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SUMMARY OF EXISTING KNOWLEDGE ABOUT HYDROLOGY, CAVE BIOLOGY, AND CAVE CONSERVATION METHODS APPLICABLE 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.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHTD	Arkansas Highway and Transportation Department
BOD	Biochemical Oxygen Demand
CAFO	Confined Animal Feeding Operation
°C	degrees Celsius
cfs	cubic feet per second
CFU	Colony Forming Unit (in reference to bacteria concentrations)
COD	Chemical Oxygen Demand
CTA	Crafton Tull Associates
D.O.	dissolved oxygen
DOC	dissolved organic carbon
°F	degrees Fahrenheit
gpm	gallons per minute
kg	kilogram
L or l	liter
ln	natural logarithm
l/s	liters per second
$l/s/km^2$	liters per second per square kilometer
mg/l	milligram per liter
ml	milliliter
mm	millimeter
N	nitrogen
ND	not detected
NO_3-N	nitrate-nitrogen

Acronyms and Abbreviations (continued)	
NTU	Nephelometric Turbidity Unit
OUL	Ozark Underground Laboratory
Pb	Lead
pers. omm..	Personal communication
pers. exp.	personal experience
pers. obs.	Personal observation
ppb	parts per billion
ppm	parts per million
sec	second
Surr.	Surrogate
TCEQ	Texas Commission on Environmental Quality
TOC	total organic carbon
ug	microgram
ug/l	microgram per liter
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VDCR	Virginia Department of Conservation and Recreation
WNS	White Nose Syndrome
Zn	Zinc
µS/cm	microSiemens per centimeter

PURPOSE AND ORGANIZATION

An annotated bibliography (Aley and Slay 2015) has been prepared summarizing relevant hydrologic, biologic, and land management information for Cave Springs. The purposes of the current report are four fold:

- To summarize the existing information identified in the annotated bibliography on a topic-by-topic basis.
- To evaluate the adequacy of this existing information in meeting the needs of the Cave Springs Conservation Initiative.
- To identify data gaps and how they are, or could be, filled.
- To recommend actions needed for management.

This report is divided into the following four major topics:

- Part 1. Hydrologic and Water Quality Data
- Part 2. Biological Issues
- Part 3. Cave Conservation Needs and Methods
- Part 4. Conclusions and Recommendations; these are subdivided into the three topics identified above.

UNITS AND NOMENCLATURE

Some of the flow rates values in the literature were reported in liters per second (l/s). To aid the general reader the Ozark Underground Laboratory (OUL) has converted these to cubic feet per second (cfs). The OUL has also converted other measurements made in the metric system into the English system. Units in milligrams per liter (mg/l) are approximately equivalent to parts per million (ppm), and units in micrograms per liter (ug/l) are approximately equivalent to parts per billion (ppb).

Throughout both the previous and current reports the terms “Cave Springs” and “Cave Springs Cave” have been used interchangeably.

The lake that is impounded immediately downstream of Cave Springs Cave has historically been called Lake Keith. More recently it has been re-named Partners Lake. Within this document, the lake has been referred to by its historical name.

PART 1. HYDROLOGIC AND WATER QUALITY DATA

The compilation and analysis of hydrologic and water quality data relevant to Cave Springs and its recharge area is Objective 1, Work Item 2a, in the Cave Springs Area Karst Conservation Study.

This section of the report is divided into the following topics:

1. Existing flow rate data for Cave Springs;
2. Existing water quality data for Cave Springs;
3. Groundwater gradients in the Cave Springs area;
4. Geology including fracture traces and lineaments;
5. Recharge area estimates and delineations for Cave Springs;
6. Possibility that Cave Springs receives some water from Osage Creek;
7. Hydrologic interactions between Cave Springs and other springs;
8. Soils and their relative abilities to protect groundwater quality;
9. Impacts of urbanization on base flow rates of springs; and
10. Hydrologic and water quality data gaps.

Existing Flow Rate Data for Cave Springs

The accuracy of the flow rate data for Cave Springs is poor for a number of reasons. These reasons include the following:

- For many years a trout farm existed at Cave Springs. There were multiple buried water lines leading from inside the cave to various raceways. As a result, during the early phase of work under this project flowing water could be seen at multiple points downgradient of the cave. While most of this water was probably derived from the cave, it is possible that there are multiple springs at Cave Springs. The former pipes leading from the cave have now been capped or otherwise sealed to the extent feasible.
- There is significant leakage that bypasses the old concrete dam at the mouth of the cave. This leakage cannot be readily reduced without a significant construction effort, and that effort could adversely impact cavefish that are sometimes found in the pool behind the dam and other cave fauna.
- There are some springs or leakage points that have long been inundated by former Lake Keith. They were visible when the lake was drained as a part of the renovation of the area, but the lake has now been refilled and the springs are again inundated.

The result of these conditions is that past flow rate measurements under-estimate the rate of water flow from the cave. The percent of under-estimation is unknown, but the percent is undoubtedly greatest during low flow conditions.

Cave Springs Cave is located at the upstream end of a springhead. Much of the valley that lies between the mouth of the cave and Highway 112 has been formed by cavern collapse. Lake Keith, created by a dam near Highway 112, now inundates much of the springhead and the associated cavern collapse. Given this hydrogeological setting, it is possible that springs within the lake basin and submerged openings around blocks of rock associated with the cavern collapse provide habitat for Ozark Cavefish.

Lamonds (1972) reported on 22 flow rate measurements made at Lake Keith Spring, an alternate name for Cave Springs, prior to his 1972 publication. The mean measured flow rate was 4.10 cubic feet per second (cfs). The maximum was 10.2 cfs measured on September 15, 1959 and again on August 10, 1961. The minimum measured flow rate was 0.31 cfs on August 15, 1962. All of these measurements were made prior to most of the urbanization in the Cave Springs recharge area.

Aley (1978a) estimated the mean annual flow rate of Cave Springs at 4.5 cfs based on information provided by Barron Collier, who operated the trout farm at the spring.

Aley and Moss (2001) made a series of flow rate measurements of Cave Springs and Reed Spring from December 2000 to March 2001. There are portions of the recharge area for Cave Springs that also contribute water to Reed Spring. Measurements were made either with a Pygmy current meter or a steel Parshall flume. Measured flow rates at Cave Springs ranged from 0.19 cfs to 8.50 cfs. Measured flow rates at Reed Spring ranged from 0.15 to 1.26 cfs. From the data it was clear that the flow rate of one of the springs could not be used to credibly estimate the flow from the other. It is possible that leakage bypassing the gauging site for Cave Springs might help explain the poor correlation between flow rates at Cave Springs and Reed Spring.

Graening and Brown (2003) made calculations of flow rates discharging from the mouth of Cave Springs Cave on 59 dates during the period November 1997 to December 1999. The measurements were based on a staff gage located at the mouth of the cave. The mean flow rate was 3.54 cfs; flow rates ranged from 0.60 to 11.79 cfs. The maximum flow rate reported in available data was 15.3 cfs on July 1, 1999 (Graening and Brown, 1999).

Given the data available and the OUL's experience with springs in the Ozarks the mean annual flow rate of Cave Springs and nearby springs that are hydrologically associated with Cave Springs is about 4.5 cfs. Peak flow rates undoubtedly exceed the maximum measured 15.3 cfs (reported by Graening and Brown, 1999) and based on the behavior of other Ozark springs could easily be 25 cfs or more. The minimum flow rate of Cave Springs is probably about 0.3 cfs.

On October 20, 2014 at 3:30 PM the OUL measured the flow rate discharging from the dam on Lake Keith. The flow rate was measured with a Pygmy current meter, and was 5.28 cfs. The staff gage anchored to the dam at the mouth of Cave Springs Cave indicated a flow rate of

4.28 cfs. The most likely explanation for the difference between the two values is leakage from portions of the cave stream upstream of this dam; this leakage is bypassing the dam.

The OUL attempted to install a weir downstream of the cave in hopes of providing more accurate flow rate measurements, but major leakage around and beneath the old flume area downstream of the dam defeated these efforts. While accurate and continuous flow rate data for the spring was not needed for our project and was not required under the contract, reasonably accurate flow rate information would benefit future management of the site. Such data would also be valuable for interpretive programs at the property.

Existing Water Quality Data for Cave Springs

Historic Water Quality Data

There is a substantial amount of historic water quality data for Cave Springs Cave. The best summary for most of the available data is provided by Graening and Brown (2003) in a table reproduced in this report as Table 1.

Important limitations for the data shown in Table 1 include the following:

- Land use in the recharge area for Cave Springs has changed dramatically from the time of these analyses to present. As a result, the water quality data are not representative of 2015 conditions. During the period 1997-1999 agricultural activities predominated in the recharge area. Graening and Brown (2003, page 1498) reported that: *"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)."* As of 2014 there are few operating confined animal feeding operations and no sewage sludge application to pasturelands in the recharge area. Substantial portions of the Cave Springs recharge area have been developed for suburban residences, and most of these are served by municipal sewers. As a result, the number of homes in the recharge area dependent upon septic tanks and leach fields has decreased from 1997-1999 conditions. Sewage sludge is no longer applied to lands in the Cave Springs recharge area, and there are no current discharges of treated municipal wastewaters within the recharge area.
- The data were not collected in a manner likely to represent either average conditions or the full range of conditions. For example, the samples were not collected at standard intervals. Instead, a number of the samples were collected during "storm events" and were often collected only a few hours or days apart. Other samples were collected under "base flow conditions", but flow rates under these conditions varied by over an order of magnitude.

Regardless of the limitations, the water quality data in Table 1 are the best historic data available and are of substantial value.

Table 1. Summary of water quality data for Cave Springs for the period November 1997 through December 1999. Table from Graening and Brown (2003, page 1504).
ND = Not Detected. Chromium, molybdenum, and silver were not detected in any sample and antimony, beryllium, cadmium, cobalt, and nickel were never detected at greater than 3 micrograms per liter.

	Unit	n	Minimum	Median	Mean	Maximum
Water temperature	°C	43	13.4	14.4	14.4	15.2
Discharge	l/s	59	17.0	83.0	100.0	333.0
Spec. Conductivity	µS/cm	51	240.0	330.0	326.0	400.0
Turbidity	NTU	44	< 1.0	4.0	5.0	48.0
Field pH	pH unit	30	6.2	6.8	6.8	7.5
Dissolved Oxygen	mg/l	37	8.3	9.4	9.6	11.6
Aluminum	µg/l	34	N.D.	24.0	66.0	275.0
Arsenic	µg/l	34	N.D.	N.D.	3.0	14.0
Barium	µg/l	18	54.	65.0	65.0	95.0
Boron	µg/l	18	N.D.	N.D.	3.0	33.0
Calcium	µg/l	18	30.1	51.0	50.7	64.0
Chloride	µg/l	17	6.1	7.7	7.8	9.5
Copper	µg/l	34	N.D.	11.0	20.0	230.0
Iron	µg/l	34	N.D.	11.0	80.0	640.0
Lead	µg/l	34	N.D.	4.0	10.0	39.0
Magnesium	mg/l	18	1.7	2.2	2.1	2.5
Manganese	µg/l	34	N.D.	2.0	8.0	45.0
Selenium	µg/l	34	N.D.	12.0	9.0	32.0
Sulfate	mg/l	16	2.4	3.7	3.7	7.1
Vanadium	µg/l	18	N.D.	N.D.	1.0	8.0
Zinc	µg/l	33	N.D.	13.0	38.0	288.0
TOC	mg/l	43	N.D.	1.2	1.6	5.1
DOC	mg/l	10	0.6	1.6	1.7	3.4
Ammonia - N	µg/l	35	N.D.	9.0	21.0	323.0
Nitrite - N	µg/l	44	N.D.	N.D.	6.0	104.0
Nitrate - N	mg/l	53	N.D.	6.0	6.2	8.8
Total Kjeldahl N	mg/l	22	N.D.	0.1	0.2	1.3
Total Phosphorous	µg/l	37	N.D.	43.0	54.0	193.0
Orthophosphate	µg/l	37	17.0	26.0	38.0	103.0
Escherichia coli	CFU/100 ml	56	< 10.0	215.0	1,826.0	20,050.0
Total Coliforms	CFU/100 ml	56	< 200.0	5,310.0	8,904.0	83,100.0

Parameters of Special Importance to Aquatic Cave Fauna

One parameter of substantial importance for cavefish and other aquatic life is dissolved oxygen. In the OUL's experience the most common cause of aquatic life kills in springs and cave streams is low concentrations of dissolved oxygen in the water; low concentrations cause suffocation of the aquatic life. Such aquatic life kills commonly result from the introduction of waters with high Biochemical Oxygen Demand (BOD) or high Chemical Oxygen Demand (COD) values.

The following case history from Ozark Spring near Johnson, Arkansas illustrates the problem. A massive kill of fish and other aquatic life occurred at Ozark Spring on July 13 and 14, 1980 and was investigated by Tom Aley of the OUL. Mr. Aley subsequently provided court testimony about the event. About 34,000 young trout and 1,500 pounds of mature trout, as well as other aquatic life, were killed. Groundwater tracing by the Arkansas Department of Pollution Control and Ecology (now Arkansas Department of Environmental Quality) and the OUL showed that water moving underground from Dry Creek subsequently discharged from Ozark Spring.

The Bradshaw Lift Station, operated by the City of Springdale, was constructed adjacent to Dry Creek. Its design was such that, in the event of a power failure, it would discharge raw sewage to Dry Creek. Under most conditions the rate at which discharged sewage would enter the groundwater system beneath Dry Creek could approximately equal the rate of sewage inflow to the lift station. The rate of sewage inflow to the lift station was variable; on July 26, 1980 at noon the rate was 77 gallons per minute (gpm). Periodic inflow rates of 100 gpm or more were likely.

On or about July 12, 1980 there was a discharge of an estimated 16,500 gallons of raw municipal sewage from the Bradshaw Lift Station. Sewage sludge was present in the channel of Dry Creek and surface vegetation was killed. The straight-line distance from the sewage spill to Ozark Spring is approximately 6,000 feet. This case history provides a relevant demonstration of the ease with which groundwater systems feeding springs can convey contaminants to associated springs. Ozark Spring and Cave Springs have similar flow rates and have similar hydrogeologic settings.

Graening and Brown (2003) reported 37 measurements of dissolved oxygen concentrations at Cave Springs. Values ranged from 8.3 to 11.6 milligrams per liter (mg/l) with a mean of 9.6 mg/l. The amount of dissolved oxygen that water can hold at saturation is a function of temperature; the higher the temperature the less dissolved oxygen can be held by the water. In Graening and Brown (2003) the dissolved oxygen concentration values are separated from temperature values, but they are unusually high. To determine if some or all of the values might in error we examined some of the earlier reports by these authors where values for dissolved oxygen and temperature at the time of collection were presented together.

The high values for dissolved oxygen in Brown et al. (1998) are questionable since they are substantially higher than values for other caves and streams with important cave fauna. Three of the twenty values measured at Cave Springs indicate more than 100% oxygen saturation; one of these was during a stormflow event which is especially unlikely. The 20 values for dissolved oxygen concentrations reported for Cave Springs in 1997 and 1998 (Brown et al., 1998) range from 78% of saturation to more than 100% saturation; most of the values were near 90% saturation. The reported concentrations ranged from 8 to 10.6 mg/l.

Hulet Spring Hole is an Ozark Cavefish population with a recharge area associated with the Northwest Arkansas Regional Airport. This spring was monitored with a data logger that made about 103 measurements of dissolved oxygen per day. The OUL obtained and reviewed the printout for the period October 2 through October 29, 1996. This is a period of the year when dissolved oxygen concentrations would tend to be somewhat lower than average. Dissolved oxygen concentrations at Hulet Spring Hole during this period ranged from 3.15 to 5.91 mg/l; these values are from about 33 to 61% of saturation.

Tumbling Creek Cave is located near Protem in Taney County, Missouri, and provides habitat for the federally endangered Tumbling Creek Cavesnail (*Antrobia culveri*). The cave has a delineated recharge area of 9.0 square miles. The recharge area is about half forested and half pasture; there is only one small confined animal feeding operation and only about 40 homes in the entire recharge area. Given these land use conditions, dissolved oxygen measurements would be expected to be higher than similar measurements from Cave Springs Cave where land use is more intensive in the recharge area.

Dissolved oxygen is monitored in the Tumbling Creek Cave stream with measurements recorded every two minutes. Table 2 provides a monthly summary of maximum, minimum, and mean values for various parameters at Tumbling Creek Cave for Water Year 2003 (October 1, 2002 through September 30, 2003). Dissolved oxygen (D.O.) is shown both in mg/l (equivalent to parts per million, ppm) and as percent of saturation. The maximum value during the year was 84.69% of saturation and the mean was 75.00% of saturation. Table 3 shows maximum, minimum, and mean dissolved oxygen as a percent of saturation for five water years where nearly complete records are available.

Slay (2011) monitored Cave Springs for dissolved oxygen using automated equipment during the period July to November 2009. Dissolved oxygen values ranged from 8.21 to 9.56 mg/l with a mean of 8.76 mg/l. At the mean reported temperature of 15.1 degrees Celsius (°C) dissolved oxygen ranged from 81% to 94% of saturation with a mean of 86% of saturation. These are very desirable values for aquatic life in a cave stream.

Given the dissolved oxygen values for other springs and caves, it is the conclusion of the OUL that the dissolved oxygen values reported in Brown et al. (1998) for Cave Springs for the period 1997-1998 are inaccurately high. Since these values are incorporated in Graening and Brown (2003), it is our conclusion that these values are also inaccurately high. Values similar to those reported by Slay (2011) appear more reasonable.

Turbidity is another important parameter for aquatic life. Turbidity is an indirect measure of sediment transport into and through the cave stream. Sediment that deposits in the cave stream can clog interstitial spaces in the gravel and reduce habitat for invertebrates upon which the cavefish feed.

Table 2. Water quality data from Tumbling Creek Cave for Water Year 2003. Unpublished data courtesy of Tumbling Creek Cave Foundation.

		Conductivity (mmhos x 10)	Temp C°	Turbidity (NTU)	Dissolved oxygen (ppm)	D.O. (% sat)	Discharge (cfs)	Precip (in) Total amt	Conductivity (mmhos)
Oct	Max	5.80	13.93	17.17	8.50	81.81	1.31		0.58
	Min	5.45	13.81	5.19	7.58	72.96	0.23		0.55
	Mean	5.73	13.90	5.81	8.25	79.34	0.37	4.15	0.57
Nov	Max	5.71	13.94	16.02	8.79	84.55	0.96		0.57
	Min	5.42	13.87	5.19	8.19	78.83	0.22		0.54
	Mean	5.48	13.91	5.75	8.45	81.32	0.37	0.97	0.55
Dec	Max	5.71	14.09	19.73	8.78	84.69	17.00		0.57
	Min	3.67	13.70	5.15	7.82	74.98	0.20		0.37
	Mean	5.04	13.94	7.28	8.34	80.32	3.84	5.14	0.50
Jan	Max	5.64	14.00	29.71	8.70	83.64	14.28		0.56
	Min	3.64	13.61	5.18	7.77	74.50	0.59		0.36
	Mean	4.66	13.89	7.28	8.25	79.33	4.46	0.82	0.47
Feb	Max	5.53	13.91	16.52	8.64	83.16	11.51		0.55
	Min	4.15	13.23	5.39	7.98	75.65	0.58		0.42
	Mean	4.66	13.52	7.70	8.25	78.71	6.03	3.84	0.47
Mar	Max	5.42	13.57	10.24	8.53	80.87	7.61		0.54
	Min	4.45	13.21	5.35	7.97	75.75	1.87		0.45
	Mean	4.86	13.33	6.59	8.20	77.92	4.86	1.71	0.49
Apr	Max	5.61	13.89	23.97	8.45	80.72	16.65		0.57
	Min	3.57	13.16	5.45	7.14	67.87	0.72		0.36
	Mean	4.85	13.49	10.01	7.81	74.51	5.15	3.18	0.48
May	Max	5.45	14.01	13.48	8.29	79.30	13.46		0.55
	Min	4.14	13.21	5.58	7.47	71.15	1.00		0.41
	Mean	4.95	13.58	7.15	7.88	75.29	4.82	5.72	0.49
Jun	Max	5.54	14.04	14.05	8.00	76.74	10.48		0.55
	Min	4.17	13.26	5.61	7.05	67.71	1.12		0.42
	Mean	5.03	13.73	7.38	7.46	71.54	4.39	4.24	0.50
Jul	Max	5.77	14.09	58.96	7.61	73.04	1.36		0.58
	Min	5.44	13.60	5.43	6.15	59.07	0.46		0.54
	Mean	5.66	13.84	6.15	7.00	67.24	0.76	1.59	0.57
Aug	Max	5.76	14.09	295.30	7.56	72.57	1.85		0.58
	Min	5.26	13.57	5.61	5.46	52.40	0.36		0.53
	Mean	5.53	13.82	7.81	7.06	67.86	0.74	6.30	0.55
Sep	Max	5.49	14.06	431.00	7.54	72.52	5.68		0.55
	Min	4.14	13.48	6.07	5.76	55.19	0.36		0.41
	Mean	4.84	13.83	10.95	6.93	66.62	1.95	5.52	0.48
Yearly	Max	5.80	14.09	431.00	8.79	84.69	17.00		0.58
	Min	3.57	13.16	5.15	5.46	52.40	0.20		0.36
	Mean	5.11	13.73	7.49	7.82	75.00	3.15	43.18	0.51

Table 3. Maximum, minimum, and mean dissolved oxygen as a percent of saturation in the stream in Tumbling Creek Cave. Unpublished data courtesy of Tumbling Creek Cave Foundation**.**

Water Year	Maximum	Minimum	Mean
2003	84.69%	52.40%	75.00%
2004	92.33%	45.55%	68.38%
2005	79.01%	40.97%	70.45%
2008	87.55%	34.44%	66.91%
2010	96.20%	41.57%	63.43%

Table 1 (presented earlier) shows that 44 measured values for turbidity at Cave Springs ranged from < 1 to 48 NTU. These are very low values, and in the experience of the OUL are substantially lower than those periodically associated with most Ozark springs (see turbidity values for Tumbling Creek Cave in Table 2). High values are potentially harmful to aquatic cave systems and cave life. While the low values for Cave Springs Cave are encouraging, much higher values associated with major storm flows and land clearing associated with urbanization would probably be detected with continuous monitoring instrumentation.

Slay (2011) reported on the results of automated sampling of turbidity in Cave Springs Cave from July to November 2009. The instrument was not always in service during this period. However, the observed values ranged from 0 to 31 NTU with a mean of 3.574 NTU. This is basically very clear water that is beneficial for aquatic life.

