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ANNOTATED BIBLIOGRAPHY OF RELEVANT HYDROLOGIC, BIOLOGIC, AND LAND MANAGEMENT INFORMATION RELATED TO CAVE SPRINGS CAVE, BENTON COUNTY, ARKANSAS

FINAL REPORT

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This report is a product of the Cave Springs Area Karst Resource Conservation Study, performed on behalf of the Northwest Arkansas Regional Planning Commission by Crafton Tull Associates, Wright Water Engineers, Ozark Underground Laboratory, and The Nature Conservancy.

Introduction

This annotated bibliography summarizes important data, findings, and conclusions from studies and reports relevant to hydrologic, biologic, and land management issues at Cave Springs. Annotations are shown in italics. Scanned copies of the references are on-line at http://www.cavespringskarststudy.com.

If metric values were used in a reference we have usually shown their English equivalents. One exception is water quality data reported in milligrams per liter or micrograms per liter. These are approximately equivalent to parts per million and parts per billion. Simple definitions of some of the less commonly used technical terms are included.

Each reference indicates the Work Item(s) to which the reference applies. These work items are identified in the Detailed Work Schedule for Objective 1 found in the proposal for this project. The identified Work Items are as follows:

- Work Item 2a. Compile and analyze hydrologic and water quality data relevant to Cave Springs and its recharge area.
- Work Item 2b. Acquire and analyze population data for the Ozark Cavefish and related cave fauna in Cave Springs Cave.
- Work Item 2c. Compile and assess bat population data in Cave Springs Cave.
- Work Item 4. Collect and compile data about existing land use and land use controls in the study area.
- Work Item 5. Collect and compile information regarding protection of existing threatened and endangered species in Cave Springs Cave.
- Work Item 6. Research, collect, and compile existing karst conservation methods in this and other karst areas.

Annotated Bibliography

Adams, G.L. and J.E. Johnson. 2001. Metabolic rate and natural history of Ozark Cavefish, *Amblyopsis rosae*, in Logan Cave, Arkansas. Environmental Biology of Fishes, Vol. 62, pp. 97-105. *Work Item 2b.*

These authors investigated how seasonal changes in temperature and organic input effects metabolic activity in Ozark Cavefish. The study occurred in Logan Cave during 1996-1997, and metabolic activity was measured for 5-6 cavefish once each season (summer, fall, winter, spring). A relationship was observed between mass and metabolism, but this relationship varied between seasons. A positive relationship was observed during the summer/fall season, while a negative relationship was observed in winter/spring. During summer/fall, cavefish have *higher metabolism; during the winter, metabolism is lower. Higher metabolism during summer/fall was thought to be related to an increase of organic input into the system from the presence of a summer colony of gray bats. The authors also made some natural history observations about Ozark Cavefish that may be relevant for the population in Cave Springs Cave. Adult female cavefish with mature ova were observed to spend time in slack water areas over silty substrate. These females were observed in late August. In July, one large cavefish and five small cavefish (10-11 mm) were observed together and remained clustered together in the same location for six weeks until higher water levels during a spate moved two of the small cavefish downstream. Based on these observations, the authors suggest reproduction can occur earlier in the season than times previously reported. One female cavefish was observed with an alphanumeric tag from a previous study that occurred 2.5 years prior, and this observation provides some additional information on longevity of this species.*

Aley, Thomas. 1976. Hydrology and surface management. Proc. 1st National Cave Management Symp., Albuquerque, NM, pp. 44-45. *Work Item 6.*

This paper discusses dye tracing from a paved parking lot at Blanchard Springs Caverns, Stone County, Arkansas. As initially constructed all runoff water from the parking lot was conveyed into gravel-filled trenches beneath the pavement where it would then infiltrate into the groundwater system. The intention of this was to not reduce the volume of water recharging the underlying cave; the potential impacts of stormwater runoff on water quality and on features in the cave were not initially given adequate consideration. Groundwater tracing showed that this water did in fact enter as ceiling drippage into portions of the Caverns developed for cave tours. The designed system allowed poor quality water to enter the cave where hydrocarbons could adversely impact cave formations. Petroleum spills on the parking lot could create serious problems in the Caverns. Based on the results of the groundwater tracing the parking lot runoff was diverted away from the infiltration trenches and instead allowed to flow in a dispersed fashion over the forest floor.

Aley and Kirkland (2012) found that the lateral distance between where water sank into the ground on the surface and where it appeared in ceiling dripping in Blanchard Springs Caverns was at least 784 feet. This transport was in the vadose zone and thus above the water table. This finding relates to the precision with which recharge area boundaries can be inferred.

Aley, Thomas. 1978a. Impacts of the proposed relocation of U.S. Highway 71 from Fayetteville north to McKisic Creek upon groundwater resources and cave fauna. May 26, 1978. Ozark Underground Laboratory contract study for Arkansas Highway and Transportation Dept. 61 p. *Included in Final Environmental Impact Statement Job 1445, Highway 71 Relocation in Washington and Benton Counties, Arkansas. Work Item 2a.*

Estimates were made of mean annual flow rates of selected springs in the Osage Creek area. Based on these flow rates the approximate size of the associated recharge areas was *estimated based upon an assumption that about 2.3 square miles was required to produce a mean annual flow rate of 1cubic foot per second (cfs). Values are shown in Table 1. [Note; Osage, North, West, and South Springs have been substantially modified by urbanization and highway construction since these estimates were made.] The values under-estimate recharge areas when multiple springs drain the same area.*

Table 1. Flow rate and recharge area estimates for selected features in the study area. *Data from Aley (1978a).*

Spring	***Location*** *(section, township, range)*	***Estimated mean annual flow*** *(cfs)*	***Estimated recharge area*** *(sq. mi.)*
Cave at Cave Springs	*1-18-31*	*4.5 (3)*	*10.4*
North Spring	*16-19-30*	*0.8 (2)*	*1.8*
South Spring	*16-19-30*	*1.5 (2)*	*3.5*
West Spring	*16-19-30*	*7.5 (2)*	*17.3*
Osage Spring	*16-19-30*	*4.5 (2)*	*10.4*
Osage plus North, South, and West Spr	*16-19-30*	*14.3 (2)*	*32.9*
Puppy Creek-first rise	*11-18-30*	*0.5 (1)*	*1.2*
Puppy Creek-second rise (Goad Spr)	*11-18-30*	*1.0 (1)*	*2.3*
Puppy Creek-third rise	*16-18-30*	*2.0 (1)*	*4.6*

Data sources for estimated mean annual flows:
(1) T. Aley, Ozark Underground Laboratory
(2) C. Bloomfield, owner of Osage Spring Fish Farm
(3) *Barron Collier, owner of Cave Springs Fish Farm*

> "The relationship of lineaments and fracture traces to springs was carefully considered in conjunction with this groundwater tracing. For example, dye injection site 2 [described below as Trace 78-02] was selected for tracer injection in part because it was located on a lineament associated with Cave Springs. The fact that water from this introduction site reappeared at Cave Springs is indicative of the importance of lineaments and fracture traces in groundwater movement to springs in the proposed project area." *(Aley (1978a, page 10).*

This report describes two successful groundwater traces to Cave Springs. The following information is abstracted from data in Appendix B of the 1978 report.

Trace Number and Name: *Trace 2 (also known as Trace 78-02; Southern Border Section 33 Trace). Area shown on the Bentonville South quadrangle map.*
Dye Type and Quantity: 2 pounds fluorescein dye mixture with dye equivalent of 50%.

Location of Introduction Point: SE ¼ SW ¼ Section 33, T19N, R30W. Introduced in a losing stream 500 feet downstream of a county road crossing. Coordinates: 36.26973N, 94.18149W.
Date and Time of Introduction: March 1, 1978 at 1130 hrs.
Flow Rate or Volume of Water Added: Flow rate about 10 gallons per minute (gpm) at time of dye introduction, but substantially larger volumes of water can enter the groundwater system in this general area.
Elevation of Introduction Point: 1,257 feet (from topographic map).
Important Detection Locations: Cave Springs, elevation about 1,150 ft. First detection in carbon sampler in place for period from 3/1 to 3/8/78 at 1610 hrs. Greatest dye concentration in sampler in place for period from 3/8 to 3/10/78 at 1405 hrs.
Comments: Straight line travel distance 13,500 ft. Mean travel rate for first dye arrival >1,880 ft. per day.
Mean gradient for the trace 7.9 feet per thousand feet.

Trace Number and Name: *Trace 4 (also known as Trace 78-04; Northern Border Section 28 Trace). Area shown on the Bentonville South quadrangle map.*
Dye Type and Quantity: 2 pounds fluorescein dye mixture with 50% dye equivalent.
Location of Introduction Point: SW ¼ SW ¼ Section 28, T19N, R30W. Losing stream at road crossing at northern border of section. Coordinates: 36.28791N, 94.18651W.
Date and Time of Introduction: March 10, 1978 at 1200 hrs.
Flow Rate or Volume of Water Added: 40 gpm flowing in stream.
Elevation of Introduction Point: 1,290 feet from topographic map.
Important Detection Locations: Cave Springs at about 1,150 ft. elevation.
Comments: Straight line travel distance 15,000 feet. Dye first detected at Cave Springs in carbon sampler in place for the period from March 10 to March 20, 1978 at 1650 hrs. Mean travel rate for first dye arrival >1,670 feet per day. Mean gradient for the trace 9.3 feet per 1,000 feet.

Appendix C in the report includes six case histories of pollution events or pollution sources that resulted in fish kills at trout farms dependent upon spring water or have apparently been responsible for substantial water quality degradation at other springs. All of these case histories were from Benton and Washington Counties, Arkansas and all involved point sources of contaminants that entered the karst groundwater system.

Aley, Thomas. 1978b. Supplemental investigations; impacts of the proposed relocation of U.S. Highway 71 from Fayetteville North to McKisic Creek upon groundwater resources and cave fauna. August 2, 1978. Ozark Underground Laboratory contract study for Arkansas Highway and Transportation Dept. 18 p. *Included in Final Environmental Impact Statement Job 1445, Highway 71 Relocation in Washington and Benton Counties, Arkansas. Work Item 2a.*

This report details results from dye traces started at two points in the channel of Puppy Creek. Both of these traces yielded readily detectable concentrations of dye at sampling stations in Puppy Creek but no detections at Cave Springs. The report notes, however, that a more *modern analytical approach might have detected small concentrations of dye at Cave Springs. Aley and Moss (2001) did more intensive tracing in this area with improved analytical equipment and found no hydrologic connection between Puppy Creek and Cave Springs. The following summarizes dye tracing results from the two 1978 traces.*

Trace Number and Name: *Trace 6 (also known as Trace 78-06; Southwest Quarter Section 10 Trace). Area shown on the Springdale 7.5 minute quadrangle map.*
Dye Type and Quantity: Two pounds fluorescein dye mixture containing 50% dye equivalent
Location of Introduction Point: SE ¼ SW ¼ Section 10, T18N, R30 W. Introduced into flow in the channel of Puppy Creek. Coordinates 36.24176N, 94.16525W.
Date and Time of Introduction: June 14, 1978 at 1645 hrs.
Flow Rate or Volume of Water Added: Flow rate about 1.0 cfs. Entire flow enters the groundwater system within 0.5 miles downstream of the dye introduction point.
Elevation of Introduction Point: 1,215 feet.
Important Detection Locations: The only dye detection site was near the mouth of Puppy Creek at an elevation of 1,155 feet.
Comments: First arrival of the dye was about June 17, 1978 at 1200 hrs. Straight-line travel distance about 9,300 feet. Estimated mean travel rate 3,330 feet per day, but part of this was surface flow. Mean groundwater gradient 6.5 feet per 1,000 feet.

Trace Number and Name: *Trace 7 (also known as Trace 78-07; Puppy Creek North of Highway 264 Trace). Area shown on Bentonville South 7.5 minute quadrangle map.*
Dye Type and Quantity: Two pounds of fluorescein dye mixture with 50% dye equivalent.
Location of Introduction Point: SW ¼ SE ¼ Section 2, T18N, R30W. Point on private property. Coordinates about 500 feet downstream of the dye introduction point: 36.25573N, 94.14560W.
Date and Time of Introduction: June 14, 1978 at 1700 hours.
Flow Rate or Volume of Water Added: Introduced into a solutional hole in the limestone where approximately 0.4 cfs was disappearing.
Elevation of Introduction Point: 1,265 feet (from topographic map).
Important Detection Locations: Dye detected at two springs a couple of hundred feet apart in Puppy Creek. Dye that discharged from these springs flowed on the surface to Puppy Creek in an area downstream of Goad Spring.
Comments: The straight-line travel distance of this trace was 1,700 feet and the elevation of the dye recovery points was 1,250 feet. The mean groundwater gradient was 8.8 feet per 1,000 feet.

A third groundwater trace (Trace 78-08) was conducted during this study with the dye being introduced into a stream now known as Blossom Way, which is a tributary to Osage Creek. Dye from this trace was detected at Cave Springs and South Spring.

Trace Number and Name: *Trace 8 (also known as Trace 78-08; Blossom Way Trace). Area shown on Bentonville South 7.5 minute quadrangle map.*
Dye Type and Quantity: Three pounds of fluorescein dye mixture containing 50% dye equivalent.

Location of Introduction Point: SE ¼ NE ¼ Section 28, T19N, R30W. Dye introduced into a losing stream. Point on private property. Coordinates for a point approximately 1,200 feet upstream of the dye introduction point are 36.29169N, 94.17176W.
Date and Time of Introduction: June 23, 1978 at 1430 hrs.
Flow Rate or Volume of Water Added: Stream flow about 30 gpm. All flow sank into the groundwater system within 100 feet of the point of dye introduction.
Elevation of Introduction Point: 1,240 feet (from topographic map).
Important Detection Locations: Cave Springs and South Spring.
Comments: The charcoal sampling packet in place at Cave Springs for the period from June 23 at 1215 hours to July 11, 1978 at 1430 hrs. was weakly positive for fluorescein dye. The charcoal sampling packet in place at South Spring for the period from June 23 at 1330 hours to July 11, 1978 at 1530 hours was moderately positive for fluorescein dye. Elevations at dye detection sites: Cave Springs = 1,150 feet; South Spring = 1,210 feet. Straight-line travel distances: Cave Springs = 19,200 feet; South Spring = 7,200 feet. Mean groundwater gradients: to Cave Springs = 4.7 feet per 1,000 feet; to South Spring 4.2 feet per 1,000 feet.
Tracing in conjunction with the present study conducted more tracing in the vicinity of this dye introduction.

Aley, Thomas. 1982. Hydrologic impacts of urbanization in the soluble rock lands of Greene County, Missouri. Proc. 5th National Cave Management Symp., Mammoth Cave, KY, pp. 61-69. *Work Item 6.*

This article discusses hazard area mapping by Aley and Thomson (1981). This reference is annotated in this report.

Recommended land development constrains for each of the four hazard area classes are included in this paper. Lands lying within 300 feet of fracture traces and lineaments are identified as posing a greater threat to groundwater quality than surrounding lands.

Aley, Thomas and Catherine Aley. 1979. Prevention of adverse impacts on endangered, threatened, and rare animal species in Benton and Washington Counties, Arkansas. Ozark Underground Laboratory contract report for Northwest Arkansas Regional Planning Commission. 35 p. *Work Items 2a and 6.*

This report shows that the Northwest Arkansas Regional Planning Commission has a long history of concern for the prevention of adverse impacts on endangered, threatened, and rare animal species in Northwest Arkansas. Important conclusions from this study included the following:

- *Figure 1 in the report provides the earliest known approximation of the recharge area for Cave Springs.*

- *The habitat sites identified in Benton and Washington Counties represented less than 2.5% of the land area.*
- "Residential and light commercial land development increases the magnitude and intensity of storm runoff. Storm runoff waters are commonly characterized by low dissolved oxygen and substantial biochemical oxygen demand (BOD). Storm waters of this quality, if they are introduced underground, can seriously deplete dissolved oxygen concentrations in cave streams, and can thereby jeopardize cavefish and cave crayfish populations. Adequate storm runoff planning can mitigate this problem. Such planning must ensure that significant quantities of poor quality water do not enter the groundwater system; this requires competent groundwater investigations during the planning and design phase of projects." *Aley and Aley (1979, pages 13-14).*
- "In cave areas, pipelines present some distinct and rather unique problems. Pipelines transport a number of materials that can either deplete oxygen in groundwater systems or otherwise injure or kill cave fauna. In most non-cavernous landscapes, leaks or breaks in pipelines can be rather quickly detected because liquids appear on the surface. In cave areas, most of the leakage moves downward into the groundwater system, thus there is no surface evidence of leakage. In such cases, major quantities of pipeline leakage enter the groundwater system. The Green River Water District in a cave region of central Kentucky provides a good example of how much leakage from pipelines can enter the groundwater system. This rural water system, which has been constructed in the last 10 to 15 years, suffers leakage into the groundwater system of about 30% of the water pumped." *Aley and Aley (1979, page 15).*
- *Relative to Cave Springs the authors note:* "There are few if any areas in the two county study area where land use could have a greater impact on endangered and threatened animal species than at this site. Extreme care must be incorporated in land use and in any land development which occurs within this identified area." *Aley and Aley (1979, page 26).*

Aley, Thomas and Catherine Aley. 1987. Final report: water quality protection studies for Logan Cave, Arkansas. Ozark Underground Laboratory contract report for Arkansas Game and Fish Commission and U.S. Fish and Wildlife Service. 61 p. + appendix materials and maps. *Work Item 6.*

Logan Spring provides habitat for the Ozark Cavefish and the Gray Bat. This cave is near Cave Springs and in the same Boone Formation limestones. In many ways Logan Cave and Cave Springs Cave are similar.

Logan Spring, which discharges from Logan Cave, has a delineated recharge area of 11.64 square miles. Only about 2% of this recharge area contributes groundwater solely to Logan Spring. The remaining 98% of the recharge area contributes water to Logan Spring as well as to four springs in the Chaney Springs Complex plus Lower Palmer Spring.

