spring 1A and Spring 3 were selected as the 2 reference sites upstream of Center Creek (Figure 2-2, Table 3-7). Spring 1A was a larger site than Spring 1B and more easily accessible. Spring 3 was selected as a smaller area with a lower density of unionids, yet with a reference level of sediment metal contaminants (Figure 2-2, Table 3-3, Table 3-7). Three (3) sites were selected between Center Creek and Empire Reservoir with Sum-PEQs between 1.1 and 2.7. The Spring River between Center Creek and Empire Reservoir was fairly swift, with loose gravel or bedrock comprising most of the substrate. Only 5 sites were found with live mussels in this reach: Spring 5, Spring 6, Spring 8A, Spring 8B, and Spring 10C (Table 3-3). Spring 6 and Spring 8A were extremely small and would be difficult to sample quantitatively. Spring 5, Spring 8B, and Spring 10C were selected due to live unionids, suitable unionid habitat, and size (Figure 2-2, Table 3-7). Five (5) sites were selected downstream of Empire Reservoir with Sum-PEQs ranging from 2.3 to 2.9. Unionids were found at 6 sites below Empire Reservoir: Spring 12B, Spring 12C, Spring 13, Spring 19, Spring 20, and Spring 22 (Table 3-3). Spring 12C was selected rather than Spring 12B as unionid habitat was better at Spring 12C (Figure 2-2, Table 3-7).

3.2.3 Center Creek

The objective in Center Creek was to select 1 reference site and 2 sites with Sum-PEQs >0.5. Only a few sites were found in Center Creek with unionids and suitable habitat, but these sites represent a wide range of Sum-PEQs. Unionids were found at 3 sites upstream of Highway 171; Center 0, Center 1G2, and Center 1F (Table 3-4). Center 0 (Sum-PEQ = 0.7; low) and Center 1G2 (Sum-PEQ = 0.3; reference) were selected for quantitative sampling due to unionid abundance, habitat characteristics, and location within Center Creek (Figure 2-2, Table 3-7). Downstream of Highway 171, Center 3 and Center 5D were the only sites that harbored unionids, and 2 additional sites had suitable unionid habitat (Center 7 and Center 10B; Table 3-4). Center 5D (Sum-PEQ=3.5), Center 7 (Sum-PEQ=19.1), and Center 10B (Sum-PEQ = 6.9) were selected for quantitative sampling due to unionid abundance, habitat characteristics, location within the river, and level of sediment metal contaminants (Figure 2-2, Table 3-7).

3.2.4 Shoal Creek

The objective in Shoal Creek was to select 1 reference site and at least 2 sites with Sum-PEQ > 0.5. Unionids were found at 8 sites in Shoal Creek, and 2 additional sites had suitable unionid habitat; Shoal at Smackout, Shoal 2, Shoal 2A, Shoal 5A, Shoal 6A, Shoal 7, Shoal 8, Shoal 10B, Shoal 15A, and Shoal 16A (Table 3-5). Shoal 5A, Shoal 8, Shoal 10B, and Shoal 16A were selected for quantitative sampling due to unionid abundance, suitable habitat, location within the river, and level of sediment metal contaminants (Sum-PEQ >0.5; Figure 2-2, Table 3-7). No sites with suitable unionid habitat and Sum-PEQ < 0.5 were identified.

3.2.5 Neosho River

The objective in the Neosho River was to select at least 1 reference site and 1 site with Sum-PEQ >0.5. Unionids were found at all 5 sites on the Neosho River (Table 3-6). Neosho at Stepps Ford (Sum-PEQ = 0.2) and Neosho 6 (Sum-PEQ = 0.8) were selected for quantitative sampling due to unionid abundance, suitable habitat, and location within the Neosho River, particularly in respect to Tar Creek (Figure 2-2, Table 3-7).

3.2.6 Tar Creek

As the 2 sites investigated on Tar Creek were devoid of live unionids and suitable unionid habitat, no sites were selected for further quantitative sampling.

3.2.7 Lost Creek

As the 1 site investigated on Lost Creek did not harbor live unionids nor suitable habitat, this site was not selected for further quantitative sampling.

3.3 2017 Quantitative Survey

3.3.1 North Fork Spring River

North Fork 2 (Sum-PEQ Category = Low)

Habitat

North Fork 2 was in the main channel of the river and consisted of a smooth run. Riparian zones along the LDB and RDB were intact (>10 m wide), and the stream was mostly shaded. Substrate was stable, and the gravel bar at the upstream end of the site had not shifted significantly between the 2016 reconnaissance survey and the 2017 quantitative survey. Depths ranged from 0.05 m to 0.85 m, and averaged 0.38 m (Table 3-8). Depths were greatest along the RDB at the upstream end of the site, immediately downstream of a riffle. Current velocity ranged from 0.00 to 0.52 ft./second, with the swiftest current at the upstream end of the site downstream of the riffle. Substrate was dominated by a stable gravel/cobble mix, with a D_{50} of 33 mm and a D_{84} of 51 mm.

Unionid community

A total of 167 live unionids of 11 species were collected in quantitative samples for an average density of 6.7 (±1.2) live unionids/m^2 (Table 3-9). Unionids were distributed evenly throughout the site. Juvenile unionids comprised 3.6% of

unionids collected for a density of 0.2 (±0.2) live unionids/m^2. Species composition was similar to what was found during the reconnaissance survey, with *A. plicata* (n=51), *T. verrucosa* (n=36), *F. flava* (n=25), and *E. dilatata* (n=20) the most commonly collected species. Other species collected include *F. ozarkensis*, *L. complanata*, *L. costata*, *L. fragilis*, *P. sintoxia*, *C. pustulosa*, and *V. ellipsiformis*. Additional species collected as weathered dead shell included *L. rafinesqueana* and *Q. quadrula*. Two (2) species, *L. cardium* and *S. undulatus*, were found in qualitative searches but not in quantitative samples (Table 3-1). Mortality was low (0.6%), with 1 fresh dead *C. pustulosa* collected. *Corbicula fluminea* were scarce, with a density of 0.4 (±0.2) live individuals/m^2.

3.3.2 Spring River

Spring 1A (Sum-PEQ Category = Reference)

Habitat

Spring 1A was in the main channel of the Spring River and extended bank to bank, with the upstream limit of the site marked by a riffle. Riparian zones along the LDB and RDB were intact, and tree cover shaded the river near the banks. A stable gravel bar covered with *Justicia americana* was present along the LDB in the middle of the site. Depth averaged 0.74 m and was greatest mid-channel (Table 3-10). Current velocity ranged from 0.00 to 1.70 ft./second and was greatest at the upstream end of the site immediately downstream of the riffle. Substrate was a stable, heterogenous mix of gravel, cobble, and silt with sporadic boulders and bedrock. Silt and clay were common along the LDB. D_{50} and D_{84} were 30 and 58 mm, respectively.

Unionid community

A total of 217 live unionids of 16 species were collected in quantitative samples, and density averaged 8.7 (±2.2) live unionids/m^2 (Table 3-11). While unionids were collected throughout the area, the downstream portion of the site yielded most of the live individuals. Similar to the reconnaissance survey, *C. pustulosa* (n=72), *T. verrucosa* (n=33), *P. sintoxia* (n=32), *F. flava* (n=23), and *L. rafinesqueana* (n=23) were the most commonly collected species. Additional species collected live include *A. plicata*, *C. aberti*, *E. dilatata*, *F. ozarkensis*, *L. cardium*, *L. siliquoidea*, *L. costata*, *L. fragilis*, *P. occidentalis*, *T. cylindrica*, and *T. metanevra*. Five (5) additional species collected as shell only included *C. tuberculata*, *O. reflexa*, *S. undulatus*, *Q. quadrula*, and *V. ellipsiformis*. *Alasmidonta marginata* was the only species collected in qualitative samples that was not found in quantitative samples (Table 3-3). Adults comprised a majority of the unionid assemblage, with a density of 8.0 (±2.0) live unionids/m^2. Mortality was low, with fresh dead individuals comprising 3.6% of all unionids collected. *Corbicula fluminea* were commonly encountered, with a density of 2.5 (±0.8) live *C. fluminea*/m^2.

Spring 3 (Sum-PEQ Category = Reference)

Habitat

Spring 3 was a smooth, slow run in a secondary channel of the Spring River. Much of the area surrounding the river had natural cover, but a house/yard was present along the RDB near the downstream end of the site. Depths were generally shallow, ranging from 0.35 m to 0.81 m and averaged 0.51 m (Table 3-10). Depths were greatest along the LDB, where

the bank was slightly cut. Current velocity was low, due to a slight pooling from a downstream gravel bar, and averaged 0.15 ft./second. Substrate was generally a stable mix of gravel and cobble, but finer constituents that may assist in stabilization, such as sand or clay, were lacking. D_{50} was 23 mm and D_{84} was 36 mm.

Unionid community

A total of 48 live unionids of 10 species were collected at Spring 3, and density averaged 3.2 (±1.3) live unionids/m^2 (Table 3-11). Juvenile unionids were infrequently encountered at a rate of 0.1 (±0.2) live juveniles/m^2. Species composition was similar to the 2016 reconnaissance survey, with *C. pustulosa* (n=15), *F. flava* (n=13), and *T. verrucosa* (n=6) the most commonly collected species. Additional species collected included *A. plicata*, *E. dilatata*, *F. ozarkensis*, *L. rafinesqueana*, *L. complanata*, *L. fragilis*, and *P. sintoxia*. Two (2) species, *T. metanevra* and *L. cardium*, were found in qualitative searches and not in quantitative samples (Table 3-3). Unionids were generally more abundant along the LDB, and no evidence of mortality was observed. Similar to Spring 1A, *C. fluminea* density was 2.1 (±0.8) live individuals/m^2.

Spring 5 (Downstream of Center Creek; Sum-PEQ Category = Low)

Habitat

Spring 5 was in a narrow secondary channel along the RDB approximately 1.4 km downstream of Center Creek, and habitat was a smooth run behind a large island. No obvious habitat changes were observed between the 2016 reconnaissance survey and 2017. Riparian zones along both banks were intact (>10 m wide) and provided shade for the secondary channel. Depths were consistently shallow throughout the site, and averaged 0.32 m (Table 3-10). Current velocity ranged from 0.09 to 2.15 ft./second, and was fastest along the RDB. Substrate was a stable mix of gravel, cobble, and sand, with a D_{50} of 28 mm and a D_{84} of 42 mm.

Unionid community

Seventy-two (72) live unionids of 11 species were collected at Spring 5, and density averaged 3.8 (±1.3) live unionids/m^2 (Table 3-11). Species composition was similar to the 2016 reconnaissance survey, with *P. sintoxia* (n=21), *C. pustulosa* (n=17), *T. verrucosa* (n=12), and *L. rafinesqueana* (n=11) the most commonly collected species. Additional species collected included *E. dilatata*, *F. flava*, *L. cardium*, *L. fragilis*, *O. reflexa*, *P. occidentalis*, and *T. cylindrica*. An additional 2 species were collected as weathered dead shells; *A. plicata* and *T. metanevra*. *Venustaconcha ellipsiformis* was the only species found during qualitative searches that was not recovered in quantitative samples (Table 3-3). Unionids were evenly distributed throughout the site, although both *T. cylindrica* were collected along the RDB at the 'toe' of the clay bank. Juvenile unionids were more abundant at Spring 5 than at upstream sites, comprising 19.4% of the unionid community for a density of 0.7 (±0.4) live juvenile unionids/m^2. Two (2) fresh dead unionids were collected for a mortality rate of 2.7%. *Corbicula fluminea* density was similar to upstream sites, averaging 2.9 (±1.3) live individuals/m^2.

Spring 8B (Downstream of Turkey Creek; Sum-PEQ Category = Low)

Habitat

Spring 8B was approximately 2.8 km downstream of Turkey Creek along an inside bend of the Spring River downstream of a small gravel bar. The LDB was steeply cut throughout this reach, and the riparian zone was narrow (<10 m) with fields/grazing land beyond. Sediment deposition was evident, with a small gravel bar located upstream of the site and areas of feathery silt/clay near the LDB. This site harbored the only suitable unionid habitat observed in this reach of river; much of the substrate upstream was bedrock and boulder, and riverward of Spring 8B substrate was loose gravel. Substrate within Spring 8B was a relatively stable mix of gravel, sand, silt, clay, and cobble (Table 3-10). D_{50} (13 mm) and D_{84} (26 mm) were lower than upstream sites due to a higher percentage of sand, silt, and clay. Depths ranged from 0.19 to 0.73 m, with depth increasing with distance from shore. Current velocities were low, averaging 0.05 ft./second.

Unionid community

Despite collecting 6 live unionids during the initial reconnaissance survey, quantitative samples yielded only 1 live juvenile *L. fragilis* for a density of 0.1 (±0.1) live unionids/m^2 (Table 3-11). This individual was collected in similar habitat where live unionids were collected during the reconnaissance survey; near the bank in somewhat stable gravel with a substantial portion of silt and clay. Species collected in qualitative searches included *L. cardium* and *P. purpuratus* (Table 3-3). *Corbicula fluminea* were present at a density of 0.4 (±0.3) live individuals/m^2 and were more common near the bank.

Spring 10C (Upper end of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 10C was a pool at the upstream end of a small secondary channel approximately 6.1 km downstream of Turkey Creek. Both banks were forested, and the site was mostly shaded. Substrate was mostly cobble and and gravel, with an underlying layer of silt and clay (Table 3-10). D_{50} and D_{84} were 26 mm and 50 mm, respectively. Depth ranged from 0.36 to 1.21 m, and velocity was ≤0.16 ft./second.

Unionid community

Spring 10C supported a very low density unionid community. Only 1 juvenile *L. teres* and 1 adult *C. pustulosa* were collected in quantitative samples, and density averaged 0.1 (±0.2) live unionids/m^2 (Table 3-11). Additional species found during the qualitative search included *A. plicata*, *L. cardium*, and *L. rafinesqueana* (Table 3-3). *Corbicula fluminea* were also scarce, with density averaging 0.1 (±0.2) live *C. fluminea*/m^2.

Spring 12C (Downstream of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 12C was approximately 13.5 km downstream of Shoal Creek and consisted of a complex secondary channel along the RDB of the Spring River containing a deep pool, swift riffle, and smooth runs. This site ran the length of the secondary channel, and the RDB consisted of a steep forested hill with a scattering of houses. Substrate throughout the

site was generally a stable mix of gravel, cobble, sand, silt, and clay, with an area of loose gravel in the pooled area mid-site and areas of embedded gravel and cobble in an area of shallow riffles extending downstream of the pool (Table 3-10). D_{50} and D_{84} were slightly larger than at upstream sites due to the abundance of cobble, measuring 42 and 72 mm, respectively. Depths were generally shallow, averaging 0.31 m. Current velocity ranged from 0.00 ft./second within the pool to 1.14 ft./second within the riffle complex, and averaged 0.16 ft./second.

Unionid community

A total of 18 live unionids of 6 species were collected at Spring 12C, and density averaged 0.7 (±0.3) live unionids/m^2 (Table 3-11). Species composition was similar to what was observed during the reconnaissance survey, with *L. cardium* (n=5), *L. fragilis* (n=3), *O. reflexa* (n=3), *P. purpuratus* (n=3), *T. verrucosa* (n=3), and *T. donaciformis* (n=1) collected alive. Juveniles comprised 33% of live unionids, for a density of 0.2 (±0.2) live juveniles/m^2. *Corbicula fluminea* density averaged 1.2 (±0.8) live individuals/m^2, with the majority aggregated in weathered dead shell collected in quadrats.

Spring 13 (Downstream of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 13 was a run within the main channel of the Spring River approximately 17.2 km downstream of Shoal Creek, with most of the site situated along both banks. Both banks had a full (>10 m wide) riparian zones, and this reach of river had few gravel bars. Depth averaged 0.33 m, reaching 0.67 m mid-channel (Table 3-10). Current velocity was low (0.00 ft./second) in areas near the bank, but reached 1.46 ft./second mid-channel. Substrate was coarse at this site, consisting of a moderately stable mix of gravel, cobble, and boulder. D_{50} and D_{84} were 61 and 110 mm, respectively.

Unionid community

Eight (8) live unionids of 5 species were collected at Spring 13, and density averaged 0.3 (±0.2) live unionids/m^2 (Table 3-11). *Tritogonia verrucosa* (n=3) and *O. reflexa* (n=2) were the most commonly collected species, with 1 live individual each of *L. cardium*, *P. purpuratus*, and *T. donaciformis*. Juveniles comprised 12.5% of the community, and 1 fresh dead *P. purpuratus* was collected for a mortality rate of 11.1%. Unionids were most commonly encountered along the LDB in embedded gravel and cobble. *Corbicula fluminea* were scattered throughout the site, with density averaging 1.3 (±0.5) live individuals/m^2.

Spring 19 (Downstream of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 19 was in a moderately swift run along the LDB of the main channel of the Spring River approximately 27.3 km downstream of Shoal Creek. The riparian zone along the LDB was intact (>10 m wide), and trees provided shade throughout the site. While there were no gravel bars within the site, a large gravel bar/island occurred on the opposite side of the river. While much of the river between the Peoria Aquaculture Facility and Spring 19 was dominated by loose gravel, this site was a stable mix of gravel and cobble, with boulder and bedrock shelves common along the LDB (Table 3-10). Due to large substrate components, D_{50} (55 mm) and D_{84} (110 mm) were amongst the largest at sites investigated

on the Spring River. Depths were generally shallow, ranging from 0.22 to 0.66 m. Current velocities were swift, averaging 0.96 ft./second.

Unionid community

A total of 25 live unionids of 5 species were collected at Spring 19, and density averaged 1.3 (±0.5) live unionids/m^2 (Table 3-11). Species composition was similar to what was observed during the reconnaissance survey, with *O. reflexa* (n=10) and *L. cardium* (n=7) comprising a majority of species collected. Additional species collected live include *L. fragilis*, *P. purpuratus*, and *T. donaciformis*. *Lampsilis rafinesqueana* and *T. verrucosa* were collected in qualitative samples, suggesting that these species occur at a low density. Juveniles were present for all species except *P. purpuratus* for a juvenile density of 0.4 (±0.3) live individuals/m^2. Unionids were found throughout the site, but were concentrated in a 'seam' along the bank where substrate transitioned from bedrock/boulder near the bank to looser gravel riverward. Distribution of *C. fluminea* generally followed unionid distribution, and were present at a density of 1.1 (±0.6) live individuals/m^2.

Spring 20 (Downstream of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 20 was approximately 27.3 km downstream of Shoal Creek, across the river from Spring 19, in a secondary channel between the RDB of the Spring River and an island mid-river. This site was characterized by a swift chute/run over a stable substrate of gravel and cobble, with silt/clay and sand along the LDB of the secondary channel and patches of bedrock along the RDB, where current velocities were greatest (Table 3-10). D_{50} and D_{84} were 28 and 45 mm, respectively. Depths and current velocities followed a similar gradient; shallow and slow along the LDB, and deep and swift along the RDB. Current velocity was fastest along the RDB, reaching 4.03 ft./second.

Unionid community

Nineteen (19) live unionids of 5 species were collected in Spring 20, and density averaged 0.8 (±0.4) live unionids/m^2 (Table 3-11). Species composition was generally similar to what was observed during the reconnaissance survey, with *O. reflexa* (n=10) and *L. cardium* (n=4) the most commonly collected species. Additional species collected live include *L. fragilis*, *P. purpuratus*, and *T. verrucosa*. Species collected only as shells include *E. lineolata*, *L. siliquoidea*, *Q. quadrula*, and *T. truncata*. *Lampsilis teres* was the only species in qualitative samples that was not represented in quantitative samples (Table 3-3). Unionids were generally scattered evenly throughout the site in areas of compact, stable gravel, sand, and cobble. Recruitment was evident, as juveniles accounted for 21.1% of all unionids for a density of 0.2 (±0.2) live individuals/m^2. Mortality was highest among all Spring River sites, with 13.6% collected as fresh dead shells. *Corbicula fluminea* were collected throughout the site, and density averaged 1.4 (±0.5) live individuals/m^2.

