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Cavefish Population Status and Environmental Quality in Cave Springs Cave, Arkansas - Final Report submitted to Arkansas Natural Heritage Commission

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CAVEFISH POPULATION STATUS AND ENVIRONMENTAL QUALITY IN CAVE SPRINGS CAVE, ARKANSAS

A Final Report Submitted to the

ARKANSAS NATURAL HERITAGE COMMISSION

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Department of Biological Sciences

ARKANSAS WATER RESOURCES CENTER

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in Cave Springs Cave, Arkansas

a report submitted to

John Beneke, Chief of Stewardship

Arkansas Natural Heritage Commission
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The cover photograph of an Ozark Cavefish in Cave Springs Cave was taken by Dr. Larry D. Willis.

EXECUTIVE SUMMARY

This report summarizes the continuing effort to monitor environmental quality in the Cave Springs Cave Natural Area and to implement the Ozark Cavefish Recovery Plan. Last year's report (Brown *et al*., 1998) identified certain environmental stressors, including a trend over 15 years of increasing nutrient pollution, a low cavefish population count of only 106, and the presence of heavy metals in the cave water and one semi-volatile organic compound (the phthalate DEHP at 500 ppb) in resident crayfish tissue. This year's monitoring effort demonstrates that fecal coliforms continue to exceed Arkansas State Water Quality Standards (Regulation 2), sometimes by a factor of 1000. The presence of heavy metals is confirmed, in not only the cave water and sediments, but in crayfish tissue, which implies that it may be bioaccumulating in the cave foodweb. Furthermore, beryllium, copper, lead, selenium, and zinc are present in concentrations in the cave water that exceeded the Regulation 2 standards for chronic, and sometimes acute, toxicity to aquatic life. Significant amounts of nitrate are also present (with a yearly average of over 5 mg NO_3-N/ L), and phosphate concentrations occasionally exceed Regulation 2 standards. Concentrations of nitrate, ortho-phosphate, total phosphate, total coliforms, and several dissolved metals (Al, Ba, Cu, Fe, and Pb) were all highly correlated with discharge, and concentrations were highest during stormflow events. No pesticides were detected in cave water, crayfish tissue or bat guano. Phthalates were again detected in crayfish tissue (DEP and DEHP at 1 ppb each), as well as the cave water (DEHP at 0.7 ppb). While the effects of these phthalates upon aquatic organisms are unknown, the U. S. Environmental Protection Agency considers phthalates to be human carcinogens and hormone disrupters. Ironically, while the cavefish habitat appears to be quite polluted, this year's population survey counted 166 Ozark cavefish, the most ever counted for this (or any other) habitat.

In order to integrate these pollution concerns and other data about this cave complex, a geographic information system was created for the Cave Springs Cave recharge zone. Preliminary analyses have detected several sensitive areas and pollution sources. The cave complex was determined to extend outside of the Natural Area boundary, and several sinkholes were identified. Photo-lineaments and fracture traces were identified, and other studies in Benton County demonstrate that these features, commonly expressed as intermittent streams on the surface, allow surface pollutants to rapidly enter the groundwater. Protection of these adjacent lands, sinkholes, and streams is recommended. The reduction or cessation of the land application of sewage sludge and agricultural waste in the recharge zone is also recommended.

INTRODUCTION

Caves exist as islands of suitable habitat for cave-adapted organisms surrounded by hostile environments. The distribution and dispersal of some cave animals is very limited. For example, the cave crayfish (*Cambarus aculabrum*) is found only in two caves in Arkansas. The adaptations that animals have undergone (including eye and pigment degeneration, lowered metabolic and developmental rates, and lowered fecundity) to make them successful in cave environments also make them extremely vulnerable to alterations of their habitats. Such rarity and sensitivity make many obligate cave-dwelling animals endangered of extinction. Cave Springs Cave (Cave Springs Cave Arkansas Natural Area, Cave Springs, Benton County) contains several such animals.

This cave complex is home to the largest population of the Ozark Cavefish (*Amblyopsis rosae*). It is formally recognized as "threatened" by the U. S. Fish and Wildlife Service (49 FR 43965), "imperiled" (global rank of G2) by the Natural Heritage Program and "extremely rare" (state rank of S1) by the State of Arkansas (Natural Heritage Database). The Ozark Cavefish Recovery Plan (USFWS, 1989) designates Cave Springs Cave as the primary recovery habitat. Historically, this cave is home to the rare amphipod, *Stygobromus ozarkensis*, with a state rank of S1, but recent surveys have not confirmed its continued presence at this site (Natural Heritage Database). Cave Springs Cave hosts one of the few maternity colonies of the endangered gray bat (*Myotis grisescens*) in Arkansas. The gray bat is formally recognized as "endangered" by the USFWS, and has a global rank of G3 and a state rank of S2 (Natural Heritage Database). Finally, the grotto salamander (*Typhlotriton spelaeus*) is found in this cave complex, and was formerly listed as "endangered" by the USFWS.

In a broader sense, these rare cave animals represent an important part of the natural heritage of the State of Arkansas. As well, cave fauna are important scientifically, including their use in medical and genetics research. Aquatic, subterranean fauna (stygobites) are also important indicators of groundwater quality (Notenboom *et al*., 1994), and knowledge of their status will help protect the region's water supply. The Springfield Plateau aquifer is the most widely used source of groundwater for Benton County residents (Ogden, 1979; Smith and Steele, 1990), and the Cave Springs Cave stream is one of the main resurgences for this aquifer. Thus, the health of this cave fauna is inextricably linked with the health (and economy) of Benton County, Arkansas. Yet, northwest Arkansas is experiencing rapid land use changes and deteriorating water quality (Steele, 1985), which makes the protection of cave fauna and groundwater quality more necessary as well as more difficult.

Historically, cavefish populations have dwindled due to overcollection, disturbance and habitat degradation (Stewart, 1984). At least one cavefish habitat in Benton Co. was destroyed by landfill leachate (Aley and Aley, 1979), and several cavefish and cave crayfish habitats have been inundated by the impoundment of rivers, such as the White River (Beaver Lake) and Grand River (Lake of the Cherokees) (Willis and Brown, 1985). The population of Ozark cavefish at Cave Springs Cave has suffered from overcollection and other disturbances (Brown and Willis, 1984). The federal listings of the species and the efforts by the ANHC, including the acquisition and fencing of the cave, have undoubtedly contributed to their recovery. Figure 1 summarizes all of the known visual counts of *A. rosae* in Cave Springs Cave.

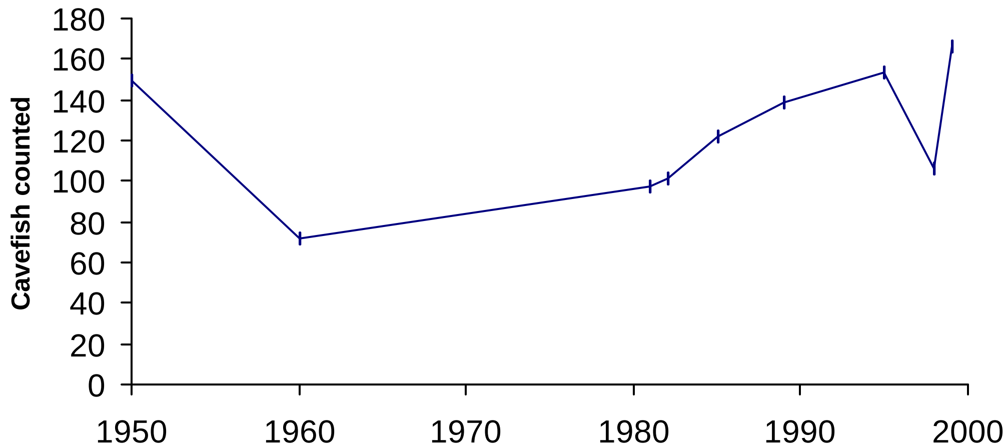

Figure 1: Summary of all known visual surveys of the *A. rosae* population in Cave Springs Cave (Poulson, 1963; Brown *et al*., 1987, 1998).

The status of endangered bat populations in Cave Springs Cave is also of concern. Gray bat populations (*Myotis grisescens*) have been declining in the Ozark mountains, with an estimated reduction of 61% of the historic population in Arkansas (Harvey, 1976). The Cave Springs Cave population is no exception. Figure 2 shows a 10-year summary of unpublished data of visual counts of gray bats performed by Dr. Michael Harvey of Tennessee Technical University and Ron Redman of the Arkansas Soil and Water Commission. In 1935, Indiana bats (*Myotis sodalis*) were reported in Cave Springs Cave (Sealander and Young, 1955), but neither the authors nor Dr. Harvey have seen any in the cave to date (M. Harvey, pers. comm.,1999). Nationally, a 90% decline in the now federally listed Indiana bats has occurred (Rick Clawson, pers. comm., 1999). The most recent survey estimates a total population of only 2700 Indiana bats in Arkansas (down from a historic high of 14,900) (USFWS, 1999). The Revised Indiana Bat Recovery Plan lists disturbance, vandalism, improper cave gates, natural hazards, scientific study and collection, land use practices, and chemical contamination as reasons for decline (USFWS, 1999).

Last year's monitoring effort detected certain stressors in the Cave Springs Cave habitat, including fecal pollution and a 14-year trend of increasing nutrient concentrations, the presence of heavy metals, one semi-volatile organic chemical, and continued illegal entry (Brown *et al*., 1998). Organic pollution is of concern in groundwater ecosystems for several reasons. Organic pollutants severely alter groundwater food webs (Notenboom *et al*., 1994). Enrichment of nutrient-poor cave ecosystems can increase the risk of competition and predation by aquatic organisms that are not restricted to caves (stygophiles) (Brown *et al*., 1994). Septic pollution alters food webs and can eradicate certain invertebrates (Simon and Buikema Jr., 1997). Obligate, cave stream – dwelling (stygobitic) isopods and amphipods were extirpated from cave pools highly polluted with septic waste in Banner's Corner Cave, Virginia (Simon and Buikema Jr., 1997). Sequoita Springs in Springfield, Missouri, has been ruined by septic system pollution, which has eradicated the native invertebrate fauna and replaced them with pollution-related fauna such as bloodworms (Aley, 1976). In general, organic pollution lowers biodiversity in caves and stygobites are more vulnerable to pollution than their surface counterparts because of their longevity and low reproduction potential (Poulson, 1964, 1976; Simon and Buikema Jr., 1997).

The heavy metals detected last year in Cave Springs Cave are also of concern. Several heavy metals are present in concentrations greater than the State of Arkansas' limits set for chronic and acute toxicity to aquatic organisms (Arkansas Pollution Control and Ecology Commission, 1998; Brown *et al*., 1998). In general, the longevity of stygobites allows them to bioaccumulate greater amounts of metals (Dickson *et al*., 1979). For example, Dickson *et al*. (1979) noted that stygobitic crayfish showed significantly greater accumulations of cadmium and lead than the other crayfish co-inhabiting the cave.