Chloride is highly mobile in water infiltrating into the karst groundwater system. Graening and Brown (2003) reported measuring this parameter 17 times at Cave Springs. They reported the measurements were in micrograms per liter; this is an obvious error. The values were undoubtedly mg/l, and will be viewed as such in this discussion. Values ranged from 6.1 to 9.5 mg/l with a mean of 7.8 mg/l. Slay (2011) measured chloride concentrations with automated equipment for part of 2009 and reported a mean chloride concentration of 9.59 mg/l with a range from 6.23 to 12.56 mg/l.

In the experience of the OUL mean chloride concentrations in springs draining recharge areas with little agricultural or residential activity are typically 5 mg/l or less. While it appears that chloride concentrations are elevated at Cave Springs, in the opinion of the OUL the concentrations probably are not so great as to create detectable adverse impacts on cavefish and other cave fauna in Cave Springs Cave.

Nitrate concentrations receive substantial attention in surface waters because they enhance the growth of undesirable plants such as algae and cyanobacteria. Elevated nitrate concentrations in cave streams are unlikely to cause detectable adverse impacts on cave systems since there is no sunlight to facilitate plant growth. However, nitrates are very mobile in infiltrating water and are a good indicator of agricultural or residential impacts on groundwater quality in karst areas. Data in Slay and Snell (2005) indicate that Arkansas caves and springs with minimal human and agricultural impacts in their recharge areas typically have nitrate-nitrogen concentrations of 1.5 mg/l or less. These results are compatible with the experience of the OUL.

Nitrate concentrations in water quality sampling can be presented in two different ways. If the data are presented as nitrate (which is NO_3) then the concentration shown as mg/l represents the weight of the entire NO_3 compound. If the data are presented as nitrate-nitrogen (NO_3-N) then the concentration shown as mg/l represents only the weight of N. As a result, a water sample containing 45 mg/l nitrate contains almost the same amount of nitrogen as a sample containing 10 mg/l nitrate-nitrogen. Unfortunately, several of the important papers reviewed confused the two methods of reporting and it is not always clear which units were being used. However, after reviewing all of the data the OUL has concluded that values at Cave Springs from the mid-1990s to present and ranging from about 4.5 to 8.8 mg/l as nitrate-nitrogen are credible values.

Graening and Brown (2003) reported nitrate-nitrogen concentrations at Cave Springs ranging from less than their detection limit (not specified, but probably 0.1 mg/l) to a maximum of 8.8 mg/l; the mean value was 6.2 mg/l. Slay and Snell (2005) reported four nitrate-nitrogen measurements made at Cave Springs during the period 2000 to 2005; the values ranged from 5.00 to 7.06 mg/l with a mean of 5.90 mg/l. No more recent nitrate-nitrogen data were found during our literature search.

More current nitrate-nitrogen monitoring of water in Cave Springs Cave is desirable. However, based on the historic data on nitrate-nitrogen concentrations, water quality in Cave Springs Cave has been detectably impacted by land use practices in the recharge area.

Water Quality Trend Analysis

Brown et al. (1998, page 2) stated the following in the abstract to their report: *"A trend analysis of known water quality studies of this cave [Cave Springs Cave] suggests that many organic and inorganic chemicals have increased in concentration in the last 14 years."* Parameters upon which this statement is based are specific conductance values and concentrations of nitrate-nitrogen, total phosphorous, ammonia, copper, and zinc; the data are presented in the Brown et al. (1998) report as Figures 1 through 4. In Graening and Brown (1999) the trend analysis is presented for conductance, nitrate- nitrogen, lead, and zinc. The trend analysis graphs, if they are credible, clearly indicate rapidly increasing concentrations of these parameters, and that the increases are linear with respect to time. Unfortunately, in the opinion of the OUL, the trend analysis is flawed and the conclusion that *"…many organic and inorganic chemicals have increased in concentration in the last 14 years"* is not supported by the data. This will be demonstrated in the following paragraphs.

The trend analysis for specific conductance in Brown et al. (1998) relied on four data points. Two additional data points are provided in Graening and Brown (1999).

- The 1984 point reflects a single measurement collected at an unknown date.

- The 1991 point is the mean of two measurements made in April 1991. The values were 280 and 205 microSiemens per centimeter (µS/cm).
- The 1996 value is a single measurement made in late August.
- The 1997 value is the mean of 2 base flow samples.
- The 1998 value is the mean of 10 base flow samples and 10 stormflow samples.
- The 1999 value is the mean of 22 measurements. Two were base flow measurements and 19 were stormflow measurements; conditions for the other measurement were not identified.
- For the entire period the recorded flow rates under "base flow" conditions varied by a factor of 11.

Several problems exist with the trend analysis for specific conductance. First, the 1984 value (130 µS /cm) is almost certainly in error. In a karst setting like this specific conductance is primarily a measure of the amount of dissolved rock in the water and a value this low is not likely for a large karst spring. Second, specific conductance values for springs vary substantially through the year with the lowest values typically occurring in winter and early spring and the highest in late summer. Third, the data available are far too limited to support a credible trend analysis. If the trend line for specific conductance shown in Graening and Brown (1999, page 20) is examined in light of the above discussion it is clear that all of the apparent increase in specific conductance is due to one questionable measurement made in 1984 and two made in April 1991. The data are inadequate for a credible trend analysis.

The trend analysis for nitrate-nitrogen presented in Brown et al. (1998) and Graening and Brown (1999) has also been reviewed.

- The 1991 point is based on the mean of two measurements made in April 1991. The reported values were 5.27 and 0.68 mg/l as nitrate (not as nitrate-nitrogen; the mean is 2.98 mg/l as nitrate. Unfortunately, Brown et al. (1998) and Graening and Brown (1999) plotted this value as though it were nitrate-nitrogen. If the mean of the two values were presented as nitrate-nitrogen the mean concentration would be 0.67 mg/l rather than 2.98.
- The 1996 point is a single measurement made in late August.
- The 1997 point is based on 3 samples.
- The 1998 point is based on 6 samples.
- The 1999 point is based on 22 samples.

While the trend analysis may suggest an increase in nitrate-nitrogen concentrations with time, the available data are extremely limited until 1998 and 1999. Assuming that the 1991 data are correct, nitrate concentrations at Cave Springs can vary by a factor of over 9 in a period of 14 days. With so few values per year and such a wide variation in a short period of time a much more robust data set would be needed for a credible trend analysis of nitrate-nitrogen concentrations through time.

Graening and Brown (1999, page 20) provide graphs that they interpret as showing a dramatic increase in lead and zinc concentrations in waters from Cave Springs from 1996 to 1999. The y-axis on the graphs are labeled "Lead (Ln of ug Pb/L) and Zinc (Ln of ugZn/L). The caption for the graphs indicates that these graphs show increases over time of lead and zinc in stream water from Cave Springs Cave during base flow using all available data.

The abbreviation "Ln" indicates that the values are natural logarithm values. While it is appropriate to calculate natural logarithm values for aquatic toxicity purposes, such values involve a calculation using the concentration of lead or zinc present and the total hardness of the water. As a result, natural logarithm values do not accurately reflect the concentrations of lead and zinc in the water.

The OUL reviewed the analytical data for lead in Brown et al. (1998) and Graening and Brown (1999). The trend plotted for lead in Graening and Brown (1999, page 20) is stated to be for base flow conditions using all available data. This appears to include one value for 1996, one for 1997, two for 1998, and two for 1999. There are 16 lead values for Cave Springs for storm flow periods; no rationale is provided for not using these values.

It is the conclusion of the OUL that the water quality data available for this report are not adequate to support a credible trend analysis or the statement that the data suggest that many organic and inorganic chemicals have increased in concentration during the period from 1984 to 1999. This conclusion relates only to the issue of whether or not parameter values at Cave Springs have increased with time. It does not suggest that water quality data in the various reports are not of great value in characterizing water quality in Cave Springs. They are extremely valuable. The conclusion of the OUL is that data do not exist that permit a conclusion that water quality at Cave Springs was deteriorating with time during the period 1984 to 1999.

Comparison of Water Quality Among Arkansas Caves and Springs

Graening (2002) compared water quality data for five biologically significant caves in Benton County. While the number of samples varied substantially among the caves, the comparison is valuable. The OUL has done recharge area delineation work for all of the caves except Rootville Cave and, as a result, has a good understanding of land use conditions in the recharge areas.

The size of the delineated recharge area for Logan Cave is 11.64 square miles (Aley and Aley 1987); 98% of this area is shared with other springs. At the time of the water quality sampling land use in this recharge area was primarily agricultural with numerous confined animal operations and land application of animal wastes. Some of the land application was in losing stream valleys where wastes could readily be flushed into groundwater supplies, especially by rainfall occurring shortly after land application or when the ground was frozen.

The size of the delineated recharge area for Civil War Cave is 3.20 square miles (Aley and Aley 2014); 56% of this area is shared with Centerton Spring. At the time of the water quality sampling land use in this recharge area was a mixture of an urbanized area (primarily within Centerton) and agricultural use with numerous confined animal feeding operations and land application of the wastes.

The size of the delineated recharge area for the point in Bear Hollow Cave where Graening collected the water samples is 2.29 square miles (Aley and Aley 1998). The total recharge area for Bear Hollow Cave upstream of the springs that drain the cave is 3.46 square miles (Aley and Aley 1998). None of the recharge area for Bear Hollow Cave appears to be shared with other springs. At the time of the water quality sampling most of the recharge area was forested hilly land with a few scattered houses served by septic systems.

The OUL knows of no recharge area delineation work for Rootville Cave. The likely recharge area is rural, and there may be some confined animal feeding operations with land application of animal wastes in the recharge area.

Table 4 compares selected water quality parameters at all of the caves for which Graening (2002) presented data. The water samples from Cave Springs Cave were collected during the period 1997 to 2001. Those for the other caves were collected in 2000 and 2001.

Elevated concentrations of chloride, nitrate, and orthophosphate are commonly associated with both human sewage and animal wastes. The water quality results from the Graening (2002) study indicate that chloride, nitrate, and orthophosphate concentrations were generally similar for Cave Springs, Civil War Cave, and Logan Cave. Data for Civil War Cave are, unfortunately, based on only two samples because access permission to the cave was lost after the study began. Rootville Cave was selected as a replacement sampling location for Civil War Cave.

Mean fecal coliform numbers are much higher for Cave Springs Cave than for any of the other sampled caves. However, because a few very high numbers can elevate the mean and result in mean values not being representative of average conditions, the more appropriate measure of average bacteria numbers is the median value. Graening (2002) indicates that the median fecal coliform number for Cave Springs Cave was 214.5. This is similar to mean numbers for Bear Hollow Cave and Rootville Cave; these are the caves with low human populations in their recharge areas. Graening (2002) did not provide median fecal coliform values for Bear Hollow Cave, Logan Cave, or Rootville Cave. The OUL does not believe that the limited fecal coliform concentration data presented in the Graening (2002) report are useful in characterizing the extent of human sewage and/or animal waste contamination in the sampled caves.

Table 4. Selected water quality parameters at five Benton County Caves.

Parameter	Cave Springs Cave	Civil War Cave	Bear Hollow Cave	Logan Cave	Rootville Cave
Chloride (mg/l)					
Number	35	2	12	12	10
Maximum	5.4	9.5	3.17	5.1	1.9
Minimum	9.9	9.6	1.06	9.1	5.1
Mean	7.8	9.5	3.17	6.8	2.5
Nitrate-Nitrogen (mg/l)					
Number	71	2	12	12	10
Maximum	8.8	8.35	3.17	6.15	1.76
Minimum	ND	7.82	0.58	3.64	0.28
Mean	5.9	8.08	1.06	4.67	0.95
Ortho Phosphate (mg/l)					
Number	55	2	12	12	10
Maximum	0.103	0.031	0.017	0.046	0.040
Minimum	0.017	0.029	0.009	0.020	0.010
Mean	0.035	0.030	0.014	0.028	0.024
Fecal coliform (Mean Probable Number/100 ml)					
Number	74	2	12	12	10
Maximum	20,050	10	640	400	528
Minimum	<10	<10	<10	<10	<10
Mean	1626*	5	211	105	321
Copper (ug/l)					
Number	51	2	12	12	10
Maximum	230	0.030	0.04	0.06	0.04
Minimum	ND	0.002	ND	0.00	ND
Mean	21	0.016	0.02	0.03	0.03
Lead (ug/l)					
Number	52	2	12	12	10
Maximum	40	ND	0.03	0.02	0.03
Minimum	ND	ND	ND	ND	ND
Mean	9	ND	0.01	0.00	0.00
Selenium (ug/l)					
Number	52	2	12	12	10
Maximum	32	ND	0.02	0.02	0.00
Minimum	ND	ND	ND	ND	ND
Mean	8	ND	0.00	0.00	0.00
Zinc (ug/l)					
Number	51	2	12	12	10
Maximum	288	0.030	0.05	0.39	0.04
Minimum	ND	0.012	ND	ND	ND
Mean	41	0.021	0.02	0.07	0.01

* Median value 214.5

Graening (2002) reported that both mean and maximum concentrations of beryllium, copper, and selenium in water samples from Cave Springs Cave exceeded Arkansas water quality standards for aquatic life and that maximum observed values for lead and zinc also exceed these standards. While not always stated, it appears that all reported metal concentrations are for dissolved metals, not total metals. Total metal values are always equal to or greater than values for dissolved metals and current Arkansas water quality standards for the protection of aquatic life are based upon dissolved metal concentrations.

A copy of the relevant pages of the Arkansas standards is shown in Table 5. Note that the current standards require that the hardness of the water be measured and used in the calculations. Hardness was not measured in the work by Graening (2002). However, hardness (in mg/l) can be estimated by assuming that it is approximately equal to the value for alkalinity (in mg/l) multiplied by 1.09. This correction factor is based on the relationship of alkalinity and hardness values for water in 24 Arkansas caves and springs measured on March 29, 2002 (Slay and Snell 2005). The correction values for those samples ranged from 0.98 to 1.33 with a median value of 1.09. The correction value for Cave Springs in this set of data was 1.33.

As shown in Table 4, the mean concentrations of dissolved copper, lead, selenium, and zinc in waters from Cave Springs Cave are two to three orders of magnitude (100 to 1,000 times) larger than at any of the other monitored caves. If the data are correct, these are clearly not natural concentrations of these heavy metals. The source(s) of these contaminants is not known, but their presence during the period November 1997 to September 2001 is clearly of concern. It is assumed that the data are accurate and are of dissolved metals in water. Sampling to determine if similar elevated concentrations are still occurring at Cave Springs is an important data gap. If the conditions still exist the source(s) of the contamination need to be found. Likely sources for some of the elevated element concentrations include small metal plating operations or illegal dumping of manufacturing wastes. In the experience of the OUL it can be difficult to discover such operations.

Synoptic Water Quality Sampling of Caves and Springs

A very useful water quality program comparing water quality conditions in water at a number of Arkansas caves and springs was conducted during the period 2000 to 2005. In this program water quality was sampled under base flow conditions on the same day (or sometimes on two consecutive days) in a large number of caves and springs. The results (available in Slay and Snell [2005]) can then be compared among caves. Cave Springs Cave was included in all of these surveys. The following measurements were made as part of these surveys:

Date of Sampling	Number of Caves and Springs
February 20-21, 2000	37
April 7-8, 2001	64
March 29, 2002	24
October 1-2, 2005	26

Table 5. Arkansas water quality standards for the protection of aquatic life (2014). Data from Arkansas Department of Environmental Quality (ADEQ 2014).

	Acute Criteria		**Chronic Criteria**	
Substance	**Formula X**	**Conversion**	**Formula X**	**Conversion**
Cadmium	$e^{[1.128(lnhardness)]-3.828}$	(a)	$e^{[0.7852(lnhardness)]-3.490}$	(c)
Chromium(III)	$e^{[0.819(lnhardness)]+3.688}$	0.316	$e^{[0.8190(lnhardness)]+1.561}$	0.860
Chromium (VI)	16	0.982	11	0.962
Copper	$e^{[0..9422(lnhardness)]-1.464}$	0.960	$e^{[0.8545(lnhardness)]-1.465}$	0.960
Lead	$e^{[1.273(lnhardness)]-1.460}$	(b)	$e^{[1.273(lnhardness)]-4.705}$	(b)
Mercury**	2.4	0.85	0.012**	NONE
Nickel	$e^{[0.8460(lnhardness)]+3.3612}$	0.998	$e^{[0.8460(lnhardness)]+1.1645}$	0.997
Selenium**	20	NONE	5	NONE
Silver	$e^{[1.72(lnhardness)]-6.52}$	0.85	-------------	NONE
	Acute Criteria (CMC) - µg/L(ppb)		**Chronic Criteria (CCC) - ug/L(ppb)**	
Substance	**Formula X**	**Conversion**	**Formula X**	**Conversion**
Zinc	$e^{[0.8473(lnhardness)]+0.8604}$	0.978	$e^{[0.8473(lnhardness)]+0.7614}$	0.986
Cyanide**	22.36	NONE	5.2	NONE

* These values may be adjusted by a site specific Water Effects Ratio(WER) as defined in 40 CFR Part 31.36 (c).

(a) Calculated as: 1.136672 - [(ln hardness)(0.041838)]

(b) Calculated as: 1.46203 - [(ln hardness)(0.145712)]

(c) Calculated as: 1.101672 - [(ln hardness)(0.041838)]

** Expressed as total recoverable. Mercury based on bioaccumulation of residues in aquatic organisms, rather than toxicity.

The OUL made an analysis of the data presented in Slay and Snell (2005) and created Tables 6, 7, 8, and 9. For each water quality parameter the minimum and maximum observed values from all caves and springs monitored are indicated, as well as the value from Cave

Springs Cave. The percent of all measured values that were equal to, or greater than, the value from Cave Springs Cave is also indicated. In cases where the measurements at Cave Springs Cave were less than the reporting limit for the parameter we indicated the percent of samples where the parameter was detected at concentrations greater than the reporting limit.

Table 6. Results of base flow water quality sampling in 37 Arkansas caves and springs on February 20-21, 2000. All metal concentrations as dissolved metals. Slay and Snell (2005).

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs
Turbidity	NTU	1.0	50.0	2.0	81%
Hardness	mg/l	26	283	146	14%
Sulfate	mg/l	1.613	13.913	3.098	76%
Total Phosphate	mg/l	0.053	0.305	0.075	54%
Ortho Phosphate	mg/l	0.001	0.229	0.019	35%
Nitrate-N*	mg/l	0.028	13.58	5.00	11%
Arsenic	ug/l	<1	<1	<1	
Barium	ug/l	<8.8	107.3	39.7	14%
Beryllium	ug/l	<0.11	0.2	<0.11	Detected in 3%
Cadmium	ug/l	<0.14	0.42	<0.14	Detected in 8%
Calcium	mg/l	6.4	73.3	56.1	11%
Chloride	mg/l	0.933	12.613	7.433	22%
Chromium	ug/l	<0.40	1.63	<0.40	Detected in 41%
Cobalt	ug/l	<0.50	<0.50	<0.50	
Copper	ug/l	0.98	21.60	2.52	41%
Iron	ug/l	<15	44.5	<15	Detected in 3%
Lead	ug/l	<0.30	3.19	<0.30	Detected in 19%
Magnesium	mg/l	0.4	35.6	1.4	46%
Manganese	ug/l	<0.5	7.5	<0.5	Detected in 59%
Mercury	ug/l	<1	<1	<1	
Potassium	mg/l	<0.46	4.70	0.60	46%
Sodium	mg/l	1.5	8.4	5.4	19%
Nickel	ug/l	<2.0	7.36	<2.0	Detected in 22%
Selenium	ug/l	<3	<3	<3	
Vanadium	ug/l	<1.0	1.28	<1.0	Detected in 8%
Zinc	ug/l	3.3	62.9	11.6	38%
E. coli	MPN/100ml	<10	20,050	20	32%

Abbreviations:

- mg/l = milligrams per liter
- ug/l = micrograms per liter
- NTU = Nephelometric Turbidity Units
- MPN/100 mg = Mean Probable Number/100 ml.

* Reported as nitrate, but determined by the OUL to be nitrate-nitrogen.

Table 7. Results of base flow water quality sampling in 64 Arkansas caves and springs on April 7-8, 2001; metal parameters measured at only 30 sites. All metal concentrations as dissolved metals. Slay and Snell (2005).

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs
Turbidity	NTU	1	73	1	97%
Hardness	mg/l	42	222	222	0%
Sulfate	mg/l	0	23.55	2.47	89%
Total Phosphate	mg/l	---	---	---	
Ortho Phosphate	mg/l	0.01	0.19	0.02	44%
Nitrate-N*	mg/l	0	13.92	7.06	3%
Arsenic	ug/l	<1	2	<1	Detected in 3%
Barium	ug/l	<8.8	40.5	40.5	0%
Beryllium	ug/l	<0.11	<0.11	<0.11	
Boron	ug/l	<4.5	16.4	<4.5	Detected in 47%
Bromide	ug/l	<0.01	0.08	<0.01	Detected in 13%
Cadmium	ug/l	<0.14	0.40	<0..14	Detected in 17%
Calcium	mg/l	8.7	58.4	53.8	7%
Chloride	mg/l	1.3	39.0	17.3	6%
Chromium	ug/l	<0.4	<0.4	<0.4	
Cobalt	ug/l	<0.5	<0.5	<0.5	
Copper	ug/l	<0.5	3.9	<0.5	Detected in 47%
Iron	ug/l	<15	70	<15	Detected in 20%
Lead	ug/l	<0.4	0.5	<0.4	Detected in 3%
Magnesium	mg/l	0.7	20.5	1.7	37%
Manganese	ug/l	<2.0	<2.0	<2.0	
Mercury	ug/l	---	---	---	
Potassium	mg/l	0.5	7.3	2.2	17%
Sodium	mg/l	0.8	6.8	6.3	3%
Nickel	ug/l	<2.0	<2.0	<2.0	
Selenium	ug/l	<3.0	<3.0	<3.0	
Vanadium	ug/l	<1.0	<1.0	<1.0	
Zinc	ug/l	<1.0	16.9	4.3	50%
E. coli	MPN/100ml	<10	1500	200	9%

Abbreviations:

- mg/l = milligrams per liter
- ug/l = micrograms per liter
- NTU = Nephelometric Turbidity Units
- MPN/100 mg = Mean Probable Number/100 ml.

* Reported as nitrate, but determined by the OUL to be nitrate-nitrogen.

Table 8. Results of base flow water quality sampling in 24 Arkansas caves and springs on March 29, 2002. All metals as dissolved metals. Slay and Snell (2005).

