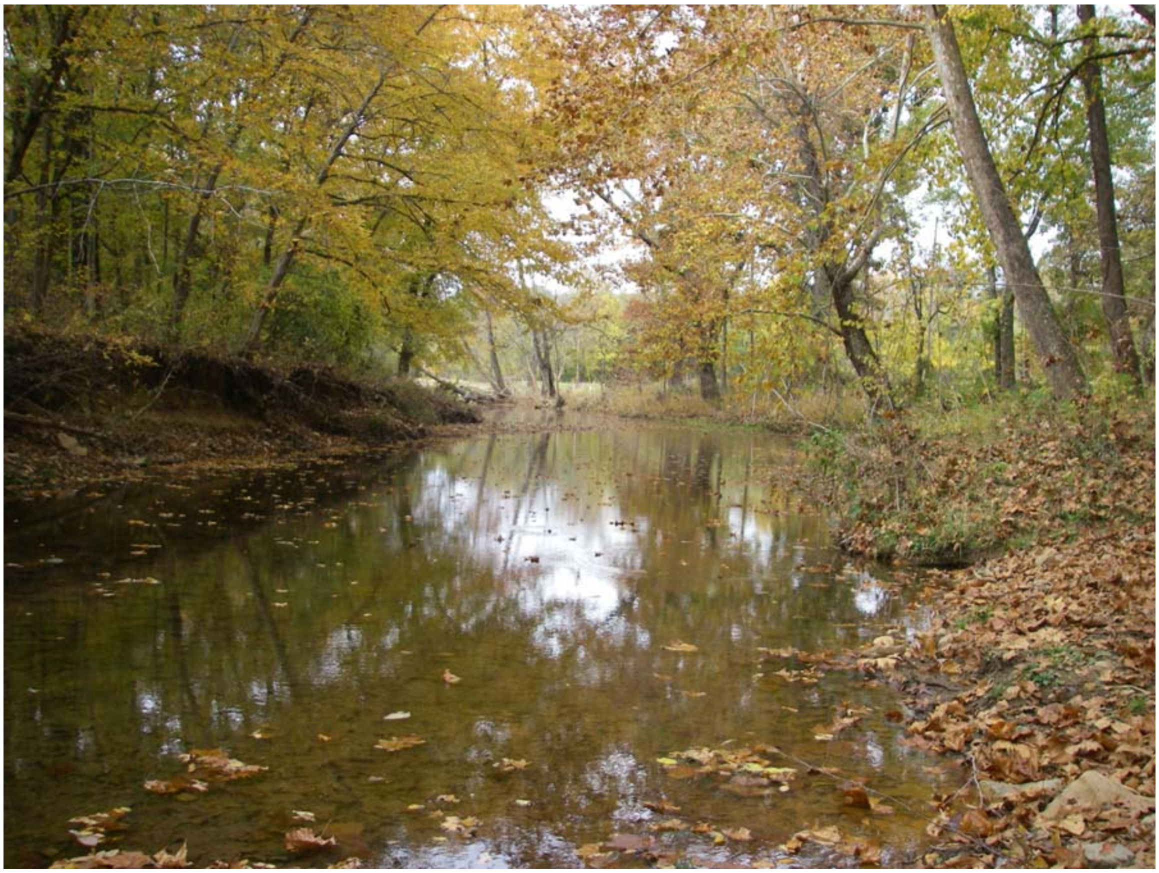
Physical, Chemical, and Biological Survey of Cove Creek Watershed



Cove Creek Study Site OUA0103

Arkansas Department of Environmental Quality

Water Division

October 2009

WQ09-10-01

Water Division Planning Branch

Mr. Steve Drown, Chief of the Water Division, is actively involved with the activities of the Water Division Planning Branch. The Planning Branch consists of ecologists and geologists who are responsible for managing the State Water Quality Monitoring Networks for both surface and ground waters, as well as investigating the physical, chemical, and biological characteristics of watersheds and/or aquifers. The data generated from these activities are used to prepare the biennial "Integrated Water Quality Monitoring and Assessment Report (305B)," the "List of Impaired Water Bodies, (303(d) list)," and develop Total Maximum Daily Loads for impaired water bodies. The data are also used to develop water quality standards and criteria for the evaluation of designated use attainment and to prioritize restoration and remediation activities.

The Groundwater Section is currently engaged in development of statewide groundwater standards and management of remediation projects that do not fall under the purview of other Arkansas Department of Environmental Quality divisions. It also oversees portions of the Groundwater Protection Program that are delegated to the Arkansas Department of Health (Wellhead Protection Program) and the Arkansas Natural Resources Commission (Groundwater Protection and Management Program).

The Education and Outreach Section develops and implements outreach and educational materials and programs. They also coordinate and implement the activities of the Arkansas Watershed Advisory Group; a group of federal, state, local, and private citizens working together to assist watershed groups in protecting and enhancing the natural environment in Arkansas.

The staff continues to develop and/or enhance ecoregion-based, biological assessment criteria for both fish and macroinvertebrates. Additionally, the staff is active in the development and updating of water quality standards and technical review and administration of the National Pollutant Discharge Elimination System Permits Biomonitoring Program. Staff members represent the Department on numerous Federal, State, local, and watershed-based advisory boards and technical support groups.

Current staff includes: Sarah Clem, ADEQ Branch Manager

Planning Section
Jim Wise, Ecologist Coordinator
Bob Singleton, Ecologist
Mary Barnett, Ecologist
Erica Shelby, Ecologist
Nathan Wentz, Ecologist
Cyndi Porter, Ecologist
Jason Hooks, Ecologist
Kristi Williams, Ecologist
Roger Miller, Geologist
Evelyn Kort, Geologist

Outreach and Education Section
Sarah DeVries, Environmental Program Coordinator
Philip Osborne, Environmental Program Coordinator
Barbara Miller, Ecologist
Kate Finefield, Ecologist

To learn more about the Water Division and other divisions of the Arkansas Department of Environmental Quality and to view a list of publications by the Planning Branch, visit www.adeq.state.ar.us or call at (501) 682-0744.

ACKNOWLEDGMENTS

Special appreciation is given to Mr. Alan Price and Ms. Kathryn Hattenhauer for their numerous hours of work in developing this report.

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EXECUTIVE SUMMARY

Beginning in 1939, barite ore was both mined and milled on a 600-acre site in the Cove Creek watershed, producing spoil piles, tailings impoundments, and a mine pit lake. In 2003, a capture/pump system began operating to collect runoff and seepage from the mine spoil remnants; the water is routed to the mine pit lake where it is treated to remove dissolved metals and adjust for the low pH.

In 2004, a 9.6 mile segment of Cove Creek was placed on Arkansas's Impaired Water Bodies List as not attaining its Fisheries Designated Use due to low pH and metals toxicity. In 2006, the same segment was further listed as not attaining its Domestic, Industrial, and Agricultural Water Supply Uses due to high concentrations of minerals. Additionally, these same designated uses were listed as not attained in two tributaries to Cove Creek, Chamberlain Creek and Lucinda Creek.

Due to the continuing impacts from the historic mining operations, ADEQ initiated a two-year physical, chemical, and biological survey of the Cove Creek watershed. Water quality samples and benthic macroinvertebrates were collected beginning in the fall of 2007 and ending in the spring of 2009; fish samples were collected during the summers of 2007 and 2008.

The most severe water quality impairments were observed within Chamberlain Creek; its pH levels were as low as 3.0 standard units and dissolved metal concentrations were as high as 100,000 µg/L for aluminum. Lack of fish communities within Chamberlain and Lucinda Creeks also indicate impairment. In the summer of 2007, fish surveys conducted on Chamberlain and Lucinda Creeks resulted in two individuals of one taxa and five individuals of two other taxa, respectively; Cove and Basin Creeks, above Chamberlain Creek, had a mean richness of 11 taxa. Benthic macroinvertebrate communities within Chamberlain Creek had lower percent EPT, lower taxa richness, lower abundance, increased percent Chironomidae, and increased percent tolerant taxa than Cove Creek above Chamberlain's confluence. The study indicates that the aquatic biota in Chamberlain Creek and portions of Lucinda and Cove Creek are degraded from acid mine drainage.

Data collected during the survey were used to characterize the water quality and biological communities in the watershed, assess the current impacts of treated acid mine drainage and stormwater runoff from mine spoil remnants, and assess ambient toxicity.

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INTRODUCTION

History

Cove Creek originates in the Ouachita Mountains of Saline County and flows southwesterly through parts of Garland and Hot Spring Counties before entering the Ouachita River downstream of Remmel Dam. Cove Creek's tributaries (Chamberlain Creek, Basin Creek, and Lucinda Creek) lie in the Ouachita Mountain Ecoregion, west of Magnet Cove (Figure 1).

The designated uses for Cove Creek, assigned by the Arkansas Pollution Control and Ecology Commission (APCEC), include Primary and Secondary Contact Recreation, Fisheries - Ouachita Mountains Ecoregion, and Domestic, Industrial, and Agricultural Water Supply (APCEC October 2007).

In 2004, the Arkansas Department of Environmental Quality (ADEQ) placed a 9.6 mile segment of Cove Creek, from the mouth of Cove Creek to its confluence with Chamberlain Creek, on the Impaired Water Bodies List (303(d) list) as not attaining its Fisheries Designated Use* due to low pH and metals toxicity. Routine water quality monitoring by ADEQ revealed that copper and zinc concentrations in Cove Creek were exceeding acute and chronic instream toxicity values. In 2006, the same segment was further listed as not attaining its Domestic, Industrial, and Agricultural Water Supply Uses due to high concentrations of minerals. Additionally, these same designated uses were listed as not attained in two tributaries to Cove Creek, Chamberlain Creek, and Lucinda Creek.

Historically, barite ore (barium sulfate) was both mined and milled in the Cove Creek watershed. Beginning in 1939, open-pit and underground mining methods were implemented to extract barite from a 600-acre site that comprises the headwaters of Cove Creek's tributary, Chamberlain Creek. Mining ceased in 1977, however stockpiled barite was milled at the site until 1982.

Mining and milling activities formed a large mine pit lake, mine spoil piles, and tailings impoundments. The mine spoil piles, which were created during the excavation of barite from the mine pit and during underground mining activities, are primarily composed of metal-rich shale that includes pyrite. Air and water interact with rock containing pyrite to produce a phenomenon know as acid rock drainage. Acid rock drainage results in increased dissolved concentrations of naturally occurring metals, such as aluminum, manganese, and zinc; and minerals, such as chloride, sulfate, and other ions. In addition, as stormwater flows over and through the mine spoil remnants it becomes acidified, helping to further dissolve the ions and metals out of the soil.

During the summer of 2003, a capture/pump system began operating to collect runoff and seepage from approximately 90 acres of the mine spoil remnants. This water is routed to the mine pit lake where it is treated and released into Chamberlain Creek at study site OUA0171E, which meets with Cove Creek approximately 2.5 miles downstream. The

*More recent 303(d) lists use the term "Aquatic Life Use."

purpose of the water treatment system is to removes dissolved metals from the water and adjusts the pH to between 6 and 9 before discharging it to the creek (in order to meet the limitations of a NPDES Permit).

Due to the continuing impacts from the historic mining operations, ADEQ initiated a two-year physical, chemical, and biological survey of the Cove Creek watershed in January 2007. Data from the survey were used to characterize seasonal changes in the water quality and biological communities in the watershed, assess the current impacts of the treated acid mine drainage and stormwater runoff from the mine spoil remnants, and to possibly develop Total Maximum Daily Loads (TMDLs).

Study Area and Description

The study area is the Cove Creek watershed from U.S. Highway 270 upstream to the headwaters of Cove Creek (Figure 1). Cove Creek's watershed is approximately 15 mi^2 (Yanchosek and Hines 1979) and the average annual precipitation in the watershed is 54 inches/year (Freiwald 1984). Cove Creek and its tributaries are intermittent streams (Hunrichs 1983); however, Chamberlain Creek's flow is now greatly influenced by the discharge of the treated water from the treatment system. Flow in Chamberlain Creek has increased in quantity and duration since discharging from the treatment system began in 2003. Consequently, Cove Creek's natural flow regime has been altered; the lower portion of Cove Creek is now more characteristic of a perennial stream.

The Cove Creek watershed lies in the Ouachita Mountain Ecoregion. The Ouachita Mountain Ecoregion varies from rolling hills to steep, east-west tending ridges. Forests in the region are a composite of hickory, oak, and shortleaf pine; surface geology is generally sandstone and shale (Bennett et al. 1987). Land use in the study area is dominated by forest (82%) (Figure 2). Urban and cropland make up 4.9% and 0.1% respectively.

Purpose and Scope

Data collected during ADEQ's two-year survey were used to characterize the water quality and biological communities of the Cove Creek watershed, assess the current impacts of treated acid mine drainage and stormwater runoff from mine spoil remnants, and assess ambient toxicity. Additionally, data collected from this survey may be used to evaluate future Use Attainability Analysis (UAA) plans and proposals submitted to ADEQ with regard to this watershed; develop total maximum daily loads for the listed constituents; and possible develop remediation plans for the watershed.

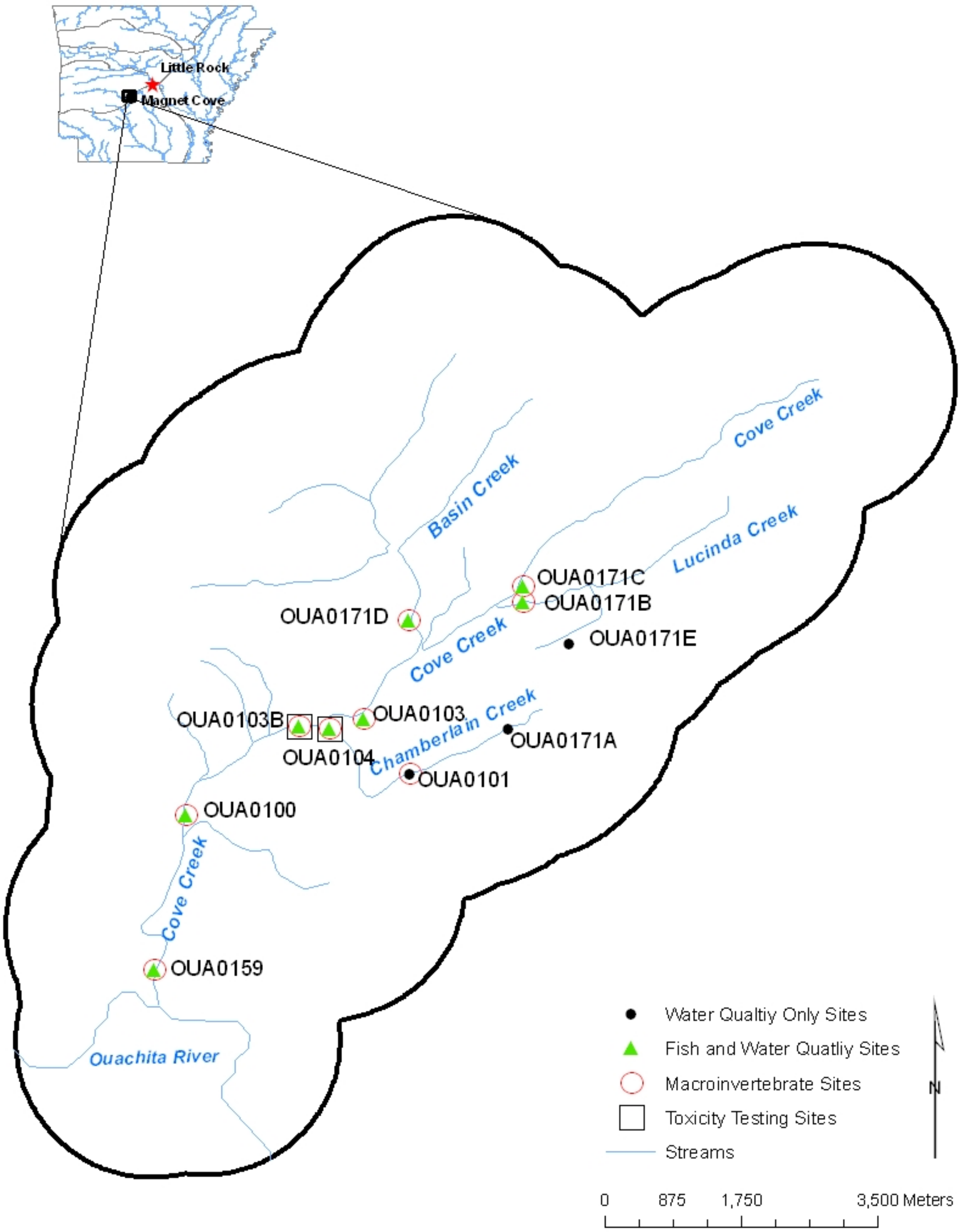

Figure 1. Map of Basin, Chamberlain, Cove, and Lucinda Creeks with sites where biological, water quality, and toxicity samples were collected.

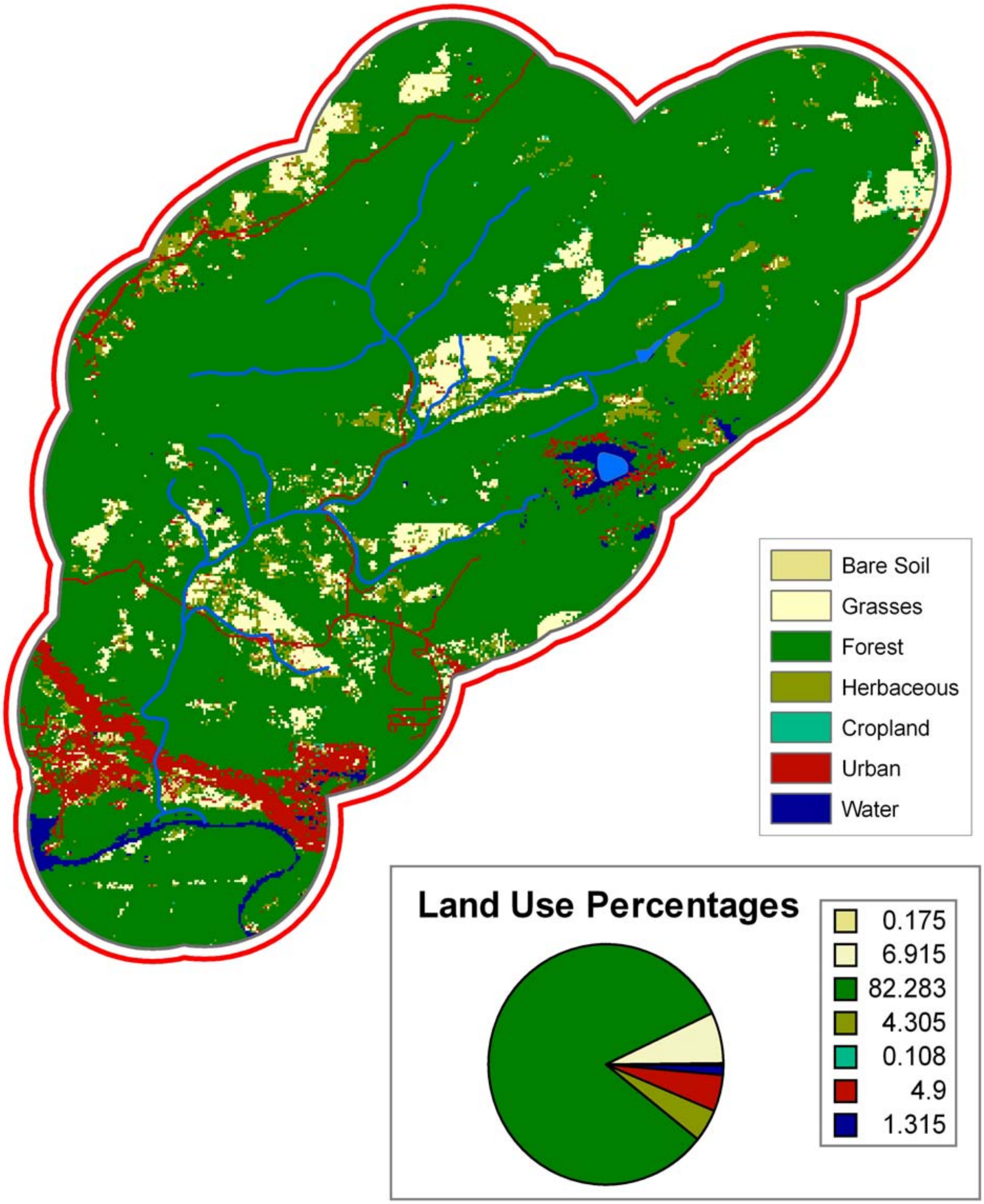

Figure 2. Map of Basin, Chamberlain, Cove, and Lucinda Creeks land use.