While the cavefish population in Cave Springs Cave appears to be approaching its previous abundance, the gray bats, Indiana bats, and cave amphipods do not appear to be. Thus, recovery and remediation efforts are still greatly needed in this Arkansas Natural Area to restore the cave community to its natural state. Besides the continued monitoring of environmental quality in this cave complex and the censusing of its fauna, this study investigated the effects of the known habitat stressors. Water quality analyses focused more on coliform densities, metal concentrations, and storm flows. Carbon and nitrogen stable isotope assays were begun to better understand the foodweb dynamics, and a recharge zone analysis was begun using a geographical information system (GIS).

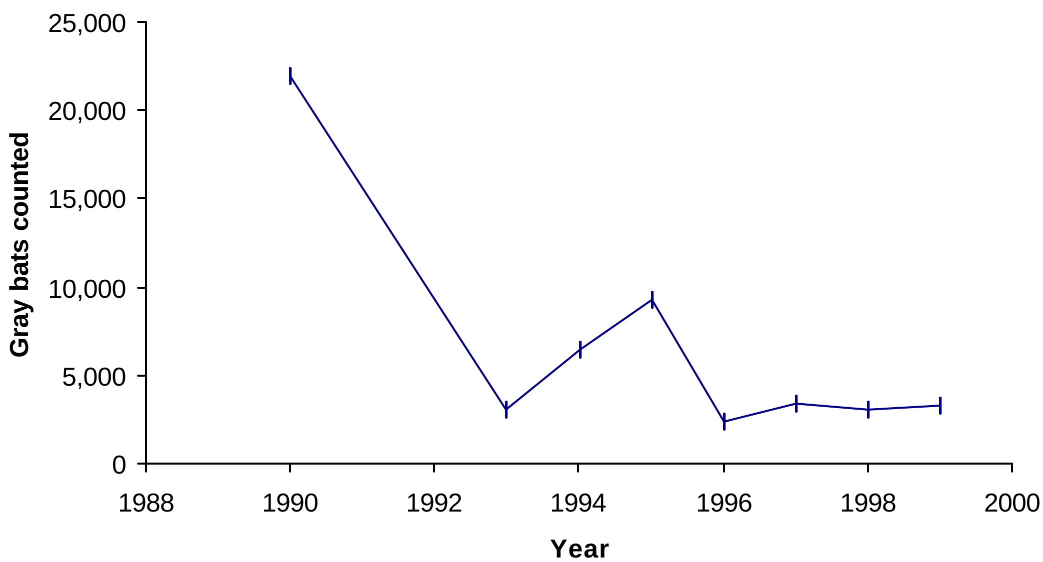

Figure 2. All known population counts of gray bat (*Myotis grisescens)* in Cave Springs Cave (Harvey, 1991; Michael Harvey and Ron Redman's unpublished data, 1999).

OBJECTIVES

Objective #1: Determine the environmental quality of the Cave Springs Cave Ecosystem

- Analyze an array of water quality parameters at baseflow during fall and spring at the mouth of the cave and deep in the cave upstream of bat roosts, for a total of four sampling sets.

- Sample at least three storm events with at least one in early fall and one in early spring, measuring the same parameters as above, with four samples per storm, for a total of 16 sampling sets.

Objective #2: Determine the status of the Ozark cavefish population in Cave Springs Cave

- Count cavefish visible in the cave during fall and spring using the same methods used in all previous surveys.

Objective # 3: Determine the source and the impact of environmental stressors in the cave ecosystem

- Analyze one sample of bat guano for organo-chlorine pesticides.

- Measure DEHP concentrations in one sample each of storm water, crayfish tissue, isopod tissue, and bat guano.

- Analyze one sample each of crayfish and isopod tissue for accumulated metals, specifically lead, mercury, selenium, and copper.

- Perform a stable isotope ratio analysis of carbon and nitrogen on septic tank waste, bat guano, chicken litter, cow manure, oak leaf leachate, fescue leachate, crayfish tissue, isopod tissue, biofilm, and particulate organic matter in cave water.

- Map the aquifer recharge zone to identify potential problem areas using a geographical information system.

MONITORING SITE

Cave Springs Cave Natural Area is located in Cave Springs, Benton County, Arkansas. The cave is located at the following coordinates: latitude = 36 15' 40" and longitude = 94 13' 37", NE ¼, SE ¼, sec. 1, T.18 N., R.31 W., Benton County (007), HU: 11110103, Bentonville South Quadrangle. The Cave Springs Cave resurgence lies in the Osage Creek drainage basin and the larger Illinois River watershed. The cave complex lies at the contact between the St. Joe limestone geological formation and the Boone formation, which is a Mississipian age, chert-bearing limestone with many faults, joints, and fractures (Willis, 1984). In general, it is part of the Springfield Plateau of the Ozark Highlands, which lies in the western portion of a large karst area extending through the central United States (Woods and Inger, 1957).

The cave complex has a diffuse recharge with an estimated recharge area of 41 km^2 (15 mi^2), based upon the recharge area boundary delineation of Williams (1991). The total fall between the general location of the recharge area and the groundwater high to the cave spring is approximately 55 m over 4.8 km (Williams, 1991). The average annual temperature is 14.4 ^{o}C, with a seasonal variation of about 1 ^{o}C during the year. The average baseflow discharge is about 4 m^3/min. Please refer to the map of the cave in Appendix I for specific references to locations in the cave.

METHODS

This research was performed under Arkansas Natural Heritage Commission research permit # S-NHCC-98-009, U. S. Fish and Wildlife Service federal fish and wildlife permit #TE 834518-1, and Arkansas Game and Fish Commission scientific collecting permit #1082.

Environmental Quality Monitoring

Meteorological data, including air temperature, barometric pressure, and rain accumulation were taken from the Rogers Automatic Weather Observing / Reporting System (KROG), Rogers, Arkansas at the following Internet address:
http://tgsv7.nws.noaa.gov/weather/current/KROG.html
and from Drake Field (KFYV), Fayetteville, Arkansas, at the following address:
http://tgsv7.nws.noaa.gov/weather/current/KFYV.html. Stage and discharge measurements were measured every time water samples or other measurements were taken. Stage was read on a gauge *in situ* at the cave orifice, and discharge was computed from the relationship published previously (Brown *et al*., 1998). Base flow samples were collected at the spring orifice in the sluice leading to the water wheel, from July 1998 through May 1999, and downstream of all bat rookeries (see the cave map in Appendix I). Base flow samples were also collected twice, December 15, 1998, and February 23, 1999, at the waterfall at the very end of the accessible cave, approximately 0.5 k from the cave mouth, and upstream of all bat rookeries. Storm flow samples were collected at the spring orifice during each of three different storm events (3/8/99, 4/2/99, and 5/2/99) before, during, and after the peak discharge. All water samples were analyzed for some or all of the following parameters: temperature, conductance, pH, turbidity, ammonia + ammonium nitrogen, nitrate-nitrogen, nitrite-nitrogen, total Kjeldhal nitrogen (TKN),

dissolved reactive phosphate (ortho-phosphate), total phosphorus, total organic carbon (TOC), dissolved metals, total coliforms, and *Escherichia coli*. The data and information gained from these samples allowed preliminary interpretations concerning the state of the water quality and the potential of future contamination to the system. Analytical procedures followed approved U.S. Environmental Protection Agency methods and appropriate quality assurance and quality control measures. The water samples were analyzed at the Water Quality Laboratory, Arkansas Water Resources Center, Fayetteville, AR, and at the Environmental Chemistry Laboratory of the Arkansas Department of Environmental Quality (DEQ), Little Rock, AR.

For metals analyses, water samples were collected in pre-washed glass containers and immediately preserved with nitric acid, following EPA guidelines. For the metals analyses of crayfish (*Orconectes punctimanus*), two whole individuals (55 cm male and 53 cm female) were captured by net and immediately frozen for transport in a glass vial with Teflon lid. The crayfish were then dried in a drying oven at 60 C, pulverized, and analyzed at the Central Analytical Laboratory (CAL), Center for Excellence in Poultry Science, University of Arkansas. For the metals analysis of sewage sludge, cave sediments and cave biofilm, the samples were collected in pre-washed glass containers, stored in ice and immediately transferred back to the University of Arkansas where they were then dried in a drying oven at 60 C, pulverized, and analyzed at CAL. The sample of sewage sludge was collected directly from the belt press at the Springdale Sewage Treatment Plant, courtesy of Gene Andrews, plant manager.

For pesticide and semi-volatile organic compound analyses, a 2 L water sample was collected in a certified pesticide-free glass jug with Teflon lid and immediately air-shipped to the DEQ lab. Ten whole crayfish *(O. punctimanus*) were collected and immediately frozen for transport in a glass vial with Teflon lid. Bat guano (feces) were collected for several weeks in floating plastic surgical trays and then immediately frozen for transport in a glass vial with Teflon lid. All of these samples were sent to the DEQ lab for analysis of pesticides and semi-volatile organics following EPA guidelines.

Stable Isotope Analyses

In general, samples for stable isotope analyses were collected in glass bottles with Teflon lids, transported on ice, oven-dried, pulverized, and passed through a 30-mesh screen. Samples were sent to the Stable Isotope Ratio Facility for Environmental Research (SIRFER), University of Utah, Salt Lake City, UT, for natural abundance carbon and nitrogen isotope ratio analyses. Particulate organic matter was filtered from cavewater onto precombusted glass fiber (GF/F) filters, dried, and then scraped off into clean glass tubes. Crayfish (*O. punctimanus*) were collected by dipnet, preserved in ice, and brought back to the lab where the abdominal muscles were excised, dried, and pulverized. Isopods (*Caecidotea sp*.) were dried and ground whole. Poultry litter (rice hull bedding) was obtained from Dr. Sauer at the Savoy Experimental Watershed, as was beef cattle manure and effluent from a confined swine facility. Septic system leachate was collected from a failed residential septic system leach field in Washington County. Biofilm was collected by scraping cave rocks with a sterile toothbrush and cave water, which was then condensed and acidified with 0.1 N HCL on a GF/F filter to evolve carbonates, dried, and then scraped off into clean glass tubes. Cave sediment was also acidified with HCl before drying and grinding. The sample of sewage sludge was collected directly from the belt press at the Springdale Sewage Treatment Plant, courtesy of Gene Andrews, plant manager.

Cavefish Population Monitoring

The visual survey was performed by the same method as previous surveys and included at least two of the people used in a previous survey (Brown and Todd, 1987: Willis and Brown, 1985). Using helmet lights as well as powerful diving lights underwater, three people moved slowly upstream and counted cavefish as they were sighted. This method can produce fairly reliable quantitative population information with minimal impact on the cave habitats and their inhabitants, endangered or otherwise. Pearson *et al*. (1995) reported that the use of powerful dive lights underwater increased significantly the number of fishes observed over typical dry caving lights. C. Stanley Todd and Brian Wagner, both of the Arkansas Game and Fish Commission, assisted with the surveys.