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs
Turbidity	NTU	---	---	---	
Hardness	mg/l	44	243	183	8%
Sulfate	mg/l	1.78	7.27	2.45	83%
Total Phosphate	mg/l	<0.005	0.100	0.020	46%
Ortho Phosphate	mg/l	---	---	---	
Nitrate-N*	mg/l	0.06	6.39	6.39	0%
Bromide	mg/l	<0.010	0.060	<0.010	Detected in 25%
Arsenic	ug/l	---	---	---	
Barium	ug/l	<8.8	55.4	55.4	0%
Beryllium	ug/l	---	---	---	
Boron	ug/l	<4.5	203.8	<4.5	Detected in 25%
Cadmium	ug/l	<0.14	0.98	<0.14	Detected in 8%
Calcium	mg/l	15.8	93.9	69.8	8%
Chloride	mg/l	1.11	8.78	6.99	4%
Chromium	ug/l	---	---	---	
Cobalt	ug/l	---	---	---	
Copper	ug/l	<0.5	3.58	<0.5	Detected in 29%
Iron	ug/l	<15.0	44.2	<15.0	Detected in 17%
Lead	ug/l	<0.40	1.96	<0.40	Detected in 13%
Magnesium	mg/l	0.5	13.4	2.0	29%
Manganese	ug/l	<0.5	5.8	<0.5	Detected in 38%
Mercury	ug/l	---	---	---	
Potassium	ug/l	<0.46	2.20	1.30	8%
Sodium	mg/l	0.5	5.2	5.1	4%
Nickel	ug/l	<2.00	2.52	2.28	4%
Selenium	ug/l	---	---	---	
Vanadium	ug/l	---	---	---	
Zinc	ug/l	10.3	39.3	12.5	75%
E. coli	MPN/100ml	<1	199	8	45%

Abbreviations:

- mg/l = milligrams per liter
- ug/l = micrograms per liter
- NTU = Nephelometric Turbidity Units
- MPN/100 mg = Mean Probable Number/100 ml.

* Reported as nitrate, but determined by the OUL to be nitrate-nitrogen.

Table 9. Results of base flow water quality sampling in 26 Arkansas caves and springs on October 1-2, 2005. All metals as dissolved metals. Slay and Snell (2005).

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs
Turbidity	NTU	---	---	---	
Hardness	mg/l	62	235	172	19%
Sulfate	mg/l	2.5	15.7	3.12	81%
Total Phosphate	mg/l	---	---	---	
Ortho Phosphate	mg/l	0.015	0.105	0.028	31%
Nitrate-N*	mg/l	0.096	5.15	5.15	0%
Arsenic	ug/l	<0.50	0.69	<0.50	Detected in 27%
Barium	ug/l	18.1	64.5	53.4	19%
Beryllium	ug/l	<.10	<.10	<.10	
Bromide	mg/l	<0.01	0.12	0.04	54%
Cadmium	ug/l	<.10	0.12	<0.10	Detected in 4%
Calcium	mg/l	15.3	86.5	66.2	15%
Chloride	mg/l	1.25	17.9	6.9	31%
Chromium	ug/l	0.71	1.41	0.99	38%
Cobalt	ug/l	<0.50	1.19	<0.50	Detected in 4%
Copper	ug/l	<0.50	3.2	<0.50	Detected in 56%
Iron	ug/l	30.4	76.9	33.3	81%
Lead	ug/l	<0.10	0.81	<0.10	Detected in 12%
Magnesium	mg/l	1.08	8.17	1.72	54%
Manganese	ug/l	<0.20	107	<0.20	Detected in 58%
Mercury	ug/l	---	---	---	
Potassium	ug/l	0.726	3.46	1.38	42%
Sodium	mg/l	1.53	8.53	4.82	27%
Nickel	ug/l	<0.50	2.84	<0.50	Detected in 4%
Selenium	ug/l	<0.50	<0.50	<0.50	
Silver	ug/l	<1.00	<1.00	<1.00	
Thalium	ug/l	<0.50	<0.50	<0.50	
Vanadium	ug/l	<0.50	<0.50	<0.50	
Zinc	ug/l	1.6	23.5	4.89	15%
E. coli	MPN/100ml	---	---	---	

Abbreviations:

- mg/l = milligrams per liter
- ug/l = micrograms per liter
- NTU = Nephelometric Turbidity Units
- MPN/100 mg = Mean Probable Number/100 ml.

* Reported as nitrate, but determined by the OUL to be nitrate-nitrogen.

Some measured parameters were not particularly relevant to this analysis and were not included in these tables. Parameters not included are water temperature, pH, conductivity, alkalinity, total Kjeldahl nitrogen, ammonia, total organic carbon, fluoride, silica dioxide, total suspended solids, total dissolved solids, total coliform, and total viable cells.

On April 7, 2001, water samples from Cave Springs Cave, Logan Cave, Rootville Cave, Tom Alley Cave, and Bear Hollow Cave were analyzed for a number of semi-volatile and volatile compounds (Slay and Snell 2005). The following six semi-volatile compounds were detected in all five sampled caves:

- 2-Fluorophenol(Surr.)
- Phenol-d6(Surr.)
- Nitrobenzene-d5(Surr.)
- 2-Fluorobiphenyl(Surr.)
- 2-4-6-Tribromophenol(Surr.)
- Terphenyl-d14(Surr.)

The only compound that was detected at a higher concentration in Cave Springs Cave than in any of the other caves was phenol-d6 (Surr.). In the opinion of the OUL, none of these detections indicate any contamination of concern at Cave Springs Cave.

On April 7, 2001, the following four volatile compounds were detected in all five of the sampled caves and at similar concentrations:

- Dibromofluoromethane
- Toluene-D8
- 4-Bromofluorobenzene
- 1,2-Dichloroethane-D4

In addition, acetone was detected at 20 ug/l in Rootville Cave. This is a common laboratory contaminant and may not be a credible detection.

Based on the synoptic sampling of water quality at a number of caves and springs during the period 2000 to 2005, concentrations of several parameters were routinely greater at Cave Springs Cave than at most other sampling stations. For the purpose of this analysis Table 10 lists all parameters and dates where parameters values at Cave Springs Cave were equaled or exceeded by 25% or less of all measurements during at least one of the synoptic sampling events.

Water hardness and calcium concentrations are routinely higher at Cave Springs Cave than in most of the other springs and cave streams sampled. This is attributable to the contact time between the limestone bedrock and water in the aquifer. The greater the contact time the larger the magnitude of these values. The high values are not indicative of groundwater contamination.

Nitrate-nitrogen concentrations in the water from Cave Springs Cave are routinely higher than at almost all other springs and cave streams sampled. This is probably attributable to land application of manure from Confined Animal Feeding Operations (CAFOs) and/or impacts from septic fields and leaking sewers.

Table 10. Parameters and dates where water quality values at Cave Springs Cave were exceeded by 25% or less of all sampled sites. Data from Slay and Snell (2005).

Parameter	Sampling Dates	Percent of Values That Equaled or Exceed Those at Cave Springs Cave
Hardness	Feb. 20-21, 2000	14
	Apr. 7-8, 2001	0
	Mar. 29, 2002	8
	Oct. 1-2, 2005	19
Nitrate	Feb. 20-21, 2000	11
	Apr. 7-8, 2001	3
	Mar. 29, 2002	0
	Oct. 1-2, 2005	0
Barium	Feb. 20-21, 2000	14
	Apr. 7-8, 2001	0
	Mar. 29, 2002	0
	Oct. 1-2, 2005	19
Calcium	Feb. 20-21, 2000	11
	Apr. 7-8, 2001	7
	Mar. 29, 2002	8
	Oct. 1-2, 2005	15
Chloride	Feb. 20-21, 2000	22
	Apr. 7-8, 2001	6
	Mar. 29, 2002	4
	Oct. 1-2, 2005	31
Sodium	Feb. 20-21, 2000	19
	Apr. 7-8, 2001	3
	Mar. 29, 2002	4
	Oct. 1-2, 2005	27
Potassium	Feb. 20-21, 2000	46
	Apr. 7-8, 2001	17
	Mar. 29, 2002	8
	Oct. 1-2, 2005	42
E. coli	Feb. 20-21, 2000	32
	Apr. 7-8, 2001	9
	Mar. 29, 2002	45
Zinc	Feb. 20-21, 2000	38
	Apr. 7-8, 2001	50
	Mar. 29, 2002	75
	Oct. 1-2, 2005	15
Nickel	Feb. 20-21, 2000	< Reporting Limit
	Apr. 7-8, 2001	< Reporting Limit
	Mar. 29, 2002	4
	Oct. 1-2, 2005	< Reporting Limit

Barium concentrations in the waters of Cave Springs Cave are routinely higher than at almost all other springs and cave streams sampled. This is probably attributable to somewhat higher barium concentrations in the soils, residuum, and bedrock in the Cave Springs Cave recharge area. No anthropogenic source for elevated barium concentrations is known to exist in the recharge area for Cave Springs Cave. The barium concentrations in water are all relatively small and are unlikely to pose any risk to the fauna in Cave Springs Cave.

Chloride and sodium concentrations are both routinely greater in the water at Cave Springs Cave than at other sampled cave streams and springs. These values are probably attributable to waste disposal from CAFOs and/or septic fields and leaking sewer lines.

Potassium concentrations are sometimes substantially higher in the water at Cave Springs Cave than in other cave streams and springs sampled synoptically. Potassium is a plant nutrient and is present in many fertilizers and in wastes from CAFOs and human sewage systems.

Concentrations of the bacteria *Escherichia coli* (*E. coli*) are routinely higher at Cave Springs than in the other waters sampled synoptically. Some of this may be attributable to guano from the bat colony in the cave. However, the elevated concentrations are likely to be a reflection of land application of wastes from CAFOs and septic systems and sewer leaks.

The zinc concentrations in water samples from Cave Springs were elevated in one of the four synoptic sampling events but not in the other three. The same applies to nickel concentrations. In the opinion of the OUL the concentrations of these two elements is most likely natural and is derived from the presence of these metals in soil, residuum, and the bedrock and not from human activities.

Based upon the synoptic sampling, the water quality of Cave Springs is similar to that for other cave streams and springs in northern Arkansas. Elevated concentrations of nitrate, chloride, and sodium at Cave Springs Cave are probably attributable to land use activities in the recharge area for the cave.

Presence of Metals in Sediments from Cave Streams and Springs

Sediments from cave streams and springs may contain appreciable loads of metals that are potentially harmful to aquatic life. These metals may be due to natural processes, but some may be associated with spills or illegal dumping within the recharge areas for the caves or springs. Slay and Snell (2005) presented data on two periods of synoptic sampling of sediments in caves and springs of northern Arkansas on April 7 and 8, 2001 and on March 27, 2002. Tables 11 and 12 summarize the data for the two sampling events.

Table 11. Concentrations of metals extracted from sediments in 55 Arkansas caves and springs on April 7-8, 2001. Slay and Snell (2005) reported the concentrations as mg/l, but the OUL believes that the units are actually milligrams per kilogram (mg/kg) and have shown the values in this fashion.

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs.
Arsenic	mg/kg	ND	20.1	ND	Detected in 38%
Barium	mg/kg	13.0	570	58.6	53%
Beryllium	mg/kg	ND	3.52	2.01	2%
Cadmium	mg/kg	ND	2.46	1.37	4%
Calcium	mg/kg	445	178,656	22,146	24%
Chromium	mg/kg	ND	51.4	ND	Detected in 33%
Cobalt	mg/kg	0.62	44.7	4.67	76%
Copper	mg/kg	1.23	57.6	16.0	20%
Iron	mg/kg	3,004	91,261	15,050	31%
Lead	mg/kg	ND	323	323	0%
Magnesium	mg/kg	61.8	5,344	391	56%
Manganese	mg/kg	137	84,501	407	67%
Molybdenum	mg/kg	ND	1.32	ND	Detected in 49%
Nickel	mg/kg	2.43	117	19.3	53%
Selenium	mg/kg	ND	0.60	ND	Detected in 7%
Silica	mg/kg	7.69	2,521	1,522	11%
Vanadium	mg/kg	5.37	198	77.5	31%
Zinc	mg/kg	6.36	638	144	13%

Abbreviations:

- ND = Not Detected; detection limit not identified.

Table 12. Concentrations of metals extracted from sediments in 14 Arkansas caves and springs on March 29, 2002. Slay and Snell (2005) reported the concentrations as mg/l, but the OUL believes that the units are actually mg/kg and have shown the values in this fashion.

Parameter	Units	Minimum	Maximum	Cave Springs Cave	Percent equal or greater than Cave Springs
Aluminum	mg/kg	315	18,386	18,386	0%
Arsenic	mg/kg	1.00	30.27	5.22	64%
Barium	mg/kg	4.02	486.60	58.30	57%
Boron	mg/kg	ND	1.47	ND	Detected in 36%
Beryllium	mg/kg	0.04	1.87	1.03	36%
Cadmium	mg/kg	ND	4.18	0.36	14%
Calcium	mg/kg	647	148,633	29,960	21%
Chromium	mg/kg	ND	201.05	4.09	29%
Cobalt	mg/kg	0.77	46.65	5.47	79%
Copper	mg/kg	3.43	97.35	18.30	29%
Iron	mg/kg	1152	37,716	18,147	36%
Lead	mg/kg	1.75	4,775.00	32.29	21%
Magnesium	mg/kg	3.18	3,209	676	50%
Manganese	mg/kg	59	6,132	346	86%
Molybdenum	mg/kg	ND	1.43	ND	Detected in 71%
Nickel	mg/kg	2.46	104.30	19.33	71%
Selenium	mg/kg	ND	3.21	ND	Detected in 29%
Vanadium	mg/kg	6.14	351.20	122.30	21%
Zinc	mg/kg	4.30	2,714.50	168.45	7%

Abbreviations:

- ND = Not Detected; detection limit not identified.

Table 13 provides a summary of parameters and dates when metal concentrations extracted from cave sediments at Cave Springs Cave were exceeded by 25% or less of results from all sampled sites. In other words, these are the parameters that had higher values at Cave Springs Cave than at most of the other caves sampled.

Metal concentrations vary substantially from point to point in a stream; they also vary with depth in the sediments. As will be discussed later in this report the stream gradient in Cave Springs Cave is very low. Deposition of metals being transported in suspension is greater under low gradient (and by inference, low velocity) cave streams than under higher gradient streams. The stream gradient in Cave Springs Cave is almost certainly lower than in many (and probably most) of the other cave streams and springs sampled. In the opinion of the OUL the concentrations of heavy metals in sediments from Cave Springs Cave are reflective of near-natural conditions for a low gradient cave stream in Benton County.

Table 13. Parameters and dates when metal concentrations extracted from cave and spring sediments at Cave Springs Cave were exceeded by 25% or less of results from all sampled sites.

Parameter	Sampling Dates	Percent of Values that Equaled or Exceed those at Cave Springs Cave.
Aluminum	April 7-8, 2001	No data
	March 29, 2002	0%
Beryllium	April 7-8, 2001	2%
	March 29, 2002	36%
Cadmium	April 7-8, 2001	4%
	March 29, 2002	14%
Calcium	April 7-8, 2001	24%
	March 29, 2002	21%
Copper	April 7-8, 2001	20%
	March 29, 2002	29%
Lead	April 7-8, 2001	0%
	March 29, 2002	21%
Silica	April 7-8, 2001	11%
	March 29, 2002	No data
Vanadium	April 7-8, 2001	No data
	March 29, 2002	21%
Zinc	April 7-8, 2001	13%
	March 29, 2002	7%

Water Quality Data Gaps

One of the purposes of the literature and data review was to identify data gaps and outline steps that could be taken to fill these gaps. A well designed program for Cave Springs specifically designed to gather data suitable for showing trends in water quality through time would certainly be beneficial. However, such programs can be very expensive, and results useful for management may not be available for a number of years. By the time the results are available much of the recharge area is likely to be urbanized and, unfortunately, the results would probably not have much practical utility. Given these considerations, the OUL does not recommend the establishment of a major water quality monitoring program designed to develop long term water quality trends at Cave Springs.

A more reasonable approach is to develop data that will help determine if the land management actions implemented for the protection of water quality in Cave Springs Cave and the protection of the associated cave fauna appear to be functioned adequately. The OUL recommends a program using automatic sampling equipment that will measure parameters important in the protection of the cave fauna. The OUL has operated such a program at Tumbling Creek Cave, Missouri for the period 2002 to present and the program has worked well.

Parameters measured in the cave stream at Tumbling Creek Cave are water temperature, specific conductance, turbidity, dissolved oxygen, and flow rate. As initially installed, the probes were queried every 10 seconds and a running mean was calculated every 2 minutes. The data collection program had a sub-routine that recorded all data every hour, but did not record the 2-minute interval values unless one or more of them changed by more than a certain limit from the previous value. This unfortunately made data reduction more challenging than desirable. Subsequently the program was changed to query the probes every 10 seconds and record a running mean value every 10 minutes.

The temperature data from Tumbling Creek Cave has allowed calculation of dissolved oxygen concentrations as a percent of saturation. This is important. Specific conductance, in combination with flow rate, has been valuable in tracking storm flow pulses through the cave system and characterizing how they impact turbidity and dissolved oxygen. Turbidity and dissolved oxygen monitoring has been very valuable.

The OUL recommends initiation of a water quality monitoring program at Cave Springs Cave similar to the one operating at Tumbling Creek Cave. The program uses automatic sampling equipment and we recommend the same parameters that have been employed in Tumbling Creek Cave. These are flow rate, turbidity, dissolved oxygen, temperature, and specific conductance. In addition, we recommend monitoring chloride as an indicator of human activity in the recharge area. Nitrate concentrations should also be monitored if dependable equipment is currently available that is capable of making many measurements at short intervals. Querying the probes every 10 seconds and recording running means every 10 minutes is recommended, and at Tumbling Creek Cave this has been adequate for management purposes focused on protecting a federally endangered aquatic species.

Groundwater Gradients in the Recharge Area

Mean groundwater gradients from groundwater traces in the Cave Springs area have been calculated from Aley (1978a and 1978b) and Aley and Moss (2001). The results are summarized in Table 14. Actual groundwater gradients are less than shown because the surface elevation of the dye introduction point is used in the calculation and this may be a substantial number of feet higher than the groundwater elevation at that point.

Table 14. Straight-line travel distances and mean gradients for previous groundwater traces in and near the Cave Springs recharge area. Data from Aley (1978a and 1978b) and Aley and Moss (2001).

Trace Number	**Discharge Point**	**Straight Line Distance** (feet)	**Mean Gradient** (feet/1000 feet)
78-02	Cave Springs	13,500	7.9
78-04	Cave Springs	15,000	9.3
78-06	Mouth Puppy Creek	9,300	6.5
78-07	Puppy Cr. Springs	1,250	8.8
78-08	Cave Springs	19,200	4.7
78-08	South Spring	7,200	4.2
00-01	Mouth Puppy Creek	13,400	5.6
00-03	Cave Springs	12,300	5.7
00-03	Reed Spring	10,000	9.0
00-04	Cave Springs	12,100	7.9
00-04	Reed Spring	8,900	12.9
01-08	Mouth Puppy Creek	1,700	52.9

Williams (1991, page 30) showed groundwater gradients in the Cave Springs recharge area varying from a minimum of about 2.2 feet per 1,000 feet to a maximum of about 40 feet per 1,000 feet. Typical values were about 12 feet per 1,000 feet.

The groundwater gradient data from previous tracing will be augmented with data from traces conducted in conjunction with the present investigations. Existing results indicate that the general groundwater gradient along major karst groundwater flow paths in the area is very gentle and is routinely between 4.2 and 12.9 feet per 1,000 feet.

Geology Including Fracture Traces and Lineaments

The geologic mapping (Glick 1970 and 1972) of the study area shows that the entire recharge area for Cave Springs is underlain by the Boone Formation of Mississippian age. There are no faults or other structural features shown on the geologic maps. The Boone Formation consists primarily of limestone and chert with the chert content varying both vertically and laterally. The beds are all relatively flat-lying.

Lineaments and fracture traces in limestone terrains are interpreted as representing linear fractures or fracture systems along which there has been preferential solution of the bedrock. Fracture traces are expressed for lateral distances of less than one mile; lineaments are expressed for distances of one mile or more. Lineaments and fracture traces are identified from aerial photographs and are expressed by topographic features. In karst areas the linear features routinely include relatively straight valley alignments and lines of sinkholes.

In some areas of northwest Arkansas lineaments are oriented along faults such as the Bella Vista Fault. These faults can dramatically influence groundwater movement (Aley and

Aley 2014). However, faults are limited in northwest Arkansas and none are known to exist in the Cave Springs recharge area. Most lineaments and fracture traces in northwest Arkansas are associated with fracture zones along which there has been little or no detectable movement of one side relative to the other.

Hansen (1973) mapped lineaments in Benton and portions of Washington Counties, Arkansas. He also mapped the location of many of the springs in Benton County and showed that many of them were on or near mapped lineaments. The OUL views this as important evidence that lineaments are routinely associated with the rapid movement of groundwater to springs.

MacDonald et al. (1974) conducted pollution susceptibility mapping that included a series of maps for an area a short distance south of the Cave Springs recharge area. One of the maps showed both lineaments and fracture traces. In this area the authors recognized that both lineaments and fracture traces provided enhanced travel routes for groundwater contaminants moving into and through the karst aquifer. Most of the lineaments and fracture traces were associated with surface valleys, many of which are losing streams.

Ogden (1980) mapped lineaments in Benton County and compared their locations with the productivity of private water supply wells. Based upon a statistical analysis the author found no statistically significant increase in well productivity for wells within 250, 500, or 1,000 feet of a mapped lineament. However, given the density of fracture traces in the area as shown by MacDonald et al. (1974), many wells identified as being remote from lineaments may have been close to fracture traces, especially since fracture traces in the area are far more abundant than lineaments. If both fracture traces and lineaments tend to increase well productivity, then the failure of the Ogden study to find a positive correlation between lineaments and well yields probably resulted from the presence of fracture traces that were not considered in the study.

Aley and Thomson (1981) mapped fracture traces and lineaments in Greene County, Missouri as part of an investigation to characterize the vulnerability of lands in the county to groundwater contamination. As is the case with Benton County, much of Greene County, Missouri is underlain by geologic units equivalent to the Boone Formation. In the Greene County, Missouri study areas within 400 feet of mapped fracture traces and lineaments were ranked as having a greater potential for introducing contaminants into the groundwater system than was the case for adjacent lands.

