TOXICITY OF SEDIMENTS AND PORE-WATERS AND THEIR POTENTIAL IMPACT ON NEOSHO MADTOM, *NOTURUS PLACIDUS*, IN THE SPRING RIVER SYSTEM AFFECTED BY HISTORIC ZINC-LEAD MINING AND RELATED ACTIVITIES IN JASPER AND NEWTON COUNTIES, MISSOURI; AND CHEROKEE COUNTY, KANSAS

FINAL REPORT TO THE U.S. FISH AND WILDLIFE SERVICE

COLUMBIA, MISSOURI

Prepared by:

ANN L. ALLERT, MARK L. WILDHABER, CHRISTOPHER J. SCHMITT,

DUANE CHAPMAN, AND ED CALLAHAN

U.S. GEOLOGICAL SURVEY, BIOLOGICAL RESOURCES DIVISION

ENVIRONMENTAL AND CONTAMINANTS RESEARCH CENTER

4200 NEW HAVEN RD., COLUMBIA, MISSOURI 65201

JULY, 1997

United States Department of the Interior

U. S. GEOLOGICAL SURVEY

Columbia Environmental Research Center
4200 New Haven Road
Columbia, Missouri 65201

January 30, 2002

James Dwyer
U.S. Fish and Wildlife Service
608 E. Cherry Street
Columbia, Missouri 65201

Dear Jim,

This letter is to inform you that in the course of reviewing our final report, titled, "Toxicity of sediment and pore-waters and their potential impact on Neosho madtom, *Noturus placidus*, in the Spring River system affected by historic zinc-lead mining and related activities in Jasper and Newton Counties, Missouri; and Cherokee County, Kansas" by A.L. Allert, et al. 1997, we discovered several errors in the data we provided. The data in error, can be found in Table 1, "Collection sites in the Spring River system, 1995".

Attached is a table with corrected descriptions and coordinates (the latter all in WGS84 datum). Some of the sections in Jasper Co. are not square; they are twice as long (latitude) as they are wide. Both the legal description and the GPS coordinates for our Site 8 (North Fork of the Spring River east of Hwy. 43) were both wrong; the Range number was incorrectly stated as 34W (should have been 33W) and the coordinates contained two typographical errors.

Should you require additional information, please feel free to contact either of me by telephone (573-875-5399) or by email (**ann_allert@usgs.gov**).

Sincerely

Ann L. Allert
Research Fishery Biologist

enclosures (as stated)

Date sampled	Site number	River (county and state)	Latitude, longitude	Legal description
09/24/95	7	Spring River just NW of Galesburg, Missouri (Jasper County, Missouri)	37°16'18.20"N 94°31'11.20"W	NW1/4, Sec10, T29N, R33W
09/24/95	7	Spring River just NW of Galesburg, Missouri (Jasper County, Missouri)	37°16'18.20"N 94°31'11.20"W	NW1/4, Sec10, T29N, R33W
09/25/01	9	Spring River just east of Waco, Missouri (Jasper County, Missouri)	37°14'33.21"N 94°34'00.32"W	NE1/4, Sec 18, T29N, R33W
09/25/01	9	Spring River just east of Waco, Missouri (Jasper County, Missouri)	37°14'33.21"N 94°34'00.32"W	NE1/4, Sec 18, T29N, R33W
09/25/95	8	North Fork of Spring River due east of State Highway 43 (Jasper County, Missouri)	37°16'22.42"N 94°28'26.62"W	SE1/4, Sec01, T29N, R33W

United States Department of the Interior

U. S. GEOLOGICAL SURVEY

Columbia Environmental Research Center
4200 New Haven Road
Columbia, Missouri 65201

June 26, 2000

James Dwyer
U.S. Fish and Wildlife Service
608 E. Cherry Street
Columbia, Missouri 65201

Dear Jim,

This letter is a formal response to our discussion of the final report made to the U.S. Fish and Wildlife Service titled, "Toxicity of sediment and pore-waters and their potential impact on Neosho madtom, *Noturus placidus*, in the Spring River system affected by historic zinc-lead mining and related activities in Jasper and Newton Counties, Missouri; and Cherokee County, Kansas" by A.L. Allert, et al. 1997. We would like to clarify our discussion of the methodology for processing our surface and pore waters samples. This correction should be included in any distribution of our report.

All of our water samples for metal analysis were filtered in the field using a Geofilter® (Geotech Inc., Denver, CO) positive-pressure apparatus through a 142-mm (dia.), 0.45 μm polycarbonate membrane filter; collected in an acid-cleaned high-density polyethylene bottle; preserved by acidification to 1% (v/v) with ultrapure nitric acid (Baker® Ultrex); and placed on ice for transport back to the laboratory. Samples were kept chilled until the analysis was completed.

In our report, we omitted to state that our surface water samples for metal analysis were processed in this manner. We regret the omission. A previous report titled, "The effects of historic zinc-lead mining and related activities in the Tri-States Mining District on aquatic ecosystems supporting the Neosho madtom, *Noturus placidus*, in Jasper County, Missouri; Ottawa County, Oklahoma; and Cherokee County, Kansas" by C.J. Schmitt, et al. 1997, states that procedures for processing surface and pore waters were the same for the previous year's work. Also, in Black and Veatch Waste Science, Inc. Trip Report (dated October 5, 1995) submitted by David Munie to the U.S. Environmental Protection Agency, the field sheets indicate that water samples were filtered and acidified.

If you have any additional concerns, comments or questions, please do not hesitate to call me (573-876-1903) or email me (ann_allert@usgs.gov).

Sincerely,

Ann L. Allert

Ann L. Allert
Fisheries Biologist, Research

cc: Schmitt, Wildhaber, Mauck

Executive Summary

The Tri-State Mining District, comprising portions of Jasper and Newton Counties, Missouri; Cherokee County, Kansas; and Ottawa County, Oklahoma, was mined intensively for zinc and lead for more than 100 yr. Wastes from historic mining, smelting, and related activities have contaminated surface and ground waters. The Tri-State District is drained by the Spring-Neosho River system, which supports populations of the Neosho madtom (*Noturus placidus*), a federally listed threatened fish species (Williams et al. 1989; Wenke and Eberle 1991). This study was designed and implemented to determine the toxicity of pore-water collected in potentially suitable *N. placidus* habitat in the Spring River system affected by mining. Pore-water was collected from sites in the Spring River and its tributaries to assess toxicity to standard test organisms. Pore-water toxicity testing provides a means for assessing sediment quality.

A field study was conducted in September, 1995 to determine the toxicity of pore-water and sediments in the Spring River and two tributaries. Sites were also sampled in an effort to better characterize the Neosho madtom habitat preferences, and benthic macroinvertebrate samples were collected and analyzed to determine associations between these organisms and *N. placidus* abundance and distribution. Samples of surface and interstitial (pore) waters were collected and analyzed for a suite of water quality parameters and for mining-derived metals, and to be used in toxicity tests. The physical characteristics of the sites were also quantified.

Biological sampling revealed that, consistent with previous studies, Neosho madtoms were generally most abundant on gravel bars containing proportionally greater amounts of fine material and lesser amounts of coarse gravel and stones. In the Spring River, this study confirmed the extension of the known range of the species from the confluence of Willow Creek, in Baxter

Springs, Cherokee County, Kansas, upstream to Waco, Jasper County, Missouri (Wilkinson et al. 1996). It may also occur as far upstream in Jasper County as the confluence of the Spring River mainstem and its North Fork but our sampling did not find any *N. placidus* at those locations. Length-frequency distributions indicated the presence of young-of-the-year at several Spring River sites, but the whereabouts of spawning sites and other aspects of the reproductive biology of the Spring River population remain unknown. *N. placidus* has not been found in any Spring River tributary sampled to date, nor has it been found in the Spring River downstream of Baxter Springs. A combination of physical, biological, and chemical factors may presently limit the distribution and abundance of the Neosho madtom in the Spring River. Among the latter, concentrations of zinc and other mining-derived metals in the Spring River below Center Creek, and in both Shoal and Center Creeks may be sufficiently high to affect *N. placidus*.

Background and Purpose

The Tri-State Mining District comprises portions of Jasper and Newton Counties, in southwestern Missouri; Cherokee County, in southeastern Kansas; and Ottawa County, in northeastern Oklahoma. The contamination of surface waters, shallow ground waters, and aquatic biota by zinc and other metals from mining and ore beneficiation in this mineralized area are well documented (Proctor et al. 1974; Pita and Hyne 1975; Czarneski 1985; Smith 1988; Neuberger et al. 1990; Davis and Schumacher 1992; Schmitt et al. 1993a,b). Cherokee and Jasper counties are Superfund sites on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL). Human health effects were attributed to mining-derived metals in the drinking water supply of Galena, Kansas, which is in Cherokee County (Neuberger et al. 1990);

mining sites in Galena have been remediated. Studies completed and underway in Cherokee County (e.g., Spruill 1987; Ferrington et al. 1988; Dames and Moore 1993a) have also shown effects on aquatic ecosystems from elevated metals and low pH emanating from sites contaminated with wastes from mining and related activities. The Tri-State Mining District is drained in its entirety by the Neosho-Spring River system, which currently supports the only remaining population of the Neosho madtom, *Noturus placidus* (Pisces, Ictaluridae), a federally listed threatened species (Williams et al. 1989; Wenke and Eberle 1991). Schmitt et al. (1997) characterized the availability, quality, and location of physically suitable habitat for Neosho madtoms in the portions of the Spring River and its tributaries potentially affected by mining. Sites were selected to characterize the extent and quality of *N. placidus* habitat in the mining portions of the Spring River system.

Objective 1: Determine the toxicity of pore-water collected in potentially suitable *N. placidus* habitat in the Spring River system affected by mining. Pore-water was collected from sites in the Spring River and its tributaries to assess toxicity to standard test organisms. Pore-water toxicity testing provides a means for assessing sediment quality.

Objective 2: Determine the relative impact of the tributaries on the distribution of Neosho madtom in the Spring River system. Sites on the Spring River were selected above and below several tributaries to examine the impact of the tributaries to habitat, water quality, metal concentration in sediments and water, and toxicity to a standard test organism.

Methods

Site Selection: Sampling sites meeting the general requirements of *N. placidus* within its general known range were identified for consideration. Sites were selected on the basis of gravel presence, accessibility to sampling teams, and historic evidence of *N. placidus* occurrence; i.e., gravel bars where the species was historically present were sampled, as were some previously found to be devoid of *N. placidus*. Sites included those historically sampled by the U.S. Fish and Wildlife Service (FWS) and known to support the species; sites in the Spring River system affected to varying degrees by mining; and sites in the lower reaches of Spring River tributaries, where *N. placidus* has not been found (Figure 1, Table 1). Additional sites were selected and established in a manner consistent with the site selection and sampling protocol used by the FWS, as follows: Based on the known distribution and habitat preferences of *N. placidus*, we defined a site as a gravel bar-riffle complex. At each site, three transects were delineated to bracket all potential *N. placidus* habitat, which we defined as the wadeable portions of the flowing stream (i.e., ≤ 1.25 m deep) associated with the bar. For bars extending completely across the stream, three stations equally spaced across the stream were defined on each transect and marked with floats. Stations were separated by at least 2 m, fewer stations were established for narrow transects. For bars occupying only one bank, the stations were spaced equally by at least 2 m across the portion of the stream that could be waded from the bar (≤ 1.25 m deep).

Field procedures: At each station, physical habitat quality measurements, based on the guidelines and procedures provided by Platts et al. (1983) and Hamilton and Bergersen (1984); water quality; and biological sampling were conducted. To avoid sampling previously disturbed

substrate, all sampling proceeded upstream and away from the bank, and the procedures were implemented in the following order: Fishes were collected by kick-seining a 4.5-m × 4.5-m area with a 3-mm (square) mesh seine; benthic invertebrates were collected with a 0.1- m^2 modified Hess sampler equipped with a 0.3-mm mesh collection bag; substrate samples (for particle size analysis) was collected with a 1.1-L [13-cm (depth) × 10-cm (dia.)] cylindrical grab sampler. The depth and current velocity at the substrate and at 60% depth were then measured with a hand-held current meter mounted on a wading rod (Swoffer® Instruments Model 2100) at each station. The dimensions of the site were then determined by direct measurement and the site was diagramed. The geospatial coordinates of the upstream and downstream limits of the site were determined with a global positioning system (GPS) receiver (Rockwell® PLGR+®) for future mapping.

All equipment used during sediment and water collection was acid-cleaned following standard procedures (Schmitt 1994a,b). Composite samples of surficial streambed sediments representing each site were collected from the upper 4 cm of depositional zones using a PVC scoop; eroding banks and other active areas were avoided. Overlying water was gently decanted from the scoop. The sediments from each site were composited into a polyethylene bucket and gently mixed with a Teflon® spoon. Aliquants of composited sediment were transferred with the spoon to three pore-water extractors (Carr and Chapman 1995), and pore-water was extracted under positive pressure (N_2 @ ≤ 30 PSI =1551 torr) into 250-mL polyethylene bottles. Pore-water samples were filtered in the field @ 600 mL/ min using an Geofilter® positive-pressure apparatus (Geotech, Denver, CO) through a 142-mm (dia.), 0.45-µm polycarbonate membrane filter; collected in polyethylene bottles; preserved by acidification to 1% (v/v) with nitric acid (Baker® Ultrex); and placed on ice for transport back to the laboratory. An equivalent

volume of ultrapure water was carried through the extraction and filtration procedure as a field blank. Using the spoon, a pre-cleaned 4-oz jar (I-Chem) was filled to capacity with a portion of the remaining sediment, capped tightly, and also placed on ice for transport back to the laboratory.

A grab-sample of surface water was collected at the middle station of the most downstream transect defining each site for nutrient and metal analysis. Conductivity, temperature, pH, and dissolved oxygen concentration of surface waters were also measured *in-situ* with water quality instruments (YSI®, Orion®).

In accordance with Endangered Species Subpermit requirements, all ictalurids were released alive, and no voucher specimens were retained. Selected ictalurid specimens were photographed for taxonomic verification, however. For taxa other than Ictaluridae, voucher specimens were preserved in ethanol and returned to the laboratory for confirmation of identification. Fishes were identified according to the criteria presented by Cross (1967), Pflieger (1975), Mayden (1988), Robinson and Buchanan (1988), and Cross and Collins (1995), with specimens assigned to subspecies according to the coding system developed and used by the Missouri Department of Conservation (MDC, Columbia, MO). Identifications of preserved specimens were confirmed by W.L. Pflieger of MDC, and occurrences were further checked against distributional maps provided by Pflieger (1975), Lee et al. (1980), Robinson and Buchanan (1988), and Cross and Collins (1995). Benthic invertebrate samples were preserved in ethanol for laboratory sorting and identification. Substrate samples were wet-sieved (38.1-, 19.0-, 9.5-, and 2-mm sieves) and the fractions were weighed in the field; all material passing the final sieve (2 mm) was retained for further particle size analysis in the laboratory.

Laboratory Procedures: Water quality analyses (i.e., nutrients, major ions, turbidity, etc.) for pore- and surface-water samples were performed by MSC personnel within 12 h of collection. Analyses followed procedures outlined in Standard Methods (APHA 1992). Lead and cadmium in pore-water and surface water were analyzed by atomic absorption spectroscopy by MSC and EPA-Region VII, respectively . All other elements in pore-water and surface water were analyzed using inductively coupled argon plasma (ICAP) emission spectroscopy by MSC and EPA-Region VII, respectively. Sediment analyses were conducted by EPA-Region VII (ICAP) and MSC [acid volatile sulfides (AVS) and simultaneously extracted metals (SEM)]. All containers and sampling equipment used to collect and store metals samples were acid-cleaned, as outlined in the Study Plan, Quality Assurance Project Plan, and Standard Operating Procedures for this investigation (Schmitt 1994a,b).

Relative risk of sediments from different sites were evaluated using the Toxic Units model developed by Wildhaber and Schmitt (1996). A toxic unit is defined as the ratio of the estimated concentration of a contaminant in the pore-water of a test sediment to the estimated chronic toxicity of that contaminant in the water as represented by the formula:

$$\text{Toxic Unit} = \frac{\hat{C}_{wp}}{C_{wqs}}$$

$\hat{C}_{wp}$ = Estimated pore-water concentration

C_{wqs} = Water quality standard.

The estimated pore-water concentrations are considered estimates of the bioavailable portions of the total concentrations of each contaminant as measured in the sediment. Toxic Units for the contaminants (here, just metals) are summed to produce a total toxicity estimate for that sediment.