Spring 22 (Downstream of Empire Reservoir; Sum-PEQ Category = Low)

Habitat

Spring 22 was within the main channel of the Spring River, on the riverward side of a large island along the LDB

approximately 30.2 km downstream of Shoal Creek. This site was generally a smooth, shallow run over a stable mix of gravel and cobble (Table 3-10). This site was upstream of a large gravel bar, and a loose, superficial layer of cobble overlaid stable substrate beneath. D_{50} and D_{84} were 33 and 64 mm, respectively. Depths were consistent throughout the site, ranging from 0.28 to 0.49 m, and current velocities were swift, averaging 1.59 ft./second. This site was adjacent to a farm along the LDB, and cattle were observed in-stream at the downstream end of the site.

Unionid community

Seven (7) live unionids of 3 species were collected at Spring 22, and density averaged 0.3 (±0.2) live unionids/m^2 (Table 3-11). *Lampsilis cardium* (n=4), *O. reflexa* (n=2), and *L. fragilis* (n=1) comprised the unionid community. *Potamilus purpuratus* and *T. donaciformis* were present as weathered dead shell, but *P. purpuratus* along with *T. verrucosa* were found live in qualitative searches (Table 3-3). No juvenile nor fresh dead shells were collected. Unionids were generally more common along the riverward section of the site, where substrate was more consolidated.

3.3.3 Center Creek

Center 0 (Sum-PEQ Category = Low)

Habitat

Center 0 was in a narrow, shallow stretch of Center Creek characterized by a large riffle/run complex amongst numerous gravel bars and islands. Center 0 itself was a small site located at the head of a riffle, with a small pool upstream. Much of the land surrounding this site was vegetated, providing shade throughout most of the site. Depths ranged from 0.18 to 0.65 m, with the greatest depths occurring at the upstream end of the site in a small pool (Table 3-12). Current velocities averaged 0.92 ft./second, with velocity highest at the downstream end of the site at the downstream end of a riffle. Substrate was generally a stable mix of gravel, cobble, and sand, with a D_{50} of 22 mm and a D_{84} of 59 mm.

Unionid community

Six (6) live unionids of 3 species were collected at Center 0, and density averaged 1.6 (±1.7) live unionids/m^2 (Table 3-13). Species composition was generally similar to what was observed during the reconnaissance survey, with *E. dilatata* (n=2), *F. flava* (n=2), and *V. ellipsiformis* (n=2) collected. Species found during qualitative searches but not in quantitative samples included *L. rafinesqueana*, *L. siliquoidea*, and *P. occidentalis* (Table 3-4). Juveniles comprised a majority of unionids collected, accounting for 83.3% of the catch. Density of *C. fluminea* at Center 0 was the highest among all Center Creek sites, averaging 58.7 (±54.3)/m^2 live individuals, with the highest density occurring in the middle of the site.

Center 1G2 (Sum-PEQ Category = Reference)

Habitat

Center 1G2 was in a secondary channel along the RDB of the Spring River. This was an isolated pocket during the reconnaissance, but opened to the river on the downstream end during quantitative sampling. Cooler water was present in the pocket possibly due to a spring. The surrounding areas were characterized by numerous gravel bars, while the site

had more consolidated substrate owing to finer sediments interspersed. This site was a run that flowed over a mix of gravel, sand, silt, and clay with minor percentages of cobble and bedrock (Table 3-12). D_{50} and D_{84} were 17 and 33 mm, respectively. Depths ranged from 0.11 to 0.57 m, and averaged 0.38 m. Current velocities ranged from 0.00 ft./second at the upstream end to 0.90 ft./second at the downstream end where it flowed into the river. Substrate was more stable in the upstream portion of this site, and looser gravel in the faster flowing downstream portion.

Unionid community

Three (3) live unionids of 2 species were collected at Center 1G2, and density averaged 0.2 (±0.2) live unionids/m^2 (Table 3-13). Species composition was similar to what was observed during the initial reconnaissance survey, with *F. flava* (n=2) and *L. subrostrata* (n=1) collected in quantitative samples. Additional species collected as weathered dead shells include *E. dilatata*, *L. rafinesqueana*, *P. sintoxia*, and *V. ellipsiformis*. *Lampsilis siliquoidea* was found during qualitative searches (Table 3-4). Live unionids were primarily in the slower flowing upstream portion of the site. Density of *C. fluminea* was much lower than at Center 0, occurring at a density of 2.3 (±1.4) live individuals/m^2. *Corbicula fluminea* were primarily in the looser substrate at the downstream end of the site.

Center 5D (Sum-PEQ Category = Low)

Habitat

Center 5D was a small site characterized by a swift riffle/run along the LDB of the Center Creek upstream of the confluence with Bens Branch. Substrate was a very loose mix of gravel, cobble, and sand with some boulder (Table 3-12). Substrate appeared less stable in 2017 than during the 2016 reconnaissance survey, when this site was determined to have stable, suitable unionid habitat. Loose gravel was fairly deep during 2017, suggesting it was washed in during high discharge events that occurred just prior to sampling. D_{50} and D_{84} were 29 and 58 mm, respectively. Depths averaged 0.49 m, and current velocities were swift, averaging 1.04 ft./second.

Unionid community

No live unionids were collected at Center 5D (Table 3-13). One (1) weathered dead *A. plicata* was collected, in contrast to the 2016 reconnaissance survey, where 12 live individuals of 4 species were collected. Substrate was much looser during the 2017 quantitative survey, suggesting that this site may have been overwhelmed by a slug of gravel during the previous year. *Corbicula fluminea* were scarce, occurring at a density of 0.3 (±0.4) live individuals/m^2.

Center 7 (Sum-PEQ Category = High)

Habitat

Center 7 was within a narrow secondary channel along the LDB of the Spring River approximately 600 m downstream of the confluence with Bens Branch. This site was characterized by a riffle/run complex running over a stable mix of gravel and cobble over clay (Table 3-12). D_{50} and D_{84} were 39 and 64 mm, respectively. Center 7 was consistently shallow, with depths ranging from 0.13 to 0.36 m. Current velocities averaged 0.47 ft./second, with flows greatest mid-site immediately downstream of a small riffle.

Unionid community

No live unionids were collected at Center 7, but 5 species were represented by weathered dead shells: *E. dilatata*, *F. flava*, *L. rafinesqueana*, *P. sintoxia*, and *T. verrucosa* (Table 3-13). While no live unionids were collected, *C. fluminea* were present at a density of 21.3 (±10.7) live individuals/m^2.

Center 10B (Sum-PEQ Category = Medium)

Habitat

Center 10B was approximately 16.6 km downstream of Bens Branch, and was a narrow site along the LDB of Center Creek, downstream of a large riffle. The area surrounding Center 10B was a large, swift riffle upstream of the site and a smooth deep run riverward of the site. Substrate within Center 10B was a stable mix of gravel, boulder, and cobble, with interstitial silt, clay and sand (Table 3-12). Due to the abundance of boulder, D_{50} and D_{84} were high at 58 and 410 mm, respectively. Depths were shallow, averaging 0.49 m, and depths increased with distance from shore. Current velocities were generally low, averaging 0.30 ft./second, and were highest at the upstream end of the site closer to the downstream end of the large riffle.

Unionid community

Despite seemingly suitable habitat, no live unionids nor *C. fluminea* were collected in quantitative samples (Table 3-13).

3.3.4 Shoal Creek

Shoal 5A (Sum-PEQ Category = Medium)

Habitat

Shoal 5A was along the RDB of Shoal Creek in a deep run upstream of a riffle. *Justicia americana* beds were present at the upstream end of the site. Depths averaged 0.69 m and ranged from 0.27 to 1.06 m (Table 3-14). Depths were generally consistent throughout the site, with depth increasing with distance from shore. Current velocities ranged from 0.03 to 1.20 ft./second, and were greatest at the riverward extent of the site. Substrate was a stable, heterogenous mix of gravel, cobble, silt, clay, and sand. D_{50} was 30 mm and D_{84} was 55 mm.

Unionid community

Fifty-four (54) live unionids of 6 species were collected at Shoal 5A, and density averaged 2.2 (±0.9) live unionids/m^2 (Table 3-15). Species composition was similar to the reconnaissance survey, with *F. flava* (n=30), *E. dilatata* (n=8), and *P. sintoxia* (n=8) the most commonly collected species. Additional species collected live include *L. cardium*, *P. occidentalis*, and *V. ellipsiformis*. One species, *L. rafinesqueana*, was collected during qualitative searches that was not found in quantitative samples (Table 3-5). Unionids were evenly distributed throughout the site, and all were collected in stable but unconsolidated mix of gravel, cobble, and sand. *Corbicula fluminea* were frequently encountered, and density averaged 24.6 (±6.1) live individuals/m^2.

Shoal 8 (Sum-PEQ Category = Low)

Habitat

Shoal 8 was in a shallow run along the RDB downstream of a riffle. Substrate within the site was a stable mix of gravel, cobble, sand, and boulder, with pockets of silt along the bank (Table 3-14). Substrate was looser riverward of the site. D_{50} was 24 mm and D_{84} was 72 mm. Depths averaged 0.39 m, and depths were consistent throughout the site, ranging from 0.27 to 0.54 m. Current velocities were moderate, averaging 0.25 ft./second and were highest riverward.

Unionid community

Nineteen (19) live unionids of 6 species were collected for a density of 1.5 (±0.8) live unionids/m^2 (Table 3-15). Species composition was similar to what was observed during the reconnaissance survey, with *F. flava* (n=7), *P. sintoxia* (n=6) and *L. rafinesqueana* (n=3) comprising the majority of unionids collected. Additional species collected included *L. cardium* and two species not collected in qualitative samples: *P. occidentalis* and *T. metanevra*. *Eurynia dilatata* was represented by a weathered dead individual and no fresh dead individuals were collected. Recruitment was low, with juveniles accounting for 5.3% of individuals. Unionids were generally more common near the bank, where suitable habitat was adjacent to a bed of water willow. *Corbicula fluminea* were abundant throughout the site, and density (123.1 [±18.2]) was highest among all study sites.

Shoal 10B (Sum-PEQ Category = Low)

Habitat

Shoal 10B was in a shallow, swift secondary channel along the LDB of Shoal Creek. This site harbored the best unionid habitat in this reach of river, which was generally characterized by swift current and loose gravel. Substrate within Shoal 10B was a stable mix of gravel, silt, sand, and clay (Table 3-14). D_{50} and D_{84} were 16 and 30 mm, respectively. Depths ranged from 0.10 to 0.36 m, and were highest at the upstream end of the site. Current velocities were swift, reaching 1.51 ft./second at the shallow downstream end of the site.

Unionid community

No live unionids were collected in quantitative samples (Table 3-15). *Corbicula fluminea* were common, occurring at a density of 40.8 (±17.7) live individuals/m^2.

Shoal 16A (Sum-PEQ Category = Low)

Habitat

Shoal 16A was in a smooth, shallow run upstream of a large riffle complex. Depths ranged from 0.17 to 0.76 m, and averaged 0.46 m (Table 3-14). Current velocities were greatest at the downstream end of the site, immediately upstream of a riffle. Velocities ranged from 0.36 to 1.66 ft./second and averaged 1.09 ft./second. Substrate was a loose mix of gravel and cobble, with sand present in interstitial spaces. D_{50} and D_{84} were 49 and 81 mm, respectively.

Unionid community

No live unionids were collected in quantitative samples (Table 3-15). *Corbicula fluminea* were scarce, occurring at a density of 0.4 (±0.2) live individuals/m^2.

3.3.5 Neosho River

Neosho at Stepps Ford (Sum-PEQ Category = Reference)

Habitat

This site was downstream of the Stepps Ford bridge along the RDB of the Neosho River and was characterized by swift current, river-wide shoals, and patches of bedrock. While the RDB was steeply cut, the riparian zone was intact (>10 m wide) with old pasture/grazing land beyond. Substrate was dominated by patches of either bedrock or stable gravel, with cobble interspersed (Table 3-16). D_{50} and D_{84} were 26 and 44 mm, respectively. Depths were shallow, averaging 0.20 m, and current velocities were swift, ranging from 0.10 to 2.77 ft./second, and averaging 1.15 ft./second.

Unionid community

Thirteen (13) live unionids of 4 species were collected at Stepps Ford, and density averaged 0.5 (±0.4) live unionids/m^2 (Table 3-17). *Theliderma metanevra* (n=7) was the most commonly collected species, followed by *T. verrucosa* (n=3), *C. pustulosa* (n=2), and *L. fragilis* (n=1). Species found during qualitative searches but not found in quantitative samples included *P. sintoxia*, *L. cardium*, *O. reflexa*, and *P. purpuratus* (Table 3-6). While live unionids were observed scattered throughout the site during the initial reconnaissance survey, the majority of live unionids collected in quantitative samples were along the RDB in a side chute separated from the main channel by a bedrock island. Bedrock patches occurred throughout the site, and although some unionids were laying on the bedrock, most were between these patches. Although density averaged 0.5 (±0.4) live unionids/m^2, density between the bedrock patches was much higher. Juvenile unionids comprised 23.1% of all unionids collected, and no mortality was observed. *Corbicula fluminea* were concentrated along the RDB, and density averaged 0.7 (±0.5) live individuals/m^2.

Neosho 6 (Sum-PEQ Category = Low)

Habitat

Neosho 6 was approximately 10 m riverward of the LDB, approximately 300 m downstream of Tar Creek and immediately downstream of the Interstate 44 bridge. This site was a small mound of suitable habitat that was shallower than the surrounding area. Whereas substrate of the surrounding area was mostly clay and silt, Neosho 6 was a stable mix of gravel, silt, clay, and sand, with sporadic cobble (Table 3-16). Because of the high percentage of fine substrate constituents, D_{50} and D_{84} were low; measuring 1 and 29 mm, respectively. Depths ranged from 0.15 to 1.69 m, with depths greatest along the shoreward portion of the site, and current velocities were low, averaging 0.09 ft./second.

Unionid community

A total of 12 live unionids of 4 species were collected, and density averaged 1.2 (±0.8) live unionids/m^2 (Table 3-17). Similar to the reconnaissance survey, *P. purpuratus* (n=6) was the most commonly collected species. Additional species

collected live include *L. fragilis*, *O. reflexa*, and *C. pustulosa*. *Potamilus ohiensis* and *T. donaciformis* were collected in qualitative samples but absent in quantitative samples (Table 3-6). Unionids were found throughout the site, in habitat ranging from embedded clay/silt among cobble at the upstream end to a looser gravel/clay mix at the downstream end. Juveniles comprised 8.3% of unionids collected for a density of 0.3 (±0.4) live individuals/m^2. One (1) fresh dead *P. purpuratus* was collected for a mortality rate of 7.7%.

4.0 Discussion

Mining has occurred throughout the Spring River watershed and portions of the Neosho River watershed over the past 100+ years. Angelo et al. (2007) conducted a mussel survey throughout the Spring River basin to determine if this mining activity had affected unionid mussel communities. Low species richness and abundance of mussels appeared to be correlated with higher levels of lead, zinc, and cadmium, however, additional quantitative data was needed to confirm the correlation. The objective of this study was to collect quantitative mussel community data (density, richness, recruitment, mortality, community composition) from sites throughout the Spring and Neosho River watersheds for comparison with zinc, lead, and cadmium concentrations in sediment, water, and tissue. As most quantitative sites were located within the Spring River, and influences of mining-affected tributaries (Center Creek, Turkey Creek, Shoal Creek) allowed comparison between sites upstream and downstream of these tributaries, most of this discussion is focused on the Spring River.

Unionid mussel habitat in the Spring River basin appears to have changed over the past 10 years since Angelo et al. (2007). Unionid mussel physical habitat is generally described as stable substrate (not mobile during high discharge events) with sufficient softer substrate to allow burrowing, but sufficient current velocity during low discharge to prevent sediment accumulation (Vaughn, 1997). Other important habitat parameters include sufficient flow to deliver dissolved oxygen, calcium, and food; temperatures allowing spawning and glochidia release; and water and sediment free of toxins (Strayer, 2008). Stream areas that typically harbor mussel communities include shoals (shallow areas with flowing water), areas above and below riffles, edges of deeper runs, and secondary channels. Sites initially selected for reconnaissance sampling eliminated river areas where the channel has changed coarse since 1963 based on GIS comparison of past and present river channel locations (unstable channel), and focused on areas where mussels were previously found (Angelo et al., 2007; MDC, USFWS, Peoria Tribe of Indians, pers. comm.) and near riffles and shoals, where stable mussel habitat typically occurs.

Several high discharge events have occurred since Angelo et al. (2007), and river banks throughout the study area showed signs of severe erosion. Trees fallen into the rivers from collapsed river banks formed gravel bars consisting of loose gravel that likely shifts during high discharge events. Many of the sites where Angelo et al. (2007) found mussels (i.e. Spring 12A, Shoal 10B) and MDC (S. McMurray and S. Faiman, pers. comm.) found mussel communities (i.e. Shoal 1) were devoid of mussels in the 2016 and 2017 surveys.

Only 22 sites distributed throughout the survey area had stable physical habitat and were selected for quantitative sampling; 1 site on the North Fork Spring, 2 sites on the Spring upstream of Center Creek, 3 sites between Center Creek and Empire Reservoir, and 5 sites downstream of Empire Reservoir; 5 sites on Center Creek; 4 sites on Shoal Creek; and 2 sites on the Neosho River (Figure 2-2, Table 2-2). Sites were typically in areas protected from high discharge (secondary channels or thin strips along channel edges downstream of some feature that diverted flow) where substrate had a clay base that added stability to gravel, cobble, and sand.

Despite occurring in stable physical habitat areas, mussel density and species richness in many sites was low, and preliminary XRF sediment samples indicated all but 1 of the qualitatively sampled sites (SP03) had some lead, zinc, and/or cadmium present in sediments (Table 3-2). Most of the previous mining activity in these watersheds occurred within Bens Branch watershed in Center Creek (between CC05D and CC07), within Turkey Creek (SP07), throughout Lost and Shoal Creek, and within Tar Creek (between NR05 and NR06) (Table 3-2; Figure 4-1).

Zinc was the only contaminant in XRF samples in the North Fork Spring River and Spring River upstream of Center Creek and Sum-PEQ was ≤0.6, unionid density was >3.0 unionids/m^2, and species richness was ≥10 at these sites (Table 3-7). Species richness and density at Spring 5, just downstream of Center Creek, was similar to Spring 3. Although Sum-PEQ was high at the lower end of Center Creek (12.3; Table 3-2), Sum-PEQ at Spring 5 was low (1.1). Turkey Creek seemed to have a much higher influence on contamination in Spring River than Center Creek. Turkey Creek entered the Spring River in a back channel, and during periods of low discharge, water flows upstream to the head of a large island, near SP06 and down the opposing side channel. Sum-PEQ at SP07 at the mouth of Turkey Creek was medium (4.6) and was low but above 2.1 throughout the remainder of the Spring River, with additional input from Shoal Creek (SH18; medium) into Empire Reservoir (Figure 4-1). Unionid density declined significantly downstream of Turkey Creek (SP08B) and recovered somewhat below Empire Reservoir (SP12C; Table 3-11; Figure 4-2). A similar pattern was observed in CPUE (Figure 4-3) and species richness (Figures 4-4 and 4-5; Table 3-7), suggesting that upstream mining activities affected downstream study sites through lower unionid density and species richness.

Although density was much lower in tributaries to the Spring River (Center and Shoal Creek, and Neosho River), mining effects were apparent. In Center Creek, density, CPUE, and species richness were all higher upstream of Bens Branch than downstream (Figures 4-2 to 4-5), and Sum-PEQ was ≤3.5 upstream and ≥11.0 downstream (Table 3-2). Mussels were found at Center 5D in a strip on the LDB in 2016, however the area was covered by loose gravel in 2017 and no mussels were found. Unionids at this site seem to be affected by unstable habitat. No live mussels were found downstream of Bens Branch. In the side channel at Center 7 (Sum-PEQ 19.1, approximately 600 m downstream of Bens Branch), fresh and weathered shells of 12 species were found burrowed in the substrate during qualitative sampling, but there was no evidence of live individuals. No sign of live or dead mussels was found at Center 10B.