Curtis (2000) developed a model intended to permit the rapid delineation of recharge areas in northwest Arkansas. The model placed substantial emphasis on lineaments and concluded that they provided the primary master flow routes for groundwater movement to springs. Curtis (2000) made no use of fracture traces in the modeling, and did not provide a rationale for not including fracture traces and some of the shorter lineaments in his model as important groundwater transport features. Curtis (2000) prepared a model for the Cave Springs recharge area and, based on the model, concluded that essentially all of the topographic basin for Blossom Way was within the Cave Springs recharge area.

It is the conclusion of the OUL that fracture traces and lineaments routinely provide preferential groundwater flow routes within the Cave Springs recharge area. This is supported by experience from other areas underlain by the Boone Formation and similar geologic units. This conclusion is also supported by the rapid groundwater travel rates demonstrated by dye traces and the very gentle mean groundwater gradients that have typified traces in the area. Rapid groundwater travel with gentle gradients requires well-integrated solutionally enlarged conduits. Such conduits in the Ozarks are routinely associated with both fracture traces and lineaments.

Most of the recharge area for Cave Springs is an upland area where topographic features are subdued and, as a result, identification of fracture traces and lineaments from aerial photographs is difficult. This difficulty is enhanced by past land uses that have obscured many topographic features and created new linear features (such as fence lines and drainage ditches) which can sometimes be incorrectly interpreted. The net result is that an accurate and intensive mapping of fracture traces and lineaments as part of groundwater vulnerability mapping, such as conducted by Aley and Thomson (1981) for Greene County, Missouri, is not feasible in the Cave Springs recharge area.

Recharge Area Estimates and Delineations for Cave Springs

Aley (1978a) estimated the size of the recharge area for Cave Springs as part of a study for the Arkansas Highway and Transportation Department (AHTD). This was based upon an estimated mean annual flow rate of the spring of 4.5 cfs and an assumption that about 2.3 square miles of recharge area was needed for each 1 cfs of mean annual flow. Based upon these values, the estimated size of the Cave Springs recharge area was 10.35 square miles (Aley 1978a). This presumed that none of the recharge area was shared with other springs. We now know that this assumption was incorrect because some of the recharge area is shared with South, Reed, Shores, and Wallis Springs.

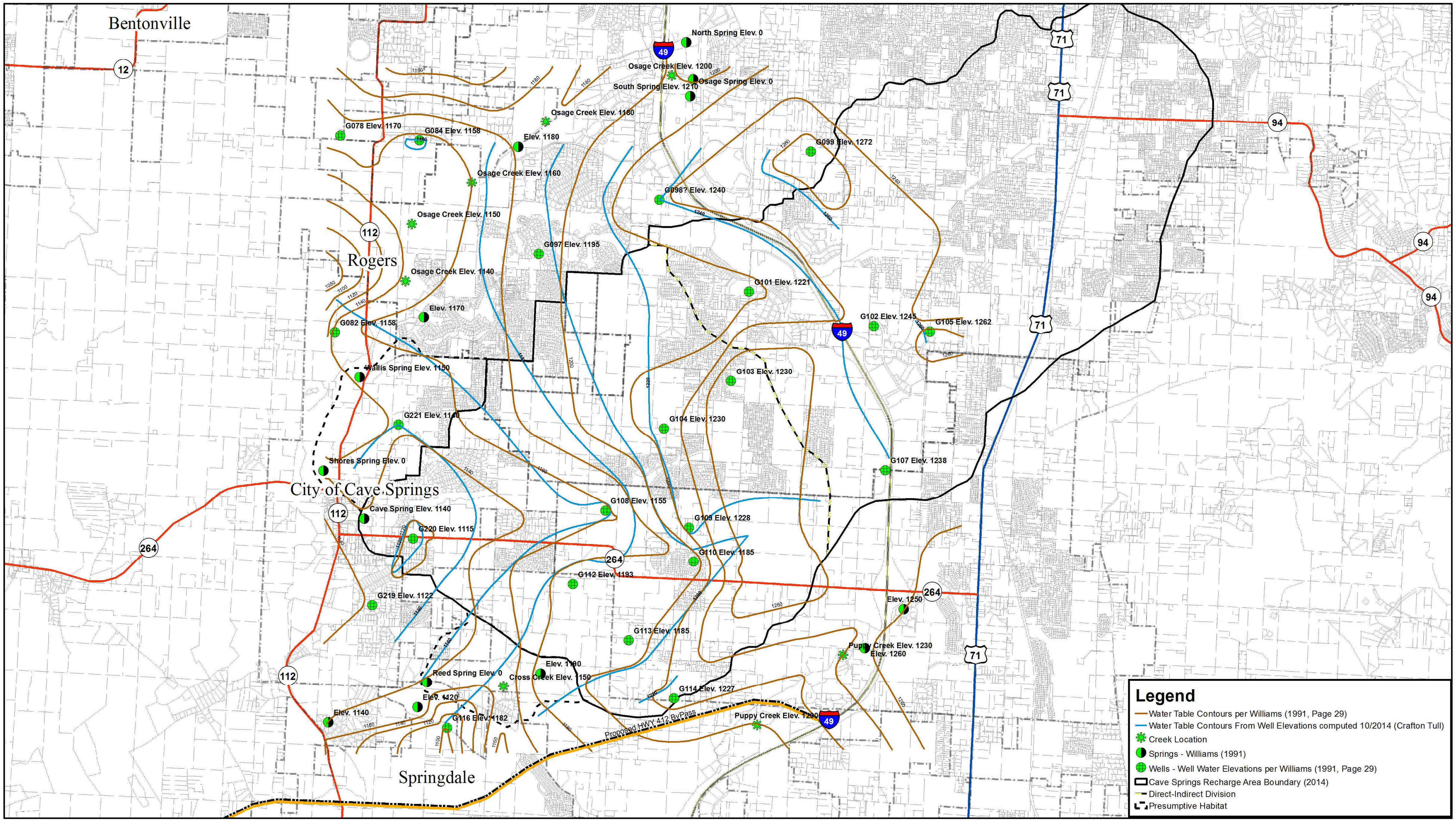
Aley (1978b) did a groundwater trace from the channel of Blossom Way Creek (Trace 78-08) that yielded dye to South Spring and a small amount to Cave Springs. This tracing was part of expanded work for the AHTD. Based upon this trace, much of the topographic basin for Blossom Way Creek was identified as an "Indirect Recharge Area" for Cave Springs. The "Direct Recharge Area" is that area where, when water enters the groundwater system, most or all of it discharges from Cave Springs. The Indirect Recharge Area is that area where little of the water that enters the groundwater system discharges from Cave Springs. The "Direct Recharge Area" for Cave Springs as delineated by Aley (1978b) lies a short distance west of the present location for Interstate 49 (formerly Interstate 540 and before that U.S. Highway 71). This highway location was chosen based in substantial part on the tracing work by Aley (1978a and 1978b). That highway corridor was chosen to minimize highway impacts on Cave Springs.

Ogden (1980) prepared a groundwater contour map (technically a potentiometric map) for Benton County with contour intervals of 50 feet. That map indicated that Cave Springs had little if any apparent influence on the location of the groundwater contours. Flow is routinely presumed to be at a right angle to potentiometric contour lines. However, this premise is often not valid in karst aquifers. If one uses the potentiometric map of Ogden (1980) and draws flow lines that are at a right angle to the contour lines then the inferred recharge area for Cave Springs would be a narrow band about 0.25 mile wide and about 7.5 miles long. This is an illogical recharge area, however it is the recharge area that one would draw if it were based on an accurate interpretation from Ogden's potentiometric map. It is the conclusion of the OUL that the Ogden (1980) map is not useful in identifying the recharge area for Cave Springs. This is probably because of the large contour interval (50 feet) used on the map.

Williams (1991), in a master's thesis at the University of Arkansas, developed estimates for the size and location of the Cave Springs recharge area by developing a series of potentiometric maps based primarily on measured water table elevations in private wells. Much of the information was from Ogden (1980). One major difference between the potentiometric maps of Ogden (1980) and Williams (1991) was that Williams' work was focused in Cave Springs while the work by Ogden (1980) was for all of Benton County. A second major difference was that Williams (1991) used a contouring program and prepared maps with a 20-foot contour interval. It is unclear how Ogden (1980) interpolated elevation data. There are dramatic differences between the Ogden (1980) and Williams (1991) maps.

Figure 1 shows two sets of computer-generated potentiometric contour lines for the Cave Springs recharge area. Both programs used the same set of data from measured water levels in wells, elevations of perennial springs, and elevations of perennial flow in surface streams. OUL concludes that this is the best available potentiometric map depicting a time when there were still a number of private wells where water elevations could be measured. The orange contour lines are from Williams (1991, Figure 8). The blue contour lines were produced by Crafton Tull in October 2014.

While there are obvious differences between the two plots shown in Figure 1, there are two important features shown on both of the plots. First, both show groundwater from portions of the Indirect Recharge Area into the Direct Recharge Area. Second, both show a trough in the potentiometric surface of the water table that runs from Cave Springs eastward for about 3.25 miles. The axis of this trough roughly parallels Arkansas Highway 264 and is located 1,000 to 2,500 feet north of this highway.



Crafton Tull

WWE WRIGHT WATER ENGINEERS, INC.

Ozark Underground Laboratory

Cave Springs Area Potentiometric Contour Map
Figure 10

N

0 1,600 3,200 4,800
Feet

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Document Path: G:\14103100_CaveRechrg\CIV\Dwg\Ozark Underground Labs Maps\Figure 10 Cave Springs Area Potentiometric contour map.mxd

The Williams (1991) potentiometric map shows a second trough that extends for about 10,300 feet. Its axis passes about 500 feet south of the confluence of the South and East Forks of Blossom Creek and extends south-southeastward from this point for about 5,000 feet and westward from this confluence for about 6,200 feet. This trough is not shown on the Crafton Tull plot (see Figure 1), and in the opinion of the OUL either does not exist or else is not significant.

The present location of I-49 and the boundary derived in the current study between the Direct Recharge Area and the Indirect Recharge Area are shown on Figure 1. Portions of the highway are within the Cave Springs recharge area as determined by Williams (1991). In addition, the South Fork of Blossom Way Creek, portions of the East Fork of Blossom Way Creek, and about 4,100 feet of Blossom Way Creek downstream of the confluence of the South and East Forks lie within the Cave Springs recharge area as shown by Williams (1991). Williams does not include areas topographically tributary to points within his delineated recharge area; this includes much of the area drained by the East Fork of Blossom Way Creek. These areas are equivalent to the “Indirect Recharge Area” as described by Aley (1978b).

Based on Williams (1991, Figure 8), the size of the Cave Springs recharge area comprises 11.8 square miles. Later in his thesis he adds some buffer areas and derives a more oval shaped recharge area that includes 14.0 square miles.

It is reasonable to expect that recharge area delineations based on potentiometric mapping and others based on dye tracing may differ somewhat. This is because:

- Dye tracing data points are usually more spatially separated than are data points associated with wells.
- Dye may not all enter the subsurface at a single point.
- Troughs in the water table surface are more readily identified from potentiometric mapping than from dye tracing.

A few of the lineaments and fracture traces have been mapped in and around the Cave Springs recharge area; those included in Ogden (1980) are typical of the mappings. Curtis (2000) placed major emphasis on lineaments in his modeling approach designed to delineate areas affected by advective groundwater transport of contaminants. With the exception of a short portion of a lineament extending eastward from near Cave Springs, the trough in the potentiometric surface north of Highway 264 is not aligned along a mapped lineament.

Brahana (1997) in a symposium paper outlined 13 types of data useful in approximating recharge areas for springs in the mantled karst terrane of the Springfield Plateau. One of the important factors was the base flow rate of the spring. In Northwest Arkansas Brahana (1997) reports that the base flow of spring basins ranges from 1.5 to 3.2 L/sec/square kilometer [0.138 to 0.294 cfs per square mile]. From a hydrological perspective, the base flow rate of a spring should be the flow rate that typically occurs during late August or September when there have been no recent appreciable flow rate increases due to precipitation events.

Brown et al. (1998) provide a table of water quality results from Cave Springs taken under what they identified as base flow conditions. The reported base flow rates at Cave Springs ranged from 1 to 11 cubic meters per minute [0.67 to 7.37 cfs] with a mean of 5.4 cubic meters per minute [3.62 cfs] for the 8 values reported. Clearly these values range too widely to all be considered as base flow conditions. However, if one uses the mean value as an approximation of base flow, and uses the Brahana's (1997) values, the recharge area for Cave Springs should be on the order of 12 to 26 square miles. Alternately, if one uses the two smallest flow rate values (0.67 cfs) from Brown et al. (1998) as a better estimate of base flow, then using Brahana's (1997) values the recharge area for Cave Springs should be between 2.3 and 4.9 square miles. Based on groundwater tracing results this value is clearly too small. Estimating the size of recharge areas based upon base flow rates can be substantially in error.

Paylor and Currens (2001) found that base flow of springs in karst landscapes of Kentucky increases dramatically with increases in the amount of urbanization. If a similar relationship exists in the study area then this is another reason that base flow rates of springs are not a good indicator of the size of the associated recharge area.

Aley and Moss (2001) conducted a series of groundwater traces along and near the southern margin of the Cave Springs recharge area in conjunction with six potential corridors for an airport connector highway that would extend from what is now Interstate 49 to the Northwest Arkansas Regional Airport. This study demonstrated that some areas contribute water to both Cave Spring and Reed Spring, and that the combined recharge area for the two springs was 19.10 square miles. This included an Indirect Recharge Area for Cave Springs. The study also showed that the two more-northern corridors for the airport connector highway have the potential to adversely impact Cave Springs/Reed Spring, but that the three more-southern corridors are outside of the recharge area for Cave Springs and Reed Spring.

Curtis (2000) used a modeling approach to estimate the location and size of the recharge area for Cave Springs. The delineated area was similar to that developed by Aley and Moss (2001) and included essentially all of the Blossom Way drainage basin. The model placed heavy reliance on the location of major lineaments. The model did not recognize that some of the recharge area for Cave Springs is shared with other springs. The model also did not recognize that the troughs in the potentiometric surface as mapped by Williams (1991) did not correspond with the lineaments that he inferred were the dominant flow routes. This is unfortunate since troughs in the potentiometric surface are clearly zones of preferential groundwater flow.

One purpose of the current study was to refine the recharge area for Cave Springs. A number of additional dye traces were conducted to accomplish this objective. Delineation of the recharge area for Cave Springs Cave has utilized a combination of data from groundwater tracing investigations and from the potentiometric mapping of Williams (1991). Important limitations to the existing potentiometric data include the following:

- The implicit assumption that the aquifer is homogeneous and isotropic when neither of these assumptions is correct.

- Not all wells are necessarily representative points.
- Potentiometric mapping does not recognize that some areas contribute water to multiple springs.
- There can be appreciable lateral movement of water from the surface to the water table, and that the direction of this flow in the vadose zone is commonly independent of groundwater gradients. Aley and Kirkland (2012) showed that lateral transport in the unsaturated zone in the Ozarks can be in excess of 750 feet and perhaps more.
- Flow routes can change as a function of the amount of water in the groundwater system and the possibility of heavy pumping at some wells.

Results from the current Cave Springs Karst Resources Conservation Study are discussed in the next report in this series which is entitled "Groundwater Tracing and Recharge Area Delineation Summary Report, Cave Springs Cave, Cave Springs, Arkansas". That report concludes that the size of the Direct Recharge area for Cave Springs encompasses 8.9 square miles and that the Indirect Recharge area includes an additional 10.6 square miles for a total recharge area of 19.5 miles.

Possibility that Cave Springs Receives Water from Osage Creek

Aley et al. (2008) summarized hydrogeologic conditions associated with the delineation of 40 biologically significant caves. Many of these caves receive some of their recharge waters from nearby surface streams, some of which have perennial flow. Osage Creek is located near the northern margin of the recharge area as delineated by Aley and Moss (2001), and this stream channel of Osage Creek upstream of Arkansas Highway 112 is higher in elevation than Cave Springs.

Moix et al. (2003) measured stream flow gains and losses along Osage Creek in portions of the area that could conceivably contribute water to Cave Springs. They identified four stream segments where flow rate decreases were noted and where elevations were greater than Cave Springs. At the time of the flow rate measurements these losses totaled almost 5 cfs. While some stream reaches showed increases in flow, their magnitude did not closely reflect a return of the "lost" water to the stream channel.

The possibility that portions of Osage Creek contribute water to Cave Springs was clearly a data gap that needed to be addressed. Three traces conducted during the current project (Traces 14-01, 14-02, and 14-03) were specifically designed to assess this possibility. No hydrologic connections were found between Osage Creek and Cave Springs.

Spring Creek is a major drainage on the south side of the Cave Springs recharge area. The elevation of Cave Springs is about 1,150 feet. All of Spring Creek downstream of the mouth of Puppy Creek is lower in elevation than Cave Springs and thus could not contribute water to the spring. Traces 78-06, 00-01, and 00-08 have all yielded water to the mouth of Puppy Creek.

Given these traces, it is the opinion of the OUL that no portions of Spring Creek upstream of the mouth of Puppy Creek could contribute water to Cave Springs.

Hydrologic Interactions between Cave Springs and Other Springs.

It is common for springs in the Ozarks to share recharge areas with other springs. This may be especially true in the case of springs that provide habitat for Ozark cavefish, and may help explain how cavefish became distributed in multiple caves and springs. Previous tracing studies in the area showed that Cave Springs shares parts of its recharge area with South Spring (Aley 1978b) and with Reed Spring (Aley and Moss 2001).

There are four springs shown on the Bentonville South 7.5 minute topographic map on the east side of the Osage Creek valley. These springs are typically located near the mouth of small tributary valleys and it is likely that these springs share some recharge areas with Cave Springs. Several of the current groundwater traces were designed to assess such shared recharge areas. In addition, we sampled some springs in the Spring Creek and Puppy Creek Valleys to determine if they possibly share recharge areas with Cave Springs.

Soils and Their Relative Abilities to Protect Groundwater Quality

Based upon work by Phillips and Harper (1977) there are three major soil associations within the recharge area for Cave Springs, as summarized below:

- **Clarksville-Nixa-Noark Association**. 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.
- **Tonti-Nixa-Captina.** 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.
- **Captina-Peridge Association**. It is described as: “Moderately well drained and well drained, nearly level to gently sloping deep loams 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.

Soil series within these soil associations have distinctly different properties related to their ability to remove contaminants and protect underlying karst groundwater systems. Data on some important hydrogeological characteristics of the major soil series found in the Cave Springs recharge area are summarized in Table 15. The data are from Table 9 in Phillips and Harper (1977).

Table 15. Hydrogeologically important characteristics of major soil series in the Cave Springs recharge area. Data from 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

The OUL has divided soils in the recharge area into three groundwater vulnerability classes as described below.

- **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.
- **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.

- **Poor Natural Soil Treatment Capability Soils.** The major soil series in this group is the Noark soil series. These soils are in this high risk group because they have 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.

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 the OUL has ranked all of the soil series found in the Direct Recharge Area for Cave Springs into three qualitative groundwater vulnerability classes. The listed soils (shown in Table 16) are arranged in order from those most likely to produce the lowest risk to groundwater quality to those most likely to produce the greatest risk.

Ransom et al. (1975) conducted studies on water flow through Peridge, Nixa, and Clarksville soils in northwest Arkansas. Pea Ridge and Nixa soils are common in the Cave Springs recharge area. Clarksville soils are absent from the Cave Springs recharge area, but in many hydrologically important respects are similar to Noark soils that are present. The testing used rhodamine B dye that sorbs onto soil surfaces through which water passes. 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. Figure 2 is a copy of one of the dye traces conducted by Ransom et al. (1975) through a Peridge soil; Figure 3 is from a Nixa soil; and Figure 4 is from a Clarksville soil.

As a part of this project Exhibit E was developed for the Cave Springs recharge area showing the three natural soil treatment capability classes. The mapping by Phillips and Harper (1977) did not separate out soil units that covered less than 5 acres. The soil series present at sites planned for stormwater detention basins should be field checked for accuracy.

Table 16. Groundwater vulnerability rankings for soils in the Direct Recharge Area. The percent of each soil series in the Cave Springs Direct Recharge Area is indicated.

GOOD NATURAL SOIL TREATMENT CAPABILITY SOILS

NeB. Newtonia Silt Loam, 1 to 3% Slopes

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-17	100	0.6-2.0	
17-61	95-100	0.6-2.0	
61-72	90-100	0.6-2.0	

Notes:

- This soil series represents 0.8% of the soils in the recharge area.
- The high percentage of materials passing the Number 4 sieve, combined with the slow to moderate infiltration rate, provides good natural treatment for runoff waters encountering this soil type.

PeB and PeC. Peridge Silt Loam, 1 to 3% Slopes and 3 to 8% Slopes

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
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	

Notes:

- This soil series represents 11.7% of the soils in the recharge area.
- Both of the slope classes are found on stream terraces.
- The high percentage of material passing the Number 4 sieve at depths up to about 3.5 feet provides good natural cleansing for runoff waters that enter the underlying groundwater system.
- Permeability rates range from moderately slow to moderate.

CnB. Captina Silt Loam 1 to 3% Slopes

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
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	
48-58	50-90	Chert fractures	Fractures filled with silty clay loam.

Notes:

- This soil series represents 24.7% of the soils in the recharge area.
- This soil series is typically found on upland areas. The high percentage of material passing the Number 4 sieve at depths up to about 21 inches provides good natural cleansing for runoff waters that enter the underlying groundwater system.
- A fragipan exists from about 21 to 48 inches below ground surface and this results in slow permeability rates through this horizon.
- Water reaching the underlying chert fractures can follow preferential flow routes into the karst groundwater system.

Table 16 (continued)

Cs. Cherokee Silt Loam

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-14	95-100	0.2-2.0	Greater than 72 inches to bedrock.
14-84	95-100	<0.06	

Notes:
- This soil series represents 1.4% of the soils in the recharge area.
- The high percentage of material passing the Number 4 sieve provides good natural cleansing for runoff waters. Beneath this horizon the permeability rate is very slow so there is appreciable surface runoff.

Jo. Johnsburg Silt Loam

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-8	95-100	0.6-2.0	
8-22	95-100	0.06-0.2	
22-56	90-100	<0.06	
56-72	45-80	0.06-2.0	

Notes:
- This soil series represents 0.5% of the soils in the recharge area.
- The high percentage of material passing the Number 4 sieve in the upper 8 inches provides good natural cleansing for runoff waters. The permeability rate from 8 to 22 inches is slow, and beneath this depth is very low. The result is that there is appreciable surface runoff from this soil series.

Good Natural Soil Treatment Capability Soils occur in 39% of the Direct Recharge Area.