Recharge Zone Analyses

The accessible portions of the cave were surveyed using a Suunto compass and 100 m fiberglass tape, over a series of three surveying trips. The U. S. Geological Survey station water level gauge at the cavemouth was used as the zero datum. At each survey station, the cross-section was described by measuring passage width, height, and substrate type, and stream width and height. The cartographic methods followed the National Speleological Society's standards (Dasher, 1994) at a scale of 1 cm: 10 m. Appendix I shows a reproduction of this cave map. The finished map was then overlayed with a grid (cm^2), and stream surface area calculated.

A geographic information system was created using ArcView 3.1 and Spatial Analyst Extension (ESRI), with the aid of Alex Johnson and Guy Graening of HSI-Geotrans (a TetraTech company, Sacramento, CA). Aerial photographs of the recharge zone were furnished by Dr. John Harris of the Arkansas State Highway and Transportation Department. The recharge zone boundary, water table contours and photo-lineaments/fracture traces were redrawn from Williams (1991) onto the Bentonville South and Springdale quads and digitized. The digital elevation model and topographic maps were acquired from the U. S. Geological Survey. A Garman III Plus global positioning system handheld unit was used to register specific locations (such as sinkholes) in the recharge zone during ground-truthing.

RESULTS

Environmental Quality

The results of the water quality analyses are shown in Tables 1 through 5, and indicate that significant amounts of nutrients, fecal bacteria, and heavy metals are present in the cave stream. Dissolved oxygen, pH, conductivity, and temperature all met Arkansas State Water Quality Standards (Regulation 2, Department of Environmental Quality), but fecal coliforms, total phosphorous, and several dissolved metals did not. Turbidity exceeded the Regulation 2 standard during every storm event measured, but it could not be determined if the cause of this turbidity was natural or due to surface activities within the spring's recharge zone.

Arkansas State Regulation 2 requires that ecologically sensitive water bodies and primary contact waters, such as the resurgence at Cave Springs Cave, do not exceed fecal coliform counts of 200 MPN/100mL between April 1 and September 30 and never exceed 1,000 MPN/100mL (Arkansas Pollution Control and Ecology Commission, 1998). During this study, the density of total coliforms in baseflow water samples averaged 5400 MPN/100mL, with the highest being 10,900 MPN/100mL. During stormflows, the density of total coliforms averaged 16,500 MPN/100mL with the highest being 83,100 MPN/100mL. Although dissolved oxygen remained at near-saturation levels, chemical analyses show that significant amounts of nutrients are in the cave system. During two storm events, total phosphorous exceeded the Regulation 2 limit of 100 µg P / L, with the highest concentration detected being almost twice the state standard.

While the cave's water did not exceed the Regulation 2 limit for total conductivity, many dissolved metals are present in significant quantities. Heavy metals are of special concern because they are in present in concentrations that the DEQ considers toxic to aquatic life. These Regulation 2 maximum contaminant levels (MCL) vary by the hardness of the water sample, and each dissolved metal MCL must be computed from the sample's hardness. Every water sample (baseflow and stormflow) exceeded the state limit of 5 µg Se / L for chronic aquatic organism selenium toxicity, and several samples exceeded the state limit of 20 µg Se/L for acute selenium toxicity. Every water sample except two exceeded the state limit of 3-4 µg Pb / L for chronic lead toxicity. One base flow and three storm samples exceeded the state limit of 130-160 µg Zn / L for acute zinc toxicity. Stormflow sampling of copper consistently detected concentrations greater than the state limit of 20-28 µg Cu / L for acute copper toxicity, and in the May storm event, exceeded the state limit 10-fold. One storm event and two baseflow samples detected beryllium in concentrations greater than the state's human health criteria of 0.076 µg Be / L. (Arkansas Pollution Control and Ecology Commission, 1998). In an effort to determine the source of these metals and any affects in the cave stream food web, samples of cave sediment, cave biofilm, crayfish, and sewage sludge were collected for metals analyses, and are shown in Table 6.

Cave water, gray bat guano, and crayfish tissue were analyzed for an array of pesticides and volatile organics, and the results are shown in Table 7. No pesticides were detected in the samples of gray bat guano, cave water, or crayfish from the cave. In the crayfish sample, eight semi-volatile organic compounds were detected: acetophenone, diethyl-phthalate (DEP), dimethyl-phthalate (DMP), diphenylamine, phenanthrene, di-n-butyl phthalate (DBP), butyl-benzyl-phthalate (BBP), and bis(2-ethylhexyl) phthalate (DEHP). Only DMP and DEP were present in concentrations significantly higher than the lab blank. In the water sample from the cave mouth, four phthalate compounds were detected (DEP, DBP, BBP, and DEHP) but only DEHP was present in a concentration significantly higher than the lab blank. The bat guano analysis detected six semi-volatile organic compounds: phenol, napthalene, DEP, DMP, BBP, and DEHP. Only phenol, DEP and DEHP were present in concentrations significantly higher than the lab blanks. Because the sample was collected in plastic trays (which could leach phthalate plasticizers), accidental contamination cannot be ruled out and the DEP and DEHP concentrations of guano must be interpreted with caution.

Combining all of the known water quality data of Cave Springs Cave (since 1984 - see summary by Brown *et al*., 1998) with this year's data, a time-series analysis was performed upon each constituent using regression techniques. Statistically significant upward trends in conductivity (p value = 0.0002), nitrate (0.028), zinc (0.002), and, with less confidence, lead (0.066) were detected. Figure 3 shows the trends of these constituents.

In order to determine any relationships among the water quality variables, pair-wise correlations were performed upon the data collected from this year's study and last year's study, with baseflow data being combined with stormflow data (Brown *et al*., 1998). Discharge was found to be directly correlated with turbidity (p value = 0.0001), TOC (0.0001), nitrate (0.0001), total P (0.014), PO_4 (0.0001), *E. coli* (0.0001), total coliforms (0.0001), and the metals Al (0.0001), Ba (0.0019), Cu (0.001), Fe (0.005), and Pb (0.072) and inversely correlated with conductivity (0.0001). Conductivity was found to be inversely correlated with turbidity (p value = 0.008), nitrate (0.002), PO_4 (0.0005). Total coliforms densities were found to be significantly correlated with turbidity (p value = 0.0004), TOC (0.0001), total P (0.003), PO_4 (0.0001), TKN (0.0002), nitrate (0.044), and the metals Al (0.0001), Ba (0.049) and Fe (0.023). *E. coli* was found to be significantly correlated to turbidity (p value = 0.0003), TOC (0.0001), total P (0.0001), PO_4 (0.0001), TKN (0.0001), and the metals Al (0.0001), Cu (0.006), Fe (0.0001) and inversely correlated with conductivity (0.030).

Table 1. Summary of baseflow water quality data at the cave mouth, Cave Springs Cave, AR, during this study (1998-1999).

	Date	7/16/98	8/17/98	9/13/98	10/5/98	11/13/98	3/8/99	5/3/99
Physical								
Water Temp.	Celsius	14.8	15	14.8	15.2	---	14.5	14.4
Water Stage	m	3.16	3.13	3.13	3.13	3.12	3.124	3.274
Discharge	m^3/min	3	2	2	2	2	2	7
Spec. Cond.	uS/cm	390	370	395	352	---	340	350
Turbidity	N.T.U.	0.7	1.1	0.7	0.3	0.3	0.8	0.9
pH, field		6.79	6.52	---	---	---	7.05	---
D. Oxygen	mg/l	11.6	11.4	10.8	9.2	---	8.9	8.3
Dissolved Metals								
Aluminum	ug/l	---	---	---	505	---	25	n.d.
Antimony	ug/l	---	---	---	6	---	n.d.	2
Arsenic	ug/l	---	---	---	5	---	2	n.d.
Barium	ug/l	---	---	---	51	---	54	61
Beryllium	ug/l	---	---	---	$\boxed{1}$	---	$\boxed{1}$	n.d.
Boron	ug/l	---	---	---	15	---	n.d.	n.d.
Cadmium	ug/l	---	---	---	n.d.	---	n.d.	$\boxed{1}$
Calcium	mg/l	---	---	---	---	---	64	54.6
Chromium	ug/l	---	---	---	4	---	n.d.	n.d.
Cobalt	ug/l	---	---	---	2	---	1	2
Copper	ug/l	---	---	---	$\boxed{16}$	---	n.d.	$\boxed{28}$
Iron	ug/l	---	---	---	221	---	10	n.d.
Lead	ug/l	---	---	---	$\boxed{32}$	---	$\boxed{10}$	$\boxed{39}$
Magnesium	mg/l	---	---	---	0.153	---	1.74	1.89
Manganese	ug/l	---	---	---	6	---	2	14
Molybdenum	ug/l	---	---	---	2	---	n.d.	n.d.
Nickel	ug/l	---	---	---	n.d.	---	n.d.	n.d.
Selenium	ug/l	---	---	---	$\boxed{6}$	---	$\boxed{13}$	$\boxed{14}$
Silicon	ug/l	---	---	---	389	---	4.08	4.17
Vanadium	ug/l	---	---	---	10	---	n.d.	n.d.
Zinc	ug/l	---	---	---	113	---	$\boxed{285}$	15
Nutrients								
T.O.C.	mg/l	1.62	1.63	1	0.77	0.86	---	---
D.O.C.	mg/l	1.98	1.4	1.46	1.48	0.77	---	---
Ammonia-N	ug/l as N	< 9	19	34	< 9	< 9	---	---
Nitrite-N	ug/l as N	---	< 3	---	< 3	< 1	2	< 1
Nitrate-N	mg/l as N	5.28	4.975	4.686	4.843	5.193	5.7	7.445
T.K.N.	mg/l as N	0.15	0.05	0.21	0.05	0.11	---	---
Total P	mg/l as P	0.04	0.033	0.047	0.07	0.043	---	---
Ortho-P	mg/l as P	0.029	0.026	0.018	0.02	0.022	0.025	0.025
Microbial								
E. coli	MPN/100ml	192	164	178	3240	32.4	73.8	150
Tot.Coliform	MPN/100ml	$\boxed{10130}$	$\boxed{10910}$	$\boxed{5310}$	$\boxed{8850}$	$\boxed{1013}$	271	$\boxed{1920}$

Legend: Box = exceeds Regulation 2 standard, "---" = no datum, "n.d." = not detected.

Table 2. Comparison of water quality data at the cave mouth (downstream of bat roosts), Cave Springs Cave, AR, and deep in the cave at the waterfall (upstream of bat roosts), 1997-1999.