Three groundwater vulnerability classes were mapped in the Logan Springs recharge area:

Vulnerability Class	***Area*** *(sq. mi.)*	***Percent of Recharge Area***
Moderate Hazard	*1.63*	*14.0*
High Hazard	*8.83*	*75.9*
Extremely High Hazard	*1.18*	*10.1*
Total	*11.64*	*100.0*

Aley, Thomas and Cathy Aley. 1993. (Symposium held 1991). Delineation and hazard area mapping of areas contributing water to significant caves. Proc. 8th National Cave Management Symp., pp. 116-122. *Work Item 6.*

This published article summarizes how recharge areas for significant caves can be delineation and how hazard areas are classified and identified. Hazard area assessment and mapping is a management approach for identifying and characterizing areas that pose differing levels of water quality risks to significant caves and/or springs. The intensity and nature of management actions on particular parcels of land can then be tailored to the relative levels of risk.

Aley, Thomas and Catherine Aley. 1998. Recharge area study, Bear Hollow Cave, Benton County, Arkansas. Ozark Underground Laboratory contract study for the Arkansas Game and Fish Commission and U.S. Fish and Wildlife Service. 59 p. + appendix materials. *Work Item 6.*

This recharge area delineation study is included in this annotated bibliography because there are similarities between Cave Springs and Bear Hollow Cave. These similarities include being formed in the same geologic unit.

This cave provides habitat for the Benton Cave Crayfish (Cambarus aculabrum), a federally endangered species. The cave is located in extreme northern Benton County in the Bella Vista area. The recharge area for those portions of the cave system accessible to people encompasses 2.29 square miles. An additional 1.17 square miles of recharge area contributes water to the karst groundwater system located downstream of accessible portions of the cave and upstream of the springs that drain the cave system. This is a presumptive habitat area. The total recharge area is 3.46 square miles. Approximately 64% of this is classified as Moderate Vulnerability Lands and the remaining 35% is classified as High Vulnerability Lands.

Aley, Tom and Cathy Aley. 2014. Recharge area delineation and vulnerability mapping for Civil War Cave, Centerton Spring, and Centerton Fish Hatchery Spring, Benton County, AR. Ozark Underground Laboratory contract report to The Nature Conservancy. 94 p. *Work Item 6.*

These recharge areas are in an area near, and hydrogeologically very similar to, the Cave Springs recharge area. Table 2 summarizes data for five delineated areas; these are:

- *The "exclusive recharge area" for the humanly accessible portions of Civil War Cave. This area does not contribute water to Centerton Spring.*
- *The "shared recharge area" that contributes water to both Centerton Spring and Civil War Cave.*
- *The "total recharge area" for Civil War Cave. This is the sum of the exclusive recharge area and the shared recharge area.*
- *The Presumptive Habitat area for Ozark Cavefish downgradient of Civil War Cave.*
- *The recharge area for Hatchery Spring.*

Table 2 also identifies the approximate percent of each of the delineated areas in each of four types of land use as of 2011. These include the following:

- *Forested*
- *Agricultural or vacant. Lands being converted from agricultural use to suburban development are often left vacant for a year or two due to delays in getting financing or meeting engineering and planning requirements.*
- *Suburban housing. Almost all of the housing in the study area is single-family residences.*
- *Commercial and urban. This is restricted to areas within the Centerton Spring recharge area.*

Finally, Table 2 identifies the percent of each of the four delineated areas in each of the identified land vulnerability classes. These are low, moderate, high, and extremely high vulnerability lands.

Table 2. Summary of current land use and groundwater vulnerability assessments for delineated areas associated with Civil War Cave, Centerton Spring, and Hatchery Spring. *Aley and Aley (2014).*

Feature	*Civil War Cave Exclusive Recharge Area*	*Civil War Cave Shared Recharge Area*	*Civil War Cave Total Recharge Area*	*Presumptive Habitat Area*	*Hatchery Spring Recharge Area*
Area (acres) *(sq. miles)*	*891* *1.39*	*1,155* *1.80*	*2,046* *3.20*	*988* *1.54*	*2,243* *3.50*
Percent of land in various land use categories as of 2011					
Forested	*5*	*5*	*5*	*45*	*10*
Agricultural or Vacant	*25*	*15*	*20*	*50*	*85*
Suburban Housing	*70*	*70*	*70*	*5*	*5*
Commercial and Urban	*<1*	*10*	*5*	*<1*	*<1*
Percent of land in various vulnerability classes					
Low	*0*	*0*	*0*	*0*	*0*
Moderate	*64.3*	*81.4*	*73.9*	*0*	*68.0*
High	*26.6*	*18.6*	*22.1*	*0*	*32.0*
Extremely High	*9.1*	*0*	*4.0*	*100.0*	*0*

Aley, Thomas; Cathy Aley; Philip Moss; and Eric Hertzler. 2008. Hydrogeological characteristics of delineated recharge area for 40 biologically significant cave and spring systems in Missouri, Arkansas, Oklahoma, and Illinois. Proc. of 2007 National Cave and Karst Management Symp., St. Louis, MO, pp. 154-167. *Work Item 6.*

This paper summarizes results from recharge area delineations of 24 sites that provide habitat for the Ozark Cavefish. Important findings include the following:

- *Epikarstic zones known or presumed to provide habitat for Ozark Cavefish populations are associated with 79% of the delineated cavefish sites. Many of these epikarstic areas are beneath perennial streams; some are beneath intermittent streams. The flow of water though such epikarstic systems is complex and varies with time. Unlike the case with a single karst conduit, pollutants unevenly impact epikarstic zones. This has been demonstrated by dye traces through the epikarstic zone where dye concentrations at different sampling points in the epikarstic zone can vary by two or more order of magnitude. Even if aquatic life kills do occur from a pollutant following particular flow routes through an epikarstic zone there are adjacent areas where the pollutant* *concentrations are lower or even non-existent. These areas can help re-populate affected portions of the epikarstic zone. As a result, aquatic fauna sites that include epikarstic zones are likely to be less subject to acute aquatic life kills that destroy much or most of the fauna than are sites lacking epikarstic zones.*

- *Based on results from 24 delineated Ozark Cavefish sites:*
    - *The mean size of recharge areas is 8.83 square miles; the range in size is from 0.12 to 40.10 square miles.*
    - *46% of the recharge areas are classed as High or Extremely High Vulnerability lands, 46% are classed as Moderate Vulnerability lands, and 8% are classed as Low Vulnerability lands.*
    - *Ten of the sites are rated as poorly defensible over the next 30 years, 8 are rated as moderately defensible, and 6 are rated as highly defensible.*

Aley, Thomas and Shiloh Kirkland. 2012. Down but not straight down: significance of lateral flow in the vadose zone of karst terrains. Carbonates and Evaporites Vol. 27, Number 2, pp. 193-198. *Work Item 2a.*

Lateral movement of subsurface water in the vadose zone (which is above the zone of saturation) can be appreciable in karst landscapes. Lateral movement in excess of 750 feet has been demonstrated by introducing tracer dyes on the surface of the land and sampling for them in ceiling drippage in caves. Much of the lateral movement is facilitated by the epikarstic zone which lies beneath the regolith and above the predominantly solid portions of the bedrock. In many areas water detained in the epikarstic zone supplies much of the so-called "base flow" for karst springs.

Aley, Thomas and Philip Moss. 2001. Northwest Arkansas Regional Airport access corridor groundwater tracing investigations. Final report. Ozark Underground Laboratory contract study for Barnard Dunkelberg, Inc., 46 p. + appendix materials. *Work Item 2a.*

This document reports on groundwater tracing to evaluate six potential corridors connecting from I-540 (now I-49) to the Northwest Arkansas Regional Airport. Dye tracing conducted during the study demonstrated that the two northernmost potential corridors (Alternate Corridors 1 and 2) contribute water to both Cave Springs and Reed Spring. Dye introduced on the south side of Potential Corridor 3 (located south of Potential Corridors 1 and 2) was not recovered at either Cave Springs or Reed Spring. The recharge area for Cave Spring and Reed Spring is drawn so that it includes part of Corridor 3. Corridors 4, 5, and 6 lie outside of the recharge area for Cave Springs and Reed Spring.

This study demonstrated that Reed Spring is hydrologically associated with Cave Springs. Because of this hydrological linkage, Reed Spring must be viewed as Presumptive

Habitat for the Ozark Cavefish. See Beeman, Aley, and Slay (2013) for a symposium paper on Presumptive Habitat.

The Cave Springs recharge area as delineated in USDOT et al. (1979) included both a Direct Recharge area and an Indirect Recharge area. The Indirect Recharge area included most of the Blossom Way topographic basin. The delineation in the 2001 study includes this area plus lands that contribute recharge water to Reed Spring.

As a result of the 2001 study, the combined recharge area for Cave Springs and Reed Spring encompasses approximately 19.10 square miles. Data from Traces 00-01 through 00-05 and Trace 01-08 are all relevant to the current Cave Springs study.

Flow rates were measured at Cave Springs and Reed Spring on several dates in 2000 and 2001. A current meter was used for making the measurements at Cave Springs and a Parshall flume was used at Reed Spring. Results were as follows:

Date	***Cave Springs*** *(cfs)*	***Reed Spring*** *(cfs)*
12/13/00	*0.30**	*0.15*
1/3/01	*0.19*	*0.64*
1/30/01	*0.86*	*0.61*
3/1/01	*8.50*	*1.26*
3/13/01	*3.72*	*0.91*
3/29/01	*2.44*	*0.87*
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Mean	*2.67*	*0.74*
Median	*1.65*	*0.76*
Max/min ratio (variability)	*44.7*	*8.4*

** Flow rate estimated by Philip Moss.*

Six dye traces were conducted that were relevant to the recharge area for Cave Springs and Reed Spring. Basic data on the traces is as follows:

***Trace Number and Name**: 00-01 Puppy Creek Trace.*
Dye Type and Quantity: 3 pounds of eosine with 75% dye equivalent
Location of Introduction Point: NE ¼ SE ¼ Sec. 10, T18N, R30W. Coordinates: 36.24738N, 94.15508W. The area is shown on the Bentonville South 7.5 minute quadrangle map.
Date and Time of Introduction: August 2, 2000 at 2003 hrs.
Flow Rate or Volume of Water Added: Stream flow about 250 gpm
Elevation of Introduction Point: 1,235 feet (from topographic map)
Important Detection Locations: Puppy Creek upstream of Spring Creek.

Comments: No recovery at either Reed Spring or Cave Springs. First recovery in Puppy Creek upstream of Spring Creek during period 7/21 to 8/16/00. Straight-line distance 13,400 feet, mean gradient 5.6 feet/1000 feet.

Trace Number and Name: *00-02. Wellington Subdivision Trace*
Dye Type and Quantity: 2 pounds of sulforhodamine B with 75% dye equivalent
Location of Introduction Point: NW ¼ NW ¼ Sec. 7, T18N, R30W. Location on private property; coordinates for a point about 200 feet downstream of the dye introduction point 36.25622N, 94.22210W. Area shown on Bentonville South 7.5 minute quadrangle map.
Date and Time of Introduction: August 2, 2000 at 1502 hrs.
Flow Rate or Volume of Water Added: Dye added to dry stream channel. Fire hydrant opened at 1502 hours and allowed to flow until about 6,000 gallons of water was discharged to the stream channel. All flow entered the groundwater system within 200 feet of the point of dye introduction.
Elevation of Introduction Point: 1,190 feet..
Important Detection Locations: Apparently discharge from Bond Spring, which was not identified until after the trace.
Comments: No dye detected at either Cave Springs or Reed Spring.

Trace Number and Name: *00-03. Cross Creek Trace.*
Dye Type and Quantity: 2 pounds fluorescein dye mixture containing 75% dye equivalent.
Location of Introduction Point: Losing stream segment of Cross Creek where Zion Road crosses it. NW ¼ NW ¼ Section 9, T18N, R30W. Coordinates: 36.25303N, 94.18623W. Area shown on Bentonville South 7.5 minute quadrangle map.
Date and Time of Introduction: Placed as dry set August 2, 2000. No storm occurred to flush it so 6,000 gallons of water added on August 17, 2000 to mobilize the dye. Dyed water flowed down channel about 100 feet before it was all in the groundwater system.
Flow Rate or Volume of Water Added: 6,000 gallons.
Elevation of Introduction Point: 1,220 ft.
Important Detection Locations: Cave Springs and Reed Spring.
Comments: Straight-line distance to Cave Springs is 12,300 feet and the mean gradient is 7.9 feet per 1000 feet. Straight-line distance to Reed Spring is 10,000 feet and the mean gradient is 9.0 feet per 1000 feet.

Trace Number and Name*: 00-04. Reynolds Trace*
Dye Type and Quantity: 3 pounds eosine mixture containing 75% dye equivalent
Location of Introduction Point: Tributary to Cross Creek on Tom Reynolds' property. SW ¼ NW ¼ Section 9, T18N, R30W. Area shown on Springdale 7.5 minute quadrangle map. Location on private property. Coordinates for a point about 1,300 feet downstream of the dye introduction: N36.24844N, 94.18636W.
Date and Time of Introduction: August 24, 2000. Dry stream channel. Water pumped from a nearby pond beginning at 1455 hrs. and continued at a rate of about 100 gpm until 1730 hrs. Dye introduced from 1526 until 1528. Surface flow of dyed water persisted for at least 800 ft.
Flow Rate or Volume of Water Added: total 15,500 gallons.

Elevation of Introduction Point: 1,245 ft.
Important Detection Locations: Cave Springs in carbon sampler from 8/25 to 8/31/00. Reed Spring from 12/31/00 to 1/3/01.
Comments: Straight-line distance to Cave Springs 12,100 feet and the mean gradient is 7.9 feet per 1000 feet. Straight-line distance to Reed Spring 8,900 feet and the mean gradient is 9.0 feet per 1000 feet.

Trace Number and Name: *00-05. Powell Trace.*
Dye Type and Quantity: 5 pounds rhodamine WT mixture containing 20% dye equivalent.
Location of Introduction Point: SW ¼ SW ¼ Section 9, T18N, R30W. Dry tributary to Cross Creek. Area shown on Springdale 7.5 minute quadrangle map. Location on private property. Coordinates for a point about 500 feet downstream of dye introduction point : 36.24141N, 94.18530W.
Date and Time of Introduction: Sept. 26, 2000. Pond water hauled by truck; four loads of 4,500 gallons each. 0910 to 1240 hrs. All dye in subsurface within 200 ft. of dye introduction point.
Flow Rate or Volume of Water Added: 18,000 gallons.
Elevation of Introduction Point: 1,250 feet.
Important Detection Locations: No dye detected at either Cave Springs or Reed Spring.

Trace Number and Name*: 01-08. Sharp Trace.*
Dye Type and Quantity: 3 pounds fluorescein dye mixture with dye equivalent of 75%.
Location of Introduction Point: NE ¼ SE ¼ Section 17, T18N, R30W. Dry streambed. Water flowed about 350 feet before it all sank in the ground. Area shown on Springdale 7.5 minute quadrangle map. Coordinates: 36.23206N, 94.19498W.
Date and Time of Introduction: Feb. 28, 2001. 1250 hrs.
Flow Rate or Volume of Water Added: 8,000 gallons of water pumped from nearby pond.
Elevation of Introduction Point: 1,250
Important Detection Locations: Puppy Creek upstream of Spring Creek.
Comments: No dye detected at either Cave Springs or Reed Spring. Distance to mouth of Puppy Creek 1,700 feet and mean gradient is 52.9 feet per 1000 feet.

Aley, Thomas and Kenneth C. Thomson. 1981. Hydrogeologic mapping of unincorporated Greene County, Missouri to identify areas where sinkhole flooding and serious groundwater contamination could result from land development. Ozark Underground Laboratory contract report to Missouri Department of Natural Resources. Map folio and project summary. *Work Item 6.*

A series of five countywide maps was prepared for this project. All maps were printed in color on a topographic base map at a scale of one inch to the mile. The map sheets were 37 inches by 25 inches. A total of 500 sets of the maps were prepared and distributed to government offices in Greene County, banks and other lending institutions, real estate companies, and the Chamber of Commerce.

Map Sheet 1 showed areas with sinkhole flooding hazards. High, moderate, and low hazard areas were shown as well as isolated individual sinkholes. In contrast with some parts of Greene County, sinkholes are rare in the Cave Springs area.

Map Sheet 2 showed lineaments, fracture traces (fracture trends), and faults. Lineaments are features with a length of 1.0 mile or more; fracture traces are shorter than this. It is well established in the technical karst literature that well yields and solutional features in the bedrock are commonly especially abundant along and near lineaments, fracture traces, and faults. Areas within 300 feet of these features are more likely to introduce contaminants into the groundwater system than is the case for lands further removed from these features. Lateral transport in the karst aquifer along these features also tends to be more rapid than is the case for portions of the aquifer further removed from these features.

Map Sheet 3 showed generalized soil suitability mapping for septic field absorption fields. The map is based upon countywide soil mapping by the USDA Soil Conservation Service (now Natural Resources Conservation Service) and their rating system for soil suitability for various soil series. Map Sheet 3 shows three levels of soil suitability for on-site septic systems. Slight limitations include the Newtonia Soil Series. Moderate limitations include soils mapped as Peridge, Pembroke, and Eldon Soil Series. All other mapped soil series in Greene County are ranked as having severe limitations due to flooding, shallow bedrock, seepage or perched water tables.

Map Sheet 4 delineates important water supply areas. These include the topographic basins for municipal water supplies and groundwater recharge areas for springs where water quality is important for a particular reason such as providing habitat for federally listed threatened or endangered species.

Map Sheet 5 combines data from the first four maps into four water contamination hazard classes. These are Low, Moderate, High, and Extremely High Hazard classes.

These maps have been used in County Planning and Zoning matters in Greene County for 34 years and are widely accepted as accurate and unbiased. Aley (1982) identified recommended development constraints based on the four hazard classes shown on Map Sheet 5.

