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Vulnerability Assessment Summary for the Cave Springs Cave Recharge Area Cave Springs, Arkansas

FINAL REPORT

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Summary report prepared in partnership with The Nature Conservancy, Crafton Tull Associates, and Wright Water Engineers for the Cave Springs Area Karst Resource Conservation Study performed in behalf of the Northwest Arkansas Regional Planning Commission.

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Note: Figures referenced in this report are Exhibits of the Cave Springs Area Karst Resource Conservation Study and are not attached to this report.

1 INTRODUCTION

The groundwater vulnerability assessment described in this report was performed as part of the Cave Springs Area Karst Resource Conservation Study. This study was conducted for the Northwest Arkansas Regional Planning Commission (NWARPC) with funding from the Arkansas Highway and Transportation Department (AHTD). The work described in this report was performed by the Ozark Underground Laboratory, Inc. (OUL) in collaboration The Nature Conservancy (TNC), Crafton Tull Associates (CTA), and Wright Water Engineers (WWE).

1.1 Purpose and Scope of Study

The purpose of the groundwater vulnerability assessment is to provide an evaluation of the relative vulnerability of lands within the groundwater recharge area for Cave Springs Cave. This assessment identifies the relative level of scrutiny needed in locations within the recharge area based on geologic, hydrogeologic, and biologic data. The vulnerability assessment will guide the recommendation of best management practices (BMPs) to support the overall goals of the Cave Springs Area Karst Resource Conservation Study.

Previous tasks completed within the Cave Springs Area Karst Conservation Study that support the vulnerability assessment included in this report include a comprehensive review of available literature relating to the hydrology, water quality, and biology of Cave Springs Cave, as well as cave and karst conservation and management. These studies are summarized as part of the larger karst conservation study in an annotated bibliography (Aley and Slay 2015) and a literature review summary report (Aley et al. 2015). Data developed during the groundwater tracer study is detailed within the Groundwater Tracing and Recharge Area Delineation Summary Report for Cave Springs Cave (Beeman and Aley 2015).

Subsequent karst conservation study objectives, supported by the vulnerability assessment summarized in this report, will allow for future land use planning and continued development of the Cave Springs area while protecting the water quality and important cave fauna in Cave Springs Cave.

1.2 Site Background

Cave Springs Cave is located in the northwest Arkansas community of Cave Springs, at the intersection of Arkansas Highways 264 and 112 in southern Benton County (see Exhibit B). Much of the cave contains a perennial cave stream that discharges from the mouth of the cave. The cave is located beneath lands owned by the Arkansas Natural Heritage Commission. The spring flows into a small lake known as Partners Lake (formerly Lake Keith). This lake and surrounding lands are being developed into a watershed sanctuary and educational center by the Illinois River Watershed Partnership (IRWP).

Cave Springs Cave is home to the largest known population of Ozark Cavefish (*Amblyopsis rosae*). This cave-adapted small fish is federally listed as a threatened species. The cave is also home to several species of bats, one of which is federally listed as endangered. In addition to providing habitat for federally protected species of concern, water quality in the cave is also an indicator of regional water quality in the shallow aquifer.

Land use in much of the Cave Springs Cave recharge area was initially developed for agricultural use. In the last decade, an increasing amount of the agricultural lands have been converted into suburban development. This continued development has lead to concerns about water quality and the future health of Cave Springs Cave and its associated cave fauna. Planning for future growth, including highway corridor construction and improvement, while protecting the unique karst resources of the area, has led to the current karst conservation study.

1.3 Geologic Setting

A vast number of literature references document the geologic setting of the Cave Springs study area. Aley and Slay (2015) and Aley et al. (2015) summarize the available technical literature. The following sections provide an overview of information relating to the geologic setting that is most relevant to the groundwater vulnerability assessment detailed in this report.

1.3.1 Geology

Geologic mapping of the study area shows that the entire recharge area for Cave Springs is underlain by the Boone Formation of Mississippian age (Glick 1970 and 1972). No faults or other structural features are 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. No major faults or lineaments are present within the Cave Springs Recharge Area.