	Location **Date**	cavemouth 12/17/97	waterfall 12/17/97	cavemouth 1/25/98	waterfall 1/25/98	cavemouth 12/15/98	waterfall 12/15/98	cavemouth 2/23/99	waterfall 2/23/99
Physical									
Water Temp.	Celsius	13.4	13.4	14.5	14.5	---	---	---	---
Water Stage	m	3.115	n/a	3.252	n/a	3.118	n/a	3.124	n/a
Discharge	m^3/min	1	n/a	6	n/a	2	n/a	2	n/a
Spec.Cond.	uS/cm	320	325	290	300	---	---	330	330
Turbidity	N.T.U.	1	3.4	0.01	0.01	---	---	---	---
pH, field		7.5	7.2	6.9	6.9	---	---	---	---
D. Oxygen	mg/l	9.5	9	10.3	8	---	---	---	---
Dissolved Metals									
Aluminum	ug/l	22	48	13	14	---	---	---	---
Arsenic	ug/l	< 12	< 12	< 12	< 12	---	---	---	---
Cadmium	ug/l	< 1	< 1	< 1	< 1	---	---	---	---
Chloride	mg/l	8.952	9.469	8.055	8.115	---	---	---	---
Copper	ug/l	27	29	24	34	---	---	---	---
Iron	ug/l	6	33	< 3	8	---	---	---	---
Lead	ug/l	< 11	< 11	< 11	14	---	---	---	---
Manganese	ug/l	0.6	2.9	0.6	1.5	---	---	---	---
Nickel	ug/l	< 24	< 24	< 24	< 24	---	---	---	---
Selenium	ug/l	< 15	< 15	< 15	< 15	---	---	---	---
Silver	ug/l	< 15	< 15	< 15	< 15	---	---	---	---
Sulfate	mg/l	7.13	7.319	3.6	4.67	---	---	---	---
Zinc	ug/l	18	18	19	29	---	---	---	---
Nutrients									
T.O.C.	mg/l	4.12	3.55	0.74	1.04	1.85	1.35	---	2.36
D.O.C.	mg/l	3.4	2.79	---	---	---	---	---	---
Ammonia-N.	ug/l as N	55	52	< 9	< 9	---	---	---	---
Nitrite-N	ug/l as N	< 3	< 3	< 3	< 3	---	---	---	---
Nitrate-N	mg/l as N	4.807	4.657	6.395	5.57	---	---	6.29	6.325
T.K.N.	mg/l as N	0.13	0.17	0.07	0.13	---	---	---	---
Total P	mg/l as P	0.029	0.027	0.023	0.023	---	---	---	---
Ortho-P	mg/l as P	0.029	0.028	0.034	0.031	---	---	---	---
Microbial									
E. coli	MPN/100ml	36.5	27.1	3.1	2	1184	738	11.1	4.2
Tot.Coliform	MPN/100ml	1445	1184	344	34.4	78.2	65.9	53.1	69.7

Note: "---" = datum not measured.

Table 3, Part 1. Summary of water quality data at the cave mouth, Cave Springs Cave, AR, during a storm event (3/8/99 to 3/20/99) with 9.7 cm rain accumulation.

	Date	3/8/99	3/8/99	3/9/99	3/10/99	3/13/99
Physical						
Rain accum.	cm	0	0	3.4	0	2.8
Water Temp.	Celsius	14.5	14.5	14.4	14.4	---
Water Stage	m	3.124	3.139	3.146	3.136	3.246
Discharge	m^3/min	2	2	3	2	6
Spec.Cond.	uS/cm	340	340	---	350	310
Turbidity	N.T.U.	0.8	12.3	1.9	1.9	12.1
pH, field	---	7.05	6.75	6.75	6.82	---
Diss. Oxygen	mg/l	8.9	9.1	9.1	9.1	---
Dissolved Metals						
Aluminum	ug/l	25	64	26	58	113
Arsenic	ug/l	2	5	4	4	3
Barium	ug/l	54	55	54	56	67
Beryllium	ug/l	$\boxed{1}$	n.d.	$\boxed{1}$	$\boxed{1}$	$\boxed{1}$
Boron	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Cadmium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Calcium	mg/L	64	62.1	62.9	61	51.5
Chromium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Cobalt	ug/l	1	1	1	n.d.	2
Copper	ug/l	n.d.	n.d.	n.d.	n.d.	10
Iron	ug/l	10	57	11	64	83
Lead	ug/l	$\boxed{10}$	$\boxed{10}$	$\boxed{11}$	$\boxed{9}$	2
Magnesium	mg/L	1.74	1.78	1.8	1.86	2.32
Manganese	ug/l	2	6	n.d.	18	13
Molybdenum	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Nickel	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Selenium	ug/l	$\boxed{13}$	$\boxed{16}$	$\boxed{7}$	$\boxed{20}$	$\boxed{14}$
Silicon	mg/L	4.08	4.01	4.06	4.09	4.18
Vanadium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Zinc	ug/l	$\boxed{285}$	$\boxed{288}$	$\boxed{159}$	2	7
Nutrients						
Ammonia-N.	mg/l as N	6.87	3.53	3.44	0.323	0.035
Nitrite-N	ug/l as N	2	4	1	104	7
Nitrate-N	mg/l as N	5.7	5.865	6.15	5.955	8.175
T.K.N.	mg/l as N	0.75	---	---	---	---
Total P	mg/l as P	$\boxed{0.193}$	0.088	0.091	0.057	0.057
PO4-P	mg/l as P	0.025	0.028	0.02	0.02	0.032
Microbial						
E. coli	MPN/100ml	73.8	1445	1091	1091	5040
Tot.Coliforms	MPN/100ml	271	$\boxed{5910}$	$\boxed{3840}$	$\boxed{5910}$	$\boxed{>20000}$

Legend: Box = exceeds Regulation 2 standard, "---" = no datum, "n.d." = not detected.

Table 3, part 2. Summary of water quality data at the cave mouth, Cave Springs Cave, AR, during a storm event (3/8/99 to 3/20/99) with 9.7 cm rain accumulation.

	Date	3/14/99	3/15/99	3/16/99	3/18/99	3/20/99
Physical						
Rain accum.	cm	1.9	0	0	0	1.6
Water Temp.	Celsius	---	---	---	14.5	14.5
Water Stage	m	3.292	3.319	3.356	3.347	3.31
Discharge	m^3/min	8	9	10	10	8
Spec.Cond.	uS/cm	310	310	310	320	---
Turbidity	N.T.U.	6.5	5.1	---	---	---
Diss. Oxygen	mg/l	---	---	---	10	---
Dissolved Metals						
Aluminum	ug/l	136	49	---	99	105
Arsenic	ug/l	5	5	---	4	7
Barium	ug/l	67	64	---	62	62
Beryllium	ug/l	$\boxed{1}$	$\boxed{1}$	---	$\boxed{1}$	$\boxed{1}$
Boron	ug/l	n.d.	n.d.	---	n.d.	n.d.
Cadmium	ug/l	n.d.	n.d.	---	n.d.	n.d.
Calcium	mg/L	49.2	50	---	50.5	53.7
Chromium	ug/l	n.d.	n.d.	---	n.d.	n.d.
Cobalt	ug/l	1	1	---	1	1
Copper	ug/l	n.d.	7	---	$\boxed{42}$	$\boxed{33}$
Iron	ug/l	88	39	---	93	61
Lead	ug/l	1	$\boxed{5}$	---	$\boxed{5}$	$\boxed{26}$
Magnesium	mg/L	2.35	2.33	---	2.32	2.21
Manganese	ug/l	5	4	---	4	n.d.
Molybdenum	ug/l	n.d.	n.d.	---	n.d.	n.d.
Nickel	ug/l	n.d.	n.d.	---	n.d.	n.d.
Selenium	ug/l	$\boxed{12}$	$\boxed{6}$	---	$\boxed{17}$	$\boxed{17}$
Silicon	mg/L	4.48	4.32	---	4.45	5
Vanadium	ug/l	n.d.	n.d.	---	n.d.	n.d.
Zinc	ug/l	n.d.	n.d.	---	12	n.d.
Nutrients						
Ammonia-N.	mg/l as N	< 0.005	< 0.005	0.013	< 0.005	< 0.009
Nitrite-N	ug/l as N	3	2	1	< 1	< 1
Nitrate-N	mg/l as N	8.172	8.256	7.6	8.74	7.46
Total P	mg/l as P	0.057	0.057	0.052	0.041	---
PO4-P	mg/l as P	0.039	0.032	0.024	0.025	0.02
Microbial						
E. coli	MPN/100ml	1110	2880	>200.5	406	101.3
Tot.Coliforms	MPN/100ml	$\boxed{>20000}$	$\boxed{>20000}$	>200.5	$\boxed{1652}$	$\boxed{1184}$

Legend: Box = exceeds Regulation 2 standard, "---" = no datum, "n.d." = not detected.

Table 4. Summary of Water Quality Data at the cave mouth, Cave Springs Cave, AR, during a storm event (4/2/99 to 4/5/99), with 7.1 cm rain accumulation.

	Date	4/3/99	4/3/99	4/4/99	4/5/99
Physical					
Rain accum.	cm	6.35	0	0	0.8
Water Temp.	Celsius	---	14.3	14.4	14.5
Water Stage	m	3.32	3.44	3.45	3.41
Discharge	m^3/min	9	13	14	12
Spec.Cond.	uS/cm	330	300	295	305
Turbidity	N.T.U.	19.3	20	14.2	5.9
pH, field		---	6.2	6.6	6.6
Diss. Oxygen	mg/l	---	9.5	9.9	10
Dissolved Metals					
Aluminum	ug/l	150	270	220	100
Antimony	ug/l	n.d.	n.d.	n.d.	n.d.
Arsenic	ug/l	2	12	12	14
Barium	ug/l	71	77	71	67
Beryllium	ug/l	n.d.	n.d.	n.d.	n.d.
Boron	ug/l	n.d.	n.d.	23	33
Cadmium	ug/l	n.d.	n.d.	n.d.	n.d.
Calcium	mg/l	53.4	46.3	45	46.7
Chromium	ug/l	n.d.	n.d.	n.d.	n.d.
Cobalt	ug/l	1	n.d.	n.d.	n.d.
Copper	ug/l	23	10	7	6
Iron	ug/l	510	640	370	150
Lead	ug/l	22	20	12	29
Magnesium	mg/l	2.13	2.33	2.29	2.29
Manganese	ug/l	29	31	22	16
Molybdenum	ug/l	n.d.	n.d.	n.d.	n.d.
Nickel	ug/l	n.d.	n.d.	n.d.	n.d.
Selenium	ug/l	8	15	18	12
Silicon	mg/L	6.7	6.8	5.5	4.7
Vanadium	ug/l	8	3	n.d.	n.d.
Zinc	ug/l	12	17	13	11
Nutrients					
T.O.C.	mg/l	3.4	3.7	3.8	2.5
Nitrite-N	ug/l as N	10	12	10	3
Nitrate-N	mg/l as N	6.74	8.021	7.374	8.235
Ortho-P	mg/l as P	0.054	0.054	0.062	0.042
Microbial					
E. coli	MPN/100ml	4060	10910	20050	2220
Tot. Coliforms	MPN/100ml	20050	20050	20050	5910

Legend: Box = exceeds Regulation 2 standard, "---" = no datum, "n.d." = not detected.

Table 5. Summary of Water Quality Data at the cave mouth, Cave Springs Cave, AR, during a storm event (5/2/99 to 5/5/99), with 6.7 cm rain accumulation.