Stable substrate areas were lacking throughout most of Shoal Creek, but a few sites with suitable habitat were found. Habitat had changed at sites where Angelo et al. (2007) and MDC previously found unionid communities and no mussels were found at Shoal 1, and areas of unionid habitat throughout Shoal Creek were small. Stable unionid habitat was found in thin strips along the bank at Shoal 5A and Shoal 8 and in a secondary channel at Shoal 10B; a low density of unionids was found at Shoal 5A and Shoal 8 and 1 live unionid and several shells were recovered in the secondary channel at Shoal 10B. The head of the riffle at Shoal 16A also had stable unionid habitat, although no unionids were found. The density of mussels does not seem to clearly relate to Sum-PEQ in Shoal Creek (Table 3-7).

Sum-PEQ in all sites in the Neosho River was <1.0 (Table 3-2). Tar Creek entered the Neosho River between Neosho 5

and Neosho 6 and elevated the Sum-PEQ from ≤0.2 upstream of Tar Creek to 0.8 downstream. Lead was absent upstream of Tar Creek. However, low density unionid communities were found both up and downstream.

Although habitat stability in much of the Spring River watershed has decreased since Angelo et al. (2007), 22 stable habitat areas were quantitatively sampled. Aggregated site data indicates a negative correlation between unionid community metrics and preliminary sediment toxicity. Qualitative CPUE was negatively correlated ($r^2 = 0.48$) with sediment toxicity (Figure 4-1). Similarly, quantitative species richness ($r^2 = 0.29$) and density ($r^2 = 0.28$) had a weak negative correlation with sediment toxicity (Figure 4-2; Figure 4-3).

The Spring River had a sufficient number of sites to detect a significant decline in unionid density downstream of Turkey Creek with an elevated Sum-PEQ. Although few sites with stable habitat were found in Center Creek, no live unionids were found within stable habitat areas downstream of Bens Branch. Similar to Center Creek, the two highest-quality unionid sites on Shoal Creek were upstream of the Newton County, Missouri Designated Waste Area. These general longitudinal patterns, along with the negative correlations between unionid community metrics and sediment toxicity, suggest that sediment metal concentrations have negatively impacted the unionid community of the Spring River basin.

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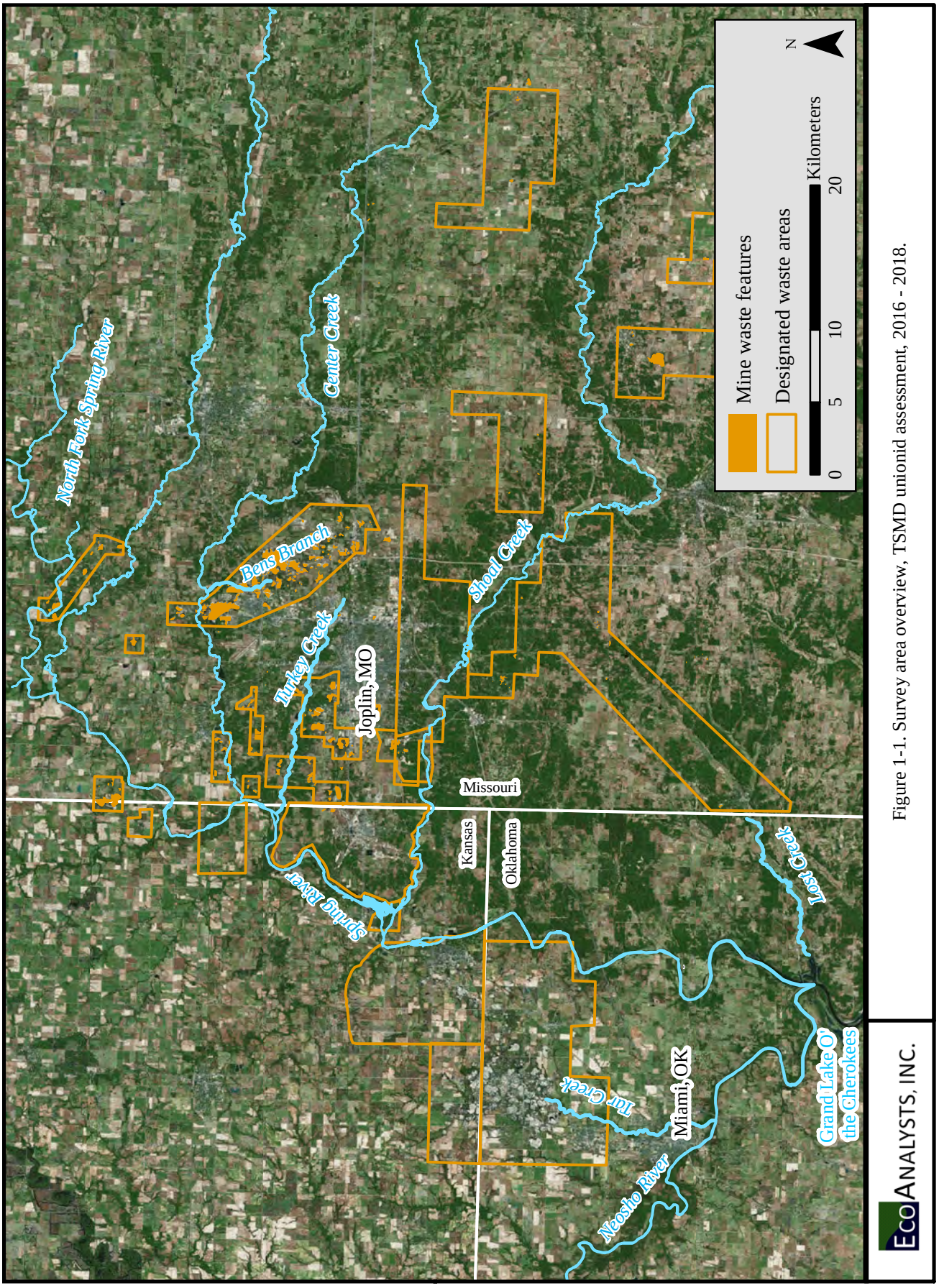

Figure 1-1. Survey area overview, TSMD unionid assessment, 2016 - 2018.

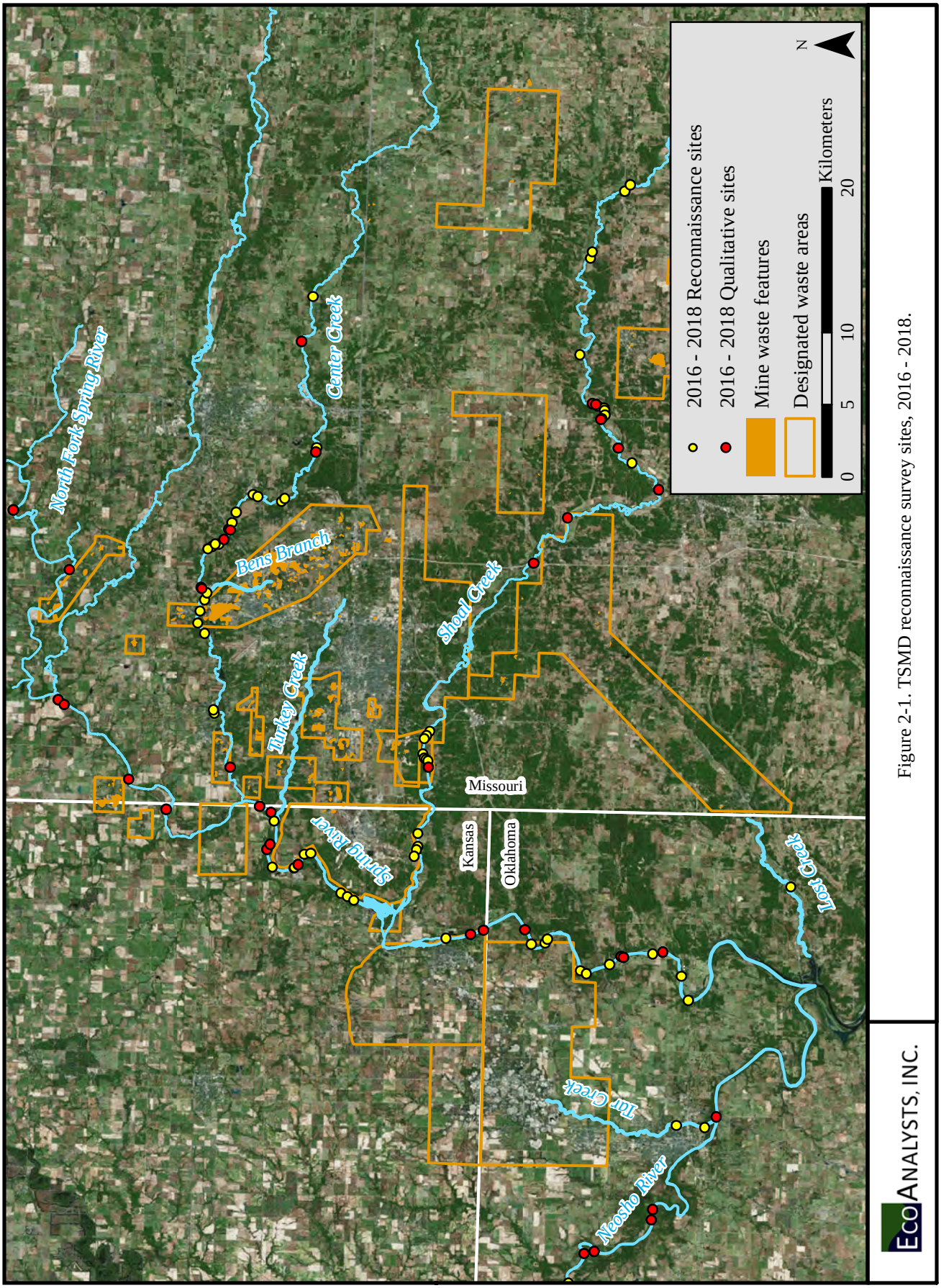

Figure 2-1. TSMD reconnaissance survey sites, 2016 - 2018.

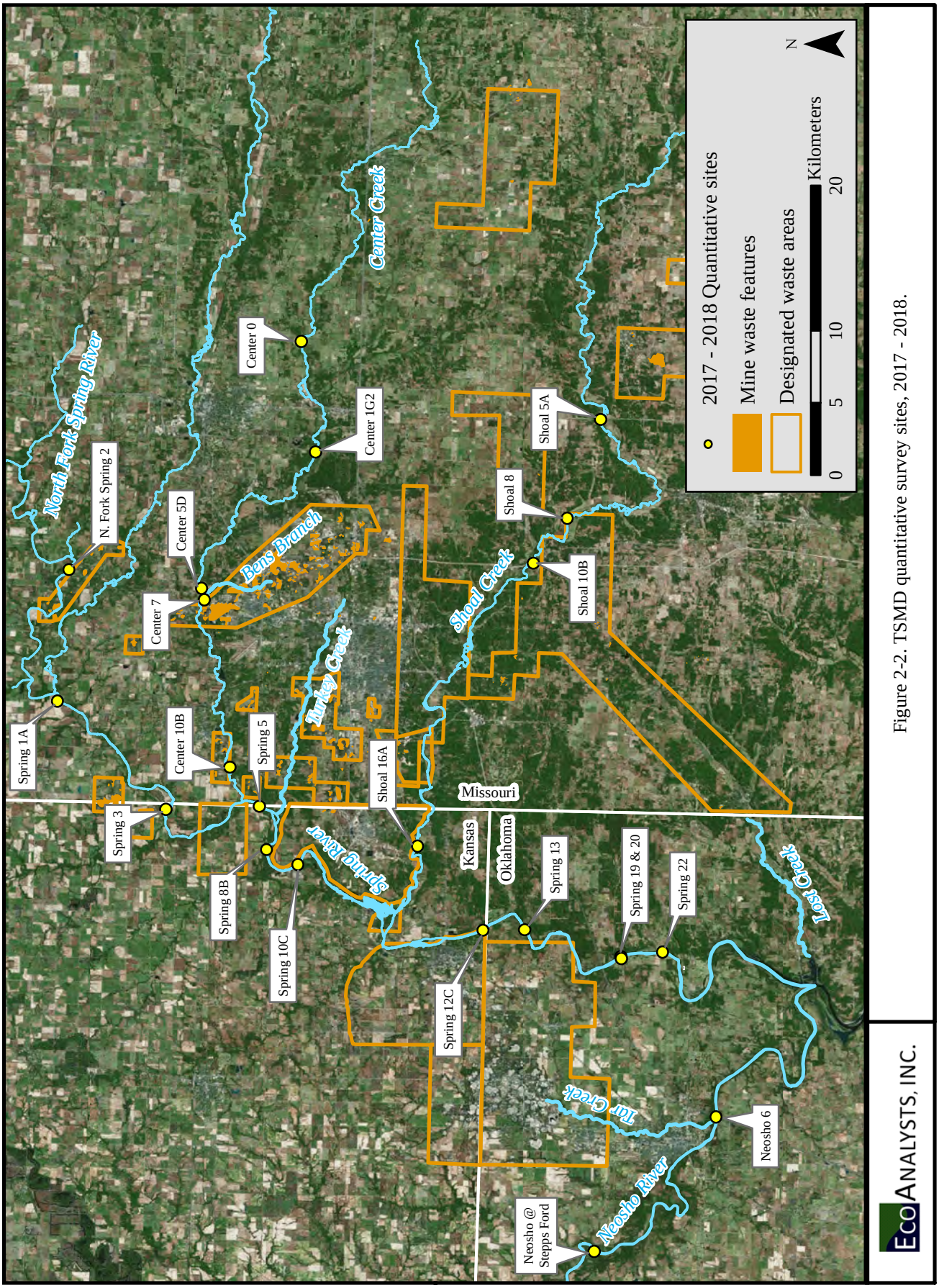

Figure 2-2. TSMD quantitative survey sites, 2017 - 2018.

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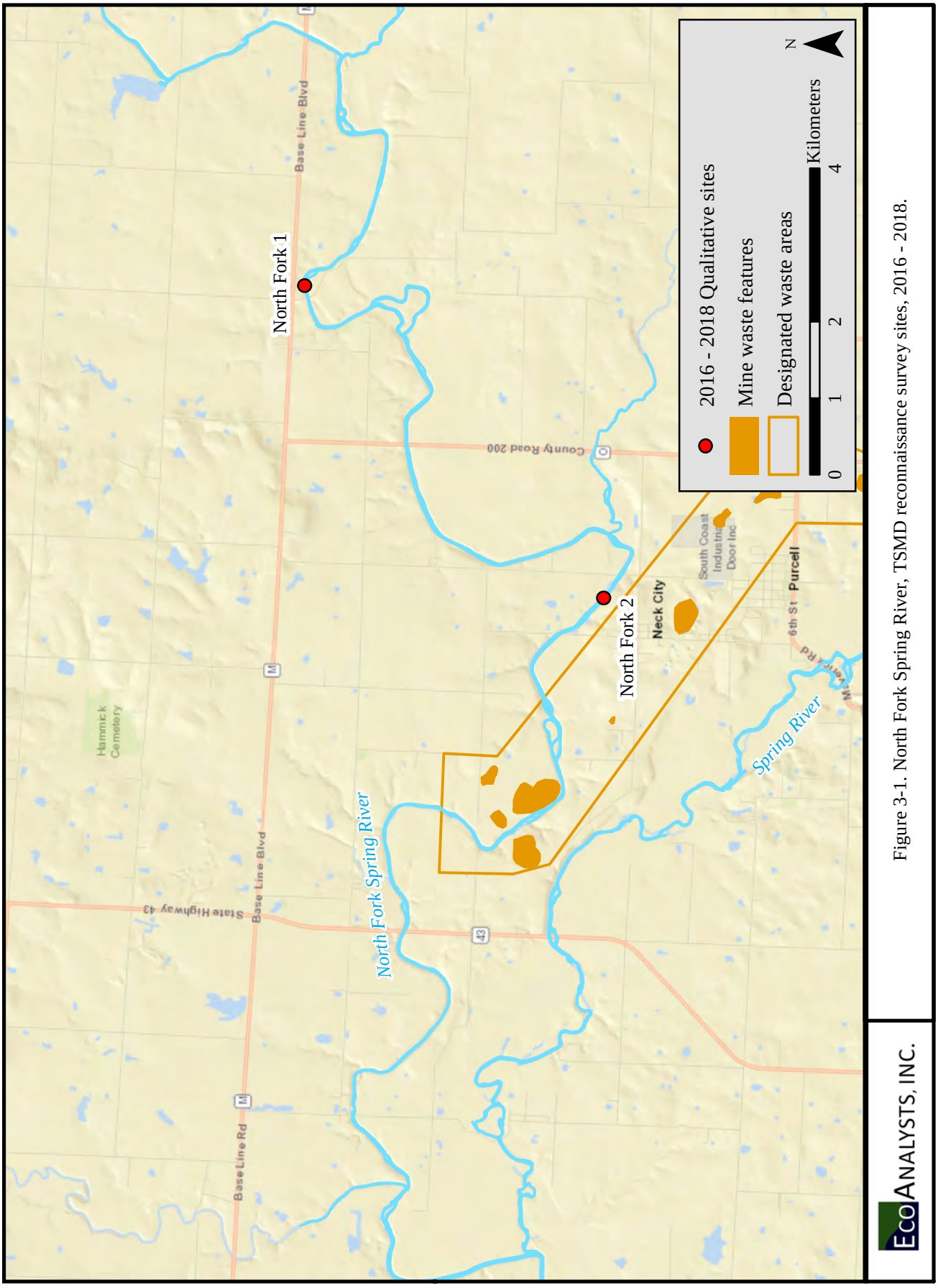

Figure 3-1. North Fork Spring River, TSMD reconnaissance survey sites, 2016 - 2018.

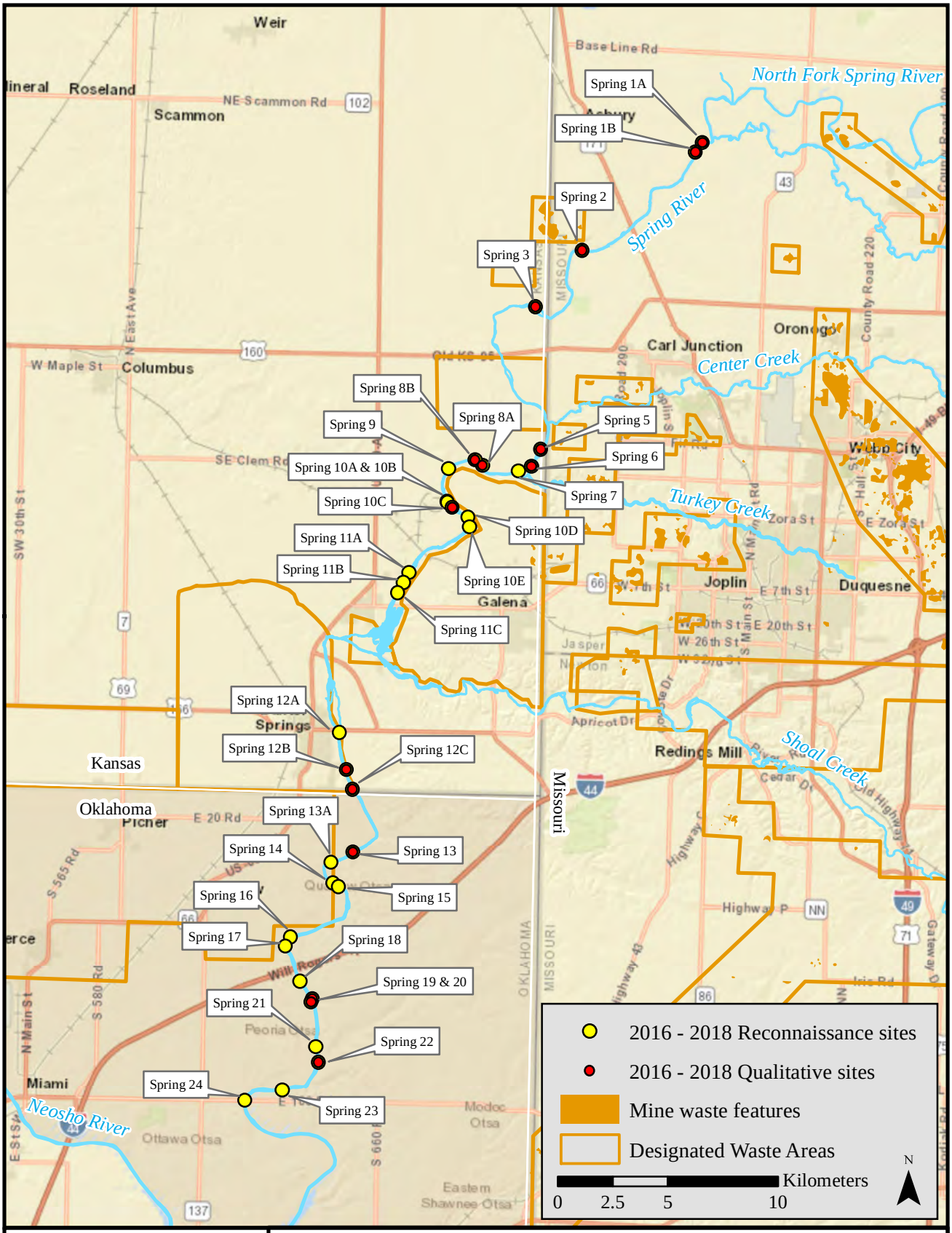

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Figure 3-2. Spring River, TSMD reconnaissance survey sites, 2016 - 2018.