Aley, Thomas and Kenneth Thomson. 1984. Septic fields and the protection of groundwater quality in Greene County, Missouri: Final report. Ozark Underground Laboratory contract report to City of Springfield, Greene County, Fantastic Caverns, Inc., and Springfield City Utilities. 161 p. *Work Item 6.*

Extensive optical brightener sampling was conducted of 75 springs in Greene County. Optical brighteners are fluorescent dyes present in laundry soaps and detergents, and are an excellent indicator of sewage contamination of groundwater supplies. The sampling indicated *that about 60% of the septic field systems in Greene County add detectable amounts of contaminants to groundwater systems, and that about 15% of the septic fields are major sources of groundwater contamination.*

Optical brightener sampling results were compared with three factors: lot size, soil factors, and geologic factors. The data demonstrate that there is no lot size that assures that groundwater quality will be protected when septic fields are used. The important factor is not the density of the housing, but how adequately each individual septic field system treats the effluents that it receives. The more houses there are in a spring recharge area, the greater the chance that some of them will introduce contaminants into the groundwater system, and the greater the chance that one or more of the septic field systems will constitute a major source of groundwater contamination. However, lots must be large enough to assure adequate space for both initial and replacement septic field systems.

The data demonstrate that inadequately designed, improperly installed, and poorly maintained septic field systems can be a major sources of groundwater contamination regardless of the soil mapping unit in which they are located.

The analysis demonstrated that substantial groundwater contamination is associated with septic field use on soil mapping units that the Soil Conservation Service (SCS) identifies as having moderate to slight limitations for septic field use. It was the conclusion of the authors that the SCS rankings gave substantially greater emphasis to <u>disposal</u> limitations rather than to <u>treatment</u> limitations. While this emphasis might be appropriate for many areas in the nation, it is not the emphasis needed in Greene County, and the Ozarks in general, to protect groundwater supplies.

In Greene County the septic fields that provide the best wastewater treatment (and the best protection for groundwater) are those where soil features and/or the design and installation of the septic field system provides the greatest contact between the soil and the wastewater. The study found that the effectiveness of septic field systems was about 5 times greater in recharge areas underlain by the Burlington Formation than in recharge areas underlain by the Elsey Formation. Stated a different way, one septic field in areas underlain by the Elsey Formation generally created about the same amount of groundwater contamination as 5 septic fields in areas underlain by the Burlington Formation. The authors concluded that the reason for the difference between these two geologic mapping units was related to the nature of subsurface water movement through the soils and residuum which is derived from the respective units. Soils and residuum derived from the Elsey Formation have a very high chert content whereas those derived from the Burlington Formation are relatively chert-free.

In Arkansas the Burlington and Elsey Formations are mapped as part of the Boone Formation. If the results from the Greene County study are to be extrapolated to northwest Arkansas then the best groundwater protection occurs on lands where the soils are relatively chert-free in the horizons exposed to contaminated waters.

Characteristics of soils are important in determining their effectiveness in removing contaminants and preventing their movement into the underlying karst groundwater system. Aley and Thomson (1984) cited a 1980 EPA design manual for on-site sewage systems. The reference is: EPA. 1980. Design manual: Onsite wastewater treatment and disposal systems. EPA-625/1-80-012. 391 p.

> *Page 207 of that manual states:*
> "Travel through two to four feet of unsaturated soil is necessary to provide adequate removals of pathogenic organisms and other pollutants from the wastewater before it reaches the groundwater." *EPA (1980)*
>
> *Aley and Thomson (1984) stated:*
> "The amount of soil necessary to provide 'adequate' removals of pathogenic organisms and other pollutants is based upon several assumptions. The first of these assumptions is that the soils are always or nearly always unsaturated. This is because saturated flow conditions are different from unsaturated flow conditions, and because saturated flow conditions in the presence of septic tank effluents tends to produce anaerobic conditions instead of the more desirable aerobic conditions."
>
> *They further stated:*
> "The second assumption upon which guidelines for adequate thickness of soils are based is that all flow paths are dispersed. Features in the soil which concentrate and localize flow routes dramatically increase the thickness of soil necessary for 'adequate' treatment. The third assumption upon which guidelines for adequate thicknesses of soils are based is that the soils include adequate amounts of particles which will provide effective adsorption. As an illustration, a sand lacking an adequate silt or clay fraction would not constitute an adequate soil. Furthermore, the soils must provide reasonably effective filtration. As an illustration, broken rock and gravel would not constitute an adequate soil."

Arkansas Department of Planning. 1974. Arkansas natural area plan, pp. 75-76.
Work Items 5 and 6.

Reports that each female Ozark Cavefish has a fecundity of about 20 eggs and approximately 20% of the population breeds each year. As of the date of this report there were only four sites known in Arkansas for this fish. All were in the Illinois River basin with the fish being known from two caves and one well in Benton County and from one cave in Washington County.

Barner, Wendell. 1997. Comparison of stormwater management techniques in a karst terrane in Springfield, Missouri. IN: Beck and Stephenson (editors). The Engineering Geology and Hydrogeology of Karst Terranes, pp. 253-258. *Work Item 6.*

The focus of this paper is on various techniques for treating sinkholes. Since sinkholes are rare in the recharge area for Cave Springs this paper is of limited utility in the Cave Springs area.

Barnes, J.K., M.E. Slay, and S.J. Taylor. 2009. Adult diptera from Ozark caves. Proceedings of the Entomological Society of Washington, Vol. 111, Number 2, pp. 335-353. *Work Item 2b.*

This paper reports on species of Diptera (flies) that have been collected from caves in the Ozark portions of Arkansas, Missouri, and Oklahoma. In general, most of the species reported from caves in the Ozarks can also be found on the surface in similar cool, dark habitats. A single species, Spelobia tenebrarum (Sphaeroceridae), is thought to only occur in caves. The authors report collecting flies in the family Sciaridae from Cave Springs Cave, but these specimens were not identified to species.

Beeman, Shiloh; Thomas Aley; and Michael Slay. 2013. The need for presumptive habitat considerations in working with subterranean aquatic species of concern: three Ozark region case histories, U.S.A. Proceedings of the 13th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Carlsbad, NM, May 6-10, 2013, pp. 377-381. *Work Item 6.*

Groundwater tracing studies sometimes show that karst groundwater that provides habitat for aquatic species of concern discharges from one or more springs downstream of humanly accessible portions of the habitat. These down-gradient areas should routinely be considered as presumptive habitat for the species of concern. The first case history is for the groundwater system that drains Tumbling Creek Cave, Taney County, Missouri; this provides habitat for the federally endangered Tumbling Creek Cavesnail (Antrobia culveri). The second case history is of epikarst habitat for the Ozark Cavefish at Neosho, Missouri. The third is a site for a cave crayfish (Cambarus zophonastes) in Marion County, Arkansas.

Black, J.D. 1936. Mammals of northwestern Arkansas. Journal of Mammalogy, Vol. 17, Number 1, pp. 29-35. *Work Item 2c.*

This paper reports on early observations of mammals in northwest Arkansas, including species of bats that were observed in caves. The author reports as many as 3,000 Gray Bats (Myotis grisescens) were observed in Denney Cave (or Horsethief Cave, Madison Co., Arkansas) *and as many or more in Cave Springs Cave and Crystal Cave (both in Benton County). He collected 52 Gray Bats from Cave Springs Cave.*

Brahana, J.V. 1997. Rationale and methodology for approximating spring-basin boundaries in the mantled karst terrane of the Springfield Plateau, northwestern Arkansas. IN: Beck and Stephenson (editors). The Engineering Geology and Hydrogeology of Karst Terranes, pp. 77-82. *Work Item 2a.*

> "The methodology draws on a model that incorporates assessment of the major processes and controls affecting ground-water flow in this karst region of the southern Ozarks. Input data include: 1) low-flow spring discharge and normalized base flow that has been empirically defined for each of the major aquifers; 2) closely-spaced wireline geophysical logs that intersect key units of the hydrogeologic framework; 3) driller's logs; 4) recurring monitoring of selected water-quality parameters; 5) field reconnaissance; 6) soil maps; 7) geologic maps; 8) karst inventories; 9) spring inventories; 10) dye tracing tests; 11) aquifer tests; 12) low-level color infrared photography; and 13) water-level maps." *Brahana (1997, Page 77).*

> "In much of the area, ground-water divides are not coincident with surface-water divides, and interbasin diversion of ground water by karst piracy is common. Regional and intermediate-scale potentiometric maps of the shallow SP [Springfield Plateau] aquifer provide a sound approximation for estimating flow directions; on a site-specific scale, the nonhomogeneity and anisotropy of the system require refined definition to identify and monitor specific flow paths." *Brahana (1997, Page 79)*

> "Although underlain by an (sic) variably-developed, generally poorly-defined, incipient karst aquifer, the regolith overlying the Boone Formation acts as a porous water-table aquifer that slowly releases water to recharge the underlying aquifer. The hydrogeology of areas where regolith is thick may not be as sensitive to specific land-use practices as those areas where regolith is thin or absent, and they also help maintain greater base flows of springs and streams." *Brahana (1997, Page 79)*

> "Nine long-term study sites in the SP [Springfield Plateau] of northwestern Arkansas have been identified using this methodology, yielding NBF [Normalized Base Flow] values of spring basins that range from 1.5 to 3.2 L/sec/km^2 [0.138 to 0.294 cubic feet per second per square mile]" *Brahana (1997, page 81)*

OUL Note: Areas that share recharge water among multiple springs would be expected to have smaller values. The Cave Springs recharge area is known to share water with Reed

Spring (Aley and Moss 2001), with South Spring (Aley 1978b), and with Wallis and Shores Springs (current study).

Brahana, John Van and Ralph K. Davis. 1999. Methodology for delineating ground-water recharge areas of springs in the carbonate-rock terrane of northwest Arkansas, and application to five separate spring basins within the region. *Appendix to Davis et al. (2000). Work Item 2a.*

This appendix document outlines a method for developing a hypothesis relative to the size and location of the recharge area for a particular spring. The methodology is similar to that outlined in Brahana (1997). In the opinion of the OUL the methodology does not provide a credible delineation unless it is tested and modified as needed by dye tracing techniques. Some dye traces, with limited supporting data, were conducted in some of the identified recharge areas.

Brown, Arthur V.; G. O. Graening; and P. Vendrell. 1998. Monitoring cavefish populations and environmental quality in Cave Springs Cave, Arkansas. Publication no. MSC-214. Arkansas Water Resources Center, Univ. of Arkansas, Fayetteville, AR, 32 p. *Work Item 2a and 2b.*

> "A trend analysis of known water quality studies of this cave complex suggests that many organic and inorganic chemicals have increased in concentration in the last 14 years. This ecologically sensitive water body did not meet Arkansas water quality regulations [standards] for fecal coliform densities, and copper, selenium, and lead concentrations exceeded limits for exposure to aquatic life." *Brown et al. (1998, page 2).*

OUL Note: Current Arkansas water quality standards for dissolved metals vary with the hardness of the water and the limits must be calculated based upon water hardness values. A continuation of the trend analysis using additional data is included in subsequent references by Brown and Graening. The credibility of the trend analysis will be discussed in the OUL report "Summary of existing knowledge about hydrology, cave biology, and cave conservation methods applicable to Cave Springs, Arkansas".

> "During the June [1998] storm event, nitrite levels reached 2 mg/l, twice the MCL [Maximum Contaminant Level] for national drinking water standards. Nitrite toxicity is known to cause severe anemia in fishes and damage their tissues. One semi-volatile organic, De(2-ethylhexyl)phthalate (DEHP) was found in significant concentration (500 ug/kg) in resident crayfish tissues. DEHP is known to bioaccumulate in fish tissue, and cause reproductive damage and reduce fertility in fish." *Brown et al. (1998, page 2).*

> "The high nitrite, total coliform, and E. coli [fecal coliform bacteria] counts suggests that septic system leakage or land application of animal waste is involved." *Brown et al. (1998, page 2).*

A population census on January 25, 1998 found 106 cavefish. The authors attributed a 30% population decline in Ozark Cavefish at Cave Springs Cave to increased levels of inorganic and organic compounds. OUL Note: The next census showed a major rebound in the population numbers. This suggests that the census of January 25, 1998 substantially under-counted the number of cavefish present and that there was not a decline in the cavefish population.

This report includes a substantial amount of water quality data. The authors included all previous water quality data for Cave Springs as appendix material. This reference is a very valuable source of water quality data for Cave Springs up to 1998.

The number of cavefish seen in Cave Springs by year was reported as follows:

1981 = 97
1982 = 101
1985 = 122
1989 = 139
1995 = 153
1998 = 106

The above fish counts were based on a standardized counting approach using three people. This approach has apparently been followed by all subsequent fish counts. Previous counts did not use this approach and the approaches used were likely to under-estimate the numbers of fish. Because of the nature of the habitat and the difficulty of seeing all fish present all census values are an under-estimate.

Brown, A.V. and S. Todd. 1987. Status review of the threatened Ozark Cavefish (*Amblyopsis rosae*). Proceedings of the Arkansas Academy of Science, Vol. 41, pp. 99-100. *Work Item 2b.*

These authors revisited 14 known populations of Ozark Cavefish in Missouri, Oklahoma, and Arkansas, and they also visited additional sites. They observed cavefish in 8 of the 14 sites, and discovered 3 new locations for Ozark Cavefish in Arkansas. Their survey of Cave Springs Cave yielded an observation of 122 fish. Since many of the habitats containing populations of Ozark Cavefish also provide habitat for colonial Gray Bats, the authors suggest that optimal habitat for cavefish includes sites where bat guano is present.

Brown, J.Z. and J.E. Johnson. 2001. Population biology and growth of Ozark Cavefish in Logan Cave National Wildlife Refuge, Arkansas. Environmental Biology of Fishes, Vol. 62, pp. 161-169. *Work Item 2b.*

These authors conducted a mark-recapture study of Ozark Cavefish in Logan Cave from September 1993 to September 1995 sampling the cave 25 times over the time period. Cavefish that were larger than 30 mm were netted, anesthetized, and implanted with a unique serial tag. They observed 52 fish that were less than 30 mm in length over the course of the study. The number of fish captured each trip ranged from 10-29 with an average of 16.8 fish per trip. About half of the cavefish tagged in this study were never recaptured (72 out of 140 tagged fish). One cavefish that was tagged in a prior study was recaptured several times in this study; the span of the first capture and last recapture was 28 months for this cavefish. In addition, the authors report that 2 cavefish kept in captivity, in order to test tag retention, survived for 4.1 years and 4.5 years, respectively. On average, 5 un-tagged cavefish were observed each sampling trip after the first 3 trips. Cavefish growth was also measured, and the absolute growth rate was 0.6 ± 0.2 mm per month. Smaller cavefish grew faster than larger cavefish, and the growth period was between April and October. Not all cavefish were observed to grow with 20 cavefish decreasing in length between recaptures (average = -2.0mm; range -1 to -5 mm). Cavefish movement was also recorded. Mean daily movement was 1.2 ± 0.5 m per day. Larger fish moved farther than smaller fish. The authors calculated an annual immigration rate of 20 ± 7.2 cavefish into Logan Cave. While the authors agree that cavefish move from the upper portions of the recharge area into Logan Cave, they do not believe cavefish move from Logan Cave back into the upper reaches. They believe that Logan Cave serves as a window into a larger area of habitat containing this population of Ozark Cavefish.

Currens, James C. 1999. Mass flux of agricultural nonpoint-source pollutants in a conduit-flow-dominated karst aquifer, Logan County, KY. Kentucky Geological Survey, Series XII, Report of Investigations 1. 151 p. + maps. *Work Item 6.*

Cave Springs is also a conduit-flow dominated karst aquifer. An important difference between the Kentucky study area and Cave Springs is that sinkholes are common in the recharge area for the spring studied in Kentucky but are rare in the Cave Springs area. Major stormwater fluxes of nitrates, sediment, and herbicides were noted. Results revealed the potential for a wide range of concentrations and flow-weighted averages from year to year.

Currens, James C. 2001. Changes in ground-water quality in a conduit-flow-dominated karst aquifer following BMP implementation. Proc. of the 8th Multidisciplinary Conf. On Sinkholes and the Engineering and Environmental Impacts of Karsts, Louisville, KY, April 1-4, 2001. Beck and Herring, Editors. Balkema Publishers, pp. 209-216. *Work Item 6.*

This is a 10,054 acre watershed where 92% of the land is used for agriculture. Approximately 72% of the recharge area was enrolled in agricultural BMPs under the U.S. Dept. of Agriculture Water Quality Incentive Program.

> "The pre-and post-BMP water quality was statistically evaluated by comparing the annual mass flux, annual descriptive statistics, and population of analyses for the two periods. Nitrate-nitrogen concentration was unchanged. Increases in atrazine-equivalent flux and triazing geometric averages were not statistically significant. Total suspended solids concentration decreased slightly, while orthophosphate concentration increased slightly. The BMP's (sic) were only partially successful because the types available and the rules for participation resulted in less effective BMP's (sic) being chosen. Future BMP programs in karst area should emphasize buffer strips around sinkholes, excluding livestock from streams and karst windows, and withdrawing land from production." *Currens (2001, page 209).*

Currens, James C. undated. Model ordinance for development on karst in Kentucky. Kentucky Geological Survey. 20 p. Available online from Kentucky Geological Survey website. *Work Item 6.*

The primary focus of this document is on preventing property damage from sinkholes or subsidence due to karst features or karst processes and to reduce the risk of flooding.

The model ordinance includes a statement that the relative risk for groundwater contamination in karst areas shall be defined and classified as low, moderate, or high, depending upon the type of proposed land use, development density, and amount of impervious area directly draining to and connected with a dry well or sinkhole. The approach is poorly suited to the hydrogeologic settings found in the Cave Springs Recharge Area.

Curtis, Darrin Lee. 2000. An integrated rapid hydrogeologic approach to delineate areas affected by advective transport in mantled karst, with an application to Clear Creek basin, Washington County, Arkansas. PhD dissertation, Univ. of Arkansas, Fayetteville, AR, 117 p. *Work Item 2a.*

This study was designed to evaluate whether modeling could be used to approximate recharge area boundaries. The modeling placed substantial data emphasis on lineaments (which are defined as having lateral persistence of over a mile) and concluded that they provided the primary master flow routes for groundwater movement to springs. Fracture traces (which are defined as having lateral persistence of less than a mile) were not used.