FAIR NATURAL SOIL TREATMENT CAPABILITY SOILS

Se. Secesh Gravelly Silt Loam, Occasionally Flooded

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-24	60-85	0.6 to 2.0	
24-72	20-70	0.6 to 2.0	

Notes:
- This soil series represents 4.5% of the soils in the recharge area.
- Localized to highly localized areas with less material passing the Number 4 sieve and with higher permeability are common and serve to introduce appreciable amounts of recharge water into the karst aquifer. These areas provide less than desirable natural cleansing for passing waters.

BtC and BtD. Britwater Gravelly Silt Loam 3 to 8% Slopes and 8 to 12% Slopes

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-6	75-90	0.6-2.0	
6-22	60-80	0.6-2.0	
22-74	35-60	0.6-2.0	

Notes:
- This soil series represents 0.7% of the soils in the recharge area.
- The soils are moderately permeable throughout the soil horizon. The percent of material passing the Number 4 sieve above a depth of about 22 inches is less than desirable for effective natural cleansing of passing waters. Soil depths below ~22 inches routinely provide less effective natural cleansing than the more shallow soils.

Table 16 (continued)

TsC. Tonti Gravelly Silt Loam, 3 to 8% Slopes

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-6	70-80	0.6-2.0	Bedrock at 40 to 60 inches.
6-19	60-85	0.6-2.0	
19-29	50-70	0.06-0.2	
29-42	35-55	0.06-0.2	

Notes:

- This soil series represents 31.9% of the soils in the recharge area.
- This soil series is most commonly found on upper hillslopes.
- The soils are moderately permeable to a depth of about 19 inches.
- Fragipan below depth of about 19 inches that extends to about the bedrock and provides only slow permeability.
- The percent of material passing the Number 4 sieve above the fragipan is less than desirable for effective natural cleansing of passing waters.
- On steeper slopes stormwater is often diverted laterally along the top of the fragipan until it discharges to the surface or passes into underlying bedrock openings along preferential flow routes.

NfC and NfD. Nixa Very Gravelly Silt Loam 3 to 8% Slopes and 8 to 12% Slopes.

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0-17	40-70	0.6-2.0	Bedrock at 40 to 60 inches.
17-30	40-70	<0.06	Fragipan with preferential flow.
30-50	15-45	0.06-0.2	Weathered chert beds with clay in crevices.

Notes:

- This soil series represents 14.9% of the soils in the recharge area.
- The top of the fragipan is at a depth of about 17 inches, and water movement through the fragipan is routinely very slow except for flow along preferential flow routes that often include root channels.
- Ransom et al. (1975) conducted dye tracing studies of Nixa series soils in northwest Arkansas and showed the routine presence of lateral preferential flow routes through the soil with these flow routes predominating along the top of the fragipan.
- The percent of soil passing the Number 4 sieve is often inadequate to provide effective natural cleansing for the passing water.
- Especially on steeper slopes this soil series sometimes presents Poor Natural Soil Treatment Capability conditions.

Fair Natural Soil Treatment Capability Soils occur in 52% of the Direct Recharge Area.

POOR NATURAL SOIL TREATMENT CAPABILITY SOILS

Eg. Elsah Soils, Occasionally and Frequently Flooded

Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0 to >60	25-60	2.0-6.0	

Notes:

- This soil series represents 0.7% of the soils in the recharge area.
- It is restricted to floodplains where it is routinely moderately to rapidly drained.
- The amount of soil passing the Number 4 sieve is routinely inadequate to provide effective natural cleansing.

Table 16 (continued)

WeC and WeD. Waben Very Gravelly Silt Loam, 3 to 8% Slopes and 8 to 12% Slopes			
Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
0 to >60	30-60	2.0-6.0	Depth to bedrock greater than 80 inches.

Notes:
- This soil series represents 0.2% of the soils in the recharge area.
- It is a hillslope soil that is routinely moderately to rapidly drained.
- The amount of soil passing the Number 4 sieve is inadequate to provide effective natural cleansing for passing water.

NoD, NoE, NoF. Noark Very Gravelly Silt Loam, 8-12% Slopes, 12-20% Slopes, and 20–45% Slopes			
Depth (inches)	**Percent Passing No. 4 Sieve**	**Permeability** (in/hr)	**Comments**
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	

Notes:
- This soil series represents 8.1% of the soils in the recharge area.
- It is a hillslope soil that is routinely moderately drained.
- The amount of soil passing the Number 4 sieve is inadequate to provide effective natural cleansing for passing water.

Soils in the Poor Natural Soil Treatment Capability class occur in 9% of the Direct Recharge Area.

Figure 2. Dye trace through Peridge silt loam (Ransom et al. (1975, p. 50))

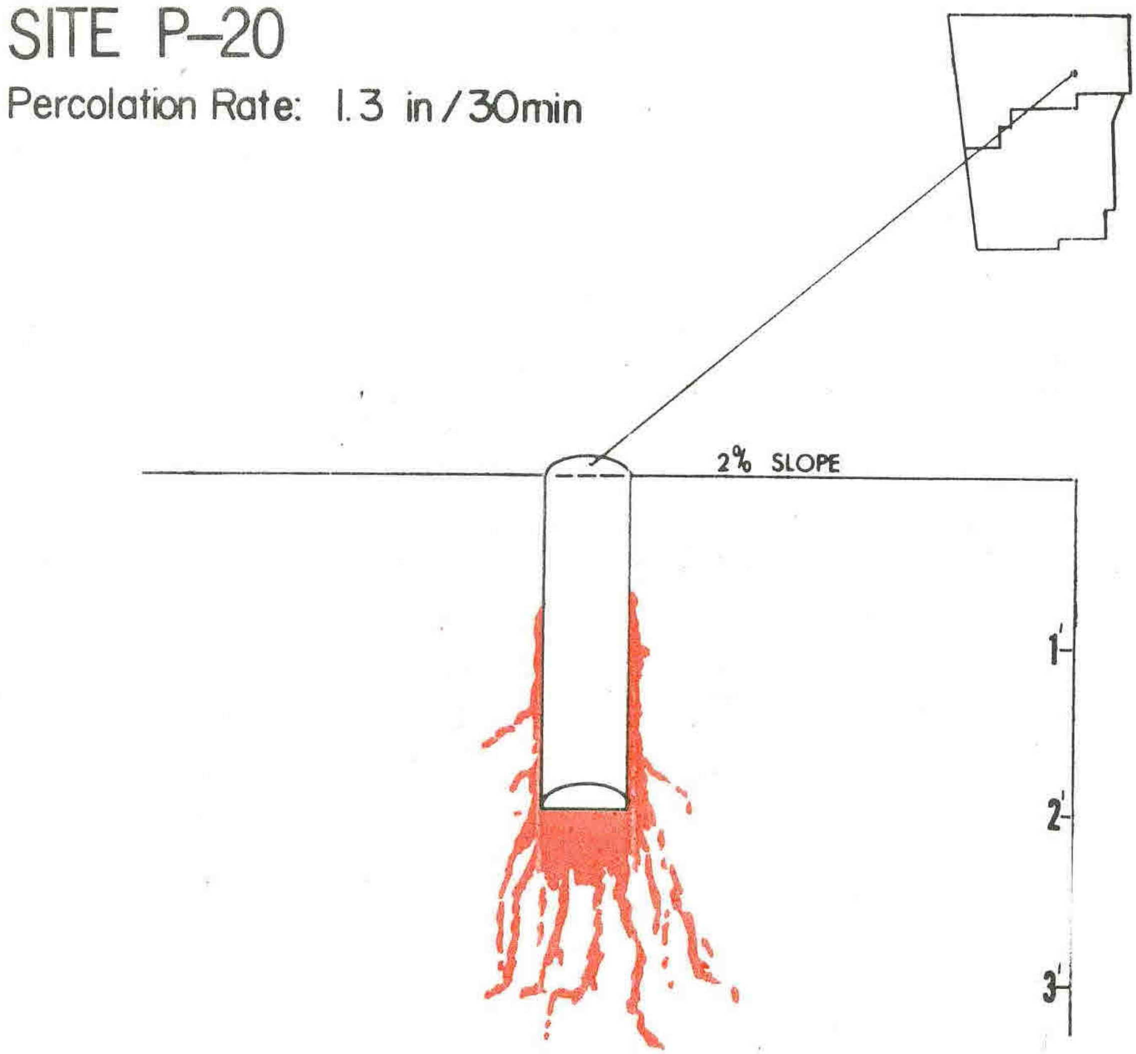


Figure 3. Dye trace through Nixa cherty silt loam (Ransom et al. (1975, p. 18)).

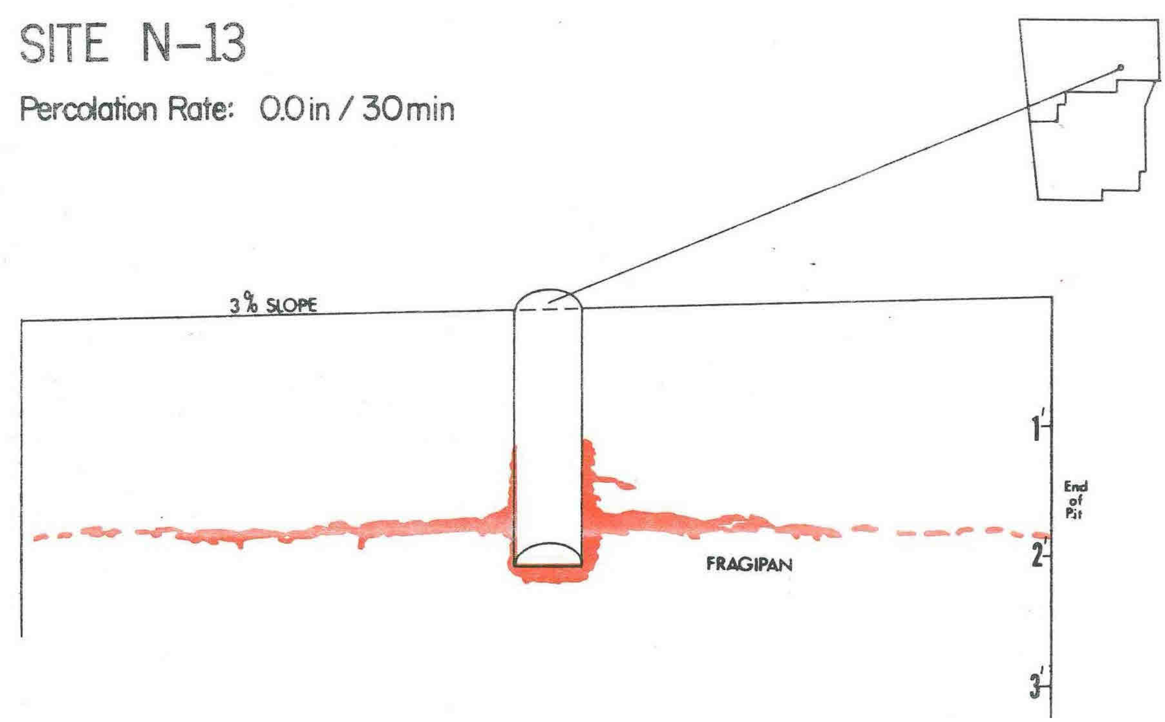
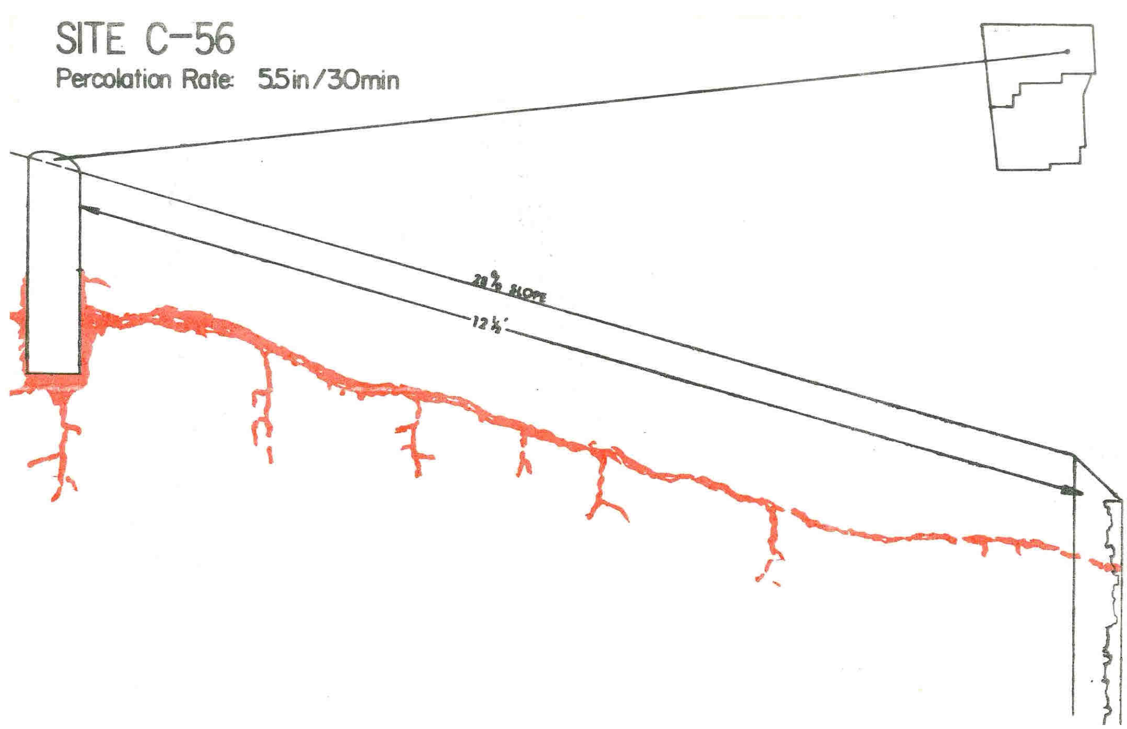


Figure 4. Dye trace through Clarksville cherty silt loam (Ransom et al. (1975, p. 40))



Impacts of Urbanization on Base Flow Rates of Springs

Paylor and Currens (2001) found a strong linear correlation between the extent of urbanization and increases in base flow rates of karst springs. They suggested that leakage from wastewater and water-supply systems was a likely explanation for this observation. In the opinion of the OUL leakage from unlined stormwater basins is a more likely explanation, and is likely to be important in the Cave Springs recharge area.

A figure from Paylor and Currens (2001) is shown below (Figure 5). Table 17 converts the metric units to common English units and shows approximate values from the graph at various intensities of urbanization. The final column in Table 17 represents the percent of total base flow that is probably attributable to anthropogenic activities as compared with areas that are only 10% urbanized.

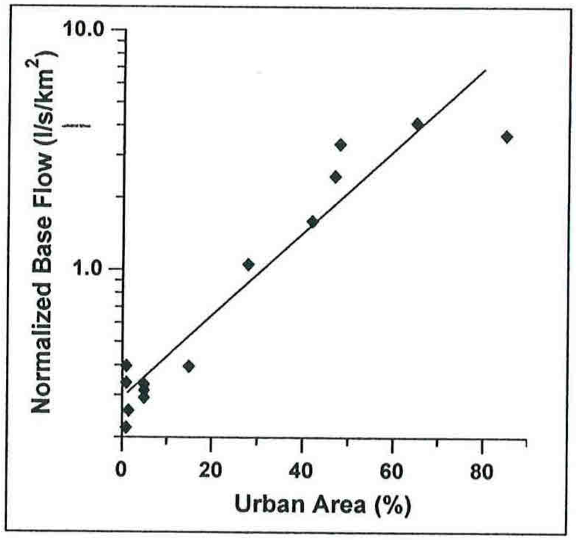


Figure 5 Inner blue grass normalized spring base flows as a function of urbanized area, showing a strong positive correlation (r^2 = 0.91). From Paylor and Currens (2001).

Table 17. Base flow rates of springs in the Blue Grass Region of Kentucky as a 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

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 human sewage or sewage effluents then these may pose a significant acute toxicity risk for the cave fauna including the Ozark Cavefish. If groundwater recharge from stormwater detention basins is a major cause of increases in base flow then major attention must be focused on contaminant trapping and/or removal within stormwater basins.

Hydrologic and Water Quality Data Gaps

Data Gap 1. One of the recognized data gaps was the possibility that some of the flow of Cave Springs was derived from water that entered the groundwater system from the channel of Osage Creek.

This data gap was addressed during the dye tracing studies performed as part of Cave Springs Area Karst Conservation Study. Three dye introductions showed that there was no detectable contribution of water to Cave Springs from Osage Creek.

Data Gap 2. Aley (1978b) divided the recharge area for Cave Springs into Direct and Indirect Recharge Areas. Refining this division and verifying that it was a credible approach was a recognized data gap.

The potentiometric contour maps (Figure 1) provided confirmation that some groundwater flow from the Indirect Recharge Area contributes water to Cave Springs. During the current tracing study several traces were initiated to focus on the divide between the Direct and Indirect Recharge Areas. This data gap has been adequately filled.

Data Gap 3. Additional data were needed to better assess the hydrologic interactions between Cave Springs and other area springs.

Several springs are located on the east side of the Osage Creek Valley and upstream of Cave Springs. Two of these (Wallis and Shores Springs) share recharge areas with Cave Springs. In addition, Cave Springs is known to share part of its recharge area with Reed Spring. Additional data were needed to better assess hydrologic interactions and recharge areas between these springs and Cave Springs.

The needed data were obtained during the groundwater tracing study.

Data Gap 4. More accurate flow rate information for Cave Springs would benefit future management of the spring and interpretive programs.

Leakage from the existing dam at the mouth of the spring and in downstream flumes and channels make the installation of a good monitoring station difficult to install without reconstructing those features.

On October 20, 2014 the flow of Cave Springs (based on the rating table for the staff gage) was 4.28 cfs. A measurement made on the same day by the OUL of discharge from Lake Keith was 5.28 cfs. The difference of 1.00 cfs suggests that some flow from Cave Springs bypasses the staff gage, discharges from springs inundated by Lake Keith, or a combination of the two.

Data Gap 5. Conflicting historical data exist regarding metals concentrations in water samples collected from Cave Springs. Additional water quality sampling is recommended to determine if Cave Springs is impacted by dissolved metals.

Graening (2002) reported that during the period 1997 to 2001 the mean concentrations of copper, lead, selenium, and zinc in water samples from Cave Springs Cave were 100 to 1,000 times greater than concentrations at four other cave streams. These findings were not supported by findings from Slay and Snell (2005). Additional water quality sampling is recommended to determine if this relationship still exists or if the water quality conditions have changed.

Data from limited OUL sampling in 2014 of Cave Springs, Reed Spring, Wallis Spring, and Shores Spring are presented in a separate data report (Beeman and Aley 2015).

PART 2 BIOLOGICAL ISSUES

General Biodiversity

Forty seven taxa have been documented from Cave Springs Cave (Graening et al. 2012). Much of this fauna is typical of species found in northwest Arkansas caves. Common to the entrance and twilight areas of the cave, species such as the cave salamander (*Eurycea lucifuga*) and dark-sided salamander (*E. longicauda melanoplura*) are observed. Adults of these species are terrestrial and occur on the walls and floors of the cave passages while the juveniles are aquatic and can be found in the cave stream near the entrance or in the spring run on the surface. In the summer, an Eastern Phoebe will often be found nesting under the drip line, and water striders (*Gerris remigis*) can be observed skating along the surface of the entrance pool. Although not often observed, the scats of Virginia Opossum (*Didelphis virginiana*) and Northern Raccoon (*Procyon lotor*) reveal that these species are consistent visitors to the cave. In the dark zone, bat guano and organics found on ledges and passages that remain above the flood line for the cave stream provide food and habitat for species such as dark-winged fungus gnats (*Corynoptera* sp.), beetles (*Ptomaphagus cavernicola*, *Platynus tenuicollis*), and springtails (Coleoptera). In addition to populations of Ozark Cavefish (*Amblyopsis rosae*) and Gray Bats (*Myotis griscesens*), the cave provides habitat for other rare species.

Stygobromus onondagaensis is a groundwater-adapted amphipod crustacean that is known from Cave Springs Cave, two additional caves, and one spring in Arkansas (Graening et al. 2005). Across the Ozarks, it is known from 21 sites in 13 Missouri counties, a spring in Butler County, Kansas, and 8 sites in 6 counties of Oklahoma (Hubricht and Mackin 1940, Hubricht 1943, Graening et al. 2006). Many of the Missouri collections were taken from drip pools in caves (Holsinger 1972) which suggests the typical habitat for this species may be the epikarst rather than cave streams. Many species of *Stygobromus* appear to predominantly inhabit the epikarst (Culver et al. 2010), so the occupation of this subterranean niche by *S. onondagaensis* is not unexpected. A few observations have been made on the life history and ecology of *S. onondagaensis*. Overigerous females were collected during summer and fall months (Holsinger 1972), and individuals in a Missouri cave were observed feeding on bat guano in drip pools (Gardner 1986). The species has been observed once in Cave Springs Cave on 30 November 2000. Because survey trips into Cave Springs Cave mainly focus on Ozark Cavefish, drip pool habitats are not routinely inspected. Therefore, the rarity of this species in the cave is unknown.

Stygobromus ozarkensis is a groundwater-adapted amphipod crustacean that is fairly widespread across Arkansas, and it has been found in 27 sites in 8 counties (Graening et al. 2005). In addition to Arkansas, it occurs at 12 sites in 4 Oklahoma counties (Graening et al. 2006) and 8 sites in 6 Missouri counties (Holsinger 1967, Holsinger 1972, Gardner 1986). The species appears limited in distribution to the cavernous limestones and dolostones of the Ozarks. With the exception of several seeps in Oklahoma, the species is recorded primarily from caves.

In Cave Springs Cave, the species was collected initially on 30 October 1972. On many of the subsequent surveys by Art Brown and G.O. Graening, this species was not observed in the cave and led them to conclude the species might be extirpated from the system (Graening and Brown 1999, 2000a, 2000b). However, the species was observed in the cave stream during subsequent survey trips (Slay and Graening, pers. obs.).

Caecidotea stiladactyla is a groundwater-adapted isopod crustacean that is fairly widespread in the western half of northern Arkansas, and it is known from 35 sites in 8 counties. In Missouri, it occurs in a cave in Crawford County (Fleming 1972) and a cave in McDonald County (Slay et al. 2006). Elliott (2007) reports *C. stiladactyla* from several additional sites in Missouri, but does not report location specifics. In Oklahoma, it is known from 10 sites in 2 counties (Fleming 1972, Lewis et al. 2006). The species has been collected mostly from caves, but it has also been collected from a few springs and seeps. The species was first reported in Cave Springs Cave in 1968 (Fleming 1972). Graening and Brown (2000) report *C. stiladactyla* to be abundant in the cave stream riffles with an estimated density of 5 individuals per square meter.