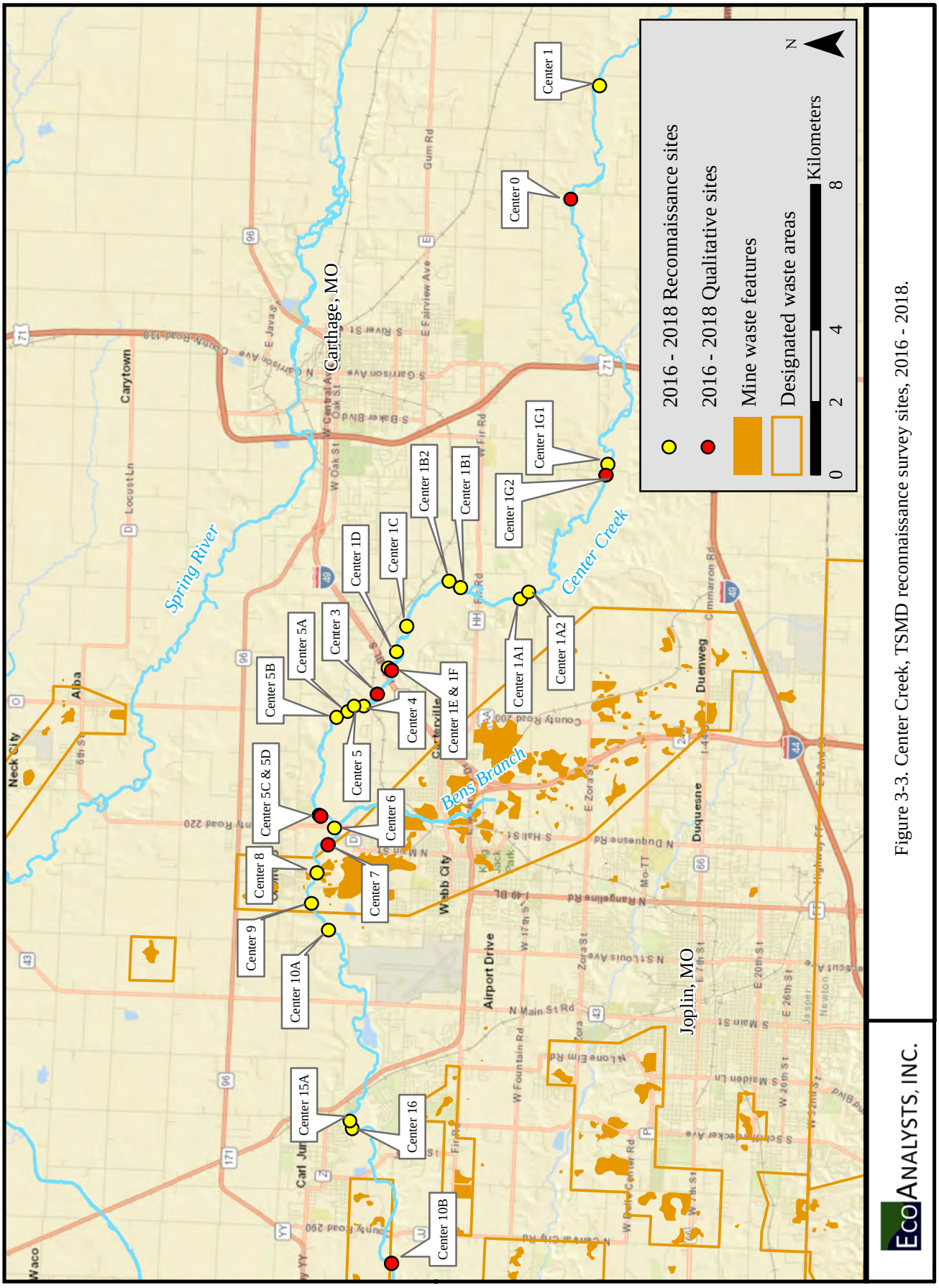

Figure 3-3. Center Creek, TSMD reconnaissance survey sites, 2016 - 2018.

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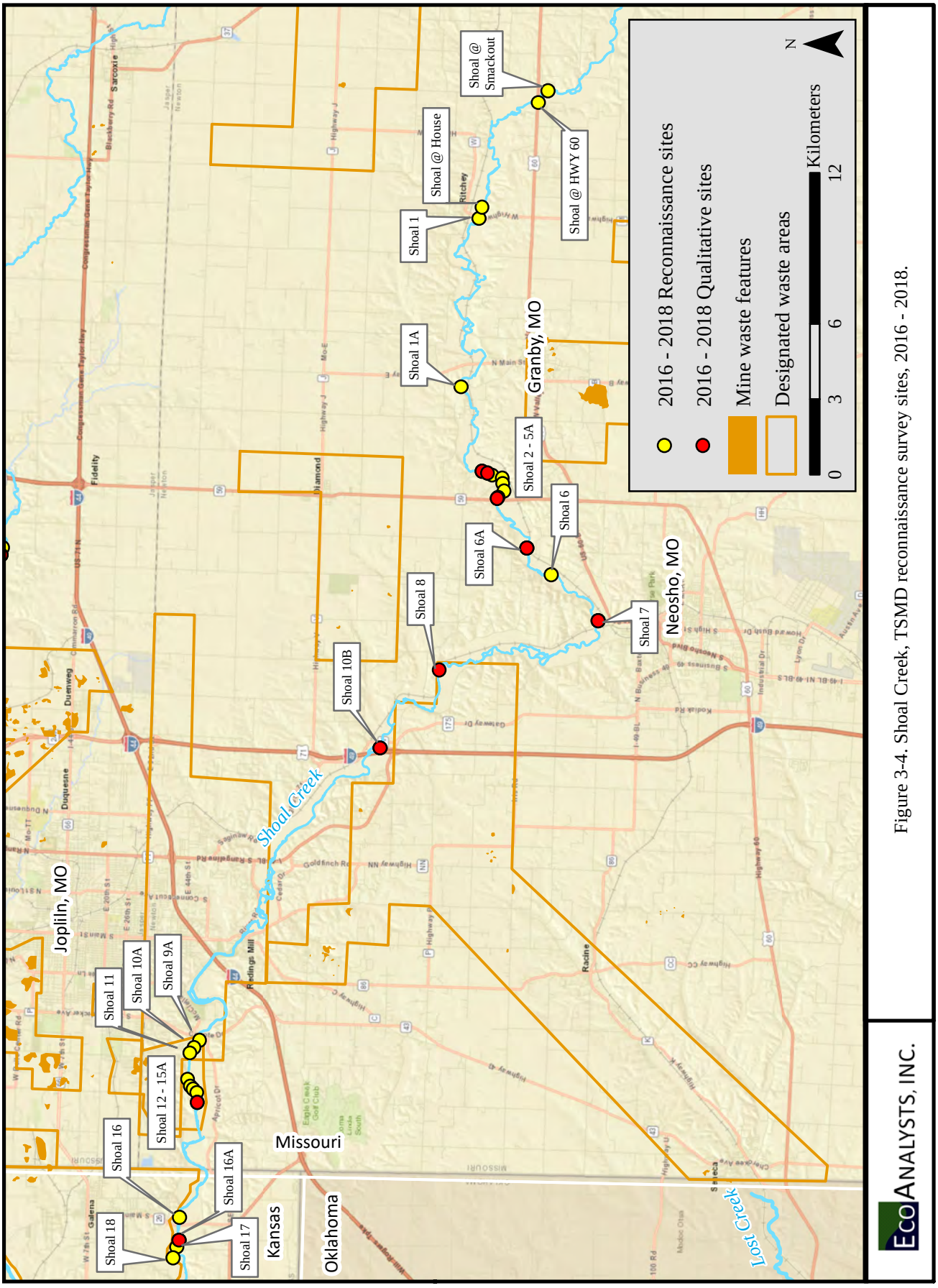

Figure 3-4. Shoal Creek, TSMD reconnaissance survey sites, 2016 - 2018.

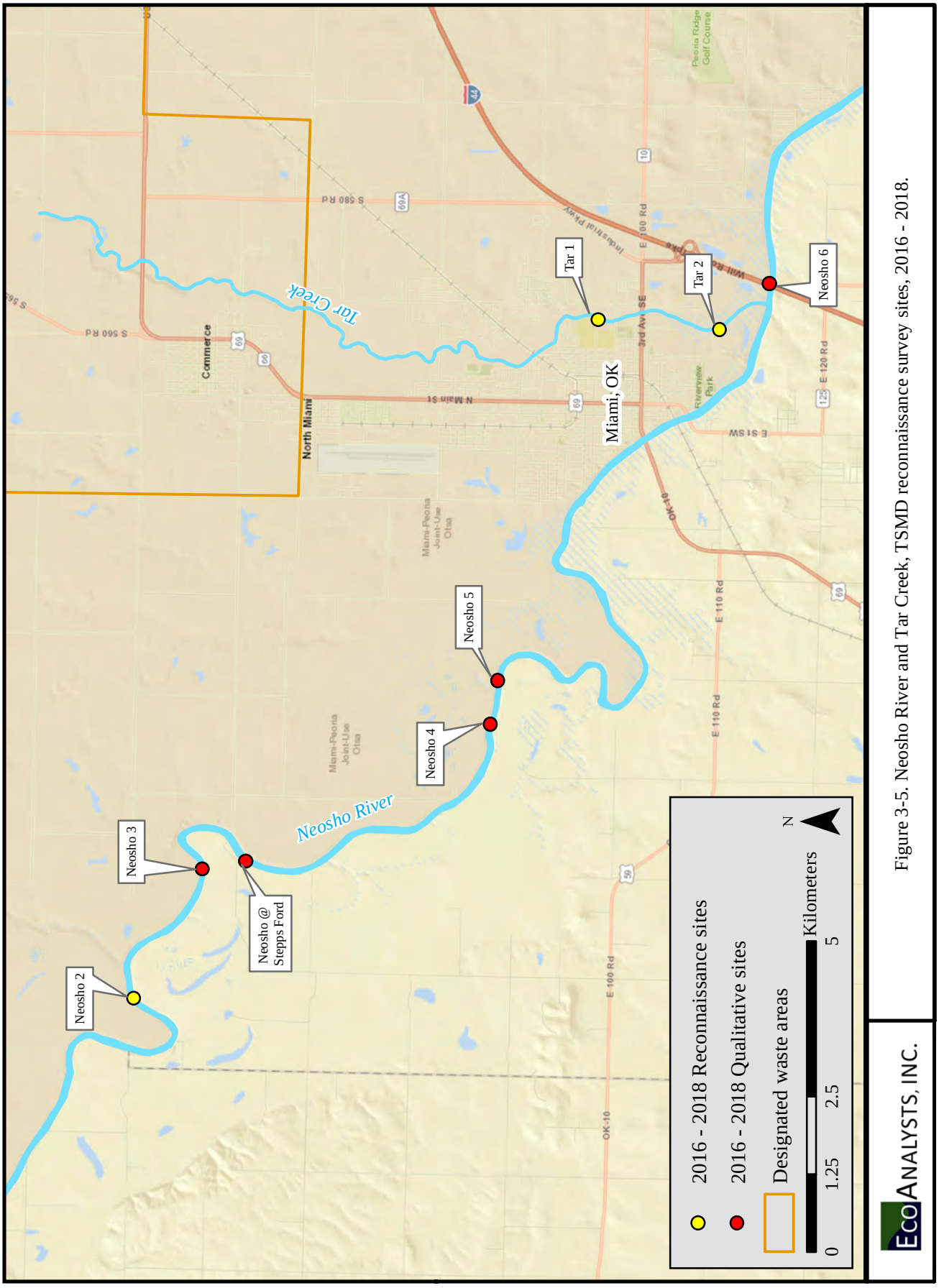

Figure 3-5. Neosho River and Tar Creek, TSMD reconnaissance survey sites, 2016 - 2018.

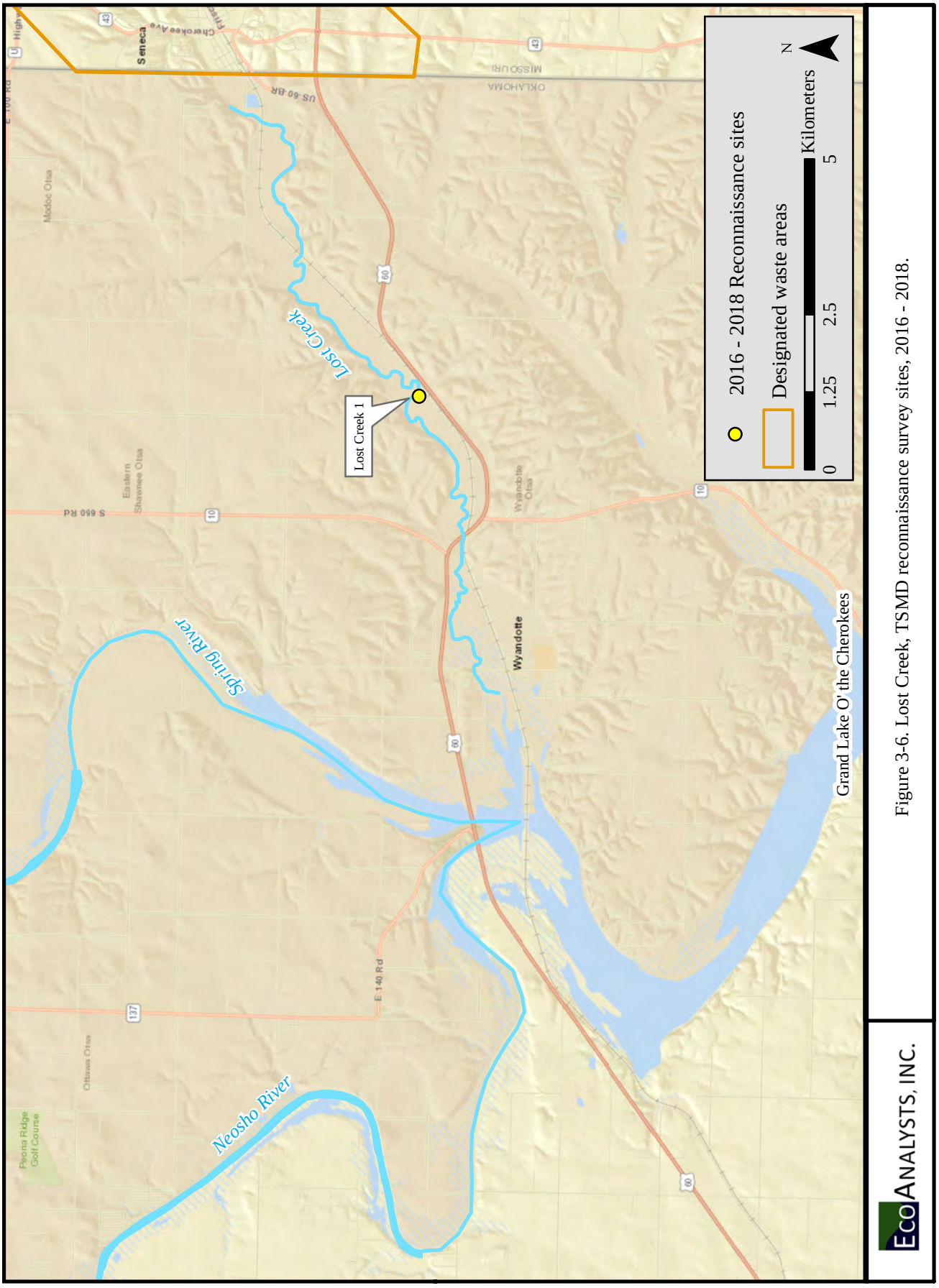

Figure 3-6. Lost Creek, TSMD reconnaissance survey sites, 2016 - 2018.

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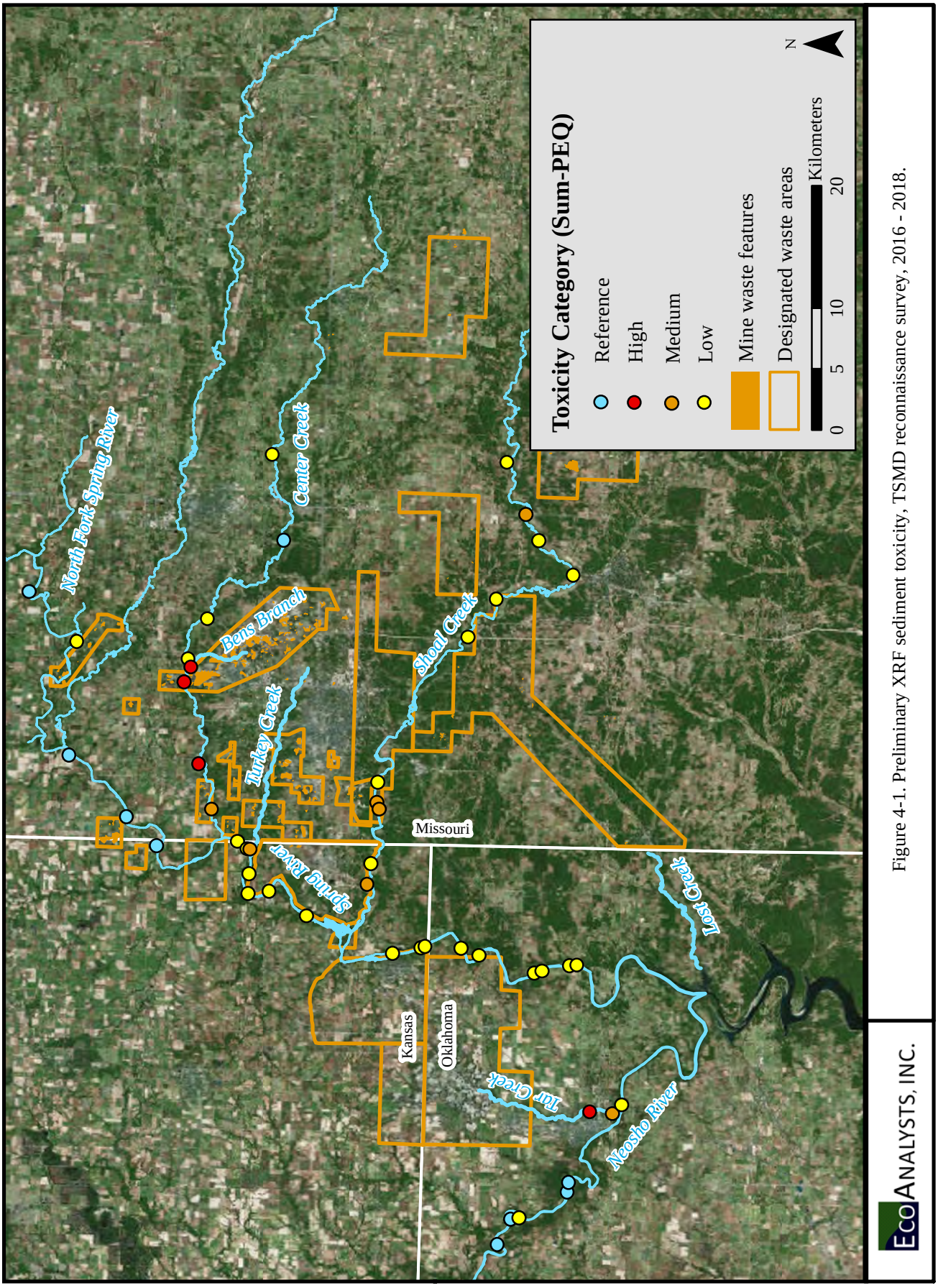

Figure 4-1. Preliminary XRF sediment toxicity, TSMD reconnaissance survey, 2016 - 2018.