As one of several study areas, the author used his methodology to delineate the recharge area for Cave Springs and compared his results with the recharge area as delineated by Aley (1978a and 1978b) and Williams (1991). The area shown as the Aley delineated recharge area in Curtis (2000) included only the Direct Recharge Area. The Indirect Recharge Area (also shown in Aley and Moss, 2001) lies northeast of the Direct Recharge Area. There was a close correspondence between the recharge area for Cave Springs as delineated by Aley and Moss

(2001) and as drawn by Curtis (2000). Both delineations included essentially all of the Blossom Way topographic basin.

The southern boundary of the Cave Springs Recharge Area as drawn by Curtis is generally similar to that drawn by Aley and Moss (2001) except that it does not include Reed Spring which shares water with some of the Cave Springs recharge area.

Davis, R.K.; J. V. Brahana; and J.S. Johnston. 2000. Ground water in northwest Arkansas: minimizing nutrient contamination from non-point sources in karst terrain. Contract study for the Arkansas Soil and Water Conservation Commission. Arkansas Water Resources Center Publication No. MSC-288. 59 p. + appendixes. *Work Item 6.*

An appendix (Appendix A) is Brahana, John V. and Ralph K. Davis. 1999. Methodology for delineating ground-water discharge areas of springs in the carbonate-rock terrane of northwest Arkansas, and application to five separate spring basins within the region. 73 p.

This five-year study focused solely on agricultural activities with major emphasis on the disposal of animal wastes. The studied springs were in Benton, Carroll, and Washington Counties, Arkansas. Appendix A presents methods similar to those reviewed in Brahana (1997).

> "The hydrogeological characteristics of the region included rapid recharge of ground water through karst features such as sinkholes or fractures, variable thickness and composition of soils, structurally and stratigraphically controlled losing stream segments, and conduit flow through solution enlarged fractures. These features allow the direct intercommunication of surface water and ground water which illustrates the importance of BMP implementation in the karst setting." *Davis et al. (2000, page 1)*

> "Although many existing BMPs were active in the project area at the initiation of the project, numerous new BMPs have been recommended and implemented as a result of the project. Karstic BMPs were selected in 1994 from the list contained in the State's non-point source (NPS) pollution management program. Additional BMPs were added in 1996 as potential karstic BMPs. Added BMPs included Filter Strips, Livestock Exclusion (Fencing), Pasture and Hayland Management, and Proper Grazing Use." *Davis et al. (2000, page 2).*

> "Karstic BMPs typically recommended and implemented include improve Waste Utilization, Nutrient Management, and Pasture and Hayland Management. Other karstic BMPs recommended and implemented included Waste Storage Structures, Filter Strips, Field Borders, Troughs or Tanks, and Composting Facilities. Some BMPs, such as Deferred Grazing or Livestock Exclusions through Fencing, were not generally accepted nor implemented by farmers…" *Davis et al. (2000, page 2).*

> "Data collection was not extended over a sufficient time for viable assessment of BMP effectiveness. Given the large seasonal and storm driven variations in water quality at each site, it may not be realistic to adequately assess BMP effectiveness over such a relatively short time [5 years]." *Davis et al.(2000, page 55.)*

> "Variance in water-quality parameters resulting from spatial and temporal variability of precipitation was greater than any benefits gained from the implementation of BMPs. Therefore, it was not possible to identify water-quality improvements related to BMP implementation." *Davis et al. (2000, page 56).*

Dougherty, Percy H. 1991. Karst management through zoning and subdivision ordinances. Proc. National Cave Management Symp., Bowling Green, KY, pp. 57-65. *Work Item 6.*

The primary focus on the zoning and subdivision ordinances in the Lehigh Valley near Allentown is on minimizing the risk of sinkhole collapses, many of which form catastrophically and in some cases with loss of human life.

One ordinance made extensive use of fracture traces and lineaments but the author and a township solicitor were concerned that they would not be legally defensible in court. The argument was that not all experts would agree on the location of these features. This may not be the case for similar features in the Cave Springs area.

> "The heart of the ordinance is the Karst Overlay District and the Karst Hazard Overlay Map." *Dougherty (1991, page 3).*

> "A set of performance standards is also adopted in the ordinance. These include the provision of having no stormwater detention facility within 30 m (100 feet) of a karst feature. This is necessary for many developers try to site detention basins in dolines [sinkholes] with disastrous consequences. The eye of the sink can open due to the excess water and added pressure. In addition, no stormwater swale or sewer pipe may be constructed within 30 m [100 feet] of a karst feature unless special precautions are taken including the installation of liners or impermeable bed. No throughflow is allowed along utility trenches and impervious dikes are required at 10 m [30 feet] intervals." *Dougherty (1991, page 3).*

> "Development within 30 m [100 feet] of karst features such as sinkholes, sinking streams, ghost lakes, faults, and any other recognizable karst features is expressly forbidden unless expert geotechnical work shows that it can be done safely." *Dougherty (1991, page 3).*

Eigenmann, C.H. 1898. A new blind fish. Proceedings of the Indiana Academy of Science 1897, p. 231. *Work Item 2b.*

In an abstract in the 1897 Indianan Academy of Science proceedings, Eigenmann gives a name to specimens of cavefish that were collected in southwest Missouri. In this paper, the author names the species, Typhlichthys rosae, and the species is named in honor of his wife. Thus, the Ozark Cavefish is first recognized in the scientific literature.

Eigenmann, C.H. 1899. A case of convergence. Science Vol. 9, pp. 280-282. *Work Item 2b.*

After more detailed study of the specimens the author named Typhlichthys rosae in the previous year, Eigenmann realizes some generic differences the Ozark Cavefish and other species in the family. Following these comparisons, he erects a new genus and renames the species, Troglichthys rosae.

Fischer, Joseph A. 1997. Limestone ordinances of New Jersey and Pennsylvania; a practitioner's experiences. Proc.of the 6th Mulltidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Springfield, MO, April 6-9, 1997. The Engineering Geology and Hydrogeology of Karst Terranes. Beck and Stephenson, Editors, pp. 463-476. *Work Item 6.*

The paper describes some typical examples of projects from the viewpoint of both the reviewer and the submitter. The author reports that the effectiveness of the ordinances is mixed, but that some are very positive.

> "In general, the Clinton Township and Model Ordinance-based legislation, which specify procedures to be used in an investigation, work well. Other ordinances refer to standards which do not exist, have requirements which cannot be met in the real world, or appear poorly related to any professional standards." *Fischer (1997, page 463).*

Fleming, L.E. 1972. The evolution of the eastern North American isopods of the genus *Asellus* (Crustacea: Asellidae) Part I. International Journal of Speleology Vol. 4, pp. 22-256. *Work item 2b.*

The paper lists a Cave Springs Cave record for the species Caecidotea (=Asellus) stiladactyla that was collected on 8/22/1968 by John R. Holsinger.

Frueh, Terry; Roxie Campbell; Robert N. Lerch. 2007. Successful watershed planning by stakeholders, Boone County, Missouri. Proc. 18th National Cave and Karst Management Symposium, St. Louis, MO, pp. 144-153. *Work Item 6.*

This paper provides a good discussion of efforts and problems encountered in planning land use and management in biologically significant recharge areas for 35 caves. Important statements from the paper include the following:

> "How do you develop a watershed plan that considers a wide range of community values? By including policy-makers, technical experts, and a diverse group of stakeholders in the planning process to help ensure the plan has community support. Getting a diverse group of stakeholders to work together is challenging. Keys to successful stakeholders-led watershed planning included giving stakeholders full control of the plan's content, building relationships and trust, mutual understanding, good communication and a well-designed process. The process employed by the Bonne Femme Watershed Project can serve as a model for people in other areas who are interested in protecting water quality, sensitive habitats such as cave ecosystems and hydrologically vulnerable areas." *Frueh et al. (2007, page 145).*

> "Within the watershed, this landform includes more than 35 caves, which provide habitat for rare, endangered, and endemic species. It also includes losing stream hydrology, including two well-characterized, karst recharge areas." *Frueh et al. (2007, page 145).*

> "The Devils Icebox and Hunters Cave recharge areas are similar in size (12 mi^2) and land uses. Currently, both recharge areas predominantly include cropland, forest and grasslands, but urban areas are increasing around the cities of Ashland and Columbia. The population in the Bonne Femme watershed grew by 40% in the ten-year period between 1990 and 2000!" *Frueh et al. (2007, page 146).*

> "The Devils Icebox Cave system, the seventh longest cave in Missouri with over 6.25 miles of mapped passage, currently ranks second in biodiversity among Missouri's approximately 6,400 caves." *Frueh et al. (2007, page 146).*

Glick, E.E. 1970. Geologic map of the Rogers, Arkansas 7.5 minute topographic map. U.S. Geological Survey. Map marked "Master Copy". Map from Arkansas Geological Commission. 1 p. *Work Item 2a.*

Map shows that the entire recharge area for Cave Springs and Reed Spring on this quadrangle map is immediately underlain by the Boone Formation and that there are no identified and mapped faults in the area.

Glick, E.E. 1972. Geologic map of the Bentonville South, Arkansas 7.5 minute topographic map. U.S. Geological Survey. Map marked "Master Copy". Map from Arkansas Geological Commission, 1 p. *Work Item 2a.*

Map shows that the entire recharge area for Cave Springs and Reed Spring on this quadrangle map is immediately underlain by the Boone Formation and that there are no identified and mapped faults in the area.

Graening, Gary O. 2000. Ecosystem dynamics of an Ozark cave. PhD dissertation, University of Arkansas, Fayetteville, AR, 99 p. *Work Items 2a, 2b, and 2c.*

This study was conducted in Cave Springs Cave and for that reason alone this is a very important reference. The study period was from November 1997 to December 1999. Important conclusions include the following:

- *The ecosystem is oligotrophic [severely nutrient limited] and receives about 2% of the energy input that the surface ecosystem above receives.*
- *95% of organic matter input to the cave is dissolved in the water; the rest is suspended.*
- *Gray Bat guano input represents only 1% of organic matter input.*
- *The Gray Bat (Myotis grisescens) summer population was about 3,000 at the time of the study, but this is only 10% of the historic abundance. The cave is a maternity site for this species. [Note: The gate now in place at the cave may help to increase the population to a level more like the historic population].*
- *Cave sediment is the major source of organic matter and stable isotope analysis indicates that particulate organic matter is its source. This illustrates the important of inputs [especially discrete recharge] from the surface.*
- *Cave Springs Cave has an ecosystem efficiency of only 4%, benthic organic matter turnover time is 6 years, and community respiration rate is half that of surface streams.*
- *Much of the organic matter input is exported by spring flow and under-utilized within the cave.*
- *Stable isotope analysis implicates septic [more accurately sewage] and agricultural wastes as sources with most transport into the cave occurring during storm flows and autumn.*
- *Ozark Cavefish (Amblyopsis rosae) are the top predator, eating mainly isopods that in turn eat imported organics.*
- *Crayfish eat benthic leaf detritus and, seasonally, guano.*
- *Nutrient pollutants appear to augment the trophic base in the cave, but may also have extirpated the rare Ozark amphipod.*

- *Reduction of septic[more accurately sewage] and agricultural waste inputs and rehabilitation of bat populations may be necessary to restore ecosystem dynamics in this cave ecosystem.*
- *Cave Springs has an exceptionally high fecal pollutant load, with average fecal coliform counts in the thousands per 100 ml and peak storm flow counts approaching one hundred thousand per 100 ml.*
- *The cave contains the largest known population of Ozark Cavefish with a maximum observed population size of 166 individuals and an estimated density of 0.2 fish per square meter (0.019 per square foot).*
- *The epigean (surface dwelling) Spot-Handed Crayfish (Orconectes punctimanus) had an estimated density of 0.5 individuals per square meter (0.048 per square foot) in the cave pools and 10 individuals per square meter (0.96 per square foot) at the cave mouth in 1999.*
- *The Ozark cave amphipod (Stygobromus ozarkensis), an Arkansas species of concern has been reported from the cave stream but has not recently been found in the cave stream. The cave amphipod Stygobromus onondagaensis has also been reported from the cave, but was not found during the Graening dissertation study.*

Graening, G.O. 2002. Trophic dynamics and pollution effects in Ozark cave streams containing endangered species. Dept. of Biological Sciences, Univ. of Arkansas contract report to the U.S. Fish and Wildlife Service. 50 p. approx. *Work Items 2a and 2b.*

> "This current study explored the food web dynamics and environmental quality of five similar caves containing federally designated endangered species to determine if the stresses occurring at Cave Springs Cave were impacting other subterranean habitats." *Graening (2002, page 2).*

This is a very important reference. Among other things it compares water quality measurements from Cave Springs Cave with other caves in Benton County that provide habitat for threatened or endangered species. The other caves were Logan Cave, Civil War Cave, Bear Hollow Cave, and Rootville Cave. The OUL has delineated the recharge areas for all of these caves except for Rootville Cave and thus has a good understanding of land use conditions in their recharge areas.

Graening (2002) notes that both mean and maximum concentrations of beryllium, copper, and selenium in water samples from Cave Springs Cave exceed Arkansas water quality standards for aquatic life and that maximum observed values for lead and zinc also exceed these standards. All measurements and standards are based on dissolved metals. OUL Note: Current Arkansas water quality standards for aquatic life vary with the hardness of the water. The author notes that the source(s) of these contaminants at Cave Springs is unknown, but their presence during the period November 1997 to September 2001 is clearly of major concern.

Graening, Gary O. and Arthur V. Brown. 1999. Cavefish population status and environmental quality in Cave Springs Cave, Arkansas. A report for Arkansas Natural Heritage Commission. Publ. No 276, Arkansas Water Resources Center, Univ. of Arkansas, Fayetteville, AR, 38 p. *Work Items 2a and 2b.*

> "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 exceed 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 higher during stormflow events." *Graening and Brown (1999, page 3).*

> "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." *Graening and Brown (1999, page 3).*

> "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 accumulation of cadmium and lead than the other crayfish co-inhabiting the cave." *Graening and Brown (1999, page 6).*

This report summarized water quality from sampled collected at the mouth of Cave Springs for the period July 16, 1998 through May 3, 1999. Hardness or alkalinity was not measured. The report also summarized water quality data during a storm period extending from March 8-13, 1999. Table 3 is a copy of the authors' Table 6 comparing various metal concentrations associated with Cave Springs and the concentrations in sewage sludge from Springdale.

Table 3. 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. *From Graening and Brown (1999) n.d.= none detected.*

	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*	*27.4*
Zinc	*454*	*384.7*	*162.3*	*100.5*	*904*

In discussing cavefish populations the paper shows a graph of all cavefish counts in Cave Springs Cave from 1981 through 1999. The number of cavefish sighted in 1996 was 153; that number decreased to 106 in 1998. This decrease was viewed with alarm by Brown et al (1998). In 1999 the number sighted was 166, which was consistent with an apparent long-term trend of increasing numbers of cavefish seen during surveys. The most likely explanation for the apparent decrease in the number of cavefish in 1998 is a substantial error in the census approach that can occur from time to time.

> "The land-application of sewage sludge is a potential metal contaminant of cave (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." *Graening and Brown (1999, page 26).*

> "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…" *Graening and Brown (1999, page 27).*

The peak flow rate of Cave Springs was 26 cubic meters per minute; this equals 15.3 cfs. This flow rate occurred on July 1, 1999 in response to a major summer thunderstorm.

"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 passages 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 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 Williams (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." *Graening and Brown (1999, page 29).*

In the recommendations section of the report the authors' state:

"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…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." *Graening and Brown (1999, page 30).*

Graening, Gary O. and Arthur V. Brown. 2000a. Trophic dynamics and pollution effects in Cave Springs Cave, Arkansas. Report to Arkansas Natural Heritage Commission. Publ. No. MSC-285. Arkansas Water Resources Center, Univ. of Arkansas, Fayetteville, AR, 44 p. *Work Items 2a and 2b.*

This report provides all known Gray Bat (Myotis grisescens) census data through 2000. The data are as follows. The bat counts were done by Dr. Michael J. Harvey and Ron Redman. Data from Graening and Brown (2000a).

Year	*Number of bats*	*Year*	*Number of bats*
1990	*22,000*	*1997*	*3,420*
1993	*3,030*	*1998*	*3,100*
1994	*6,400*	*1999*	*3,300*
1995	*9,330*	*2000*	*2,300*
1996	*2,320*		

"The results of this and previous studies indicate that the Cave Springs Cave ecosystem is under stress from habitat degradation. The water quality has steadily declined in the past two decades… The recharge area has many pollution sources, especially from application of confined animal wastes and municipal sewage sludge to pastures, and the increasing numbers and decreasing effectiveness of septic systems." *Graening and Brown (2000a, Executive Summary).*

"Most dissolved metals (aluminum, barium, beryllium, calcium, chloride, copper, iron, magnesium, manganese, and lead) were significantly correlated to discharge. Constrained least squares analyses of metal profiles (As, Be, B, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Se, V, Zn) of cave ecosystem components and potential pollution sources revealed possible inter-relationships, and the results are shown in Table 8. For example, the cave isopod metal profile can be constructed by taking 33% of the sewage sludge metal profile, 21% of the septic waste profile, and 46% of the cow manure profile, with a goodness of fit (R^2) of 0.928, among other possible combinations." *Graening and Brown (2000a, page 13).*

The report provides water quality data for Cave Springs for 5 dates in 1999 and 2000 where the flow rates are identified as "base flow". The flow rate values range from 1 to 11 cubic meters per minute (0.59 to 6.49 cfs). The report also includes water quality data for four "storm events" in 1999 and 2000. The flow rates during those events are shown in Table 4. All values have been converted from cubic meters per minute to cfs.

Table 4. Water quality data for four "storm events" in 1999 and 2000. *From Graening and Brown (2000a).*

Period	***Day 1*** *(cfs)*	***Day 2*** *(cfs)*	***Day 3*** *(cfs)*	***Day 4*** *(cfs)*
9/8-9/9/99	*2.95 and 2.95*	*2.95*	---	---
10/29-11/2/99	*1.18*	*1.18*	*1.18*	*1.18*
12/4-12/6/99	*1.18*	*1.18*	*1.18*	---
4/11-4/13/00	*0.59*	*0.59*	*0.59*	---

The distinction between base flow and storm flow as used by the authors is not hydrologically reasonable. First, the authors base storm flows on periods with between 1.7 cm and 6.7 cm of accumulated precipitation; no consideration is given to the fact that these precipitation events yielded no increases in the flow rate of the spring. Second, none of the "storm flow" periods has a flow rate as great as that which occurred on 2 of the 5 "base flow" periods. As a result, the report does not include any true storm flow data from Cave Springs for the 1999-2000 period. The two periods with the highest flow rates are identified as base flow, but are potentially more reflective of storm flow periods.