Pore-water concentrations of metals were estimated from the bulk sediment concentrations by correcting for AVS by using the concentrations of metals simultaneously extracted with AVS adjusted for AVS (DiToro et al. 1990). Estimated pore-water concentrations are calculated by multiplying the estimated bioavailable concentration by the dry weight-to-moisture content ratio of the sediment. Only those metals extractable with a weak acid (1-N HCl) and adjusted by potential sulfide salts that could be formed by the extracted metals are considered bioavailable. For analytes in water quality standards that are dictated by hardness (i.e., cadmium, lead, zinc) the hardness values used in the calculations for individual sediments were those measured in the surface water from each site.

The AVS model is based on the assumption that under the reducing conditions present within sediments, sulfides control pore-water concentrations and hence bioavailability of divalent metals. Sulfide salts of the metals are relatively insoluble; the formation of these salts thereby renders the divalent metals relatively unavailable. AVS was allotted to metals in the following order: copper, cadmium, lead, zinc, nickel and iron. Water quality standards were based on EPA standards (1984a, b, c; 1987) and are listed in Appendix A, Table A1.

In the laboratory, the total mass of the dried, 2-mm fraction of each substrate sample was determined. The percentages of sand-, silt-, and clay-sized particles were determined by the Bouyoucos density gradient method. Particle size was also determined for each sediment sample

collected for metal analysis. Benthic invertebrate samples were sub-sampled and analyzed by an expedited procedure: From each site, a maximum of three samples (one from each of three transects) was chosen at random. The selected samples were randomly sub-sampled and sorted by a procedure modified from Plafkin et al. (1989). Organisms sorted from these sub-samples were then identified to the lowest taxon possible without mounting individual specimens for compound microscopy. References used to identify invertebrates included Brown (1972), Lewis (1974), Schuster and Etnier (1978), Bednarik and McCafferty (1979), Morihara and McCafferty (1979), Wiederholm (1983), Merritt and Cummins (1984), Schefter and Wiggins (1986), Pennak (1989), Poulton and Stewart (1991), and Thorp and Covich (1991).

Toxicity tests were conducted at MSC using pore-waters collected from each site. Standard test procedures using *Ceriodaphnia dubia* as the test organism include a dilution series with five concentrations for each site water. Ten replicates are run for each dilution, with each replicate renewed daily with 15 mL of water. Ten replicates are also run for controls using dilution and culture waters. Organisms are fed 1.0 μL of a mixture of Yeast-Trout chow-Cerophyll leaves (YTC), and 1.0 μL of algae. Standard procedures were modified for this study due to the limited amount of pore-water collected. Four dilutions (100, 50, 25, 12.5%) were tested for each site water, except at Sites 1 and 2; only three dilutions (50, 25, 12.5%) could be tested. Daily renewals of 10 mL were made. *C. dubia* were fed 0.66 μL of YTC and 0.66 μL of algae. MSC well-water and Tavern Creek pore-water were used as controls. MSC well-water was used for a dilution water.

Results

Physical - Chemical Habitat Analyses: The site means of the chemical and physical habitat variables measured at the 12 sites are given in Tables 2-12. Values for individual stations are presented in Appendix A, Tables A2-A3. Average depths were generally greater at sites in the Spring River and Shoal Creek than in Center Creek (Table 2). Current velocities were highest at Shoal Creek sites. Greater than 80% of the substrate particles in riffle sediments were classified as > 9 mm dia. at all but two sites (Sites 4 and 12). Very little clay was found in the riffle sediments at any station at any of the sites. Particle size analysis of sediment collected for chemical analysis in the depositional areas was predominately sand (> 70%) except at Site 12 (Appendix A, Table A4). Sediment from Site 12 was predominately clay (> 54%). The range of of average temperatures was greatest among Spring River samples (13.1 - 25.0°C). Temperatures in Shoal and Center Creek were similar (15.0 -17.5°C and 14.0 -15.0°C, respectively). Surface water were alkaline at all sites (135 - 190 mg/L, pH 7.60 - 8.20) and moderately hard to hard (144 - 184 mg/L) (Table 3). Turbidity were greatest at the Spring River sites, but variable (5.7 - 24.0 NTU). Turbidities in the tributaries were all low (< 10 NTU).

Metal Analyses: Cation (Ba, Ca, K, Mg, Na, Mn) concentrations were higher in the Spring River than the tributaries. Sulfate concentrations were generally low (≤ 60 mg/L) in the Spring River and even lower in the tributaries (Shoal Creek 2.0 - 20.0 mg/L). Concentrations of other water constituents were generally low throughout the river system. Three sites (Sites 1, 4, 5) in the Spring River had ammonia concentrations exceeding 0.1 mg/L. Nitrate levels were highest at Center Creek sites, ranging from 2.0 - 3.1 mg/L. Phosphorous concentrations were also generally

low, with the highest concentrations found in the tributaries (Shoal Creek, 0.45- 0.76 mg/L; Center Creek, 0.22 - 0.47 mg/L).

Concentrations of metals in water and sediment indicated an overall enrichment in Center and Shoal Creeks, and in Empire Lake. Among the mining-derived metals of concern in the Spring River system, only zinc occurred at ICAP - detectable concentrations in surface waters (Tables 4 - 5). Zinc concentrations were generally higher in the tributaries (Shoal Creek, 17.4 - 94.9 μg/L; Center Creek, 171 -182 μg/L) than in the Spring River. The highest concentration (< 61.3 μg/L) occurred below the two tributaries and Empire Lake at Site 1. Concentrations of zinc in Shoal and Center creeks were similar to those reported in 1994 (49.4 - 153.0 μg/L and 208 μg/L, respectively -- Schmitt et al. 1997).

The pattern for zinc in pore-water followed that of surface water; zinc concentrations in pore-water were greatest in Center Creek (197 - 1681 μg/L) (Table 6). Zinc concentrations were generally higher in Shoal Creek (36 - 87 μg/L) than in the Spring River except at Sites 1 and 5 which were below Center Creek (28 and 467 μg/L, respectively). Detectable concentrations of cadmium, lead, copper, and nickel were also found in pore-water at all sites (Table 6). Concentrations of cadmium and lead (2.6 μg/L and 3.1 μg/L, respectively) were highest at the mouth of Center Creek -- Site 12. Cadmium concentrations increased from upstream (0.27 μg/L at Site 11) to downstream (1.4 μg/L at Site 2) in Shoal Creek. Copper concentrations were greatest in Shoal Creek (1.2 - 13.0 μg/L), at the mouth of Center Creek (2.0 μg/L), and at Spring River sites below Center Creek (1.6 - 1.8 μg/L) . Concentrations of nickel were highest at Site 1 (15 μg/L) and at Site 8 in the mainstem of the Spring River (6.8 μg/L). Nickel concentrations were similar in Shoal Creek and Center Creek (3.6 - 5.7 μg/L and 2.2 - 7.2 μg/L, respectively).

Iron concentrations were elevated at several sites in Center Creek (Sites 6 and 12 -- 1170 and 2240 mg/L, respectively), in the Spring River mainstem (Sites 1 and Site 8 -- 7760 and 14600 mg/L, respectively).

Concentrations of mining-derived metals in sediments paralleled those found in surface and pore-waters (Tables 7 - 8). Lead and zinc concentrations were also higher in Center Creek (301- 2120 μg/g and 2060 - 13800 μg/g, respectively) and at those sites (Sites 1 and 5) in the Spring River below Center Creek (69.5 - 138 μg/g and 659 - 1490 μg/g, respectively). Concentrations of lead and zinc were higher in Shoal creek (66.7 - 116 μg/g and 761 - 1160 μg/g, respectively) than at Spring River sites above Center Creek. Nickel concentrations were similar in the two tributaries and were generally higher than Spring River sites except those located downstream of Center and Shoal Creeks. Cadmium concentrations were below detection limits at sites in the Spring River except at Site 8, in the Spring River mainstem. The concentration of cadmium at Site 12 was much greater (84.1 μg/g) than any other site; aluminum and copper concentrations were also elevated at this site (160000 μg/g and 51.2 μg/g, respectively).

SEM and AVS analysis of the sediment was consistent with the ICAP analysis (Table 9-12). SEM / AVS ratios and SEM - AVS differences were calculated for elements which are known to form sulfides less soluble than the sulfide salts of iron or manganese, and are listed in Tables 10 - 11. Sediments having an SEM / AVS ratio > 1 and positive SEM - AVS differences are considered potentially toxic to organisms in the aquatic ecosystem.

The SEM - AVS difference is generally more meaningful for samples with low AVS because it better reflects the magnitude of SEM metal excess (e.g., Site 3, Shoal Creek at the Sewage Treatment plant). Sediments having SEM / AVS rations less then 1 should not be acutely

toxic due to metals, but this does not preclude potential bioavailability of toxic metals through the food chain or if sediments become oxidized. No samples exhibited SEM / AVS ratios > 1 for cadmium or copper. Two samples from Shoal Creek (Sites 3 and 11) exhibited SEM / AVS ratios > 1 for nickel. Samples from these two sites, and Site 12 (Center Creek mouth) exhibited SEM / AVS ratios > 1 for lead, and all samples except the control site sediment (Tavern Creek) exhibited SEM / AVS ratios > 1 for zinc. In terms of SEM - AVS excess, two Center Creek sites (Site 12 and 6) had much greater values than two Shoal Creek sites (Sites 2 and 3) and the third site on Center Creek (Site 10). Metal excess at sites in the Spring River below the tributaries and the uppermost site in Shoal Creek were lower. Sites above the tributaries showed the smallest SEM - AVS excess.

Total Toxic Units were calculated for each site and are shown in Table 12. The site located at the mouth of Center Creek (Site 12) had the highest sum of Toxic Units (1427) as compared to the other sites (3.7 - 114). The Spring River site below Center Creek (Site 5, located near the mouth of Turkey Creek) had the second highest sum of Toxic Units. Zinc and nickel were bioavailable at all sites based on calculated Toxic Units. Lead was bioavailable at sites 3, 11, and 12, and cadmium was bioavailable at Site 12.

Distribution and Relative Dominance of Aquatic Macroinvertebrates: A total of 84 benthic macroinvertebrate taxa were identified from benthic samples collected during this study. Results are summarized in Table 13; the contents of individual samples are presented in Appendix A, Tables A5-A16. In general, the Spring River and its tributaries contain similar benthic compositions typical of late summer and autumn. The fauna of these systems can best be

described by comparing individual tributaries, and considering sites on the Spring River above Center Creek (upper Spring River) separate from those sites located below Center Creek (lower Spring River). The upper Spring River and the uppermost site on Shoal Creek contained the highest number taxa representing the orders Ephemeroptera, Plecoptera, and Trichoptera--the so-called EPT taxa. The lower Spring River, Site 6 in Center Creek and Site 3 in Shoal Creek contained slightly lower numbers of EPT taxa. The lowest numbers of EPT taxa were observed in samples from the sites in Center Creek and the lowermost site in Shoal Creek. The reduced representation of EPT taxa in Center Creek, and the dominance of Chironomidae and nematodes in both tributaries suggests that water or habitat quality is degraded.

The benthic fauna of the Spring River was typically dominated by mayflies (Ephemeroptera) of the families Baetidae (*Baetis* sp.), Heptageniidae (*Stenonema* spp., *Stenacron interpunctatum*, *Leucrocuta* sp.), Tricorythidae (*Tricorythodes* sp.), Caenidae (*Caenis* sp.), and Potamanthidae (*Anthopotamus* sp.); net-spinning caddisflies (Trichoptera) of the family Hydropsychidae; predaceous stoneflies (Perlidae: *Neoperla* sp.); Chironmidae/Ogligochitae and riffle beetles of the family Elmidae (*Stenelmis* sp.). Additional taxa, such as water mites (Acarina), blackflies (*Simulium* sp.), micro-caddisflies (Hydroptilidae), Isopoda, Pelecypoda, and Nematoda, were occasionally dominant at some sites or in a few individual samples. Sites in the upper Spring River yielded the following taxa that were not collected at any other sites: *Ephron* sp. and *Leucrocuta* sp. (Ephemeroptera); *Perlinella ehyra* (Perlidae); *Sialis* sp. (Megaloptera); *Corbicula* sp. (Pelecypoda), and *Elima* sp. (Arachnoidea). *Antocha* sp. (Diptera) was the only taxon found exclusively in Center Creek, and *Atherix* sp. (Diptera) was the only species found exclusively in Shoal Creek.

Distribution and Relative Abundance of Fishes: A total of 29 fish species were found in the Spring River, Shoal Creek, and Center Creek. (Tables 14-16). Of these, sixteen were collected exclusively in the Spring River; the stippled darter (*Etheostoma punctulatum*) occurred exclusively in Center Creek . Three species, the banded sculpin *(Cottus carolinae)*, longear sunfish *(Lepomis megalotis)*, and spotted bass (*Micropterus punctulatus*) were found only below Empire Lake at Site 1 . The northern hogsucker (*Hypentelium nigricans*), speckled darter (*E. stigmaeum*), channel darter (*Percina copelandi*), western slim minnow (*Pimephales t tenellus*), channel catfish (*Ictalurus punctatus*), stonecat (*Noturus flavus*), and bluntface shiner (*Cyprinella camurus*) were only found at the upper Spring River sites. Densities of all species except cardinal shiner *(Luxilus cardinalis)* and slender madtom *(Noturus exilis)* were higher in the Spring River than in Center Creek or Shoal Creek.

The dominant fishes at all collection sites were minnows (Cyprinidae) of the genera *Notropis*, *Erimystax*, *Pimephales* and *Luxilus*; darters (Percidae); and native North American catfishes (Ictaluridae). Stonerollers (*Campostoma* spp.), cardinal shiners, rosyface shiners (*N. rubellus*) gravel chubs (*Erimystax X-punctatus*), northern orangethroat darters (*Etheostoma s. spectabile*), greenside darters (*E. blennioides*), and banded darters (*E. zonale*), occurred frequently in riffle samples from all sites. Other Percidae which were commonly found included the slenderhead darter *(Percina phoxocephala)*, fantail darter (*E. f flabellare*), and the ozark logperch (*P. c fulvitaenia*).

In the Spring River system, the slender madtom was the most common ictalurid. The stonecat (*N. flavus*), Neosho madtom, channel catfish (*I. punctatus*), and flathead catfish (*Pylodictis olivaris*) were found in only the Spring River.

Distribution and abundance of *N. placidus*: Neosho madtoms were found 4 of the 12 sites sampled: Sites 1 ($n = 9$), 4 ($n = 6$), 5 ($n = 1$), and 9 ($n = 1$) (Tables 15 and 16). All of these sites were in the Spring River (Figure 1). Neosho madtoms were found at 9 of 19 mainstem sites in 1994 (Schmitt et al. 1997). No Neosho madtoms were collected at Site 5 (listed as Site 27) during in the 1994 study. Water in the eastern channel of the Spring River flowed north (upstream) around an island located at the mouth of Turkey Creek due to low flow in the Spring River, which resulted in this site being below the discharge from Turkey Creek in 1994. Both channels in the Spring River had flowing water in 1995, so Site 5 was not receiving water from Turkey Creek. The other six sites where madtoms had been collected in 1994 were not sampled in 1995. All of those sites were located above Center Creek.

Neosho madtoms considered to be young-of-the-year (y-o-y) were found at all sites except Site 9. Young-of-the-year madtoms had been collected at Site 9 in 1994 (listed as Site 23-Schmitt et al. 1997). Fish densities (0.38889 individuals / m^2) in the Spring River were similar to that found in 1994 (0.30 individuals / m^2).

Pore-water Toxicity Tests: Pore-water from two sites (Site 6, 12) in Center Creek and Site 1 were toxic to *C. dubia* (Table 17). All other sites had greater than 80% survival of adults. Toxicity results paralleled high concentrations of zinc in sediment, surface, and pore-waters at those sites and calculated Toxic Units.

Discussion

Concentrations of Mining-Derived Metals: The aquatic toxicity of lead, zinc, and cadmium are

moderated by pH, alkalinity, and hardness. The chronic Water Quality Criterion for total recoverable zinc (C_{Zn}), lead (C_{Pb}) and cadmium (C_{Cd}), in μg/l, are defined in Appendix A, Table A1 with hardness in units of mg/L. Hardness in the Spring River and its tributaries was typically 130-175 mg/L (Table 3). As computed from the equation above, C_{Zn} = 149 µg/l at a hardness of 150 mg/L. The Missouri Aquatic Life Criterion (MALC)--chronic for dissolved zinc in warm-water streams with a hardness of 125-200 mg/L is 340 μg/l (Missouri Department of Natural Resources 1992). Consequently, measured zinc levels in surface waters are potentially toxic to aquatic life at the four sites: All Center Creek sites (Sites 6, 10, 12) and the lowermost site in Shoal Creek (Site 2). Zinc concentrations in pore-waters exceed MALC at two Center Creek sites (Sites 6 and 12) and at the lowermost Spring River site (Site 1).