Originally described as *Pseudozaona occidentalis* by Hoff and Bolsteri (1956), the pseudoscorpion *Hersperochernes occidentalis* was subsequently transferred to the genus *Hesperochernes* by Muchmore (1974). Pseudoscorpions are small arachnids (less than 0.5 inches in length; most less than 0.2 inches in length) that look superficially like scorpions but lack a stinging tail. Under the original name, it was reported from just 2 sites in Washington County (Hoff and Bolsterli 1956). However, the species, as *H. occidentalis*, is more common and has been reported from over 20 caves in Arkansas (Graening et al. 2012). In Missouri, individuals were most often associated with bat guano or other animal feces, but specimens were also collected from organic debris and soil (Gardner 1986). In Cave Springs Cave, the species was associated with Gray Bat guano deposits.

The Grotto Salamander, *Eurycea spelaea* (as *Typhlotriton speleaus*), was described from specimens collected from Rock House Cave, Barry County, Missouri (Stejneger 1892). Some of the first records in Arkansas were specimens collected by Bishop (1944). Although described as a new species (*Typhlotriton nereus*), these specimens were ultimately referred to *E. spelaea* (Bishop 1944, Brandon 1966). Similarly, specimens identified as *Typhlotriton braggi* were also synonymized with *E. spelaea* (Smith 1968, Brandon and Black 1970). Based on molecular analysis, Bonett and Chippendale (2004) placed the Grotto Salamander within the plethodontid genus *Eurycea* and identified the Oklahoma Salamander (*E. tynerensis*) as the closest sister species. In addition, they suggested, based on mitochondrial sequence divergence, that *E. spelaea* may be a complex of species. However, additional molecular analysis is needed to delineate these lineages (Bonett per. comm.). In Arkansas, *Eurycea spelaea* is known from scattered locations across northern part of the state in the Springfield and Salem plateaus of the Ozarks Ecoregion (Trauth et al. 2004, Fenolio and Trauth 2005). The Grotto Salamander has a somewhat unusual life history. As larvae, individuals occur outside caves in spring runs and possess pigment and functional eyes. Upon metamorphosis, Grotto Salamanders lose pigment and eye functionality, and they spend the remainder of their lives deep within caves (Trauth et al.

2004, Fenolio and Trauth 2005). Breeding is thought to occur from spring to early summer corresponding with an increase in food supply (Trauth et al. 2004). Adults are known to prey on diptera, beetles, and isopods, while larvae are known to prey on isopods (Smith 1968, Brandon 1971, Fenolio and Graening 2009). There is also evidence that suggests larval salamanders will consume bat guano for sustenance (Fenolio et al. 2006). Juvenile Grotto Salamanders are more commonly observed in Cave Springs Cave than are the adults, however observations are likely biased because survey trips only occur during winter months when the Gray Bat maternity colony is not present. In general, adult Grotto Salamanders are more commonly observed in the spring and summer months.

There is one historic observation of an Indiana Bat from Cave Springs Cave. Sealander and Young (1954) report a 1935 observation by J. Black. The species has never been reported from the cave since this initial observation. The Tri-colored Bat (also known as the Eastern Pipistrelle Bat), *Perimyotis subflavus*, is also known from Cave Springs Cave, and it is typically observed hibernating in the cave during the winter months. Currently, Tri-colored Bats are commonly found in Arkansas caves during the winter months; however this species is suffering high mortality across much of its range due to a fungal infection known as White Nose Syndrome (WNS). Hibernating colonies of bats suffering with infections of WNS may lose more than 90% of the individuals to the disease over several winter seasons. In Arkansas, WNS has been documented in several counties, including adjacent Washington County to the south. Therefore, the potential exists for the disease to spread into Cave Springs Cave and impact hibernating bats that use the cave. The abundance and diversity of hibernating bats in Cave Springs Cave is not well documented.

Gray Bats

Cave Springs Cave harbors a maternity colony of Gray Bats. The Gray Bat is the largest member of the genus *Myotis* in the eastern United States. Its forearm measures 40-46 mm, and it weighs from 7-16 grams. It is easily distinguished from all other bats within its range by its unicolored dorsal fur. All other eastern bats have distinctly bi- or tri-colored fur on their backs. Following molting in July or August, Gray Bats are dark gray, but they often bleach to chestnut brown or russet between molts (especially apparent in reproductive females during May and June). The wing membrane connects to the foot at the ankle rather than at the base of the first toe, as in other species of the genus *Myotis* (USFWS 1982).

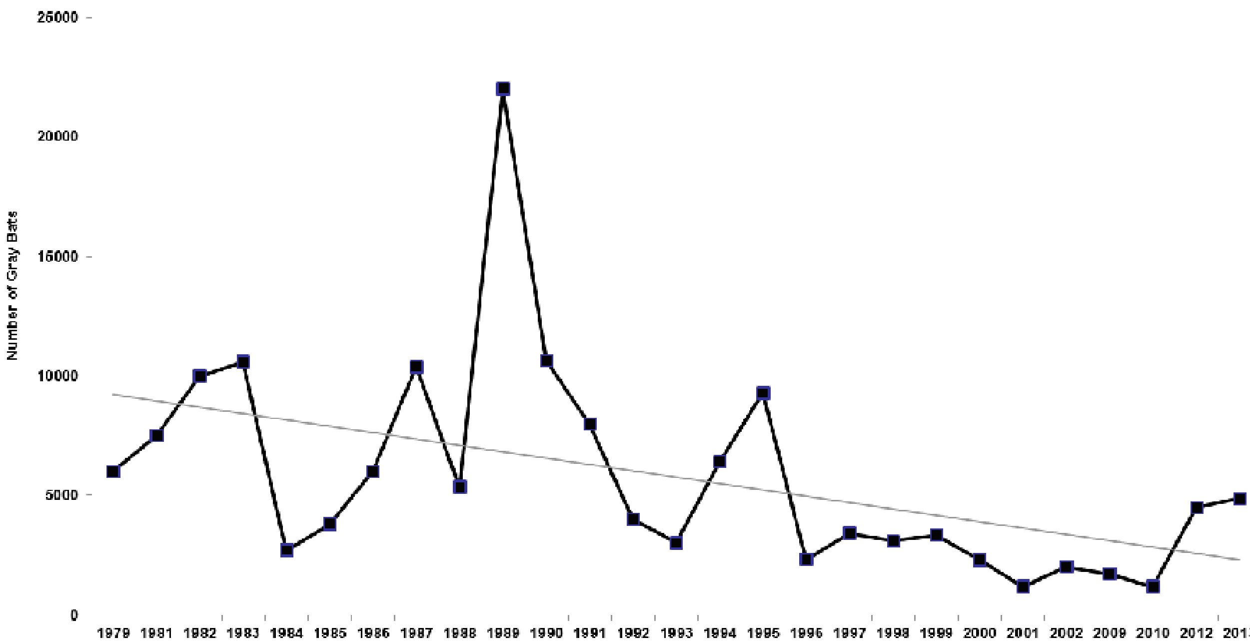
The Gray Bat is distributed in karst areas of the southeastern United States, mainly in Alabama, Arkansas, Kentucky, Missouri, and Tennessee, but a few occur in Florida, Georgia, Kansas, Indiana, Illinois, Oklahoma, Mississippi, Virginia, and North Carolina. It is estimated that approximately 95 percent of the entire known population hibernates in only 17 caves in Alabama, Tennessee, Arkansas, Kentucky and Missouri (Harvey et al. 2005). Of these caves, roughly one third of the population hibernates in a single cave in Alabama (Martin 2007).

In Arkansas, Gray Bats are distributed throughout the Ozark Plateaus ecoregion in at least 40 sites. Rivers and reservoirs as well as surrounding forested areas are used as foraging habitat because flying insects constitute a large part of the diet. Gray Bats use caves year round (and occasionally mines). During the winter, they hibernate in caves with low temperatures (6–11 °C, or 43–52 °F). Warmer caves with restricted rooms or domed ceilings within 1-4 kilometers of rivers or reservoirs are used during the summer as maternity sites. Some Gray Bats enter hibernation sites as early as the first of September and leave as late as mid-May. At Gray Bat hibernacula, all disturbances must be avoided between mid-August and mid-May (USFWS 1982). Maternity season occurs from late May through mid-July (USFWS 1982). Disturbance must be avoided at Gray Bat maternity caves between early April and the end of July. Female Gray Bats give birth between late May and early June. During the time, flightless young are on roosts, and many could die from a single disturbance (USFWS 1982).

The most recent survey at Cave Springs Cave occurred on 11 July 2013, and 4,870 Gray Bats were observed during the exit count. The highest count occurred in 1989 when 22,000 Gray Bats were estimated to be using the cave. The lowest count was in 2002 when only 1,200 Gray Bats were observed. Because maternity counts have been estimated from 1979 to 2013 (27 counts), trend analysis can be used to determine if the population is increasing, stable (no trend), or decreasing. Sasse et al. (2007) analyzed data from 1979 to 2002 and found that, in general, Gray Bats in the Ozarks are increasing in number. At Cave Springs Cave, however, the population was declining over this same time period. Maternity colony size varies among Gray Bat sites and some caves are more conducive to large colonies. For example, the maternity colony in Bone Cave, Independence County, Arkansas was estimated to be 136,000 bats in 2002. Average maternity size for Cave Springs Cave is 5,768 bats (number of counts = 27). During five of the surveys, the number of Gray Bats estimated to be in Cave Springs Cave was over 10,000, and these higher than average estimates are difficult to explain. One possible explanation is that Gray Bats move to nearby caves if primary caves are disturbed. In 1982, Harvey (1982) suggested that human disturbance at Logan Cave caused the maternity colony to abandon the cave and take up residence in Cave Springs Cave. On 19 July 1982, Arkansas Natural Heritage Commission staff observed several thousand Gray Bats in Logan Cave. On 22 July 1982, Harvey observed only 40 bats. If Gray Bats move from Logan Cave to Cave Springs Cave because of human disturbance during the maternity season, then the five Cave Springs Cave estimates greater than 10,000 bats may be outlier data points that mask attempts to understand trends associated with Gray Bat abundance at Cave Springs Cave. Therefore we excluded these survey years and re-analyzed the counts to assess trends. In addition, Sasse (pers. com.) provided maternity counts for 2009, 2010, 2012, and 2013, and we included these years in the updated trend assessment. However, excluding the years with more than 10,000 bats did not change the decreasing trend in maternity size. All Gray Bat maternity estimates for Cave Springs Cave are included in Figure 6.

The acquisition of the cave entrance by Arkansas Natural Heritage Commission and the installation of a fence around the entrance of Cave Springs Cave have benefitted the maternity colony by reducing the probability that the bats will be disturbed by human visitation. The purchase of the surrounding acres by the Illinois River Watershed Partnership also benefits the bats by buffering illegal access to the cave by increased on-site presence and by providing forging habitat along the impounded spring run on the property. Colony size fluctuation may be due more to impacts at nearby sites that cause bats to move to Cave Springs Cave in some years. A more typical estimate of bats per year may fluctuate between 4,000 to 6,000 bats. If so, the recent surveys suggest the population may be stabilizing. However, it may take another 10 survey periods to generate enough data to detect a new trend. If Cave Springs Cave does occasionally provide refuge for Gray Bats from other sites, then the maintenance of the fence and protection against human disturbance provide additional benefits to the species.

Figure 6. Gray Bat maternity exit counts at Cave Springs Cave 1979-2013.



Ozark Cavefish

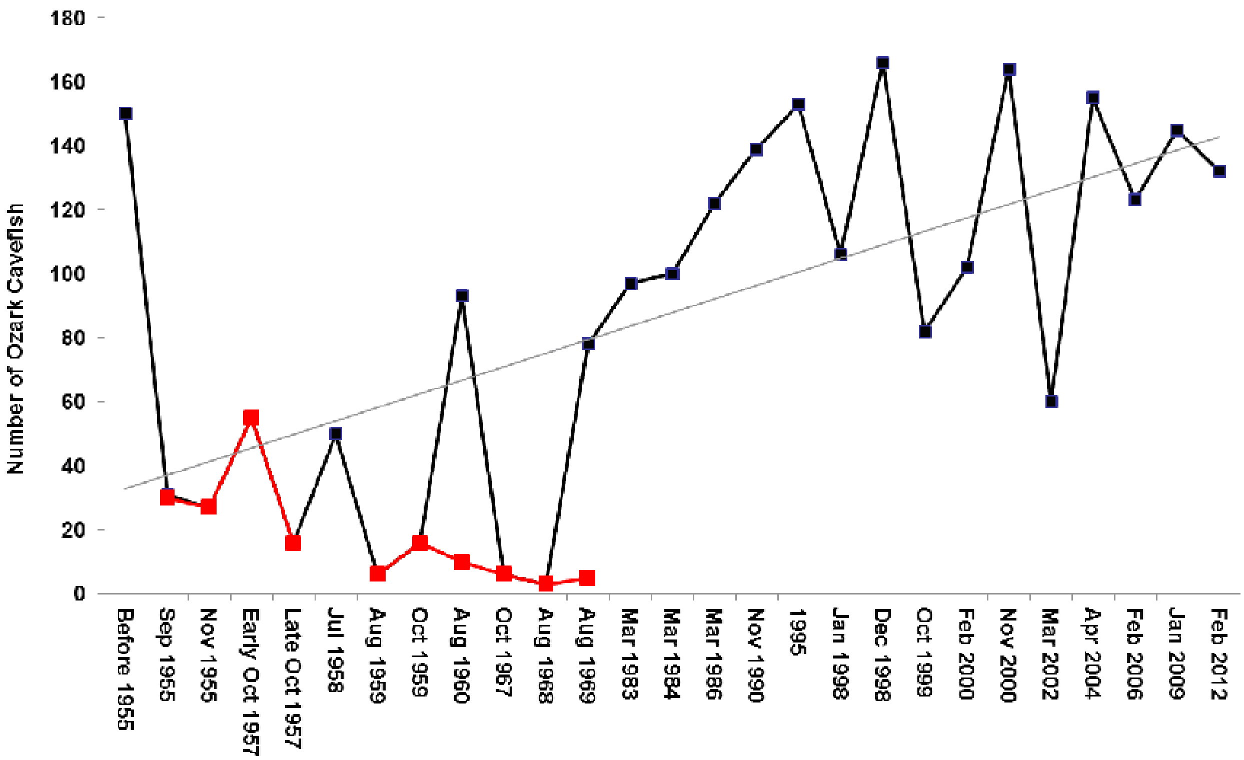
Cave Spring Cave provides habitat for the largest population of Ozark Cavefish known. The Ozark Cavefish is a small fish, reaching a maximum total length of about 50 mm. (2 inches). Ozark Cavefish lack pigment, and appear pinkish-white because their translucent skin reveals red blood and organs. The cavefish appear to have no eyes – their eyes are vestigial, and there is no remnant of the optic nerve in adults. The lower jaw slightly protrudes and the head is flattened. The dorsal fin and anal fin are located more forward than most other fishes and there are no pelvic fins. The caudal fin is rounded and has two to three rows of sensory pits (papillae) on the lower and upper halves. They can be differentiated from non-cave adapted, surface fish in the field by the absence of pelvic fins, pigment, and eyes. However, it is difficult to distinguish the Ozark Cavefish from other cavefish species in the field. Ozark Cavefish differ from the Southern Cavefish (*Typhlichthys subterraneus*) and the Northern Cavefish (*Amblyopsis spelaeus*) in the absence of a postcleithrum bone and in the arrangement of cutaneous sense organs and number of dorsal, anal, and caudal rays (Poulson 1961, USFWS 1989, Romero 1998).

Ozark Cavefish distribution is restricted to the Springfield Plateau of Arkansas, Missouri, and Oklahoma, and historically occurred at approximately 53 sites (Brown and Todd 1987). The Ozark Cavefish occurs in groundwater (the Springfield Plateau Aquifer) within Boone and Burlington Formation limestones, especially in cave streams with chert rubble substrate, and occasionally in wells and sinkholes, and even in the soil phreatic zone (Poulson 1961, 1963; USFWS 1989). In Arkansas, Ozark Cavefish are found only in Benton County, currently at seven sites, and historically at 11 sites (Graening et al. 2010). Ozark Cavefish or another cavefish species probably occurred in at least 15 more sites in surrounding counties, especially Washington County. However, these additional records remain unsubstantiated. Willis and Brown (1985) found a strong correlation between the presence of Ozark Cavefish and the presence of a maternity colony of Gray Bats, the presence of cave crayfish and/or the presence of a planktonic or benthic invertebrate community. However, Graening and Brown (2000a) did not find a correlation between presence of Ozark Cavefish and presence of bat colonies.

At Cave Springs Cave, studies on the Ozark Cavefish have been ongoing since the 1950's when Tom Poulson visited the cave during his dissertation research. The earliest population estimate was a pre-1955 estimate of 150 cavefish prior to the collections made by Tulane University (Pouslon 1960). From 1955-1957, researchers from Tulane collected 128 specimens (Graening et al. 2010). During this time period and into the early 1960's, the number of cavefish observed (and/or collected) was low with the exception of 1960 when 93 cavefish were observed. Over-collection of cavefish appears to have depressed the Cave Springs Cave population for a time period; however, surveys from the 1980s to 2012 suggest a return to pre-1955 population size. Graening et al. (2010) also observed a similar pattern by investigating population trends over the broader time period. They found that the population had significantly increased and inferred that counts were stabilizing around 130 cavefish. All the survey data including recent trips in 2009 and 2012 were reanalyzed and the same pattern was found (see Figure 7).

While little information is available about the population of Ozark Cavefish in Cave Springs Cave, research and observations on Ozark Cavefish in nearby locations provide some clues. In Logan Cave, cavefish metabolism was higher in the summer/fall months than in the winter months and was thought to be due to an increase in availability of organic input into the system by the presence of a maternity colony of Gray Bats (Adams and Johnson 2001). Because Cave Springs Cave also has a maternity colony of Gray Bats, a similar pattern of higher metabolism is expected. Higher metabolism, increased food availability, and the observation of pregnant females and fry in summer months suggest that reproduction is timed to benefit from the increase in organics. Inputs of guano from summer bat colonies may not be critical to sustain every population of cavefish since a number of cavefish sites do not contain large numbers of bats. In other Ozark Cavefish sites, organic input comes in the form of suspended matter introduced during precipitation events.

Figure 7. Ozark Cavefish counts, 1955-2012 in Cave Springs Cave. Note: The black line represents the total count while the red line represents the number taken, a practice that was discontinued in 1969.



In places such as Cave Springs Cave and Logan Cave, the influx of guano likely contributes to the higher number of individuals observed. During a mark-recapture study in Logan Cave, Brown and Johnson (2001) found that Ozark Cavefish grow faster during the summer/fall months, and absolute growth rates in the cave were reported as 0.6 ± 0.2 mm per month. Clearly, the influx of organic material, whether from guano or flooding events, during the summer months is important to the health of the cavefish.

The influx of organic material provides resources to the community of species in Cave Springs Cave that are prey for Ozark Cavefish. Gut analysis by Poulson (1961) found that cavefish in Cave Springs Cave were mainly eating copepods along with a few isopods and amphipods. Estimates of copepod and amphipod availability have not been assessed; however, Graening and Brown (2000) report a density of 5 isopods (*C. stiladactyla*) per square meter (10 square feet) in the riffle portions of the cave stream. Ozark Cavefish are more resistant to starvation than other cavefish and maintain more than 90% of their weight after 20 days and can last 401 days without food (Poulson 1961). In the laboratory, Ozark Cavefish were observed feeding on the substrate and under rocks, and they could orient to prey from 30-45 mm (1.2-1.8 inches) away.

The Ozark Cavefish may be the oldest cavefish in North America. One of the recent molecular clock studies estimated the split of Ozark Cavefish from its ancestor occurred 10 million years ago (Niemiller et al. 2013). Within the species, lineages seem to be related to surface hydrologic basins. Ozark Cavefish in Cave Springs are part of a group delimited by the Illinois River watershed, whereas other Ozark Cavefish groups are associated with the White River drainage in southwestern Missouri, Neosho River drainage in southwestern Missouri, and Neosho River drainage in northeastern Oklahoma. The Illinois River populations of Ozark Cavefish are only known from Arkansas sites making this lineage endemic to the state. Recent molecular analysis has also indicated that Ozark Cavefish have no close genetic relative, and that the species should not be classified in the genus *Amblyopsis* that includes the Northern Cavefish (*Amblyopsis spelaea*). Niemiller et al. (2013) suggest the genus name, *Troglichthys,* originally erected by Eigenmann (1899) be used instead. The widespread adoption of the name *Troglichthys rosae* rather than *Amblyopsis rosae* has not occurred, and in order to minimize confusion with older literature and Endangered Species Act documents, we will continue to use the name *Amblyopsis rosae*. The molecular studies provide additional support that the population of Ozark Cavefish in Cave Springs Cave is unique at multiple levels, and therefore conserving the population is very important.

Mark-recapture studies in Logan Cave provide some additional observations on Ozark Cavefish that are relevant to Cave Springs Cave. One cavefish was tagged and recapture 28 months later indicating that some cavefish may live in nature more than 2 years. In captivity, two cavefish survived for 4.1 years and 4.5 years, respectively (Brown and Johnson 2001). Tagged fish moved from upper stream sections to lower stream sections, but were not observed to move upstream. About half the 140 fish that were tagged by Brown and Johnson (2001) were never recaptured. These fish were either lost to the system or moved into places not accessible to researchers. Immigration into Logan Cave was estimated to be 20 ± 7.2 cavefish per year, and these fish were thought to enter the studied portion of the cave stream from humanly inaccessible areas upstream within the recharge area (Brown and Johnson 2001). Cavefish lost to Logan Cave during the mark recapture study might have occurred from deaths associated with implanting the pit tags that were used or from natural causes. Alternatively, these fish may have deliberately or inadvertently exited the cave into the surface spring run. The phenomenon of animals deliberately moving downstream is known as drift, and drift has been well studied in surface streams, particularly for stream invertebrates and juvenile fishes. Herbert (1994) studied drift at Logan Cave from May 1992 to April 1993. Over 23 sampling periods, drifting organisms that were leaving the cave included isopods, amphipods, larval salamanders, and Banded Sculpin. No Ozark Cavefish were collected during the study which suggests that cavefish do not commonly drift.

Biological Data Gaps

Data Gap 1. The extent to which cavefish are flushed from the cave needs to be assessed. It could represent a significant threat to the population in Cave Springs Cave.