The report contains some data on metal concentrations in mg/kg dry weight basis for sewage sludge, cave sediments, cave biofilm, septic biosolids, cow manure, poultry litter cave isopods, surface crayfish, and Ozark Cavefish. These values are used to calculate potential contaminant sources for cave isopods, cave crayfish, and Ozark Cavefish. Isotopic analysis is used to identify potential food sources for members of the cave fauna.

In discussing census data for Ozark Cavefish the authors note that the low number of individuals noted in 1998 and 2000 add variability to what was previously believed by Brown et al. (1998) and Graening and Brown (1999) to be a significant trend of increase in the population size. As of the date of the current report there is not a significant trend indicating an increase in the population of Ozark Cavefish. Ozark Cavefish numbers by year since 1981 are as shown below.

1981 = 97
1982 = 101
1985 = 122
1989 = 139
1995 = 153
1998 = 106
1999 = 166
2000 = 102

Graening, Gary O. and Arthur V. Brown. 2000b. Status survey of aquatic cave fauna in Arkansas. Report to Arkansas Game and Fish Commission. Arkansas Water Resources Center, Publication MSC-286. 43 p. *Work Items 2a and 2b.*

This report contains water quality data for 37 caves in northwest Arkansas. The data are based on grab samples, and all data were collected on either February 19 or 20, 2000. The survey focused on biologically significant caves. Of the 152 Ozark Cavefish seen during the survey, 107 of them were in Cave Springs Cave.

Graening, Gary O. and Arthur V. Brown. 2001. Protection of Cave Springs Cave biota and groundwater basin. Report to Arkansas Natural Heritage Commission. Arkansas Water Resources Center, Publication MSC-297. 37 p. *Work Items 2a and 2b.*

> "We have been monitoring the environmental quality of the habitat and censusing the cavefish population for the ANHC under contracts since 1998 (Brown et al., 1998; Graening and Brown, 1999, 2000). The project for year 2000-2001 has been a continuation of these activities, and is a final chapter in the series of studies." *[Page 2].*
>
> "Cavefish and other stygobionts occasionally wash out of caves and into surface streams. Graening has incidentally found three cavefish in the fish hatchery raceways downstream of Cave Springs Cave during the course of our studies there, although no planned effort to watch for them was involved…It is quite certain that the white, blind cavefish would not survive for long in the clear, well-lit water with trout and other predatory fish present. Some losses from cavefish populations in this manner may be natural but even so, some effort to preserve them from this fate seems appropriate. Besides, the resurgence for Cave Spring Cave, like many other cave springs, has been highly modified and this may have exacerbated the situation.*"* *[Page 2].*

Using grab samples, water quality was monitored at Cave Springs for this study on ten dates during 2000 and 2001 identified as "storm flows". Flow rates ranged from 1 to 24 cubic meters per minute (0.59 cfs to 14.16 cfs) with flow rate measurement made in association with only 5 of these dates. Grab samples of water were analyzed during 2000 and 2001 for three periods identified as "base flow". Flow rates were measured on two of the three occasions and ranged from 1.18 to 2.36 cfs. A table is also enclosed that shows maximum, minimum, and mean parameter concentrations; it presumably averages both base flow and storm flow periods.

Graening, Gary O. and Arthur V. Brown. 2003. Ecosystem dynamics and pollution effects in an Ozark cave system. Jour. of the Amer. Water Resources Association. December 2003. pp. 1497-1507. *Work Items 2a and 2b.*

The focus of this paper is Cave Springs Cave, and much of the data are from the Graening (2000) dissertation. Important findings and conclusions (without duplicating those already ascribed to Graening {2000}) include the following:

- *Cave Springs has a surveyed length of 515 meters (1,690 feet).*
- "Organic pollution has adverse effects on cave ecosystems, including alteration of community assemblages, impoverishment of biodiversity, and increased risk of predation by epigean [surface] fauna." *Graening and Brown (2003, page 1504).*
- "The recharge area contains at least 40 confined animal feeding operations (poultry and swine) and hundreds of septic systems; municipal sewage sludge was applied on pastures for at least six years (1990 to 1996)." *Graening and Brown (2003, page 1498).*
- "Results of organic matter budgeting documented a dissolved organic matter (DOM) influx of 4,730 gms/square meter per year [0.97 pounds per square foot per year] and bat guano deposition rate of 10.4 grams per square meter per year [0.002 pounds per square foot per year]…. Mean yearly export was 5,330 kilograms [11,726 pounds] per year as dissolved output and 280 kilograms [616 pounds] per year as particulate output, with the majority of particulate transport occurring during storm events." *Graening and Brown (2003, page 1501).*
- "Metals analyses…detected beryllium, copper, lead, selenium, and zinc in concentrations in cave water that exceeded state of Arkansas limits for chronic and acute toxicity to aquatic life…Toxic metals were also detected in FBOM [fine benthic organic matter] and in tissues of crayfish, isopods, and cavefish." *Graening and Brown (2003, page 1503)*
- "Because of the longevity of stygobitic organisms, even low concentrations of dissolved metals are of concern because they could bioaccumulate to lethal concentrations." *Graening and Brown (2003, page 1505)*
- "The reduction of anthropogenic pollution input into this ground water basin is necessary to restore ecosystem dynamics in Cave Springs Cave to its former undisturbed condition. It is imperative that cave streams be managed with respect to their tributary ground water basins and historic energy fluxes, with a special focus on indicator species such as stygobitic crustaceans and sensitive areas such a sinkholes, losing streams, fissures, and other karst features." *Graening and Brown (2003, page 1506).*
- *The mean annual discharge of the spring is estimated to be 100 l/sec (3.54 cfs). This value is based on 59 flow rate measurements from November,1997 to December , 1999. [This value may not represent a long term mean flow rate]. The measurements were based on staff gage readings made at the cave entrance and the following stage/discharge relationship: stage (m) x 35.79 (m^2 / min) –110 = discharge (m^3/min). This is based on U.S. Geological Survey unpublished data. Observed flow rates for the 59 observations (converted to English units) ranged from a minimum of 0.60 cfs to a maximum of 11.79 cfs with a median value of 2.94 cfs and a mean of 3.54 cfs. [Note:*

these values underestimate the total flow because of leakage through pipes and other nearby small springs].

- *Page 1504 includes a summary of water quality results from Cave Springs during the study period. Many parameters varied widely; for example:*
    - *Turbidity varied from <1 NTU to 48.0 NTU.*
    - *Dissolved oxygen varied from 8.3 to 11.6 mg/liter.*
    - *Copper [probably total copper] varied from less than the unspecified detection limit to 230.0 micrograms per liter.*
    - *Escherichia coli varied from <10 to 20,050 colony forming units per 100 ml.*
    - *Total coliform varied from < 200 to 83,100 colony forming units per 100 ml.*

Graening, Gary O.; Dante B. Fenolio; Matthew L. Niemiller; Arthur V. Brown; and Jonathan B. Beard. 2010. The 30-year recovery effort for the Ozark Cavefish (*Amblyopsis rosae*): Analysis of current distribution, population trends, and conservation status of this threatened species. Environ. Biol. Fish, Vol. 87, pp. 55-88. DOI 10.1007/s10641-009-9568-2. *Work Item 2b.*

Important findings/conclusions were as follows:

- *The two largest Ozark Cavefish populations are at Cave Springs Cave and Logan Cave (both in Benton Co., Ark.) These populations have stabilizing or increasing survey counts.*
- *The number of active cavefish sites has decreased over 50% since 1990, but the number of individuals found in surveys has not decreased during this period.*
- *At the time of federal listing as threatened the primary identified threat was over-collecting. That has now shifted to habitat degradation.*
- *The Ozark Cavefish has one of the lowest reported population densities of any stygobiotic [underground dwelling] fish, ranging from 0.005 to 0.15 individuals per square meter.*
- *Based on information from Thomas Poulson, the entire cavefish population in Cave Springs Cave probably was 150 before extensive collections were made [those collections were made in the 1950s; at least 174 were collected from Cave Springs] . In the 1960s census counts ranged from 39 to 97.*
- "The number of cavefish surveyed in Cave Springs Cave…is significantly increasing since T. Poulson began the survey effort in 1960… Protocol surveys ranged from 93 to 166, with relatively small variance (mean 123, standard deviation 29.7, Coefficient of variation 24%)…The Mann-Kendall Test indicated a significant upward trend…while Sen's Slope Estimator Method indicated a rate of increase of approximately two cavefish per year." *Graening et al. (2010, page 73).*

- "Several important studies have been performed, and indicate that many cavefish populations are experiencing chronic, low-level exposure to a suite of anthropogenic contaminants. Delisting conditions are largely unattainable as currently worded. We suggest that recovery criteria be amended such that habitat protection goals are attainable, that the list of Recovery Caves can be periodically updated, and that the recovery population goal is increased and distributed between more sites." *Graening et al. (2010, pages 55-56).*
- "We agree with Poulson (1960) who concluded that floods, expelling fish out of subterranean habitats is another important, but poorly documented, mortality factor. Smith (1980) reported major flood events washing Southern cavefish (*Typhlichthys subterraneus)* from caves. An Ozark Cavefish was apparently collected outside of a cave circa 1889: the museum catalogue (MCZ-27587) note states, *'From brook outside of Wilson's Cave near Sarcoxie; 50 feet from entrance to cave.'* Graening observed three live Ozark Cavefish in the trout runs downstream of the Cave Springs Cave resurgence after a major storm event in 1999…Another live Ozark Cavefish was observed in the pond downstream of Logan Cave, again after a major flow event…These fish were carefully returned to their subterranean streams, but we cannot predict how many other expelled cavefish have perished in epigean [surface] environments." *Graening et al. (2010, page 88).*

Graening, Gary O.; Michael Slay; Art Brown. Undated; about 2002. Subterranean biodiversity in the Ozark Plateaus of Arkansas. Subterranean Biodiversity Project, Dept. of Biological Sciences, Univ. of Arkansas, Fayetteville, AR, 46 p. *Work Items 2a and 2b.*

> "Thirty-seven caves and springs in 2000 and 64 in 2001 were analyzed for base-flow water quality, with focus upon metals in sediments and water, nutrients, and bacteria. Results indicated some degree of fecal contamination in all sites sampled, and some of these caves had nutrient concentrations well above regional averages. No significant relationship was detected between the presence of bats and the presence of coliform bacteria, indicating that bat guano cannot explain this fecal contamination entirely—septic system leachate, grazing livestock, and the land-application of confined animal feeding operation wastes were probable sources. Concentrations of metals in water and sediments appeared to be below toxic levels, even for regions known to be lead-zinc mining districts." *Graening et al. (2001, abstract, page 1).*

This report includes analytical water quality results from 37 caves in northwest Arkansas that were sampled on either February 19 or 20, 2000 under what were reported to be base flow conditions. The same data for the 37 caves sampled on February 19 or 20 were reported in Graening and Brown (2000b).

The current report also includes analytical water quality results from 64 caves in northwest Arkansas that were sampled on either April 7 or 8, 2001. Graening and Brown

(2000b) did not contain any of these data. Water quality data collected on the same dates from a large number of caves or springs is very valuable in indicating whether or not the values for particular water quality parameters measured at Cave Springs are similar to values from other caves in the region. This similarity will be discussed in the Ozark Underground Laboratory's (OUL) report "Summary of existing knowledge about hydrology, cave biology, and cave conservation methods applicable to Cave Springs, Arkansas".

Graening, G.O.; M.E. Slay; D.B. Fenolio; and H.W. Robison. 2007. Annotated list of the Isopoda of Arkansas and Oklahoma. Proceedings of the Oklahoma Academy of Science Vol. 87, pp. 1-14. *Work Item 2b.*

In a survey of the isopods, mainly groundwater habitats in Arkansas and Oklahoma, the authors repeat the Fleming (1972) record of Caecidotea stiladactyla from Cave Springs Cave. Because of the number of records for C. stiladactyla, the authors suggest downgrading the Arkansas and Oklahoma state conservation rank for the species.

Graening, G.O.; M.E. Slay; and J. Holsinger. 2005. Checklist of the Amphipoda of Arkansas with emphasis upon ground water habitats. Journal of the Arkansas Academy of Science, Vol. 59, pp. 63-70. *Work Item 2b.*

The authors summarize all the historic records for amphipods in Arkansas and provide new collections from their more recent work. Two species are listed as occurring in Cave Springs Cave: Stygobromus onondagaensis and Stygobromus ozarkensis. S. onondagaensis is relatively common in Missouri, but has only been reported from 4 sites in Benton County, Arkansas. Because of this reason, the authors suggest upgrading its Arkansas state conservation rank to indicate its rarity in the state. S. ozarkensis is more widespread. Both species appear to be endemic to groundwater habitats in the Ozarks.

Haggard, B.E.; Andrew Sharpley; and Leslie Massey (Editors). 2010. Handbook of best management practices for the Upper Illinois River Watershed and other regional watersheds. Arkansas Water Resources Center Technical Publication MSC 357. 117 p. *Work Item 6.*

A heavily illustrated document that addresses, in a very general sense, management actions that can be taken by municipalities, industrial facilities, households, managers of landscape and turf area, agricultural operations, forestry activities, and managers of unpaved roads and by-products. The report focuses on surface water considerations and gives negligible attention to best management practices designed to protect karst groundwater systems and associated cave faunas. It is not necessarily the case that management practices that help protect surface water quality protection will also protect karst groundwater systems. As an illustration, a stormwater detention pond that captures the first quarter to half-inch of *stormwater runoff and introduces much of it into the subsurface may improve surface water quality but concurrently degrades groundwater quality.*

On page 9 the report states that urban development changes watershed hydrology and streams must respond to a number of listed factors; the listed factors include decreased recharge of shallow and medium-depth aquifers. This is true in karst areas when stream channels are paved, but is not necessarily true in other cases. For example, Paylor and Currens (2001) showed that the base flow rates of springs in karst areas of the Inner Bluegrass Area of Kentucky increased with increases in the extent of urbanization.

Hanson, Bradford C. 1973. A fracture pattern analysis employing small scale photography with emphasis on groundwater movement in Northwest Arkansas. MS thesis, Univ. of Arkansas, Fayetteville, AR, 72 p. *Work Item 2a.*

The thesis includes an extensive list of the springs in Benton County and their locations. In a few cases flow rate estimates were made for the springs. Lineaments and fracture traces in and around the Cave Springs recharge area are shown. Many of the springs in Benton County are associated with fracture traces and lineaments.

Harvey, Michael J.; John J. Cassidy; and Gary G. O'Hagan. 1981. Endangered bats of Arkansas; distribution, status, ecology, and management. Ecological Research Center, Memphis State University report to Arkansas Game and Fish Commission, U.S. Forest Service, and National Park Service. 137 p. *Work Item 2c.*

These authors summarize their research on Ozark Big-eared Bats, Gray Bats, and Indiana Bats in Arkansas from the period of 1978 to 1981. The focus of the project was to determine the status and distribution of these bats in Arkansas, make observations on the ecology of these species, and make management recommendations. Forty six caves were surveyed including sites with maternity and transient colonies and hibernacula. In addition, mist nets were used to survey bat presence over local streams, and exiting bats were caught, banded, and released to investigate movement between sites. Cave Springs Cave was visited during the study period, and through a combination of bat exit counts, mist netting over the summer months, and observations of lactating females, the authors concluded that a maternity colony was present. In the summer of 1980, 144 Gray Bats were banded at Cave Springs Cave, and several of these bats were re-located in Bonanza Cave, a major hibernaculum in Baxter County, Arkansas. The straight-line distance between these two caves is approximately 100 miles.

Cave Springs Cave is identified as a maternity colony site for the Gray Bat (<u>Myotis grisescens</u>). On June 9, 1979 an estimated 6,000 bats existed in the cave. The authors were only allowed to monitor bat activity at the cave entrance. This information is from p. 52-53.

Herbert, K.A. 1994. Drift of aquatic macrofauna in Logan Cave stream, Benton County, Arkansas. Arkansas Cooperative Fish and Wildlife Research Unit. Publication No. 22. *Work Item 2b.*

A study was conducted Logan Cave to determine the diversity and frequency of drifting organisms associated with the cave stream. Drift is a well-known phenomenon of surface streams, but little studied in cave streams, resurgences, or spring runs. In this project, drifting animals were collected in nets places in four locations associated with the cave stream. Two of these sampling stations were inside the cave, one just outside the entrance, and one slightly downstream of the entrance. Sampling occurred 23 times from May 1992 to April 1993. The main organisms collected were invertebrates (amphipods in the genus Gammarus and Stygobromus; isopods in the genus Caecidotea), larval salamanders, and Banded Sculpin. No cavefish were collected during the project suggesting that cavefish do not drift.

Holsinger, J.R. 1972. The freshwater amphipod crustaceans (Gammaridae) of North America. Biota of Freshwater Ecosystems: Identification Manual # 5. U. S. Environmental Protection Agency, Washington, D.C., 89 p. *Work Item 2b.*

This paper discusses the amphipod species found in aquatic habitats in North America, broadly describes species distributions, and provides a dichotomous key for identifying specimens. A record for Stygobromus (as Stygonectes) ozarkensis is reported for Cave Springs Cave.

Hutchison, V.H. 1956. Notes on the Plethodontid salamanders, *Eurycea lucifuga* (Rafinesque) and *Eurycea longicauda longicauda* (Green). Occasional Papers of the National Speleological Society, Number 3, 24 p. *Work Item 2b.*

This paper discusses in general some observation made on two plethodontid species of salamander that are often found near cave entrances, Eurycea lucifuga (cave salamander) and E. longicauda (long-tailed salamander). Two collections of the cave salamander are reported for Cave Springs Cave.