Concentrations of lead and cadmium in surface water were not detectable; however, dissolved lead concentrations of pore-waters averaged 1.6 μg/l, 1.33 μg/L, and 0.97 μg/L in the Spring River below Center Creek, in Center Creek and in Shoal Creek, respectively. Dissolved cadmium concentrations in pore-water averaged 1.8 μg/L, 0.88 μg/L, and 0.83 μg/L below Center Creek, in Center Creek and in Shoal Creek, respectively. The chronic MALC for lead in warm-water streams of 125-200 mg/L hardness is 16 μg/L, and for dissolved cadmium it is 5 μg/l. Generally, the chronic criteria incorporate bioaccumulation, and the dietary route of exposure is accounted for; nevertheless, the lead, zinc, and cadmium concentrations present at Spring River mainstem sites may be toxic, either individually or in combination, and especially if the benthic invertebrate food supply is heavily contaminated (e.g., Wildhaber et al. 1997, Woodward et al. 1994).

Moss (1981) described the diet of larger adults as comprising invertebrates characteristic

of mainstem riffles, mostly caddisflies (e.g., *Cheumatopsyche*, and *Hydropsyche*) and including mayflies (e.g., *Stenonema*, *Choroterpes*, and *Baetis*). Both young and adults feed extensively on dipterans. Although metal concentrations in benthic invertebrates were not examined, Wildhaber et al. (1997) found that concentrations of lead, zinc and cadmium in benthic invertebrates (e.g., Decapoda, Megaloptera) were highest at the mouth of Center Creek (Site 12), at the lowermost site in Shoal Creek (Site 2), at the mouth of Turkey Creek, and just downstream of Turkey Creek (Site 5). These concentrations, results of the toxicity tests and the Toxic Units analysis suggest that mining-derived metals in the lower reaches of the Spring River and its tributaries may be toxic to *N. placidus* and other aquatic organisms.

Present Distribution and Abundance of *N. placidus*: We found Neosho madtoms at Sites 1, 4, 5, and 9. Except for Site 1, these sites were all in the Missouri and Kansas portions of the Spring River mainstem, in the reach from the confluence of the mainstem and its North Fork, in Jasper County, Missouri downstream to the mouth of Turkey Creek, in Cherokee County, Kansas (Table 1, Fig. 1). Site 1 was situated in the West channel of the Spring River mainstem, downstream of Empire Lake and upstream of the confluence of Willow Creek, in Cherokee County. The collection of *N. placidus* at Baxter Springs and Waco confirmed collections made in 1994 (Wilkinson et al. 1996, Schmitt et al. 1997). As with other studies (Dames and Moore 1993b, Femmer and Joseph 1994), no Neosho madtoms were captured in either Spring River tributaries.

Fusilier and Edds (1994, 1995) reported the predominance of two length-age groups in the Cottonwood River population of Neosho madtoms during the period July-September: Young-of-the-year (y-o-y), which ranged in total length from 15 mm to about 40 mm; and age-1,

which ranged from about 40 mm to 60 mm. Larger, age-3 fish also occurred, but rarely. In the Spring River, where we captured only 17 specimens, an accurate length-frequency distribution could not be developed; nevertheless, specimens characteristic of all three age-length classes were obtained (30 - 66 mm). Specimens of a size that could be considered y-o-y were collected at Sites 1, 4, and 5, where no apparent y-o-y had been collected in 1994 (Schmitt et al. 1997). No apparent y-o-y were collected at the Waco site (Site 9), although they were collected at this site in 1994 (Schmitt et al. 1997). The fish collected at Site 9 is considered at least an age-2 fish.

Toxic Units at Sites 1, 4, 9, where *N. placidus* were sampled, totaled less then 11 units, and ranked ("1" having the lowest Total Toxic Units) 5, 3 and 1, respectively. Site 5 had the second highest sum of Toxic Units (114), which was an order of magnitude smaller then the highest sum (1427) found at Site 12. Toxicity tests, Toxic Units analysis, and chemical analysis suggest that Sites 1 and 5 may be toxic to *N. placidus*. It is unknown whether these individuals are residents of this portion of the Spring River or whether they were washed downstream from upstream sites. Young-of-the-year ($n = 3$) were found below Empire Lake (Site 1) in 1995, which suggests that this population may be capable of reproduction and be self-sustaining. Only one individual was found at Site 5, which suggest that this population may be displaced from sites above Center Creek.

Fuselier and Edds (1994) found that Neosho madtoms generally do not leave riffle habitats which contain loosely embedded sediments. Organic material does not accumulate in this habitat as it does in depositional, backwater or pool habitats where our sediment and pore-water samples were taken. Toxic effects may be reduced due to less organic material, which enhances the mobility of bioavailable metals (Besser and Rabeni 1987). Concentration of metals may also be

lower in riffle sediments, as seen in the pore-water collected from riffle habitats in 1994 (Wildhaber et al. 1996, Schmitt et al. 1997).

Summary and Conclusions

Collectively, studies conducted in the 1990's have confirmed the presence of a remnant, reproducing population of *N. placidus* in the Spring River in the reach from the confluence of the mainstem and North Fork, near Galesburg, Missouri downstream to Baxter Springs, Kansas (Wilkinson et al. 1996). The population persists in what may be the only remaining *N. placidus* habitat in the Spring River system. The most recent surveys have succeeded in finding Neosho madtoms on suitable gravel bars in the Waco-Baxter Springs reach when sampling has been conducted in late August and September. Sampling during other periods has been less successful (D. Edds, personal communication). Consequently, it is not possible to determine whether recent increases in the frequency of sightings in the Spring River reflect increasing numbers and expanding range, or simply that the whereabouts and habits of *N. placidus* are becoming better known and have been sampled more intensively in recent years. Toxicity tests, contaminant data, and analysis of the bioavailability of metals using the Toxic Units method suggest that the *N. placidus* population of the Spring River may be limited by mining-derived contaminants.

Acknowledgments: This study was jointly funded and undertaken by the U.S. Environmental Protection Agency, Region VII (EPA); the U.S. Department of the Interior (USDI), National Biological Service (NBS), now the Biological Resources Division of the U.S. Geological Survey, Environmental and Contaminants Research Center; and the USDI, Fish and Wildlife Service

(FWS), through its Ecological Services (ES) Field Office in Columbia, MO. Assistance with field collections and data processing were provided by Phil Crockett, Phil Lovely, Brad Mueller, and Dave Whites of MSC; by Dave Munie contracted through EPA; Colette Charbonneau from FWS-ES Field Office in Columbia, Missouri; and Shane Ruessler from the NBS (formerly) Florida-Carribean Science Center, Gainesville, FL. Missouri Southern State College provided laboratory space throughout the study. In addition, we gratefully acknowledge the cooperation of the many private landowners in Kansas and Missouri who granted us permission to sample on their property.

References

American Public Health Association (APHA) 1992. *Standard Methods for the Examination of Water and wastewater*. (18th Edition). Washington, DC, American Public Health Association.

Bednarik, A.F., and W.P. McCafferty. 1979. Biosystematic revision of the genus *Stenonema* (Ephemeroptera: Heptageniidae). Can. Bull. Fish. Aquat. Sci. No. 201. 73 pp.

Besser, J.M., and C.F. Rabeni. 1987. Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates. *Environ. Tox. and Chem.* 6:879-890.

Brown, H.P. 1972. Aquatic Dryopoid Beetles (Coleoptera) of the United States. Biota of Freshwater Ecosystems, Identification Manual #6 for U.S. EPA, Proj. No. 18050, Contract # 14-12-894. 82 pp.

Carr, R.S., and D.C. Chapman. 1995. Comparison of methods for conducting marine and estuarine sediment porewater toxicity tests- extraction, storage and handling techniques. *Arch. Environ. Contamin. Toxicol.* 28:(1):69-77.

Cross, F.B. 1967. Handbook of fishes of Kansas. Univ. Kansas Mus. Nat. Hist., Misc. Publ. No. 45. 45 pp.

Cross, F.B., and J.T. Collins. 1995. *Fishes in Kansas*. University of Kansas Natural History Museum, Public Education Series, No. 14. 315 pp.

Czarneski, J. 1985. Accumulation of lead in fish from Missouri streams affected by lead mining. *Bull. Environ. Contam. Toxicol.* 34:736-745.

Dames and Moore, Inc. 1993a. Final remedial investigation for Cherokee County, Kansas CERCLA site, Baxter Springs/Treece subsites. Denver, Colo.

Dames and Moore, Inc. 1993b. Draft site characterization memo: Neck/Alba, Snap, Oronogo/Duenweg, Joplin, Thoms, Carl Junction, and Waco Designated Areas, Jasper County Site, Jasper County, Missouri. Denver, Colo.

Davis, J.V., and J.G. Schumacher. 1992. Water quality characterization of the Spring River basin, southwestern Missouri and southeastern Kansas. U.S. Geological Survey, Water Resources Investigations Report 90-4176. Rolla, Mo. 112 pp.

DiToro, D.M., J.D. Mahony, D.J. Hansen, K.J. Scott, M.B. Hicks, S.M. Mayr, and M.S. Redmond. 1990. Toxicity of cadmium in sediments: the role of acid volatile sulfide. *Environ. Toxicol. Chem.* 9:1487-1502.

Ferrington, L.C. Jr., O.K. Galle, M.A. Blackwood, C.A. Wright, W.A. Bird, J.M. Jobe, and P.B. Grant. 1988. Preliminary assessment of cadmium, lead, manganese, and zinc in the Short Creek/Empire Lake aquatic system, Cherokee County, Kansas. Phase I. Kansas Water Resources Research Institute, University of Kansas, Lawrence. Contract No. 271. 88 pp.

Fusilier, L., and D. Edds. 1994. Seasonal variation in habitat use by the Neosho madtom (Teleostei: Ictaluridae: *Noturus placidus*). *Southwest Natur.* 39(3): 217-223.

Fuselier, L., and D. Edds. 1995. An artifical riffle as restored habitat for the Threatened Neosho madtom. *N. A. J. Fisheries Management.* 15:499-503.

Hamilton, K., And E.P. Bergersen. 1984. Methods to estimate aquatic habitat variables. U.S. Fish and Wildlife Service, Cooperative Fishery Research Unit, Colorado State University, Fort Collins, Colo. 70 pp.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. *Atlas of North American freshwater fishes.* N.C. State Museum of Natural History, Raleigh. 866 pp.

Lewis, P.A. 1974. Taxonomy and Ecology of *Stenonema* mayflies (Ephemeroptera: Heptageniidae). U.S. Environmental Protection Agency, Cincinnati, Ohio. Environmental Monitoring Series Report EPA-670/4-74-006. 89 pp.

Mayden, R.L. 1988. Systematics of the *Notropis zonatus* species group, with description of a new species from the Interior Highlands of North America. *Copeia* 1988:153-173.

Merritt, R.W., and K.W. Cummins. 1984. *An introduction to the aquatic insects of North America*. Kendall/Hunt, Dubuque, Iowa. 722 pp.

Morihara, D.K., and W.P. McCafferty. 1979. The *Baetis* larvae of North America (Ephemeroptera: Baetidae). *Trans. Amer. Entomol. Soc.* 105:139-221.

Moss, R. 1981. Life history information for the Neosho madtom (*Noturus placidus*). Kansas Department of Wildlife and Parks, Contract No. 38. 28 pp.

Neuberger. J.S., M. Mulhall, M.C. Pomatto, J. Sheverbush, and R. Hassenein. 1990. Health problems in Galena, Kansas: A heavy metal mining Superfund site. *Sci. Total Environ.* 94:261-272.

Pennak, R.W. 1989. *Fresh-water Invertebrates of the United States: Protozoa to Mollusca.* John Wiley & Sons, Inc. New York. 803 pp.

Pflieger, W.L. 1975. *The fishes of Missouri*. Missouri Department of Conservation, Jefferson City.

Pita, F.W., and N.J. Hyne. 1975. The depositional environment of zinc, lead, and cadmium in reservoir sediments. *Water Res.* 9:701-706.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers. U.S. Environmental Protection Agency, Washington, D.C. EPA/444/4-89-001.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. Gen. Tech. Rep. INT-138. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. 70 pp.

Poulton, B.C., and K.W. Stewart. 1991. The Stoneflies of the Ozark and Ouachita Mountains (Plecoptera). *Mem. Amer. Entomol.* Soc #38. 116 pp.

Proctor, P.D., G. Kisvarsanyi, E. Garrison, and A. Williams. 1974. Heavy metal content of surface and ground waters of the Springfield-Joplin area, Missouri. *In* D.D. Hemphill (ed.), *Proceedings of the 7th Annual Conference on Trace Substances in Environmental Health.* University of Missouri-Columbia, p. 63.

Robinson, H.W., and T.M. Buchanan. 1988. *Fishes of Arkansas.* University of Arkansas Press, Fayetteville. 536 pp.

Schefter, P.W., and G.B. Wiggins. 1986. A systematic study of the Nearctic larvae of the *Hydropsyche morosa* group (Trichoptera: Hydropsychidae). Life Sciences Misc. Pub., Royal Ontario Museum Issn 0082-5093.

Schmitt, C.J., M.L. Wildhaber, A.L. Allert, and B.C. Poulton. 1997. The Effects of Historic Zinc-Lead Mining and Related Activities in the Tri-State Mining District on Aquatic Ecosystems Supporting the Neosho Madtom, *Noturus placidus*, Jasper County, Missouri; Ottawa County, Oklahoma; and Cherokee County, Kansas. Final Report to the U.S. Environmental Protection Agency, Region VII, Kansas City, Kansas. 88 pp.

Schmitt, C.J. 1994a. The effects of historic zinc-lead mining and related activities on ecosystems supporting the Neosho madtom, *Noturus placidus*, in Jasper County, MO; Ottawa County, OK; and Cherokee County, Kansas. National Biological Service, Midwest Science Center, Columbia, Mo. Study Plan No. 40095. 20 pp.

Schmitt, C.J. 1994b. Quality assurance project plan for the effects of historic zinc-lead mining and related activities on ecosystems supporting the Neosho madtom, *Noturus placidus*, in Jasper County, MO; Ottawa County, OK, and Cherokee County, KS. National Biological Service, Midwest Science Center, Columbia, Mo. 46 pp.

Schmitt, C.J., M.L. Wildhaber, J.B. Hunn, M.N. Tieger, B.L. Steadman, and T. Nash 1993a. Biomonitoring of lead-contaminated Missouri streams with an assay for δ-aminolevulinic acid dehydratase (ALA-D) activity in fish blood. U.S. Fish and Wildlife Service, National Fisheries Research Contaminant research Center, Columbia, Mo. Report to the U.S. Fish and Widlife Service, Region 3, Columbia, MO. 43 pp.

Schmitt, C.J., M.L. Wildhaber, J.B. Hunn, M.N. Tieger, B.L. Steadman, and T. Nash. 1993b. Biomonitoring of lead-contaminated Missouri streams with an assay for δ-aminolevulinic acid dehydratase (ALA-D) activity in fish blood. *Arch. Environ. Contam. Toxicol.* 25:464-475.

Smith, B.J. 1988. Assessment of water quality in non-coal mining areas of Missouri. U.S. Geological Survey, Water Resources Investigations Report 87-4286. Rolla, Mo. 50 pp.

Spruill, T.B. 1987. Assessment of water resources in lead-zinc mined areas in Cherokee County, Kansas, and adjacent areas. U.S. Geological Survey, Water-Supply Paper 2268. Lawrence, Kansas. 68 pp.

Thorp, J.H., and A.P. Covich. 1991. *Ecology and Classification of North American freshwater invertebrates.* Academic Press, San Diego, Calif. 911 pp.

U.S. Environmental Protection Agency. 1984a. Ambient water quality criteria for: Mercury. EPA 440/5-80-058. Washington, D.C.

U.S. Environmental Protection Agency. 1984b. Ambient water quality criteria for: Lead. EPA 440/5-84-027. Washington, D.C.

U.S. Environmental Protection Agency. 1984c. Ambient water quality criteria for: Cadmium. EPA 440/5-84-032. Washington, D.C.

U.S. Environmental Protection Agency. 1987. Ambient water quality criteria for: Zinc. EPA 440/5-87-003. Washington, D.C.