	Date	5/3/99	5/4/99	5/4/99	5/5/99	5/6/99
Physical						
rain accumul.	cm	2	0	4.5	0.2	0
Water Temp.	Celsius	14.4	14.4	14	14.4	14.3
Water Stage	m	3.274	3.292	3.52	3.633	3.545
Discharge	m^3/min	7	8	16	20	17
Spec.Cond.	uS/cm	350	360	250	280	280
Turbidity	N.T.U.	0.9	1.2	48	18.1	8.1
Diss. Oxygen	mg/l	8.3	8.9	9	8.8	8.7
Dissolved Metals						
Aluminum	ug/l	n.d.	39	275	220	201
Antimony	ug/l	2	n.d.	n.d.	n.d.	n.d.
Arsenic	ug/l	n.d.	n.d.	n.d.	n.d.	6
Barium	ug/l	61	62	95	66	67
Beryllium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Boron	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Cadmium	ug/l	$\boxed{1}$	n.d.	n.d.	n.d.	n.d.
Calcium	mg/l	54.6	54.3	30.1	39.1	38.1
Chromium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Cobalt	ug/l	2	2	2	2	2
Copper	ug/l	$\boxed{28}$	11	$\boxed{31}$	$\boxed{230}$	$\boxed{27}$
Iron	ug/l	n.d.	n.d.	156	147	156
Lead	ug/l	$\boxed{39}$	$\boxed{38}$	$\boxed{15}$	$\boxed{36}$	$\boxed{28}$
Magnesium	mg/l	1.89	1.91	2.53	1.96	2.08
Manganese	ug/l	14	14	45	24	19
Molybdenum	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Nickel	ug/l	n.d.	n.d.	1	3	n.d.
Selenium	ug/l	$\boxed{14}$	$\boxed{17}$	$\boxed{17}$	$\boxed{18}$	$\boxed{16}$
Silicon	mg/l	4.17	4.27	3.74	4.08	4.42
Vanadium	ug/l	n.d.	n.d.	n.d.	n.d.	n.d.
Zinc	ug/l	15	6	20	$\boxed{133}$	19
Nutrients						
T.O.C.	mg/l	2.7	2.7	5.1	4.7	4.6
Ammonia-N	mg/l as N	0.017	< 0.005	---	< 0.005	< 0.005
Nitrite-N	ug/l as N	< 1	< 1	26	13	< 1
Nitrate-N	mg/l as N	7.445	6.14	8.245	6.218	7.595
Total P	mg/l as P	0.026	0.027	$\boxed{0.149}$	$\boxed{0.174}$	$\boxed{0.123}$
PO4-P	mg/l as P	0.025	0.025	0.057	0.103	0.096
Microbial						
E. coli	MPN/100ml	150	782	5300	16520	10130
Tot.Coliforms	MPN/100ml	$\boxed{1920}$	$\boxed{5310}$	$\boxed{38400}$	$\boxed{40600}$	$\boxed{83100}$

Legend: Box = exceeds Regulation 2 standard, "---" = no datum, "n.d." = not detected.

Table 6. Metal concentration (dry matter basis, mg/kg) of sediment, biofilm, crayfish, and guano from Cave Springs Cave, AR, and sewage sludge from Springdale Sewage Treatment Plant, Springdale, AR.

	Sludge	Sediment	Biofilm	Crayfish	Guano
Aluminum	7574	42616	21651	772.5	2294
Antimony	n.d.	n.d.	n.d.	n.d.	n.d.
Arsenic	1.95	20.3	10.1	n.d.	1.4
Barium	237	161.95	---	129.8	163.7
Beryllium	0.07	5.4	1.9	n.d.	0.31
Boron	21.5	n.d.	n.d.	n.d.	1
Cadmium	1.09	5	0.98	1.67	9.4
Calcium	22900	15000	144000	148600	3652
Chromium	23.1	39.1	24.6	1.88	5
Cobalt	3.74	18.2	9.2	0.61	6.7
Copper	190.3	34.4	18	118	434.9
Iron	6995	32977	16400	339.8	5044
Lead	25.5	45	17.3	2.37	19.9
Magnesium	8400	2805	1870	1413	2055
Manganese	192.5	---	---	51.2	112.9
Molybdenum	10.4	0.69	0.38	n.d.	8.3
Nickel	57.6	86.5	27.1	2.27	18.2
Selenium	4.27	3.4	2.6	3.39	n.d.
Silicon	1194	2001	1710	1505	1334
Vanadium	20.4	138	74	1.79	27.2
Zinc	454	384.7	162.3	100.5	904

Note: "---" indicates no datum, "n.d." indicates not detected.

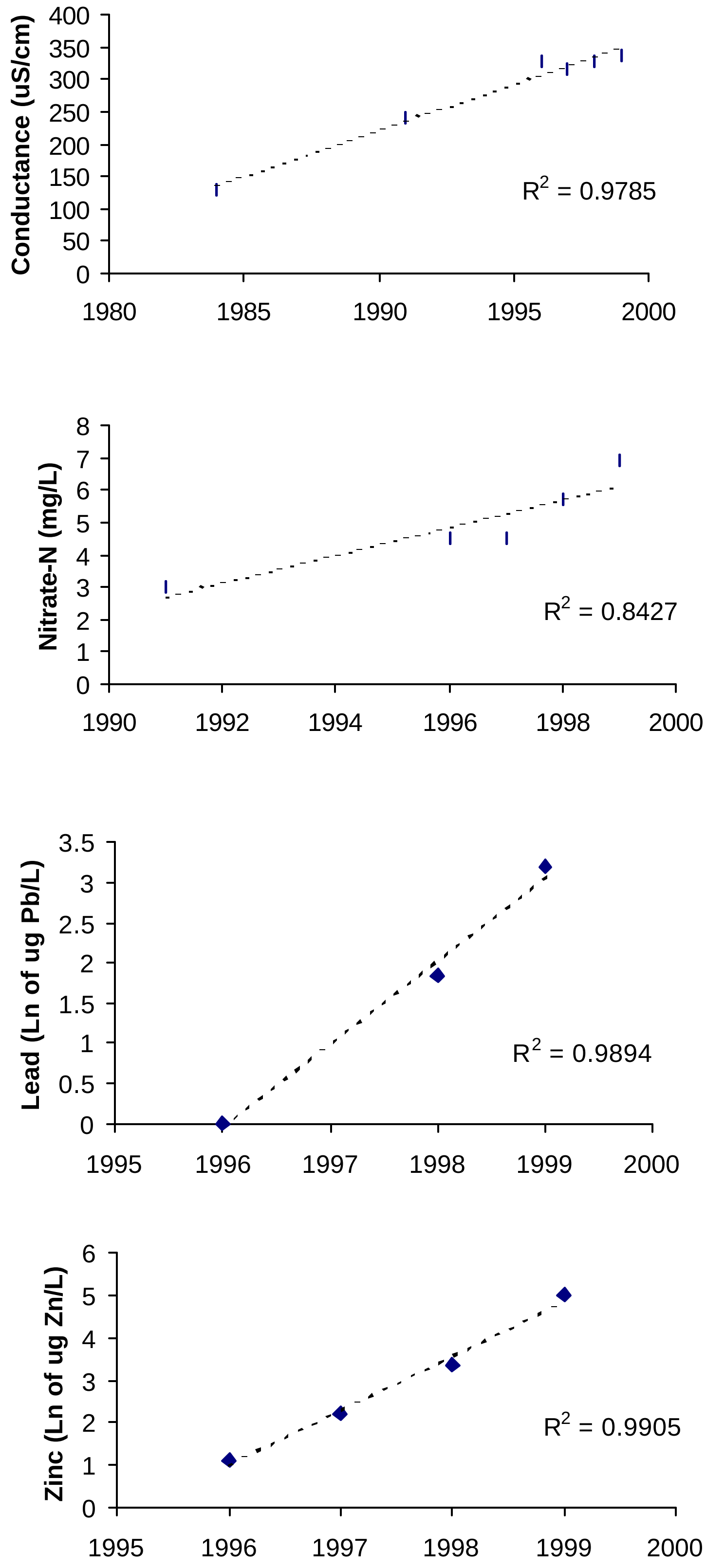

Figure 3. Graphs showing the increase over time of conductance, nitrate, lead, and zinc in Cave Springs Cave, AR, stream water during base flow using all available data.

Table 7. Selected results of the semi-volatile organic compound testing, in µg/L, at Cave Springs Cave at the cave mouth during base flow. Abbreviations: BBP = butyl-benzyl-phthalate; DBP = di-n-butyl-phthalate; DEP = diethyl-phthalate; DEHP = di-ethylhexyl-phthalate; and DMP = di-methyl-phthalate.

	BBP	DBP	DEP	DEHP	DMP
Water	0.10	0.15	0.04	0.72	
Blank	0.17	0.42	0.05	0.19	
Guano	0.15		0.26	0.40	0.02
Blank	0.35		0.22	0.23	0.01
Crayfish	0.52	1.48	0.99	0.99	0.21
Blank	0.30	1.30	0.19	0.19	0.21

Table 8. Results of the stable isotope analyses of constituents in the Cave Springs Cave foodweb and potential organic matter inputs, using delta (per mil) notation.

	Date	Carbon C13/C12	Nitrogen N15/N14
Bat Guano	1/1/98	-24.1	11.3
	3/1/98	-24.6	13.3
	9/1/98	-25.0	9.7
	12/1/98	-24.3	13.9
Crayfish	1/1/98	-29.6	9.0
	3/12/98	-29.9	11.5
	8/1/98	-28.1	10.7
	12/1/98	-24.8	13.6
Cave Biofilm	6/20/98	-36.1	6.3
	7/1/98	-31.9	5.7
Septic Waste	10/1/98	-21.9	4.0
	10/1/98	-21.2	4.0
Cave Sediment	10/1/98	-24.9	6.9
	11/1/98	-26.5	6.6
Isopod	12/1/98	-21.8	11.6
Fescue	11/1/98	-28.8	6.3
Cow Manure	12/1/98	-25.1	3.5
Chicken Litter	12/1/98	-15.2	7.9
Swine Effluent	12/1/98	-16.3	4.8

Stable Isotope Analyses

The results of the carbon and nitrogen stable isotope assays by SIRFER are still pending. The partial results are shown in Table 8. It is difficult to make any interpretations of these preliminary data until the analyses are complete. However, preliminary inspection indicates that swine effluent, cow manure, and poultry litter may not be contributing significantly to the foodweb. The data also suggests that biofilm may be important in the diet of crayfish.

Cavefish Population Status

In the latest survey, 166 individuals were counted, the most ever recorded for this habitat (and for any other habitat). Figure 4 shows all of the surveys conducted by Brown and colleagues. Cavefish counts in Cave Springs Cave increased steadily from 1981 through 1995 (Figure 4). We found only 106 fish in the cave in January 1998 using the same survey methods. During this survey, few large cavefish were seen and little other cavelife was observed. Later, in December 1998 we returned to repeat the survey and observed 166 fish. Nine were observed in the south passage, and 157 were seen in the north passage (95 upstream to the first bat roost, then 60 upstream to the first waterfall, and 2 above the waterfall). On this survey, many large cavefish were seen and many cave salamanders were present.