Jenkins, Dwight. 1988. Development of storm water management criteria for sensitive karst areas in north-central Florida, USA. Proc. Second Conf. on Environmental Problems in Karst Terranes and Their Solution. Assoc. of Ground Water Scientists and Engineers, pp. 333-343. *Work Item 6.*

> "In portions of North-central Florida, however, the Floridan aquifer is thinly covered, existing virtually at land surface. Because the limestones are only thinly covered, there is greater potential for contamination of the Floridan aquifer from

> surface pollution sources. The St. Johns River Water Management District has designated these areas as 'Sensitive Karst Areas'." *Jenkins (1988, page 333).*

This paper focuses much of its attention on stormwater detention basins and on the risks they pose to groundwater quality from induced sinkhole collapses. Such basins for residential land uses must have a minimum of 3 feet of unconsolidated soil material between the bottom and sides of a retention basin and the surface of the limestone bedrock. Industrial and commercial project requirements are more stringent and, among other things, require groundwater monitoring and greater amounts of soil between the bottom and sides of the retention basins and the surface of the limestone bedrock. Lesser thicknesses require an impermeable basin liner to isolate stormwater from the aquifer. The authors state that in most cases the use of impermeable liners is not possible due to the large volume of storm water that would have to be stored. A detailed description of the site hydrogeology is required to be submitted with all stormwater permit applications.

Keith, James H.; John L. Bassett; and J. A. A. Duwelius. 1995. Karst geohazards; engineering and environmental problems in karst terrane. Edited by Barry F. Beck. Proc. of the 5th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Gatlinburg, TN, April 2-5, 1995, pp. 273-284. *Work Items 2a and 6.*

> "…a 7 km [4.3 mile] section of Indiana State Road 37 on the Mitchell Plain in Lawrence County, Indiana was widened to four lanes. The Mitchell Plain is developed on a belt of limestones of middle Mississippian age, and is characterized by sinkholes, sinking streams, swallow holes and caverns. Construction work included the placement of storm water drainage structures in eleven sinkholes, three of which were also fitted with peat filters. The structures were designed to facilitate drainage of storm water runoff, and to improve runoff quality through detention, adsorption, dilution and filtration prior to directing the flow underground. …semiannual storm water sampling has been conducted…to monitor the performance of the drainage structures. …Results from four sampling events indicate that a peat filter installed at Sinkhole 9 is removing an average 80 percent of suspended particulates (measured as TSS and selected total recoverable metals) and almost 50 percent of dissolved copper and zinc. Rock filters are removing from 35.8 percent to 55 percent of total recoverable metals, and from 32.7 percent to 76 percent of TSS. Rock filters do not appear to remove dissolved metals. In order to be effective and remain effective, rock filters and peat filters must be protected from the introduction of excess sediment. Drainage systems along State Road 37 are provided with upgradient detention basins wherever possible. Small ditch line detention basins have also been installed in a number of areas to intercept and retain spills or releases of hazardous materials. These basins not only offer an additional buffer against spills, they provide protection to the filter systems as well. Ongoing structure inspections suggest that the installed filters will continue to function as intended, at least for the next few

years. The actual working life of peat and rock filters remains to be determined."
Keith et al. (1995, page 273).

Keith, James H.; John L. Bassett; and J.A. Duwelius. 1997. Findings from MOU-related karst studies for Indiana State Road 37, Lawrence County, Indiana. Proc.of the 6th Mulltidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Springfield, MO, April 6-9, 1997. The Engineering Geology and Hydrogeology of Karst Terranes. Beck and Stephenson, Editors, pp. 157-171. *Work Items 2a and 6.*

This paper provides the results of additional monitoring of features described in Keith et al. (1995). It includes drawings of some of the installed features and tables of estimated efficiencies of selected filters.

Kirkland, Shiloh and Thomas Aley. 2012. Groundwater recharge area delineation and vulnerability assessment of the cave crayfish (*Cambarus zophonastes*) site at Yellville's Legion Spring, Marion County, Arkansas. Ozark Underground Laboratory contract report to The Nature Conservancy, Fayetteville, AR, 66 p. + appendixes. *Work Item 6.*

The spring in which the cave crayfish has been found is located in the upper portions of the Cotter Formation of Ordovician Age. The recharge area comprises 4,530 acres. Of this, 530 acres is mapped as High Vulnerability, 900 acres as Moderate Vulnerability, and 3,100 acres as Low Vulnerability. This includes approximately 500 acres of Presumptive Habitat located down-gradient of the spring. All of the Presumptive Habitat area is mapped as High Vulnerability.

Lamonds, A.G. 1972. Water-resources reconnaissance of the Ozark Plateaus Province, Northern Arkansas. U.S. Geological Survey Hydrologic Investigations Atlas HA-383. 2 map sheets. *Work Item 2a.*

This reference includes a summary of flow rate measurements made of Lake Keith Spring. This is an alternate name for Cave Springs. There were a total of 22 measurements made. The maximum measured flow rate was 10.2 cfs; this flow rate was measured once on September 15, 1959 and again on August 10, 1961. The minimum measured flow rate was 0.31 cfs on August 15, 1962. The mean measured flow rate was 4.10 cfs. These flow rate measurements were reflective of conditions prior to much of the urbanization of at least the direct portion of the Cave Springs recharge area.

Lewis, Julian J. 1996. The devastation and recovery of caves affected by industrialization. Proc. 1995 National Cave Management Symposium, pp. 214-227. *Work Item 6.*

This is a case history of two cave systems that supported important cave fauna. The caves were severely impacted by groundwater pollution for a number of years before the inflow of pollutants was largely curtailed. Cavefish and cave crayfish (different species than those found in Cave Springs Cave) have recolonized the cave stream and are once again present in Hidden River Cave at Horse Cave, Kentucky. Prior to the cleanup efforts waters in the Hidden River cave stream had become anaerobic due to treated municipal sewage from two towns that was introduced into sinkholes and wastes from a creamery. In addition, metal plating wastes from an industrial plating operation also contaminated Hidden River Cave. Table 5 shows observed dissolved heavy metal concentrations in the South Branch of Hidden River Cave before legal action was taken against the metal plating plant.

Table 5. Observed range of selected dissolved heavy metal concentrations detected in the water of South Branch, Hidden River Cave. Based on 8 samples. *Data from Lewis (1996).*

Parameter	***EPA criteria for aquatic life toxicity****	***Range of Concen. Detected in Hidden River Cave***
Total Chromium (mg/l)	*0.05 mg/l*	*0.202 to 8.90*
Nickel (mg/l)		*1.15 to 19.4*
Copper (mg/l)	*0.02*	*0.30 to 1.17*
Zinc (mg/l)	*5.0*	*0.074 to 2.12*

* *Values have changed since 1996.*

The importance of this reference is to demonstrate that cave fauna can be recovered to at least some extent even after major cases of pollution.

MacDonald, H.; H. Jeffus; K. Ftelle; T. Coughlin; K. Kerr; and G. Wagner. 1974. Pollution susceptibility mapping for rural development and land use planning in carbonate terrain-Northwest Arkansas. Univ. of Arkansas, Fayetteville, AR, 98 p. *Work Item 2a.*

> "In carbonate terrain the airphoto linears are the surface expression of underlying solution channels developed along fracture zones in the soluble bedrock. Because groundwater travels much more rapidly along these solution channels than in the intergranular pore spaces of non-carbonate rocks, the solution channel groundwater is much more susceptible to rapid input and spreading of pollutant materials." *MacDonald et al. (1974, page 81).*

This report provided a detailed suite of maps for an area just south of the Cave Springs recharge area. Plate 3 in the report shows both fracture traces and lineaments. The fracture traces have lateral persistence of less than one mile; lineaments persist for a mile or more. The map shows that almost every stream channel in the area, even if it is not shown with a blue line *on the quadrangle maps, is underlain by a fracture trace or lineament. In contrast with this intensity of mapping, most of the other mapping of fractures in the area incorporated only lineaments. It is highly unlikely that effective and rapid drainage of the karst aquifer could be accomplished if only major lineaments were involved.*

MacDonald, H.C.; Kenneth F. Steele; and Elizabeth Gaines. 1977. Landsat linear trend analysis; a tool for groundwater exploration in northern Arkansas. Arkansas Water Resources Research Center Publ. No. 49, 108 p. *Work Item 2a.*

Shows mapped lineaments on a county-by-county basis. However, the map for Benton County is poorly printed and on a poor base and does not provide any new information for the Cave Springs recharge area.

McCann, Molly S. and James L. Smoot. 1999. A review of stormwater best management practices for karst areas. Proc. of the 7th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Harrisburg-Hershey, PA April 10-14, 1999. IN: Beck, Pettit, and Herring, Editors. Hydrogeology and engineering geology of sinkholes and karst, 1999. A.A. Balkema, Rotterdam. pp. 395-398. *Work Item 6.*

"For controlling water quality, the use of skimmers, wet retention ponds, wetlands, and filtration systems may be applicable. These BMPs would be effective if installed near the sinkhole area or throughout the watershed." McCann and Smoot (1999, page 395).

> "Typically, non-karst settings provide for some infiltration and natural removal of pollutants through the soil mantle, where many contaminants are adsorbed or further removed by microbes and vegetation. In contrast, karst settings usually provide little or no natural pollutant attenuation and can quickly transport contaminants through solution features to other locations. In addition, encouraging infiltration in karst areas may lead to sinkhole collapse." *McCann and Smoot (1999, page 395).*

Means, M.L. and J.E. Johnson. 1995. Movement of threatened Ozark Cavefish in Logan Cave National Wildlife Refuge, Arkansas. Southwestern Naturalist Vol. 40, pp. 308–313. *Work Item 2b.*

These authors conducted a mark-recapture study of Ozark Cavefish in Logan Cave from June 1992 to September 1993 sampling the cave 12 times over the time period. Cavefish that were larger than 30 mm (1.2 inches) were netted, anesthetized, and implanted with a unique serial tag. They observed 6 fish that were less than 30 mm (1.2 inches) in length over the course of the study. The number of fish captured each trip ranged from 15-30 with an average of 22.7 fish per trip. Cavefish were observed to move within the system in both upstream and *downstream directions with an average daily movement of 3.8 meters (12.5 feet). Larger cavefish moved farther than smaller cavefish. About 20% of cavefish that were captured each trip were un-tagged. Based on the observation that most of the fish captured in September 1993 (22 total; 5 with tags; 17 without tags) were not tagged compared to cavefish captured 9 months earlier (Dec 1992: 20 total; 15 with tags; 5 without tags), the authors suggest that most of the observable population of cavefish had been replaced over this 9 month period. Rather than losing cavefish due to predation or death, they believe cavefish re-enter portions of aquatic habitat not accessible by researchers.*

Moix, Matthew W.; C. Shane Barks; and Jaysson E. Funkhouser. 2003. Water quality and streamflow gains and losses of Osage and Prairie Creeks, Benton County, AR, July 2001. U.S. Geological Survey, Water-Resources Investigations Report 03-4187. 29 p. *Work Item 2a.*

A series of flow rate measurements were made on Osage Creek on July 24, 2001. Decreases in flow likely to be indicative of stream segments on Osage Creek that might contribute water to Cave Springs were noted in four stream segments. The apparent losing stream segments were as follows:

Upstream Station	***Coordinates***	***Downstream Station***	***Coordinates***	***Flow rate decrease** (cfs)*
OCM 11	*36.1856 94.1120*	*OCM 10*	*36.1848 94.1134*	*0.30*
OCM 10	*36.1848 94.1134*	*OCM 9*	*36.1841 94.1150*	*0.71*
OCM 4	*36.1801 94.1310*	*OCM 3*	*36.1748 94.1320*	*2.40*
OCM 2	*36.1732 94.1318*	*OCM 1*	*36.1719 94.1327*	*1.50*

This document also includes some water quality data from the flow rate measurement stations. These data were also collected on July 24, 2001. No flow rate measurements were made at Cave Springs. A waste water treatment plant for the City of Rodgers is located upstream of station OCM 4.

Niemiller M.L.; B.M. Fitzpatrick; P. Shah; L. Schmitz; and T.J. Near. 2013. Evidence for repeated loss of selective constraint in rhodopsin of amblyopsid cavefishes (Teleostei: Amblyopsidae). Evolution Vol. 67, pp. 732–748. *Work Item 2b.*

These authors provide the most current phylogeny of the cavefish family. In addition, they provide some time estimates for when these species diverged. The Ozark Cavefish is the oldest cave species in this group diverging from the group containing the other North American cavefishes in the Miocene around 10 million years ago. In addition, they found that the *taxonomic grouping of the Ozark Cavefish and the Northern cavefish into the genus Amblyopsis was not supported. Therefore, in this paper, an older genus name is used for the Ozark Cavefish. The genus used is the original genus created for the Ozark Cavefish by Eigenmann, Troglichthys. Throughout the rest of the paper, the Ozark Cavefish is listed as Troglichthys rosae. Because this name change is very recent, most researchers and resource managers have not yet adopted the new genus name. Therefore, for the purposes of this bibliography and project, we will continue to use the older genus name, Amblyopsis. The use of Amblyopsis will also provide continuity of discussion with partners and ease of access to the available literature. In addition, the species was listed as a threatened species under the Endangered Species Act, and all of the federally associated conservation projects are associated with the scientific name, Amblyopsis rosae.*

Niemiller, M.L. and T.L. Poulson. 2010. Subterranean fishes of North America: Amblyopsidae. pp. 169–280 in Trajano E., M.E. Bichuette, and B.G. Kapoor (eds.). The Biology of Subterranean Fishes. Science Publishers, Enfield, New Hampshire, USA. *Work Item 2b.*

These authors review, summarize, and discuss the existing literature on the fish family Amblyopsidae, including everything known about the Ozark Cavefish. Much of the summary for the Ozark Cavefish is based on previously published data, however the authors do provide information from their own observations. Based on observations about A. spelaea that this species' young are brooded in the gill chambers, previous authors have suggested gill-brooding for the Ozark Cavefish. However, no one has ever actually observed gill-brooding in Ozark Cavefish, and these statements have caused some lively discussion among fish specialists. The authors of this chapter go to significant lengths to suggest that Ozark Cavefish are indeed gill-brooders, but, to date, this kind of parental care has not been observed for A. rosae.

The authors also summarize some of the previous genetic studies associated with Ozark Cavefish. Based on molecular studies, the Ozark Cavefish is differentiated into 4 groups that correspond with surface watersheds: 1) Illinois River in northern Arkansas, 2) White River drainage in southwestern Missouri, 3) Neosho River drainage in southwestern Missouri, and 4) Neosho River drainage in northeastern Oklahoma. In Arkansas, only two Ozark Cavefish populations were included in these analyses and both of these caves, Logan Cave and Cave Springs Cave, occur in the Illinois River watershed. Although not included in the genetic studies, several addition Ozark Cavefish populations (James Ditto Cave, Hulet Spring Hole, and Mule Hole Sink) occur in the Illinois River drainage. Mule Hole Sink is probably hydrologically related to Cave Springs Cave, but this relationship has not been documented with groundwater tracing. Hulet Spring Hole occurs on a tributary to Little Osage Creek, and James Ditto Cave is found along Flint Creek. In addition to occurring in the Illinois River drainage, Arkansas populations of Ozark Cavefish occur in the 3 other watershed basins, and these populations are likely members of the respective genetic lineages. Currently, the Illinois River populations of Ozark Cavefish are known only from Arkansas sites making this lineage endemic to the state.

Noltie, D.B. and C.M. Wicks. 2001. How hydrogeology has shaped the ecology of Missouri's Ozark Cavefish, *Amblyopsis rosae*, and southern cavefish, *Typhlichthys subterraneus*: Insights on the sightless from understanding the underground. Environmental Biology of Fishes, Vol. 62, pp. 171-194. *Work Items 2a and 2b.*

This paper attempts to provide a hydrogeologic framework for the distribution of the Ozark Cavefish and southern cavefish in Missouri and interpret the ecology of these fishes within this framework. The Ozark Cavefish occurs in caves and karst windows in Mississippian-aged rocks in the southwest part of the state in what is considered the Springfield Plateau. The caves containing Ozark Cavefish are often found occur at the base of bluffs in dissected valleys. Groundwater in these systems is moving laterally due to close contact with underlying non-permeable layers such as the Chattanooga Shale. Karst windows, where Ozark Cavefish occur, are often found farther upslope or on hilltops of the surrounding valleys. These karst windows (vertical shallow wells) intersect conduits that contain cavefish. Because the limestone units containing Ozark Cavefish are close to the surface and bounded beneath by impermeable rock layers, groundwater recharge for these systems are discrete (and more easily definable) and on the order of 10-100 km^2 (3.8 to 38 square miles). Because these systems are smaller and shallower than southern cavefish habitats, there is a greater risk that catastrophic environmental events that move through the entire system will leave no individuals to recolonize the cave.

Ogden, Albert. 1980. Hydrogeologic and geochemical investigation of the Boone-St. Joe limestone aquifer in Benton County, Arkansas. Project No. A-044-ARK, Office of Water Research and Technology. Arkansas Water Resources Research Center Publ., No 68, Univ. of Arkansas, Fayetteville, AR, 133 p. *Work Item 2a.*

This report includes a mapping of lineaments in Benton County, including areas in and near the recharge area for Cave Springs. A statistical analysis was conducted to determine if there was a relationship between aquifer productivity in the Boone-St. Joe Aquifer and proximity to mapped photo-lineaments as measured by well yield, transmissibility, or specific capacity. The tests showed no increased aquifer productivity for wells within 250, 500, or 1,000 feet of a mapped photo-lineament.

Lineaments and fracture traces in many karst areas are associated with increased susceptibility of the karst aquifer to the introduction of contaminants and to preferential flow routes conveying water to associated springs. The Ogden (1979) report did not assess these issues.

A water table map for Benton County was also produced. The contour interval on the map is 50 feet. Groundwater gradients in conduits feeding major springs in Northwest Arkansas are routinely very low; those in and near the recharge area for Cave Springs are typically less than 10 feet per 1000 feet. As a result, the map cannot be used to credibly delineate the recharge area for Cave Springs.