Wenke, T.L., and M.E. Eberle. 1991. Neosho madtom *Noturus placidus* Taylor recovery plan. Natural Science Research Associates, Hays, KS, for the U.S. Fish and Wildlife Service, Denver, Colo. 42 p.

Wiederholm, T. 1983. Chironomidae of the Holarctic region. Keys and Diagnosis. Part I--Larvae. *Entomol. Scand. Suppl.* 19:1-457.

Wildhaber, M.L., C.J. Schmitt, and A. L. Allert. 1997. Elemental Concentrations in Benthic Invertebrates collected from the Neosho, Cottonwood, and Spring Rivers. Final Report to the U. S. Fish and Wildlife, Region 6, Manhattan, Kansas. 17 pp.

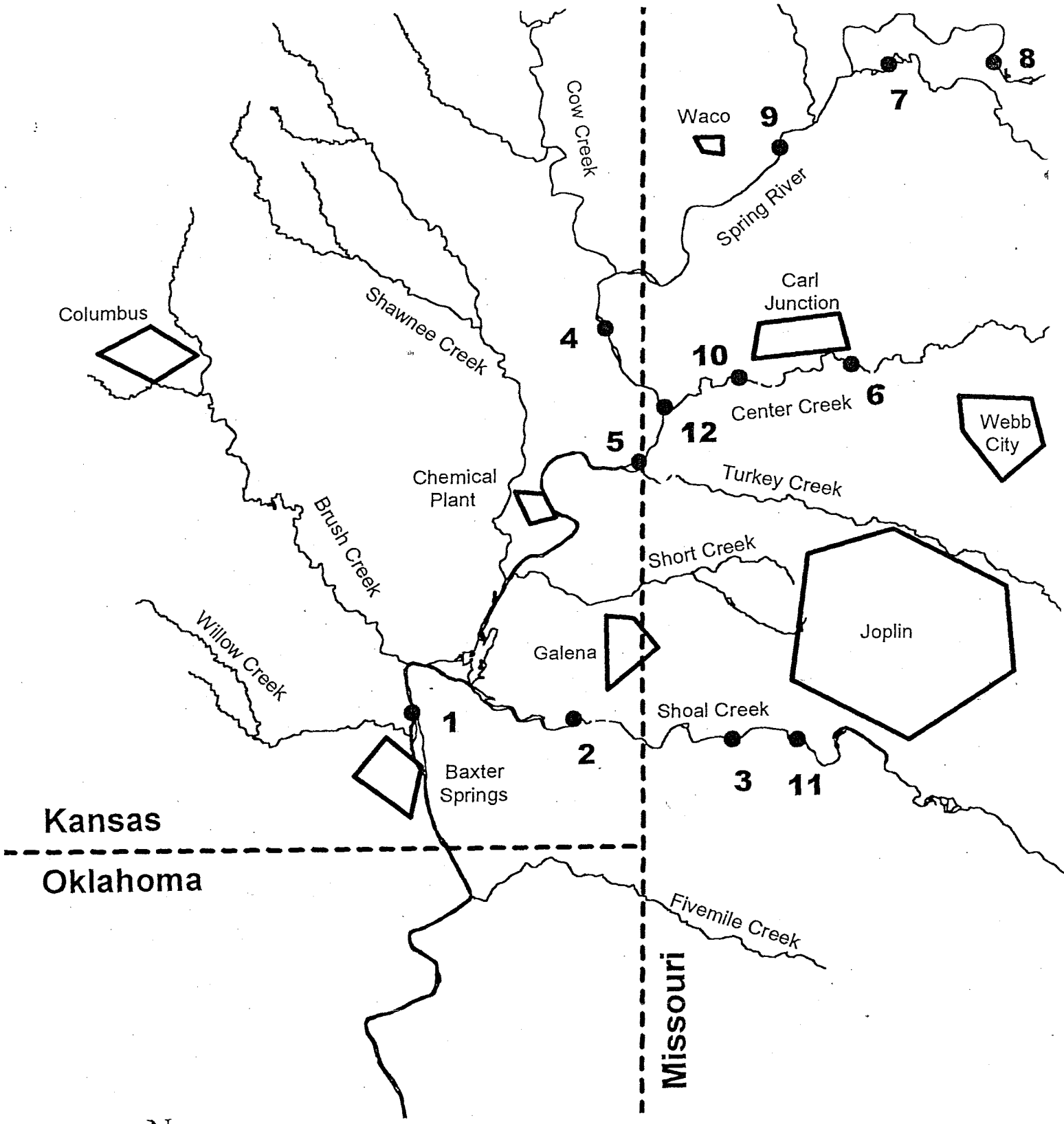
Wildhaber, M.L., C.J. Schmitt, and A.L. Allert. 1996. Historic Zinc-Lead Mining and Related Activities and their Effects on Aquatic Ecosystems Supporting the Neosho Madtom, *Noturus placidus*, Jasper County, Missouri; Ottawa County, Oklahoma; and Cherokee County, Kansas. Final Report to the U.S. Environmental Protection Agency, Region VII, Kansas City, Kansas. Appendix A: Tables A1- A35. 221 pp. Appended July, 1997.

Wildhaber, M.L., and C.J. Schmitt. 1996. Estimating aquatic toxicity as determined through laboratory tests of Great Lakes sediments containing complex mixtures of environmental contaminants. *Environ. Monit. Assess.* 41:255 - 289.

Wilkinson, C., D. Edds, J. Dorlac, M.L. Wildhaber, C.J. Schmitt, and A. Allert. 1996. Neosho madtom distribution and abundance in the Spring River. *Southwest Natur.* 41(1):78-81.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern, 1989. *Fisheries* 14:2-20.

Woodward, D.F., W.G. Brumbaugh, A.J. DeLonay, E.E. Little, and C.E. Smith. 1994. Effects on rainbow trout fry of a metals-contaminated diet of benthic invertebrates from the Clark Fork River, Montana. *Trans. Am. Fish. Soc.* 123:51-62.



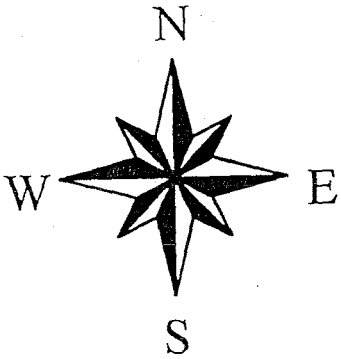


Figure 1. Map of the Spring River system illustrating Collection sites. See Table 1 for site descriptions.

Table 1. Collection sites in the Spring River system, 1995.

Date sampled	Site number	River (county and state)	Legal description (latitude, longitude)
9/20/95	1	Spring River just north of Baxter, Kansas in western channel (Cherokee County, Kansas)	NE 1/4, Sec 36, T34S, R24E (37° 02' 42.00" N, 94° 43' 35.40" W)
9/21/95	2	Shoal Creek southwest of Galena, Kansas (Cherokee County, Kansas)	NW 1/4, Sec 34, T34S, R25E (37° 02' 33.20" N, 94° 39' 23.85" W)
9/21/95	3	Shoal Creek upstream of Sewage Treatment Plant (Newton County, Missouri)	NE 1/4, Sec 25, T27N, R34W (37° 02' 07.74" N, 94° 35' 14.15" W)
9/22/95	4	Spring River upstream of State Highway 96 bridge (Cherokee County, Kansas)	SW 1/4, Sec 11, T33S, R25E (37° 10' 45.87" N, 94° 38' 32.49" W)
9/23/95	5	Spring River just west of Kansas-Missouri border (Cherokee County, Kansas)	NW 1/4, Sec 36, T33S, R25E (37° 07' 57.25" N, 94° 37' 39.36" W)
9/23/95	6	Center Creek just downstream of State Highway 171 bridge (Jasper County, Missouri)	NE 1/4, Sec 09, T28N, R33W (37° 10' 00.03" N, 94° 32' 10.09" W)
9/24/95	7	Spring River just northwest of Galesburg, Missouri (Jasper County, Missouri)	NW 1/4, Sec 10, T29N, R33W (37° 16' 18.50" N, 94° 31' 11.20" W)
9/25/96	8	North Fork of Spring River due east of State Highway 43 (Jasper County, Missouri)	SE 1/4, Sec 01, T29N, R34W (37° 16' 22.42" N, 94° 08' 06.62" W)
9/25/95	9	Spring River just east of Waco, Missouri (Jasper County, Missouri)	NE 1/4, Sec 18, T29N, R33W (37° 14' 33.21" N, 94° 34' 00.32" W)

Date sampled	Site number	River (county and state)	Legal description (latitude, longitude)
9/26/95	10	Center Creek downstream of State Highway JJ bridge (Jasper County, Missouri)	SE 1/4, Sec 12, T28S, R34W (37° 09' 43.34" N, 94° 35' 03.94" W)
9/26/95	11	Shoal Creek just downstream of State Highway P (Newton County, Missouri)	NE 1/4, Sec 29, T27N, R34W (37° 02' 07.00" N, 94° 33' 34.30" W)
9/27/95	12	Center Creek just upstream of mouth (Jasper County, Missouri)	SW 1/4, Sec 14, T28N, R34W (37° 09' 06.20" N, 94° 36' 58.46" W)

Table 2. Means habitat variables and water quality variables determined in the field. Water quality measurements were made at the lowermost transect at a site. For substrate proportions, the mean was calculated based on the arcsin square root transformation which was then transformed back to a proportion (i.e., the mean proportions do not all sum to 1). Except temperature pH, dissolved oxygen, and conductivity, n = 9 at each site except for Sites 5 and 8 where n = 8; there was only one surface grab sample per site for water, and thus, one measurement per water quality variable per site.

Site	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature C°	pH	Dissolved oxygen (ppm)	Conduc-tivity (μmhos/cm)	Proportion of substrate >38 mm	Proportion of substrate <38 and >19 mm	Proportion of substrate <19 and <9 mm	Proportion of substrate <9 and >2 mm	Proportion of substrate < 2 mm
1	1.42	0.34	0.68	23.00	8.16	8.30	0.3550	0.089	0.422	0.248	0.111	0.038
2	1.30	0.58	0.98	17.50	8.08	8.40	0.2950	0.164	0.400	0.173	0.138	0.031
3	1.20	0.36	0.87	17.00	8.20	10.2	0.2700	0.340	0.261	0.100	0.124	0.046
4	1.10	0.35	0.60	14.50	8.20	9.60	0.3500	0.021	0.298	0.256	0.226	0.109
5	1.49	0.38	0.63	13.50	7.91	9.70	0.3350	0.441	0.269	0.128	0.083	0.039
6	1.01	0.61	0.83	14.50	7.89	8.90	0.4900	0.225	0.287	0.141	0.111	0.167
7	1.57	0.18	0.48	13.10	7.90	10.2	0.3000	0.231	0.350	0.228	0.116	0.034
8	0.43	0.24	0.34	14.00	7.60	7.60	0.3600	0.552	0.289	0.061	0.049	0.012
9	1.26	0.40	0.69	15.00	8.10	8.70	0.3100	0.227	0.399	0.169	0.129	0.052
10	0.96	0.20	0.36	15.00	8.00	9.30	0.6000	0.854	0.060	0.027	0.014	0.002
11	1.28	0.40	0.80	15.00	8.30	10.4	0.5500	0.562	0.240	0.098	0.061	0.013
12	0.97	0.52	0.73	14.00	7.60	9.40	0.6500	0.039	0.343	0.213	0.237	0.109

Table 3. Water quality variables determined in the laboratory. Measurements were made on the surface grab sample taken at the lowermost transect at a site. '.' represent values not measured (i.e., no data).

Site	pH	Alkalinity (mg/L)	Hardness (mg/L)	Conductivity (μmhos/cm)	Turbidity (NTU)	NH_3 (mg/L)	NO_2 and NO_3 (mg/L)	SO_3 (mg/L)	PO_4 (mg/L)	Cl (mg/L)	Ca (mg/L)
1	8.64	148.0	164.0	275.0	24.00	0.1070	1.500	24.00	0.330	12.90	86.80
2	8.23	139.0	148.0	245.0	8.00	0.0620	1.600	8.00	0.520	10.90	62.20
3	8.52	135.0	144.0	240.0	9.50	0.0350	1.400	2.00	0.760	7.00	54.00
4	8.46	152.0	184.0	320.0	9.00	0.4160	1.300	36.00	0.360	18.70	111.4
5	8.23	176.0	137.0	.	5.70	0.1030	1.900	35.00	0.360	18.30	76.00
6	7.24	170.0	131.0	.	4.50	0.0600	3.100	32.00	0.470	7.10	43.10
7	7.58	174.0	152.0	.	7.20	0.1340	1.600	9.00	0.350	14.60	59.50
8	7.41	190.0	146.0	.	11.00	0.0830	0.300	66.00	0.130	10.80	51.30
9	7.96	155.0	174.0	.	14.00	0.0470	1.500	16.00	0.300	13.60	51.30
10	8.21	140.0	172.0	.	5.00	0.0300	2.300	33.00	0.220	8.00	34.90
11	8.41	144.0	152.0	.	7.00	0.0340	1.500	10.00	0.450	6.10	26.70
12	8.23	141.0	174.0	.	4.00	0.0210	2.000	32.00	0.250	9.00	59.50

Table 4. Concentrations (μg/L) of first 11 analytes in surface waters. Grab samples were collected at the center station of the lowermost transect. All elements were analyzed by ICAP, except for lead and cadmium which were analyzed by atomic absorption.

Site	Ag	Al	As	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
1	<10	<50	<50	67.4	<5	55400	<0.1	<10	<10	<10	<20
2	<10	<50	<50	59.0	<5	53150	<0.1	<10	<10	<10	<20
3	<10	<50	<50	55.2	<5	51600	<0.1	<10	<10	<10	<20
4	<10	<50	<50	70.0	<5	61600	<0.1	<10	<10	<10	<20
5	<10	<50	<50	70.8	<5	61100	<0.1	<10	<10	<10	<20
6	<10	<50	<50	69.8	<5	59500	<0.1	<10	<10	<10	<20
7	<10	<50	<50	71.3	<5	61800	<0.1	<10	<10	<10	<20
8	<10	<50	<50	93.7	<5	66400	<0.1	<10	<10	<10	<20
9	<10	<50	<50	65.2	<5	60400	<0.1	<10	<10	<10	<20
10	<10	<50	<50	74.4	<5	61700	<0.1	<10	<10	<10	<20
11	<10	<50	<50	62.2	<5	54500	<0.1	<10	<10	<10	<20
12	<10	<50	<50	69.3	<5	59200	<0.1	<10	<10	<10	<20

Table 5. Concentrations (μg/L) of last 11 analytes in surface waters. Grab samples were collected at the center station of the lowermost transect. All elements were analyzed by ICAP, except for lead and cadmium which were analyzed by atomic absorption.

Site	K	Mg	Mn	Na	Ni	Pb	Sb	Se	Tl	V	Zn
1	2440	3820	14.5	9730	<10	<1	<50	<100	<100	<10	13.4
2	2400	3285	<10	8560	<10	<1	<50	<100	<100	<10	94.9
3	2160	3120	<10	7260	<10	<1	<50	<100	<100	<10	31.8
4	2420	5820	45.6	13800	<10	<1	<50	<100	<100	<10	<10
5	2420	4920	35.7	1380	<10	<1	<50	<100	<100	<10	61.3
6	1430	3120	49.0	11300	<10	<1	<50	<100	<100	<10	182
7	1890	3820	<10	8180	<10	<1	<50	<100	<100	<10	<10
8	3040	4220	114	14000	<10	<1	<50	<100	<100	<10	<10
9	1880	3680	11.6	7710	<10	<1	<50	<100	<100	<10	<10
10	1380	3200	25.5	8110	<10	<1	<50	<100	<100	<10	171
11	2110	3400	<10	7550	<10	<1	<50	<100	<100	<10	17.4
12	1310	3130	15.0	7860	<10	<1	<50	<100	<100	<10	176

Table 6. Dissolved concentrations (μg/L) of 8 elements in porewaters as measured by ICP-MS ([a]). and Zeeman atomic absorption ([b]) Porewaters were collected from depositional areas at each site.