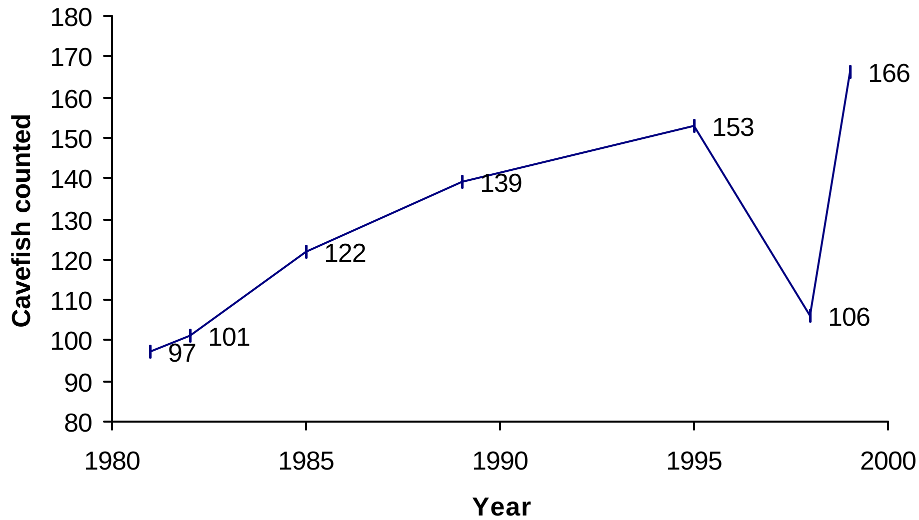

Figure 4. Summary of all visual surveys performed by Brown and colleagues in Cave Springs Cave (Brown *et al*, 1987, 1998).

Recharge Zone Analyses

The cave survey produced a final map, shown in Appendix 1. A total of 481 meters of cave passage were surveyed, with several tight leads left unexplored. Based upon the final map, it was determined that there is about 900 m^2 of stream surface area at average baseflow. An ArcView 3.1 GIS was created and the various data layers combined. Some data layers are still pending but some analyses are complete. When the cave map was overlayed upon the Cave Springs Cave Natural Area property boundary, it was determined that the cave extends significantly past the Natural Area boundary (see Appendix II). Several sinkholes were also found within 1000 m of the cave complex (and within the recharge zone) that may connect surface runoff to groundwater in the cave stream.

DISCUSSION

Environmental Quality in Cave Springs Cave

The fractured and dissolved carbonate terrain (karst) of Northwest Arkansas is highly susceptible to pollution from land application of animal wastes and other waste disposal practices (MacDonald *et al*., 1976). Karst conduits can modify transport of surface pollutants to groundwater such that non-point source pollution is concentrated, and behaves more like point source pollution (Pasquarell and Boyer, 1996). Karst terrains allow livestock-related bacteria to be transported by water from the surface, through the aquifer, and back out through resurgent springs (Pasquarell and Boyer, 1996). Bacterial contamination (especially from septic system leachate) is considered the most serious threat to Ozark groundwater quality (MacDonald *et al*., 1974; MacDonald *et al*., 1976; Steele, 1985). Seventy-eight percent of the wells and an estimated 90% of the springs in Northwest Arkansas are contaminated with coliform bacteria (Ogden, 1979; Steele, 1985). The spring issuing out of Cave Springs Cave has an exceptionally high fecal pollutant load with average fecal coliform counts in the thousands (MPN/100mL) and peak storm flow counts approaching one hundred thousand (MPN/100mL).

It is difficult to determine the source of the fecal coliforms because the microflora of humans, bats, and livestock are quite similar. Measurements upstream of bat colony roosts indicate that the source of fecal bacteria originates from the recharge zone (see Table 2) and not bat guano. While Williams (1991) lists bat guano as a possible fecal coliform source, he discounted it because surrounding streams that recharge Cave Springs Cave stream had similarly high levels of coliforms. It is especially unlikely that guano input is significant in the winter season because most of the bats do not overwinter in this cave and, in general, the reduced metabolism of bats during hibernation would result in negligible guano inputs into the cave foodweb during winter (Harvey, 1992). Septic system leachate, livestock manures, and sewage sludge are other possible sources of the high fecal coliform loads in this groundwater ecosystem. Total coliform densities were found to be significantly correlated with turbidity, ortho-phosphate, nitrate, and discharge in this system. Such correlations strengthen the conclusion that the fecal coliforms originate from the surface and are being flushed in during storm events.

Studies have shown that land uses such as manure application, grazing, and septic system treatment have directly contaminated the Springfield Plateau aquifer with nitrate (see review by Smith and Steele, 1990), and nitrates do not occur naturally in the rocks of northwest Arkansas (Willis, 1978). Nitrate is not a direct toxicant, but nitrate can be reduced to nitrite by humans and aquatic organisms in their gastrointestinal tracts (U.S. Environmental Protection Agency, 1998). Nitrite exposure can cause anoxemia, which causes tissue damage or even death, and nitrite is implicated as a cause of stomach cancer and birth defects (see review by Smith and Steele, 1990; USEPA, 1998). High nitrite levels can cause anemia and tissue damage in fishes (Eddy and Williams, 1987). Ogden (1979) implicated septic leachate and animal waste in the pollution of the Boone-St. Joe aquifer by nitrates, sulfates, phosphates, and chlorides. Steele and Adamski (1987) confirmed these pollution effects in a study that compared water quality in wells near septic systems and confined animal operations and those far from these land uses. Smith and Steele (1990) attributed unusually high nitrate concentrations of groundwater to faulty septic systems, and they found an average of 2.6 mg/L and 1.8 mg/L of NO_3-N in the Springfield Plateau aquifer of Benton County in wet and dry seasons, respectively. Cave Springs Cave groundwater has a yearly average of over 5 mg/L NO_3-N.

Eutrophication is commonly defined as a process that increases the nutrients, especially nitrogen and phosphorous, in an aquatic system, with a corresponding increase in algae populations and a decrease in diversity (Academic Press Dictionary of Science and Technology, 1992). Brown *et al.* (1998) noticed a statistically significant upward trend in some of the water quality parameters in Cave Springs Cave, including conductivity (p value = 0.033) and ammonia (0.035). At the 90% confidence level, nitrate, total phosphorous, chloride, copper, lead, and zinc were also significant. This trend of increase continues with water quality data collected since the 1998 publication, with statistically significant upward trends in conductivity (p value = 0.0002), nitrate (0.028), zinc (0.002), and, with less confidence, lead (0.066). To control nuisance aquatic vegetation, Regulation 2 sets a standard of 100 μ/L of phosphorous for streams. Several stormflow water analyses of the cave stream detected total phosphorous levels well above this limit. On March 8, 1999, for example, concentrations of total phosphorous reached 193 μ/L. In 1998, water analysis of Lake Keith detected only 26 μ/L of total phosphorous, which is well below the Regulation 2 limit of 50 μ/L total phosphorous for lakes and reservoirs (Brown *et al.*, 1998). However, Lake Keith appears to be eutrophying, with algae covering all submerged surfaces and a constant nuisance odor of decaying algae coming from the lake. Mark Collier, landowner of Lake Keith, believes that the amount of algae in the lake has increased noticeably in the twenty years that his family has owned the lake (Mark Collier, pers. comm., 1999).

A study conducted by the DEQ (1984) determined that the Springdale Sewage Treatment Plant's discharges were nutrifying Osage Creek and compromising the water quality, the invertebrate community, and the entire ecosystem in Spring Creek. Since then, remedial measures were taken and Williams (1991) reports improved water quality in Spring Creek. The data from our monitoring efforts and other studies indicates that not only the Cave Springs Cave stream, but the entire Osage Creek drainage basin, is experiencing pollution enrichment and degradations in water quality. Because of the lack of sunlight in the cave ecosystem, the growth of aquatic vegetation is not an issue. Nevertheless, nutrient enrichment has negative effects on cave ecosystems, including the alteration of the community assemblage, the impoverishment of biodiversity, and the increased risk of predation and competition from surface animals. Septic pollution has eradicated the invertebrates from other cave systems (e.g. Aley, 1976). We have not seen the rare and state-listed amphipod, *Stygobromus ozarkensis,* in Cave Springs Cave, where it was formerly reported (Natural Diversity Database, ANHC, 1999). However, isopods (*Caecidotea* sp.) are abundant in Cave Springs Cave, which parallels the findings of Simon and Buikema Jr. (1997) in a cave system polluted with septic waste (Banners Corner Cave, VA). Simon and Buikema Jr. (1997) found that stygobitic isopods (*Caecidotea recurvata*) could use sewage-fed bacteria as a food source and that population densities were higher in cave pools with moderate sewage enrichment, while amphipods (*Stygobromus mackini*) were very sensitive to sewage pollution and were absent from Banners Corner Cave. The similar dearth of amphipods and abundance of isopods and organic pollution in Cave Springs Cave may implicate the many septic systems in the recharge zone of this cave stream in the alteration of the community assemblage.

No pesticides were detected in the samples of water, crayfish tissue, and bat guano from this study, and none have been detected in past studies at this site (Aley and Aley, 1979; Brown *et al*., 1998). A USGS study of water quality in the Ozark Plateaus (Petersen *et al*., 1998) detected pesticides in 90% of surface stream study sites and about 30% of groundwater study sites, with Atrazine and its metabolites being the most common pesticide detected. While some studies have implicated pesticides in bat mortalities (Clark Jr. and Donald, 1981), the lack of pesticides in this cave complex suggests that pesticides are not responsible for the decline of gray bats in Cave Springs Cave. Several semi-volatile organic compounds were detected in the cave ecosystem. Of special concern is the confirmed presence of phthalates, especially DEHP. The crayfish tissue analysis detected at least two phthalate compounds (DEP and DEHP) and the cave water analysis detected DEHP. Last year's study also detected DEHP in crayfish tissue (Brown *et al*., 1998). Because of their widespread use and persistence, phthalates are ubiquitous environmental contaminants (Jobling *et al*., 1995; U.S. EPA, 1998b). Phthalates act as hormone disrupters (Jobling *et al*., 1995), and DEHP is a probable human carcinogen and teratogen, and is known to bioaccumulate in aquatic organisms, including fish (U.S. EPA, 1998b). The compound DEHP has low acute toxicity to aquatic life, but long-term effects are unknown. Chronic toxic effects on humans include shortened lifespan, reproductive problems, lower fertility, and behavior changes (U.S. EPA, 1998b). Because the half-life of DEHP is only one to two weeks in aquatic systems (U.S. EPA, 1998b), such bioaccumulation in crayfish tissue implies a reoccurring presence of DEHP in the cave complex, and thus a significant surface pollution source in the recharge zone.