MacDonald et al. (1974) mapped a much greater density of fracture traces and lineaments than did Ogden (1979) in the area where the two studies overlapped. The results of a test of aquifer productivity related to proximity of photo-linears might have yielded different results if a higher density of features had been used in the analysis.

Paylor, Randall L. and James C. Currens. 2001. Mapping karst ground-water basins in the Inner Bluegrass as a nonpoint-source pollution management tool. Proc. 8th Multidisciplinary Conf. on Sinkholes and the Engineering and Environmental Impact of Karsts, Louisville, KY, April 1-4, 2001. Beck and Herring, Editors. Geotechnical and Environmental Applications of Karst Geology and Hydrology, Balkema Publishers, pp. 229-234. *Work Item 2a.*

This is a very important paper with substantial implications for the Cave Springs recharge area.

> "Groundwater basin boundaries are being delineated by dye tracing, topographic analysis, normalized base-flow measurements, and sinkhole lineament analysis…The completed dye traces support past research that indicates karst ground-water flow in the Blue Grass is primarily controlled by fractures and faults. Analysis of normalized base flow has revealed significant increases in base discharge from urbanized ground-water basins, increasing the potential for nonpoint-source pollution in those basins.*" Paylor and Currens (2001, page 229).*

> "The cause of the increased base flow is unknown, but leakage from wastewater and water-supply systems is one likely culprit, pointing to the stronger possibility of NPS [Non-Point Source] pollution at these springs." *Paylor and Currens (2001, page 232. [In the opinion of the OUL leakage from unlined stormwater basins is another likely factor.]*

Figures 3 from Paylor and Currens (2001) is reproduced below. Table 6 converts the metric units to common English units and shows approximate values from the graph at various intensities of urbanization. The final column in the table represents the percent of total base flow that is probably attributable to anthropogenic activities as compared with areas that are only 10% urbanized.

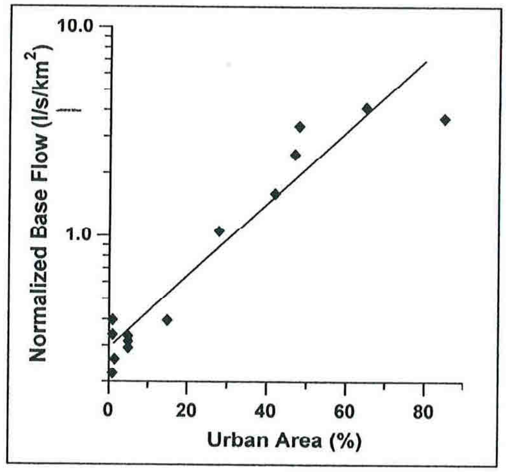

Figure 3: Inner Blue Grass normalized spring base flows as a function of urbanized area, showing strong positive correlation ($r^2 = 0.91$).

The risk of acute toxicity to aquatic life in springs and cave systems is routinely elevated under base flow conditions because there is less water to dilute or attenuate contaminants from anthropogenic activities. Sewage effluents derived from septic fields or sewer line leaks are likely to contain elevated concentrations of bacteria and viruses, heavy metals, and pharmaceuticals plus elevated BOD and COD. If a major cause of the increased base flow values under increasing urbanization is sewage effluents then these may pose a significant acute toxicity risk for the cave fauna including the Ozark Cavefish.

Table 6. Base flow rates of springs in the Blue Grass Region of Kentucky as a function of the percent of the recharge area that is urbanized. *Data derived from Paylor and Currens (2001).*

Percent of Recharge Area Urbanized	*Base Flow in Cubic Feet per Second per Square Mile*	*Percent of Total Base Flow Attributable to Anthropogenic Activities As Compared with 10% Urbanized Base Flow*
10	0.032	---
20	0.060	47
30	0.084	62
40	0.184	83
50	0.285	89
60	0.368	91
70	0.497	94
80	0.644	95

Peck, S.B. 1973. A systematic revision and the evolutionary biology of the *Ptomaphagus* (Adelops) beetles of North America (Coleoptera; Leiodidae; Catopinae), with emphasis on cave-inhabiting species. Bulletin of Museum of Comparitive Zoology, Vol. 145, pp. 29-162. *Work Item 2b.*

This paper is a revision of a group of beetles that occur in several terrestrial habitats across North America, and includes species, known mainly from caves in the eastern U.S., that are cave limited. In the Ozarks, only two species are reported from caves. Ptomophagus shepardi is a deep soil species that is occasionally collected from caves. The other species, P. cavernicola, can be quite common in Ozark caves, and records for this species are numerous across the region. Included in the paper is a record for P. cavernicola from Cave Springs Cave.

Phillips, William W. and M. Dean Harper. 1977. Soil survey of Benton County, Arkansas. U.S. Soil Conservation Service. 87 p. + maps. *Work Item 2a.*

A critically important reference for groundwater vulnerability assessments in the recharge area for Cave Springs Cave.

There are three major soil associations within the recharge area for Cave Springs. The first is the Clarksville-Nixa-Noark Association. It is described as: "Somewhat excessively drained to moderately well drained, gently sloping to steep, deep and moderately deep, cherty soils on hills and ridges." *The authors report that this soil association in Benton County is comprised of 42% Clarksville soils, 33% Nixa soils, and 12% Noark soils. The remaining 13% is comprised of Britwater, Elsah, Secesh, Waben, Tonti, and Captina soils.*

The second major soil association is the Tonti-Nixa-Captina. It is described as: "Moderately well drained, nearly level to moderately sloping, deep and moderately deep, loamy and cherty soils on ridges and broad uplands." *The authors report that this soil association in Benton County is comprised of 33% Tonti soils, 25% Nixa soils, and 17% Captina soils. The remaining 25% is comprised of Cherokee, Clarksville, Elsah, Noark, Peridge, and Secesh soils.*

The third major soil association is the Captina-Peridge Association. It is described as: "Moderately well drained and well drained, nearly level to gently sloping deep loamy soils on broad upland divides." *The authors report that this soil association in Benton County is comprised of 60% Captina soils and 30% Peridge soils. The remaining 10% is comprised of Cherokee, Johnsburg, Newtonia, and Tonti soils.*

Particular soil series within these soils associations have distinctly different properties relative to a number of factors related to their ability to remove contaminants and protect underlying karst groundwater systems. Data on some important characteristics of the major soil series found in the Cave Springs recharge area are summarized in Table 7. The data are from Table 9 in Phillips and Harper (1977).

Table 7. Hydrologically important characteristics of major soil series in the Cave Springs recharge area. *(Phillips and Harper, 1977).*

Soil Series	***Depth to Bedrock*** *(in)*	***Depth Below Surface*** *(in)*	***% less than 3 inches passing #4 sieve***	***Permeability*** *(in/hr)*
Captina	*>42*	*0-7*	*100*	*0.6-2.0*
		7-21	*95-100*	*0.6-2.0*
		21-30	*80-100*	*0.06-0.2*
		30-48	*50-90*	*0.06-0.2*
Nixa	*40-60*	*0-17*	*40-70*	*0.6-2.0*
		17-30	*40-70*	*<0.06*
		30-50	*15-45*	*0.06-0.2*
Noark	*>60*	*0-10*	*20-50*	*0.6-2.0*
		10-17	*20-50*	*0.6-2.0*
		17-30	*20-50*	*0.6-2.0*
		30-72	*10-40*	*0.6-2.0*
Peridge	*>60*	*0-9*	*95-100*	*0.6-2.0*
		9-42	*95-100*	*0.6-2.0*
		42-54	*60-80*	*0.6-2.0*
		54-74	*60-80*	*0.6-2.0*
Tonti	*40-60*	*0-6*	*70-80*	*0.6-2.0*
		6-19	*60-85*	*0.6-2.0*
		19-29	*50-70*	*0.06-0.2*
		29-42	*35-55*	*0.06-2.0*

Based on the soil survey of Benton County (Phillips and Harper 1977), the hydrogeologic mapping of Greene County, Missouri by Aley and Thomson (1981), the septic field study in Greene County, Missouri by Aley and Thomson (1984), and experience of the OUL in the Ozarks we have divided the soils found in the Cave Springs recharge area into three qualitative classes relative to their abilities to remove stormwater contaminants from waters passing through them. These classes and the major soil series in each class are shown below:

- ***Poor Natural Soil Treatment Capability soils.*** *The major soil series in this group is the Noark soil series. It is in this group because it has high percolation rates and a relatively low percentage of material that will pass through a Number 4 sieve. It is the fine textured material that provides much of the natural cleansing present in soils.*
    - *Minor amounts of the following soil series are found in the recharge area and are also Poor Natural Soil Treatment Capability soils: Elsah and Waben soil series.*
- ***Fair Natural Soil Treatment Capability soils.*** *Major soil series that are in this group are the Nixa and Tonti soil series. Nixa soils are in this group because they have a*

relatively low percentage of material that will pass through a Number 4 sieve and because they have a fragipan typically located 17 to 30 inches below the surface. If undisturbed, soils above the fragipan become saturated during wet-weather conditions and appreciable lateral flow often occurs along preferential flow routes toward discrete recharge zones where the fragipan is breached or where other soil series lacking a fragipan exist. If the fragipan is breached in constructing stormwater detention ponds the low percentage of material that will pass through a Number 4 sieve and the moderate permeability of the soils above and below the fragipan provide ineffective natural cleansing for passing waters. Tonti Series soils are in this group because they have more fine textured material in their upper horizons than the Poor Natural Soil Treatment Capability soils. However, below a depth of about a foot and a half the Tonti Series soils have characteristics similar to Poor Natural Soil Treatment Capability soils.

  - *Minor amounts of Britwater and Secesh series soils are found in the recharge area and are also Moderate Natural Soil Treatment Capability soils.*

- ***Good Natural Soil Treatment Capability soils.*** *The major soil series in this group are Captina and Peridge. Captina and Peridge Series soils are in this group because they have a high percent of material that will pass through a Number 4 sieve and thus provide good natural cleansing. When constructing stormwater detention basins the upper horizons of these soils can be stockpiled and then used to blanket the bottom of the detention pond to enhance contaminant removal.*

  - *Minor amounts of the following soil series are found in the recharge area and are also Good Natural Soil Treatment Capability soils: Newtonia, Cherokee, and Johnsburg.*

Poulson, T.L. 1960. Cave adaptation in Amblyopsid fishes. PhD Dissertation, Department of Zoology, University of Michigan, Ann Arbor, MI. University Microfilms 61-2787. *Work Item 2b.*

This dissertation was the first study of North American cavefishes that addressed not only the phylogenetic relationships between family members and the basis of some of the evolutionary characters found in subterranean animals, but also gathered information on the ecology and life history of the species. Poulson visited many of the known cavefish locations making in-cave observations and collecting live animals for study back in the laboratory. He made several trips into Cave Springs Cave as part of his research. Most of the Ozark Cavefish he observed in Cave Springs Cave were in the first 300 m of the northern passage. He also noted a colony of approximately 750 Gray Bats (Myotis griscescens), but did not observe any other terrestrial fauna. His notation of the bat colony suggests that many of his observations occurred in section of stream passage where the bats roost in the summer. He describes the substrate of the cave stream as predominately angular chert rubble with little exposed silt. He also noted considerable guano. Larger Ozark Cavefish were observed in midstream, whereas smaller fish were observed along the banks. Poulson estimated the population to be around 150 fish, but *noted that this was before extensive collections by researchers from Tulane. A few cavefish were observed in the cave stream above the waterfall.*

Poulson noted large fat deposits and full stomachs in cavefish within the cave, and a gut content analysis of 21 cavefish yielded copepods (183), isopods (11), amphipods (9), and miscellaneous other prey items. Water levels, from spring rains, fluctuated 1 m over a year, and he noted that the water became cloudy after rains. He incorrectly attributed the cloudiness to suspended guano rather that sediment and colloidal material derived from the surface of the land.

Poulson, T.L. 1963. Cave adaptation in Amblyopsid fishes. American Midland Naturalist Vol. 70, pp. 257-290. *Work Item 2b.*

Much of Poulson's dissertation on North American cavefishes was published in this paper in American Midland Naturalist. Based on the observation of "growth rings" on the scales of cavefish, he estimated that growth in the Ozark Cavefish occurs from July to December. Reproduction is also though to occur during this time, as adult females were observed with eggs and cavefish fry were observed in the caves. From observations both in the caves and in the laboratory, Poulson observed that Ozark Cavefish spent roughly the same amount of in rheotaxis (holding a position facing into the current), thigmotaxis (in contact with a surface), and swimming. Reproductive individuals are at least 3 years old, and the oldest individuals were estimated to be 3.7-4.7 years old. In Cave Springs Cave, the age distribution of cavefish was skewed to larger individuals. Ozark Cavefish are more resistant to starvation than other cavefish in the family maintaining more than 90% of their weight after 20 days and lasting 401 days before spontaneous activity ceases. Observations were also made on foraging behavior in the laboratory, and the species was observed to feed on the substrate and under rocks. Ozark Cavefish could sense and orient to prey (Daphnia magna) from 30-45 mm (1.2 to 1.8 inches) away.

Poulson, Thomas L. 1976. Management of biological resources in caves. Proc. 1st National Cave Management Symp., Albuquerque, NM, pp. 46-52. *Work Items 2b and 5.*

Important conclusions in this paper include the following:

- "Aquatic ecosystems are more sensitive to disturbance than are terrestrial ecosystems. Aquatic habitats are more restricted in number and area and localized water input makes them more vulnerable to pollutants. Aquatic species are more vulnerable and rebound more slowly because they live 10 to 30 times as long as terrestrial [surface] species, have a very low reproductive potential, and breed at infrequent intervals." *Poulson (1976, page 46).*
- "The most spectacular members of aquatic cave ecosystems—fish, salamander, and crayfish—are long-lived species which grow slowly, mature late, breed infrequently, and

have a very low reproductive potential. These characteristics are adaptations to a low food supply and organic pollution will favor short-lived opportunists and simplify the community. The long lives and low reproductive potential mean slow or no recovery from even one-time physical disturbance or collecting. Mark-recapture growth studies suggest that some of the cavefish live to 20 years and some of the crayfish from 50 to 60 years." *Poulson (1976, page 51).*

Ransom, Michel D.; W. Wallace Phillips; E. Moye Rutledge; and Dee T. Mitchell. 1975. Wastewater disposal by septic tank systems in selected soils of northwest Arkansas. Contract study for Northwest Arkansas Regional Planning Commission, Vol. 2, 76 p. *Work Item 2a.*

Rhodamine B dye, which is readily adsorbed onto soil particles, was used to assess the nature of water movement through Clarksville, Nixa, and Peridge soils in northwest Arkansas. Nixa and Peridge soils are common in the Cave Springs recharge area, and Clarksville soils have hydrologic similarities with Noark soils that are also common in the Cave Springs recharge area. After introducing the dye the test plots were excavated and the vertical profile of the flow paths taken by the water (as indicated by the dye staining on the soil) were mapped. A number of the maps are included in the report.

The testing showed that preferential flow routes (rather than dispersed flow) are commonly the predominant mode of water movement within these soil series. Soils with preferential flow routes provide much less contact between contaminated waters and the soil matrix than is the case with soils where the flow is predominantly dispersed. The result is that these soil series do not provide dependable natural cleansing for waters passing through them and moving into the karst groundwater system. The Clarksville soils were the most prone to preferential flow routes, and the Peridge soils the least prone.

Sasse, D.B.; R.L. Clawson; M.J. Harvey; and S.L. Hensley. 2007. Status of populations of the endangered Gray Bat in the western portion of its range. Southeastern Naturalist, Vol. 6, pp. 165-172. *Work Item 2b.*

These authors investigated population trends of Gray Bat maternity sites in the Ozarks, and they included populations in Arkansas, Missouri, and Oklahoma. Based on data collected from 48 Gray Bat sites from the period of 1978 to 2002, the authors believe that Gray Bats are recovering in the Ozarks. Population estimating techniques varied between sites and included guano pile measurements, covered ceiling area estimates, and visual counts of exiting bats, but the technique used at a particular site was consistent. Increasing trends were observed at 21 sites, while no trend was observed at 17 sites. Decreasing trends were observed at 10 sites including Cave Springs Cave. From 1979-2002, Cave Springs Cave was surveyed 23 times, and the most recent count (2002) was 2,030 bats.

Sealander, J.A., and H. Young. 1954. Preliminary observations on the cave bats of Arkansas. Proceedings of the Arkansas Academy of Science Vol. 7, pp. 21-31. *Work Item 2b.*

These authors report on observations of bats using caves in Arkansas by both the authors and others. They also provide a taxonomic key for identifying bats, and summarize their bat banding work. One observation of an Indiana Bat in Cave Springs is reported for 1935, and the bat was observed by J.D. Black. In addition, a few Tri-colored Bats were also observed in 1953 by H.G. Dowling and P. Callahan. No bats were banded at Cave Springs Cave.

Slay, Michael. 2011. Long term groundwater quality monitoring program at Cave Springs Cave. The Nature Conservancy report for Arkansas state wildlife grant agreement T20-5. 268 p. *Work Item 2a.*

A YSI datasonde was installed in the water at Cave Springs and operated for a total of 102 days between July 20 and November 5, 2009. During this period the instrument was removed three times for calibration and, for some parameters, replacement of sensors. Parameters that were measured were temperature, specific conductance, pH, chloride, turbidity, and dissolved oxygen. The resulting data represent recent and credible water quality results reflective of summer and fall conditions.

Mean chloride concentrations were 9.585 mg/l and the range was from 6.33 to 12.56 mg/l. Chloride concentrations sometimes increased for a short period in response to precipitation events but rather quickly decreased as an apparent result of dilution by surface runoff water that has entered the karst aquifer through losing stream segments. The chloride probe was out of operation for two of the four monitoring periods.

As is common in karst aquifer, specific conductance and pH values declined in response to major precipitation events. The dissolved oxygen probe was out of operation during one of the four monitoring periods and was not functioning during the more significant precipitation events. Dissolved oxygen averaged 8.758 mg/l and ranged from 8.21 to 9.56 mg/l. The turbidity probe was out of operation during the same sampling period as the dissolved oxygen probe. Turbidity during the study period averaged 3.574 NTU and ranged from 0 to 31 NTU. Turbidity responded sharply to precipitation events.