	Element										
Site	Ca	Cd[a]	Cd[b]	Cu[a]	Cu[b]	Fe	Mg	Ni	Pb[a]	Pb[b]	Zn
1	171500	3.2	2.9	1.8	2.1	7760	24500	15.0	2.0	1.8	467.0
2	44500	1.4	1.2	2.5	2.6	75.0	3370	5.6	0.69	0.70	87.0
3	43700	1.0	0.97	13.0	9.5	15.0	3290	7.2	1.3	1.2	77.0
4	60300	0.44	0.38	1.6	1.9	38.0	8250	9.0	0.48	0.61	19.0
5	57500	0.70	0.71	1.6	1.3	32.0	7650	6.3	0.90	1.3	28.0
6	43100	0.16	0.24	0.8	0.62	2240	2660	4.9	0.75	0.69	197.0
7	43000	0.39	0.33	1.2	1.6	77.0	3050	2.4	0.62	1.0	20.0
8	104700	0.35	0.27	2.6	2.2	14600	7840	6.8	0.70	0.58	19.0
9	39000	0.32	0.23	1.2	1.3	73.0	3070	3.0	0.51	0.43	8.1
10	49500	0.13	0.12	0.88	0.77	49.0	3120	3.6	0.75	0.90	68.0
11	40400	0.27	0.24	1.2	1.1	22.0	2850	2.2	0.9	1.0	36.0
12	46600	2.6	2.3	2.0	2.0	1170	3010	5.7	3.1	2.4	1681
TC	34200	0.68	0.61	1.6	1.4	2780	24200	2.7	0.98	1.0	18.0

Table 7. Concentrations (μg/L) of first 11 analytes in sediment. All samples were analyzed using ICAP.

Site	Ag	Al	As	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
1	<2.32	6520	<11.6	80.1	<1.16	2360	9.16	13	38.4	12.1	26600
2	<2.61	3975	<13.1	41.7	<1.31	4345	4.21	4.21	34.3	5.10	14100
3	<2.51	2390	<12.5	50.1	<1.25	1240	3.81	5.59	35.7	4.03	15000
4	<2.46	4140	<12.3	74.7	<1.23	1370	<1.23	16.7	30.6	5.86	28100
5	<2.48	3740	<12.4	69.0	<1.24	2200	3.02	14.4	48.5	5.77	29800
6	<2.44	2460	<12.2	37.0	<1.22	2460	19.5	8.34	30.7	11.7	22300
7	<2.49	4310	<12.4	54.7	<1.24	5730	<1.24	15.4	85.3	7.06	30200
8	<2.42	2410	<12.1	44.5	<1.21	2790	2.88	5.74	14.5	2.62	11900
9	<2.29	2500	<11.4	123	<1.14	1920	<1.14	8.83	23.0	2.65	15200
10	<2.69	3660	<13.4	35.6	<1.34	2800	7.75	6.93	44.6	6.53	20000
11	<2.67	3400	<13.4	39.6	<1.34	8410	2.08	7.08	37.8	3.45	23400
12	<3.45	16000	<17.2	190	<1.72	6200	84.1	9.72	49.6	51.2	28500

Table 8. Concentrations (μg/L) of last 11 analytes in sediment. All samples were analyzed using ICAP.

Site	K	Mg	Mn	Na	Ni	Pb	Sb	Se	Tl	V	Zn
1	555	667	631	23.4	21.8	138	<11.6	<23.2	<23.2	32.8	1490
2	297	878	276	27.3	18.7	113	<13.1	<26.1	<26.1	27.6	901
3	145	231	537	23.1	12.1	116	<12.5	<25.1	<25.1	30.2	1160
4	343	329	982	36.4	27.5	9.77	<12.3	<24.6	<24.6	35.9	202
5	297	802	845	30.0	24.5	69.5	<12.4	<24.8	<24.8	46.2	659
6	419	262	233	32.6	15.5	454	<12.2	<24.4	<24.4	42.4	3720
7	248	294	434	45.2	25.4	34.4	<12.4	<24.9	<24.9	67.7	203
8	205	1060	127	20.1	9.16	13.9	<12.1	<24.2	<24.2	17.9	615
9	193	205	989	22.3	10.6	6.77	<12.4	<22.9	<22.9	25.8	103
10	287	437	189	36.0	16.4	301	<13.4	<26.9	<26.9	37.0	2060
11	235	243	437	37.0	17.7	66.7	<13.4	<26.7	<26.7	48.1	761
12	1490	2050	475	59.8	29.1	2120	<17.2	<34.5	<34.5	40.1	13800

Table 9. Percent moisture, loss on ignition (LOI), concentrations of acid volatile sulfide (AVS) and simultaneoulsy extracted metals (SEM) in sediment. AVS are μmol/g dry weight and SEM concentrations are expressed in μg/g dry weight.

Site	% Moisture	LOI	AVS	Cd	Cu	Fe	Ni	Pb	Zn
1	28.06	1.5	2.10	3.60	2.30	1490	9.0	78.0	573
2	30.72	1.2	0.85	6.20	5.10	2640	4.9	94.0	756
3	36.05	0.8	0.06	2.50	1.40	797	4.2	71.0	777
4	21.89	2.3	0.16	0.39	1.40	1570	4.4	5.6	75.0
5	19.75	1.2	0.53	2.00	1.60	2430	4.8	42.0	355
6	41.04	1.5	6.00	21.0	13.0	3170	6.8	821	3570
7	26.94	1.8	0.50	0.57	1.80	1960	2.4	10.0	60.0
8	24.97	0.7	0.68	0.65	0.75	2940	1.1	4.4	46.0
9	23.48	1.2	0.31	0.18	0.79	1050	1.3	3.3	22.0
10	26.57	0.9	4.80	4.60	1.80	2130	3.0	127	997
11	23.34	0.9	0.04	1.40	1.10	777	4.1	44.0	270
12	40.13	3.2	1.20	108	45.0	13300	20.4	3410	14500
Tavern Creek	21.26	0.8	1.00	0.03	1.10	684	1.0	2.7	4.8

Table 10. SEM / AVS[a] and SEM - AVS[b] for cadium, copper, nickel, lead and zinc.

Site	Cd[a]	Cd[b]	Cu[a]	Cu[b]	Ni[a]	Ni[b]	Pb[a]	Pb[b]	Zn[a]	Zn[b]
1	0.015	-2.07	0.017	-2.06	0.073	-1.95	0.18	-1.72	4.2	6.67
2	0.065	-0.79	0.094	-0.77	0.098	-0.77	0.53	-0.4	13.6	10.7
3	0.37	-0.04	0.37	-0.04	1.2	0.01	5.7	0.28	198	11.8
4	0.022	-0.16	0.14	-0.14	0.47	-0.09	0.17	-0.13	7.2	0.99
5	0.034	-0.51	0.048	-0.5	0.15	-0.45	0.38	-0.33	10.2	4.9
6	0.031	-5.81	0.034	-5.8	0.019	-5.88	0.66	-2.04	9.1	48.6
7	0.01	-0.49	0.057	-0.47	0.082	-0.46	0.097	-0.45	1.8	0.42
8	0.009	-0.67	0.017	-0.67	0.028	-0.66	0.031	-0.66	1.0	0.02
9	0.005	-0.31	0.04	-0.3	0.071	-0.29	0.051	-0.29	1.1	0.03
10	0.009	-4.76	0.006	-4.77	0.011	-4.75	0.13	-4.19	3.2	10.5
11	0.3	-0.03	0.41	-0.02	1.7	0.03	5.1	0.17	98	4.09
12	0.8	-0.24	0.59	-0.49	0.29	-0.85	13.7	15.3	185	221
Tavern Creek	0	-1.0	0.017	-0.98	0.017	-0.98	0.013	-0.99	0.073	-0.93

Table 11. AVS and Molar Equalivalents (SEM / molecular weight) for each element.

Site	AVS	Cd	Cu	Fe	Ni	Pb	Zn
1	2.10	0.032	0.036	57.30	0.153	0.376	8.76
2	0.85	0.055	0.080	101.5	0.083	0.454	11.56
3	0.06	0.022	0.022	30.65	0.715	0.343	11.88
4	0.16	0.003	0.022	60.38	0.075	0.027	1.14
5	0.53	0.018	0.025	93.46	0.082	0.203	59.17
6	6.00	0.187	0.204	121.9	0.116	3.962	54.60
7	0.50	0.005	0.028	75.38	0.041	0.005	0.918
8	0.68	0.006	0.012	113.1	0.019	0.021	0.70
9	0.31	0.002	0.012	350.0	0.221	0.159	0.336
10	4.80	0.041	0.028	81.92	0.511	0.613	15.25
11	0.04	0.012	0.017	29.88	0.070	0.212	4.13
12	1.20	0.961	0.708	511.5	0.348	16.46	221.8
Tavern Creek	1.00	0.000	0.017	26.3	0.017	0.013	0.073

Table 12. Total Toxic Units (Estimated Pore-water Concentrations / Water Quality Standard) available and those available for cadmium, lead, zinc, nickel and iron.

Site	Cd	Pb	Zn	Ni	Fe	∑TU
1			7.2	0.94	3.725	11.0
2			11.3	0.05	5.966	17.3
3		23.7	9.52	0.03	1.410	34.7
4			1.36	0.06	5.605	7.02
5			104.2	0.09	9.866	114.1
6			37.4	0.05	4.565	42.0
7			0.53	0.03	5.311	5.9
8			0.08	0.01	8.820	8.9
9			0.25	0.02	3.423	3.7
10			12.0	0.03	5.879	17.9
11		25.2	5.86	0.06	2.549	33.7
12	43.9	773.2	584.5	5.50	19.8	1426.9
Tavern Creek					2.445	2.4

Table 13. Macroinvertebrate taxonomic richness, as numbers of taxa and as numbers of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, for the Spring River system.

Stream System	Taxa (n)	EPT taxa (n)
Upper Spring River		
4	23	16
7	40	20
8	26	16
9	29	19
Lower Spring River		
1	22	10
5	27	16
Shoal Creek		
2	15	6
3	27	11
11	35	17
Center Creek		
6	14	6
10	23	12
12	19	9

Table 14. Number of fish of the indicated taxon found at each site on the Spring River. The total area sampled per site was 40.5 m^2 for Sites 1-4, 6-7, 9-12 and 36 m^2 for Sites 5, 8.

Scientific name (common name)	Site 1	2	3	4	5	6	7	8	9	10	11	12
ATHERINIDAE												
Labidesthes sicculus (brook silverside)	4	0	0	0	0	0	0	0	0	0	0	0
CATOSTOMIDAE												
Hypentelium nigricans (northern hogsucker)	0	0	0	0	0	0	0	0	1	0	0	0
CENTRARCHIDAE												
Lepomis megalotis (longear sunfish)	2	0	0	0	0	0	0	0	0	0	0	0
Micropterus punctulatus (spotted bass)	1	0	0	0	0	0	0	0	0	0	0	0
COTTIDAE												
Cottus carolinae (banded sculpin)	2	0	0	0	0	0	0	0	0	0	0	0
CYPRINIDAE												
Campostoma anomalum (central stoneroller)	3	17	1	13	0	21	18	26	1	1	0	1
Cyprinella camurus (bluntface shiner)	0	0	0	10	0	0	1	4	1	0	0	0
Erimystax X-punctatus (gravel chub)	2	4	4	3	1	0	0	0	3	0	1	1

Scientific name (common name)	Site 1	2	3	4	5	6	7	8	9	10	11	12
Luxilus cardinalis (cardinal shiner)	3	13	10	14	0	0	5	0	1	0	8	0
Notropis rubellus (rosyface shiner)	27	6	0	23	0	0	39	1	10	2	1	0
Notropis volucellus (mimic shiner)	1	0	0	0	1	0	2	1	0	0	0	0
Phenacobius mirabilis (suckermouth minnow)	0	2	0	4	0	0	0	0	0	0	0	0
Pimephales notatus (bluntnose minnow)	10	5	0	33	0	0	0	1	0	0	0	0
Pimephales t tenellus (western slim minnow)	0	0	0	3	0	0	0	0	0	0	0	0
ICTALURIDAE												
Ictalurus punctatus (channel catfish)	0	0	0	8	0	0	0	7	0	0	0	0
Noturus exilis (slender madtom)	0	2	0	3	1	9	9	4	6	0	2	3
Noturus flavus (stonecat)	0	0	1	1	0	0	1	0	1	0	0	0
Noturus placidus (neosho madtom)	9	0	0	6	1	0	0	0	1	0	0	0
Pylodictis olivaris (flathead catfish)	0	0	0	0	0	0	0	1	0	0	0	0
PERCIDAE												
Etheostoma blennioides (greenside darter)	0	3	1	5	2	1	8	23	6	0	5	13

Scientific name (common name)	Site 1	2	3	4	5	6	7	8	9	10	11	12
Etheostoma f flabellare (barred fantail darter)	0	0	0	22	2	0	2	23	11	0	0	1
Etheostoma punctulatum (stippled darter)	0	0	0	0	0	0	0	0	0	0	0	1
Etheostoma stigmaeum (speckled darter)	0	0	0	0	0	0	1	0	0	0	0	0
Etheostoma s spectabile (northern orangethroat darter)	0	0	1	2	11	5	22	44	7	3	0	26
Etheostoma zonale (banded darter)	8	17	36	96	48	16	35	38	96	11	18	63
Percina copelandi (channel darter)	0	0	0	1	3	0	1	0	0	0	0	0
Percina c fulvitaenia (ozark logperch)	2	6	1	0	0	0	2	0	1	0	0	0
Percina phoxocephala (slenderhead darter)	6	0	1	1	1	0	6	0	0	0	0	1
POECILIIDAE												
Gambusia affinis (mosquitofish)	0	0	0	5	0	0	0	0	0	0	0	2

Table 15. Density (individuals/m^2) and the number of sites at which the indicated taxa were captured in the Spring River and its tributaries.

Scientific Name	Density	Number of Sites
Campostoma anomalum	0.94074	10
Cottus carolinae	0.22222	2
Cyprinella camurus	0.40741	4
Etheostoma punctulatum	0.22222	1
Erimystax X-punctatus	0.27778	8
Etheostoma blennioides	0.39598	10
Etheostoma f flabellare	0.51429	6
Etheostoma s spectabile	0.75068	9
Etheostoma stigmaeum	0.22222	1
Etheostoma zonale	1.20476	12
Gambusia affinis	0.77778	2
Hypentelium nigricans	0.22222	1
Ictalurus punctatus	0.61111	2
Labidesthes sicculus	0.88889	1
Lepomis megalotis	0.44444	1
Luxilus cardinalis	0.56931	7
Micropterus punctulatus	0.22222	1
Notropis rubellus	1.11620	8
Notropis volucellus	0.22222	4
Noturus exilis	0.36132	9
Noturus flavus	0.22222	4
Noturus placidus	0.38889	4
Percina c fulvitaenia	0.35556	5
Percina copelandi	0.25926	3

Scientific Name	Density	Number of Sites
Phenacobius mirabilis	0.44444	2
Pimephales notatus	0.99074	4
Pimephales t tenellus	0.66667	1
Pylodictis olivaris	0.22222	1

Table 16. Density (individuals per m^2) and the number of sites at which the indicated taxa were captured in the Spring River, Center Creek, and Shoal Creek.