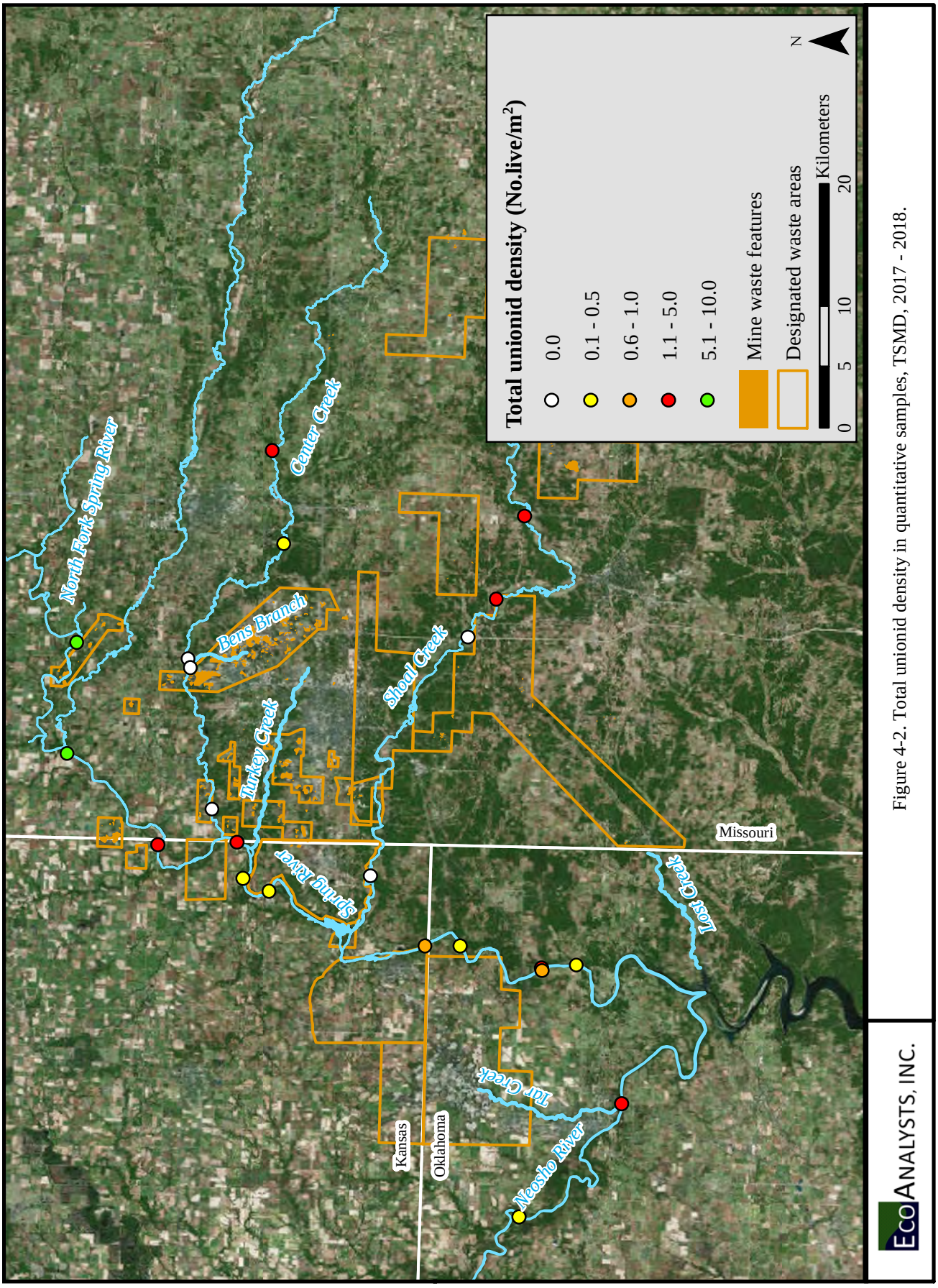

Figure 4-2. Total unionid density in quantitative samples, TSMD, 2017 - 2018.

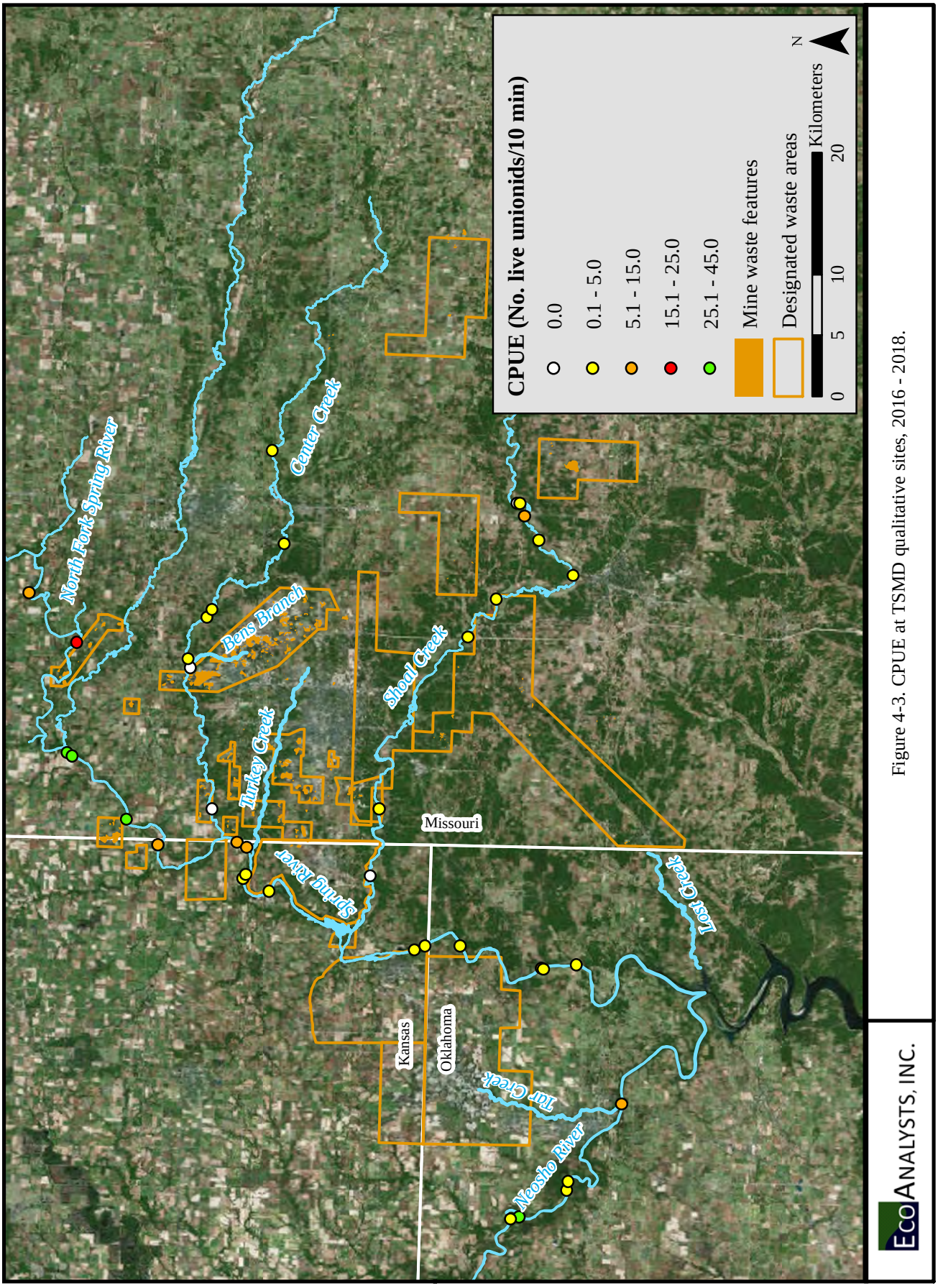

Figure 4-3. CPUE at TSMD qualitative sites, 2016 - 2018.

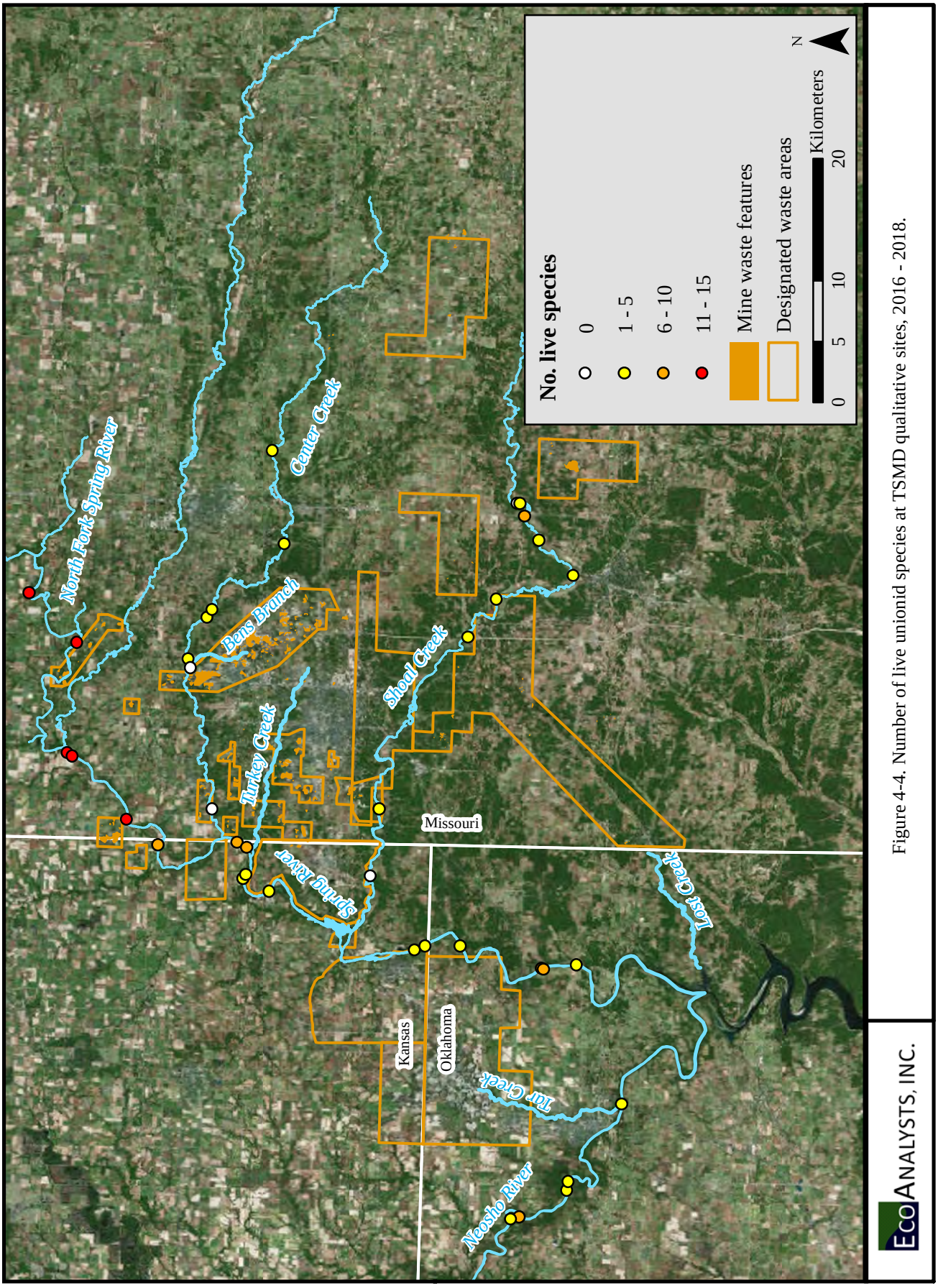

Figure 4-4. Number of live unionid species at TSMD qualitative sites, 2016 - 2018.

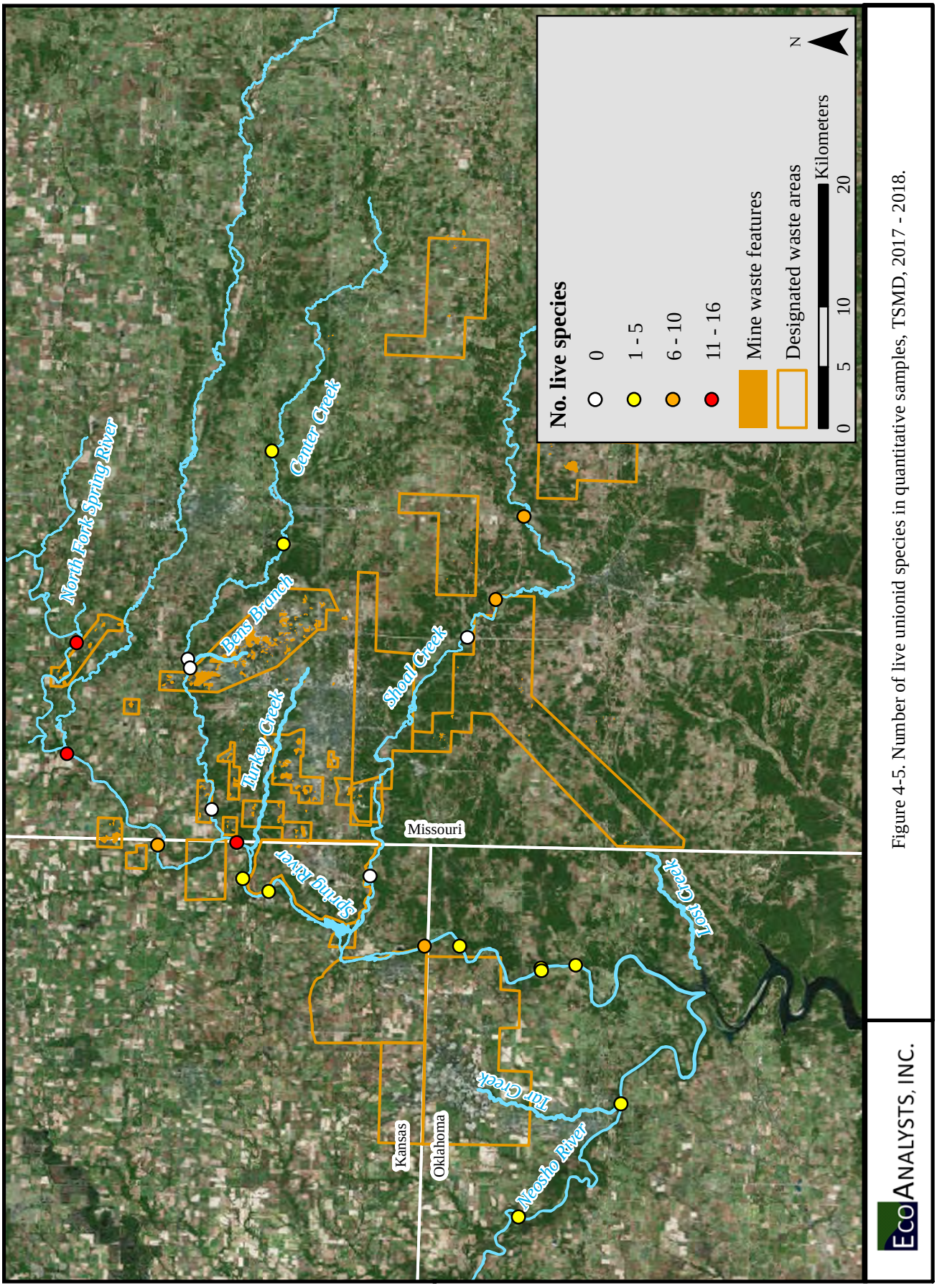

Figure 4-5. Number of live unionid species in quantitative samples, TSMD, 2017 - 2018.

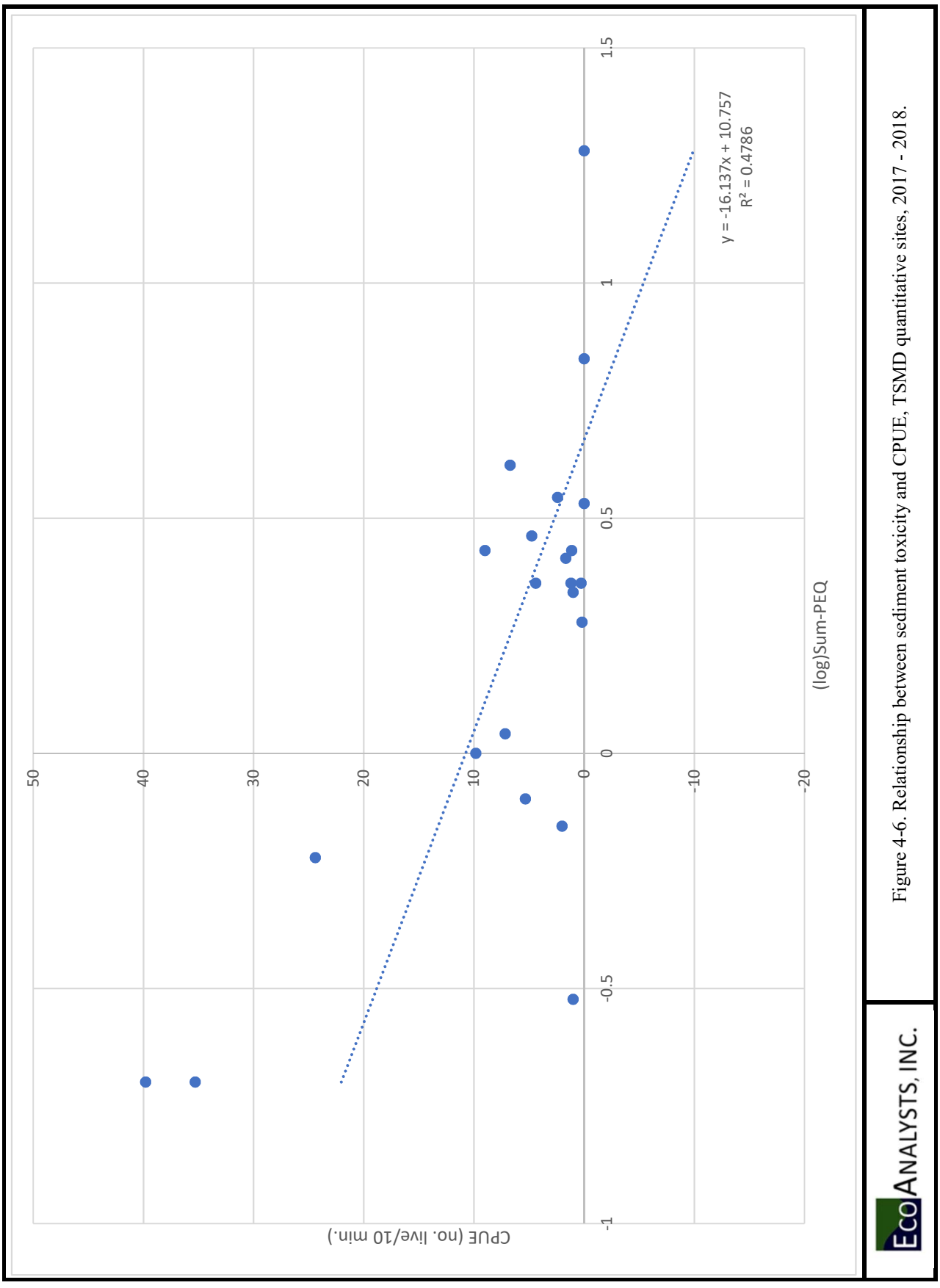

Figure 4-6. Relationship between sediment toxicity and CPUE, TSMD quantitative sites, 2017 - 2018.