METHODS OF STUDY

Stream Flow Data Collection

A total of 116 flow samples were taken from January 22, 2007 to May 11, 2009, from 11 sites. Stream flow was measured with either a Marsh-McBirney Flowmate 2000 or a SonTec Flow Tracker velocity meter by obtaining a representative number of depths and velocities across a relatively uniform segment of stream channel. Data collected were not analyzed due to an equipment malfunction and subsequent data loss.

Water-Quality Data Collection

All water quality samples were collected, processed, and analyzed per the methodologies in *Arkansas's Water Quality and Compliance Monitoring Quality Assurance Project Plan*. A total of 13 sample events were conducted over the two year study. Three samples were taken quarterly (beginning in March) during 2007 and ten samples were taken bi-monthly during 2008 and 2009 (ending in May) on 11 sites (Figure 1, Table 1).

In situ measurements included: pH, dissolved oxygen (D.O.), water temperature, and conductivity.

Water samples were collected mid stream, preserved on ice, and transported to the ADEQ water-quality laboratory in North Little Rock, Arkansas for analysis. A field (duplicate sample) quality-assurance sample (QA) was collected on every sampling event. Additionally matrix spikes and blank samples analyses were conducted.

Water quality samples were analyzed for:

Ammonia as Nitrogen (mg/L)	Aluminum (µg/L)	Magnesium (µg/L)
Chlorides (mg/L)	Barium (µg/L)	Manganese (mg/L)
Nitrate-Nitrite as Nitrogen (mg/L)	Beryllium (µg/L)	Nickel (µg/L)
Orthophosphorus as Phosphorus (mg/L)	Boron (µg/L)	Potassium (mg/L)
Sulfates (mg/L)	Cadmium (µg/L)	Sodium (mg/L)
Total Dissolved Solids (TDS) (mg/L)	Calcium (mg/L)	Vanadium (µg/L)
Total Hardness (mg/L)	Chromium (µg/L)	Zinc (µg/L)
Total Organic Carbon (mg/L)	Cobalt (µg/L)	
Total Phosphorus (TP)(mg/L)	Copper (µg/L)	
Total Suspended Solids (TSS) (mg/L)	Iron (µg/L)	
Turbidity (NTU)	Lead (µg/L)	

Table 1. Water quality, stream flow, and biological sites for the Cove Creek watershed.

Site Name	Stream	Latitude in decimal degrees	Longitude in decimal degrees	Stream flow	Water Quality	Macroinvertebrates	Fish Community	Ambient Toxicity
OUA0171C	Cove Creek	34.4831	-92.8272	X	X	X	X	
OUA0171B	Lucinda Creek	34.4812	-92.8272	X	X	X	X	
OUA0171D	Basin Creek	34.4792	-92.8431	X	X	X	X	
OUA0171E	Chamberlain Creek at Magcobar effluent	34.4764	-92.8208	X	X			
OUA0171A	Chamberlain Creek	34.4667	-92.8292	X	X			
OUA0101	Chamberlain Creek	34.4614	-92.8430	X	X	X		
OUA0104	Chamberlain Creek	34.4667	-92.8541	X	X	X	X	X
OUA0103	Cove Creek	34.4678	-92.8494	X	X	X	X	
OUA0103B	Cove Creek	34.4670	-92.8585	X	X	X	X	X
OUA0100	Cove Creek	34.4567	-92.8742	X	X	X	X	
OUA0159	Cove Creek	34.4389	-92.8786	X	X	X	X	

Biological Data Collection

All benthic macroinvertebrate and fish samples were collected, processed, and analyzed per the methodologies in *Arkansas's Water Quality and Compliance Monitoring Quality Assurance Project Plan.*

Benthic Macroinvertebrate Community

Macroinvertebrate samples were collected during fall 2007, spring and fall 2008, and spring 2009. The fall sampling period for aquatic macroinvertebrates is defined by ADEQ as September 15 to October 3; the spring sampling period is defined as April 1 to June 15. Insufficient or excessive flow prevented collection at some sites during fall sampling periods, therefore sampling was performed later in the season when flows were at adequate levels.

Macroinvertebrates were collected within a single riffle using the 5-minute traveling kick method (Montana Department of Environmental Quality 2006) along a diagonal transect, enabling all microhabitats present to be sampled. A D-frame dip net with 500 μ mesh was placed on the streambed while the substrate was disturbed upstream and macroinvertebrates were swept into the net aided by the current. All kicks along the diagonal transect were combined into a composite sample for that site. The samples were cleaned of larger debris in the field, preserved in 70% denatured ethanol, labeled with the appropriate identifying information, and stored at the ADEQ lab until sub sampled.

A modified version of Caton (1991) was used for sub sampling composite samples. This procedure eliminates investigator bias since all organisms within a square are easily sorted and heavy debris loads are effectively dealt with.

The sub sampling process consisted of transferring a composite sample to a rectangular 500 μ mesh sieve (30.48 cm x 76.2 cm x 4 cm) marked into 5.08 cm squares labeled alpha-numerically. The sieve tray was placed into a larger pan of water to allow thorough mixing and distribution of the sample. Once the sample was evenly distributed on the grid, it was quickly lifted out of the larger pan and allowed to drain. The sieve was placed onto wet paper towels on a flat surface where squares were selected using dice.

A 6 cm x 6 cm stainless steel cookie cutter was placed on the randomly chosen square; the cookie cutter defines the sub-sample area and cuts through debris. The entire contents of the square were placed into a sorting dish using a 6 cm scoop and 2 inch paint brush. Water was added to the sorting dish to facilitate macroinvertebrate removal; all organisms were removed from the selected square. A visual inspection of each sampled square was done using a 10X lens to ensure all organisms were collected. This process was repeated one square at a time until 300 organisms were obtained. Once a square was started, it was completed. In some cases, an entire sample was sub sampled without the target number of 300 organisms being reached.

Sub samples were placed in a 4 oz. Nalgene® jar containing 70% ethanol and stored until identification. Macroinvertebrates were identified to the lowest possible taxonomic level using Merritt et al. (2008). Identification was facilitated by use of a dissecting microscope.

Fish Community

A Smith-Root model 15-B backpack electrofishing device with pulsed DC current was used to collect fish samples from all available habitats in the summers of 2007 and 2008. Pool samples were collected by placing the pulsed DC current upstream and dipping the stunned fish from the water with D-frame dip nets. Riffle samples were collected by posting a twenty foot seine near the toe of the riffle and working the 15-B backpack electrofisher in a downstream direction through the riffle while disturbing the stream's substrate, causing the fish to be herded into the seine or washed in by the current.

Fish specimens were collected from all available habitat from the site until it was concluded that a fully representation of the habitat in the area was sampled and that a representative sample of the fish community was obtained. Larger specimens were field identified and released; smaller specimens and those needing further identification were preserved in a 10% formalin solution, labeled with the appropriate identifying information, and returned to the lab. Fish were identified to the lowest possible taxonomic level using Robison and Buchanan (1988).

Physical Habitat

Benthic Macroinvertebrate Community Habitat

A two-tier approach was employed to evaluate aquatic macroinvertebrate habitat for all study streams. This approach employs more quantitative data collection, which allows for a higher level of precision when comparing sites. Physical habitat data was used to calculate metrics on the following attributes: wetted width and mean channel depth; bank characteristics; substrate embeddedness, mean diameter, and stability; in-channel cover; channel habitat types; and riparian vegetation structure, complexity and disturbance. The close connectivity of various parameters should impact multiple metrics if habitat alteration is occurring.

Tier one is an observational (qualitative) approach to assessing various habitat parameters that assigns a numeric score (0-20) to each parameter (EPA 1999; Appendix FS). Scores are separated into four broad categories/conditions consisting of poor, 0-5; marginal, 6-10; sub-optimal, 11-15; and optimal, 16-20. Habitat parameters assessed in all streams are epifaunal substrate/available cover, sediment deposition, channel flow status, channel alteration, bank stability, vegetative protection, riparian vegetative zone width, frequency of riffles (or bends), velocity/depth regime, and embeddedness.

Tier two combines both a qualitative (visual estimates) and quantitative (in-stream measurements) approach to developing a habitat profile for each sample reach based on several broad categories. These categories include measurements/estimates of the in-channel cover, substrate, canopy cover, large woody debris within bankfull width, flow, visual riparian quality, and human influence estimates.

No physical habitat activities were conducted in the stream until all biological collections were completed. Any deviations from the previously mentioned methods were noted in the project field notebook. All information was recorded in the field on appropriate data forms. A photograph was taken at each site.

Fish Community Habitat

Fish habitat evaluations were performed at all study sites and were comprised of five parameters, each consisting of three to seven variables. These parameters included: 1) habitat type, 2) habitat quantity, 3) quantity of substrate type based on fish use, 4) quantity of instream cover, and 5) sediment on substrate. Each parameter for substrate type and instream cover was given a score depending on its abundance. Scores given to the substrate parameters were multiplied by an adjustment factor based relatively to fish habitat quality. Length, depth, and width measurements were estimated for each habitat type and recorded in feet. The sediment on substrate parameter was scored according to the degree of embeddedness.

A total score for each habitat type was calculated by summing the scores for the substrate type, instream cover, and sediment on substrate. The scores from similar habitat types were averaged for each sampling station. The lengths of each habitat type were also summed. The total habitat type lengths were divided by 100 and multiplied by the average habitat type score. This score is the Ichthyofauna Habitat Index (IHI).

Whole Effluent Toxicity (WET) Testing

Ambient toxicity samples were collected concurrently with the water quality samples. A total of 13 ambient toxicity samples were collected from Chamberlain Creek at site OUA0104 from June 25, 2007 to May 11, 2009. One ambient toxicity sample was collected prior to the project begin date on April 16, 2007. A total of 11 ambient toxicity samples were collected from Cove Creek at site OUA0103B from October 22, 2007 to May 11, 2009.

Samples were collected in low density polyethylene (LDPE) collapsible, 2.5 gallon cubitainers and labeled with collection date, time, and site name and number. They were then held and shipped via FedEx priority overnight on ice, in coolers, to the U.S. EPA Region 6 Laboratory in Houston. Arkansas Department of Environmental Quality Chain of Custodies and U.S. EPA Lab Sample Forms were completed and sealed in the cooler prior to shipment.

Ambient toxicity tests were conducted according to U.S. EPA's Methods for Measuring the Acute Toxicity of Effluents in Freshwater and Marine Organisms (EPA 600/4/90/027F). The analysis was a 96-Hour Static Acute Toxicity Test using fathead minnow larvae (*Pimephales promelas*) and the water flea (*Ceriodaphnia dubia*). The control was moderately hard synthetic water prepared by the laboratory, and the test solution was 100% undiluted sample. Twenty *C. dubia* were exposed to each sample and the control; forty *P. promelas* were exposed to each sample and the control. The endpoint of the test is mortality.

Data Analysis

Water-Quality Data Analysis

"Arkansas's Assessment Methodology for the Preparation of the 2008 Integrated Water Quality Monitoring and Assessment Report" outlines the procedures utilized to analyze the water quality data collected during the survey. This information can be found in the 2008 Integrated Water Quality Monitoring and Assessment Report at the following web site: http://www.adeq.state.ar.us/water.

Biological Data Analysis

Benthic Macroinvertebrate Community

Evaluation and analysis of the macroinvertebrate communities consisted of comparison of 21 metrics among sites and Ouachita Mountain Ecoregion reference streams. Metrics measured included, but were not limited to: taxa richness, abundance, percent tolerant/intolerant taxa, percent Ephemeroptera, Plecoptera, Trichoptera, percent Diptera, percent Chironomidae, and Hilsenhoff Biotic Index (HBI). Tolerance values from 0-5 were classified as intolerant and values from 6-10 were tolerant (Barbour et al. 1999). The HBI was developed by Hilsenhoff (1977) to summarize overall organic pollution tolerance of the benthic arthropod community with a single value (Table 2). Currently, the HBI is used to detect organic loading and low dissolved oxygen in lotic systems. Calculation of the HBI is completed by summing the number in a given taxa multiplied by its tolerance value, then divided by the total number of organisms in the sample.

Table 2. Hilsenhoff Biotic Index water quality degree of organic pollution.

0.00–3.50	Excellent:	No apparent organic pollution
3.51–4.50	Very good:	Possible slight organic pollution
4.51–5.50	Good:	Some organic pollution
5.51–6.50	Fair:	Fairly significant organic pollution
6.51–7.50	Fairly poor:	Significant organic pollution
7.51–8.50	Poor:	Very significant organic pollution
8.51–10.0	Very poor:	Severe organic pollution

Fish Community

Fish communities were evaluated by directly comparing the community structures at each study site to the fish communities of least-disturbed, Ouachita Mountains ecoregion reference streams of similar watershed sizes. In summer 2008, the fish community of Tigre Creek, an adjacent watershed that has no AMD, was sampled for comparison. A fish community similarity index (CSI) was calculated using parameters based on ecoregion reference stream data to generate the scoring criteria (Table 3). Seventeen different parameters were compared between each of the communities and the ecoregion stream data.

The final determination of similarity is derived by utilizing all of the indices, the overall fish community, and the habitat and stream characteristics. Best professional judgment is also used in those unique situations when the metrics can not properly delineate the status of the fish communities based on the data collected.

The fish CSI is determined by summing the scores for each metric for each fish community. The relative scores were developed from average values from data collected from least disturbed ecoregion reference streams to determine similarity (Table 4). The different scores are based on one and two standard deviation units from the average.

Table 3. Fish community biocriteria for the Ouachita Mountain ecoregion.

Ouachita Mountains (>10 mi^2 Watershed)			
Metric (% community, except Diversity Index)	SCORE 4	2	0
Cyprinidae	45 - 60	36 – 46 or 60 - 67	<36 or >67
Ictaluridae	>1[1]	<1 – 0.5[1]	<0.5 or >2% bullheads
Centrarchidae	8 - 26[2]	3 - 8 or 26 - 33[2]	<3 or >33 or >7% Green sunfish
Percidae	>14	8 - 14	<8
Sensitive Individuals	>24	16 - 24	<16
Primary TFL	<48	48 - 58	>58
Key Individuals	>23	20 - 23	<10
Diversity Index	>2.63	2.63 – 2.11	<2.11

1 – no more that 2% bullheads 2 – no more than 7% Green sunfish

Table 4. Fish community scoring criteria for the Ouachita Mountain ecoregion.

Total Score	**Similarity Explanation**
0-8	Not Similar
9-16	Somewhat Similar
17-24	Generally Similar
25-32	Most Similar

WATER-QUALITY CHARACTERISTICS

pH

The average pH of Cove Creek upstream of the influence of the acid mine drainage is 6.0 standard units. The average pH of Basin Creek, which does not receive acid mine drainage, is 6.5 standard units (Figure 3). This pH is typical of other very small Ouachita Mountains Ecoregion streams with watersheds of less than 10 square miles. However, in Lucinda and Chamberlain Creeks, the average pH is below 5.0 standard units with the lowest readings near 4.5 and 3.0 standard units, respectively. The pH in Cove Creek below the confluence of both Lucinda Creek and Chamberlain Creek drops to below 5.0 standard units. The pH recovers to an average just below 7.0 standard units near its confluence with the Ouachita River.

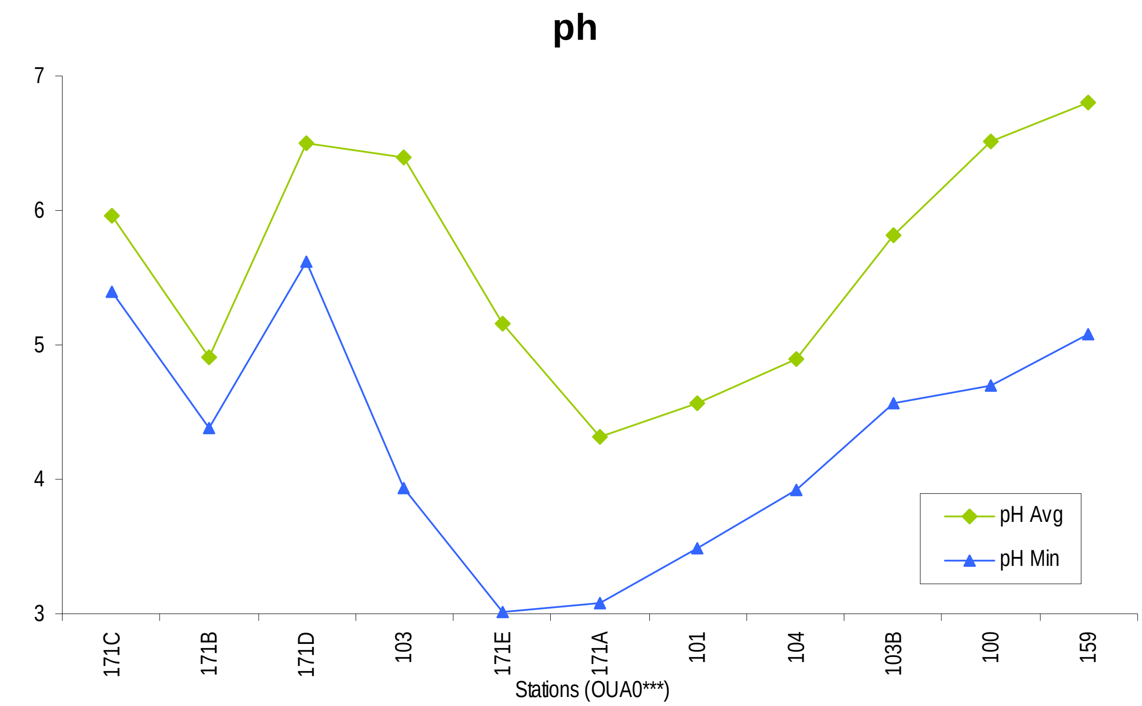

Figure 3. Minimum and average pH values for Cove and Chamberlain Creek watershed.

The minimum pH standard for Arkansas's waterbodies is six standard units (6 su), as established by Regulation No. 2, Regulation Establishing Water Quality Standards For Surface Waters Of The State Of Arkansas, October 26, 2007 (APCEC, 2007). This value was set forth to protect the early life stages of aquatic life. It is routinely exceeded at all of the sample locations within the watershed. Discharge from the mine pit lake as well as runoff and seepage from the spoil piles from the historical mining activities in the watershed are directly influencing the pH in the watershed.