Scientific name	Spring River		Center Creek		Shoal Creek	
(common name)	Density	Number of sites	Density	Number of sites	Density	Number of sites
Atherinidae						
Labidesthes sicculus (brook silverside)	0.88889	1	0	0	0	0
Catostomidae						
Hypentelium nigricans (northern hogsucker)	0.22222	1	0	0	0	0
Centrarchidae						
Lepomis megalotis (longear sunfish)	0.44444	1	0	0	0	0
Micropterus punctulatus (spotted bass)	0.22222	1	0	0	0	0
Cottidae						
Cottus carolinae (banded sculpin)	0	0	0.22222	1	0.22222	1

Scientific name	Spring River		Center Creek		Shoal Creek	
(common name)	Density	Number of sites	Density	Number of sites	Density	Number of sites
Cyprinidae						
Campostoma anomalum (central stoneroller)	1.18519	5	0.66667	3	0.74074	2
Cyprinella camurus (bluntface shiner)	0.40741	4	0	0	0	0
Erimystax X-punctatus (gravel chub)	0.27778	4	0.22222	1	0.29630	3
Luxilus cardinalis (cardinal shiner)	0.49074	4	0	0	0.67407	3
Notropis rubellus (rosyface shiner)	1.56370	5	0.44444	1	0.33333	2
Notropis volucellus (mimic shiner)	0.22222	4	0	0	0	0
Phenacobius mirabilis (suckermouth minnow)	0.44444	1	0	0	0.44444	1
Pimephales notatus (bluntnose minnow)	1.13580	3	0	0	0.55556	1
Pimephales t tenellus (western slim minnow)	0.66667	1	0	0	0	0

Scientific name	Spring River		Center Creek		Shoal Creek	
(common name)	Density	Number of sites	Density	Number of sites	Density	Number of sites
Ictaluridae						
Ictalurus punctatus (channel catfish)	0.61111	2	0	0	0	0
Noturus exilis (slender madtom)	0.29481	5	0.66667	2	0.22222	2
Noturus flavus (stonecat)	0.22222	3	0	0	0.22222	1
Noturus placidus (neosho madtom)	0.38889	4	0	0	0	0
Pylodictis olivaris (flathead catfish)	0.22222	1	0	0	0	0
Percidae						
Etheostoma blennioides (greenside darter)	0.44677	5	0.40000	2	0.30864	3
Etheostoma f flabellare (barred fantail darter)	0.57270	5	0.22222	1	0	0
Etheostoma punctulatum (stippled darter)	0	0	0.22222	1	0	0
Etheostoma stigmaeum (speckled darter)	0.22222	1	0	0	0	0

Scientific name	Spring River		Center Creek		Shoal Creek	
(common name)	Density	Number of sites	Density	Number of sites	Density	Number of sites
Etheostoma s spectabile (northern orangethroat darter)	0.93492	5	0.61975	3	0.22222	1
Etheostoma zonale (banded darter)	1.53483	6	0.87901	3	0.87037	3
Percina copelandi (channel darter)	0.25926	3	0	0	0	0
Percina c fulvitaenia (ozark logperch)	0.37037	3	0	0	0.33333	2
Percina phoxocephala (slenderhead darter)	0.34444	4	0.22222	1	0.22222	1
Poeciliidae						
Gambusia affinis (mosquitofish)	1.11111	1	0.44444	1	0	0

Table 17. Summary of acute toxicity tests (*Ceriodaphnia dubia*) using site waters. Reproduction was calculated according to EPA guidelines. Site 1 - Site 7 and Tavern Creek were included in Test 1. Site 8 - Site 12 were included in Test 2. [a] = 50% dilution water.

Site	Number of Replicates	% Survival	Reproduction
1[a]	10	0	0
2[a]	10	90	29.0
3	10	90	25.6
4	10	100	28.4
5	10	90	22.9
6	9	22.2	0
7	9	100	27.1
8	10	90	19.5
9	10	80	20.4
10	9	100	28.1
11	10	100	25.0
12	10	0	0
Tavern Creek	10	100	23.9
Well Water - Test 1	10	100	24.6
Well Water - Test 2	10	100	24.6

Table A1. Estimation of the chronically toxic pore-water concentration defining a toxic unit for each contaminant used in the toxic unit model.

Contaminant	Toxic Unit Calculations (μg/L)	Reference
Cadmium	$e^{(0.7852 \times \ln(\text{hardness}) - 3.49}$	USEPA 1984b
Copper	5.6	USEPA 1980j
Iron	1000	USEPA 1976
Lead	$e^{(1.273 \times \ln(\text{hardness}) - 4.705}$	USEPA 1984d
Nickel	$e^{(0.864 \times \ln(\text{hardness}) + 1.1645}$	USEPA 1986c

Table A2. Habitat and water quality variables determined in the field. Water quality measurements were made at only one point at a site associated with the surface grab samples taken at that site. Transect 1 was the uppermost on a gravel bar, and Transect 3 the lowermost. On each transect, Station 1 was closest to the gravel bar and station 3 was the farthest. For substrate >38 mm, 99999.0 represents only bedrock was found at that station.

Site	Transect	Station	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature (C°)	pH	Dissolved Oxygen (ppm)	Conduc-tivity (μmhos/cm)	Substrate > 38 mm (g wet weight)	Substrate < 38 and > 19 mm (g wet weight)	Substrate < 19 and > 9 mm (g wet weight)	Substrate <9 and > 2 mm (g wet weight)	Substrate < 2 (g wet weight)
1	1	1	0.9	0.33	0.56	23.0	8.16	8.3	0.355	54.6	529.1	261.0	98.6	55.5
1	1	2	1.6	0.35	0.50	23.0	8.16	8.3	0.355	50.7	562.0	333.2	131.0	99.7
1	1	3	1.9	0.23	0.46	23.0	8.16	8.3	0.355	0.0	407.9	327.7	120.3	9.9
1	2	1	1.3	0.20	0.37	23.0	8.16	8.3	0.355	181.0	169.3	265.0	378.3	141.4
1	2	2	1.7	0.24	0.85	23.0	8.16	8.3	0.355	184.9	180.0	159.7	53.8	29.0
1	2	3	1.6	0.11	0.98	23.0	8.16	8.3	0.355	0.0	438.0	242.5	155.5	67.2
1	3	1	1.8	0.58	0.97	23.0	8.16	8.3	0.355	0.0	804.7	153.7	23.7	2.6
1	3	2	1.1	0.64	0.81	23.0	8.16	8.3	0.355	625.9	178.3	105.2	13.4	0.9
1	3	3	0.9	0.40	0.64	23.0	8.16	8.3	0.355	98.6	426.7	313.1	144.1	34.1
2	1	1	1.0	0.54	0.88	17.5	8.08	8.4	0.295	210.3	258.4	97.8	104.3	45.3
2	1	2	1.6	0.79	1.28	17.5	8.08	8.4	0.295	0.0	168.0	171.5	174.7	67.6
2	1	3	0.9	0.32	0.53	17.5	8.08	8.4	0.295	0.0	284.8	190.0	131.6	55.0
2	2	1	1.8	0.77	1.25	17.5	8.08	8.4	0.295	380.3	388.6	137.6	142.3	16.9
2	2	2	1.5	0.67	1.26	17.5	8.08	8.4	0.295	75.6	293.5	481.0	347.1	31.2
2	2	3	0.6	0.38	0.44	17.5	8.08	8.4	0.295	477.7	377.9	59.7	21.0	36.9
2	3	1	2.1	0.70	1.35	17.5	8.08	8.4	0.295	256.2	295.7	119.5	125.6	15.4
2	3	2	1.3	0.75	1.23	17.5	8.08	8.4	0.295	59.8	599.0	124.4	144.7	1.0
2	3	3	0.9	0.29	0.60	17.5	8.08	8.4	0.295	375.0	534.1	77.9	9.1	1.8

Site	Transect	Station	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature (C°)	pH	Dissolved Oxygen (ppm)	Conduc-tivity (μmhos/cm)	Substrate > 38 mm (g wet weight)	Substrate < 38 and > 19 mm (g wet weight)	Substrate < 19 and > 9 mm (g wet weight)	Substrate <9 and > 2 mm (g wet weight)	Substrate < 2 (g wet weight)
3	1	1	1.5	0.55	0.97	17.0	8.20	10.2	0.270	819.2	151.5	6.9	1.5	2.1
3	1	2	0.9	0.54	0.94	17.0	8.20	10.2	0.270	552.0	186.0	158.9	204.9	59.1
3	1	3	0.6	0.19	0.46	17.0	8.20	10.2	0.270	0.0	325.6	254.3	356.8	207.1
3	2	1	1.6	0.33	1.03	17.0	8.20	10.2	0.270	761.1	263.2	71.1	120.8	16.2
3	2	2	1.2	0.38	0.96	17.0	8.20	10.2	0.270	0.0	427.8	222.7	267.0	132.9
3	2	3	0.8	0.34	0.91	17.0	8.20	10.2	0.270	573.1	289.0	141.2	132.7	42.3
3	3	1	1.7	0.29	0.98	17.0	8.20	10.2	0.270	558.4	416.7	126.0	64.4	4.6
3	3	2	1.5	0.27	1.05	17.0	8.20	10.2	0.270	584.0	197.7	17.9	23.4	4.5
3	3	3	1.0	0.38	0.54	17.0	8.20	10.2	0.270	72.3	377.2	160.4	345.1	191.2
4	1	1	0.8	0.95	1.24	14.5	8.20	9.6	0.350	0.0	436.3	322.6	281.6	108.4
4	1	2	1.0	0.11	0.41	14.5	8.20	9.6	0.350	0.0	23.4	401.0	461.7	237.1
4	1	3	1.5	0.03	0.00	14.5	8.20	9.6	0.350	109.7	384.4	313.4	259.5	149.5
4	2	1	2.2	0.25	0.73	14.5	8.20	9.6	0.350	0.0	321.0	269.5	379.6	180.4
4	2	2	0.7	0.28	0.52	14.5	8.20	9.6	0.350	153.8	361.2	302.3	114.5	4.0
4	2	3	1.6	0.31	0.38	14.5	8.20	9.6	0.350	0.0	154.6	158.9	162.7	310.9
4	3	1	0.8	0.27	0.56	14.5	8.20	9.6	0.350	0.0	664.4	410.7	305.9	146.8
4	3	2	0.4	0.41	0.74	14.5	8.20	9.6	0.350	0.0	488.6	468.0	401.1	88.1
4	3	3	0.9	0.53	0.84	14.5	8.20	9.6	0.350	334.6	523.7	108.7	95.7	31.2
5	1	1	0.4	0.40	0.50	13.5	7.91	9.7	0.335	207.6	442.2	176.6	158.7	66.0
5	1	2	1.4	0.57	1.10	13.5	7.91	9.7	0.335	472.1	245.5	56.2	9.0	1.3
5	2	1	1.4	0.36	0.52	13.5	7.91	9.7	0.335	357.0	340.4	195.7	122.6	55.1
5	2	2	1.7	0.26	0.53	13.5	7.91	9.7	0.335	462.5	241.9	160.3	32.0	0.9

Site	Transect	Station	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature (C°)	pH	Dissolved Oxygen (ppm)	Conduc-tivity (μmhos/cm)	Substrate > 38 mm (g wet weight)	Substrate < 38 and > 19 mm (g wet weight)	Substrate < 19 and > 9 mm (g wet weight)	Substrate <9 and > 2 mm (g wet weight)	Substrate < 2 (g wet weight)
5	2	3	1.7	0.55	0.81	13.5	7.91	9.7	0.335	695.1	221.2	118.0	104.2	50.3
5	3	1	1.7	0.20	0.33	13.5	7.91	9.7	0.335	770.0	197.1	78.2	77.3	27.5
5	3	2	2.1	0.30	0.60	13.5	7.91	9.7	0.335	408.1	353.3	95.3	67.2	20.7
5	3	3	1.5	0.38	0.66	13.5	7.91	9.7	0.335	286.2	176.4	239.1	252.5	310.6
6	1	1	1.7	0.22	0.91	14.5	7.89	8.9	0.490	0.0	59.5	40.9	56.4	39.8
6	1	2	1.3	0.88	1.37	14.5	7.89	8.9	0.490	114.8	39.4	13.5	3.5	10.6
6	1	3	1.2	0.77	1.21	14.5	7.89	8.9	0.490	33.3	71.4	36.5	21.3	34.0
6	2	1	1.3	1.04	0.38	14.5	7.89	8.9	0.490	76.5	58.5	23.2	28.2	12.1
6	2	2	0.5	0.72	1.02	14.5	7.89	8.9	0.490	64.2	57.1	23.0	27.5	64.9
6	2	3	0.4	0.71	0.75	14.5	7.89	8.9	0.490	35.4	88.1	43.4	27.6	42.2
6	3	1	1.1	0.42	0.84	14.5	7.89	8.9	0.490	95.7	58.6	39.9	33.2	59.7
6	3	2	1.2	0.26	0.50	14.5	7.89	8.9	0.490	74.1	72.0	25.7	7.6	7.4
6	3	3	0.4	0.51	0.45	14.5	7.89	8.9	0.490	11.3	70.3	48.2	42.8	142.9
7	1	1	2.1	0.15	0.47	13.1	7.90	10.2	0.300	62.3	64.4	112.7	26.4	7.6
7	1	2	2.4	0.13	0.50	13.1	7.90	10.2	0.300	624.9	210.5	183.7	92.4	24.8
7	1	3	2.3	0.07	0.13	13.1	7.90	10.2	0.300	180.4	240.0	180.9	226.6	183.0
7	2	1	1.0	0.27	0.62	13.1	7.90	10.2	0.300	156.7	625.6	273.5	113.1	22.1
7	2	2	1.6	0.03	0.02	13.1	7.90	10.2	0.300	83.2	621.1	282.1	77.8	12.1
7	2	3	0.9	0.44	1.00	13.1	7.90	10.2	0.300	300.4	257.1	183.1	118.7	20.8
7	3	1	0.6	0.05	0.11	13.1	7.90	10.2	0.300	108.7	504.9	403.0	321.9	51.6
7	3	2	1.5	0.32	1.08	13.1	7.90	10.2	0.300	173.1	553.6	181.2	33.6	6.8
7	3	3	1.7	0.20	0.40	13.1	7.90	10.2	0.300	469.3	215.3	155.2	141.0	59.7

Site	Transect	Station	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature (C°)	pH	Dissolved Oxygen (ppm)	Conduc-tivity (μmhos/ cm)	Substrate > 38 mm (g wet weight)	Substrate < 38 and > 19 mm (g wet weight)	Substrate < 19 and > 9 mm (g wet weight)	Substrate <9 and > 2 mm (g wet weight)	Substrate < 2 (g wet weight)
8	1	1	0.6	0.14	0.27	14.0	7.60	7.6	0.360	337.6	347.5	203.8	378.0	194.9
8	1	2	0.8	0.20	0.28	14.0	7.60	7.6	0.360	507.5	357.6	39.0	21.1	2.4
8	2	1	0.2	0.31	0.36	14.0	7.60	7.6	0.360	739.6	334.5	21.5	13.4	1.7
8	2	2	0.2	0.27	0.40	14.0	7.60	7.6	0.360	640.6	302.3	38.9	25.7	1.5
8	2	3	0.6	0.59	0.70	14.0	7.60	7.6	0.360	791.5	203.3	28.1	17.5	2.7
8	3	1	0.3	0.18	0.28	14.0	7.60	7.6	0.360	708.8	354.4	54.2	20.2	1.9
8	3	2	0.5	0.17	0.18	14.0	7.60	7.6	0.360	693.4	331.7	69.9	46.8	8.8
8	3	3	0.2	0.08	0.28	14.0	7.60	7.6	0.360	431.8	371.3	214.7	150.9	49.3
9	1	1	0.8	0.16	0.26	15.0	8.10	8.7	0.310	141.5	580.2	408.8	328.6	53.8
9	1	2	1.6	0.21	0.44	15.0	8.10	8.7	0.310	332.2	458.4	150.0	179.1	69.5
9	1	3	1.8	0.24	0.52	15.0	8.10	8.7	0.310	176.7	710.6	168.5	31.5	3.6
9	2	1	1.2	0.28	0.50	15.0	8.10	8.7	0.310	482.5	391.3	216.1	158.2	45.9
9	2	2	1.4	0.23	0.55	15.0	8.10	8.7	0.310	356.4	439.0	282.3	255.0	79.9
9	2	3	1.5	0.40	0.64	15.0	8.10	8.7	0.310	315.8	577.3	188.8	71.7	31.2
9	3	1	0.8	0.51	0.67	15.0	8.10	8.7	0.310	555.0	453.1	183.1	280.4	127.2
9	3	2	1.0	0.84	1.10	15	8.1	8.7	0.31	269.2	491.3	289.3	294.8	183.5
9	3	3	1.2	0.74	1.50	15	8.1	8.7	0.31	132.6	414.2	136.0	86.9	95.2
10	1	1	0.6	0.16	0.23	15	8.0	9.3	0.60	109.0	651.6	308.3	289.2	114.0
10	1	2	1.4	0.16	0.33	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0
10	1	3	1.3	0.04	0.12	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0
10	2	1	1.1	0.01	0.08	15	8.0	9.3	0.60	328.0	478.4	289.9	108.6	5.7
10	2	2	1.4	0.10	0.54	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0