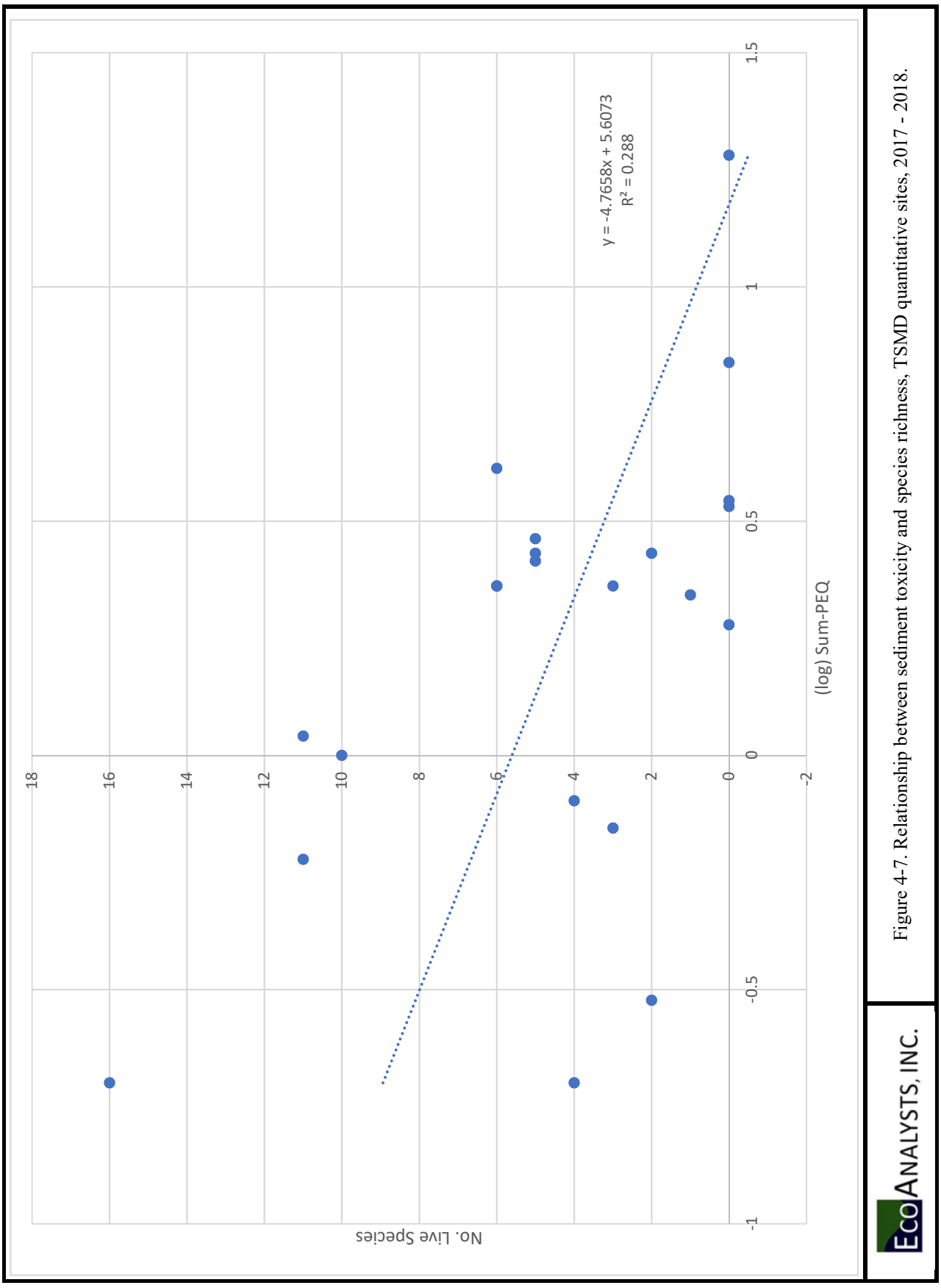

Figure 4-7. Relationship between sediment toxicity and species richness, TSMD quantitative sites, 2017 - 2018.

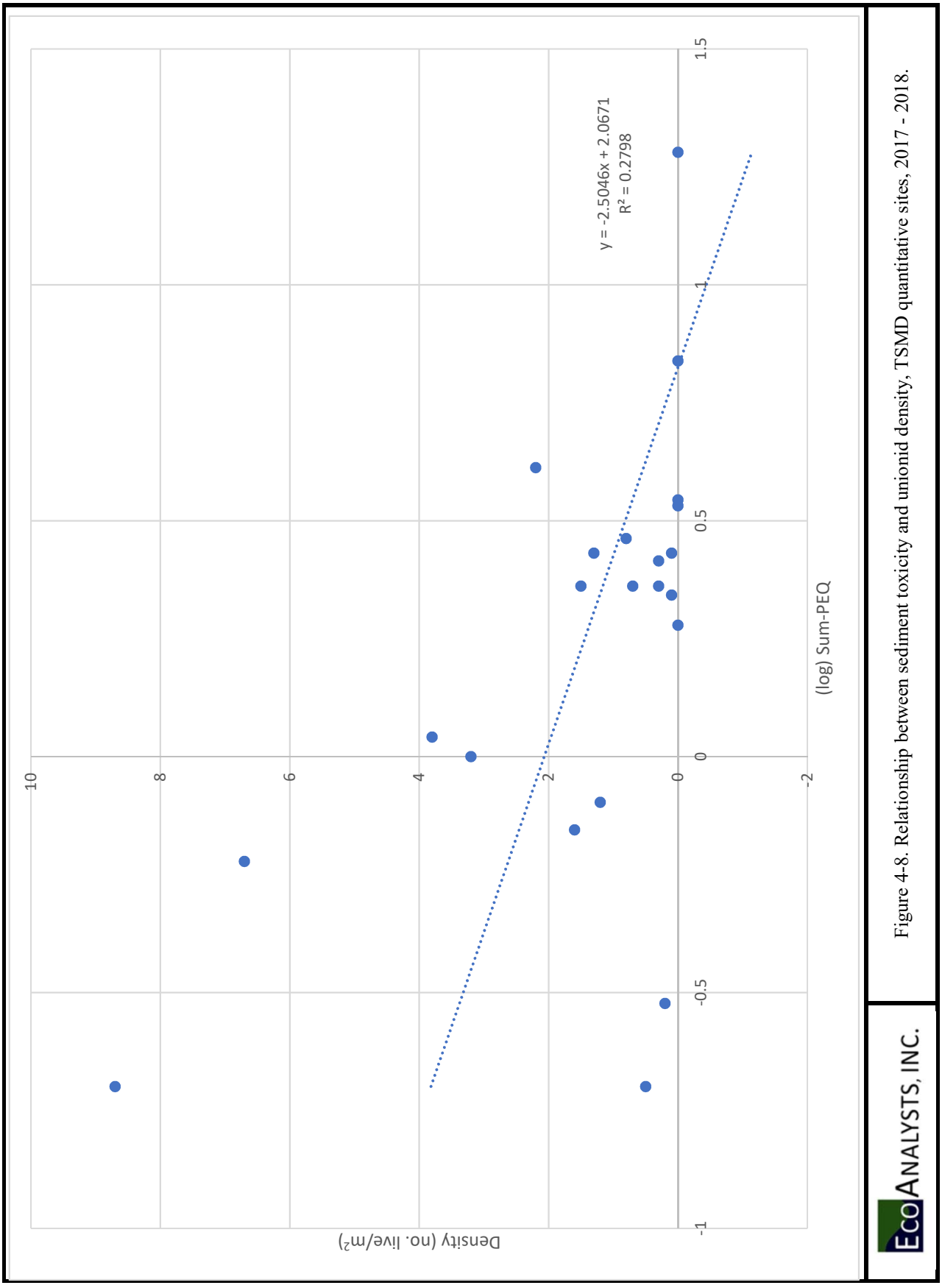

Figure 4-8. Relationship between sediment toxicity and unionid density, TSMD quantitative sites, 2017 - 2018.

Table 1-1. Unionid species reported from the Spring and Neosho River basins, Kansas, Missouri, and Oklahoma.

Species[1]	Status[2]	Branson (1966)[3]	Frazier (1977)[3]	Clarke & Obermeyer (1996)[3]	Angelo et al. (2007)[3]
Amblemini					
Amblema plicata		X	L	L	L
Pleurobemini					
Eurynia dilatata		X	L	L	L
Fusconaia flava		X	L	L	L
Fusconaia ozarkensis				L	L
Plethobasus cyphyus	FE, ME	X			
Pleurobema sintoxia		X	L	L	L
Pleurobema rubrum		X	L		
Uniomerus tetralasmus		X	L		FD
Quadrulini					
Cyclonaias nodulata		X	L		
Cyclonaias pustulosa		X	L	L	L
Megalonaias nervosa			L		
Quadrula quadrula		X	L	L	L
Theliderma cylindrica	FT, KE, ME			L	L
Theliderma metanevra			L	L	L
Tritogonia verrucosa		X	L	L	L
Lampsilini					
Actinonaias ligamentina	KE	X			
Cyprogenia aberti	KE			L	L
Ellipsaria lineolata	KT		L		
Lampsilis cardium		X	L	L	L
Lampsilis rafinesqueana	FE, KE, ME			L	L
Lampsilis siliquoidea		X		L	L
Lampsilis teres		X	L	L	L
Leptodea fragilis		X	L		L
Ligumia recta		X	WD	WD	R
Ligumia subrostrata		X	L	L	L
Obliquaria reflexa			L	WD	L
Potamilus ohiensis		X			L
Potamilus purpuratus		X	L		L
Ptychobranchus occidentalis	KT	X	L	L	L
Toxolasma lividum				L	L
Toxolasma parvum		X	L		L
Truncilla donaciformis		X	L		L
Truncilla truncata		X	L		
Venustaconcha ellipsiformis	KE			L	L
Anodontini					
Alasmidonta marginata	KE	X		WD	FD
Alasmidonta viridis	ME			L	
Lasmigona complanata		X	L	L	L
Lasmigona costata	KT	X	WD	L	L
Pyganodon grandis		X	L	L	L
Strophitus undulatus		X	L	L	L
Utterbackia imbecillis		X		FD	L
No. live species		-	26	24	30
Total no. species		30	28	28	33

[1]Species names follow Williams et al. (2017)

[2]FE=federally endangered, FT=federally threatened (USFWS, 2016); KE=Kansas endangered, KT=Kansas threatened (KDWPT, 2017); ME=Missouri endangered, MT=Missouri threatened (MNHP, 2017)

[3]X=present (unknown status), L=live, FD=fresh dead, WD=weathered dead, R=relict

Table 2-1 (1/3). TSMD reconnaissance survey sites, 2016 - 2018.

Site	Stream	State	Date	Coordinates (UTM 15N) Y	X
N. Fork Spring 1	North Fork Spring River	MO	7/19/2016	37.296865	-94.392979
N. Fork Spring 2	North Fork Spring River	MO	7/19/2016	37.261181	-94.438470
Spring 1A	Spring River	MO	7/19/2016	37.267034	-94.540292
Spring 1B	Spring River	MO	7/19/2016	37.263279	-94.543766
Spring 2	Spring River	MO	7/20/2016	37.222241	-94.600969
Spring 3	Spring River	KS	10/19/2016	37.198770	-94.624229
Spring 5	Spring River	KS	10/18/2016	37.140613	-94.620271
Spring 6	Spring River	KS	10/18/2016	37.133342	-94.624889
Spring 7	Spring River	KS	10/17/2016	37.131302	-94.631751
Spring 8A	Spring River	KS	10/19/2016	37.133371	-94.650109
Spring 8B	Spring River	KS	9/22/2017	37.135539	-94.653939
Spring 9	Spring River	KS	10/5/2016	37.131711	-94.667544
Spring 10A	Spring River	KS	10/14/2016	37.118427	-94.667837
Spring 10B	Spring River	KS	10/14/2016	37.118127	-94.667631
Spring 10C	Spring River	KS	10/14/2016	37.116011	-94.665053
Spring 10D	Spring River	KS	10/14/2016	37.112145	-94.656870
Spring 10E	Spring River	KS	10/14/2016	37.108047	-94.656239
Spring 11A	Spring River	KS	10/3/2016	37.088902	-94.686827
Spring 11B	Spring River	KS	10/3/2016	37.084935	-94.689406
Spring 11C	Spring River	KS	10/3/2016	37.080747	-94.692147
Spring 12A	Spring River	KS	10/5/2016	37.021041	-94.720686
Spring 12B	Spring River	KS	10/5/2016	37.005368	-94.716118
Spring 12C	Spring River	KS	9/29/2017	36.999785	-94.713692
Spring 13	Spring River	OK	8/23/2016	36.973150	-94.714440
Spring 13A	Spring River	OK	8/23/2016	36.969859	-94.723878
Spring 14	Spring River	OK	8/23/2016	36.961355	-94.722602
Spring 15	Spring River	OK	8/23/2016	36.959889	-94.719829
Spring 16	Spring River	OK	8/24/2016	36.939119	-94.743741
Spring 17	Spring River	OK	8/24/2016	36.934984	-94.746023
Spring 18	Spring River	OK	8/24/2016	36.921069	-94.738960
Spring 19	Spring River	OK	8/24/2016	36.913964	-94.732117
Spring 20	Spring River	OK	8/24/2016	36.913243	-94.733629
Spring 21	Spring River	OK	8/25/2016	36.894199	-94.729871
Spring 22	Spring River	OK	8/25/2016	36.887940	-94.728440
Spring 23	Spring River	OK	8/25/2016	36.876171	-94.746768
Spring 24	Spring River	OK	8/25/2016	36.871541	-94.765506
Center 1	Center Creek	MO	7/20/2016	37.111940	-94.223298
Center 0	Center Creek	MO	10/6/2016	37.118670	-94.258547
Center 1G1	Center Creek	MO	7/26/2016	37.108574	-94.340900
Center 1G2	Center Creek	MO	7/26/2016	37.109057	-94.344270
Center 1A2	Center Creek	MO	7/24/2016	37.127835	-94.380856
Center 1A1	Center Creek	MO	7/24/2016	37.129919	-94.382990
Center 1B1	Center Creek	MO	7/24/2016	37.144818	-94.379842
Center 1B2	Center Creek	MO	7/24/2016	37.147701	-94.377952

Table 2-1 (2/3). TSMD reconnaissance survey sites, 2016 - 2018.

Site	Stream	State	Date	Coordinates (UTM 15N) Y	X
Center 1C	Center Creek	MO	7/24/2016	37.158096	-94.392109
Center 1D	Center Creek	MO	7/24/2016	37.160492	-94.400043
Center 1E	Center Creek	MO	7/24/2016	37.162444	-94.405156
Center 1F	Center Creek	MO	7/24/2016	37.161672	-94.405964
Center 3	Center Creek	MO	7/21/2016	37.165174	-94.413304
Center 4	Center Creek	MO	7/20/2016	37.168370	-94.417019
Center 5	Center Creek	MO	7/20/2016	37.170754	-94.417123
Center 5A	Center Creek	MO	7/20/2016	37.172390	-94.418843
Center 5B	Center Creek	MO	7/20/2016	37.175138	-94.420750
Center 5C	Center Creek	MO	7/21/2016	37.179126	-94.451130
Center 5D	Center Creek	MO	7/21/2016	37.178712	-94.451662
Center 6	Center Creek	MO	7/21/2016	37.175299	-94.455168
Center 7	Center Creek	MO	7/21/2016 & 8/20/17	37.176260	-94.459686
Center 8	Center Creek	MO	7/21/2016	37.179480	-94.469157
Center 9	Center Creek	MO	7/21/2016	37.180711	-94.478617
Center 10A	Center Creek	MO	7/21/2016	37.176373	-94.486907
Center 15A	Center Creek	MO	7/26/2016	37.170243	-94.546082
Center 16	Center Creek	MO	7/26/2016	37.169560	-94.548532
Center 10B	Center Creek	MO	9/19/2017	37.159309	-94.590259
Shoal @ Smack Out	Shoal Creek	MO	7/20/2016	36.915384	-94.133620
Shoal @ HWY 60	Shoal Creek	MO	7/20/2016	36.918824	-94.138827
Shoal @ House	Shoal Creek	MO	7/20/2016	36.938448	-94.185948
Shoal 1	Shoal Creek	MO	7/20/2016	36.939512	-94.190891
Shoal 1A	Shoal Creek	MO	7/22/2016	36.945237	-94.266153
Shoal 2	Shoal Creek	MO	7/23/2016	36.937138	-94.303893
Shoal 2A	Shoal Creek	MO	7/23/2016	36.935173	-94.304523
Shoal 3A	Shoal Creek	MO	7/23/2016	36.933566	-94.305394
Shoal 4A	Shoal Creek	MO	7/23/2016	36.929841	-94.306853
Shoal 4B	Shoal Creek	MO	7/23/2016	36.929668	-94.309012
Shoal 4C	Shoal Creek	MO	7/23/2016	36.929106	-94.312448
Shoal 5	Shoal Creek	MO	7/23/2016	36.931245	-94.315233
Shoal 5A	Shoal Creek	MO	7/23/2016	36.931687	-94.315760
Shoal 6A	Shoal Creek	MO	7/22/2016	36.920757	-94.337816
Shoal 6	Shoal Creek	MO	7/22/2016	36.911890	-94.349549
Shoal 7	Shoal Creek	MO	7/22/2016	36.894948	-94.369737
Shoal 8	Shoal Creek	MO	7/10/2018	36.951418	-94.393048
Shoal 10B	Shoal Creek	MO	9/14/2017	36.972353	-94.427972
Shoal 9A	Shoal Creek	MO	7/25/2016	37.035301	-94.559906
Shoal 10A	Shoal Creek	MO	7/25/2016	37.037315	-94.563278
Shoal 11	Shoal Creek	MO	7/25/2016	37.038691	-94.565630
Shoal 12	Shoal Creek	MO	7/25/2016	37.039356	-94.577377
Shoal 13	Shoal Creek	MO	7/25/2016	37.038403	-94.580477
Shoal 14	Shoal Creek	MO	7/25/2016	37.037317	-94.581787
Shoal 15	Shoal Creek	MO	7/25/2016	37.036114	-94.583160
Shoal 15A	Shoal Creek	MO	7/25/2016	37.035731	-94.587824

Table 2-1 (3/3). TSMD reconnaissance survey sites, 2016 - 2018.

Site	Stream	State	Date	Coordinates (UTM 15N) Y	X
Shoal 16	Shoal Creek	KS	10/6/2016	37.041150	-94.639396
Shoal 16A	Shoal Creek	KS	10/6/2016	37.041605	-94.648967
Shoal 17	Shoal Creek	KS	10/6/2016	37.042411	-94.652424
Shoal 18	Shoal Creek	KS	10/6/2016	37.043548	-94.657518
Neosho 2	Neosho River	OK	8/26/2016	36.943015	-94.985225
Neosho 3	Neosho River	OK	8/26/2016	36.933105	-94.962829
Neosho @ Stepps Ford	Neosho River	OK	9/16/2017	36.926907	-94.961200
Neosho 4	Neosho River	OK	8/26/2016	36.891738	-94.935150
Neosho 5	Neosho River	OK	8/26/2016	36.890343	-94.927493
Neosho 6	Neosho River	OK	8/27/2016	36.852684	-94.855155
Tar 1	Tar Creek	OK	8/25/2016	36.877325	-94.862287
Tar 2	Tar Creek	OK	8/27/2016	36.859684	-94.863671
Lost Creek 1	Lost Creek	OK	8/25/2016	36.808683	-94.675962

Table 2-2. TSMD quantitative sites, 2017 - 2018.