Karst development of the carbonate bedrock in the area is well known. Springs and caves are well documented on the USGS topographic map, as well as in the literature and in the local nomenclature (i.e., Cave Springs, Spring Creek, etc.). Aley et al. (2015) summarizes the technical literature related to the karst development of the area.

1.3.2 Soils

Based upon the Benton County soil survey, (Phillips and Harper 1977), the following three major soil associations are present within the Cave Springs recharge area.

- **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.** Described as: "Moderately well drained and well drained, nearly level to gently sloping deep loams soils on broad upland divides, " this soil association is reportedly is comprised of 60% Captina soils and 30% Peridge soils in Benton County. The remaining 10% of these soils 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 study area are summarized in Table 1 and are illustrated in Exhibit F. Soils in the recharge area are discussed further in Section 3.1.

Table 1. Major Soil Series and Hydrogeologically Important Characteristics. Data from Phillips and Harper (1977).

Soil Series	Depth to Bedrock (in)	Depth Below Surface (in)	Percent 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

1.4 Recharge Area Delineation

The recharge area delineation for Cave Springs Cave is described in the Groundwater Tracing and Recharge Area Delineation Summary Report for Cave Springs Cave (Beeman and Aley 2015). The recharge area delineation is shown in Exhibits A and B. The recharge area delineation was based upon 11 historic groundwater traces and 13 traces performed in 2014 (see Exhibit K), as well as available groundwater potentiometric data (see Exhibit E).

The Cave Springs recharge area is divided into two segments: the Direct Recharge Area and the Indirect Recharge Area. The Direct Recharge Area comprises 5702 acres (8.9 square miles) and provides most of the recharge water for Cave Springs. The northeastern boundary of the Direct Recharge Area lies roughly parallel to, and west of, Interstate 49. The Indirect Recharge Area comprises 6813 acres (10.6 square miles) and lies to the northeast of the Direct Recharge Area. Groundwater tracing has shown that very little of the water from sinking streams in this area reaches Cave Springs. However, the groundwater potentiometric contour map indicates that there is some groundwater movement from the Indirect Recharge Area into the Direct Recharge Area and ultimately to Cave Springs. Given this information, the OUL has concluded that the division of the Cave Springs recharge area into Direct and Indirect Recharge Areas is both technically reasonable and of practical value.

The total recharge area for Cave Springs is 12,515 acres (19.6 square miles); this is the sum of the Direct and Indirect Recharge Areas. Interstate 49 lies entirely within the Indirect Recharge Area. The Cave Springs recharge area encompasses lands that are included in the municipalities of Cave Springs, Rogers, Lowell, and Springdale.

Based on contoured water level elevations from prior to 1991, a trough in the groundwater potentiometric surface is located from Cave Springs to the east. This trough is located roughly parallel to Highway 264. The presence of this trough is supported by groundwater tracing data. This groundwater trough represents a preferential pathway whereby contaminants can enter the Cave Springs groundwater system.

2 METHODOLOGY

Previous investigations by the OUL have demonstrated that the vulnerability of a karst groundwater system and its associated biological community is a function of the hydrobiological characteristics of its particular groundwater system and is intimately connected with land use within its recharge area (Aley and Aley 1991). The vulnerability map developed during this project qualitatively depicts risks posed to groundwater quality by various portions of its recharge area.

- **Low Vulnerability lands.** These are areas that contribute relatively minor amounts of water to a spring and are unlikely to have significant deleterious impacts on water quality and cave fauna in the associated spring.
- **Moderate Vulnerability lands.** These are lands where the hydrobiological setting and existing and/or foreseeable land uses pose moderate risks of groundwater impacts likely to adversely affect Ozark Cavefish and the associated biological community. These are typically upland areas underlain by soils capable of removing many contaminants. Moderate Vulnerability lands are remote from sinkholes or losing streams and are areas where land use does not include localized groundwater contamination hazards such as suburban development utilizing on-site disposal of sewage or concentrated or confined animal operations (including poultry).
- **High Vulnerability lands.** These are lands where the hydrobiological setting and existing and/or foreseeable land uses pose high risks of groundwater impacts likely to adversely affect Ozark Cavefish and the associated biological community.
- **Extremely High Vulnerability lands.** These are lands where the hydrobiological setting and existing and/or foreseeable land uses pose extremely high risks of impacts likely to adversely affect Ozark Cavefish and the associated biological community.

Localized land use activities likely to create significant adverse groundwater quality impacts were located by field reconnaissance from public thoroughfares. Potentially hazardous land use activities were mapped during the field reconnaissance. The following potentially hazardous land uses were included in the survey:

- Agricultural and forestry;
- Sewage disposal facilities or concentrated housing served by on-site sewage systems;
- Landfills, dumps, and salvage yards;
- Industrial sites;
- Transportation routes, including pipelines;
- Petroleum storage sites;
- Other chemical storage sites; and
- Other types of sites or facilities.

The identified hazard features and designated vulnerability areas in each of the delineated recharge areas are discussed in Section 3.

3 VULNERABILITY ASSESSMENT

Vulnerability mapping is based on the concept that not all lands pose equal risks of introducing contaminants into karst groundwater systems. Vulnerability mapping is based on physical and hydrogeologic conditions of the land being mapped. The approach permits planners and others to tailor the level of management attention to the likely severity of groundwater impacts from particular land uses.

3.1 Vulnerability Factors

Various factors affect the relative level of risk. Key among these factors is the type of groundwater recharge that is related to various land areas. Discrete recharge is localized and concentrated. In contrast, diffuse recharge is not localized; instead, it is dispersed.

Discrete recharge zones include sinkholes, losing stream segments, and some features that lack surface expression. In the Cave Springs recharge area sinkholes are rare. In contrast, losing stream segments are common throughout the recharge area. This is demonstrated by the observation that most of the stream channels in the recharge area large enough to be shown on 7.5 minute topographic maps cease flowing within a few following a precipitation event. The flow ceases when the rate at which losing stream segments can transport water into the groundwater system exceeds the flow rate in the surface stream. In addition, flow rates at Cave Springs respond within a few hours to substantial precipitation events. This rapid response is due in large measure to discrete recharge that quickly enters the groundwater system through losing stream segments and is then rapidly transported through the karst groundwater system.

Diffuse recharge is water that slowly infiltrates through soils before reaching the epikarstic zone. The epikarst is the weathered upper portion of the bedrock. The thickness of the epikarst is variable, but based on observations from road cuts in the Boone Formation it is commonly 30 feet or less. The epikarstic zone is drained by localized solutionally widened fractures and other karst features that ultimately convey recharging waters into the conduits feeding cave streams and springs. Substantial quantities of water are routinely detained within the epikarstic zone. The slow discharge of this detained water from the epikarst zone is largely responsible for sustaining the flow of Cave Springs during drier periods of the year.

Waters entering karst groundwater systems through diffuse recharge receive more effective natural cleansing than is the case for discrete recharge waters. As contrasted with discrete recharge waters, diffuse recharge water has more contact with soil particles. This increases the effectiveness of filtration and the removal of contaminants by adsorption onto soil particles.

Vulnerability mapping in the Cave Springs recharge area focuses substantial attention on areas likely to contain discrete recharge zones. These areas include losing stream corridors, the groundwater trough identified in the Recharge Area Delineation study (Beeman and Aley 2015), as well as the natural soils treatment capability.

3.1.1 Losing Stream Corridors

The most significant discrete recharge zones in the Cave Springs recharge area are losing stream corridors. These stream corridors contain little or no perennial stream flow due to the loss of surface flow to the groundwater system. Recharge to the Cave Springs that enters the groundwater system through losing stream corridors receive very little natural effective cleansing. Losing stream corridors were identified by field reconnaissance of streams within the Direct Recharge Area.

3.1.2 Groundwater Trough

A trough in the groundwater potentiometric surface is located from Cave Springs to the east based on contoured water level elevations from prior to 1991. This trough is located roughly parallel to Highway 264. The presence of this trough is supported by groundwater tracing data. This groundwater trough represents a preferential pathway whereby contaminants can enter the Cave Springs groundwater system.

3.1.3 Natural Soils Treatment Capability

Soils provide natural cleansing of contaminants in infiltrating waters through filtration and the removal of contaminants by adsorption onto soil particles. Therefore, the mapped soils series summarized in Section 1.3.2 were grouped into classifications that describe their relative natural soil treatment capability (Aley et al. 2015). These natural soil treatment capability classifications are illustrated in Exhibit G.

3.1.4 Direct and Indirect Recharge Areas

The relative location of lands within the Direct versus Indirect Recharge Area was another factor that was considered during the vulnerability assessment. Lands within the Indirect Recharge Area have been shown to provide less groundwater recharge to the Cave Springs groundwater system than lands within the Direct Recharge Area.

3.2 Vulnerability Classifications

Vulnerability mapping for Ozark Cavefish delineation studies has qualitatively depicted risks posed to groundwater quality by various portions of the recharge areas. The OUL has routinely depicted the following four categories in these assessments, as described in Section 2 (see Exhibit L):

- Low Vulnerability,

- Moderate Vulnerability,
- High Vulnerability, and
- Extremely High Vulnerability.

Low Vulnerability lands in the recharge area for Cave Springs are identified as areas within the Indirect Recharge Area. This area includes Interstate Highway 49 (I-49) and lands along Blossom Way Creek. The potentiometric map of the area (see Exhibit E) shows groundwater movement from the western portion of the Indirect Recharge Area into the Direct Recharge Area. Dye tracing has shown that this area contributes only a small portion of its water yield to Cave Springs. Dye for Trace 78-08 was introduced in the Indirect Recharge Area and detected (Aley 1978b) at both South Spring (in the channel of Blossom Way Creek) and Cave Springs (see Exhibit K). While the majority of the dye from this trace was detected at South Spring, the trace verified that there is groundwater flow from the Indirect Recharge Area to Cave Springs.

The location of I-49 across the Cave Springs recharge area is largely along Blossom Way Creek. The high volume of traffic causes an increased potential for spills during highway accidents as well as potentially poor quality stormwater runoff. Due to these reasons and its location along Blossom Way Creek, additional scrutiny is necessary along this corridor within this vulnerability classification. To address this concern, stormwater detention ponds are being constructed to collect the first half-inch of stormwater runoff from the interstate highway.

Moderate Vulnerability lands in the Cave Springs recharge area include areas within the Direct Recharge Area for Cave Springs. Moderate Vulnerability lands are underlain by soil series that have been identified as having good natural soil treatment capability (Aley et al. 2015). These areas are shown on Exhibit L. The predominant soil series in this group are Peridge Silt Loam and Captina Silt Loam; they are both characterized by 1 to 3% slopes. These soils occur on approximately 41% of the Direct Recharge Area.

High Vulnerability lands in the Cave Springs recharge area are underlain by soils that have fair natural soil treatment capability (see Exhibit L). Major soil series in these categories are Secesh Gravelly Silt Loam, Tonti Gravelly Silt Loam, and Nixa Very Gravelly Silt Loam. Where these soils are identified within losing stream corridors and within the delineated potentiometric trough associated with Cave Springs Cave, additional scrutiny is required.

Extremely High Vulnerability lands are areas where the hydrogeologic setting is routinely associated with discrete groundwater recharge or where the area overlies the potentiometric trough associated with Cave Springs. These areas include soils with poor natural treatment capability. Location within a losing stream corridor is also a factor that is considered within the highest vulnerability classification. . These stream segments have (or under natural conditions had) a gravel stream channel. This highest level of vulnerability is also considered for lands overlying the delineated potentiometric trough area associated with Cave Springs Cave.

3.3 Groundwater Hazard Areas

Hazard areas are localized land use activities that have the potential to create significant adverse groundwater quality impacts. Current land uses in the Direct Recharge Area for Cave Springs that present the greatest potential for adversely impact groundwater quality and the survival of the Ozark Cavefish include the following:

- Runoff and spills from highways;
- Sewage conveyance, treatment and disposal facilities; and
- Stormwater detention basins.

3.3.1 Highways

The first highway of concern is Interstate 49. Based in large part on groundwater tracing work (Beeman and Aley 2015), the highway was located outside of the area initially identified as the Direct Recharge Area for Cave Springs. The current hydrologic study has verified that none of I-49 is within the Direct Recharge Area for Cave Springs. However, approximately 2.9 miles of this highway is within the Indirect Recharge Area in a Low Vulnerability area.

Interstate 49 is in the process of being up-graded to three lanes each way and with stormwater detention basins capable of retaining the first 0.5 inch of runoff from the highway. The OUL provided a hydrogeologic review of strategies and locations for the stormwater detention basins and concurred with the decisions that were made. Given the vulnerability classification for the highway corridor, the stormwater detention basins represent an appropriate and adequate action for protecting water quality and the cave fauna in Cave Springs Cave.

The second highway of potential concern is the US Highway 412 Springdale Bypass. Findings from the current hydrogeologic studies confirm that this highway corridor lies outside of the recharge area for Cave Springs. It also lies outside of the recharge area for Reed Spring. This is important because Reed Spring provides presumptive habitat for the Ozark Cavefish.

The third highway of concern is Arkansas Highway 264. It extends for approximately 3.9 miles across the Direct Recharge Area for Cave Springs, and much of this corridor is within High or Extremely High Vulnerability lands. The highway is near (and in some cases within) the delineated groundwater trough in the potentiometric surface that is associated with Cave Spring Cave.

Arkansas Highway 264 is a heavily traveled two-lane highway with hills, two 90-degree curves, and a number of unprotected intersections with other streets and roads. Completion of the US 412 Bypass will undoubtedly decrease traffic on this road, especially truck traffic. Highway 264 through the Cave Springs recharge area undoubtedly poses the single-most severe threat to water quality in Cave Springs Cave and its cave fauna.

Actions that reduce the extent of truck traffic on Highway 264 would be beneficial. Additionally, highway improvements that increase safety on the highway would also be helpful. While hazardous cargoes are of special concern, even some common cargoes can present severe threats to groundwater quality and underground fauna. An example is milk. Milk, when added to water, creates a solution with a very high BOD/COD value. The resulting solution quickly depletes dissolved oxygen concentrations in the receiving water and can suffocate aquatic life.

3.3.2 Sewage Conveyance, Treatment, and Disposal

Sewage conveyance, treatment and disposal facilities are a second category of hazard areas. If sewage conveyance lines in a karst landscape develop leaks, the liquid frequently migrates downward into the groundwater system rather than surfacing where it can be readily discovered and the leak repaired. A catastrophic break in a major sewer trunk line at Springfield, Missouri lost an estimated 10 million gallons of raw sewage into the karst groundwater system and created a large sinkhole. The geologic units at the Springfield site and at Cave Springs are the same.

Areas in the Cave Springs recharge area that pose the greatest risks for undetected leakage are in losing stream valleys. These areas are often unstable due to localized subsidence or sinkhole formation, and this can result in leaks or breaks in sewer lines. The problem is compounded when sewage conveyance lines are routinely routed along valley floors. The Caveland Sanitation Authority in Kentucky dealt with the sewage conveyance line problem by using high density polyethylene pipe that would stretch rather than break in areas where there was differential subsidence. Other engineering approaches may be viable.

Large scale onsite septic system treatment and disposal of wastewater, such as on a subdivision scale, should be avoided within the Cave Springs recharge area. At least three subdivisions were identified with onsite septic systems and community soil adsorption and disposal fields. These existing systems should be properly maintained for optimum performance.

Aley et al. (2015, page 10) discussed a major aquatic life kill at Ozark Spring. It occurred when the electric power failed at a sewage lift station and raw sewage discharged to the adjacent losing stream. There was no source of emergency power for the lift station. At a minimum, backup power capable of preventing any uncontrolled discharge at lift stations or other similar facilities should be required in the Cave Springs recharge area. There is one current facility located adjacent to a losing stream about 1,700 feet northeast of Cave Springs that does not appear to have backup power.

An engineering evaluation of lift stations and other sewage facilities in the Cave Springs recharge area is needed. It should determine if there are facilities that need to be upgraded to prevent uncontrolled discharges.

3.3.3 Stormwater Detention Ponds

Stormwater runoff from urban and suburban areas, and particularly from paved surfaces, is a well recognized source of surface and groundwater contamination. Meister and Kefer (1981) compared the quality of urban stormwater runoff with similar values from an area of forest and meadows. BOD values indicate the amount of oxygen required to break down organic matter, and thus are a good indicator of the amount of organic matter contained in water. Meister and Keifer (1981) found that the BOD values of urban stormwater were about 10 times greater than those for forest and meadow runoff.

Nutrients, such as nitrates, aid in the breakdown of organic matter. Meister and Kefer (1981) found that urban runoff contained an average of about 20 times more nitrates than did runoff from forests and meadows. Urban stormwater runoff also contains unnaturally large concentrations of other materials that can adversely impact caves fauna and groundwater quality.

As should be expected, the concentration of contaminants in stormwater runoff is much greater in the first flush of runoff water. Jenkins (1988) notes that the first half-inch of runoff water from storms often contains 80 to 95% of the total annual pollutant load.

Portions of the study area have experienced suburban development. These developments have included a number of stormwater detention ponds. While these ponds decrease the magnitude of downstream surface flows, they have the potential to adversely impact groundwater quality in karst areas for five reasons:

1. The stormwater retention basins are often constructed in small water courses and these areas are routinely characterized by more rapid water infiltration into the subsurface than is the case for adjacent lands.
2. The detention ponds spread impounded stormwater runoff onto larger areas than under natural conditions. The design of the detention ponds also prolongs the duration of ponding thereby increasing total groundwater recharge.
3. The waters detained in the ponds are routinely the first flush of stormwater runoff, and this water is routinely the most highly contaminated runoff water.
4. Stormwater detention ponds as currently designed and constructed in the study area provide little if any water quality improvement for the detained waters.
5. During construction, upper horizons of the soil are often removed from the floor of the retention basins and are used as dike material. These upper horizons are routinely the best suited natural earth material for detaining or removing groundwater contaminants.

4 SUMMARY AND CONCLUSIONS

A groundwater vulnerability assessment was conducted for the recharge area for Cave Springs Cave, a biologically significant cave and namesake for the northwest Arkansas community in Benton County, Arkansas. The assessment described in this report was performed as part of the larger Cave Springs Area Karst Resource Conservation Study.

Vulnerability assessment is based on the concept that not all lands pose equal risks of introducing contaminants into karst groundwater systems. Vulnerability mapping is based on physical and hydrogeologic conditions of the land being mapped. The approach permits planners and others to tailor the level of management attention to the likely severity of groundwater impacts from particular land uses.

The vulnerability of a karst groundwater system and its associated biological community is a function of the hydrobiological characteristics of its particular groundwater system and is intimately connected with land use within its recharge area. The vulnerability map developed during this project qualitatively depicts risks posed to groundwater quality by various portions of its recharge area. Areas within the Cave Springs recharge area were mapped into the following categories of relative risk:

- **Low Vulnerability Lands** including lands within the Indirect Recharge Area for Cave Springs, with additional scrutiny required along the I-49 corridor;
- **Moderate Vulnerability Lands** including lands within the Direct Recharge Area with soils that have been classified as having good natural soil treatment capability;
- **High Vulnerability Lands** including lands within the Direct Recharge Area with soils that have been classified as having fair natural soils treatment capability; and
- **Extremely High Vulnerability Lands** including lands within the Direct Recharge Area with soils that have been classified as having poor natural soils treatment capability. Locations within the groundwater trough and along losing stream corridors are also considered as extremely high vulnerability factors.

Potential hazards to groundwater quality were also identified within the Cave Springs recharge area. The major groundwater hazards identified include runoff and spills from highways; sewage conveyance, treatment and disposal facilities; and stormwater detention basins. These hazards will be addressed during subsequent development of BMPs in the next phase of the Cave Springs Area Karst Resource Conservation Study. The vulnerability mapping performed in this assessment helps to ensure that land development BMPs are only applied to necessary areas where they will do the most good in protecting water quality at Cave Springs.

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