Site	Transect	Station	Depth (m)	Velocity at Substrate (m/sec)	Velocity at 60% Depth (m/sec)	Temper-ature (C°)	pH	Dissolved Oxygen (ppm)	Conduc-tivity (μmhos/cm)	Substrate > 38 mm (g wet weight)	Substrate < 38 and > 19 mm (g wet weight)	Substrate < 19 and > 9 mm (g wet weight)	Substrate <9 and > 2 mm (g wet weight)	Substrate < 2 (g wet weight)
10	2	3	0.9	0.33	0.51	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0
10	3	1	0.2	0.28	0.28	15	8.0	9.3	0.60	154.8	697.5	295.2	129.0	7.7
10	3	2	1.2	0.20	0.64	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0
10	3	3	0.5	0.48	0.55	15	8.0	9.3	0.60	99999.0	0.0	0.0	0.0	0.0
11	1	1	1.5	0.37	1.14	15	8.3	10.4	0.55	648.7	430.6	119.9	19.1	4.3
11	1	2	1.0	0.37	0.80	15	8.3	10.4	0.55	506.8	308.9	187.5	179.0	11.9
11	1	3	0.7	0.30	0.47	15	8.3	10.4	0.55	778.0	396.9	179.2	63.7	22.4
11	2	1	1.2	0.50	1.06	15	8.3	10.4	0.55	532.2	286.2	229.2	230.1	107.2
11	2	2	1.2	0.53	1.26	15	8.3	10.4	0.55	987.0	315.2	92.2	75.6	11.5
11	2	3	1.7	0.66	0.84	15	8.3	10.4	0.55	1175.4	202.7	58.4	10.9	0.9
11	3	1	1.1	0.37	0.54	15	8.3	10.4	0.55	319.7	563.3	259.4	151.1	70.0
11	3	2	1.1	0.40	0.60	15	8.3	10.4	0.55	684.0	385.2	108.6	62.7	5.4
11	3	3	2.0	0.14	0.53	15	8.3	10.4	0.55	1538.1	118.8	45.2	81.2	2.7
12	1	1	0.6	0.17	0.20	14	7.6	9.4	0.65	0.0	331.5	335.2	332.5	154.7
12	1	2	1.2	0.62	1.40	14	7.6	9.4	0.65	547.3	454.5	203.5	250.2	105.9
12	1	3	0.6	0.59	0.91	14	7.6	9.4	0.65	371.1	387.3	366.4	409.7	159.2
12	2	1	0.7	0.73	0.82	14	7.6	9.4	0.65	0.0	583.6	274.0	255.3	174.5
12	2	2	1.3	0.59	0.82	14	7.6	9.4	0.65	0.0	572.1	244.2	251.0	141.0
12	2	3	0.9	0.41	0.57	14	7.6	9.4	0.65	155.0	588.2	326.1	288.5	259.4
12	3	1	0.6	0.78	0.80	14	7.6	9.4	0.65	0.0	342.6	407.4	501.7	159.0
12	3	2	1.6	0.32	0.42	14	7.6	9.4	0.65	158.0	312.4	241.6	448.0	162.8
12	3	3	1.2	0.45	0.59	14	7.6	9.4	0.65	0.0	764.5	297.2	266.3	80.4

Table A3. Particle size analysis of substrate material <2 mm. A 'nes' indicates not enough sample (i.e., < 10 g) to adequately estimate sand, silt, and clay percentages..

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
1	1	1	55.5	94.82	3.60	1.58
1	1	2	99.7	92.10	3.51	4.39
1	1	3	9.9	nes	nes	nes
1	2	1	141.4	95.85	2.12	2.03
1	2	2	29.0	91.81	5.17	3.02
1	2	3	67.2	92.37	4.46	3.16
1	3	1	2.6	nes	nes	nes
1	3	2	0.9	nes	nes	nes
1	3	3	34.1	92.30	2.93	4.77
2	1	1	45.3	98.07	1.93	0.00
2	1	2	67.6	96.49	2.03	1.48
2	1	3	55.0	91.14	2.73	6.14
2	2	1	16.9	98.52	2.22	-0.74
2	2	2	31.2	100.40	4.41	-4.81
2	2	3	36.9	95.26	2.37	2.37
2	3	1	15.4	96.75	6.49	-3.25

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
2	3	3	1.8	nes	nes	nes
3	1	1	2.1	nes	nes	nes
3	1	2	59.1	96.19	1.48	2.33
3	1	3	207.1	96.74	1.87	1.39
3	2	1	16.2	97.69	3.09	-0.77
3	2	2	132.9	94.54	2.16	3.29
3	2	3	42.3	99.11	0.00	0.89
3	3	1	4.6	nes	nes	nes
4	1	1	108.4	91.58	4.61	3.81
4	1	2	237.1	96.05	1.69	2.27
4	1	3	149.5	86.54	6.02	7.44
4	2	1	180.4	80.53	7.21	12.26
4	2	2	4.0	nes	nes	nes
4	2	3	310.9	92.56	3.22	4.22
4	3	1	146.8	93.44	2.64	3.92
4	3	2	88.1	76.02	8.51	15.47
4	3	3	31.2	85.18	3.21	11.62
5	1	1	66.0	91.86	2.84	5.30

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
5	1	3	0.0	0.00	0.00	0.00
5	2	1	55.1	96.60	1.59	1.81
5	2	2	0.9	nes	nes	nes
5	2	3	50.3	96.27	2.73	0.99
5	3	1	27.5	87.73	6.82	5.45
5	3	2	20.7	90.34	2.42	7.25
5	3	3	310.6	93.60	2.37	4.02
6	1	1	39.8	81.47	8.48	10.05
6	1	2	10.6	101.18	3.54	-4.72
6	1	3	34.0	94.49	4.04	1.47
6	2	1	12.1	80.37	11.36	8.26
6	2	2	64.7	97.87	0.58	1.55
6	2	3	42.2	94.37	0.89	4.74
6	3	1	59.7	83.46	2.30	14.24
6	3	2	7.4	nes	nes	nes
6	3	3	142.9	96.94	1.31	1.75
7	1	1	7.6	nes	nes	nes
7	1	2	24.8	96.47	-0.50	4.03

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
7	2	1	22.1	80.20	6.22	13.57
7	2	2	12.1	88.64	3.10	8.26
7	2	3	20.8	93.99	4.21	1.80
7	3	1	51.6	63.66	7.51	28.83
7	3	2	7.4	nes	nes	nes
7	3	3	59.7	80.95	14.87	4.19
8	1	1	194.9	96.15	2.05	1.80
8	1	2	2.4	nes	nes	nes
8	1	3	0.0	0.00	0.00	0.00
8	2	1	1.7	nes	nes	nes
8	2	2	1.5	nes	nes	nes
8	2	3	2.7	nes	nes	nes
8	3	1	1.9	nes	nes	nes
8	3	2	8.8	nes	nes	nes
8	3	3	49.3	86.82	7.10	6.09
9	1	1	53.8	87.45	2.56	9.99
9	1	2	69.5	67.81	8.45	23.74
9	1	3	3.6	nes	nes	nes

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
9	2	2	79.9	86.39	4.22	9.39
9	2	3	31.2	83.97	8.01	8.01
9	3	1	127.2	86.73	3.83	9.43
9	3	2	183.5	89.17	3.47	7.36
9	3	3	95.2	93.30	3.02	3.68
10	1	1	114.0	89.58	2.96	7.46
10	1	2	0.0	0.00	0.00	0.00
10	1	3	0.0	0.00	0.00	0.00
10	2	1	5.7	nes	nes	nes
10	2	2	0.0	0.00	0.00	0.00
10	2	3	0.0	0.00	0.00	0.00
10	3	1	7.7	nes	nes	nes
10	3	2	0.0	0.00	0.00	0.00
10	3	3	0.0	0.00	0.00	0.00
11	1	1	4.3	nes	nes	nes
11	1	2	11.9	92.65	3.15	4.20
11	1	3	22.4	58.15	8.37	33.48
11	2	1	107.2	93.00	1.75	5.25

Site	Transect	Station	Sample dry weight (g)	% Sand	% Silt	% Clay
11	2	3	0.9	nes	nes	nes
11	3	1	70.0	93.04	2.68	4.29
11	3	2	5.4	93.06	6.94	0.00
11	3	3	2.7	nes	nes	nes
12	1	1	154.7	90.06	3.15	6.79
12	1	2	105.9	97.76	1.30	0.94
12	1	3	159.2	94.11	4.95	0.94
12	2	1	174.5	93.48	3.08	3.44
12	2	2	141.0	89.10	3.19	7.71
12	2	3	259.4	91.18	3.42	5.40
12	3	1	159.0	81.92	3.93	14.15
12	3	2	162.8	82.88	5.53	11.59
12	3	3	80.4	76.06	6.84	17.10

Table A4. Particle size analysis of substrate material < 2 mm collected for chemical analysis and extraction of pore-water.

Site	% Sand	% Silt	% Clay
1	74.52	10.10	15.38
2	91.72	2.02	6.25
3	92.75	1.96	5.30
4	79.00	8.86	12.15
5	92.87	2.78	4.36
6	71.54	15.13	13.33
7	80.50	5.35	14.15
8	93.12	3.08	3.81
9	86.35	4.55	9.10
10	90.72	2.71	6.57
11	94.37	1.88	3.75
12	15.04	30.27	54.69
Tavern Creek	97.10	1.12	1.79

Table A5. Density (m^2) of benthic macroinvertebrates collected from each station at Site 1.

	Transect, station		
Scientific name	1, 2	2, 2	3, 3
NEMATODA			
Nematoda sp.	117.65	0	117.65
ANNELIDA			
Oligochaeta	117.65	117.65	235.29
Hirudinea	0	117.65	0
EPHEMEROPTERA			
Baetidae	117.65	0	0
Heptageniidae	0	0	235.29
Tricorythodes sp.	2078.43	8000.00	2470.59
Paraleptophlebia sp.	0	0	117.65
ODONATA			
unidentified Zygoptera	0	117.65	0
PLECOPTERA			
unidentified Plecoptera	117.65	117.65	0
TRICHOPTERA			
Cernotina sp.	0	117.65	0
Hydropsychidae	1333.33	470.59	1372.55
Cheumatopsyche sp.	274.51	411.76	411.76
Hydropsyche orris (Ross)	0	0	117.65

Scientific name	Transect, station 1, 2	2, 2	3, 3
Potamyia flava (Hagen)	117.65	117.65	0
Hydroptila sp.	235.29	745.10	352.94
Oecetis sp.	411.76	666.67	176.47
unidentified Trichoptera	235.29	0	0
COLEOPTERA			
Stenelmis sp.	3372.55	2470.59	1490.20
Stenelmis beameri (Sanderson)	117.65	0	0
LEPIDOPTERA			
Petrophila sp.	0	117.65	117.65
DIPTERA			
Chironomidae/Oligochitae	14156.86	10980.39	9764.71
Hexatoma sp.	117.65	0	0
Simuliidae	0	0	117.65
Hemerodromia sp.	0	0	117.65
ARACHNOIDEA			
Acarina	117.65	117.65	274.51

Table A6. Density (m^2) of benthic macroinvertebrates collected from each station at Site 2.

	Transect, station		
Scientific name	1, 3	2, 2	3, 3
NEMATODA			
Nematoda sp.	0	352.94	0
ANNELIDA			
Oligochaeta	0	117.65	0
EPHEMEROPTERA			
Baetis sp.	196.08	196.08	117.65
Heptageniidae	235.29	313.73	588.24
Stenacron (*interpunctatum* gp.)	117.65	0	0
Stenonema sp.	235.29	0	235.29
Tricorythodes sp.	8980.39	980.39	1607.84
Caenis sp.	0	117.65	0
ODONATA			
Coenagrionidae	294.12	0	0
Argia sp.	117.65	0	0
Gomphidae	176.47	0	176.47
TRICHOPTERA			
Hydropsychidae	0	117.65	0
COLEOPTERA			

Scientific name	Transect, station 1, 3	2, 2	3, 3
Stenelmis sp.	235.29	0	117.65
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	176.47	117.65	0
LEPIDOPTERA			
Petrophila sp.	117.65	0	0
unidentified Lepidoptera	0	0	117.65
DIPTERA			
Chironomidae/Oligochitae	3450.98	941.18	1294.12
ARACHNOIDEA			
Acarina	7411.76	2627.45	2431.37

Table A7. Density (m^2) of benthic macroinvertebrates collected from each station at Site 3.

	Transect, station		
Scientific name	1, 1	2, 3	3, 2
PLATYHELMINTHES			
Planariidae	0	117.65	O
NEMATODA			
Nematoda sp.	29.41	117.65	117.65
ISOPODA			
Caecidotea sp.	0	0	117.65
EPHEMEROPTERA			
Baetis sp.	264.71	352.94	352.94
Isonychia sp.	0	0	117.65
Heptageniidae	156.86	176.47	0
Stenacron (interpunctatum gp.)	19.61	0	0
Stenonema sp.	49.02	0	117.65
Stenonema mediopunctatum (McDunnough)	0	117.65	117.65
Tricorythodes sp.	1029.41	7490.20	1960.78
Caenis sp.	166.67	235.29	117.65
Caenis hilaris	127.45	176.47	0
Ephoron sp.	9.80	0	0

Scientific name	Transect, station 1, 1	2, 3	3, 2
ODONATA			
Coenagrionidae	9.80	0	176.47
Gomphidae	9.80	0	0
HEMIPTERA			
unidentified Hemiptera	9.80	0	0
TRICHOPTERA			
Psychomyia sp.	0	117.65	0
Hydropsychidae	39.22	235.29	0
Cheumatopsyche sp.	9.80	294.12	176.47
Hydroptila sp.	0	117.65	0
Oecetis sp.	0	0	117.65
unidentified Trichoptera	0	235.29	0
COLEOPTERA			
Psephenus herricki (DeKay)	19.61	0	0
Optioservus sp.	0	156.86	117.65
Stenelmis sp.	88.24	705.88	117.65
LEPIDOPTERA			
Petrophila sp.	0	117.65	0
unidentified Lepidoptera	9.80	0	117.65

Scientific name	Transect, station 1, 1	2, 3	3, 2
DIPTERA			
Chironomidae/Oligochitae	401.96	3803.92	2705.88
Atherix sp.	0	117.65	0
Hemerodromia sp.	0	0	117.65
ARACHNOIDEA			
Acarina	852.94	3921.57	3058.82
GASTROPODA			
Hydrobiidae	137.25	117.65	0
unidentified Gastropoda	0	0	411.76
PELECYPODA			
unidentified Pelecypoda	0	0	117.65

Table A8. Density (m^2) of benthic macroinvertebrates collected from each station at Site 4.

	Transect, station		
Scientific name	1, 1	2, 3	3, 2
ANNELIDA			
Oligochaeta	470.59	117.65	549.02
EPHEMEROPTERA			
Baetis sp.	117.65	235.29	313.73
Isonychia sp.	235.29	117.65	235.29
Heptageniidae	666.67	1450.98	1254.90
Leucrocuta sp.	294.12	235.29	274.51
Stenonema sp.	509.80	176.47	274.51
Stenonema terminatum (Walsh)	352.94	117.65	117.65
Tricorythodes sp.	784.31	1686.27	1058.82
Caenis hilaris	0	117.65	0
Leptophlebia sp.	0	117.65	0
Paraleptophlebia sp.	0	0	235.29
Anthopotamus sp.	235.29	431.37	0
Ephemera sp.	0	117.65	117.65
unidentified Ephemeroptera	0	117.65	0
PLECOPTERA			
Perlidae	705.88	117.65	274.51
Agnetina flavescens (Walsh)	117.65	0	0
Neoperla sp.	352.94	0	0

Scientific name	Transect, station 1, 1	2, 3	3, 2
TRICHOPTERA			
Hydropsychidae	117.65	117.65	235.29
Cheumatopsyche sp.	274.51	235.29	176.47
Hydroptila sp.	431.37	549.02	1176.47
Nectopsyche sp.	0	0	117.65
Oecetis sp.	176.47	588.24	352.94
unidentified Trichoptera	117.65	0	117.65
COLEOPTERA			
Stenelmis sp.	1058.82	509.80	196.08
Stenelmis beameri (Sanderson)	117.65	0	0
Stenelmis crenata (Say)	117.65	0	0
DIPTERA			
Chironomidae/Oligochitae	6509.80	3372.55	6313.73
ARACHNOIDEA			
Acarina	549.02	117.65	392.16
GASTROPODA			
unidentified Gastropoda	470.59	117.65	235.29
PELECYPODA			
unidentified Pelecypoda	1254.90	1411.76	1411.76

Table A9. Density (m^2) of benthic macroinvertebrates collected from each station at Site 5.