Site	USGS ID	Stream	State	No. Quantitative Samples	Date	Coordinates (UTM 15N) Y	Coordinates (UTM 15N) X
N. Fork Spring 2	NF02	North Fork Spring River	MO	100	9/15/2017	37.261181	-94.438470
Spring 1A	SP01	Spring River	MO	100	8/21/17 & 9/14/17	37.267034	-94.540292
Spring 3	SP03	Spring River	KS	60	9/23/2017	37.198770	-94.624229
Spring 5	SP05	Spring River	KS	75	9/22/2017	37.140613	-94.620271
Spring 8B	SP08	Spring River	KS	75	9/24/2017	37.135539	-94.653939
Spring 10C	SP10	Spring River	KS	60	9/26/2017	37.116011	-94.665053
Spring 12C	SP12	Spring River	KS	100	9/29/2017	36.999785	-94.713692
Spring 13	SP13	Spring River	OK	100	9/25/2017	36.973150	-94.714440
Spring 19	SP19	Spring River	OK	75	9/28/2017	36.913964	-94.732117
Spring 20	SP20	Spring River	OK	100	9/18/2017	36.913243	-94.733629
Spring 22	SP22	Spring River	OK	100	9/21/2017	36.887940	-94.728440
Center 0	CC00	Center Creek	MO	15	8/18/2017	37.118670	-94.258547
Center 1G2	CC01	Center Creek	MO	74	8/19/2017	37.109057	-94.344270
Center 5D	CC05	Center Creek	MO	25	8/20/2017	37.178712	-94.451662
Center 7	CC07	Center Creek	MO	15	9/16/2017	37.176260	-94.459686
Center 10B	CC10	Center Creek	MO	25	9/19/2017	37.159309	-94.590259
Shoal 5A	SH05	Shoal Creek	MO	100	9/20/2017	36.931687	-94.315760
Shoal 8	SH08	Shoal Creek	MO	50	7/11/2018	36.951418	-94.393048
Shoal 10B	SH10	Shoal Creek	MO	25	9/16/2017	36.972353	-94.427972
Shoal 16A	SH16	Shoal Creek	KS	100	9/17/2017 & 9/19/17	37.041605	-94.648967
Neosho @ Stepps Ford	NRSF	Neosho River	OK	40	9/27/2017	36.926907	-94.961200
Neosho 6	NR06	Neosho River	OK	100	9/27/2017	36.852684	-94.855155

Table 3-1. Unionids collected at qualitative sites, North Fork Spring River, Missouri, 2016.

	North Fork 1	North Fork 2	Total
Amblemini			
Amblema plicata	6	64	70
Pleurobemini			
Eurynia dilatata	4	12	16
Fusconaia flava	WD	10	10
Pleurobema sintoxia	1	1	2
Quadrulini			
Cyclonaias pustulosa	6	12	18
Quadrula quadrula	-	WD	WD
Tritogonia verrucosa	15	16	31
Lampsilini			
Lampsilis cardium	-	1	1
Lampsilis rafinesqueana	WD	-	WD
Leptodea fragilis	-	1	1
Ptychobranchus occidentalis	WD	-	WD
Truncilla truncata	WD	-	WD
Anodontini			
Lasmigona complanata	1	3	4
Lasmigona costata	2	1	3
Strophitus undulatus	-	1	1
Total no. live	35	122	157
No. live species	7	11	11
Total no. species	11	12	15
Effort (min)	50	50	100
CPUE (no. live/10 min)	7.0	24.4	15.7

WD = weathered dead

Table 3-2. Reconnaissance site sediment metal concentrations, Spring River and Neosho River basins, 2016 - 2018.

		Metal Concentrations (ug/g)[1]			Probable Effects Quotients (conc./PEC)				
River	USGS Site	Lead	Zinc	Cadmium	Pb-PEQ	Zn-PEQ	Cd-PEQ	Sum-PEQ	Category[2]
N. Fork Spring River	NF01	<LOD	22.9	<LOD	-	0.0	-	0.0	Ref
	NF02	<LOD	294.2	<LOD	-	0.6	-	0.6	Low
Spring River	SP01	<LOD	71.4	<LOD	-	0.2	-	0.2	Ref
	SP02	<LOD	99.2	<LOD	-	0.2	-	0.2	Ref
	SP03	< LOD	< LOD	< LOD	-	-	-	0.0	Ref
(Center Creek)	SP05	36.4	397.0	< LOD	0.3	0.9	-	1.1	Low
	SP06	30.0	387.5	< LOD	0.2	0.8	-	1.1	Low
(Turkey Creek)	SP07	122.3	1659.3	< LOD	1.0	3.6	-	4.6	Med
	SP08	61.0	772.7	< LOD	0.5	1.7	-	2.2	Low
	SP09	60.3	1118.7	<LOD	0.5	2.4	-	2.9	Low
	SP10C	46.8	1091.4	<LOD	0.4	2.4	-	2.7	Low
	SP11	75.7	1070.0	<LOD	0.6	2.3	-	2.9	Low
(Shoal Creek)	SP12A	44.8	910.0	<LOD	0.4	2.0	-	2.3	Low
	SP12A_DUP	44.3	951.8	<LOD	0.3	2.1	-	2.4	Low
	SP12B	63.3	984.8	<LOD	0.5	2.1	-	2.6	Low
	SP12C	66.3	825.5	<LOD	0.5	1.8	-	2.3	Low
	SP13	78.4	899.5	<LOD	0.6	2.0	-	2.6	Low
	SP15	61.9	966.6	<LOD	0.5	2.1	-	2.6	Low
	SP18	47.8	787.3	<LOD	0.4	1.7	-	2.1	Low
	SP19	68.7	998.8	<LOD	0.5	2.2	-	2.7	Low
	SP20	79.7	1025.3	<LOD	0.6	2.2	-	2.9	Low
	SP21	64.5	1045.9	<LOD	0.5	2.3	-	2.8	Low
	SP22	6.7	1021.6	<LOD	0.1	2.2	-	2.3	Low
Center Creek	CC00	< LOD	315.8	<LOD	-	0.7	-	0.7	Low
	CC01G	10.7	114.2	< LOD	0.1	0.2	-	0.3	Ref
	CC03	27.1	498.4	<LOD	0.2	1.1	-	1.3	Low
	CC05D	206.5	860.7	<LOD	1.6	1.9	-	3.5	Low
(Bens Branch)	CC07	337.6	5269.9	24.7	2.6	11.5	5.0	19.1	High
	CC08	321.0	2872.5	10.9	2.5	6.3	2.2	11.0	High
	CC16	282.7	3367.6	13.9	2.2	7.3	2.8	12.3	High
	CC10	245.5	2274.5	<LOD	1.9	5.0	-	6.9	Medium
Shoal Creek	SH01A	42.6	543.1	< LOD	0.3	1.2	-	1.5	Low
	SH05A	102.8	1533.1	<LOD	0.8	3.3	-	4.1	Med
	SH06A	90.6	996.2	<LOD	0.7	2.2	-	2.9	Low
	SH07	48.5	850.6	<LOD	0.4	1.9	-	2.2	Low
	SH08	65.1	823.8	<LOD	0.5	1.8	-	2.3	Low
	SH10B	65.0	646.4	<LOD	0.5	1.4	-	1.9	Low
	SH10A	77.9	1208.3	<LOD	0.6	2.6	-	3.2	Low
	SH14	150.8	1682.6	<LOD	1.2	3.7	-	4.8	Med
	SH15A	164.7	2160.1	<LOD	1.3	4.7	-	6.0	Med
	SH16	94.2	1237.5	<LOD	0.7	2.7	-	3.4	Low
	SH18	103.3	1515.3	<LOD	0.8	3.3	-	4.1	Med
Neosho River	NR02	<LOD	43.3	<LOD	-	0.1	-	0.1	Ref
	NR03	<LOD	43.3	<LOD	-	0.1	-	0.1	Ref
	NRSF	9.7	69.2	<LOD	0.1	0.2	-	0.2	Ref
	NR04	< LOD	72.0	< LOD	-	0.2	-	0.2	Ref
	NR05	<LOD	65.0	<LOD	-	0.1	-	0.1	Ref
(Tar Creek)	NR06	42.9	229.6	<LOD	0.3	0.5	-	0.8	Low
Tar Creek	TC01	203.6	4794.3	<LOD	1.6	10.4	-	12.0	High
	TC02	280.5	2217.5	<LOD	2.2	4.8	-	7.0	Medium

Dashed line indicates tributary influence (tributary name in parenthesis)

[1]LOD = Limit of Detection

[2]Categories modified from MacDonald et al. (2010); Ref = Sum-PEQ≤0.5, Low = Sum-PEQ >0.5 to ≤4.0, Medium = Sum-PEQ >4.0 to ≤6.5, High = Sum-PEQ >6.5

Table 3-3. Unionids collected at qualitative sites, Spring River, 2016 - 2017.

	Missouri			Kansas								Oklahoma				
	Spring 1A	Spring 1B	Spring 2	Spring 3	Spring 5	Spring 6	Spring 8A	Spring 8B	Spring 10C	Spring 12B	Spring 12C	Spring 13	Spring 19	Spring 20	Spring 22	Total
Amblemini																
Amblema plicata	8	2	29	FD	-	1	-	-	2	-	-	-	-	-	-	42
Pleurobemini																
Eurynia dilatata	12	12	8	4	-	-	-	-	-	-	-	-	-	-	-	36
Fusconaia flava	23	22	20	13	-	2	WD	-	FD	-	-	-	-	-	-	80
Pleurobema sintoxia	33	7	32	12	11	4	WD	-	-	-	-	-	-	-	-	99
Quadrulini																
Cyclonaias pustulosa	44	22	16	16	10	-	-	-	3	FD	-	-	-	-	-	111
Quadrula quadrula	WD	-	-	-	-	-	-	-	WD	-	-	-	-	-	-	WD
Theliderma cylindrica	-	L	-	-	1	1	-	-	-	-	-	-	-	-	-	2
Theliderma metanevra	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	3
Tritogonia verrucosa	26	20	30	5	3	2	-	-	-	2	2	-	4	1	-	95
Lampsilini																
Cyprogenia aberti	1	3	1	-	-	-	-	-	-	-	-	-	-	-	-	5
Lampsilis cardium	-	2	1	1	1	-	1	4	2	2	2	3	9	11	1	40
Lampsilis rafinesqueana	41	35	73	6	13	29	WD	-	1	-	-	-	5	-	-	203
Lampsilis siliquoidea	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Lampsilis teres	-	-	-	-	-	-	-	-	-	FD	-	-	-	1	-	1
Leptodea fragilis	5	3	1	-	-	1	1	FD	WD	FD	FD	-	4	1	-	16
Ligumia subrostrata	WD	-	-	-	-	-	-	-	-	WD	-	-	-	-	-	WD
Obliquaria reflexa	-	-	-	-	-	-	-	-	-	FD	2	1	5	1	1	10
Potamilus purpuratus	-	-	-	-	-	1	-	2	-	5	1	5	9	3	L	26
Ptychobranchus occidentalis	2	1	1	1	3	3	-	-	-	-	-	-	-	FD	-	11
Truncilla donaciformis	-	-	-	-	-	-	-	-	-	-	-	1	-	1	WD	2
Venustaconcha ellipsiformis	WD	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Anodontini																
Alasmidonta marginata	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lasmigona complanata	-	-	2	FD	-	-	-	-	-	-	-	-	-	-	-	2
Lasmigona costata	3	4	1	-	-	-	-	-	-	-	-	-	-	-	-	8
Pyganodon grandis	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Strophitus undulatus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Total no. live	199	135	216	59	43	44	3	6	9	9	7	10	36	19	2	797
No. live species	12	15	14	9	8	9	3	2	5	3	4	4	6	7	3	24
Total no. species	15	15	14	11	8	9	6	3	8	8	5	4	6	8	3	26
Effort (min)	50	30	50	60	60	60	60	60	80	360	60	60	40	40	75	1145
CPUE (no. live/10 min)	39.8	45.0	43.2	9.8	7.2	7.3	0.5	1.0	1.1	0.3	1.2	1.7	9.0	4.8	0.3	7.0

L=found live at the site during initial search, but not recovered in timed searches (included in live species count), WD = weathered dead, FD = fresh dead, SF = subfossil

Table 3-4. Unionids collected at qualitative sites, Center Creek, Missouri, 2016 - 2017.

	Center 0	Center 1G2	Center 1F	Center 3	Center 5D	Center 7	Center 10B	Total
Amblemini								
Amblema plicata	-	-	-	-	SF	FD	-	FD
Pleurobemini								
Eurynia dilatata	4	FD	-	-	-	WD	-	4
Fusconaia flava	5	3	-	-	7	WD	-	15
Fusconaia ozarkensis	-	-	-	-	-	WD	-	WD
Pleurobema sintoxia	-	FD	-	1	-	WD	-	1
Quadrulini								
Quadrula quadrula	-	-	-	-	-	WD	-	WD
Lampsilini								
Cyprogenia aberti	-	-	-	-	-	WD	-	WD
Lampsilis cardium	-	-	-	-	1	WD	-	1
Lampsilis rafinesqueana	1	WD	-	-	2	FD	-	3
Lampsilis siliquoidea	1	2	1	1	-	WD	-	5
Ligumia subrostrata	WD	1	-	WD	-	-	-	1
Ptychobranchus occidentalis	1	WD	-	-	2	-	-	3
Toxolasma lividum	-	-	-	-	-	WD	-	WD
Venustaconcha ellipsiformis	WD	WD	-	-	-	WD	-	WD
Total no. live	12	6	1	2	12	0	0	33
No. live species	5	3	1	2	4	0	0	8
Total no. species	7	8	1	3	5	12	0	14
Effort (min)	60	60	45	50	50	60	60	385
CPUE (no. live/10 min)	2.0	1.0	0.2	0.4	2.4	0.0	0.0	0.9

FD = fresh dead, WD = weathered dead, SF = subfossil

Table 3-5. Unionids collected at qualitative sites, Shoal Creek, Missouri, 2016 - 2018.

	Shoal 2	Shoal 2A	Shoal 5A	Shoal 6A	Shoal 7	Shoal 8	Shoal 10B	Shoal 15A	Shoal 16A	Total
Pleurobemini										
Eurynia dilatata	WD	-	30	-	-	WD	WD	-	-	30
Fusconaia flava	WD	1	46	5	5	16	1	SF	-	74
Pleurobema sintoxia	-	WD	24	1	2	3	-	SF	-	30
Quadrulini										
Theliderma metanevra	-	-	-	-	-	WD	-	-	-	WD
Lampsilini										
Lampsilis cardium	WD	WD	2	-	-	3	WD	1	-	6
Lampsilis rafinesqueana	WD	WD	2	-	L	13	WD	-	-	15
Ligumia subrostrata	-	WD	-	-	-	-	-	-	-	WD
Ptychobranchus occidentalis	-	WD	13	2	L	-	-	-	-	15
Venustaconcha ellipsiformis	WD	-	4	-	-	-	-	-	-	4
Anodontini										
Alasmidonta viridis	WD	-	WD	-	-	-	-	-	-	WD
Total no. live	0	1	121	8	7	35	1	1	0	174
No. live species	0	1	7	3	4	4	1	1	0	7
Total no. species	6	6	8	3	4	6	4	3	0	10
Effort (min)	60	30	180	220	50	80	60	30	60	770
CPUE (no. live/10 min)	0.0	0.3	6.7	0.4	1.4	4.4	0.2	0.3	0.0	2.3

L=found live at the site during initial search, but not recovered in timed searches (included in live species count), WD = weathered dead, SF = subfossil

Table 3-6. Unionids collected at qualitative sites, Neosho River, Oklahoma, 2016 - 2017.

	Neosho 3	Neosho @ Stepps Ford	Neosho 4	Neosho 5	Neosho 6	Total
Pleurobemini						
Pleurobema sintoxia	-	1	-	-	-	1
Quadrulini						
Cyclonaias pustulosa	WD	26	-	-	-	26
Theliderma metanevra	-	94	-	-	-	94
Tritogonia verrucosa	WD	17	1	-	-	18
Lampsilini						
Lampsilis cardium	WD	1	-	-	-	1
Lampsilis teres	WD	-	-	-	-	WD
Leptodea fragilis	-	-	5	-	3	8
Obliquaria reflexa	WD	1	-	-	9	10
Potamilus ohiensis	1	-	-	-	1	2
Potamilus purpuratus	2	1	10	2	18	33
Truncilla donaciformis	-	FD	-	-	1	1
Anodontini						
Lasmigona complanata	-	-	2	-	-	2
Total no. live	3	141	18	2	32	196
No. live species	2	7	4	1	5	11
Total no. species	7	8	4	1	5	12
Effort (min)	240	40	60	60	60	460
CPUE (no. live/10 min)	0.1	35.3	3.0	0.3	5.3	4.3

FD = fresh dead, WD = weathered dead

Table 3-7. Sediment metal concentration, TSMD quantitative sites, 2017 - 2018.

				2016 - 2017 Reconnaissance Results					2017 - 2018 Results		
				Sediment Cont.		Qualitative Data			Quantitative Data		
Stream	Site	USGS Site	State	Sum-PEQ	Category[1]	No. live	No. live spp.	CPUE (no. live/ 10 min.)	No. live spp.	Density[2]	Total no. live species
North Fork Spring	North Fork 2	NF02	MO	0.6	Low	122	11	24.4	11	6.7 (±1.2)	13
Spring River	Spring 1A	SP01	MO	0.2	Reference	199	12	39.8	16	8.7 (±2.2)	17
Spring River	Spring 3	SP03	KS	0.0	Reference	59	9	9.8	10	3.2 (±1.3)	13
Spring River	Spring 5	SP05	KS	1.1	Low	43	8	7.2	11	3.8 (±1.3)	12
Spring River	Spring 8B	SP08	KS	2.2	Low	6	2	1.0	1	0.1 (±0.1)	3
Spring River	Spring 10C	SP10C	KS	2.7	Low	9	5	1.1	2	0.1 (±0.2)	7
Spring River	Spring 12C	SP12C	MO	2.3	Low	7	4	1.2	6	0.7 (±0.3)	6
Spring River	Spring 13	SP13	OK	2.6	Low	10	4	1.7	5	0.3 (±0.2)	5
Spring River	Spring 19	SP19	OK	2.7	Low	36	6	9.0	5	1.3 (±0.5)	7
Spring River	Spring 20	SP20	OK	2.9	Low	19	7	4.8	5	0.8 (±0.4)	7
Spring River	Spring 22	SP22	OK	2.3	Low	2	3	0.3	3	0.3 (±0.2)	3
Center Creek	Center 0	CC00	MO	0.7	Low	12	5	2.0	3	1.6 (±1.7)	5
Center Creek	Center 1G2	CC01G	MO	0.3	Reference	6	3	1.0	2	0.2 (±0.2)	3
Center Creek	Center 5D	CC05D	MO	3.5	Low	12	4	2.4	0	0.0 (±0.0)	4
Center Creek	Center 7	CC07	MO	19.1	High	0	0	0.0	0	0.0 (±0.0)	0
Center Creek	Center 10B	CC10	MO	6.9	High	0	0	0.0	0	0.0 (±0.0)	0
Shoal Creek	Shoal 5A	SH05A	MO	4.1	Medium	121	7	6.7	6	2.2 (±0.9)	7
Shoal Creek	Shoal 8	SH08	MO	2.3	Low	35	4	4.4	6	1.5 (±0.8)	8
Shoal Creek	Shoal 10B	SH10B	MO	1.9	Low	1	1	0.2	0	0.0 (±0.0)	1
Shoal Creek	Shoal 16A	SH16	KS	3.4	Low	0	0	0.0	0	0.0 (±0.0)	0
Neosho River	Neosho @ Stepps Ford	NRSF	OK	0.2	Reference	141	7	35.3	4	0.5 (±0.4)	8
Neosho River	Neosho 6	NR06	OK	0.8	Low	32	5	5.3	4	1.2 (±0.8)	6

[1]Modified from MacDonald et al. (2010); Ref = Sum-PEQ ≤0.5, Low = Sum-PEQ >0.5 to ≤4.0, Medium = Sum-PEQ >4.0 to ≤6.5, High = Sum-PEQ >6.5

[2]Density = Average no. live/m^2 (±2SE)

Table 3-8. Habitat characteristics, North Fork Spring River, Missouri, 2017.