Anecdotally, individual Ozark Cavefish have been observed downstream of their respective cave systems. At Logan Cave, a cavefish was found downstream in the spring run (Graening, pers. com.). The discovery of a cavefish in a Centerton Fish Hatchery fish pond that is fed by a large spring resulted in the recognition and recharge delineation of a new Arkansas population of Ozark Cavefish in northwest Arkansas (Aley and Aley 2014). At Cave Springs Cave, cavefish were occasionally observed in the former raceways downstream of the entrance (Graening pers. comm.; Slay, pers. obs.). At the Centerton Fish Hatchery site and at Cave Springs Cave, these observations were made after high discharge events that likely flushed the cavefish out. Flushing of cavefish from Logan Cave during storm events may help explain the number of individuals lost during the mark recapture studies. However, there are no studies that have attempted to address the magnitude of loss of cavefish from cave systems. We identify as a data gap, the lack of knowledge regarding how often Ozark Cavefish flush from cave systems during elevated discharge events.

Data Gap 2. Land conversion from agricultural uses to urban uses typically increase non-permeable surface areas. As a result, Cave Springs Cave may experience changes in hydrologic response during precipitation events in the future.

Ozark Cavefish are occasionally observed in the entrance pool, and elevated discharge events could easily flush a cavefish over the entrance pool lip. If the average number and intensity of discharge events increase because of land use changes in the recharge area, the potential for additional loss of cavefish due to flushing out is greater. Understanding the relationship between discharge rates and cavefish flushing out is an important data gap.

PART 3. CAVE CONSERVATION NEEDS AND METHODS

Introduction

Cave Springs Cave is well protected by a gate that prevents unauthorized entry into the cave. The gate is designed in such a manner as to not restrict natural air or water flow patterns into or out of the cave, and provides bats with essentially unimpaired access to the cave. The challenge of further protecting the cave and its fauna must be focused on protecting water quality.

The studies at Cave Springs Cave have two fundamental objectives:

- To develop approaches needed to protect and maintain the cave fauna in Cave Springs Cave. This fauna includes a maternal population of the federally endangered Gray Bat (*Myotis grisescens*) and the federally threatened Ozark Cavefish (*Amblyopsis rosae*). Cave Springs Cave has by far the largest known population of the Ozark Cavefish.
- To develop approaches that are both practical and science-based, and that will permit continued growth of human populations in the recharge area for the cave while ensuring groundwater quality protection necessary for the well-being of the cave fauna.

The OUL conducted a comprehensive review of existing information about Cave Springs Cave including its hydrology, water quality, and biological conditions. This historic information has been augmented by a detailed groundwater tracing program to refine and characterize the recharge area for the cave. The review and studies clearly demonstrate that both of the fundamental objectives of the project can be met. It is the conclusion of the OUL that, with appropriate actions, the people of Benton County can protect and maintain threatened and endangered species and experience further suburban growth in the recharge area for Cave Springs Cave. The remainder of this section identifies actions needed to make this possibility a reality.

Results from the Literature Review

Important Hydrologic Conditions

Based on recharge area studies in the Ozarks, it is the OUL's estimate that at least 40% of all water entering karst groundwater systems enters from points along the floors of the valleys. About 10% of the land area is in valleys. While the percentages vary among areas, the important point is that valley areas are disproportionally important in introducing water and waterborne contaminants into karst groundwater systems. As a result, efforts to protect groundwater quality need to focus major management attention on the quality of water reaching the valleys and then entering the groundwater system.

Essentially every valley in the karst portions of the Ozarks contains losing stream segments that can introduce water at rates of tens to hundreds of gallons per minute into very localized areas. These losing stream segments provide ineffective natural cleansing for waters that pass through them and into the karst groundwater system. The management challenge is to provide reasonably good water quality to the valleys since the valleys themselves do not function as effective natural cleansing systems.

Lateral water movement through the karst groundwater system is often very rapid with flow rates for the first arrival of tracer dyes at springs or caves often a mile per day and occasionally more. The most rapid travel rates typically occur during periods of high flow. It is common for detectable concentrations of tracer dyes to discharge from a receiving spring for a month or two and sometimes longer. However, it is typical for 50% or more of all dye detected from a particular trace to discharge from the receiving spring within a week or two of the time of first dye arrival.

Groundwater recharge is the movement of water from the surface of the land into the aquifer where most voids are filled with water. In karst areas two types of groundwater recharge occur. These are Diffuse Recharge and Discrete Recharge.

Diffuse Recharge is relatively slow and dispersed. Except in the presence of readily mobile contaminants, most diffuse recharge water in the Ozarks receives a reasonable degree of natural cleansing as it passes downward through the soil. The effectiveness of natural cleansing is greatest for the soil series the OUL has identified as “Good Natural Soil Treatment Capability Soils” and least for those identified as “Poor Natural Soil Treatment Capability Soils”.

Discrete Recharge is the relatively rapid movement of water into the karst aquifer through localized (and often highly localized) flow paths. Sinkholes and losing stream segments are examples of discrete recharge zones. Unfortunately, most discrete recharge zones have no surface expression that permits their identification. A critical characteristic of discrete recharge zones is that they routinely do not provide effective natural cleansing for waters passing through them. They routinely provide ineffective natural filtration because the openings are larger than most pathogenic bacteria. Adsorption of contaminants in discrete recharge zones is ineffective because so much water follows the localized flow routes that the there is little remaining adsorptive capacity available. Groundwater quality protection strategies developed by the OUL in the Ozarks focus primary attention on the protection of discrete recharge waters.

There can be substantial lateral movement of discrete recharge waters before they ultimately reach the water table. Aley and Kirkland (2012) demonstrated lateral movement in excess of 750 feet in the Ozarks. Valley floors and adjacent lower valley slopes are locations routinely associated with large volumes of discrete recharge.

Vulnerability Mapping of Recharge Areas

The OUL has conducted a number of studies focused on protecting Ozark Cavefish populations in northwest Arkansas, northeast Oklahoma and southwest Missouri. This experience has shown that conducting groundwater tracing studies to delineate the recharge areas for populations of federally listed cave-dwelling species is a critically important first management step. The second step is assessing how land use and land management activities are likely to impact the delineated sites and their faunas. An important result of this work has been the recognition that all lands in a recharge area do not pose equal potential for benefiting populations. Similarly, all lands do not pose equal potential for adverse impacts. The majority of potential adverse impacts on cave fauna populations result from activities and conditions on a small fraction of the total land area within a recharge area.

Aley and Thomson (1981) developed a set of groundwater vulnerability maps for Greene County, Missouri. These maps have been used by Greene County as a fundamental tool in protecting groundwater quality and in making zoning and other land use decisions. Lands in the county have been divided into four vulnerability classes: low, moderate, high, and extremely high groundwater vulnerability. The maps have successfully enabled the county and others to give lesser levels of attention to lands likely to represent only minor problems and more attention on lands where the impacts are much greater. Similar mapping has been conducted for the Cave Springs recharge area.

Among the hydrogeologic features mapped in Greene County were fracture traces and lineaments. Areas within 400 feet of a mapped fracture trace or lineament were identified as having a vulnerability class one level greater than adjacent lands. As an example, if adjacent lands were mapped as having moderate vulnerability then the lands within 400 feet of the fracture trace or lineament were mapped as having high vulnerability. The 800 feet wide zone associated with fracture traces and lineaments was based on previous experience with land subsidence and sinkhole formation in similar settings in the Ozarks and recognized that such features often consisted of multiple sub-parallel fracture zones.

Fracture traces and lineaments in portions of the Ozarks underlain by the Boone Formation and similar units represent zones of particularly intense fracturing and subsequent solutional action. In many cases a fracture trace or lineament represents a zone of relatively parallel fracturing with some cross fracturing rather than a single fracture. This helps explain why valleys oriented along fracture traces and lineaments commonly are not V-shaped, but instead have relatively flat-floors that are often several hundred feet wide.

A common OUL approach in vulnerability mapping in the Boone Formation is to routinely delineate a zone of higher groundwater vulnerability in an area 300 feet on either side of a stream segment oriented along a fracture trace or lineament. Unless there is additional information is used, the centerline for the stream course shown on the U.S. Geological Survey (USGS) 7.5 minute topographic maps is used as the center of the zone of fracturing. The fracture trace or lineament is often terminated 300 feet upstream of the upstream terminus of the stream channel shown by a blue line on the topographic map.

Aley and Aley (2014) used a 300-feet wide zone as a higher vulnerability classification zone for lands on either side of fracture traces, lineaments, and losing streams in the recharge area for Civil War Cave, Centerton Spring, and the spring supplying water to the Centerton Fish Hatchery. All of these recharge areas are in Benton County and in areas hydrogeologically similar to Cave Springs Cave.

Buffer Zones Around Karst Features

Buffer zones are commonly recommended along losing streams and sinkholes in karst areas. The objective is to provide a strip of vegetation to trap sediment and capture plant nutrients before these materials reach the losing stream or sinkhole and subsequently enter the karst groundwater system.

A number of the papers reviewed dealt with management around sinkholes. Sinkholes are relatively rare features in the Cave Springs recharge area. However, from a hydrologic perspective, sinkholes and losing streams function in a similar manner and neither provide effective natural cleansing for waters passing through them and entering the groundwater system. Dougherty (1991) recommended a setback of 100 feet around sinkholes including a provision for no stormwater detention basins within this setback distance. Such setbacks are typically measured from the lip of the sinkhole, so the setback from the actual drainage point or points in the sinkhole are greater (and often substantially greater) than 100 feet. The Texas Commission on Environmental Quality (2007) in areas overlying the Edward Aquifer recommended (page 3):

> *"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."*

Widths of recommended buffer zones in the karst literature vary widely. They are potentially subject to challenge as being arbitrary, and in many cases are established as uniform values based on compromises. This is clearly not an ideal approach. For the Cave Springs recharge zone the U.S. Fish and Wildlife Service (2005) recommend that buffers for losing streams should be at least 300 feet wide on each side of the stream.

The following factors affect the necessary width of buffer zones within the Cave Springs recharge area:

- Nature of the vegetation and degree of maintenance. A buffer zone with a well-planned and site-appropriate vegetated strip will be more effective than one that is mostly weeds and volunteer vegetation. A mowed grass strip is less effective than an un-mowed strip. A well-designed woodland corridor is more desirable than a grassed buffer. Finally, effective riparian strips require periodic maintenance.

- Slope of the land. The steeper the slope the wider the buffer strip must be to provide the same level of water quality protection.
- Nature of the soils in the buffer strip and their ability to support good vegetative cover and to provide treatment for passing waters. The OUL's risk rating of soils can be used for this assessment.
- Nature of the upgradient land use. As an illustration, commercial land uses require a wider buffer strip than suburban homes with large lots and municipal sewers.
- Volume of anticipated overland runoff reaching the buffer zone.
- Percent of contributing area that is paved and covered with roofs and how connected these areas are.
- Amount of runoff passing through stormwater detention basins and the effectiveness of those basins in detaining and treating stormwater runoff waters.

Important differences exist between the vulnerability mapping conducted by the OUL in the Ozarks and regulatory strategies outlined in Missouri, Kentucky, and Texas. The regulatory approach, such as that in the Edwards Aquifer of Texas, creates zones in which many land uses are prohibited. The OUL approach has been to identify particular areas as being characterized by greater or lesser degrees of potential impacts on the groundwater system. This creates opportunities for water quality management strategies that are more flexible than simply the creation of buffer zones. A benefit of this approach is the possibility of concurrently minimize the extent of buffer zones while providing water quality improvements that equal or exceed those that would be required by finite setback regulations.

Water Quality Treatment Provided By Soils

Soils series in the Cave Springs recharge area were divided into three groundwater quality risk classes based on characteristics of the soil profiles. The classes are Good, Fair, and Poor Natural Soil Treatment Capability Soils. Discharge of poor quality waters onto soils identified as having Poor or Moderate Natural Soil Treatment Capability are of particular management concern. This is especially true when these discharges are located on or near fracture traces, lineaments, or troughs in the water table. The risks posed by such discharges are substantially increased if upper horizons of the soils receiving the discharges are removed by construction projects. This occurs for two reasons. First, the upper soil horizons routinely have more natural cleansing capacity for contaminants than is the case for underlying horizons. Second, removal of any of the soil reduces the total mass of soil that can potentially remove passing groundwater contaminants.

Water Quality Treatment in Stormwater Detention Ponds

Stormwater detention ponds in karst landscapes must protect both surface and groundwater supplies. In northwest Arkansas stormwater detention ponds have routinely given little attention to the protection of groundwater quality and, in many cases, have degraded groundwater quality by effectively introducing much of the “first flush” of runoff waters into the groundwater system. The "first flush" waters are typically the first quarter to half inch of runoff, and this water has a disproportionally large portion of total stormwater contaminants.

Keith et al. (1995 and 1997) described stormwater ponds and other designed features associated with Indiana Route 37 in the Mitchell Plain karst aquifer. Substantial water quality sampling was conducted after the features were installed and their effectiveness was assessed. A peat filter in one sinkhole removed an average of 80% of suspended particulates and almost 50% of dissolved copper and zinc. In contrast, rock filters did not appear to remove dissolved metals.

McCann and Smoot (1999) reviewed stormwater best management practices in karst areas, with a primary focus on highway runoff. They considered the use of skimmers, wet retention ponds, wetlands, and filtration systems. Smoot et al. (1997) also focused on highway runoff and reported that such waters were contaminated with heavy metals, oil and grease, and many other contaminants. Laboratory testing indicated pollutant removals generally ranged from about 90% to more than 99% for the selected heavy metals and for total polyaromatic hydrocarbons. A substantial amount of work on treating stormwater runoff has been conducted in the Austin, Texas area.

Stormwater detention basins that provide treatment for runoff waters will be needed in the recharge area for Cave Springs if the Ozark Cavefish is to be adequately protected. Suitable basins that detain and treat stormwater runoff will reduce the size of buffer zones that would otherwise be needed along losing streams. Much of the work on this project by Wright Water Engineers is focused on these issues.

Interactions between Hydrogeologic Conditions and Cave Fauna

Extent and Localization of Cavefish Habitat

The humanly-accessible length of known cave passages in Cave Springs Cave is about 1,690 feet (Graening and Brown 2003, page 1498). The maximum length of adult Ozark Cavefish is 3 inches (USFWS 2010, page 8). Because of their small size, the available habitat for cavefish in the Cave Springs Cave system is much more extensive than simply the short humanly-accessible segment of cave passage. While the cavefish population in the accessible portion of the cave system is very important, it is only part of the cave ecosystem that is the focus of this project.

Past speculation exists regarding the best cavefish populations being associated with bat guano. However, the dissertation by Graening (2000) indicates that cavefish primarily eat isopods that in turn feed upon organic matter derived from the surface of the land. Graening (2000) also indicates that 95% of the organic matter input to the cave stream ecosystem in Cave Springs Cave is dissolved in the water and the remainder is suspended material. Given these considerations, adequate habitat for cavefish extends well beyond areas accessible to bats.

Ozark Cavefish populations were historically known from a number of shallow dug wells. Many of these wells were dug in valleys at points where groundwater routinely or occasionally discharged to the surface. The OUL has delineated recharge areas for a number of these wells in the Ozarks and has found them to often be substantial distances from the springs to which they contribute water. A good illustration of this is provided by an Ozark Cavefish population in Johnson Well, Lawrence County, Missouri. This dug well is in a small tributary valley with only intermittent flow. The well occasionally discharges water to the surface during storm flow periods. The straight-line distance from this well to the downgradient spring that receives water from the well is 1.76 miles. The recharge area for the well is 808 acres and the recharge area for the associated spring is 2,088 acres. There are no known humanly-accessible cave passages associated with either Johnson Well or its hydrologically related spring.

Ozark Cavefish populations in Cave Springs Cave exist not only near the cave entrance but also within a substantial part of the delineated recharge area. As a result, increasing distances from Cave Springs do not imply that land management practices pose lesser risks to the survival of Ozark Cavefish. In fact, increasing distances from the spring are typically associated with smaller groundwater flow rates; this could increase the adverse impacts of introduced contaminants at locations more remote from Cave Springs due to less water for contaminant dilution or re-oxygenation of input waters.

Cavefish within the Cave Springs aquifer are not distributed uniformly. They exist in areas that have experienced the greatest solutional modification of the bedrock because this creates openings the fish need for suitable habitat. Areas with preferential solutional development within the bedrock are commonly associated with fracture traces and lineaments, which in turn are commonly located beneath topographic valleys. Preferential solutional development is also likely along the trough in the water table shown in Figure 1. Areas associated with fracture traces, lineaments, and troughs in the water table routinely receive more groundwater recharge per overlying unit area than areas beneath uplands. Furthermore, the surface valleys routinely contain numerous losing stream segments. Dissolved and suspended organic matter enters the karst groundwater system through losing stream segments and this supplies food for the cave ecosystem and favors increased localized concentrations of cave fauna including the Ozark Cavefish.

Benefits of Dispersed Cavefish Populations

A positive benefit of dispersed populations of cavefish in the Cave Springs recharge area is that a pollution event would follow a localized flow route (or routes) and thus be unlikely to kill most of the cavefish within the recharge area. Cavefish populations not impacted by such a pollution event would be available to repopulate impacted flow routes after most of the pollutants have been flushed from the groundwater system.

For many years the water in Hidden River Cave, Kentucky, was grossly polluted with inadequately treated municipal sewage and heavy metals from a metal plating plant (Lewis 1996, and Aley pers. exp.). A regional sewage treatment system and legal action resulted in major improvement to water quality in the cave stream. Within a few years Southern Cavefish (*Typhlichthys subterraneus*) and cave crayfish repopulated the main cave stream. However, recovery times for aquatic life in cave streams are routinely substantially longer than for surface streams. This is due to low reproductive rates for cave animals and physical impediments to their migration within the groundwater system.

Impacts of Low Reproductive Rates for Ozark Cavefish

The role of low reproductive rates for Ozark Cavefish in Cave Springs Cave appears to have been illustrated by the time required for the population of cavefish in accessible portions of the cave to recover from heavy biological collecting. That collecting occurred in the 1950s when at least 174 cavefish were removed from the cave (Graening et al. 2010). Cavefish populations in accessible portions of Cave Springs Cave in the 1960s ranged from 39 to 97, and did not reach a maximum of 166 until 1999. While this suggests a 40-year recovery period, it is likely that some fish were flushed out of the cave by floods and others might have been lost to predation, pollutants, or other processes. These losses would shorten the apparent recovery period, but the important point is that cavefish population recovery times from pollution events are likely to be on the order of at least several decades.

Impacts of Low Metabolic Rates for Cavefish

Cave species routinely grow more slowly and have longer life spans than similar surface species. Obligatory cave fauna, and especially Ozark Cavefish, have lower metabolic rates than most surface aquatic species. Lower metabolic rates correlate with greater tolerance for low dissolved oxygen concentrations in the water. The OUL has found no scientific literature indicating how tolerant the cavefish are to very low dissolved oxygen concentrations, but dissolved oxygen concentrations in an Ozark Cavefish population at Hulet Spring Hole, Benton County, Arkansas, were measured as low as 3.15 mg/l during October 1996 with no apparent harm to the cavefish. Additionally, cavefish populations in accessible portions of Cave Springs Cave are close to their long-time record number. This has occurred in spite of the introduction of substantial amounts of oxygen demanding compounds in recent years from urbanization and from a substantial number of CAFOs that were land applying wastes in the recharge area.

Urbanization and Risk of Flushing Cavefish from the Cave

High flows from Cave Springs Cave are known to have flushed Ozark Cavefish out of the cave. They would not be able to swim back into the cave and would be lost to the population. We have not yet received permission from the U.S. Fish and Wildlife Service to put a net downgradient of the cave entrance to capture any cavefish that may flush out of the cave, but hope for such permission in the future. This study will be important in assessing the potential severity of this risk to the cavefish population in Cave Springs Cave.

Urbanization increases the total volume of runoff from storm events. In addition, as contrasted with natural flow conditions, stormwater retention basins undoubtedly increase the total volume of water entering the groundwater system. Finally, Paylor and Currens (2001) found that the extent of urbanization in karst basins substantially increased the base flow rates of receiving streams. The combination of these factors will increase the frequency and magnitude of storm flows from the cave and would be expected to increase the frequency with which cavefish are flushed out of the cave stream. Assessing the severity of this potential problem and designing a management strategy to offset the problem (if needed) will need to wait until the appropriate permit is obtained from the U.S. Fish and Wildlife Service and data are collected and evaluated.

Modes of Aquatic Toxicity

Aquatic life is subject to both chronic and acute toxicity. Chronic toxicity is routine exposure to a harmful compound or condition. Acute toxicity is relatively short-term exposure to an unusually high concentration of a harmful condition or compound. Bioaccumulation of compounds such as heavy metals and pesticides are examples of chronic toxicity that might be present in some cases. Major leaks or spills of a toxic compound or a compound that depletes dissolved oxygen in the groundwater system is an example of acute toxicity. Both chronic and acute problems may exist and potentially act synergistically, and management strategies must focus on preventing damage or mortality from both.

Most aquatic life kills in karst areas are related to acute toxicity from spills or infrastructure failures (such as loss of power to a sewage lift station with a resulting discharge of raw sewage to a losing stream). Acute toxicity problems can also occur when an intense summer rainstorm follows a long dry period and runoff rapidly introduces large volumes of water with high BOD values into the karst groundwater system. Stormwater management systems must be designed to ensure that unusual storm events do not result in the introduction of water with excessive BOD values into the groundwater system. Management must recognize that karst groundwater systems have substantially less ability than surface streams to re-oxygenate waters that have depleted dissolved oxygen. This is because bedrock voids that are totally filled with water have little access to air containing oxygen and thus cannot effectively re-oxygenate water when dissolved oxygen in the water is depleted.

Actions to Prevent Catastrophic Spills and Discharges

It is well established that catastrophic spills and discharges can have devastating impacts on springs and cave streams. Aley (1978a) discussed six case histories of pollution events or pollution sources that resulted in fish kills at trout farms dependent upon spring water or that 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.

A particularly appropriate case history was a raw sewage discharge from a City of Springdale sewage lift station in 1980 that killed about 34,000 young trout and about 1,500 pounds of mature trout at Ozark Spring. This was discussed in the hydrology portion of this report under the heading "Parameters of Special Importance to Aquatic Cave Fauna". The fundamental problem was a lack of backup power for this lift station. Its location and design were such that any discharge would directly enter the karst groundwater system.