	Transect, station		
Scientific name	1, 1	2, 1	3, 3
NEMATODA			
Nematoda sp.	235.29	117.65	176.47
ANNELIDA			
Oligochaeta	117.65	117.65	0
EPHEMEROPTERA			
Baetis sp.	117.65	0	0
Heptageniidae	1294.12	1058.82	784.31
Leucrocuta sp.	0	0	117.65
Stenacron (interpunctatum gp.)	117.65	0	0
Stenonema sp.	117.65	117.65	235.29
Tricorythodes sp.	235.29	470.59	294.12
Caenis sp.	0	235.29	117.65
Leptophlebia sp.	0	0	117.65
Anthopotamus sp.	117.65	117.65	117.65
Ephemera sp.	117.65	0	0
ODONATA			
Coenagrionidae	117.65	0	117.65
Argia sp.	117.65	0	0
Gomphidae	0	0	117.65
PLECOPTERA			

Scientific name	Transect, station 1, 1	2, 1	3, 3
Perlidae	941.18	784.31	274.51
Neoperla sp.	235.29	117.65	117.65
TRICHOPTERA			
Polycentropodidae	0	0	117.65
Hydropsychidae	117.65	235.29	176.47
Cheumatopsyche sp.	352.94	117.65	235.29
Hydropsyche simulans/incommoda	117.65	0	0
Hydroptila sp.	784.31	588.24	294.12
Nectopsyche sp.	0	117.65	0
Oecetis sp.	470.59	156.86	549.02
unidentified Trichoptera	0	117.65	0
COLEOPTERA			
Stenelmis sp.	3176.47	3333.33	1843.14
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	117.65	0	0
DIPTERA			
Chironomidae/Oligochitae	11411.76	14588.24	3490.20
Hexatoma sp.	235.29	117.65	0
Hemerodromia sp.	627.45	411.76	117.65

Scientific name	Transect, station		
	1, 1	2, 1	3, 3
ARACHNOIDEA			
Acarina	705.88	745.10	666.67
PELECYPODA			
unidentified Pelecypoda	117.65	176.47	117.65

Table A10. Density (m^2) of benthic macroinvertebrates collected from each station at Site 6.

Scientific name	Transect, station 1, 2	2, 3	3, 1
PLATYHELMINTHES			
Planariidae	156.86	352.94	117.65
NEMATODA			
Nematoda sp.	117.65	235.29	0
EPHEMEROPTERA			
Heptageniidae	470.59	627.45	1254.90
Stenonema sp.	0	352.94	1058.82
Stenonema terminatum (Walsh)	117.65	117.65	117.65
Tricorythodes sp.	352.94	274.51	235.29
Caenis sp.	0	0	235.29
ODONATA			
Argia sp.	0	0	117.65
PLECOPTERA			
Perlidae	117.65	0	0
TRICHOPTERA			
Cheumatopsyche sp.	0	117.65	117.65
Oecetis sp.	0	0	117.65
unidentified Trichoptera	117.65	0	0

Scientific name	Transect, station 1, 2	2, 3	3, 1
COLEOPTERA			
Stenelmis sp.	352.94	196.08	117.65
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	0	117.65	0
DIPTERA			
Chironomidae/Oligochitae	2588.24	7607.84	4274.51
Hemerodromia sp.	0	235.29	117.65
ARACHNOIDEA			
Acarina	1019.61	6352.94	1882.35

Table A11. Density (m^2) of benthic macroinvertebrates collected from each station at Site 7.

Scientific name	Transect, station 1, 1	2, 3	3, 2
PLATYHELMINTHES			
Planariidae	0	117.65	0
ANNELIDA			
Oligochaeta	431.37	0	294.12
ISOPODA			
Caecidotea sp.	0	117.65	0
AMPHIPODA			
Hyallella azteca (Saussure)	0	117.65	0
DECAPODA			
Oronectes sp.	0	0	117.65
EPHEMEROPTERA			
Baetis sp.	0	509.80	1058.82
Isonychia sp.	0	0	117.65
Heptageniidae	392.16	470.59	470.59
Leucrocuta sp.	235.29	176.47	117.65
Stenacron (interpunctatum gp.)	0	117.65	117.65
Stenonema sp.	294.12	117.65	196.08

Scientific name	Transect, station 1, 1	2, 3	3, 2
Stenonema mediopunctatum (McDunnough)	0	117.65	117.65
Stenonema terminatum (Walsh)	0	117.65	117.65
Tricorythodes sp.	745.10	823.53	2117.65
Caenis sp.	274.51	0	352.94
Caenis hilaris	235.29	0	117.65
Leptophlebiidae	352.94	117.65	0
Paraleptophlebia sp.	117.65	0	0
Anthopotamus sp.	274.51	196.08	392.16
Ephemera sp.	1058.82	235.29	431.37
ODONATA			
Coenagrionidae	117.65	0	0
Gomphidae	117.65	0	0
Gomphus sp.	117.65	0	0
PLECOPTERA			
Perlidae	117.65	235.29	411.76
Agnetina flavescens (Walsh)	0	235.29	117.65
Perlinella ehyre (Newman)	0	117.65	0
TRICHOPTERA			
Polycentropodidae	0	117.65	117.65
Hydropsychidae	294.12	176.47	666.67
Cheumatopsyche sp.	470.59	509.80	1254.90

Scientific name	Transect, station 1, 1	2, 3	3, 2
Hydropsyche simulans/incommoda	0	235.29	0
Agapetus sp.	117.65	0	196.08
Hydroptila sp.	294.12	117.65	235.29
Helicopsycle borealis	117.65	0	117.65
Leptoceridae	117.65	0	0
Oecetis sp.	117.65	0	0
unidentified Trichoptera	117.65	0	0
COLEOPTERA			
Psephenus sp.	0	0	117.65
Psephenus herricki (DeKay)	117.65	117.65	0
Optioservus sp.	117.65	0	0
Stenelmis sp.	1372.55	470.59	1333.33
Stenelmis beameri (Sanderson)	117.65	0	0
MEGALOPTERA			
Sialis sp.	117.65	0	0
Corydalus cornutus (Linnaeus)	0	0	117.65
LEPIDOPTERA			
Petrophila sp.	0	156.86	0
DIPTERA			

Scientific name	Transect, station 1, 1	2, 3	3, 2
Chironomidae/Oligochitae	2666.67	470.59	1294.12
Hexatoma sp.	0	117.65	0
Hemerodromia sp.	235.29	117.65	470.59
ARACHNOIDEA			
Acarina	352.94	1098.04	509.80
Elima sp.	0	0	176.47
GASTROPODA			
Ancyclidae	431.37	0	0
unidentified Gastropoda	627.45	0	235.29
PELECYPODA			
Corbicula sp.	0	0	117.65
unidentified Pelecypoda	313.73	117.65	0

Table A12. Density (m^2) of benthic macroinvertebrates collected from each station at Site 8.

Scientific name	Transect, station 1, 2	2, 3	3, 1
ANNELIDA			
Oligochaeta	58.82	117.65	274.51
EPHEMEROPTERA			
Baetis sp.	29.41	117.65	0
Isonychia sp.	9.80	117.65	0
Heptageniidae	0	705.88	117.65
Leucrocuta sp.	0	117.65	117.65
Stenonema sp.	49.02	117.65	0
Stenonema mediopunctatum (McDunnough)	9.80	176.47	0
Stenonema terminatum (Walsh)	49.02	0	0
Tricorythodes sp.	3754.90	2509.80	2784.31
Caenis sp.	29.41	117.65	0
Leptophlebiidae	39.22	117.65	176.47
Anthopotamus sp.	78.43	0	274.51
Ephemera sp.	0	117.65	117.65
ODONATA			
Coenagrionidae	9.80	117.65	0
Argia sp.	0	0	117.65

Scientific name	Transect, station 1, 2	2, 3	3, 1
PLECOPTERA			
Perlidae	49.02	117.65	117.65
Agnetina flavescens (Walsh)	0	117.65	0
Neoperla sp.	0	0	117.65
TRICHOPTERA			
Polycentropodidae	9.80	0	0
Hydropsychidae	176.47	588.24	235.29
Cheumatopsyche sp.	205.88	470.59	117.65
Hydroptila sp.	29.41	117.65	0
Oecetis sp.	107.84	352.94	156.86
unidentified Trichoptera	0	117.65	0
COLEOPTERA			
Stenelmis sp.	88.24	235.29	352.94
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	19.61	0	0
DIPTERA			
Chironomidae/Oligochitae	1284.31	1843.14	3215.69
Hemerodromia sp.	19.61	0	0

Scientific name	Transect, station 1, 2	2, 3	3, 1
ARACHNOIDEA			
Acarina	264.71	117.65	392.16
GASTROPODA			
Ancyclidae	0	0	117.65
PELECYPODA			
unidentified Pelecypoda	1137.25	509.80	2039.22

Table A13. Density (m^2) of benthic macroinvertebrates collected from each station at Site 9.

Scientific name	Transect, station 1, 2	2, 3	3, 2
NEMATODA			
Nematoda sp.	0	117.65	0
ANNELIDA			
Oligochaeta	431.37	588.24	274.51
ISOPODA			
Caecidotea sp.	0	117.65	0
EPHEMEROPTERA			
Baetis sp.	156.86	0	0
Isonychia sp.	0	117.65	0
Heptageniidae	1058.82	862.75	274.51
Leucrocuta sp.	470.59	117.65	176.47
Stenacron (interpunctatum gp.)	352.94	0	0
Stenonema sp.	529.41	470.59	352.94
Stenonema mediopunctatum (McDunnough)	117.65	117.65	0
Stenonema terminatum (Walsh)	176.47	117.65	117.65
Tricorythodes sp.	4235.29	2627.45	1215.69
Caenis sp.	176.47	0	117.65
Caenis hilaris	117.65	0	0
Leptophlebiidae	117.65	0	392.16

Scientific name	Transect, station 1, 2	2, 3	3, 2
Anthopotamus sp.	549.02	196.08	1607.84
Ephemera sp.	176.47	117.65	117.65
Ephron sp.	0	117.65	0
ODONATA			
Argia sp.	117.65	0	0
Gomphidae	117.65	0	117.65
PLECOPTERA			
Perlidae	392.16	235.29	352.94
Neoperla sp.	117.65	117.65	0
TRICHOPTERA			
Hydropsychidae	235.29	352.94	0
Cheumatopsyche sp.	470.59	235.29	117.65
Agapetus sp.	352.94	196.08	117.65
Hydroptila sp.	588.24	294.12	235.29
Oecetis sp.	117.65	117.65	0
Helicopsyche borealis	0	117.65	0
unidentified Trichoptera	235.29	0	0
COLEOPTERA			
Psephenus herricki (DeKay)	117.65	0	0
Stenelmis sp.	352.94	1372.55	1137.25

Scientific name	Transect, station 1, 2	2, 3	3, 2
Stenelmis beameri (Sanderson)	117.65	117.65	176.47
DIPTERA			
Chironomidae/Oligochitae	4666.67	1882.35	4156.86
ARACHNOIDEA			
Acarina	823.53	588.24	274.51
GASTROPODA			
Ancyclidae	274.51	352.94	823.53
unidentified Gastropoda	196.08	176.47	294.12
PELECYPODA			
unidentified Pelecypoda	294.12	117.65	431.37

Table A14. Density (m^2) of benthic macroinvertebrates collected from each station at Site 10.

Scientific name	Transect, station 1, 1	2, 1	3, 1
NEMATODA			
Nematoda sp.	235.29	107.84	117.65
EPHEMEROPTERA			
Baetis sp.	0	19.61	0
Heptageniidae	117.65	166.67	117.65
Stenonema sp.	0	117.65	117.65
Stenonema terminatum (Walsh)	0	29.41	0
Tricorythodes sp.	117.65	9.80	117.65
Caenis latipennis	1098.04	235.29	313.73
Leptophlebiidae	117.65	0	0
ODONATA			
Coenagrionidae	823.53	127.45	470.59
Argia sp.	117.65	9.80	156.86
Gomphidae	117.65	0	0
Gomphus sp.	0	0	117.65
unidentified Anisoptera	176.47	0	0
PLECOPTERA			
Perlidae	0	9.80	0
unidentified Plecoptera	117.65	0	0

Scientific name	Transect, station 1, 1	2, 1	3, 1
TRICHOPTERA			
Psychomyia sp.	235.29	49.02	0
Cernotina sp.	117.65	0	0
Hydropsychidae	0	0	117.65
Hydroptila sp.	117.65	0	0
Nectopsyche sp.	117.65	0	0
Oecetis sp.	588.24	0	0
COLEOPTERA			
Psephenus herricki (DeKay)	117.65	0	0
Stenelmis sp.	1411.76	39.22	0
Stenelmis beameri (Sanderson)	117.65	0	0
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	0	19.61	0
DIPTERA			
Chironomidae/Oligochitae	24901.96	3500.00	5098.04
Antocha sp.	0	9.80	0
Hemerodromia sp.	0	98.04	470.59
ARACHNOIDEA			
Acarina	862.75	215.69	235.29

Table A15. Density (m^2) of benthic macroinvertebrates collected from each station at Site 11.

Scientific name	Transect, station 1, 3	2, 2	3, 1
NEMATODA			
Nematoda sp.	0	117.65	117.65
ANNELIDA			
Oligochaeta	509.80	0	0
Hirudinea	235.29	0	0
ISOPODA			
Lirceus hoppineau hoppineau (Faxon)	176.47	176.47	0
EPHEMEROPTERA			
Baetis sp.	0	1254.90	235.29
Isonychia sp.	0	392.16	0
Heptageniidae	1019.61	1568.63	666.67
Stenacron (interpunctatum gp.)	392.16	117.65	0
Stenonema sp.	431.37	784.31	235.29
Stenonema mediopunctatum (McDunnough)	176.47	431.37	117.65
Stenonema terminatum (Walsh)	0	235.29	117.65
Tricorythodes sp.	1411.76	1764.71	3019.61
Caenis sp.	1568.63	549.02	549.02
Caenis hilaris	1294.12	705.88	0
Caenis latipennis	941.18	0	0

Scientific name	Transect, station 1, 3	2, 2	3, 1
Ephemera sp.	274.51	0	0
ODONATA			
Coenagrionidae	313.73	0	0
Argia sp.	117.65	0	0
Gomphidae	117.65	0	0
unidentified Anisoptera	117.65	0	0
PLECOPTERA			
Agnetina flavescens (Walsh)	0	117.65	0
TRICHOPTERA			
Psychomyia sp.	117.65	0	0
Polycentropodidae	117.65	0	0
Hydropsychidae	0	117.65	0
Cheumatopsyche sp.	0	470.59	0
Hydropsyche morosa	0	117.65	0
Agapetus sp.	0	0	117.65
Hydroptila sp.	117.65	176.47	0
Helicopsyche borealis	117.65	0	0
Oecetis sp.	313.73	117.65	117.65

Scientific name	Transect, station 1, 3	2, 2	3, 1
COLEOPTERA			
Psephenus herricki (DeKay)	588.24	117.65	0
Dubiraphia sp	235.29	0	0
Optioservus sp.	117.65	0	0
Stenelmis sp.	509.80	313.73	235.29
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	0	117.65	0
DIPTERA			
Chironomidae/Oligochitae	3019.61	5960.78	9333.33
Hemerodromia sp.	117.65	0	117.65
ARACHNOIDEA			
Acarina	235.29	901.96	1019.61
GASTROPODA			
Ancyclidae	352.94	176.47	0
unidentified Gastropoda	470.59	1490.20	1019.61
PELECYPODA			
unidentified Pelecypoda	745.10	117.65	627.45

Table A16. Density (m^2) of benthic macroinvertebrates collected from each station at Site 12.

Scientific name	Transect, station 1, 2	2, 1	3, 3
NEMATODA			
Nematoda sp.	0	235.29	705.88
ANNELIDA			
Oligochaeta	0	235.29	0
ISOPODA			
Caecidotea sp.	0	352.94	0
EPHEMEROPTERA			
Baetis sp.	117.65	0	0
Heptageniidae	980.39	117.65	117.65
Stenonema sp.	784.31	117.65	0
Tricorythodes sp.	411.76	176.47	235.29
Caenis sp.	0	0	117.65
Caenis latipennis	0	0	588.24
ODONATA			
Coenagrionidae	0	0	117.65
PLECOPTERA			
Perlidae	117.65	352.94	235.29

Scientific name	Transect, station 1, 2	2, 1	3, 3
TRICHOPTERA			
Chimarra sp.	117.65	352.94	117.65
Hydropsychidae	117.65	0	0
Cheumatopsyche sp.	529.41	352.94	0
Hydroptila sp.	0	0	352.94
Neotrichia sp.	0	0	117.65
COLEOPTERA			
Stenelmis sp.	117.65	941.18	352.94
MEGALOPTERA			
Corydalus cornutus (Linnaeus)	117.65	0	0
DIPTERA			
Chironomidae/Oligochitae	3098.04	1882.35	12901.96
Simulium sp.	117.65	0	0
Hemerodromia sp.	117.65	117.65	313.73
ARACHNOIDEA			
Acarina	1411.76	1882.35	666.67