Slay, Michael E. and Tim Snell. 2005. Supporting water quality monitoring for Ozark Karst Ecoregion. Final report to U.S. Fish and Wildlife Service, Conway, AR, by The Nature Conservancy. 50 p. approx. *Work Item 2a.*

Twenty six cave or spring sites in Arkansas were monitored under base flow conditions on October 1-2, 2005. The sites were ranked as high, moderate, or low impact from human activity based on the relationship of nitrate concentrations to chloride concentrations. Cave Springs was identified as a high impact site and had the highest nitrate concentration of any of *the sites. Eight of the 26 sites had higher chloride concentrations than those found at Cave Springs Cave. Another illustration shows the results of the nitrate/chloride relationship for 2000, 2001, 2002, and 2005. Civil War Cave had the highest nitrate concentration of any of the sites; the year in which it was monitored is not indicated. Aley and Aley (2014) delineated the recharge area for Civil War Cave and found that 70% of the recharge area is in suburban housing and 20% is vacant or in agricultural uses.*

Appendix B to this report presents data on dissolved heavy metal concentrations in water samples from numerous caves and springs where the collections were made during the same two-day period (a one-day period in one case). Similar data are presented for heavy metal concentrations in sediment samples from a number of caves and springs. Several of the reports by Graening or Graening and Brown indicated major concern about heavy metal concentrations in water and sediment from Cave Springs Cave. Based on these concerns the OUL has extracted some relevant data from Appendix B for 5 metals and, in three cases, for fecal coliform colony counts. All data analysis was by the ADEQ laboratory. The data for water samples are shown in Table 8. Similar data for heavy metals in sediment samples from selected caves is also included in Appendix B; we have included some of these data in Table 9. The table in Slay and Snell (2005) indicates that the units are mg/l, but since they are extractions from sediment samples the OUL has concluded that the correct units are mg/kg.

Table 8. Selected dissolved metal concentrations (micrograms/l) in water samples from Arkansas caves and springs. Fecal coliform (E. coli) colonies per 100 ml are shown if the data were available. Collection dates are as noted. *Data from Slay and Snell (2005).*

Samples collected Feb. 20-21, 2000 from 37 caves and springs.

Parameter	*Cave Springs Cave*	*Caves With Higher Concentrations*	*Range of Concentrations*
Chromium	*<0.40*	*15*	*<0.40 to 1.63*
Copper	*2.52*	*15*	*0.72 to 21.60*
Lead	*<0.30*	*7*	*<0.30 to 3.19*
Nickel	*<2.00*	*8*	*<2.00 to 7.36*
Zinc	*11.6*	*12*	*3.3 to 62.9*
E. coli	*20*	*10*	*<10 to 20,050*

Samples collected April 7-8, 2001 from 30 caves and springs.

Parameter	*Cave Springs Cave*	*Caves With Higher Concentrations*	*Range of Concentrations*
Chromium	*<0.4*		*All are <0.4*
Copper	*<0.5*	*14*	*<0.5 to 3.9*
Lead	*<0.4*	*1*	*All <0.4 except 1*
Nickel	*<2.00*		*All <2.00*
Zinc	*4.3*	*15*	*<1.0 to 16.9*
E. coli (60 sites)	*200*	*4*	*<10 to 1,500*

Table 8. Continued.
Samples collected March 29, 2002 from 24 caves and springs.

Parameter	*Cave Springs Cave*	*Caves With Higher Concentrations*	*Range of Concentrations*
Chromium	*No data*		
Copper	*<0.5*	*7*	*<0.5 to 3.58*
Lead	*<0.4*	*3*	*<0.4 to 1.96*
Nickel	*2.28*	*1*	*<2.00 to 2.52*
Zinc	*12.5*	*18*	*10.3 to 39.3*
E. coli	*8*	*10*	*<1 to 199*

Samples collected October 1-2, 2005 from 26 caves and springs.

Parameter	*Cave Springs Cave*	*Caves With Higher Concentrations*	*Range of Concentrations*
Chromium	*0.99*	*11*	*0.71 to 1.41*
Copper	*<0.50*	*15*	*<0.50 to 3.2*
Lead	*<0.10*	*3*	*<0.10 to 0.24 (most <0.10)*
Nickel	*<0.50*	*1*	*<0.50 to 2.84 (only 1 >0.50)*
Zinc	*4.99*	*5*	*1.45 to 23.5*
E. coli	*No data*		

Table 9. Selected metal concentrations (mg/kg) in sediment samples from 55 Arkansas caves and springs. Samples collected April 7-8, 2001. *Data from Slay and Snell (2005).*

Parameter	***Cave Springs Cave***	***Caves With Higher Concentrations***	***Range of Concentrations***
Chromium	*ND*	*18*	*ND to 51.4*
Copper	*16.0*	*11*	*1.23 to 57.6*
Lead	*323*	*0*	*ND to 323*
Nickel	*19.3*	*29*	*3.39 to 117*
Zinc	*144*	*4*	*6.36 to 638*

Smith, Charles R. and Kenneth F. Steele. 1990. Nitrate concentrations of ground water, Benton County, Arkansas. Contract report by Arkansas Water Resources Center to Arkansas Department of Pollution Control and Ecology. Arkansas Water Resources Center Publication No. MSC-073. 48 p. *Work Item 2a.*

> "Nitrate concentrations for wells and spring of the Springfield Plateau aquifer [Cave Springs is in this aquifer] were higher than those of the Ozark aquifer [the deeper confined aquifer] during both seasons. Mean concentrations for the shallow aquifer are 2.63 mg/L NO_3-N in the wet season and 1.80 mg/L in the dry.

> The nitrate concentrations are higher during the wet season: a period of maximum recharge. Wells producing from the Ozark aquifer had significantly lower mean values as a population. Mean values for this confined aquifer were 0.11 and 0.15 mg/L for the wet and dry seasons, respectively." *Smith and Steele (1990, abstract).*

The table on page 38 of the report is in error. Nitrate concentrations are identified in the table as nitrate, but are actually nitrate-nitrogen values. This is a useful table that summarizes nitrate-nitrogen values from a number of studies in northwest Arkansas.

While not identified in the report, dry season nitrate concentrations are also lower because this is the season when most plant growth occurs and nitrates are more readily bound up in vegetative growth. Values from the Ozark aquifer are probably representative of nitrate concentrations of both aquifers before impacts from human activities.

> "Ground water nitrate concentrations in areas devoid of cattle and poultry production (control area) were compared with concentrations in areas of active production (experimental area). Mean concentrations for the experimental areas were higher than those of the control. Presence of grazing cattle, septic systems, and poultry litter application in the area made the precise source of contaminants difficult to determine. However, because of the greater volume of poultry litter generated annually in the experimental area, the authors attributed the greatest input of nitrate to the system to be from the land application of poultry litter." *Smith and Steele (1990, page 3).*

> "Septic systems are numerous in the rural areas of the county and each represents a potential point source for nitrate contamination. Large municipal sewage collection networks, through leakage, are possible non-point sources of the contaminant. Additionally, municipal sewage treatment facilities should be considered as potential point sources." *Smith and Steele (1990, page 4).*

Smith, Timothy W. and Bryan Vance. 1997. Greene County, Missouri's sinkhole regulations. IN: Beck and Stephenson (editors). The Engineering Geology and Hydrogeology of Karst Terranes, pp. 457-461. *Work Items 2a and 6.*

Much of Greene County is within the same geologic units as the Cave Springs recharge area. Sinkholes are the focus of this paper, and they are common and important in Greene County. However, sinkholes are almost totally absent from the Cave Springs recharge area. As a result, this paper has limited utility to the Cave Springs area.

Smoot, J. L.; C. D. Cox; and A. M. Turpin. 1997. Laboratory testing of a system to treat highway stormwater in karst areas. Proc.of the 6th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Springfield, MO, April 6-9, 1997. The Engineering Geology and Hydrogeology of Karst Terranes. Beck and Stephenson, Editors, pp. 183-188. *Work Items 2a and 6.*

> "Non-point source pollution is thought to account for approximately 80% of the degradation of waters of the United States. One significant source of this pollution is stormwater runoff from highways and parking lots. This runoff contains heavy metals, oil and grease, and many other contaminants that pollute receiving waters. The problem is further compounded in karst areas because the runoff contaminates groundwater directly through drainage entering sinkholes. The reduction of contamination from stormwater has become a national priority." *Smoot et al. (1997, page 183).*

> "The laboratory work necessary to support the design of the [treatment] system was broken into two phases. The first phase involved batch studies to determine the relative removal characteristics of several candidate materials proposed as sorption/filtration media. The second phase involved column studies to simulate the field use of the system." *Smoot et al. (1997, page 183).*

> "Results of the laboratory testing showed that the pollutant removal efficiency of the system generally ranged from about 90 percent to more than 99 percent for the selected indicator heavy metals (copper, lead, and zinc) throughout the expected life of the system. Similar removals were also seen for total polyaromatic hydrocarbons (an indicator of organic contamination.)" *Smoot et al. (1997, page 183).*

Stephenson, J. Brad; W.F. Zhou; Barry F. Beck; and Tom S. Green. 1997. Highway stormwater runoff in karst areas—preliminary results of baseline monitoring and design of a treatment system for a sinkhole in Knoxville, Tennessee. Proc.of the 6th Mulltidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Springfield, MO, April 6-9, 1997. The Engineering Geology and Hydrogeology of Karst Terranes. Beck and Stephenson, Editors, pp. 173-181. *Work Item 6.*

The main goal of this study was the development and evaluation of practical remediation methods for treating highway runoff draining into sinkholes. While the Cave Springs recharge area does not have sinkholes, the movement of water from losing stream segments into the groundwater system is often as rapid, and with as little natural cleansing, as is the case with groundwater recharge through sinkholes.

A pilot scale stormwater runoff treatment system was designed that used peat, sand, and rock to remove contaminants by sedimentation, filtration, and adsorption. The paper includes an illustration of the preliminary design of the treatment system.

Taylor, Kent R. 1991. Developing urban nonpoint source management plans in karst areas of south-central Kentucky. Proc. National Cave Management Symp., Bowling Green, KY, pp. 66-69. *Work Item 6.*

This paper deals with an area where sinkholes are abundant and is thus very different from the Cave Springs recharge area. No specific plans are identified.

> "Urban storm water in Bowling Green, for example, is disposed of by means of karst sinkholes, dry wells and swallets where untreated urban runoff is allowed to quickly penetrate shallow aquifers, potentially contaminating domestic water supplies, impairing cave uses and discharging pollutants at springs to surface watercourses, downstream such as the Barren River and the Green River." *Taylor (1991, page 66).*

> "In newly urbanizing groundwater basins, nonpoint problems can be minimized by requiring relatively inexpensive 'best management practices' (BMPs) and environmental ordinance controls for new developments. In already developed watersheds with identified use impairments, it will be more difficult and expensive to identify and implement the kinds of controls necessary to fully remedy the observed impaired conditions." *Taylor (1991, page 66).*

Texas Commission on Environmental Quality (TCEQ). 2007. Optional enhanced measures for the protection of water quality in the Edwards Aquifer (Revised). Appendix A to RG-348--Complying with the Edwards Aquifer Rules: Technical guidance on Best Management Practices. RG-348A. 29 p. *Work Item 6.*

A current and very useful collection of Best Management Practices for a karst area that supplies groundwater to several federally-listed species as well as domestic water supplies. Some similar approaches are likely to be appropriate for use in the Cave Springs Recharge Area. One difference is that soil and residuum depths in the Cave Springs area are much deeper than in most of the Texas area. As a result, gates and other structures to protect caves and other sensitive areas are more commonly needed in the Texas area than in the vicinity of Cave Springs.

> "The natural buffer around a feature should extend a minimum of 150 feet in all directions. Where the boundary of the drainage area to the feature lies more than 150 feet from the feature, the buffer should extend to the boundary of the drainage area or 300 feet, whichever is less." *TCEQ (2007, page 3).*

The widths of buffer zones are likely to be an important issue in the Cave Springs Recharge Area. Losing stream channels in this recharge area should be viewed as karst features and should therefore be buffered. If we were to use the same strategy as used in the Edwards

Aquifer area and identified above, each losing stream would have a buffer of 300 feet on each side of the channel of the losing stream.

U.S. Department of Transportation and Arkansas State Highway Department. 1979. Draft environmental impact statement for Highway 71 relocation Fayetteville to McKissick *(sic)* Creek. FWHA-ARK-EIS-75-02-1. 95 p. *Work Item 5.*

This draft Environmental Impact Statement (EIS) evaluated two potential routes for the highway (which is now Interstate 49). Public comments resulted in major groundwater tracing work (see Aley 1978a and 1978b) that led to moving the eastern-most alignment further to the east to minimize impacts on Cave Springs.

U. S. Fish and Wildlife Service. 2005. Community growth best management practices for conservation of the Cave Springs Cave recharge zone. 14 p. *Work Item 4.*

This report discusses erosion and sediment control for construction projects, including the following:

- *Filter fences and straw bales.*
- *Sediment traps.*
- *Mulching and revegetation*
- *Permanent stabilization.*

Additional measures are recommended for construction in sensitive areas such as stream channels and karst and for stormwater management including stormwater detention basins.

U. S. Fish and Wildlife Service. 2007. Community growth best management practices for conservation of the Elm Springs/Tontitown recharge zone. 15 p. *Work Item 4.*

This publication is similar to U.S. Fish and Wildlife Service (2005) for Cave Springs.

U. S. Fish and Wildlife Service (USFWS). 2010. Ozark Cavefish (*Amblyopsis rosae*) 5 –Year Review: Summary and Evaluation. 28 p. *Work Item 2b.*

The purpose of the 5-year reviews is to summarize available data and determine if a change is needed in the status of the species. Statements made in the report include the following:

- “There is no evidence over the past year to indicate population declines. However, 17 of 35 occupied sites have not had a documented cavefish in 6+years. Sufficient documentation does not exist at this time to indicate whether the loss of these sites is indicative of large-scale population declines or site-specific declines at the extant localities." *USFWS (2010, page 2).*

- "Species Recovery Priority Number at start of review: 8... The "8" indicates a moderate degree of threat and high recovery potential." *USFWS (2010, page 3).*
- "Of the 41 active sites, urbanization/development is suggested as another primary threat in recharge zones." *USFWS (2010, page 10).*
- "While surface streams have water quality standards that are monitored and enforced, groundwater generally does not. Existing regulatory mechanisms regarding the protection of groundwater resources are limited." *USFWS (2010, page 12).*
- "In 2007, a dye study was conducted by the city of Rogers wastewater treatment facility to determine if contaminants found during recent water quality work at the cave originated from the plant. Results of this study showed no connectivity to Cave Springs Cave." *USFWS (2010, page 17).*

Virginia Dept. of Conservation and Recreation (VDCR). Undated. Hydrologic modeling and design in karst. Technical Bulletin No. 2. 13 p. *Work Item 6.*

Much of the focus of this publication is on sinkholes and the prevention of new sinkhole collapses or land subsidence in karst areas. These are not major issues in the Cave Springs recharge area. However, the following comments are appropriate for the Cave Springs area:

- "Obviously, karst areas present problems to those attempting to work with conventional hydrologic models. Typically, modeling of a karst site or watershed via SCS or other traditional methods provides poor representation of runoff rates, with regard to both flooding and over-design of conduits and stormwater management facilities. This is largely because standard hydrologic modeling methods lack allowances for losses into sinkholes, fractures, crevices or caves that may exist in the carbonate units. Neither do models typically account for the stormwater that joins surface runoff as 'interflow' when the collective capacity of interconnected conduits and cavities in the subsurface is exceeded." *VDCR (undated, page TB2-1)*
- "Pre-development runoff rates for karst areas versus non-karst areas can differ by a large percentage even when two sites exhibit similar soil and topographic characteristics." *VDCR (undated, page TB2-1)*
- "Where practical, drainage facilities should consist of embankments at or above grade. Excavation into the existing soil profile to construct swales and basins should be minimized to the degree possible." *VDCR (undated, page TB2-9).*
- "Sediment basins and traps should be used as a last resort for sediment control in karst areas, and should be used only after other designs have been considered and rejected. The erosion and sediment control plan should attempt to minimize drainage area sizes and therefore the need for basins or large traps." *VDCR (undated, page TB2-10).*

Williams, R. 1991. Water quality and groundwater recharge for the Cave Springs complex and associated streams near Cave Spring. MS thesis, Univ. of Arkansas, Fayetteville, AR, 134 p. *Work Item 2a.*

The author developed estimates for the size and location of the Cave Springs recharge area by compiling data on water table elevations in private wells. He then compared these estimates with what he believed to be the recharge area delineated by Aley (1978a and 1978b). The Aley (1978a and 1978b) delineations included two recharge area components; these were the Direct Recharge Area and the Indirect Recharge Area. Dye tracing demonstrated that both of these areas contributed water to Cave Springs.

In his thesis, Williams showed only his interpretation of the Direct Recharge Area. In addition, tracing associated with potential airport connector corridors (Aley and Moss 2001) has demonstrated that part of the recharge area for Cave Springs also contributes water to Reed Spring. As a result of these factors the comparisons of recharge areas included in the thesis do not accurately depict the 19.1 square mile Cave Springs recharge area as delineated based on all of the tracing by Aley (1978a and 1978b) and Aley and Moss (2001). The final delineation that Williams (1991) derived for the Cave Springs recharge area encompassed 14.0 square miles. This includes some "safety margins". The recharge area based solely on the potentiometric mapping was 11.8 square miles.

The thesis includes a small amount of water quality data on Cave Springs.

Woods, L.P., and R.F. Inger. 1957. The cave, spring, and swamp fishes of the family Amblyopsidae of central and eastern United States. American Midland Naturalist Vol. 58, pp. 232-256. *Work Item 2a.*

These authors undertake a morphological study of species in the family Amblyopsidae which includes the Ozark Cavefish. Prior to this study, the Ozark Cavefish was placed in the genus Troglichthys. The authors compared specimens of Ozark Cavefish with those of the Northern Cavefish (Amblyopsis spelea) and concluded that these two species were related. Subsequently, they placed the Ozark Cavefish in the same genus, renaming it Amblyopsis rosae.