	North Fork Spring 2
Qualitative	
Dominant Land Use	Forest/Natural
Site Habitat	Primary Channel; Run
Riparian Zone	
Left Descending Bank	>10 m
Right Descending Bank	>10 m
Canopy Cover	Mostly Shaded
Substrate Stability	Stable
In-stream Depositional Features	Gravel Bars
Quantitative	
Depth (m)	
Min.	0.05
Max.	0.85
Avg.	0.38
Velocity (ft./sec.)	
Min.	0.00
Max.	0.52
Avg.	0.14
Substrate	
% Silt/Clay	0.0
% Sand	0.0
% Gravel	95.6
% Cobble	4.2
% Boulder	0.0
% Bedrock	0.2
D_{50}	33 mm
D_{84}	51 mm

Table 3-9. Unionids collected in quantitative samples, North Fork Spring River, Missouri, 2017.

	North Fork 2
Amblemini	
Amblema plicata	51
Pleurobemini	
Eurynia dilatata	20
Fusconaia flava	25
Fusconaia ozarkensis	1
Pleurobema sintoxia	4
Quadrulini	
Cyclonaias pustulosa	21
Quadrula quadrula	WD
Tritogonia verrucosa	36
Lampsilini	
Lampsilis rafinesqueana	WD
Leptodea fragilis	2
Venustaconcha ellipsiformis	2
Anodontini	
Lasmigona complanata	4
Lasmigona costata	1
Total no. live	167
No. live species	11
Total no. species	13
Total unionid density (±2SE)[1]	6.7 (±1.2)
Adult unionid density (±2SE)	6.4 (±1.2)
Juvenile unionid density (±2SE)	0.2 (±0.2)
% Juvenile	3.6
% Unionid mortality	0.6
Corbicula fluminea density (±2SE)	0.4 (±0.2)

WD = weathered dead

[1]Density = Average no. live/m^2

Table 3-10. Habitat characteristics, Spring River, 2017.

	Missouri	Kansas					Oklahoma			
	Spring 1A	Spring 3	Spring 5	Spring 8B	Spring 10C	Spring 12C	Spring 13	Spring 19	Spring 20	Spring 22
Qualitative										
Dominant Land Use	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural	Forest/Natural
Site Habitat	Primary Channel; Riffle/Run	Secondary Channel; Run	Secondary Channel; Run	Primary Channel; Run/Pool	Secondary Channel; Pool	Secondary Channel; Run	Primary Channel; Run	Primary Channel; Run	Secondary Channel; Run	Primary Channel; Run
Riparian Zone										
Left Descending Bank	>10 m	>10 m	>10 m	≤10 m	>10 m	≤10 m	>10 m	>10 m	≤10 m	>10 m
Right Descending Bank	>10 m	≤10 m	>10 m	>10 m	>10 m	≤10 m	>10 m	>10 m	≤10 m	≤10 m
Canopy Cover	Mostly Shaded	Mostly Shaded	Shaded	Shaded	Mostly Shaded	Mostly Shaded	Mostly Open	Shaded	Mostly Open	Mostly Shaded
Substrate Stability	Stable	Somewhat Stable	Stable	Somewhat Stable	Somewhat Stable	Stable	Somewhat Stable	Somewhat Stable	Stable	Stable
In-stream Depositional Features	Gravel Bars	None	None	Detritus	Detritus	Gravel Bars	None	None	None	Gravel Bars
Quantitative										
Depth (m)										
Min.	0.24	0.35	0.11	0.19	0.36	0.09	0.08	0.22	0.14	0.28
Max.	1.11	0.81	0.52	0.73	1.21	0.79	0.67	0.66	1.39	0.49
Avg.	0.74	0.51	0.32	0.40	0.74	0.31	0.33	0.49	0.73	0.39
Velocity (ft./sec.)										
Min.	0.00	0.01	0.09	0.00	0.00	0.00	0.00	0.18	0.04	0.91
Max.	1.70	0.33	2.16	0.15	0.16	1.14	1.46	1.88	4.03	2.92
Avg.	0.65	0.15	1.05	0.05	0.05	0.16	0.68	0.96	1.54	1.59
Substrate										
% Silt/Clay	0.4	0.0	0.0	17.5	18.3	0.4	0.0	0.0	0.6	0.0
% Sand	4.0	0.0	0.5	11.8	0.0	0.8	0.0	0.0	0.8	0.0
% Gravel	83.6	99.0	96.5	70.0	76.0	78.0	53.0	60.0	95.2	84.2
% Cobble	9.4	1.0	2.9	0.7	5.7	20.8	46.0	33.9	3.2	15.8
% Boulder	1.8	0.0	0.0	0.0	0.0	0.0	1.0	1.9	0.0	0.0
% Bedrock	0.8	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.2	0.0
D_{50}	30 mm	23 mm	28 mm	13 mm	26 mm	42 mm	61 mm	55 mm	28 mm	33 mm
D_{84}	58 mm	36 mm	42 mm	26 mm	50 mm	72 mm	110 mm	110 mm	45 mm	64 mm

Table 3-11. Unionids collected in quantitative samples, Spring River, 2017.

	Missouri	Kansas					Oklahoma				
	Spring 1A	Spring 3	Spring 5	Spring 8B	Spring 10C	Spring 12C	Spring 13	Spring 19	Spring 20	Spring 22	Total
Amblemini											
Amblema plicata	7	2	WD	–	–	–	–	–	–	–	9
Pleurobemini											
Eurynia dilatata	9	1	1	–	–	–	WD	–	–	–	11
Fusconaia flava	23	13	3	–	–	–	–	–	–	–	39
Fusconaia ozarkensis	3	4	–	–	–	–	–	–	–	–	7
Pleurobema sintoxia	32	4	21	–	–	–	–	–	–	–	57
Quadrulini											
Cyclonaias tuberculata	WD	–	–	–	–	–	–	–	–	–	WD
Cyclonaias pustulosa	72	15	17	–	1	–	SF	–	–	–	105
Quadrula quadrula	FD	–	–	–	WD	–	–	–	WD	–	FD
Theliderma cylindrica	1	–	2	–	–	–	–	–	–	–	3
Theliderma metanevra	1	–	WD	–	–	–	–	–	–	–	1
Tritogonia verrucosa	33	6	12	–	–	3	3	–	3	–	60
Lampsilini											
Cyprogenia aberti	2	–	–	–	–	–	–	–	–	–	2
Ellipsaria lineolata	–	–	–	–	–	–	–	–	WD	–	WD
Lampsilis cardium	1	–	1	–	WD	5	1	7	4	4	23
Lampsilis rafinesqueana	23	1	11	–	–	–	–	–	–	–	35
Lampsilis siliquoidea	1	–	–	–	–	–	–	–	FD	–	1
Lampsilis teres	–	–	–	–	1	–	–	–	–	–	1
Leptodea fragilis	2	1	1	1	–	3	–	4	1	1	14
Obliquaria reflexa	WD	–	1	–	–	3	2	10	10	2	28
Potamilus purpuratus	–	–	–	–	–	3	1	3	1	WD	8
Ptychobranchus occidentalis	4	–	2	–	–	–	–	–	–	–	6
Truncilla donaciformis	–	–	–	–	–	1	1	1	–	WD	3
Truncilla truncata	–	–	–	–	–	–	–	–	WD	–	WD
Venustaconcha ellipsiformis	WD	–	–	–	–	–	–	–	–	–	WD
Anodontini											
Lasmigona complanata	–	1	–	–	–	–	–	–	–	–	1
Lasmigona costata	3	–	–	–	–	–	–	–	–	–	3
Strophitus undulatus	WD	–	–	–	–	–	–	–	–	–	WD
Total no. live	217	48	72	1	2	18	8	25	19	7	417
No. live species	16	10	11	1	2	6	5	5	5	3	21
Total no. species	21	10	13	1	4	6	7	5	9	5	27
Total unionid density (±2SE)[1]	8.7 (±2.2)^{A}	3.2 (±1.3)^{B}	3.8 (±1.3)^{B}	0.1 (±0.1)^{C}	0.1 (±0.2)^{C}	0.7 (±0.3)^{D}	0.3 (±0.2)^{CD}	1.3 (±0.5)^{E}	0.8 (±0.4)^{D}	0.3 (±0.2)^{CD}	
Adult unionid density (±2SE)	8.0 (±2.0)	3.1 (±1.3)	3.1 (±1.1)	0.0 (±0.0)	0.1 (±0.1)	0.5 (±0.3)	0.3 (±0.2)	1.0 (±0.5)	0.6 (±0.3)	0.3 (±0.2)	
Juvenile unionid density (±2SE)	0.6 (±0.3)	0.1 (±0.2)	0.7 (±0.4)	0.1 (±0.1)	0.1 (±0.1)	0.2 (±0.2)	0.0 (±0.1)	0.4 (±0.3)	0.2 (±0.2)	0.0 (±0.0)	
% Juvenile	7.4	4.2	19.4	100.0	50.0	33.3	12.5	28.0	21.1	0.0	
% Unionid mortality	3.6	0.0	2.7	0.0	0.0	0.0	11.1	7.4	13.6	0.0	
Corbicula fluminea density (±2SE)	2.5 (±0.8)^{A}	2.1 (±0.8)^{AD}	2.9 (±1.3)^{AE}	0.4 (±0.3)^{BC}	0.1 (±0.2)^{B}	1.2 (±0.8)^{C}	1.3 (±0.5)^{D}	1.1 (±0.6)^{CD}	1.4 (±0.5)^{DE}	0.6 (±0.3)^{BC}	

FD = fresh dead, WD = weathered dead, SF = sub-fossil

[1]Density = Average no. live/m^2; different letters within rows indicate a significant difference (Kruskal-Wallis, ≤0.05)

Table 3-12. Habitat characteristics, Center Creek, Missouri, 2017.

	Center 0	Center 1G2	Center 5D	Center 7	Center 10B
Qualitative					
Dominant Land Use	Forest/Natural	Forest/Natural	Forest; Agriculture	Forest/Natural	Forest/Natural
Site Habitat	Primary Channel; Riffle/Run	Secondary Channel; Run	Primary Channel; Riffle/Run	Secondary Channel; Riffle/Run	Primary Channel; Run
Riparian Zone					
Left Descending Bank	>10 m	>10 m	≤10 m	>10 m	>10 m
Right Descending Bank	>10 m	>10 m	≤10 m	≤10 m	>10 m
Canopy Cover	Mostly Shaded	Mostly Open	Mostly Open	Shaded	Shaded
Substrate Stability	Somewhat Stable	Somewhat Stable	Very Loose	Stable	Stable
In-stream Depositional Features	Gravel Bars	Gravel Bars; Detritus	Gravel Bars; Detritus	Gravel Bars; Detritus	Gravel Bars
Quantitative					
Depth (m)					
Min.	0.18	0.11	0.27	0.13	0.20
Max.	0.65	0.57	0.68	0.36	0.73
Avg.	0.40	0.38	0.49	0.27	0.49
Velocity (ft./sec.)					
Min.	0.12	0.00	0.00	0.20	0.02
Max.	2.50	0.90	2.70	0.90	0.86
Avg.	0.92	0.21	1.04	0.47	0.30
Substrate					
% Silt/Clay	0.0	3.5	0.0	0.0	4.8
% Sand	2.7	7.7	4.8	0.0	0.8
% Gravel	84.0	86.7	82.5	84.2	48.0
% Cobble	13.3	1.1	9.5	15.8	20.0
% Boulder	0.0	0.0	3.2	0.0	26.4
% Bedrock	0.0	1.1	0.0	0.0	0.0
D_{50}	22 mm	17 mm	29 mm	39 mm	58 mm
D_{84}	59 mm	33 mm	58 mm	64 mm	410 mm

Table 3-13. Unionids collected in quantitative samples, Center Creek, Missouri, 2017.

	Center 0	Center 1G2	Center 5D	Center 7	Center 10B	Total
Amblemini						
Amblema plicata	–	–	WD	–	–	WD
Pleurobemini						
Eurynia dilatata	2	WD	–	WD	–	2
Fusconaia flava	2	2	–	WD	–	4
Pleurobema sintoxia	–	WD	–	WD	–	WD
Quadrulini						
Tritogonia verrucosa	–	–	–	WD	–	WD
Lampsilini						
Lampsilis rafinesqueana	–	WD	–	WD	–	WD
Ligumia subrostrata	–	1	–	–	–	1
Venustaconcha ellipsiformis	2	WD	–	–	–	2
Total no. live	6	3	0	0	0	9
No. live species	3	2	0	0	0	4
Total no. species	3	6	0	5	0	8
Total unionid density (±2SE)[1]	1.6 (±1.7)^{A}	0.2 (±0.2)^{B}	0.0 (±0.0)^{B}	0.0 (±0.0)^{B}	0.0 (±0.0)^{B}	
Adult unionid density (±2SE)	0.3 (±0.5)	0.2 (±0.2)	–	–	–	
Juvenile unionid density (±2SE)	1.3 (±1.3)	0.0 (±0.0)	–	–	–	
% Juvenile	83.3	0.0	–	–	–	
% Unionid mortality	0.0	0.0	–	–	–	
Corbicula fluminea density (±2SE)	58.7 (±54.3)^{A}	2.3 (±1.4)^{B}	0.3 (±0.4)^{BC}	21.3 (±10.7)^{D}	0.0 (±0.0)^{C}	

WD = weathered dead

[1]Density = Average no. live/m^2; different letters within rows indicate a significant difference (Kruskal-Wallis, $p \leq 0.05$)

Table 3-14. Habitat characteristics, Shoal Creek, 2017 - 2018.

	Missouri			Kansas
	Shoal 5A	Shoal 8	Shoal 10B	Shoal 16A
Qualitative				
Dominant Land Use	Agriculture	Pasture/Agriculture	Forest/Natural, Residential	Agriculture
Site Habitat	Primary Channel; Run	Primary Channel; Run	Secondary Channel; Run	Primary Channel; Run
Riparian Zone				
Left Descending Bank	≤10 m	None	≤10 m	≤10 m
Right Descending Bank	≤10 m	≤10 m	≤10 m	≤10 m
Canopy Cover	Mostly Open	Mostly Open	Mostly Open	Mostly Open
Substrate Stability	Stable	Stable	Somewhat Stable	Very Loose
In-stream Depositional Features	None	Gravel Bars	Gravel Bars; Detritus	Gravel Bars
Quantitative				
Depth (m)				
Min.	0.27	0.27	0.10	0.17
Max.	1.06	0.54	0.36	0.76
Avg.	0.69	0.39	0.22	0.46
Velocity (ft./sec.)				
Min.	0.03	0.05	0.02	0.36
Max.	1.20	0.46	1.51	1.66
Avg.	0.60	0.25	0.57	1.09
Substrate				
% Silt/Clay	1.0	2.4	15.2	0.0
% Sand	0.0	10.4	8.8	0.0
% Gravel	88.2	68.4	76.0	70.2
% Cobble	10.8	14.0	0.0	29.8
% Boulder	0.0	4.8	0.0	0.0
% Bedrock	0.0	0.0	0.0	0.0
D_{50}	30 mm	24 mm	16 mm	49 mm
D_{84}	55 mm	72 mm	30 mm	81 mm

Table 3-15. Unionids collected in quantitative samples, Shoal Creek, 2017 - 2018.

	Missouri			Kansas	
	Shoal 5A	Shoal 8	Shoal 10B	Shoal 16A	Total
Pleurobemini					
Eurynia dilatata	8	WD	–	–	8
Fusconaia flava	30	7	WD	–	37
Pleurobema sintoxia	8	6	–	–	14
Quadrulini					
Theliderma metanevra	–	1	–	–	1
Lampsilini					
Lampsilis cardium	1	1	–	–	2
Lampsilis rafinesqueana	–	3	WD	–	3
Ptychobranchus occidentalis	5	1	–	–	6
Venustaconcha ellipsiformis	2	–	–	–	2
Total no. live	54	19	0	0	73
No. live species	6	6	0	0	8
Total no. species	6	7	2	0	8
Total unionid density (±2SE)[1]	2.2 (±0.9)^{A}	1.5 (±0.8)^{A}	0.0 (±0.0)^{B}	0.0 (±0.0)^{B}	
Adult unionid density (±2SE)	2.2 (±0.9)	1.4 (±0.8)	–	–	
Juvenile unionid density (±2SE)	0.0 (±0.0)	0.1 (±0.2)	–	–	
% Unionid mortality	0.0	0.0	–	–	
% Juvenile	0.0	5.3	–	–	
Corbicula fluminea density (±2SE)	26.4 (±6.1)^{A}	123.1 (±18.2)^{B}	40.8 (±17.7)^{A}	0.4 (±0.2)^{C}	

WD = weathered dead

[1]Density = Average no. live/m^2; different letters within rows indicate a significant difference (Kruskal-Wallis, $p \leq 0.05$)

Table 3-16. Habitat characteristics, Neosho River, Oklahoma, 2017.

	Neosho @ Stepps Ford	Neosho 6
Qualitative		
Dominant Land Use	Agriculture/Pasture	Forest/Natural; Urban
Site Habitat	Primary Channel; Riffle/Run	Primary Channel; Run/Pool
Riparian Zone		
Left Descending Bank	≤10 m	>10 m
Right Descending Bank	≤10 m	>10 m
Canopy Cover	Mostly Shaded	Mostly Shaded
Substrate Stability	Stable	Stable
In-stream Depositional Features	Gravel Bars	Detritus
Quantitative		
Depth (m)		
Min.	0.07	0.15
Max.	0.40	1.69
Avg.	0.20	0.91
Velocity (ft./sec.)		
Min.	0.10	0.01
Max.	2.77	0.22
Avg.	1.15	0.09
Substrate		
% Silt/Clay	0.0	31.0
% Sand	0.0	19.0
% Gravel	45.0	42.9
% Cobble	3.8	7.1
% Boulder	0.0	0.0
% Bedrock	51.2	0.0
D_{50}	26 mm	1 mm
D_{84}	44 mm	29 mm

Table 3-17. Unionids collected in quantitative samples, Neosho River, Oklahoma, 2017.

	Neosho @ Stepps Ford	Neosho 6	Total
Quadrulini			
Cyclonaias pustulosa	2	1	3
Theliderma metanevra	7	—	7
Tritogonia verrucosa	3	—	3
Lampsilini			
Leptodea fragilis	1	3	4
Obliquaria reflexa	—	2	2
Potamilus purpuratus	—	6	6
Total no. live	13	12	25
No. live species	4	4	6
Total no. species	4	4	6
Total unionid density (±2SE)[1]	0.5 (±0.4)^{A}	1.2 (±0.8)^{B}	
Adult unionid density (±2SE)	0.5 (±0.3)	0.9 (±0.7)	
Juvenile unionid density (±2SE)	0.0 (±0.1)	0.3 (±0.4)	
% Juvenile	23.1	8.3	
% Unionid mortality	0.0	7.7	
Corbicula fluminea density (±2SE)	0.7 (±0.5)^{A}	0.1 (±0.2)^{B}	

[1]Density = Average no. live/m^2; different letters within rows indicate a significant difference (Kruskal-Wallis, $p \leq 0.05$)