There are several sewage lift stations within the Cave Springs recharge area. Not all currently have backup power (such as a generator that would immediately power the station in the event of an electrical outage). The adequacy of all components of sewage systems within the Cave Springs recharge area should be evaluated to ensure that the risk of major sewage discharges to the groundwater system is extremely remote and that all facilities receive routine maintenance. When large-scale failures of sewage systems occur in karst settings much or all of the discharging water commonly enters the groundwater system and may not be detected until terrible odors emanate from a distant spring and a major aquatic life kill has occurred.

Historically, there have been a substantial number of poultry and hog CAFOs in the Cave Springs recharge area. Land application of wastes from such facilities routinely involves large quantities of wastes, and land applications do not always coincide with favorable weather conditions. The result has undoubtedly been introduction into the groundwater system of substantial short-duration pulses of oxygen demanding materials. Some of these impacts have, at least locally, exceeded the magnitude of impacts from suburban stormwater runoff.

Cave Conservation Data Gaps

Data Gap 1. Data are needed to evaluate the potential severity of cavefish being flushed out of Cave Springs Cave.

This work will be accomplished as soon if a permit can be obtained from the U.S. Fish and Wildlife Service. A net will be placed where it will trap most, and hopefully all cavefish that are flushed from the cave during higher flow events.

Data Gap 2. Vulnerability mapping and hazard area identification needs to be conducted for the Cave Springs recharge area.

This work has been conducted by the OUL in the Direct Recharge Area for Cave Springs. It is the conclusion of the OUL that similar mapping is not needed for the Indirect Recharge Area. The mapping is similar to that conducted for the Fish Hatchery Spring, Centerton Spring, Civil War Cave, and Coler Spring (Aley and Aley 2014).

Data Gap 3. The current locations of sewage lift stations and stormwater detention ponds should be mapped within the Direct Recharge Area for Cave Springs. An evaluation should be made to determine if any of the sewage lift stations have the potential to discharge untreated sewage to losing streams in the event of a power failure.

PART 4. CONCLUSIONS AND RECOMMENDATIONS

HYDROLOGIC AND WATER QUALITY DATA

Conclusion 1. Given the data available and the OUL's experience with springs in the Ozarks the mean annual flow rate of Cave Springs is estimated to be about 4.5 cfs. Peak flow rates undoubtedly exceed the maximum measured 15.3 cfs (reported by Graening and Brown, 1999) and based on the behavior of other Ozark springs could easily be 25 cfs or more. Since some of the smaller springs near Cave Springs are hydrologically connected with Cave Springs, the minimum flow rate of Cave Springs is about 0.3 cfs.

Conclusion 2. The OUL attempted to install a weir downstream of the cave in hopes of providing more accurate flow rate measurements, but major leakage around and beneath the old flume area downstream of the dam defeated these efforts. While accurate and continuous flow rate data for the spring were not needed for this project, and were not required under the contract, reasonably accurate flow rate information would be valuable for the future understanding and management of the site.

Conclusion 3. Graening and Brown (2003) provided summary data on a number of water quality parameters measured at the mouth of Cave Springs Cave during the period November 1997 through December 1999. These data were included in the current report as Table 1. It is the conclusion of the OUL that these data provide a good characterization of water quality conditions at Cave Springs during that sampling period. However, during that period there were at least forty CAFOs for poultry and swine in the recharge area, hundreds of septic systems, and some land application of municipal sewage sludge. As of 2014 there are few if any confined animal feeding operations and little or no sewage sludge application to pasturelands in the recharge area. Substantial portions of the Cave Springs recharge area have been developed for suburban residences, and most of these are served by municipal sewers. The number of homes in the recharge area dependent upon septic tanks and leach fields has decreased from 1997-1999 conditions. Sewage sludge is no longer applied to lands in the Cave Springs recharge area, and current discharges of treated municipal wastewaters within the recharge area are limited and localized.

Conclusion 4. The water quality data summarized by Graening and Brown (2003) are of historic value. However, given the changes in land uses that have occurred in the Cave Springs recharge area since 1999, it is not reasonable to assume that this earlier data adequately represents current water quality conditions at Cave Springs. Given the land use changes that have occurred it is possible (but unproven) that present water quality conditions at Cave Springs have improved since the 1997-1999 period. An adequate water quality monitoring program capable of assessing current conditions at Cave Springs does not presently exist.

Conclusion 5. In the OUL's experience the most common cause of aquatic life kills in springs and cave streams is low dissolved oxygen concentrations. Low concentrations cause suffocation of the aquatic life. Such aquatic life kills commonly result from the introduction of waters with high BOD or COD values. A case history from Ozark Spring near Johnson, Arkansas was used in the text to illustrate the problem. A massive kill of fish and other aquatic life occurred at Ozark Spring on July 13 and 14, 1980. About 34,000 young trout and 1,500 pounds of mature trout, as well as other aquatic life, were killed. The aquatic life kill was attributed to a power failure at the Bradshaw Lift Station that resulted in the discharge of untreated municipal sewage to a losing stream segment of Dry Creek. There are sewage lift stations in the Cave Springs Cave recharge area that have the potential to discharge untreated municipal sewage to losing streams. This situation needs to be remedied as soon as possible.

Conclusion 6. Turbidity is another important parameter for aquatic life in cave streams. It is an indirect measure of sediment transport into and through the cave stream. Sediment that deposits in the cave stream can clog the interstitial spaces in the gravel and, among other things, reduce habitat for invertebrates upon which the cavefish feed. Measured turbidity values from Cave Springs have ranged from < 1 to 48 NTU. These are very low values, and in the experience of the OUL are substantially lower than those periodically associated with most Ozark springs. While the low values for Cave Springs Cave are encouraging, much higher values associated with major storm flows would almost certainly be detected with continuous monitoring instrumentation.

Conclusion 7. Nitrate-nitrogen concentrations receive substantial attention in surface waters because they enhance the growth of undesirable plants. Elevated nitrate-nitrogen concentrations in cave streams are unlikely to cause significant adverse impacts on cave systems since there is no sunlight to facilitate plant growth. However, nitrates are very mobile in infiltrating water and are a good indicator of agricultural and residential impacts on groundwater quality in karst areas.

Data in Slay and Snell (2005) indicate that Arkansas caves with minimal human and agricultural impacts in their recharge areas typically have nitrate-nitrogen concentrations of 1.5 mg/l or less. These results are compatible with the experience of the OUL. Graening and Brown (2003) reported nitrate-nitrogen concentrations at Cave Springs ranging from less than their detection limit (not specified, but probably 0.1 mg/l) to a maximum of 8.8 mg/l; the mean value was 6.2 mg/l. Slay and Snell (2005) reported four nitrate-nitrogen measurements made at Cave Springs during the period 2000 to 2005; the values ranged from 5.00 to 7.06 mg/l with a mean of 5.90 mg/l. No more recent nitrate-nitrogen data were found during our literature search.

More current nitrate-nitrogen monitoring of water at Cave Springs is desirable. However, based on the historic data on nitrate-nitrogen concentrations, water quality in Cave Springs has been detectably impacted by past land use practices in the recharge area.

Chloride and sodium are also very mobile in infiltrating water and are good indicators of agricultural and residential impacts on groundwater quality in karst areas.

Both of these parameters are elevated in waters at Cave Springs Cave.

Conclusion 8. Brown et al. (1998) and Graening and Brown (1999) used selected water quality data to conclude that some water quality parameters at Cave Springs Cave were substantially increasing with time from about 1984 to 2000. It is the conclusion of the OUL that the water quality data available were not adequate to support a credible trend analysis or the statement that the data suggest that many organic and inorganic chemicals had increased in concentration during the period from 1984 to 2000. This conclusion relates only to the issue of whether or not parameter values at Cave Springs were increasing with time. It does not suggest that water quality data in the various reports by these authors are not of great value in characterizing water quality in Cave Springs.

Conclusion 9. Graening (2002) compared water quality data for five biologically significant caves in Benton County. The mean concentration of copper, lead, selenium, and zinc in waters from Cave Springs Cave were reported to be two to three orders of magnitude (100 to 1,000 times) larger than at any of the other monitored caves. The OUL assumes that all measurements were for dissolved metals and not as total metals; this is not clearly stated. However, if all measurements were for dissolved metals and are accurate, the values from Cave Springs are clearly substantially above expected concentrations for these heavy metals. The source(s) of these contaminants is not known, but their presence during the period November 1997 to September 2001 is clearly of concern. Sampling to determine if similar elevated concentrations are still occurring at Cave Springs is an important data gap. If the conditions still exist the source(s) of the contamination need to be found. Likely sources for some of the elevated element concentrations include manufacturing operations or illegal dumping of manufacturing wastes. In the experience of the OUL it can be difficult to discover such operations.

Conclusion 10. Slay and Snell (2005) reported on four periods of synoptic sampling of water quality at a number of cave streams and springs in Arkansas during the period 2000 to 2005. Based upon the synoptic sampling, the water quality of Cave Springs is similar to that for other cave streams and springs in northern Arkansas. Elevated concentrations of nitrate, chloride, and sodium at Cave Springs Cave are attributable to land use activities in the recharge area for the cave. In distinct contrast with the results obtained by Graening (2000), measured concentrations of copper, lead, selenium, and zinc in Cave Springs Cave were similar to concentrations in other caves.

Conclusion 11. Slay and Snell (2005) reported on two periods of synoptic sampling of heavy metal concentrations in sediments from a number of cave streams and springs in Arkansas during 2001 and 2002. Based upon this sampling, heavy metal concentrations in Cave Springs Cave are generally similar to those in other cave streams and springs in northern Arkansas. If the mean concentration of copper, lead, selenium, and zinc in waters from Cave Springs Cave had been two to three orders of magnitude larger than at other monitored caves during the period November 1997 to September 2001, substantially elevated concentrations of these elements in sediments from the cave stream in 2001 and 2002 would have been expected. They were not found.

Conclusion 12. There is a significant inconsistency in heavy metal concentration data for copper, lead, selenium, and zinc at Cave Springs. If these heavy metals were present in Cave Springs at the highly elevated concentrations reported by Graening (2002) for the period between November 1997 and September 2001, it is unlikely that elevated concentrations of these metals would not have been detected in sediment samples collected in 2001 and 2002. The OUL recommends that a series of water samples be analyzed from Cave Springs for heavy metals with particular attention focused on copper, lead, selenium, and zinc.

Conclusion 13. The OUL recommends initiation of a water quality monitoring program at Cave Springs Cave similar to the one operating at Tumbling Creek Cave. This program uses automatic sampling equipment to measure and record flow rate, turbidity, dissolved oxygen, temperature, and specific conductance. In addition, monitoring chloride as an indicator of human activity in the recharge area is recommended. Nitrate concentrations should also be monitored if dependable equipment is currently available that is capable of making many measurements at short intervals. Querying the probes every 10 seconds and recording running means every 10 minutes is recommended, and at Tumbling Creek Cave this has been adequate for management focused on protecting a federally endangered aquatic species.

Conclusion 14. The groundwater gradient data from previous tracing has been augmented with data from traces conducted in conjunction with the present investigations. The results indicate that the general groundwater gradient along major karst groundwater flow paths in the area is very gentle and is routinely between 4.2 and 12.9 feet per 1,000 feet. In the opinion of the OUL data are now sufficient to characterize groundwater gradients in the Cave Springs recharge area.

Conclusion 15. The geologic mapping (Glick 1970 and 1972) of the study area shows that the entire recharge area for Cave Springs is underlain by the Boone Formation of Mississippian age. There are no faults or other structural features shown on the geologic maps. The Boone Formation consists primarily of limestone and chert with the chert content varying both vertically and laterally. The beds are all relatively flat-lying.

Conclusion 16. It is the conclusion of the OUL that fracture traces and lineaments routinely provide preferential groundwater flow routes within the Cave Springs recharge area. This is supported by experience from other areas underlain by the Boone Formation and similar geologic units. This conclusion is also supported by the rapid groundwater travel rates demonstrated by dye traces and the very gentle mean groundwater gradients that have typified traces in the area. Rapid groundwater travel with gentle gradients requires well-integrated solutionally enlarged conduits. Such conduits in the Ozarks are routinely associated with both fracture traces and lineaments.

Conclusion 17. Most of the recharge area for Cave Springs is an upland area where topographic features are subdued and, as a result, identification of fracture traces and lineaments from aerial photographs is difficult. This difficulty is increased by past land uses that have obscured many topographic features and created new linear features (such as fence lines and drainage ditches) which can sometimes be incorrectly interpreted. The net result is that an accurate and intensive mapping of fracture traces and lineaments as part of groundwater vulnerability mapping, such as conducted by Aley and Thomson (1981) for Greene County, Missouri, would not be feasible in the Cave Springs recharge area.

Conclusion 18. Potentiometric mapping shows a major trough in the potentiometric surface that extends eastward from the spring. The axis of this trough is roughly parallel to Highway 264 and runs 1,000 to 2,500 feet north of that highway. The axis of this trough extends for about 17,000 feet. Since much of the recharge area is now urbanized, most of the wells have been destroyed and the best available data for mapping the potentiometric surface are those from Williams (1991).

Conclusion 19. Delineation of the recharge area for Cave Springs Cave utilized a combination of data from groundwater tracing investigations and from the potentiometric mapping. Important limitations of the existing potentiometric data include:

- The implicit assumption that the aquifer is homogeneous and isotropic when neither of these assumptions is correct.
- Not all wells are necessarily representative points.
- Potentiometric mapping does not recognize that some areas contribute water to two or more springs.
- There can be appreciable lateral movement of water as it descends from the surface of the land to the water table, and the direction of this flow in the unsaturated (vadose) zone is commonly independent of groundwater gradients. Aley and Kirkland (2012) showed that lateral transport distances in the unsaturated zone in the Ozarks can be 750 feet and perhaps more.
- Flow routes can change as a function of the amount of water in the groundwater system and the possibility of heavy pumping at some wells.

Important limitations of the groundwater tracing data include:

- Dye tracing data points are more spatially separated than are data points associated with wells.
- Dye may not all enter the subsurface at a single point.

Conclusion 20. Moix et al. (2003) measured stream flow gains and losses along Osage Creek in portions of the area that could conceivably contribute water to Cave Springs. They identified four stream segments where flow rate decreases were noted and where elevations were greater than Cave Springs. The possibility that portions of Osage Creek contribute water to Cave Springs was clearly a data gap that needed to be addressed. Three traces conducted during the current project (Traces 14-01, 14-02, and 14-03) were specifically designed to assess this possibility. No hydrologic connections were found between Osage Creek and Cave Springs.

Conclusion 21. 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. If groundwater recharge from stormwater detention basins is a major cause of increases in base flow then major attention must be focused on contaminant trapping and removal within stormwater basins.

CONCLUSIONS AND RECOMMENDATIONS ON BIOLOGICAL ISSUES

Conclusion 1. In addition to providing habitat for a maternity colony of Gray Bats and the largest population of Ozark Cavefish, Cave Springs Cave harbors a diverse assemblage of other species. These species will benefit from the conservation efforts designed to protect habitat for the cavefish and Gray Bat populations. Cave Spring may also provide habitat for other rare organisms yet to be observed because in-cave surveys have typically focused only on cavefish and bats. Cave-limited species such as springtails (Collembola), spiders, millipedes, and litocampid diplurans (Diplura) may also occur in Cave Springs Cave, since many of these types of species are known from surrounding caves in Benton County. Survey trips that visit the humanly accessible portion of Cave Springs Cave should allocate time for documenting additional species.

Conclusion 2. Besides Ozark Cavefish, Cave Springs Cave provides aquatic habitat for two groundwater-limited amphipods (*Stygobromus ozarkensis* and *S. ononadagaensis*), an isopod (*Caecidotea stiladactyla*), and copepods. These species are known to be preyed upon by cavefish, and tracking the abundance of these species over time may provide additional insight into the health of the population. Because *S. onondagaensis* may be an epikarst species rather than a cave stream species, drip pools in the cave should be inventoried for the presence of these amphipods. Survey trips that visit the humanly accessible portion of Cave Springs Cave should allocate time for assessing the abundance of these species.

Conclusion 3. Gray Bats use Cave Springs Cave as a maternity site and are found in the cave during the summer months. Population estimates have previously been as high as 22,000 bats, but the number of bats has declined. During the last 15 years, population estimates have been less than 5,000 bats. Bats from surrounding caves may use Cave Springs Cave if the primary maternity sites are disturbed, but this phenomenon needs more study. The cave is fenced, owned by Arkansas Natural Heritage Commission, and it is closed to visitation during the summer months to minimize disturbance to the maternity colony. The Illinois River

Watershed Partnership owns land adjacent to the cave that provides additional buffer for minimizing disturbance. Maintaining the integrity of the cave fence and minimizing the potential for human disturbance during the maternity season will continue to benefit the bat colony. Summer bat surveys will need to continue in order to determine if the bat population is stabilizing.

Conclusion 4. White Nose Syndrome (WNS) is a fungal disease that is decimating hibernating cave bats across the central and eastern United States, and the disease is currently spreading across the Ozarks. While WNS has not been documented in Benton County, the fungus has been reported from Washington County to the south. The spread of WNS into Benton County will almost certainly occur. The abundance and diversity of hibernating bats in Cave Springs Cave is not known, but developing a baseline of winter bat use should occur prior to detection of WNS.

Conclusion 5. The Ozark cavefish is an extremely ancient species and it is not closely related to any other member of the cavefish family. Recent molecular studies suggest that the species should be in a separate genus from the Northern Cavefish. The population of cavefish at Cave Springs Cave is part of a genetically distinct group of Ozark cavefish that only occur in caves within the Illinois River watershed, and this distinct group of cavefish is endemic to Arkansas. The Cave Springs Cave population is the largest within the overall distribution of this species. The population has been significantly increasing in size from the over-collection of specimens in the 1950s, and the number of cavefish observed during bi-annual surveys fluctuate around 130 individuals. The population should continue to be monitored to ensure the population does not decline.

Conclusion 6. At Cave Springs Cave, Ozark Cavefish are occasionally observed in the entrance pool, and elevated discharge events can easily flush a cavefish over the entrance pool lip. Anecdotally, cavefish have been observed in the raceways downstream of the entrance following heavy precipitation events. The number of cavefish flushed out of the cave is unknown and represents a data gap that needs to be addressed. Land use conversions in the recharge area suggest the cave may experience changes in hydrologic response to precipitation events in the future. If the average number and intensity of discharge events increases because of these land use changes, the potential for loss of cavefish due to flushing out is greater.

CONCLUSIONS AND RECOMMENDATIONS ON CAVE CONSERVATION NEEDS AND METHODS

Conclusion 1. It is the conclusion of the OUL that, with appropriate actions, the people of Benton County can protect and maintain threatened and endangered species and experience further suburban growth in the recharge area for Cave Springs.

Conclusion 2. All lands in the Cave Springs recharge area do not pose equal potential for benefiting populations of cave fauna. Similarly, all lands do not pose equal potential for adverse impacts. The majority of potential adverse impacts on cave fauna result from activities and conditions on a small fraction of the total land area.

Conclusion 3. The OUL estimates that at least 40% of all water entering the karst groundwater system enters from points along the floors of the valleys, but only about 10% of the land area is in valleys. As a result, efforts to protect groundwater quality need to focus major management attention on the quality of water reaching the valleys and then entering the groundwater system.

Conclusion 4. Vulnerability mapping identifies areas having greater or lesser degrees of potential impacts on the groundwater system. This creates opportunities for water quality management strategies that are more flexible than buffer zones of uniform widths.

Conclusion 5. Ozark Cavefish populations in Cave Springs Cave exist not only near the cave entrance but also within a substantial part of the delineated recharge area. As a result, increasing distances from Cave Springs do not imply that land management practices pose lesser risks to the survival of Ozark Cavefish.

Conclusion 6. Fracture traces and lineaments in karst portions of the Ozarks represent zones of particularly intense fracturing and subsequent solutional action. In many cases a fracture trace or lineament represents a zone of relatively parallel fracturing with some cross fracturing rather than a single fracture. This helps explain why valleys oriented along fracture traces and lineaments commonly are not V-shaped, but instead have relatively flat-floors that are often several hundred feet wide. Valley settings are likely to provide cavefish habitat due to enhanced bedrock solution and greater than average input of dissolved and suspended organic matter that serves as a food source for cave fauna.

Conclusion 7. Soil series in the recharge area were divided into Good, Fair, and Poor Natural Soil Treatment Capability Soils. Discharges of poor quality waters onto soils having Poor or Fair capability classifications are of particular management concern. The risks posed by discharges of poor quality water are substantially increased if upper horizons of the soils are removed by construction projects. This occurs for two reasons. First, the upper soil horizons routinely have more cleansing capacity for removing contaminants than is the case for underlying soil horizons. Second, removal of any of the soil reduces the total mass of soil that can potentially remove passing groundwater contaminants.

Conclusion 8. Many, and perhaps all, stormwater detention basins in the recharge area for Cave Springs Cave should provide a reasonable level of water treatment for discharged waters. This treatment should be designed to protect both groundwater and surface water supplies.

Conclusion 9. A number of factors determine the necessary width of buffer zones along losing stream valleys. These include:

- Nature of the vegetation and degree of maintenance.
- Slope of the land.
- Natural Soil Treatment Capability class of the soil.
- Nature of upgradient land use.
- Volume of anticipated overland runoff reaching the buffer zone.
- Percent of contributing area paved or under roof.
- Amount of runoff passing through stormwater detention basins and effectiveness of the basins in detaining and treating runoff waters.

Conclusion 10. Most aquatic life kills in karst areas are related to acute toxicity from spills or infrastructure failures (such as loss of power to a sewage lift station with a resulting discharge of raw sewage to a losing stream). Acute toxicity problems can also occur when an intense summer rainstorm follows a long dry period and rapidly introduces large volumes of water with high BOD values into the karst groundwater system. Management must recognize that karst groundwater systems have substantially less ability than surface streams to re-oxygenate waters with depleted dissolved oxygen.

Conclusion 11. There are several sewage lift stations within the Cave Springs Cave recharge area. Not all currently have backup power in the event of an electrical outage. The adequacy of all components of sewage systems within the Cave Springs recharge area needs to be evaluated to ensure that the risk of major sewage discharges to the groundwater system is extremely remote. Routine maintenance of the facilities is also required.

Conclusion 12. In the past there have been a substantial number of poultry and hog CAFOs in the Cave Springs Cave recharge area. Land application of wastes from such facilities routinely involves large quantities of wastes, and land applications do not always coincide with favorable conditions. This has undoubtedly resulted in the introduction into the groundwater system of substantial short-duration pulses of oxygen demanding materials. Some of these impacts have, at least locally, exceeded impacts from suburban stormwater runoff. These impacts have decreased as land use has changed in recent years.

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