The presence of heavy metals in the water and foodweb are also of concern. Selenium, zinc, and copper are present in concentrations that are acutely toxic to aquatic life, and lead is present in concentrations that are toxic to aquatic life when chronically exposed, such as in the Cave Springs Cave stream. Beryllium is present in concentrations that are toxic to human health. The source of these heavy metals is still unknown, and may consist of several point and non-point sources. It is very unlikely that the metals naturally occur in this cave complex. Of all the trace metals, only iron and manganese occur in St. Joe and Boone limestones in sufficient concentrations to contaminate groundwater (Wagner *et al*., 1975). Some cavefish habitats such as Cave Springs Ranch Cave in Oklahoma have high zinc levels because of their proximity to abandoned zinc mines (Brown and Willis, 1984). Although surrounding Arkansas counties have potential commercial amounts of zinc (and associated cadmium and lead), Benton County is not known to contain significant zinc deposits (Steele, 1984). Metal pollution of groundwater in Washington County has been attributed to landfill leachate, confined animal operations, and industrial waste ponds (MacDonald *et al*., 1974). A USGS study of water quality in the Ozark Plateaus (Petersen *et al*., 1998) compared stream sites associated with mining to those sites considered not to be influenced by mining. The lead and zinc concentrations at these background sites are compared to this study's findings in Table 9 below. Lead concentrations in samples of water, bed sediment, and crayfish tissue in Cave Springs Cave exceed the background levels for the Ozark Plateaus region. Zinc concentrations in samples of water and sediment in Cave Springs Cave exceed the background levels for the Ozark Plateaus region.

Table 9: Comparison of lead and zinc concentrations in water, sediment, and crayfish tissue at Cave Springs Cave and background sites of the USGS NAWQA study (Petersen *et al*., 1998). Lead and zinc concentrations for water in Cave Springs Cave are an average of base flow values during this study (1998-1999).

	Lead			**Zinc**		
Location	**Water (ug/l)**	**Sediment (ug/g)**	**Tissue (ug/g)**	**Water (ug/L)**	**Sediment (ug/g)**	**Tissue (ug/g)**
Cave Springs	27	45	2.4	138	385	101
USGS study sites	<1 - 20	15-28	< 0.1- 0.6	< 1 -44	43 -140	57 -230

Some of the trace elements identified by the EPA to be of greatest environmental concern (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn) are added to animal feed as biocides or growth stimulators (As, Cu, Se, and Zn) (Sims, 1995). All of these metals have been detected in Cave Springs Cave water and sediment (except for mercury, which was not measured). During an inspection of the Cave Springs Cave Natural Area, we found at least seven, empty 5-gallon buckets of aluminum roof coating discarded in a dry wash upstream of the spring resurgence. It could not be determined if the contents of these buckets had been dumped on the land or not, but if so, could contribute metals to the groundwater, especially aluminum. The land-application of sewage sludge is a potential metal contaminant of caves (McReynolds, 1976). At least ten dry tons of sewage sludge was applied on 94 acres of pasture that lies within the recharge zone boundary of Cave Spring Cave between the years of 1990 and 1996 (G. Andrews, Springdale Sewage Treatment Plant Manager, pers. comm.). While the concentrations of metals in sewage sludge from the Springdale STP fall within the ceiling concentrations for sewage sludge pollutants determined by the National Sewage Sludge Rule (Part 503 of the Clean Water Act, 1993), the fractured limestone terrain of Benton County could allow sludge to quickly enter the Springfield Plateau aquifer and the cave complex. Analysis of Cave Springs Cave stream sediment reveals that heavy metals are present in similar concentrations as in the sludge (see Table 6). Similar concentrations are also present in microbial films (biofilm) and crayfish tissue in the cave, implying that these metal contaminants are bioaccumulating in the foodweb. Because sewage sludge is a probable organic and metal contaminant of this Arkansas Natural

Area, the cessation of sludge application in the recharge zone is suggested. Furthermore, remediation measures may be appropriate, such as passive collection by activated charcoal.

Cavefish Population Dynamics

Ironically, cavefish numbers in Cave Springs Cave are at an all time high while their aquatic habitat appears to be polluted. If the low count of January 1998 is treated as an outlier, the cavefish population has significantly increased in the last 20 years, with a yearly rate of increase of 3% and a population doubling time of 23 years, as shown in Figure 5. In his definitive study on Amblyopsid cavefishes, Poulson (1969) reported a density of 0.15 *A. rosae* / m^2. Based upon our cave survey, we calculate that Cave Springs Cave has 900 m^2 of stream surface area, which would yield an estimated population of 135 individuals. Using the 1999 population index of 166, the density of *A. rosae* in Cave Springs Cave is 0.18 fish / m^2, implying a density greater than average for Ozark cavefish habitats. In a summary of surveys using visual counting and mark/recapture methods, Pearson *et al*. (1995) report an average of 20 Northern cavefish (*A. spelaea*) / 100 m stream. Cave Springs Cave has an estimated 480 m of stream length, giving an average of 35 Ozark cavefish / 100 m of stream. Compared to these other studies, the density of cavefish in this cave complex appears to be greater than average.

Estimating the true population size of this population is difficult. The fish seen during a survey do not represent the entire population but some fraction of it. Similar surveys in Logan Cave indicate that about half of the fish in that population are seen during each census (Means 1993, Means & Johnson 1995, Brown 1996). Pearson *et al*. (1995) concluded that between 24% and 60% of the population were counted on a typical occular survey in cave streams no greater than 2 m deep. Explaining the variation in this visual survey method is also difficult.
During our visit when few cavefish were counted, many fish could have been in areas inaccessible to us, and subsequently fish could have moved into the main cave pools by the next census in December 1998. Since there are many shallow regions in the cave stream that are inaccessible to us, variations in individuals seen may simply be the result of timing. Increasing the number of population censuses would improve accuracy and precision, but this benefit must be weighed against the impact of wading through the cavefish habitat repeatedly.

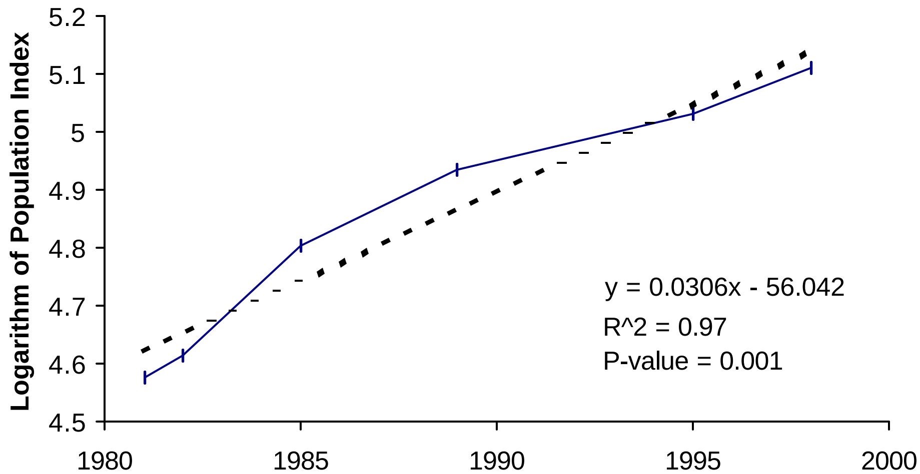

Figure 5. Population model based upon visual surveys by Brown and colleagues (natural rate of increase of 0.03, doubling time of 23 years, lambda of 1.03) (1998 low count omitted).

Another factor in cavefish population dynamics is flooding. On March 4, 1999, Graening found two live cavefish downstream of the cave in the defunct trout fishery raceways after a storm event. The cavefish were returned to the cave pool unharmed. Historically, at least one other cavefish has been seen washed downstream of the cave (Mark Collier, pers. comm., 1999). During periodic visits to the cave, many crayfish (*O. punctimanus*) have been observed being washed out of the cave by the current. Poulson (1963) concluded from his extensive research on *Amblyopsis* populations that removal from the cave by flood flows was a major mortality factor. In the spring of 1999, Benton County received unusually large amounts of rain, resulting in many record flood events. On July 1, 1999, Cave Springs Cave was discharging a record 26 cubic meters per minute. Since trout were reintroduced into the raceways downstream of the cave pool in the summer of 1999, no cavefish have been seen outside of the cave. A retaining device or collecting pool could be constructed to hold and protect cavefish that have washed out of the cave until they can be returned to the cave pool. Alternatively, a net could be placed in the cave pool that would prevent the cavefish from being washed out of the entrance pool.

Recharge Zone Management Concerns

While the creation of the geographical information system of the recharge zone is still in progress, several analyses have been performed. The first analysis of the Cave Springs Cave recharge zone was done by the Ozark Underground Laboratory on the impacts of the construction of U. S. Highway 71 (Aley, 1978). Aley (1978) recommended that U. S. Highway 71 be routed outside of the recharge area delineated in his report because of the potential of contamination of the spring by construction activities and chemical spills on the completed highway. The final environmental impact statement prepared by the Arkansas State Highway and Transportation Department (1979) incorporated this recommendation and U. S. Highway was rerouted outside of this recharge delineation. Yet, Williams (1991) stated that U. S. Highway 71 is still hydrologically connected to Cave Springs Cave. Thus, construction and maintenance activities as well as accidental spills of chemicals could still compromise the groundwater that feeds the cave stream.

When the cave map is overlayed upon the topographical map (the Bentonville South and Springdale quads) as shown in Appendix II, it becomes evident that the cave complex extends well beyond the Arkansas Natural Area boundary. If this adjacent land, which is used as cattle pasture, is directly connected to the cave complex via conduits of fractured limestone, it could contribute to the fecal and nutrient loads in the cave stream.

The major photo-lineaments and fracture traces of the Cave Springs Cave recharge zone have been entered into the GIS (see Williams, 1991). Lineaments are defined according to Lattman (1958) as natural features (topographic, vegetative, or soil tonal alignments) identifiable on aerial photographs and at least one mile long (if less than one mile long, it is called a fracture trace). Straight cave passage orientation is correlated to photo-lineament orientation in Benton County and northwest Arkansas in general, which implies that straight cave passages form along fracture zones, which are expressed as photo-lineaments at the surface (Barlow and Ogden, 1979). Willis (1978) and Ogden (1979) found significant relationships between high nitrate, sulfate, and chloride concentrations and wells on photo-lineaments in Benton County, and implicated the poor filtration of surface pollutants in these fracture zones as the cause. Willis (1978) also found that the yield of wells near photo-lineaments was significantly higher than wells distant from photo-lineaments. Ogden (1979) determined the zone of influence of photo-lineaments (where surface pollutants were highly correlated to proximity to lineaments) to be up to 2000 feet for chloride and 250 feet for sulfate. Williams (1991) defined critical areas for pollution of Cave Springs Cave as those areas that lie along intermittent stream segments, especially those segments that coincide with fracture traces and photo-lineaments. All of the stream segments in William's (1991) study coincide with fracture traces and photo-lineaments. These studies suggest that these intermittent streams and other lineaments in the Cave Springs Cave recharge zone merit special protection.

RECOMMENDATIONS

Ultimately, the goal of this continuing monitoring effort is to aid in management decisions regarding this Arkansas Natural Area. Having examined the environmental quality and the sources of the problems associated with it, our recommendations fall under two broad categories: 1) increasing protection for sensitive areas and 2) the reduction of pollution inputs.

Sensitive areas include any lands that fall within the Cave Springs Cave recharge zone or adjacent lands that contain photo-lineaments or fracture traces that intersect the recharge zone. Of special concern is an adjacent Ozark cavefish habitat, Mule Hole Sink, containing several cavefish. Protection of this site is recommended, possibly by arranging a cooperative agreement with the landowner of Mule Hole Sink to manage surface runoff and groundwater quality. Other sensitive areas include sinkholes near the cave, the intermittent stream along Midway Avenue, and the land that overlies the cave, directly east of the Natural Area boundary (see map in Appendix II).