Chlorides, Sulfates and Total Dissolved Solids

Minerals concentrations follow the same pattern as pH. Average background concentrations in Cove Creek upstream of Lucinda Creek and in Basin Creek generally range from 2.0 mg/L of chlorides, 5.0 mg/L of sulfates, and <40 mg/L of total dissolved solids (TDS) (Figure 4). Runoff and seepage from spoil piles entering Lucinda Creek increases average sulfate concentrations to near 40 mg/L and average TDS concentrations to near 55 mg/L. Average mineral concentrations in Chamberlain Creek just upstream of Cove are increased to near 26 mg/L of chlorides, 762 mg/L of sulfates, and 1,096 mg/L of TDS. This increases the average mineral concentrations in Cove Creek downstream of Chamberlain Creek almost ten fold; chlorides near 10 mg/L, sulfates near 200 mg/L, and TDS near 335 mg/L.

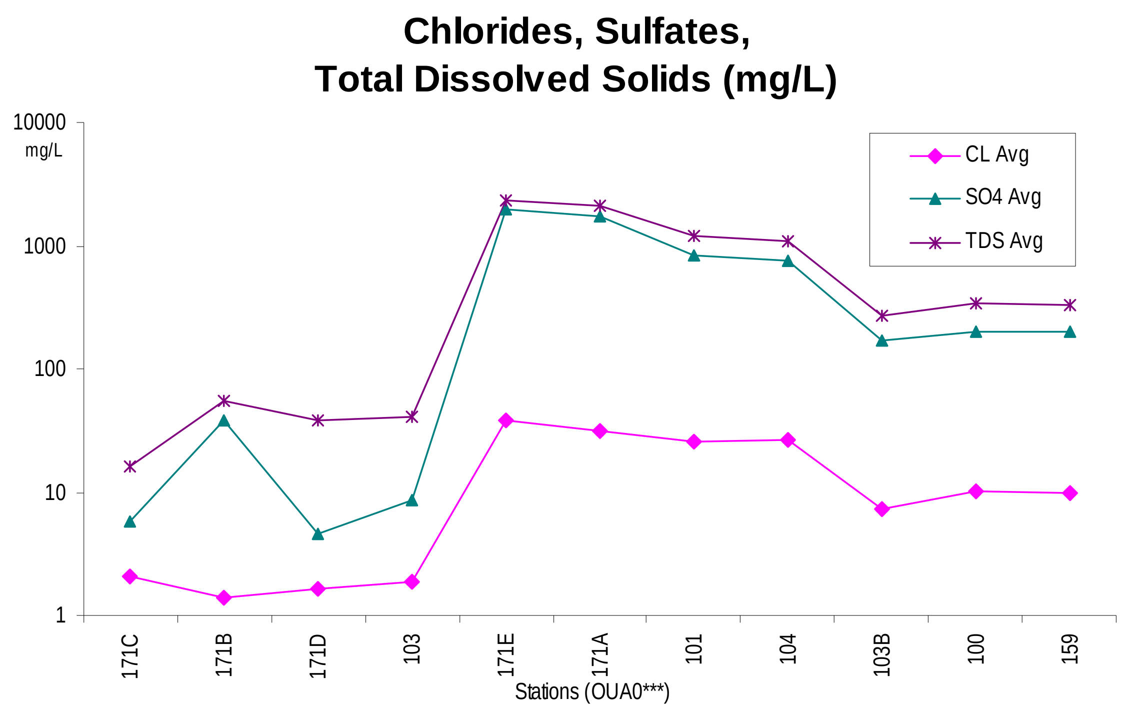

Figure 4. Average chloride, sulfate, and total dissolved solids (TDS) mg/L for Cove and Chamberlain Creek.

The water quality standards for chlorides, sulfates and total dissolved solids are 250/250/500 mg/L respectively (APCEC, 2007). The sulfate and TDS standards are routinely exceeded in Chamberlain Creek and in Cove Creek below the Chamberlain Creek confluence. Discharge from the mine pit lake is directly influencing these concentrations.

Total Hardness

Total hardness concentrations also follow the same pattern as the pH and the minerals. Average total hardness in Cove Creek upstream of Lucinda Creek and in Basin Creek is <20 mg/L. This is similar to Ouachita Mountains Ecoregion reference streams. One noticeable difference is that the total hardness of Lucinda Creek is slightly elevated, averaging near 25 mg/L. The maximum concentration of 132 mg/L occurred after a storm event. However, the average total hardness concentrations of Chamberlain Creek range from almost 1,200 mg/L at the discharge point, to 652 mg/L near its confluence with Cove Creek. The average total hardness concentration in Cove Creek increases from <25 mg/L upstream of Chamberlain Creek to near 200 mg/L downstream of the confluence (Figure 5).

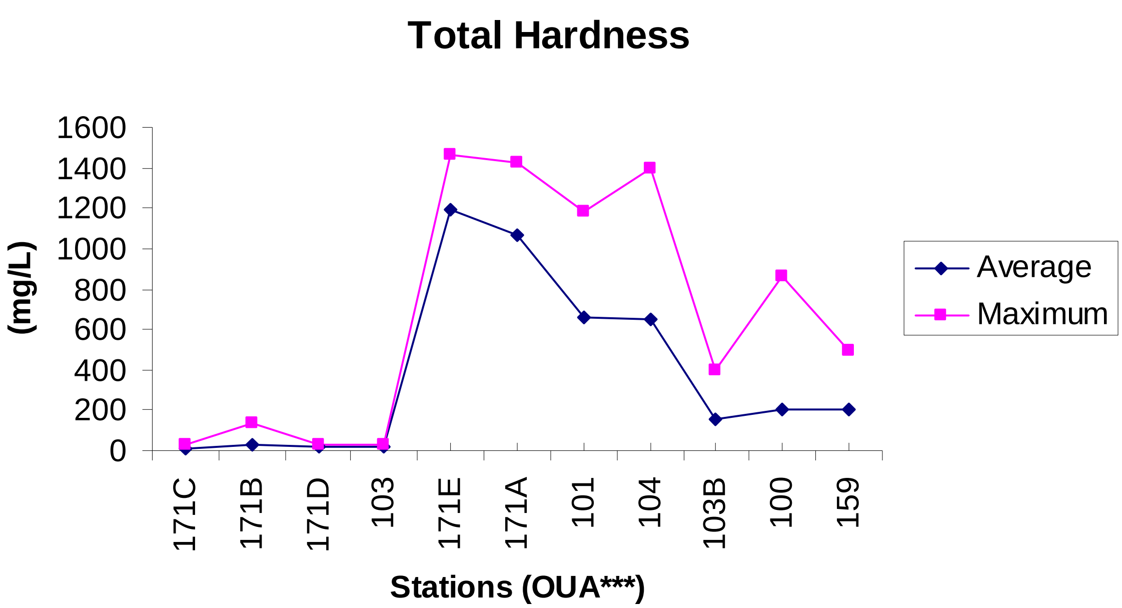

Figure 5. Maximum and mean total hardness (mg/L) values reported for nine sites from Cove and Chamberlain Creeks.

Dissolved Metals

Dissolved metals concentration patterns are very similar to the other water constituent patterns discussed earlier. The average aluminum concentration in Lucinda Creek was over 1,300 ug/L with maximum concentration 10,000 μg/L. The average aluminum concentration in Chamberlain Creek ranged from over 41,000 μg/L near the effluent to almost 5,400 μg/L near its mouth. Maximum aluminum concentrations ranged from almost 119,000 μg/L at the effluent to 16,500 μg/L near its mouth. Cove Creek downstream of Chamberlain Creek had an average and maximum aluminum concentration of almost 400 μg/L and 2,010 μg/L respectively. The average and maximum concentrations fall to near 27 μg/L and near 60 μg/L near the mouth of Cove Creek (Figure 6).

Beryllium and Cadmium concentrations also displayed this same pattern, but with much lower concentrations. However, concentrations of these constituents went from non-detect in Cove Creek upstream of Lucinda Creek and in Basin Creek, to detectable levels ranging from 0.14 µg/L in Cove Creek near its mouth, to <66 µg/L in Chamberlain Creek (Figure 6).

Concentrations of copper, manganese, and zinc in Cove Creek all increased from background average concentrations of <5 µg/L and maximum concentrations of <20 µg/L, to average concentrations near 4 µg/L for copper, 1,028 µg/L for manganese, and 51 µg/L of zinc and maximum concentrations of 5.19 µg/L for copper, 1,028 µg/L of manganese, and 51 µg/L of zinc Chamberlain Creek had average concentrations ranging from near 9.0 µg/L to 64 µg/L of copper, with a maximum of 130 µg/L; average concentrations of manganese of >5,600 µg/L to almost 27,000 µg/L, with a maximum of almost 77,000 µg/L; and average concentrations of zinc ranging from 167 µg/L to almost 676 µg/L with a maximum concentration of 1690 µg/L (Figure 7).

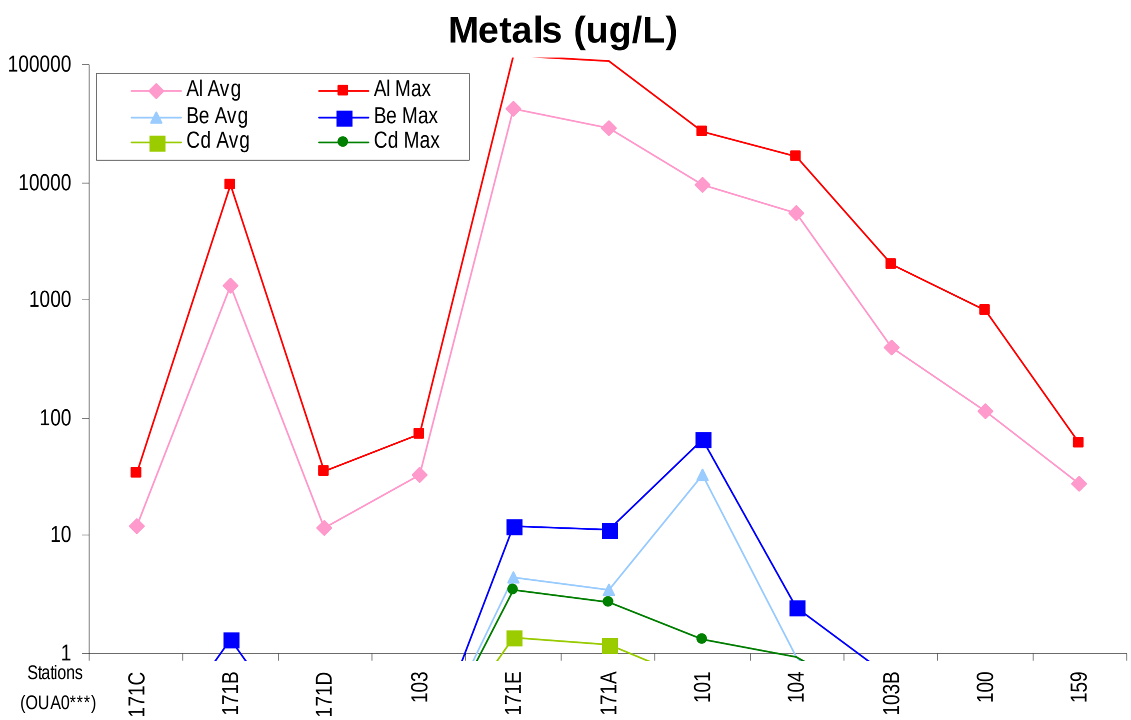

Figure 6. Mean and maximum aluminum (Al), beryllium (Be), and cadmium (Cd) (µg/L) concentrations.

Metals toxicity is directly dependant on instream hardness. As instream hardness values increase, metals toxicity decreases. Average instream hardness values in Chamberlain Creek below the discharge were near 1200 mg/L. Even at this extreme hardness value, the instream metals concentrations are at toxic levels throughout Chamberlain Creek and in Cove Creek below Chamberlain Creek. The discharge from the mine pit lake is directly influencing the metals concentrations in these waterbodies.

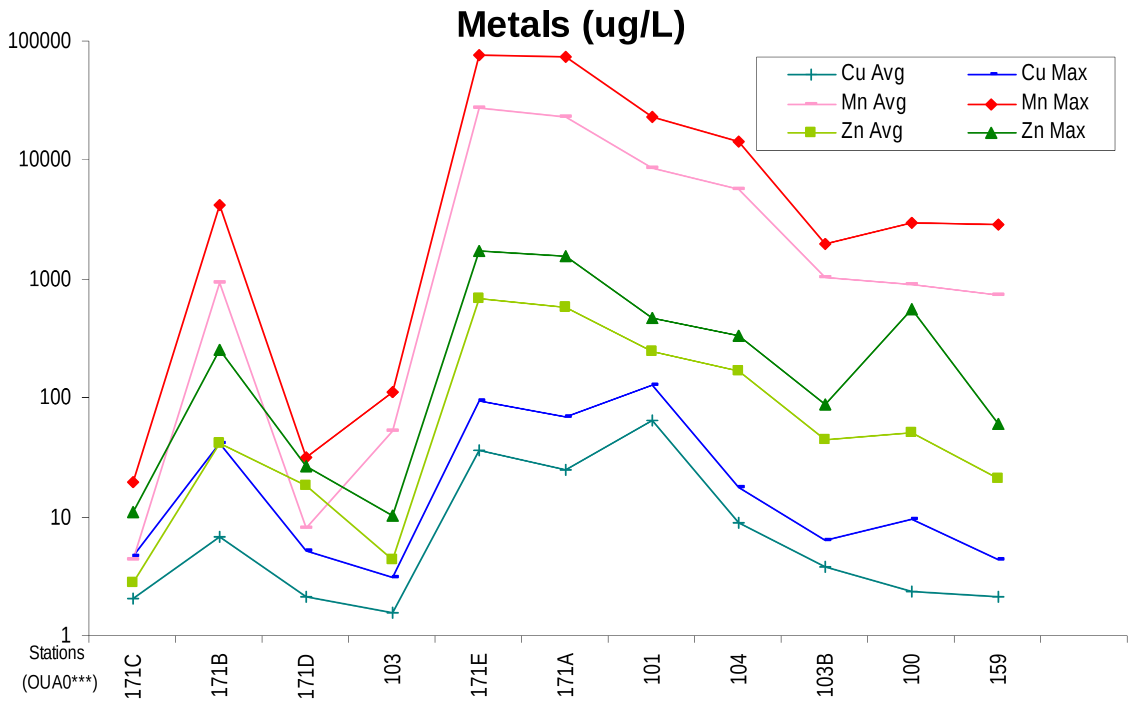

Figure 7. Copper (Cu), manganese (Mn), and zinc (Zn) (µg/L) average and maximum concentrations.

Discussion

The discharge from the mine pit lake into Chamberlain Creek, and the storm water runoff entering Lucinda Creek and Chamberlain Creek from the spoil piles of the historical mining activities are adversely impacting the water quality in the watershed. Extremely high concentrations of minerals and metals, and low pH values are common. As a result, pH, chlorides, sulfates, total dissolved solids, beryllium, cadmium, copper, and zinc concentration can not meet state water quality standards.

BIOLOGICAL CHARACTERISTICS

Benthic Macroinvertebrate Community

Instream and Riparian Habitat

Habitat among most study sites scored as suboptimal during the four sampling periods of fall 2007, spring 2008, fall 2008, and spring 2009. Spring 2008 and 2009 had more sites score as marginal than fall 2007 and 2008. Fall 2007 habitat scores ranged from 89 at OUA0104 to 181 at OUA0159; spring 2008 habitat scores ranged from 160 at sites OUA0101 and OUA0100 to 197 at OUA0103B. Minimum and maximum habitat scores for fall 2008 were 124 and 190 at sites OUA0104 and OUA0171D, respectively. Study site OUA0100 had the lowest observed habitat score for all sampling periods, with a value of 84 (Figures 8-11). Wetted width, depth, and canopy cover were comparable among all sites and all sampling periods.

Abundance and Taxa Richness

Nine sites were sampled during the four sampling periods of fall 2007, spring 2008, fall 2008, and spring 2009. Over the course of the four sampling periods, a total of 112 taxa (5,529 individuals) were collected. During the fall 2007 sampling period, 1,404 individuals were collected; ranging from 13 individuals at site OUA0103B to 282 individuals at OUA0103. Taxa richness in the fall 2007 sampling period ranged from 8 taxa at sites OUA0103B and OUA0104 to 22 taxa at OUA0171D (Figures 12 and 13).

Richness value ranges increased during the spring 2008 sampling period; 12 taxa were collected from site OUA0159 and 36 taxa collected from OUA0103. Spring 2008 abundance ranged from 30 individuals at OUA0171B to 303 individuals at OUA0171C, with a total of 1138 individuals collected. Abundance values for the fall 2008 sampling period increased from spring collections. A total of 1,626 individuals were collected, ranging from 10 to 337 individuals at sites OUA0103B and OUA0171B, respectively. Richness values decreased from the spring 2008 with a range of 8 to 27 taxa collected at OUA0104, OUA0103B, and OUA0103 (Figures 12 and 13).

Total abundance decreased in the spring of 2009 to 1361 individuals and a range of 11 to 318 individuals at sites OUA0103B and OUA0103. Taxa richness range also decreased to 4 taxa observed at OUA0104 and 28 taxa observed at OUA0103 (Figures 12 and 13).

Sites above Chamberlain Creek's confluence with Cove Creek (OUA0171C, OUA0171D, and OUA0103) had higher richness and abundance values than those of Chamberlain Creek (OUA0104 and OUA0101) and Cove Creek below the confluence (OUA0103B, OUA0100, and OUA0159). Upper Cove Creek had a mean richness and abundance of 20 taxa and 270 individuals during fall 2007; lower Cove Creek had a mean of 11 taxa and 58 individuals. Chamberlain Creek's mean richness and abundance values were 9 taxa and 80 individuals.

Spring 2008 mean taxa richness and abundance were 24 and 254 for upper Cove Creek, 11 and 89 for Chamberlain Creek, and 16 and 82 for lower Cove Creek. Fall 2008, upper Cove Creek mean richness and abundance dropped slightly to 22 taxa and

208 individuals, while Chamberlain Creek mean richness remained at 9 taxa; mean abundance increased to 289 individuals.

Mean spring 2009 values for upper Cove Creek were nearly unchanged from previous samples with 20 taxa and 286 individuals. Chamberlain and lower Cove Creeks had lower mean richness and abundance in the spring 2009 sample than in previous samples, with 4 and 8 taxa observed and a mean of 70 organisms at both (Figures 12 and 13).

Species Composition

When assessing the components of the Ephemeroptera, Plecoptera, Trichoptera (EPT) metrics, a water quality index based on the abundance of three highly sensitive orders of macroinvertebrates relative to hardy species, Trichoptera of the Hydropsychidae taxa were observed. Hydropsychidae taxa generally have a tolerance value of 7, which is higher than most other Trichoptera; therefore, Hydropsychidae were excluded from the EPT metrics to avoid misinterpretation of data.

Fall 2007 adjusted percent EPT ranged from 1.0% at study site OUA0159 to 71.6% at OUA0171B (Figure 14). Isopods and Chironomids were also prevalent at many sites, especially those with low EPT indices. Isopoda and Chironomidae percentages ranged from 0.0% at OUA0101 to 58.2% at OUA0103 and 5.2% at OUA0159 to 25.8% at OUA0171D, respectively. *Lirceus* (Isopoda: Asellidae) was the dominate taxa at 4 sites during the fall 2007 sampling period. *Perlomyia* (Plecoptera: Leuctridae), a sensitive taxon, was dominate at sites OUA0171B and OUA0104, comprising 66% and 62% of the communities, respectively. Other dominant taxa included *Optioservus* (Coleoptera: Elmidae) at OUA0100, Nemouridae (Plecoptera) at OUA0103, and *Gammarus* (Amphipoda: Gammaridae) at OUA0101

Spring 2008 collections had a slightly higher number of sensitive taxa; percent EPT ranged from 13.3% at OUA0171B to 57.8% at OUA0103B (Figure 14). Only one site, OUA0101, had Plecoptera as a dominate taxa, specifically *Neoperla* (Plecoptera: Perlidae). An increase from fall 2007 to spring 2008 occurred within the minimum percent Isopoda observed, 13.3% at OUA0171B; however, a decrease was observed for the maximum percent, 37.6% at OUA0171C. Chironomidae percentages ranged from 1.1% at study site OUA0103 to 20.0% at OUA0171B, which was a decrease from the previous sampling period. Fall 2008 Ephemeroptera, Plecoptera, and Trichoptera numbers once again decreased at four sites (OUA0100, OUA0101, OUA0103B, OUA0104), but increased at the remaining four sites (OUA0103, OUA0171B, OUA0171C, OUA0171D). The percent EPT ranged from 0.0% at OUA0104 to 75.1% at OUA0171B during this sampling period; *Perlomyia* was the dominate taxa at OUA0171B (Figure 14). Several taxa of previously low abundance in past samples became dominate in the fall of 2008, two of which are coleopterans, Dubiraphia and Stelnelmis (Coleoptera: Elmidae), followed by *Simulium* (Diptera: Simuliidae) and *Asellus* (Isopoda: Asellidae). Isopod numbers were greatly reduced within the fall 2008 collections as 5 of the 8 samples had less than 1.0% isopods (OUA0100, OUA0101, OUA0103B, OUA0104, and OUA0171B), while the remaining two sites (OUA0103 and OUA0171C) were comprised of 7.9% and 29.6% isopods, respectively. Chironomid percentages during fall 2008 increased drastically from the previous sample. Most fall samples had at least 10.0% of the community as chironomid; OUA0104 had the highest percentage (96.6%).

In spring 2009, percent EPT decreased 20%-30% from the first sample in fall of 2007. Percent EPT values for spring 2009 ranged from 0.0% at study site OUA0101 to 25.9% at OUA0171C (Figure 14). Seven of the nine sites sampled (78%) had communities comprised of greater than 50% chironomids, with a maximum of 92.0% at OUA0100 and a minimum of 21.9% at OUA0171D.

Tolerant and Intolerant Taxa

During the fall 2007 sampling period, study sites OUA0171B and OUA0104 were comprised of the highest percentage of intolerant taxa, 73% and 72% respectively. *Perlomyia*, a stonefly nymph, was the dominant taxa at both sites. Site OUA0171C had the lowest percentage of intolerant taxa, totaling 9%. Tolerant taxa dominated the communities of sites OUA0171C (54%), OUA0103 (63%), and OUA0159 (63%) (Figures 15 and 16).

In the spring of 2008, the highest percentage of intolerant taxa was observed at OUA0103B, comprising 60% of the community; the lowest percentage of intolerant taxa (13%) occurred at OUA0171B. Both sites also had the highest and lowest percentages of tolerant taxa, 10% at OUA0103B and 46% at OUA0171B. Intolerant taxa generally decreased among fall 2008 samples with the exception of sites OUA0171D, OUA0103B, and OUA0100, which increased to 26%, 40%, and 78%. Tolerant taxa increased at all but one site (OUA0171B) during the fall 2008 sampling period, with the largest fluctuation occurring at OUA0104, which increased from 39% to 88%.

Spring 2009 intolerant taxa decreased drastically from the previous sample, 78% of the sites had less than 20% intolerant taxa communities. The maximum percentage of intolerant taxa occurred at site OUA0159 totaling 27%. Tolerant taxa increased among all sites in the spring of 2009 with a maximum of 92% at OUA0100 and a minimum of 55% at OUA0159 (Figures 15 and 16).

Hilsenhoff Biotic Index

The HBI was used to determine if organic nutrient loading was affecting D.O. concentrations and ultimately macroinvertebrate communities (Hilsenhoff 1977, 1982, 1987). Hilsenhoff Biotic Index values for the fall 2007 sampling period ranged from excellent or no impairment (2.0) at study site OUA0171B to fair or fairly significant impairment (6.3) at OUA0159 (Figure 14). Spring 2008 HBI values showed lower variability with no apparent degradation at OUA103B (3.3) to only some perturbation at OUA0171C (5.2). Loading increased slightly at two sites, OUA0101 and OUA0104, with values of 6.6 and 6.9, respectively. Spring 2009 HBI values indicated fairly significant organic loading with a range of values from 5.1 at OUA0103 to 6.8 at OUA0101 (Figure 17).

Discussion

The results of this study indicate that the macroinvertebrate communities of Chamberlain Creek and Cove Creek, below its confluence with Chamberlain Creek, are affected by acid mine drainage (AMD). Acid mine drainage, in conjunction with low pH, has been well documented to negatively effect macroinvertebrate communities (Hariman and Morrison 1982, Simpson et al. 1985, Ormerod et al 1987., Winterbourn and Collier 1987, Rosemond 1992, Stoertz et al. 2002). Macroinvertebrate richness, abundance, and EPT composition within and below Chamberlain Creek were lower than that of upstream communities.

Comparison of habitat quality among study sites indicate that OUA0101 and OUA0104 were generally of lower habitat quality, but never ranked below marginal. The remaining sites ranked optimal to suboptimal, except in the spring of 2009. Sufficient similarities exist among habitat for the assumption that spatial variability is not a factor influencing macroinvertebrate communities. Therefore, if AMD were not present, similar macroinvertebrate communities would be expected among all sample sites.

Data collected from this study indicate that organic pollution is occurring, as evident by the decreased percent EPT, increased Chironomidae abundance, and increased HBI values among all sites and sampling periods. Increased organic loading ultimately leads to decreased dissolved oxygen levels. Combining this scenario with low pH and AMD could result in a severely impacted macroinvertebrate community, as is evident in Chamberlain Creek.

Fall 2007 Instream/Riparian Habitat

Station ID		ES	EM	VE/PV	SD	CF	CA	RF	LBS	RBS	LRV	RRV	TS	
Basin Cr	OUA0171D	18	17	9	14	15	19	8	20	20	15	10	**165**	**Suboptimal**
Cove Creek	OUA0171C	15	16	13	16	11	19	6	13	12	16	19	**156**	**Suboptimal**
Lucinda Cr	OUA0171B	14	13	7	12	9	19	8	12	14	2	14	**124**	**Suboptimal**
Cove Creek	OUA0103	18	13	12	12	9	15	10	19	19	14	20	**161**	**Suboptimal**
Chamberlain Creek	OUA0101	8	13	9	2	10	15	18	16	18	2	20	**131**	**Suboptimal**
Chamberlain Creek	OUA0104	6	6	8	10	8	17	16	6	5	5	2	**89**	**Marginal**
Cove Creek	OUA0103B	12	12	17	6	19	20	4	19	17	20	4	**150**	**Suboptimal**
Cove Creek	OUA0100	15	12	14	9	19	14	17	14	14	19	13	**160**	**Suboptimal**
Cove Creek	OUA0159	18	17	19	10	13	15	17	18	16	19	19	**181**	**Optimal**

Figure 8. Instream and riparian corridor habitat evaluation from fall 2007.

Spring 2008 Instream/Riparian Habitat

Station ID		ES	EM	VE/PV	SD	CF	CA	RF	LBS	RBS	LRV	RRV	TS	
Basin Cr	OUA0171D	16	18	19	19	19	19	16	17	17	13	9	**182**	**Optimal**
Cove Creek	OUA0171C	15	19	14	17	19	19	18	12	13	18	19	**183**	**Optimal**
Lucinda Cr	OUA0171B	11	17	14	18	19	14	18	14	14	15	15	**169**	**Optimal**
Cove Creek	OUA0103	16	18	18	15	18	18	16	19	15	15	20	**188**	**Optimal**
Chamberlain Creek	OUA0101	15	15	14	15	17	17	18	12	18	3	16	**160**	**Suboptimal**
Chamberlain Creek	OUA0104	15	16	15	18	16	16	16	11	16	10	20	**169**	**Optimal**
Cove Creek	OUA0103B	16	17	19	18	19	20	17	18	18	15	20	**197**	**Optimal**
Cove Creek	OUA0100	18	18	20	19	17	18	17	18	18	18	13	**194**	**Optimal**
Cove Creek	OUA0159	19	17	20	18	19	18	17	18	16	19	3	**184**	**Optimal**

Figure 9. Instream and riparian corridor habitat evaluation from spring 2008.

Fall 2008 Instream/Riparian Habitat

Station ID		ES	EM	VE/PV	SD	CF	CA	RF	LBS	RBS	LRV	RRV	TS	
Basin Cr	OUA0171D	19	19	19	19	13	19	18	20	20	20	4	**190**	**Optimal**
Cove Creek	OUA0171C	14	13	9	15	15	15	10	11	16	17	19	**154**	**Suboptimal**
Lucinda Cr	OUA0171B	18	19	10	19	7	15	12	16	17	8	13	**154**	**Suboptimal**
Cove Creek	OUA0103	14	14	15	7	14	16	13	17	10	6	16	**142**	**Suboptimal**
Chamberlain Creek	OUA0101	5	8	8	12	13	18	6	18	19	3	20	**130**	**Suboptimal**
Chamberlain Creek	OUA0104	13	8	8	1	6	18	13	15	16	6	20	**124**	**Suboptimal**
Cove Creek	OUA0103B	19	12	13	12	15	20	6	20	20	20	7	**164**	**Suboptimal**
Cove Creek	OUA0100	18	19	9	18	16	16	12	19	19	20	2	**168**	**Optimal**
Cove Creek	OUA0159	17	17	16	18	18	15	17	19	19	20	1	**177**	**Optimal**

Figure 10. Instream and riparian corridor habitat evaluation from fall 2008.

Spring 2009 Instream/Riparian Habitat

Station ID		ES	EM	VE/PV	SD	CF	CA	RF	LBS	RBS	LRV	RRV	TS	
Basin Cr	OUA0171D	16	19	8	19	19	16	15	10	10	2	7	**141**	**Suboptimal**
Cove Creek	OUA0171C	15	19	8	19	18	15	10	5	6	7	10	**132**	**Suboptimal**
Lucinda Cr	OUA0171B	9	8	7	13	17	15	12	8	9	3	5	**106**	**Marginal**
Cove Creek	OUA0103	5	4	10	8	11	15	15	8	8	9	2	**95**	**Marginal**
Chamberlain Creek	OUA0101	15	17	11	10	18	15	18	9	10	2	9	**134**	**Suboptimal**
Chamberlain Creek	OUA0104	6	6	8	10	8	17	16	6	5	5	2	**89**	**Marginal**
Cove Creek	OUA0103B	7	5	11	6	10	16	17	6	6	2	9	**95**	**Marginal**
Cove Creek	OUA0100	6	7	7	10	11	11	11	6	6	2	7	**84**	**Marginal**
Cove Creek	OUA0159	8	14	11	14	15	13	17	8	9	2	10	**121**	**Suboptimal**

Figure 11. Instream and riparian corridor habitat evaluation from spring 2009.

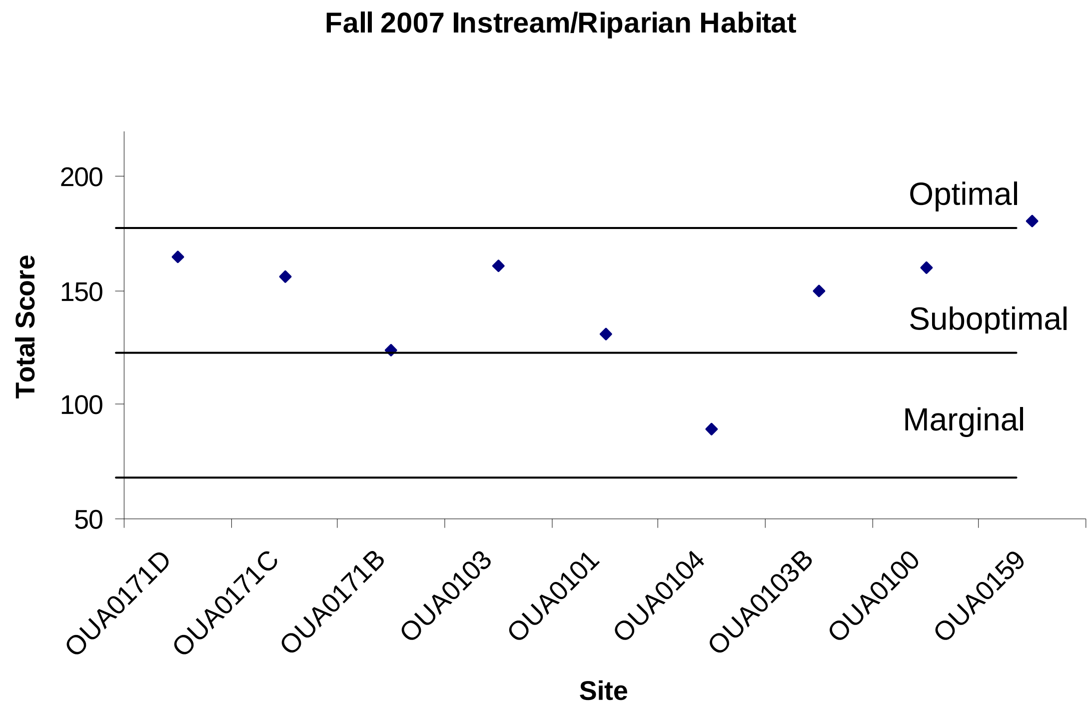

Figure 12. Instream and riparian corridor habitat assessment values for fall 2007 Cove and Chamberlain Creeks.

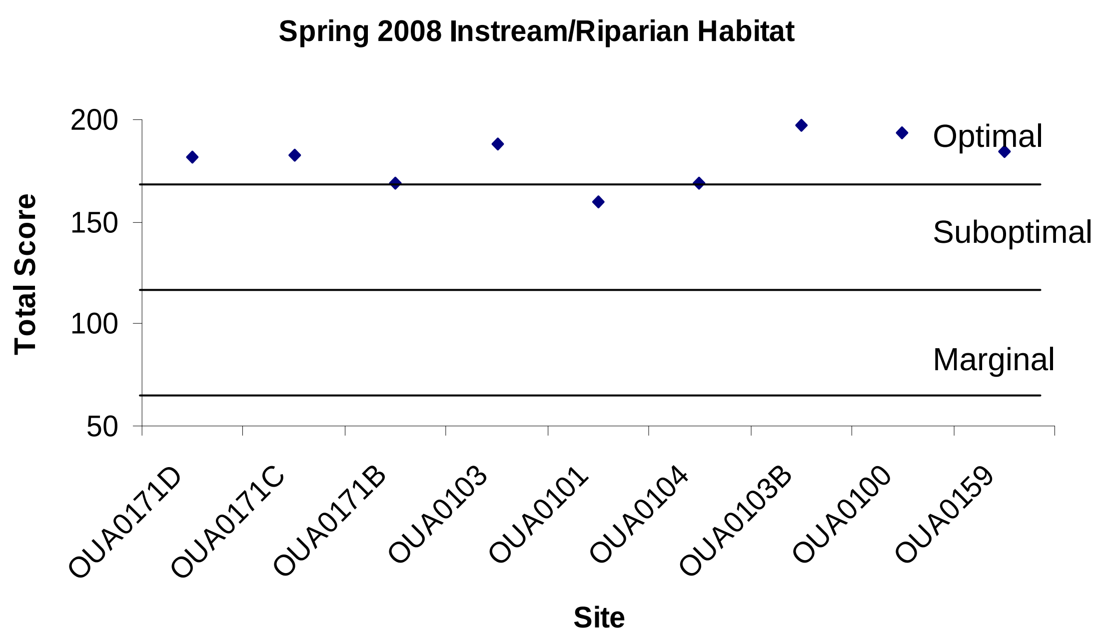

Figure 13. Instream and riparian corridor habitat assessment values for spring 2008 Cove and Chamberlain Creeks.

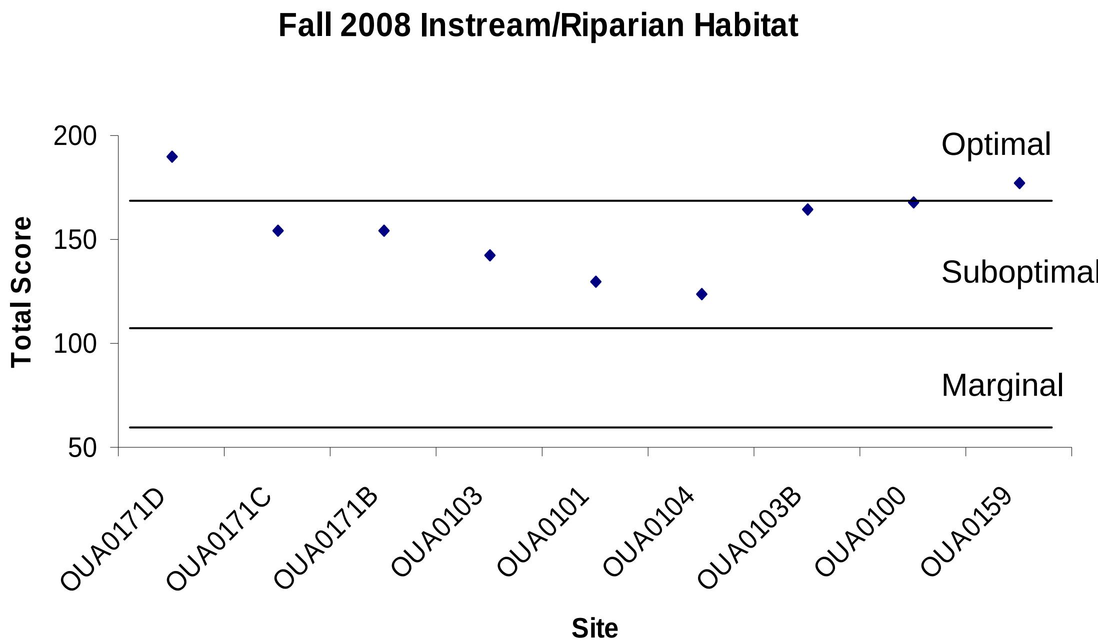

Figure 14. Instream and riparian corridor habitat assessment values for fall 2008 Cove and Chamberlain Creeks.

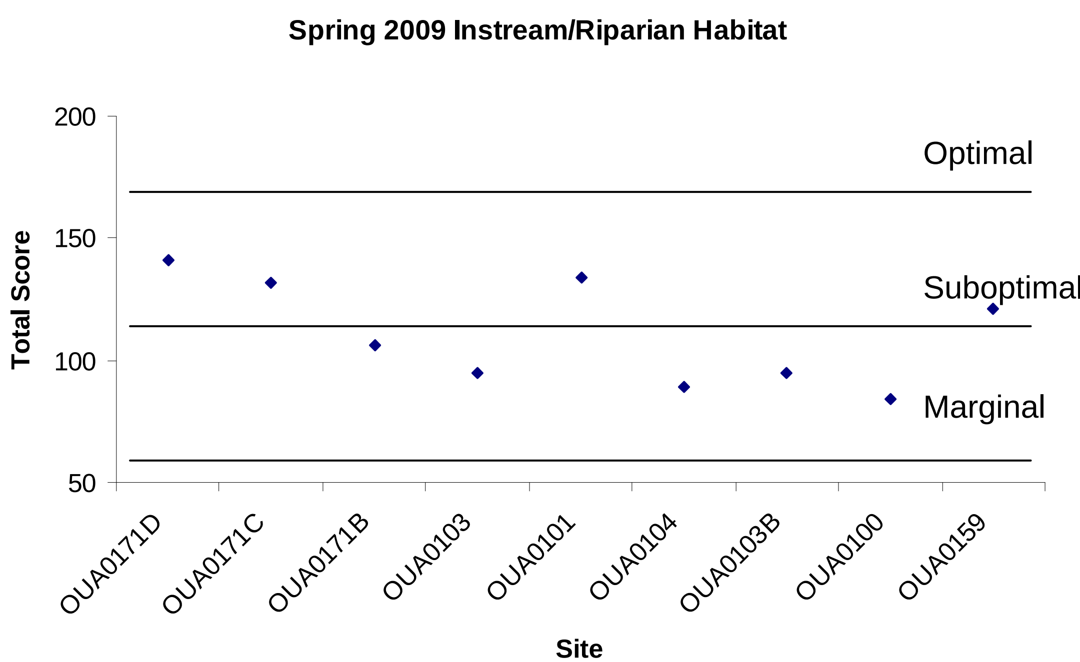

Figure 15. Instream and riparian corridor habitat assessment values for spring 2009 Cove and Chamberlain Creeks.

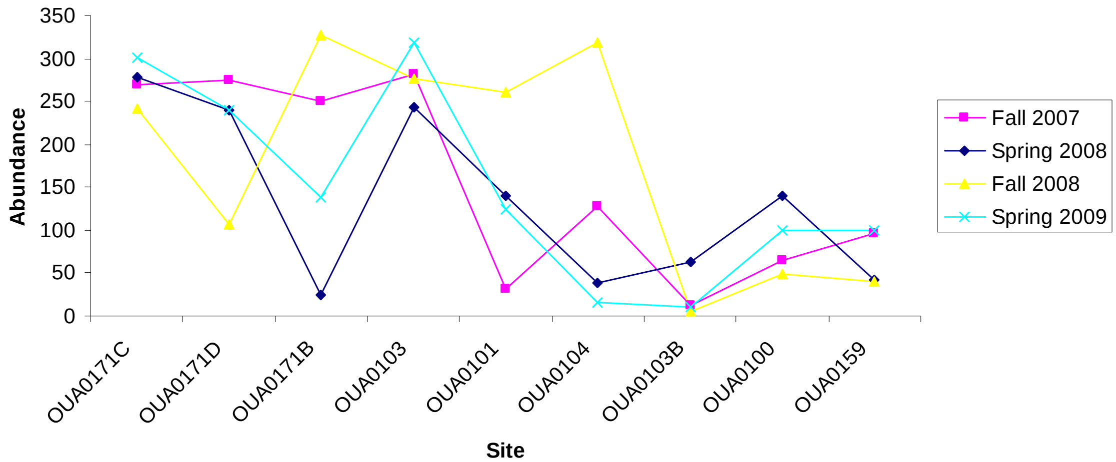

Figure 16. Benthic macroinvertebrate abundance values for four sampling periods collected from nine Cove and Chamberlain Creek sites.

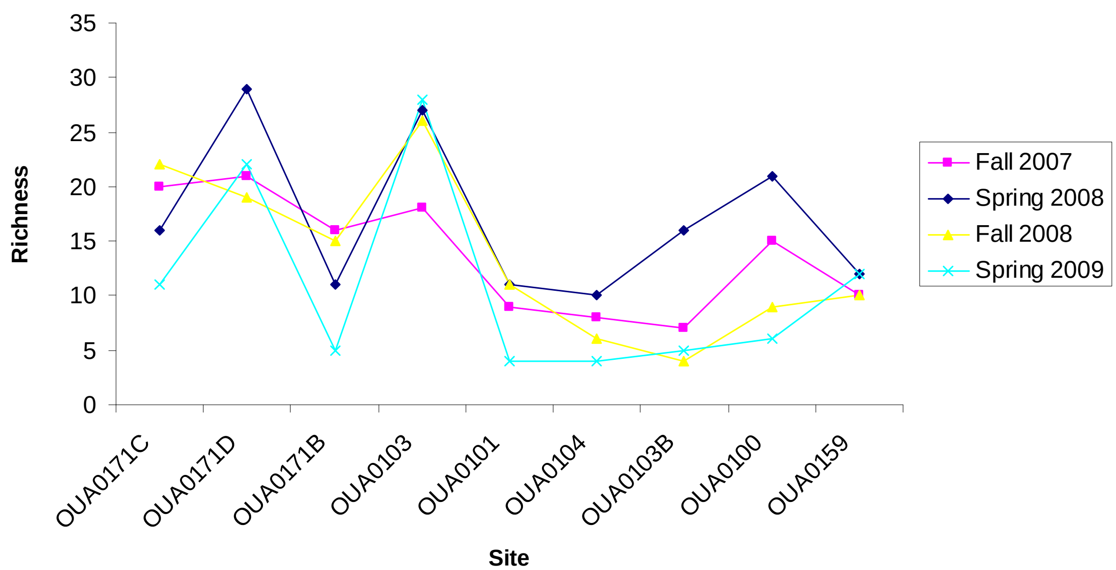

Figure 17. Benthic macroinvertebrate richness values for four sampling periods collected from nine Cove and Chamberlain Creek sites.

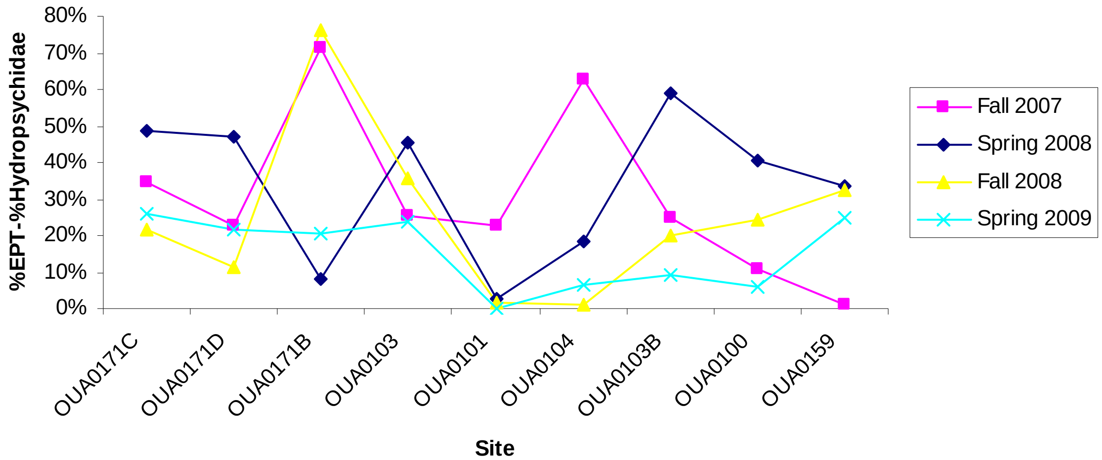

Figure 18. Percent Ephemeroptera, Plecoptera, Trichoptera (excluding Hydropsychidae) for four sampling periods from nine Cove and Chamberlain Creek sites.

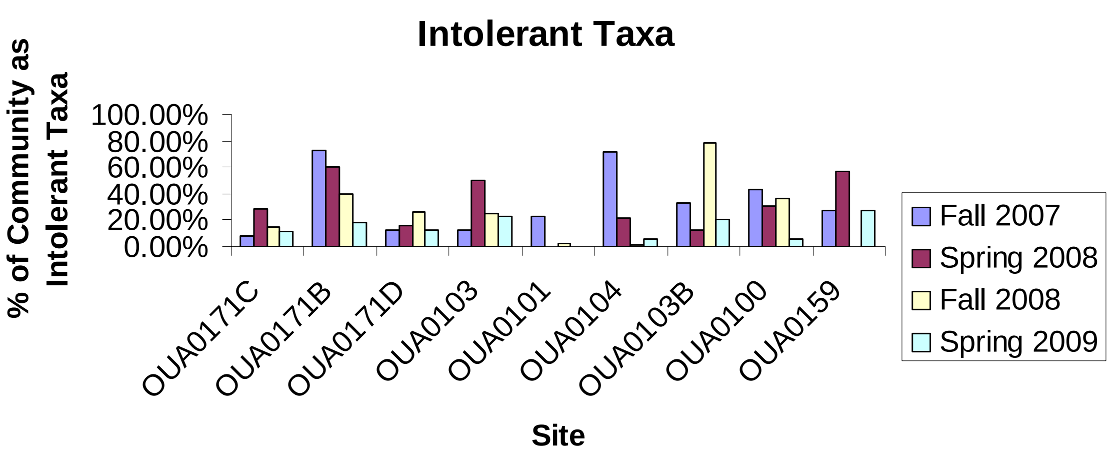

Figure 19. Percent of intolerant macroinvertebrate taxa (0-5) values for four sampling periods collected from nine Cove and Chamberlain Creek sites.

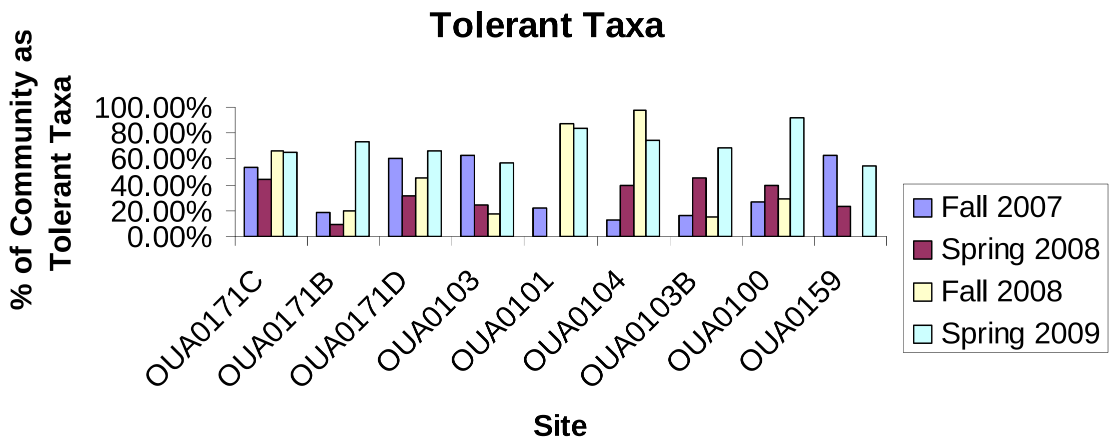

Figure 20. Percent of tolerant macroinvertebrate taxa (6-10) values for four sampling periods collected from nine Cove and Chamberlain Creek sites.

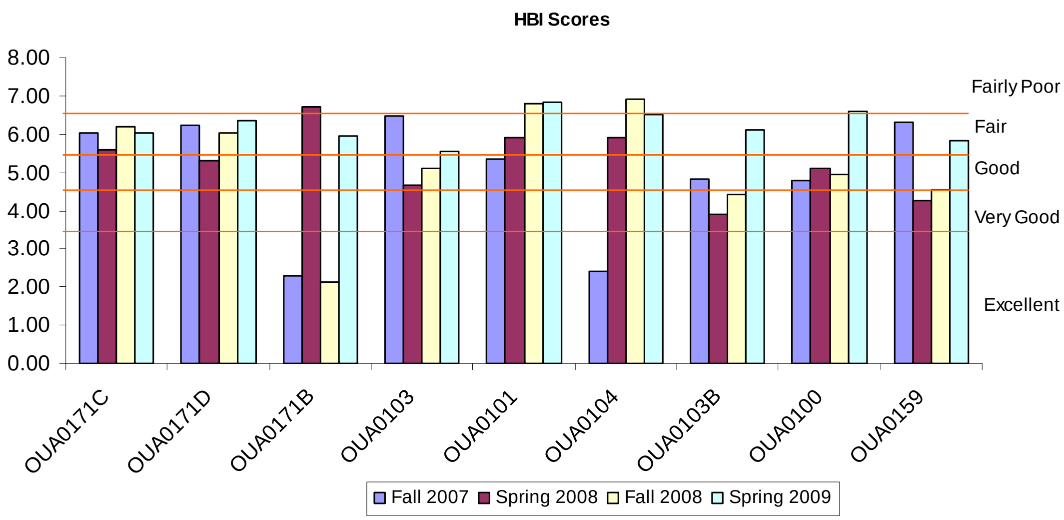

Figure 21. Hilsenhoff Biotic Index values for four sampling periods for Cove and Chamberlain Creeks with impairment ranging from no apparent organic degradation and excellent condition (0-3.5) to significant organic pollution and fairly poor condition (6.51-7.5).

Fish Community

Taxa Richness and Abundance

A total of 25 taxa and 2,500 individuals were collected during the two sampling periods of summer 2007 and 2008. Taxa richness was highest at OUA0159 and OUA0171D during 2007 sampling with 16 and 15 taxa, respectively. The lowest richness and abundance were collected at OUA0104 and OUA0171B during 2007, with only one taxon collected at OUA0104 and two taxa at OUA0171B. Sampling during 2008 resulted in higher taxa richness at OUA0171D, OUA0103, and Tigre Creek with a total of 18, 17, and 17 taxa being collected, respectively (Tables 4 and 5).

Species Composition

Species composition from the 2007 and 2008 sample periods were primarily comprised of cyprinids (minnows), percids (darters), and centrachids (sunfish). During 2007, cyprinids and centrachids each comprised 43% of the fish communities (Tables 4 and 5). The highest percentage of the community composed of cyprinids occurred at OUA0159 with 62.8%, of which 55.8% were central stonerollers (*Campostoma anomalum*). In 2008, cyprinids dominated the communities of all sites with 52.9% as the lowest percentage of the community observed and 68.9% being the highest. Of the cyprinids observed in 2008, creek chubs (*Semotilus atromaculatus*) and central stonerollers were the most abundant.

Community Structure Index (CSI)

Community Structure Index values indicate that streams in the Cove and Chamberlain Creek watersheds ranged from Not Similar to Highly Similar in 2007 and Fairly Similar to Highly Similar in 2008 (Tables 6 and 7). Sites OUA0171B and OUA0104 had the lowest CSI scores due the lack of fish communities. Community Structure Index values above the Chamberlain and Cove Creek confluence in 2007 were Generally Similar and Highly Similar, while Chamberlain Creek (OUA0104) CSI was Not Similar. Lucinda Creek (OUA0171B) which is above the confluence of Cove and Chamberlain Creek, but impacted by mining spoil, was also Not Similar (Figures 22-27).

In 2007 the sites on Cove Creek downstream of the Chamberlain Creek confluence all had CSI values of Fairly Similar. Community Structure Index values for 2008 were again highest above the Cove and Chamberlain Creek confluence with OUA0171D as Generally Similar and OUA0103B as Highly Similar. Sites immediately below the confluence, OUA0100 and OUA0103, again scored the lowest of the sampled sites as being Fairly Similar. The furthermost downstream site OUA0159 improved to Generally Similar in 2008 from Fairly Similar in 2007. Tigre Creek was sampled once in 2008 in an attempt to collect unimpaired reference data. Community Structure Index values for Tigre Creek suggest that it is Generally Similar to Ouachita Mountain ecoregion streams (Tables 6 and 7).

Discussion

The results of the study indicate that fish communities at two sites within Chamberlain and Lucinda Creeks are severely impacted by past mining and milling activities. Sites most impacted were OUA0104 (Chamberlain Creek) and OUA0171B (Lucinda Creek), due to AMD from mine pit lake effluent and large, widespread piles of mine spoil. Although the CSI values of these two sites were heavily impaired and considered Not Similar to Ouachita Mountain ecoregion streams, the remaining sites sampled over the two year period ranged from Fairly Similar to Highly Similar. Sites that were Highly Similar were above the Cove-Chamberlain Creek confluence; while the three sites below the confluence in 2007 were all Fairly Similar to ecoregion reference streams. In 2008 only one site remained Fairly Similar with the lowest two sites improving to Generally Similar. The 2008 results suggest that the distance is great enough to allow fish communities of the lower two sites, OUA0100 and OUA0159, to begin to recover. Tigre Creek, an adjacent watershed without AMD, sampled as an unaltered reference stream, had similar community composition to that of upper Cove Creek. Therefore, portions of Cove Creek above Chamberlain Creek are intact and have sustainable fish communities.

Results of this study indicated higher CSI values than the 2002 ADEQ study where fish communities were sampled at three locations: above Chamberlain Creek, below Chamberlain Creek, and OUA0159. Reported CSI values for the 2002 study indicated that Cove Creek sites were Not Similar to Fairly Similar (values 8-10) to ecoregion reference streams (ADEQ unpublished data). This study was preformed prior to the 2003 pump system installation that allows for pH adjustment. The current study indicated similar richness and abundance among the 2007 and 2002 study, but increased richness in 2008. The results of this study also observed comparable numbers of sensitive individuals and number of sensitive taxa between the current study and the 2002 study. It is possible that data from the 2007 sampling period may also have been skewed due to the high conductivity and its effect on the efficiency of the backpack electrofishing unit.

Low CSI values at OUA0104 and OUA0171B can be explained in part by low pH, which was recorded as low as 3.65 at OUA0104; however, lower pH values were recorded at sites were fish communities were not sampled. Fish community loss has been reported to occur when pH falls below 5.5 (Appleberg et al. 1993). Acid mine drainage and stream acidification have been documented to negatively impact Index of Biotic Integrity (IBI), more specifically the taxa richness and abundance of fish communities (Baldigo and Lawrence 2000, Stoertz et al. 2002). In isolated areas, fish communities are susceptible to stream acidification due to harmful effects on osmotic regulation and increased metal solubility (most notably aluminum), but populations have been documented to emigrate from acidified waters (Muniz and Leivestad 1980a,b, Rosseland 1980, Staurnes et al. 1984, Neville 1985, Mason 1989, Norrgren et al. 1991). However, due to the seasonal dryness of streams within the Ouachita Mountain ecoregion, fish populations within Cove and Chamberlain Creeks affected by AMD may be unable to escape during periods of low flow, ultimately exacerbating an already severe problem. The high metal concentrations in combination with low pH values are likely causes for decreased fish community abundance and richness and ultimately low CSI scores within Chamberlain Creek and lower portions of Cove and Lucinda Creeks.

Table 5. Fish community structure index metrics for Cove and Chamberlain Creeks during summer 2007 sampling period.

	2007 Sample Sites						
Parameter	OUA0171C	OUA0171D	OUA0171B	OUA0104	OUA0103B	OUA0100	OUA0159
No. Sens. Taxa	2	3	0	0	1	3	7
No. Sens. Inds.	102	33	0	0	1	19	32
% Sens. Taxa	46.8	21.7	0	0	6.7	22.6	18.6
% Cyprinidae	51.8	46.7	0	0	6.7	30.9	62.8
% Catostomidae	0.5	1.9	0	0	0	4.8	1.2
% Ictaluridae	0	1.3	0	100	53.3	4.8	2.9
% Centrarchidae	0	19.7	100	0	33.3	34.5	19.8
% Percidae	46.8	19.7	0	0	0	2.4	11.1
No. Primary Inds.	78	19	0	0	0	7	96
% Primary Inds.	35.8	12.5	0	0	0	8.3	55.8
No. Key Inds.	34	48	0	0	3	28	36
% Key Inds.	15.6	31.6	0	0	20	33.3	20.9
Total No. Taxa	7	15	2	1	5	12	16
Total No. Inds.	218	152	5	2	15	84	172
Diversity Index	2.06	3.3	0	0	1.9	3	2.4
Catch/Unit Effort	5.8	0.2	8.5	0.2	0.2	2.4	3.7

Table 6. Fish community structure index metrics for Cove and Chamberlain Creeks during summer 2008 sampling period.

	2008 Sample Sites					
Parameter	OUA0171D	OUA0103	OUA0103B	OUA0100	OUA0159	TIGRE CREEK
No. Sens. Taxa	6	5	2	3	5	6
No. Sens. Inds.	73	113	10	11	90	83
% Sens. Taxa	24.4	24.3	7.4	10.6	20.6	20.2
% Cyprinidae	60.9	59.1	55.6	52.9	56.2	68.9
% Catostomidae	1.7	2.2	1.5	0	0	0.9
% Ictaluridae	2.7	1.5	5.9	2.9	2.29	2.7
% Centrarchidae	12.7	17	29.6	33.7	24.3	11.9
% Percidae	18.4	16.1	1.5	9.6	12.4	14.1
No. Primary Inds.	20	217	25	23	185	242
% Primary Inds.	6.7	46.7	18.5	22.1	42.4	58.9
No. Key Inds.	87	138	37	32	130	99
% Key Inds.	29.1	29.7	27.4	30.8	29.8	24.1
Total No. Taxa	18	17	8	10	14	17
Total No. Inds.	299	465	135	104	436	411
Diversity Index	2.8	2.8	2.3	2.4	2.9	2.5
Catch/Unit Effort	6.7	10.3	3.5	2.5	7.3	9.8

Table 7. Fish Community Structure Index (CSI) for the summer 2008 on Cove and Chamberlain Creeks.

	2007 Sample Sites						
Parameter	OUA0171C	OUA0171D	OUA0171B	OUA0104	OUA0103B	OUA0100	OUA0159
% Cyprinidae	4	4	0	0	0	0	2
% Ictaluridae	0	4	0	0	0	0	0
% Centrarchidae	0	0	0	0	0	0	4
% Percidae	4	4	0	0	0	0	2
% Sens. Taxa	4	2	0	0	0	2	2
% Primary Inds.	4	4	0	0	0	4	2
% Key Inds.	2	4	0	0	2	4	2
Diversity Index	0	4	0	0	0	4	2
Total Score	18	26	0	0	2	14	16
Degree of Similarity	GS	HS	NS	NS	FS	FS	FS

Table 8. Fish Community Structure Index (CSI) for the summer 2008 on Cove and Chamberlain Creeks.

	2008 Sample Sites					
Parameter	OUA0171D	OUA0103	OUA0103B	OUA0100	OUA0159	TIGRE CREEK
% Cyprinidae	0	4	4	4	4	0
% Ictaluridae	0	4	0	0	0	4
% Centrarchidae	4	0	2	0	4	4
% Percidae	4	4	0	2	2	4
% Sens. Taxa	4	4	0	0	2	2
% Primary Inds.	4	4	4	4	4	4
% Key Inds.	4	4	4	4	4	4
Diversity Index	4	4	2	2	4	2
Total Score	24	28	16	16	24	20
Degree of Similarity	GS	HS	FS	FS	GS	GS

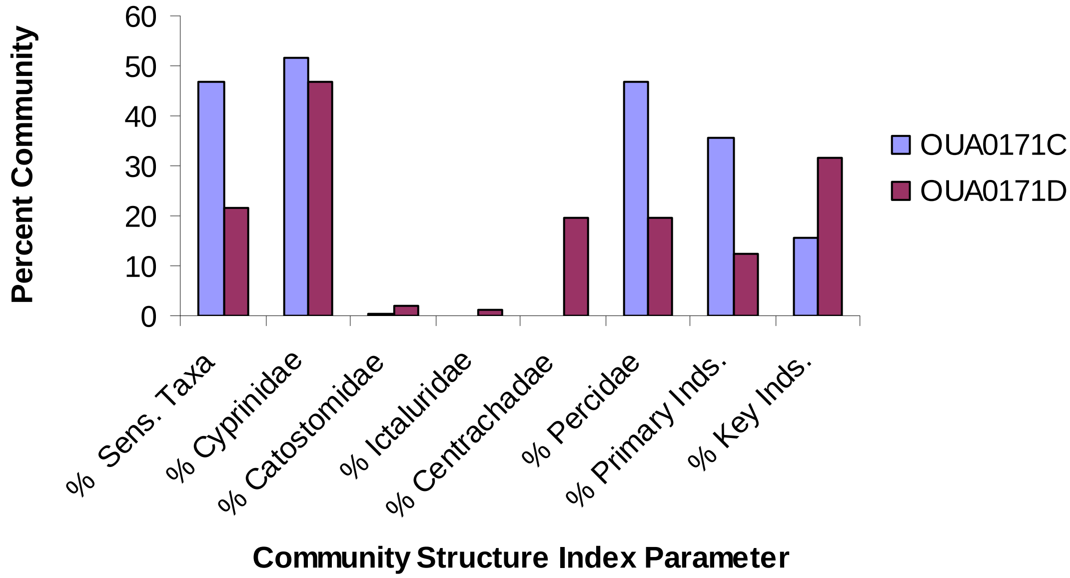

Figure 22. Fish Community Structure Index parameters for 2007 sites sampled above the Chamberlain confluence.

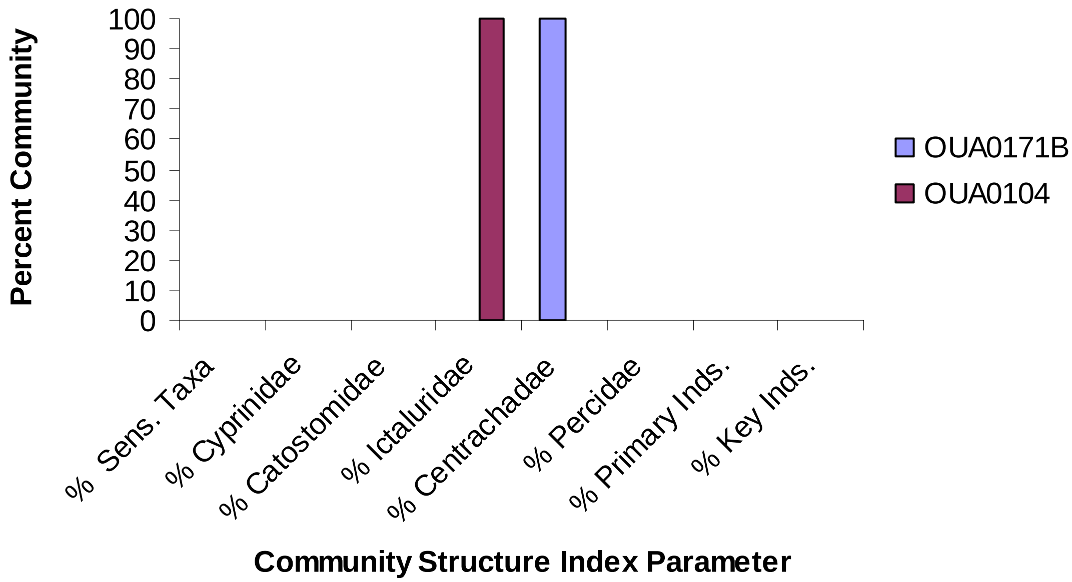

Figure 23. Fish Community Structure Index parameters for 2007 sites sampled within Chamberlain confluence.

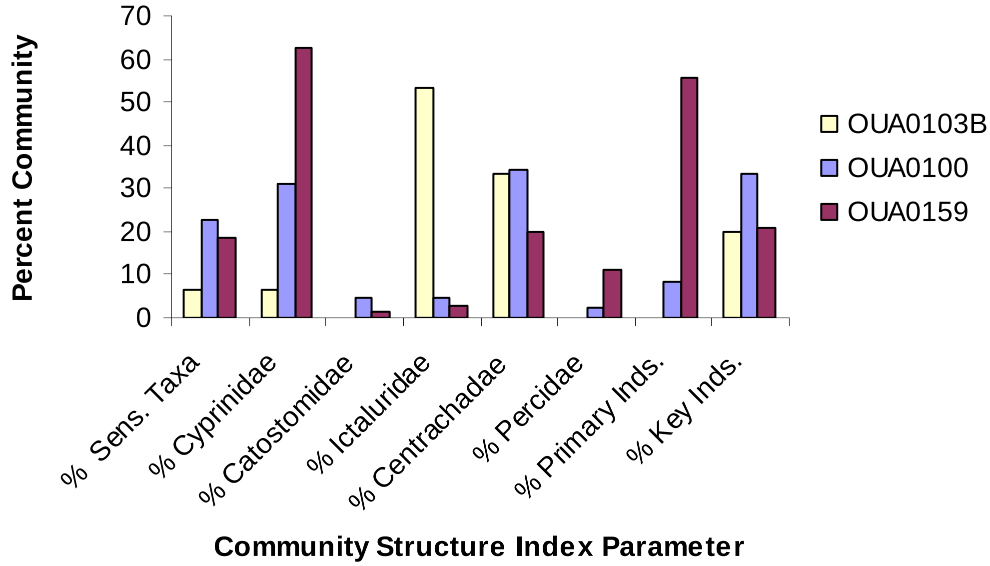

Figure 24. Fish Community Structure Index parameters for 2007 sites sampled below the Chamberlain confluence.

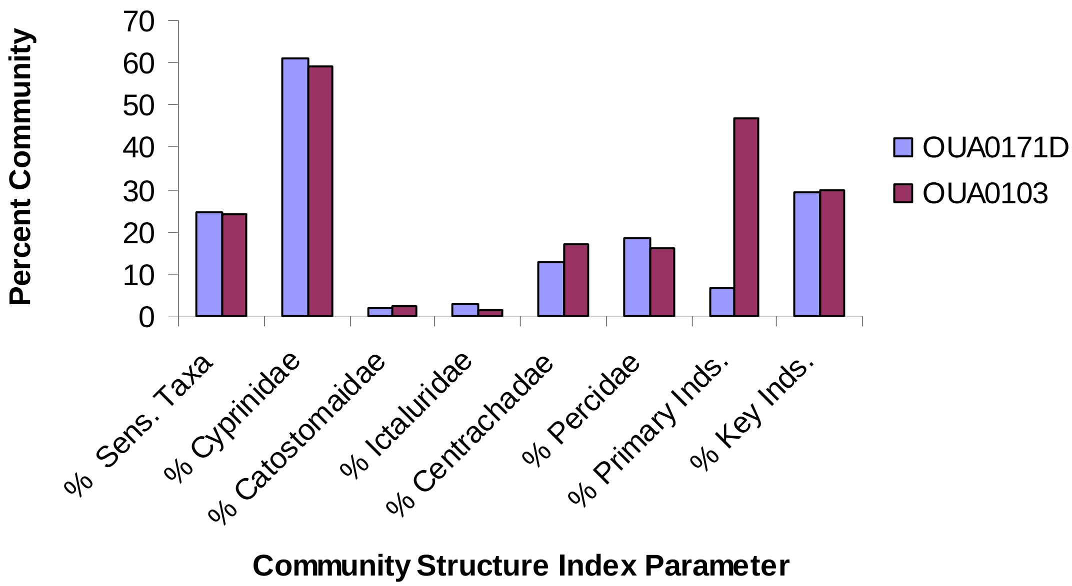

Figure 25. Fish Community Structure Index parameters for 2008 sites sampled above the Chamberlain confluence.

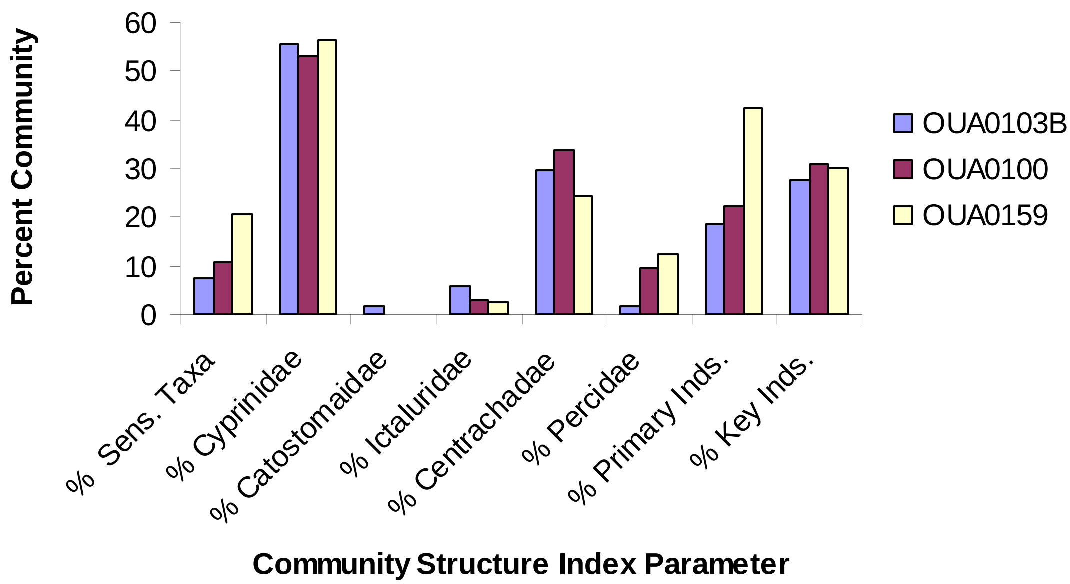

Figure 26. Fish Community Structure Index parameters for 2008 sites sampled below the Chamberlain confluence.

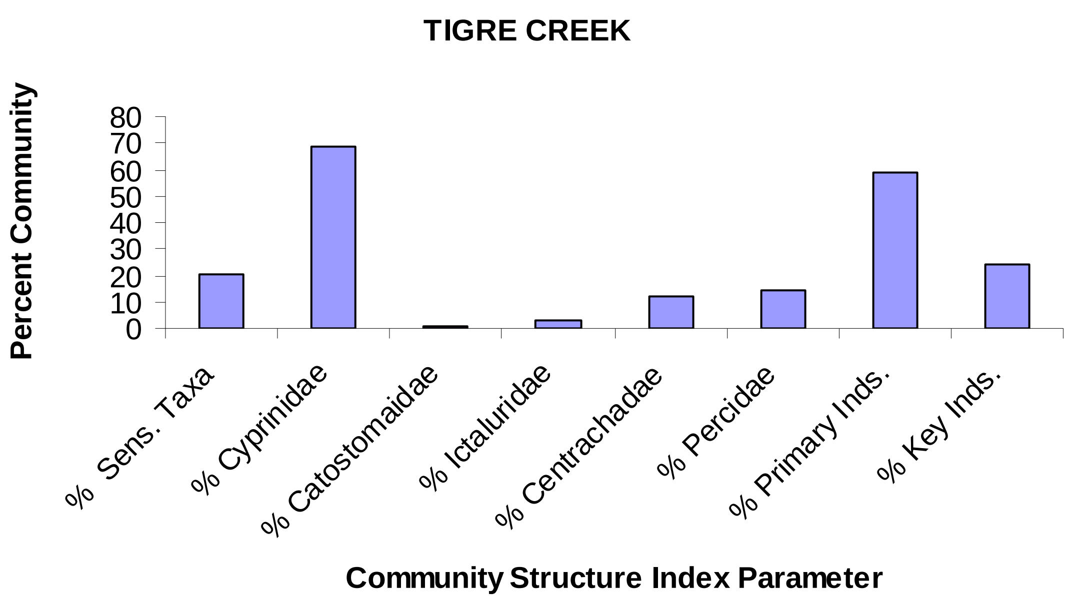

Figure 27. Fish Community Structure Index parameters for Tigre Creek.

Toxicity Testing

Water samples collected from Chamberlain Creek (OUA0104) showed very low survival for both *P. promelas* and *C. dubia*. Eleven of the fourteen toxicity tests for each test taxa exhibited 0% survival (100% mortality). Maximum survival was 35% for each taxa. Assuming that ≥80% survival suggests no acute toxicity, toxicity occurred in 100% of *P. promelas* and *C. dubia* tests at Chamberlain Creek (Figures 28 and 29, Tables 9 and 10)

Samples from Cove Creek, below the Chamberlain Creek confluence (OUA0130B), showed great variance in results with both test organisms exhibiting 0% to 100% survival (100% to 0% mortality). One *P. promelas* toxicity test and three *C. dubia* toxicity tests for Cove Creek exhibited 100% survival; three toxicity tests for *P. promelas* and only one test for *C. dubia* showed 0% survival. Assuming that ≥80% survival suggests no acute toxicity, toxicity occurred in 45% of *P. promelas* tests and 73% of *C. dubia* at Cove Creek (Figures 28 and 29, Tables 9 and 10).

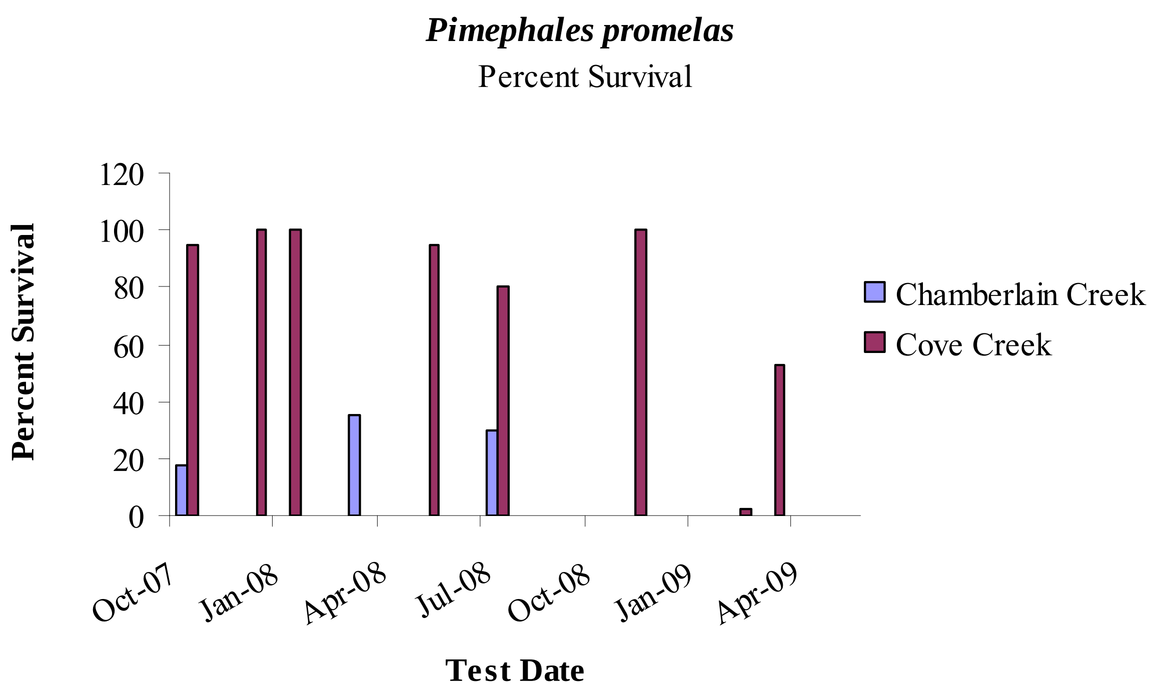

Figure 28. Percent survival for the fathead minnow, *Pimephales promelas*, in Cove and Chamberlain Creek toxicity testing.

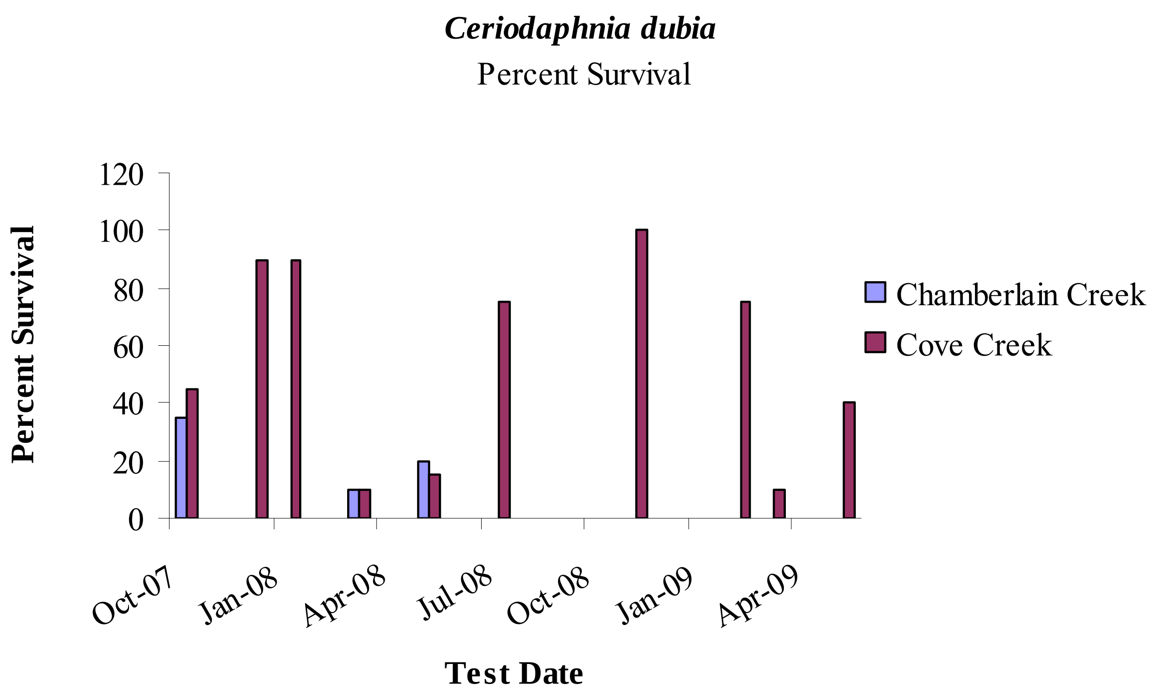

Figure 29. Percent survival for the water flea, *Ceriodaphnia dubia*, in Cove and Chamberlain Creek toxicity testing.

Table 9. Summary of routine biomonitoring results and associated water chemistry at Chamberlain Creek (OUA0104).

	% Survival		Chemical Measurements		
Sample Date	***C. dubia***	***P. promelas***	**Conductivity (µS)**	**pH**	**Al**
4/16/2007	35	17.5		5.55	963
6/25/2007	0	0		4.53	4360
8/20/2007	0	0			
10/22/2007	10	35	1923	5.32	840
12/3/2007	20	0	1240	5.50	1000
1/28/2008	0	30	1180	5.68	753
3/24/2008	0	0	420	4.72	7830
5/12/2008	0	0	695	4.39	14600
7/7/2008	0	0	690	4.25	2480
9/8/2008	0	0	755	3.92	16500
11/3/2008	0	0	637	4.21	12700
2/2/2009	0	0	931	4.82	3870
3/23/2009	0	0	1290	4.74	3490
5/11/2009	0	0	651	4.10	9660

Table 10. Summary of routine biomonitoring results and associated water chemistry at Cove Creek (OUA0103B).

Sample Date	% Survival		Chemical Measurements		
	C. dubia	*P. promelas*	Conductivity (μS)	pH	Al
10/22/2007	45	95	830	5.96	52.6
12/3/2007	90	100	458	5.98	45.2
1/28/2008	90	100	472	6.11	29.1
3/24/2008	10	0	93	5.34	801.0
5/12/2008	15	95	160	6.13	65.5
7/7/2008	75	80	111	7.19	48.3
9/8/2008	0	0	164	4.95	2010.0
11/3/2008	100	100	143.1	6.13	24.9
2/2/2009	75	2	259	5.79	86.2
3/23/2009	10	52.5	465	5.89	60.4
5/11/2009	40	0	158	4.57	1150.0

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CONCLUSION

Information from ADEQ's two-year Cove Creek watershed survey allowed the characterization of changes in both water quality and biological communities, assessment of the current impacts of treated acid mine drainage and stormwater runoff from mine spoil remnants, and assessment of ambient toxicity.

Spoil piles are known sources of AMD, which is leached from the piles during rain events (Good et al. 1970). This study documented that acid mine drainage into Cove Creek and Chamberlain Creek is negatively impacting the fish and macroinvertebrate communities. However, the portions of Cove and Basin Creeks that were sampled above Chamberlain Creek supported fish and macroinvertebrate communities that are comparable to Ouachita Mountain ecoregion streams, thus implicating no impact from acid mine drainage.

The most notable evidence of AMD was indicated from the water chemistry data, more specifically pH and metal concentrations. Decreased pH levels in concurrence with increased metal concentrations (aluminum, beryllium, cadmium, and zinc) have long been documented to have negative impacts on aquatic life. Toxicity tests of Cove and Chamberlain Creeks reiterate the harmful effects of AMD and the inability of the streams to sustain the aquatic life communities.

The results from this survey will be used to evaluate use attainability analysis plans, develop total maximum daily loads, establish restoration plans, and evaluate other proposals submitted to ADEQ with regard to this watershed.

LITERATURE CITED

Appelberg, M., E. Degerman, and L. Norrgren. 1993. Effects of acidification on fish in Sweden-a review. Finnish Fisheries Research 13: 77-91.

Arkansas Department of Environmental Quality. 2006. Arkansas's Water Quality and Compliance Monitoring Quality Assurance Project Plan. Water Quality Management Planning Section, Water Division. Unpublished.

Arkansas Pollution Control and Ecology Commission. October 26, 2007. Regulation No. 2. Regulation Establishing Water Quality Standards for Surface Waters Of The State Of Arkansas.

Baldigo, B.P. and G.B. Lawrence. 2000. Composition of Fish Communities in Relation to Stream Acidification and Habitat in the Neversink River, New York. Transactions of the American Fisheries Society 129: 60-76.

Barbour, M.T, J. Gerrisen, B.D. Snyder and J.B. Stribling. 1999. Rapid Bioassessment of Protocols for use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, 2nd Edition. EPA 841-B-99-002. U.S. Environmental

Protection Agency; Office of Water, Washington, D.C., USA. 1987. Bennett, C., J. Giese, B. Keith, R. McDaniel, M. Maner, N. O'Shaughnessy, and R. Singleton. Physical, chemical, and biological characteristics of least disturbed reference steams in Arkansas' ecoregions, volume I: Data compilation: Arkansas Department of Pollution Control and Ecology, 299 p.

Caton, L. W. 1991. Improving subsampling methods for the EPA "Rapid Bioassessment" benthic protocols. Bulletin of the North American Benthological Society 8(3): 317-319.

Freiwald, D.A. 1984. Average annual precipitation and runoff for Arkansas, 1951-1980: U.S. Geological Survey Water-Resources Investigations Report 83-4363, 1 sheet.

Good, D.M., V. T. Ricca, and T. S. Shumate. 1970. The relations of refuse pile hydrology to acid production. Symposium on Coal Mine Drainage Res., 3rd 141-511. Monroeville, Pa, Bituminous Coal Research Inc.

Harriman, R. and B.R.S. Morrison. 1982. Ecology of streams draining forested and non-forested catchments in an area of central Scotland subject to acid precipitation. Hydrobiologia 88: 251-263.

Hilsenhoff, W.L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin. Wisconsin Department of Natural Resources. 16p.

Hilsenhoff, W.L. 1982. Using a biotic index to evaluate water quality in streams. Technical Bulletin. Wisconsin Department of Natural Resources. 132 p.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist 20: 31-39.

Hunrichs, R.A. 1983. Identification and classification or perennial streams of Arkansas: U.S. Geological Survey Water-Resources Investigations Report 83-4063, 1 sheet.

Mason, J.M. 1989. The causes and consequences of surface water acidification. In *Acid Toxicity and Aquatic Animals* ed. R. Morris, E.W. Taylor, D.J.A. Brown, and J.A. Brown, pp. 1-12.

Merritt, R. W., K. W. Cummins, and M. B. Berg (editors). 2008. An introduction to the aquatic insects of North America, 4th ed. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Montana Department of Environmental Quality. 2006. Sample collection, sorting, and taxonomic identification of benthic macroinvertebrates. Montana Department of Environmental Quality, WQPBWQM-009.
Muniz, I.P. and H. Leivestad. 1980a. Acidification-effects on freshwater fish. In *Proceedings of the International Conference on the Ecological Impact of Acid Precipitation*, ed. D. Drablos and A. tollan, pp. 84-92. Oslo-As: SNSF Project.
Muniz, I.P. and H. Leivestad. 1980b. Toxic effects of aluminum on the brown trout, *Salmo trutta* L. In *Proceedings of the International Conference on the Ecological Impacts of Acid Precipitation*, ed. D. Drablos and A. tollan, pp. 84-92. Oslo-As: SNSF Project.
Neville, C.M. 1985. Physiological response of juvenile rainbow trout, *Salmo gairdneri*, to acid and aluminum-prediction of field responses from laboratory data. Canadian Journal of Fisheries and Aquatic Science 42: 2004-2019.
Norrgren, L., A. Wicklund-Glynn, and O. Malmborg. 1991. Accumulation and effects of aluminum in the minnow (*Phonxinus phoxinus*) at different pH levels. Journal of Fisheries Biology 39: 833-847.
Ormerod, S.J., P. Boole, C.P. McCahon, N.S. Weatherley, D. Pascoe, and R.W. Edwards. 1987. Short-term experimental acidification of a Welsh stream: comparing the biological effects of hydrogen ions and aluminum. Freshwater Biology 17: 341-356.
Robison, H. W., T. M. Buchanan. 1988. Fishes of Arkansas. University of Arkansas Press, Fayetteville, Arkansas.
Rosemond, A.D., S.R. Reice, J.W. Elwood, and P.J. Mulholland. 1992. The effects of stream acidity on benthic invertebrate communities in the Southeastern United States. Freshwater Biology 27: 193-209.
Rosseland, B.O. 1980. Physiological responses to acid water in fish. 2. Effects of acid water on metabolism and gill ventilation in brown trout, *Salmo trutta* L., andbrook trout, *Salveninus fontinalis* Mitchell. In *Proceedings of the International Conference on the Ecological Impacts of Acid Precipitation*, ed. D. Drablos and A. tollan, pp. 348-349. Oslo-As: SNSF Project.
Simpson, K.W., R.W. Bode, and J.R. Coquhoun. 1985. The macroinvertebrate fauna of an acid-stressed headwater stream system in the Adirondack Mountains, New York. Freshwater Biology 15: 671-681.
Staurnes, M., T. Stigholt, and O.B. Reite. 1984. Reduced carbonic anhydrase and acid water. Experientia 40: 226-227.
Stoertz, M.W., H. Bourne, C. Knotts, and M.M. White. 2002. The Effects of Isolation and Acid Mine Drainage on Fish and Macroinvertebrate Communities of Monday Creek, Ohio, USA. Mine Water and the Environment 21: 60-72.
US EPA. 2002. Methods for Measuring the Acute Toxicity of Effluents in Freshwater and Marine Organisms (EPA 600/4/90/027F).
Winterbourn, M.J. and K.J. Collier. 1987. Distribution of benthic invertebrates in acid, brown water streams in the South Island of New Zealand. Hydrobiologia 153: 277-286.
Yanchosek, J.J. and M.S. Hines. 1979. Drainage Areas of Streams in Arkansas – Ouachita River Basin: U.S. Geological Survey Open-File Report 80-344, 13 p.

APPENDIX 1

Macroinvertebrate community, trophic, and feeding metrics analyzed for comparison among nine sample sites from Cove and Chamberlain Creeks during fall 2007, spring 2008, fall 2008, and spring 2009.

Fall 2007

		OUA0171C	OUA0171D	OUA0171B	OUA0103	OUA0101	OUA0104	OUA0103B	OUA0100	OUA0159
Total Organisms	decrease	270	274	250	282	31	128	12	64	97
Total Taxa	decrease	20	21	16	18	9	8	7	15	10
No. Total EPT	decrease	97	76	180	78	7	91	3	8	5
No. of Ephemeroptera Taxa	decrease	74	24	0	35	0	0	0	0	0
No. of Plecoptera Taxa	decrease	16	14	171	18	5	79	3	0	1
No. of Trichoptera Taxa	decrease	7	38	9	25	2	12	0	8	4
% EPT	decrease	35.93%	27.74%	72.00%	27.66%	22.58%	71.09%	25.00%	12.50%	5.15%
% Hydropsychidae	either	1.11%	5.11%	0.40%	2.48%	0.00%	8.59%	0.00%	1.56%	4.12%
%EPT- %Hydropsychidae	decrease	34.81%	22.63%	71.60%	25.18%	22.58%	62.50%	25.00%	10.94%	1.03%
%Isopoda	increase	42.96%	32.48%	2.80%	58.16%	3.23%	0.00%	0.00%	20.31%	54.64%
% Chironomidae	increase	10.74%	25.91%	14.00%	4.61%	19.35%	13.28%	16.67%	6.25%	5.15%
% Diptera	either	14.81%	33.58%	16.00%	6.38%	45.16%	27.34%	50.00%	6.25%	6.19%
% scrapers	increase	29.26%	10.58%	0.00%	11.35%	0.00%	0.78%	8.33%	34.38%	23.71%
% collector/filter	increase	1.85%	14.23%	1.60%	8.87%	3.23%	9.38%	0.00%	10.94%	6.19%
% Herpobenthos (BU+SP)	increase	59.26%	67.52%	20.40%	66.31%	48.39%	27.34%	50.00%	34.38%	62.89%
% Haptobenthos (CR+CLG)	decrease	38.89%	31.75%	70.00%	31.91%	45.16%	71.88%	41.67%	51.56%	36.08%
Hilsenhoff Biotic Index (HBI)	increase	6.0	6.2	2.3	6.5	5.4	2.4	4.8	4.8	6.3
HBI Interpretation		Fair	Fair	Excellent	Fair	Good	Excellent	Good	Good	Fair
% Intolerant (1-3)	increase	8.52%	12.04%	72.80%	12.77%	22.58%	71.88%	33.33%	43.75%	27.84%
% Tolerant (7-10)	decrease	53.70%	60.95%	18.80%	62.77%	22.58%	13.28%	16.67%	26.56%	62.89%
Dominant Taxa #1		116	89	166	164	8	79	3	19	53
Dominant Taxa #2		*Lirceus*	*Lirceus*	*Perlomyia*	*Lirceus*	*Gammarus*	*Perlomyia*	*Neumoridae*	*Optioservus*	*Lirceus*

Spring 08

		OUA0171C	OUA0171D	OUA0171B	OUA0103	OUA0101	OUA0104	OUA0103B	OUA0100	OUA0159
Total Organisms	decrease	279	239	24	244	140	38	63	140	42
Total Taxa	decrease	16	29	11	27	11	10	16	21	12
No. Total EPT	decrease	135	115	2	129	22	14	42	63	20
No. of Ephemeroptera Taxa	decrease	59	90	0	38	3	1	8	28	2
No. of Plecoptera Taxa	decrease	72	11	0	50	0	6	28	26	9
No. of Trichoptera Taxa	decrease	4	14	2	41	19	7	6	9	9
% EPT	decrease	48.39%	48.12%	8.33%	52.87%	15.71%	36.84%	66.67%	45.00%	47.62%
% Hydropsychidae	either	0.00%	0.84%	0.00%	7.38%	12.86%	18.42%	7.94%	4.29%	14.29%
%EPT- %Hydropsychidae	decrease	48.39%	47.28%	8.33%	45.49%	2.86%	18.42%	58.73%	40.71%	33.33%
%Isopoda	increase	40.86%	29.29%	12.50%	23.36%	13.57%	31.58%	7.94%	32.86%	19.05%
% Chironomidae	increase	2.15%	1.26%	25.00%	1.23%	41.43%	5.26%	1.59%	5.00%	4.76%
% Diptera	either	8.24%	2.09%	50.00%	11.07%	46.43%	21.05%	9.52%	7.86%	9.52%
% scrapers	increase	18.64%	37.24%	0.00%	19.26%	17.14%	2.63%	9.52%	15.00%	33.33%
% collector/filter	increase	3.94%	1.67%	4.17%	14.75%	20.71%	26.32%	15.87%	5.00%	16.67%
% Herpobenthos (BU+SP)	increase	46.24%	38.91%	50.00%	30.74%	75.00%	52.63%	17.46%	46.43%	26.19%
% Haptobenthos (CR+CLG)	decrease	51.97%	52.30%	29.17%	60.25%	25.00%	44.74%	71.43%	51.43%	73.81%
Hilsenhoff Biotic Index (HBI)	increase	5.6	5.3	6.7	4.7	5.9	5.9	3.9	5.1	4.3
HBI Interpretation		Fair	Good	Fairly Poor	Good	Fair	Fair	Very Good	Good	Very Good
% Intolerant (1-3)	increase	28.67%	15.90%	12.50%	50.00%	15.71%	21.05%	60.32%	30.71%	57.14%
% Tolerant (7-10)	decrease	44.44%	30.96%	45.83%	25.00%	55.00%	39.47%	9.52%	39.29%	23.81%
Dominant Taxa #1		114	70	6	57	58	12	12	46	9
Dominant Taxa #2		*Lirceus*	*Lirceus*	Chironomidae	*Lirceus*	Chironomidae	*Lirceus*	*Neoperla*	*Lirceus*	*Stenelmis*

Fall 2008

		OUA0171C	OUA0171D	OUA0171B	OUA0103	OUA0101	OUA0104	OUA0103B	OUA0100	OUA0159
Total Organisms	decrease	242	107	327	276	260	318	5	49	40
Total Taxa	decrease	22	19	15	26	11	6	4	9	10
No. Total EPT	decrease	53	23	255	124	5	3	1	12	19
No. of Ephemeroptera Taxa	decrease	42	3	0	59	0	0	0	0	1
No. of Plecoptera Taxa	decrease	8	1	222	27	3	1	1	12	9
No. of Trichoptera Taxa	decrease	3	19	33	38	2	2	0	0	9
% EPT	decrease	21.90%	21.50%	77.98%	44.93%	1.92%	0.94%	20.00%	24.49%	47.50%
% Hydropsychidae	either	0.41%	10.28%	1.83%	9.42%	0.38%	0.00%	0.00%	0.00%	15.00%
%EPT- %Hydropsychidae	decrease	21.49%	11.21%	76.15%	35.51%	1.54%	0.94%	20.00%	24.49%	32.50%
%Isopoda	increase	29.75%	33.64%	0.61%	7.97%	0.00%	0.00%	0.00%	0.00%	20.00%
% Chironomidae	increase	36.36%	12.15%	13.76%	9.06%	86.92%	97.17%	20.00%	28.57%	5.00%
% Diptera	either	41.32%	23.36%	18.96%	34.06%	91.92%	98.74%	20.00%	51.02%	7.50%
% scrapers	increase	11.98%	21.50%	0.00%	16.67%	0.00%	0.31%	0.00%	10.20%	35.00%
% collector/filter	increase	2.89%	23.36%	1.83%	34.42%	0.38%	0.94%	0.00%	0.00%	17.50%
% Herpobenthos (BU+SP)	increase	73.14%	27.10%	19.57%	21.74%	91.92%	98.43%	20.00%	59.18%	25.00%
% Haptobenthos (CR+CLG)	decrease	25.21%	71.96%	78.59%	77.54%	1.92%	1.57%	80.00%	40.82%	75.00%
Hilsenhoff Biotic Index (HBI)	increase	6.2	6.0	2.1	5.1	6.8	6.9	4.4	5.0	4.6
HBI Interpretation		Fair	Fair	Excellent	Good	Fairly Poor	Fairly Poor	Very Good	Good	Good
% Intolerant (1-3)	increase	14.46%	26.17%	77.98%	25.00%	1.92%	1.26%	40.00%	36.73%	52.50%
% Tolerant (7-10)	decrease	66.53%	45.79%	14.98%	17.39%	87.69%	97.17%	20.00%	28.57%	25.00%
Dominant Taxa #1		88	36	222	61	226	309	2	14	9
Dominant Taxa #2		Chironomidae	*Asellus*	*Perlomyia*	*Simulium*	Chironomidae	Chironomidae	*Dubiraphia*	Chironomidae	*Stenelmis*

Spring 09

		OUA0171C	OUA0171D	OUA0171B	OUA0103	OUA0101	OUA0104	OUA0103B	OUA0100	OUA0159
Total Organisms	decrease	301	240	138	318	124	16	11	100	100
Total Taxa	decrease	11	22	5	28	4	4	5	6	12
No. Total EPT	decrease	78	52	28	77	0	1	1	6	25
No. of Ephemeroptera Taxa	decrease	45	33	0	28	0	0	0	0	6
No. of Plecoptera Taxa	decrease	21	10	11	45	0	0	1	4	18
No. of Trichoptera Taxa	decrease	12	9	17	4	0	1	0	2	1
% EPT	decrease	25.91%	21.67%	20.29%	24.21%	0.00%	6.25%	9.09%	6.00%	25.00%
% Hydropsychidae	either	0.00%	0.00%	0.00%	0.63%	0.00%	0.00%	0.00%	0.00%	0.00%
%EPT- %Hydropsychidae	decrease	25.91%	21.67%	20.29%	23.58%	0.00%	6.25%	9.09%	6.00%	25.00%
%Isopoda	increase	6.98%	40.83%	0.00%	2.52%	0.81%	0.00%	9.09%	0.00%	24.00%
% Chironomidae	increase	52.49%	22.92%	68.12%	54.09%	83.06%	75.00%	63.64%	92.00%	30.00%
% Diptera	either	67.11%	24.58%	79.71%	62.89%	99.19%	93.75%	81.82%	92.00%	30.00%
% scrapers	increase	7.64%	21.25%	0.00%	10.69%	0.00%	0.00%	0.00%	1.00%	7.00%
% collector/filter	increase	13.62%	0.83%	0.00%	7.55%	0.00%	0.00%	0.00%	0.00%	1.00%
% Herpobenthos (BU+SP)	increase	60.47%	74.58%	79.71%	58.81%	100.00%	93.75%	90.91%	93.00%	55.00%
% Haptobenthos (CR+CLG)	decrease	39.53%	22.08%	20.29%	41.19%	0.00%	6.25%	9.09%	7.00%	45.00%
Hilsenhoff Biotic Index (HBI)	increase	6.0	6.4	5.9	5.6	6.8	6.5	6.1	6.6	5.8
HBI Interpretation		Fair	Fair	Fair	Fair	Fairly Poor	Fairly Poor	Fair	Fairly Poor	Fair
% Intolerant (1-3)	increase	10.96%	12.08%	20.29%	22.96%	0.00%	6.25%	18.18%	6.00%	27.00%
% Tolerant (7-10)	decrease	65.12%	66.25%	68.12%	56.92%	83.87%	75.00%	72.73%	92.00%	55.00%
Dominant Taxa #1		158	98	94	172	103	12	7	92	30
Dominant Taxa #2		Chironomidae	*Lirceus*	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae

Macroinvertebrate communities collected from nine sample sites along Cove and Chamberlain Creeks during four sampling periods.

Order	Family	Genus	Fall 2007									Spring 2008									Fall 2008									Spring 2009								
			OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Amphipoda	Hyalellidae	Hyalella azteca	1																									1		3							4	
Amphipoda	Gammaridae	Gammarus								1			1			1						1						5			2			8				
Arachnida	Hydracacina	Arrhenurus															1											1										
Arachnida	Hydracacina							1																														
Bivalvia	Corbiculidae	Corbicula																							1	1		1		2								1
Coleoptera	Dryopidae	Helichus																								2												
Coleoptera	Dytiscidae	Agabus														1		1																		11		
Coleoptera	Dytiscidae	Laccophilus																									2											
Coleoptera	Elmidae	Ancyronyx						1																														
Coleoptera	Elmidae	Oulimnius																	1																			
Coleoptera	Elmidae	Heterelmis						1																														
Coleoptera	Elmidae	Microcylloepus						1									8																					
Coleoptera	Elmidae	Dubiraphia	11					1		1				2			2						1					2									1	
Coleoptera	Elmidae	Optioservus																													19	1						
Coleoptera	Elmidae	Stenelmis	6					21				9	4		1		10		4		9	3		1		16		2		23			1		8			1
Coleoptera	Gyrinidae	Dineutus																1																				
Coleoptera	Haliplidae	Haliplus																														1						
Coleoptera	Haliplidae	Peltodytes																		1																		
Coleoptera	Psephenidae	Psephenus		1				6		8		1	1				8		5	2	1	4	5		7	7		11	3		3				7		6	9
Collembola	Collembola	Collembola																2																				
Collembola	Isotomidae	Isotoma	0																	10																3		
Decapoda	Cambaridae	Cambarinae																		2		3						8		1		1		1	3	1		

Order	Family	Genus	Fall 2007									Spring 2008									Fall 2008									Spring 2009								
			QUA0159	QUA0100	QUA0103B	QUA0104	QUA0101	QUA0103	QUA0171B	QUA0171D	QUA0171C	QUA0159	QUA0100	QUA0103B	QUA0104	QUA0101	QUA0103	QUA0171B	QUA0171D	QUA0171C	QUA0159	QUA0100	QUA0103B	QUA0104	QUA0101	QUA0103	QUA0171B	QUA0171D	QUA0171C	QUA0159	QUA0100	QUA0103B	QUA0104	QUA0101	QUA0103	QUA0171B	QUA0171D	QUA0171C
Diptera	**Empididae**	**Hemerodromia**			1			1		2			3				2						1						1			1						
Decapoda	Cambarinae	Orconectes																											2		7							1
Decapoda	**Paleomonetes**																																		1			
Diptera	Brachycera	Atherix			1					1										2	1															1	5	
Diptera	**Ceratopogonidae**	**Bezzia**				2	19	1	13						4	12		2						4	1		1			1		3	13	5		1		
Diptera	Chironomidae		30	92	7	12	103	172	94	55	158	2	14	1	309	226	25	45	13	88	2	7	1	2	58	3	6	3	6	5	4	2	17	6	13	35	71	29
Diptera	**Simulidae**	**Simulium**	0					22			41	1			1		61		7	6	1	1	4	2	6	15	1	1	10						1		2	
Diptera	Tabanidae																									1												
Diptera	**Tabanidae**	**Chrysops**																																				2
Diptera	Tabanidae	Hybomitra						1																														
Diptera	**Tabanidae**	**Tabanus**																2																				
Diptera	Tipulidae	Antocha															1																					
Diptera	**Tipulidae**	**Dactylolabis**						1		1																												
Diptera	Tipulidae	Hexatoma				1		1	3		3					1	3	2		4		2				5	2		3							3		3
Diptera	**Tipulidae**	**Tipula**					1	1					8				2	11	5			1				3	2	1	3				5	3	4		14	6
Diptera	Tipulidae	Pseudolimnophila																									1											
Ephemeroptera	**Baetidae**	**Americabaetis**															43			3																		
Ephemeroptera	Baetidae	Baetis																				3				2									11			4
Ephemeroptera	**Baetidae**	**Fallceon**	5					22			16																		2									
Ephemeroptera	Baetidae	Procloen																	1																			
Ephemeroptera	**Baetidae**									2										11								21										
Ephemeroptera	Caenidae	Caenis						1		1																2									2			

Order	Family	Genus	Fall 2007									Spring 2008									Fall 2008									Spring 2009								
			OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Ephemeroptera	Ephemerellidae																																				1	
Ephemeroptera	Ephemerellidae	Dannella																			1	13													1			1
Ephemeroptera	Ephemerellidae	Eurylophella								8							1			1			7			22		13	3									
Ephemeroptera	Ephemeridae	Ephmemera																	1																4			
Ephemeroptera	Heptageniidae	Epeorus															10																					
Ephemeroptera	Heptageniidae	Macaffertium						4		2		1					5			1		9				2		6	49								19	
Ephemeroptera	Heptageniidae	Stenacron																										2									1	
Ephemeroptera	Heptageniidae	Stenonema	1							14	12									5						2		48							17			69
Ephemeroptera	Heptageniidae																		1	19	1		1			7												
Ephemeroptera	Isonychidae	Isonychia																						1	3				1								1	
Ephemeroptera	Leptophlebiidae																									1												
Ephemeroptera	Neoephemeridae	Neoephemera																				3																
Ephemeroptera	Siphonluridae	Siphlonurus						1		6	17																		4								2	
Gastropoda	Pleuroceridae									21							2											15									3	
Gastropoda	Planorbidae																					2															1	
Gastropoda	Planorbidae	Heliosoma																										1										
Gastropoda	Viviparidae																		9						17													
Hemiptera	Gerridae	Aquarius														2																						
Hemiptera	Gerridae	Trepobates														1											3											
Hemiptera	Herbridae	Hebrus																						1														
Hemiptera	Saldidae																1																			5		
Hemiptera	Veliidae	Microvelia														11		4		1													1			2		1

Order	Family	Genus	Fall 2007									Spring 2008									Fall 2008									Spring 2009								
			OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Hemiptera	**Veliidae**	**Rhagovelia**																	1																			
Isopoda	Asellidae	Asellus																2	36								3											
Isopoda	**Asellidae**	**Lirceus**	24		1		1	8		98	21	8					22			72	8	46	5	12	19	57		70	114	53	13			1	164	7	89	116
Lepidoptera	Pyralidae	Petrophila						1											2							2												
Megaloptera	**Corydalidae**	**Corydalus**	2										2																		1							
Megaloptera	Corydalidae	Nigronia												1																								1
Odonata	**Aeshinidae**	**Anax or Aeshna**																													1							
Odonata	Calopterygidae	Caleopteryx																									1				1							
Odonata	**Calopterygidae**	**Hetaerina**																												4					3			
Odonata	Cordulegasteridae	Cordulegaster																													1					1		
Odonata	**Gomphidae**	**Erpetogomphus**											4															1										
Odonata	Gomphidae	Gomphus																					1															
Odonata	**Gomphidae**	**Stylogomphus**		1													1		1			3				3		1			1							3
Oligochaeta	Oligochaeta	Oligochaeta	1														3			1		4	3	2	9				2		3						2	
Plecoptera	**Capniidae**	**Allocapnia**											12									3																
Plecoptera	Chloroperlidae	Alloperla										2								5																		
Plecoptera	**Chloroperlidae**	**Suwallia**		4	1			18	11		11				1		6		1				6					2										
Plecoptera	Chloroperlidae	Swelsta								6											1															5		5
Plecoptera	**Chloroperlidae**	**Utaperla**																								4												
Plecoptera	Leuctridae	Perlomyia														3		222		3													79			166		
Plecoptera	**Neumoridae**	**Amphinemura**	15					13				7											10			38		3	72									

Fall 2007

Order	Family	Genus	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Plecoptera	**Neumoridae**										
Plecoptera	Perlidae	Eccoptura									
Plecoptera	**Perlidae**	**Neoperla**	3					11		3	
Plecoptera	Perlodidae	Isoperla						3		1	10
Trichoptera	**Glossomatidae**	**Agapetus**								4	
Trichoptera	Glossomatidae	Glossoma									11
Trichoptera	**Heliopsychidae**	**Helicopsyche**								2	
Trichoptera	Hydropsychidae	Ceratopsyche									
Trichoptera	**Hydropsychidae**	**Cheumatopsyche**									
Trichoptera	Hydropsychidae	Homoplectra									
Trichoptera	**Hydropsychidae**	**Hydropsyche**						2			
Trichoptera	Hydropsychidae	Macrostemum									
Trichoptera	**Lepidostomatidae**	**Lepidostoma**									
Trichoptera	Limnephilidae	Pycnopsyche									
Trichoptera	**Philopotomodae**	**Chimarra**	1								
Trichoptera	Philopotomodae	Wormaldia								2	
Trichoptera	**Polycentropodidae**	**Cyrnellus**									
Trichoptera	Polycentropodidae	Neureclipsis									
Trichoptera	**Polycentropodidae**	**Polycentropus**		1		1		1	17	1	1
Trichoptera	Psychomiidae	Psychomia									
Trichoptera	**Rhyacophilidae**	**Rhyacophila**		1				1			

Spring 2008

Order	Family	Genus	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Plecoptera	**Neumoridae**										
Plecoptera	Perlidae	Eccoptura									
Plecoptera	**Perlidae**	**Neoperla**						21			
Plecoptera	Perlodidae	Isoperla									
Trichoptera	**Glossomatidae**	**Agapetus**									
Trichoptera	Glossomatidae	Glossoma	3								
Trichoptera	**Heliopsychidae**	**Helicopsyche**						3		1	
Trichoptera	Hydropsychidae	Ceratopsyche					1		3		
Trichoptera	**Hydropsychidae**	**Cheumatopsyche**	6					26			
Trichoptera	Hydropsychidae	Homoplectra							3		
Trichoptera	**Hydropsychidae**	**Hydropsyche**								5	1
Trichoptera	Hydropsychidae	Macrostemum								6	
Trichoptera	**Lepidostomatidae**	**Lepidostoma**									
Trichoptera	Limnephilidae	Pycnopsyche					1				
Trichoptera	**Philopotomodae**	**Chimarra**						8		7	
Trichoptera	Philopotomodae	Wormaldia									
Trichoptera	**Polycentropodidae**	**Cyrnellus**									
Trichoptera	Polycentropodidae	Neureclipsis				2					
Trichoptera	**Polycentropodidae**	**Polycentropus**							26		2
Trichoptera	Psychomiidae	Psychomia							1		
Trichoptera	**Rhyacophilidae**	**Rhyacophila**						1			

Fall 2008

Order	Family	Genus	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Plecoptera	**Neumoridae**										
Plecoptera	Perlidae	Eccoptura		5							
Plecoptera	**Perlidae**	**Neoperla**			12			7		2	
Plecoptera	Perlodidae	Isoperla						1		4	
Trichoptera	**Glossomatidae**	**Agapetus**									
Trichoptera	Glossomatidae	Glossoma	3	3							
Trichoptera	**Heliopsychidae**	**Helicopsyche**						9		6	
Trichoptera	Hydropsychidae	Ceratopsyche					18				
Trichoptera	**Hydropsychidae**	**Cheumatopsyche**	6	6	4	7		18		2	
Trichoptera	Hydropsychidae	Homoplectra									
Trichoptera	**Hydropsychidae**	**Hydropsyche**									
Trichoptera	Hydropsychidae	Macrostemum			1						
Trichoptera	**Lepidostomatidae**	**Lepidostoma**									
Trichoptera	Limnephilidae	Pycnopsyche									
Trichoptera	**Philopotomodae**	**Chimarra**			1		1	2			
Trichoptera	Philopotomodae	Wormaldia									
Trichoptera	**Polycentropodidae**	**Cyrnellus**									
Trichoptera	Polycentropodidae	Neureclipsis									
Trichoptera	**Polycentropodidae**	**Polycentropus**							2	5	
Trichoptera	Psychomiidae	Psychomia						12			4
Trichoptera	**Rhyacophilidae**	**Rhyacophila**								1	

Spring 2009

Order	Family	Genus	OUA0159	OUA0100	OUA0103B	OUA0104	OUA0101	OUA0103	OUA0171B	OUA0171D	OUA0171C
Plecoptera	**Neumoridae**				3		5			2	
Plecoptera	Perlidae	Eccoptura	1					18		12	
Plecoptera	**Perlidae**	**Neoperla**									11
Plecoptera	Perlodidae	Isoperla									
Trichoptera	**Glossomatidae**	**Agapetus**									
Trichoptera	Glossomatidae	Glossoma									
Trichoptera	**Heliopsychidae**	**Helicopsyche**									
Trichoptera	Hydropsychidae	Ceratopsyche									
Trichoptera	**Hydropsychidae**	**Cheumatopsyche**	4	1				7		14	3
Trichoptera	Hydropsychidae	Homoplectra									
Trichoptera	**Hydropsychidae**	**Hydropsyche**				11			1		
Trichoptera	Hydropsychidae	Macrostemum									
Trichoptera	**Lepidostomatidae**	**Lepidostoma**					1	1		2	
Trichoptera	Limnephilidae	Pycnopsyche		1					5		3
Trichoptera	**Philopotomodae**	**Chimarra**		6		1		17		22	1
Trichoptera	Philopotomodae	Wormaldia									
Trichoptera	**Polycentropodidae**	**Cyrnellus**					1		3		
Trichoptera	Polycentropodidae	Neureclipsis									
Trichoptera	**Polycentropodidae**	**Polycentropus**									
Trichoptera	Psychomiidae	Psychomia									
Trichoptera	**Rhyacophilidae**	**Rhyacophila**									

APPENDIX 2

Richness and abundance for 2007 and 2008 sampling periods within the Cove and Chamberlain Creek watersheds
Blanks indicate no samples were collected.

		OUA171C		**OUA171B**		**OUA171D**		**OUA103**		**OUA103B**		**OUA104**		**OUA100**		**OUA159**		**Tigre Creek**	
		2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
SCIENTIFIC NAME	**COMMON NAME**																		
Esox americanus	redfin pickerel					1	1												1
Campostoma anomalum	central stoneroller	78				8	15		201		25			2	23	96	185		234
Cyprinella whipplei	steelcolor shiner															5			
Luxilus chrysocephalus	striped shiner					23	43		30							3			19
Lythurus umbratilis	redfin shiner						1		1						1		16		
Notropis boops	bigeye shiner						10		20								15		22
Pimephales notatus	bluntnose minnow					11	5		16					5		2			8
Pimephales tenellus	slim minnow						3												
Pimephales vigilax	bullhead minnow									1				7					
Semotilus atromaculatus	creek chub	35				29	105		7		50			12	31	1	29		
Erimyzon oblongus	creek chubsucker	1				3	2		7		2			4		1			2
Hypentelum nigricans	Northern hogsucker						3		3							1			2
Ameiurus natalis	yellow bullhead					2	8		7	8	8	2		4	3	5	10		1
Noturus lachneri	Ouachita madtom																		10
Aphredoderus sayanus	Pirate Perch					1	4		1							3	1		
Fundulus catenatus	Northern studfish					1	2		15	1	8			15	1	1	18		1
Fundulus olivaceus	blackspotted topminnow	2				13	4		3					4			2		2
Ambloplites ariommus	shadow bass					1								2		6	3		
Lepomis cyanellus	green sunfish	68		3		11	18		36		5			1	7	1	18		28
Lepomis macrochirus	bluegill sunfish			2					1	2					5		23		2
Lepomis megalotis	longear sunfish					18	20		42	3	35			26	23	27	62		19
Micropterus punctulatus	spotted bass																		2
Etheostoma blennioides	greenside darter					3	1		2						1	10	1		2
Etheostoma radiosum	orangebelly darter	34				30	54		73		2			2	9	8	53		56
Etheostoma zonatum	banded darter															1			
	Total No. Inds.	218		5		155	299		465	15	135	2		84	104	171	436		411
	Total Taxa	6		2		15	18		17	5	8	1		12	10	16	14		17

Examples of Substrate Conditions in the Cove Creek Watershed

Basin Creek

Cove Creek above Chamberlain Creek

Chamberlain Creek

Cove Creek below Chamberlain Creek