Also of special concern is the historic application of sewage sludge in this recharge zone. While it is difficult to identify the exact source(s) of the organic and metal pollutants in Cave Springs Cave, it is recommended that the application of sewage sludge or agricultural waste be reduced or ceased, especially on lands adjacent to intermittent streams or photo-lineaments.

According to Regulation 2, the Cave Springs Cave resurgence meets the criteria for the designation, "ecologically sensitive," because it contains threatened and endangered species, and has the designated use, "primary contact," because its watershed is greater than 10 square miles (Pollution Control and Ecology Commission, 1998). Under this same regulation, the resurgence at Cave Springs Cave also meets the criteria of a "Fisheries waterbody" because it sustains a significant fish and invertebrate community. It has not, however, formally been given any of these designations. Formal declaration is recommended, and designating this cave spring an "extraordinary resource water" would give it further protection under Regulation 2, which sets more strict water quality standards for these water bodies. Ultimately, protection will only occur if these regulations are enforced.

Because of its diffuse nature and the heterogeneity of the landscape, non-point source pollution is more difficult to monitor and to enforce remediation than point sources (Zublena, 1995). One alternative to traditional control regulations for non-point source nutrient pollution that is gaining interest is the market-based concept of nutrient trading (similar to emissions trading) (Zublena, 1995). In this management technique, nutrient budgets are constructed for each watershed that set maxima for nutrient discharge concentrations and total loads that may not be exceeded, but individual nutrient discharge permits may be sold or traded as waste operations expand or contract. However regulated, setting maximum loads of organic pollutants must be done to halt the eutrophication of Benton County's groundwater supply and the further degradation of these aquatic ecosystems.

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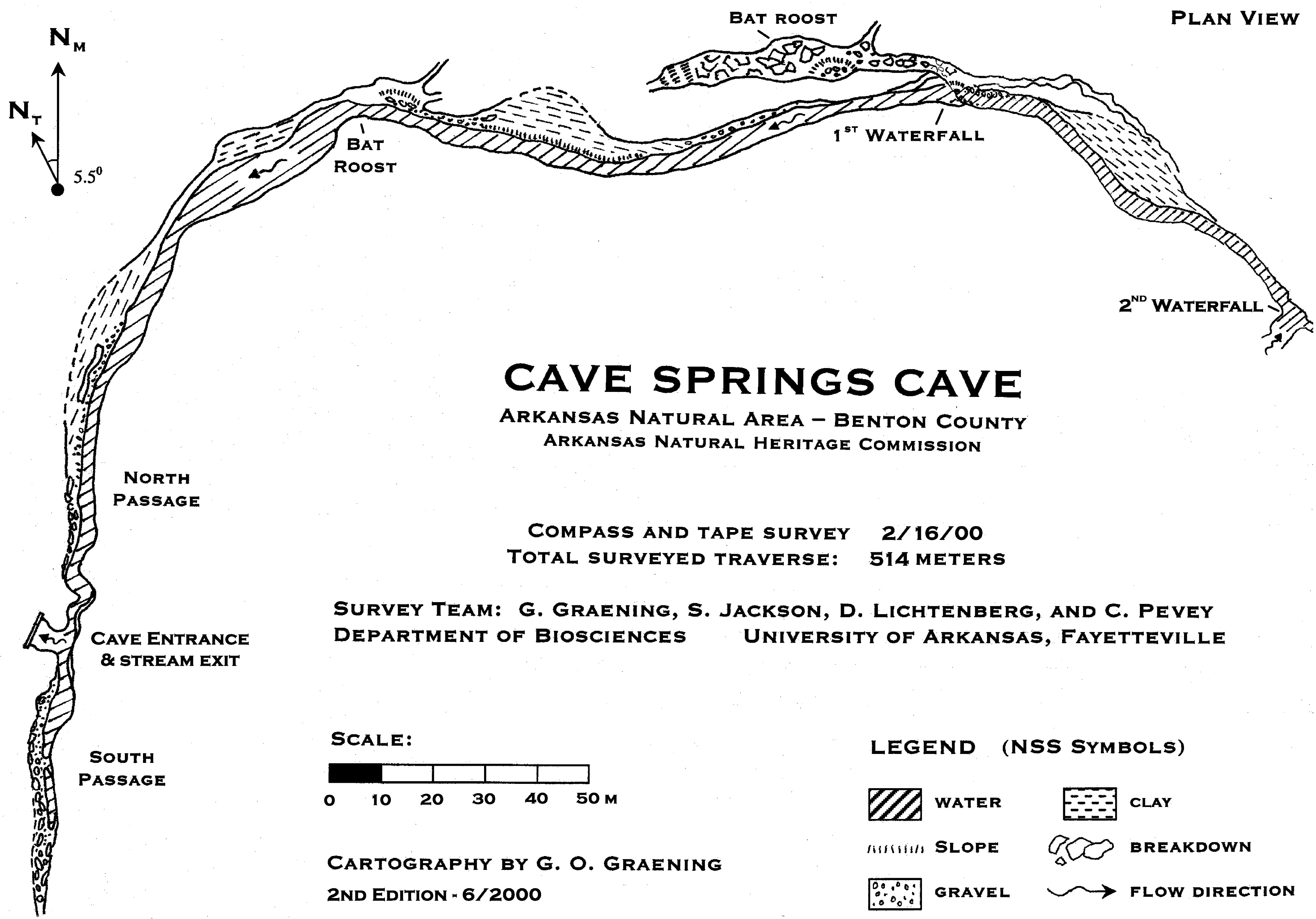
APPENDIX I

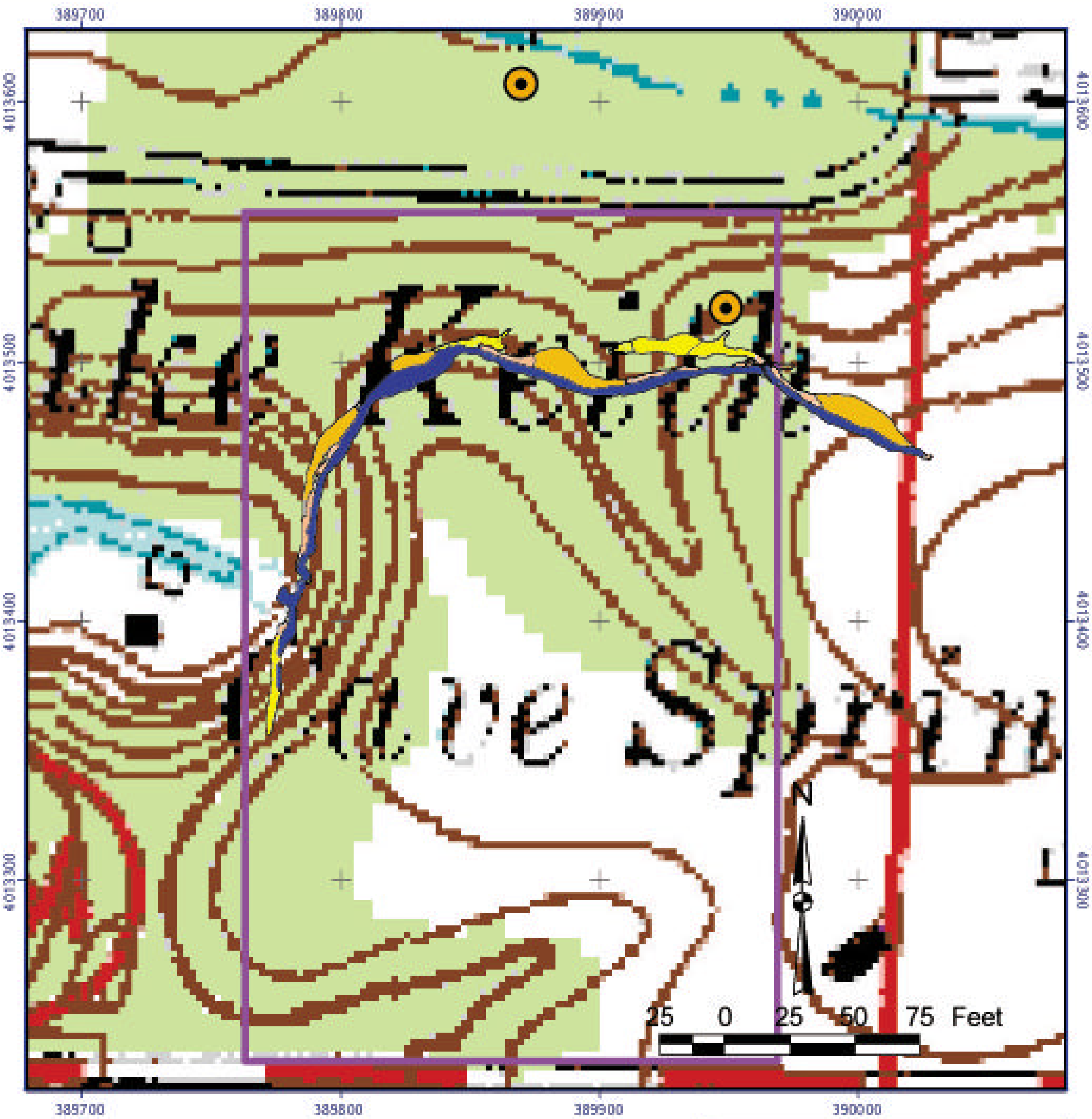
Map of Cave Springs Cave



PLAN VIEW
N M
N T
5.5°
BAT ROOST
BAT ROOST
1ST WATERFALL
2ND WATERFALL
NORTH PASSAGE
CAVE ENTRANCE & STREAM EXIT
SOUTH PASSAGE
CAVE SPRINGS CAVE
ARKANSAS NATURAL AREA – BENTON COUNTY
ARKANSAS NATURAL HERITAGE COMMISSION
COMPASS AND TAPE SURVEY 2/16/00
TOTAL SURVEYED TRAVERSE: 514 METERS
SURVEY TEAM: G. GRAENING, S. JACKSON, D. LICHTENBERG, AND C. PEVEY
DEPARTMENT OF BIOSCIENCES UNIVERSITY OF ARKANSAS, FAYETTEVILLE
SCALE:
0 10 20 30 40 50 M
LEGEND (NSS SYMBOLS)
WATER
CLAY
SLOPE
BREAKDOWN
GRAVEL
FLOW DIRECTION
CARTOGRAPHY BY G. O. GRAENING
2ND EDITION - 6/2000

APPENDIX II

Map of the cave superimposed upon the topographic map
with the Arkansas Natural Area boundary



Sinkholes

Cave Springs Arkansas Natural Area

Cave Springs Cave

- Breakdown
- Gravel
- Mud
- Water

TITLE:

Cave Springs

LOCATION: Benton County, AR

CHECKED BY:	FILENAME: cvspgs2.avp
PREPARED BY: A. Johnson	DATE: 10 July 1999

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FIGURE: