



# George Veni & Associates

Hydrogeologists and Biologists  
Environmental Management Consulting  
Cave and Karst Specialists

## DELINEATION OF HYDROGEOLOGIC AREAS AND ZONES FOR THE MANAGEMENT AND RECOVERY OF ENDANGERED KARST INVERTEBRATE SPECIES IN BEXAR COUNTY, TEXAS

Prepared for:

U.S. Fish and Wildlife Service  
10711 Burnet Road, Suite 200  
Austin, Texas 78758

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11304 Candle Park, San Antonio, Texas 78249-4421  
(210) 558-4403 • Fax (413) 383-2276  
gveni@satx.rr.com

# DELINEATION OF HYDROGEOLOGIC AREAS AND ZONES FOR THE MANAGEMENT AND RECOVERY OF ENDANGERED KARST INVERTEBRATE SPECIES IN BEXAR COUNTY, TEXAS

by  
**George Veni Ph.D.**

## Introduction

The Bexar County, Texas, region is hydrogeologically and biologically complex. Species living in its caves have become physically isolated from each other through time, resulting in genetic isolation that has produced new species known to occur only within small geographic areas. The northward expansion of San Antonio onto the karst where these species occur poses a threat to their survival due to the destruction of caves, sealing of caves, changes in nutrient and moisture input into caves, contaminants introduced into caves, and competition with and predation by non-native species introduced by urbanization (Elliott, 1993 and 2000).

To insure their survival, nine species of karst invertebrates were federally listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in December 2000 (USFWS, 2000):

|  |                              |
|--|------------------------------|
| <i>Batrissodes (Excavodes) venyivi</i> | <i>Neoleptoneta microps</i>  |
| <i>Cicurina (Cicurella) baronia</i>    | <i>Rhadine exilis</i>        |
| <i>Cicurina (Cicurella) madla</i>      | <i>Rhadine infernalis</i>    |
| <i>Cicurina (Cicurella) venii</i>      | <i>Texella cokendolpheri</i> |
| <i>Cicurina (Cicurella) vespera</i>    |                              |

The purpose of this investigation is to assist USFWS in designating critical habitat for the species through direct consultation and, through this report, the delineation of hydrogeologic zones and areas important to the species' management and recovery. This report will build on previous studies that conducted partial and/or initial research on this topic.

Veni (1994) examined the effects of the geology of the Bexar County area on the distribution of the species, which were petitioned for listing at the time, and that of other troglobite species identified by Reddell (1993). That report included a series of 14 maps drawn on the U.S. Geological Survey (USGS) 7.5' topographic quadrangles for the area that delineated five zones that identified the probability of the presence of rare or endemic species. Those zones, slightly redefined here in recognition that the species are now listed, are:

**Zone 1.** Areas known to contain listed invertebrate karst species.

**Zone 2.** Areas having a high probability of containing suitable habitat for listed invertebrate karst species.

**Zone 3.** Areas that probably do not contain listed invertebrate karst species.

**Zone 4.** Areas which require further research but are generally equivalent to Zone 3, although they may include sections which could be classified as Zone 2 or Zone 5 as more information becomes available.

**Zone 5.** Areas which do not contain listed invertebrate karst species.

Investigations prior to this report include hydrogeologic research that has been used to delineate surface and groundwater drainage basins for caves known to contain the listed species. These studies include work by Veni (1996a, 1997a) for USFWS and several studies at Camp Bullis Military Reservation for the Department of Defense, cited later in this report.

This report has three purposes:

- 1) Re-evaluate and redraw, as necessary, areas designated as Zone 1 in Bexar County.
- 2) Compile existing data on the surface and groundwater drainage basins for all caves known to contain federally listed species.
- 3) Using the best available information, estimate the surface and groundwater drainage basins for any of the caves for which this information does not currently exist.

## Methodology

Work for this project to delineate karst zones and drainage basins began with reviews of the existing cave and karst research conducted in Bexar County, literature related to the listed species, and consultation with other specialists and environmental management personnel as needed in order to collect all existing information relevant to this project. The Texas Speleological Survey (TSS) provided access to files which include a significant amount of unpublished information on Bexar County caves.

### **Karst zone delineation methods**

ArcGIS version 8.2 was used first to check the accuracy of the digital transcription of the karst zones conducted by the USGS, which were originally drawn on paper maps. Where the original maps joined, some had a few small inconsistencies which I corrected in consultation with the USGS when the maps were digitized. No significant errors were found during this verification process. However, numerous minor modifications were made in the karst zone boundaries to overcome limitations of the initial zone delineation method.

The original paper maps were drawn by interpolating the position of geologic boundaries shown on other paper maps, including draft mapping by the USGS that has since been updated and published by Stein and Ozuna (1995). The USGS (George Ozuna, Chief, Water Resources Division, San Antonio, personal communication, 2002) provided digital versions of Stein and Ozuna's (1995) mapping of the Edwards Aquifer recharge zone plus provisional mapping of the Glen Rose Formation in Bexar County. Where the two maps overlapped and differed, the more recent map was used, since it probably improved upon the older map. The digital versions allowed precise overlay and correlation of the geologic and karst zone boundaries, important since many zone boundaries are determined by the geology. The level of precision was the limit of distinguishing little or no visual differences at a scale of 1:1,000 for the study area or a distance of about 1-2 m. However, the accuracy of the boundaries is based on the accuracy of the USGS geologic and topographic maps, which is not known and probably varies. The Glen Rose mapping, while provisional, is far superior to previous mapping of that unit and the best available information. Non-digital geologic maps by Barnes (1983) and Collins (2000) were used to draw and update karst zones south of the Edwards recharge zone. For the part of the Edwards recharge zone extending into Medina County, a non-digital map by Lambert, Grimm, and Lee's (2000) was used.

Although the scope of work called only for the revision of Zone 1, the remaining zones were also revised with ArcGIS based on the geologic mapping now available, further studies of cave and karst development, and the most current information available on the distribution of listed and non-listed troglobite species. These revisions proved useful in more accurately redefining Zone 1 to recognize the localities for species discovered since the original zone map was produced in 1994. Also, based on the collected data, surface and groundwater drainage basins were drawn in ArcGIS for each cave known to contain listed species. Future reexamination of the karst zones and drainage basins may change the boundaries as new information becomes available and as geologic maps are refined.

The bulk of this report describes the rationale in defining the Zone 1 and drainage basin boundaries and their limitations. Table 1 is a list of all 78 caves known or reported to contain the listed

species, the listed species that occur in each cave, and the karst fauna regions (defined at the beginning of the next section) in which the caves occur. The species are confirmed in 74 caves. The four caves where listed species have been reported, presumably based on a taxonomist's examination of specimens, but not yet confirmed to USFWS are italicized in Table 1. Caves with only sight records of possible listed species are discussed in this report but are not included in Table 1. There are many caves in Bexar County where listed species are suspected to occur based on collections of troglobites identifiable to genera that included listed species, but that are the wrong gender and/or insufficiently mature for identification to species level.

The principles used to delineate specific Karst Zone 1 boundaries in this report are to identify geologic or topography features that may restrict the distribution of the listed species and examine the distribution of listed and non-listed troglobites for indications that the boundaries are valid. The karst fauna regions, described later in this report, are partly defined by geologic units where caves are common or rare. Contacts between such units are the most reliable factors in delimiting Zone 1 boundaries. These sometimes occur in valleys where erosion has removed one unit and exposed another. They also occur along some faults where one unit may be juxtaposed against another.

Many Zone 1 boundaries are not that simple to define. Where there is no known discontinuity in the cavernous limestone and for lack of other possible options, Zone 1 boundaries may be drawn along creek beds and the locally narrowest or lowest drainage divide. These locations are where the limestone is thinnest and may pose some restrictions on species distribution. Faults with cavernous rock on either side do not seem to restrict species distribution, but they may be selected as a Zone 1 boundary if other possibilities are exhausted. While some caves form along faults, fault planes filled with calcite or gouge are unlikely sites for cave development. Other factors considered in the delineation of Zone 1 boundaries include:

- 1) The lowest known cave elevation should be compared with the lowest topographic elevation to be sure at least the known cavernous zone in the rock is encompassed.
- 2) The distribution of listed and non-listed troglobites in different caves should be examined. If the troglobite and especially the listed fauna are similar, the caves may warrant grouping into a single zone. The quality of the collections should be weighed as well. Collections conducted only once, under poor conditions, cursorily, and/or by non-specialists in the collection of cave species, should be given greater weight for similarity of species, since more detailed studies would likely yield more similarities.
- 3) The type and extent of cave development in the area will indicate how realistic it may be for cavernous voids to occur in locations considered as zone boundaries.
- 4) The presence of other caves in the area, especially if they occur between caves with listed species, demonstrates the presence of potential habitat for the species, unless the caves have been carefully surveyed and the species were not found; this latter point is one of principle and was not encountered.

These factors are not always consistent. For example, the geology may suggest a restriction, but the biology may indicate the opposite. All available factors and information are considered to determine which features and locations are the mostly likely boundaries.

**Table 1**  
**List of Bexar County Caves with Endangered Species as of 23 December 2002**  
**(abbreviations defined at end of table)**

| Cave Name                    | Karst Fauna Region | Cic mad | Cic bar | Cic ven | Cic ves | Neo mic | Tex cok | Rha exi | Rha inf ewe | Rha inf nssp | Rha inf inf | Bat ven | Tot ES |
|------------------------------|--------------------|---------|---------|---------|---------|---------|---------|---------|-------------|--------------|-------------|---------|--------|
| B-52 Cave                    | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Backhole                     | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Black Cat Cave               | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Bone Pile Cave               | Gov. Canyon        |         |         |         |         |         |         |         |             |              | X           |         | 1      |
| Boneyard Pit                 | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Braken Bat Cave              | Culebra Anti.      |         |         | X       |         |         |         |         |             |              |             |         | 1      |
| Bunny Hole                   | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Canyon Ranch Pit             | Gov. Canyon        |         |         |         |         |         |         |         |             | X*           |             |         | 1      |
| Caracol Creek Coon Cave      | Culebra Anti.      |         |         |         |         |         |         |         | X           |              |             |         | 1      |
| Christmas Cave               | Helotes            | X       |         |         |         |         |         | X       |             |              | X           | X       | 4      |
| Continental Cave             | Gov. Canyon        |         |         |         |         |         |         |         |             | X*           |             |         | 1      |
| Creek Bank Cave              | Gov. Canyon        |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Cross the Creek Cave         | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Crownridge Canyon Cave       | UTSA               |         |         |         |         |         |         |         |             |              | X           |         | 1      |
| Dancing Rattler Cave         | Gov. Canyon        |         |         |         |         |         |         |         |             |              | X           |         | 1      |
| Dos Viboras Cave             | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Eagles Nest Cave             | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Fat Man's Nightmare Cave     | Gov. Canyon        |         |         |         |         |         |         |         |             | X*           |             |         | 1      |
| Flying Buzzworm Cave         | Stone Oak          |         |         |         |         |         |         |         | X           |              |             |         | 1      |
| 40mm Cave                    | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Game Pasture Cave No. 1      | Culebra Anti.      |         |         |         |         |         |         |         |             | X            |             |         | 1      |
| Genesis Cave                 | Stone Oak          |         |         |         |         |         |         |         |             |              | X           |         | 1      |
| Government Canyon Bat Cave   | Gov. Canyon        |         |         |         | X       | X       |         | X       |             |              | X           |         | 4      |
| Hackberry Sink               | Gov. Canyon        |         |         |         |         |         |         |         |             |              | X           |         | 1      |
| Hairy Tooth Cave             | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Headquarters Cave            | Stone Oak          | X       |         |         |         |         |         | X       | X           |              |             |         | 3      |
| Helotes Blowhole             | Helotes            | X       |         |         |         |         |         | X       |             |              | X           |         | 3      |
| Helotes Hilltop Cave         | Helotes            |         |         |         |         |         |         | X       |             |              |             | X       | 2      |
| Hilger Hole                  | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Hills and Dales Pit          | UTSA               | X       |         |         |         |         |         | X       |             |              |             |         | 2      |
| Hold Me Back Cave            | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Hornet's Last Laugh Pit      | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Isocow Cave                  | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Isopit                       | Culebra Anti.      |         |         |         |         |         |         |         |             | X            |             |         | 1      |
| John Wagner Ranch Cave No. 3 | UTSA               |         |         |         |         |         |         | X       |             |              | X           |         | 2      |
| Kamikazi Cricket Cave        | UTSA               |         |         |         |         |         |         | X       |             |              | X           |         | 2      |
| Kick Start Cave              | Stone Oak          |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| King Toad Cave               | Culebra Anti.      |         |         |         |         |         |         |         |             | X            |             |         | 1      |
| La Cantera Cave No.1         | UTSA               |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| La Cantera Cave No.2         | UTSA               |         |         |         |         |         |         | X       |             |              |             |         | 1      |
| Lithic Ridge Cave            | Gov. Canyon        |         |         |         |         |         |         | X       |             |              | X           |         | 2      |

**Table 1 (continued)**  
**List of Bexar County Caves with Endangered Species as of 23 December 2002**

| Cave Name                                      | Karst Fauna Region | Cic mad  | Cic bar  | Cic ven  | Cic ves  | Neo mic  | Tex cok  | Rha exi   | Rha inf ewe | Rha inf nssp | Rha inf  | Rha inf inf | Bat ven  | Tot ES |
|--|--------------------|----------|----------|----------|----------|----------|----------|-----------|-------------|--------------|----------|-------------|----------|--------|
| Logan's Cave                                   | Helotes            |          |          |          |          |          |          | X         |             |              |          | X           |          | 2      |
| Lost Pothole                                   | Gov. Canyon        | X        |          |          |          |          |          |           |             |              |          |             |          | 1      |
| Low Priority Cave                              | Stone Oak          |          |          |          |          |          |          |           | X           |              |          |             |          | 1      |
| Madla's Cave                                   | Helotes            | X        |          |          |          |          |          |           |             |              |          | X           |          | 2      |
| Madla's Drop Cave                              | Helotes            | X        |          |          |          |          |          |           |             |              |          | X           |          | 2      |
| MARS Pit                                       | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| MARS Shaft                                     | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Mastodon Pit                                   | UTSA               |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Matke Cave                                     | UTSA               |          |          |          |          |          |          |           |             |              |          | X           |          | 1      |
| Obvious Little Cave                            | Culebra Anti.      |          |          |          |          |          |          |           |             | X            |          |             |          | 1      |
| Pain in the Glass Cave                         | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Pig Cave                                       | Gov. Canyon        |          |          |          |          |          |          | X         |             |              | X*       |             |          | 2      |
| Platypus Pit                                   | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Poor Boy Baculum Cave                          | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| <i>Porcupine Squeeze Cave</i>                  | UTSA               |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Ragin' Cajun Cave                              | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Robber Baron Cave                              | Alamo Heights      |          | X        |          |          |          | X        |           |             |              |          |             |          | 2      |
| Robber's Cave                                  | UTSA               | X        |          |          |          |          |          | X         |             |              |          | X           |          | 3      |
| Root Canal Cave                                | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Root Toupee Cave                               | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| San Antonio Ranch Pit                          | Gov. Canyon        |          |          |          |          |          |          | X         |             |              | X*       |             | X        | 3      |
| Scenic Overlook Cave                           | Gov. Canyon        |          |          |          |          |          |          |           |             |              | X*       |             | X        | 2      |
| Scorpion Cave                                  | UTSA               |          |          |          |          |          |          |           |             |              |          | X           |          | 1      |
| Springtail Crevice                             | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Stevens Ranch Trash Hole Cave                  | Culebra Anti.      |          |          |          |          |          |          |           |             | X            |          |             |          | 1      |
| Strange Little Cave                            | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| <i>Sunray Cave</i>                             | UTSA               |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Surprise Sink                                  | Gov. Canyon        |          |          |          |          | X        |          |           |             |              |          | X           |          | 2      |
| Three-Fingers Cave                             | UTSA               |          |          |          |          |          |          | X         |             |              |          | X           |          | 2      |
| Tight Cave                                     | Gov. Canyon        |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| unnamed cave 800 m north of Helotes            | Helotes            |          |          |          |          |          |          | X         |             |              |          |             | X        | 2      |
| unnamed cave 8 km NE of Helotes (Cave 23)      | UTSA               |          |          |          | **       |          |          |           |             |              |          |             | X        | 1      |
| <i>unnamed cave no. 1 in Iron Horse Canyon</i> | Gov. Canyon        |          |          |          |          |          |          |           |             |              |          |             |          | ?      |
| <i>unnamed cave no. 2 in Iron Horse Canyon</i> | Gov. Canyon        |          |          |          |          |          |          |           |             |              |          |             |          | ?      |
| Up the Creek Cave                              | Stone Oak          |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| Wurzbach Bat Cave                              | Culebra Anti.      |          |          |          |          |          |          |           |             | X            |          |             |          | 1      |
| Young Cave No. 1                               | UTSA               |          |          |          |          |          |          | X         |             |              |          |             |          | 1      |
| <b>Totals: 78 caves</b>                        | --                 | <b>7</b> | <b>1</b> | <b>1</b> | <b>1</b> | <b>2</b> | <b>1</b> | <b>49</b> | <b>3</b>    | <b>7</b>     | <b>6</b> | <b>19</b>   | <b>6</b> | --     |

\* These species are probably *Rhadine infernalis infernalis* but are either not fully identified or reported.

\*\* *Ciurina vespera* was incorrectly identified from this cave. Further study proved the specimen was a new species (James Cokendolpher, personal communication, 2002).

Abbreviations used in Table 1:

Cic mad = *Cicurina madla*  
Cic bar = *Cicurina baronia*  
Cic ven = *Cicurina venii*  
Cic ves = *Cicurina vespera*  
Neo mic = *Neoleptoneta microps*  
Tex cok = *Texella cokendolpheri*  
X = known occurrence

Rha exi = *Rhadine exilis*  
Rha inf ewe = *Rhadine infernalis ewersi*  
Rha inf nssp = *Rhadine infernalis new subspecies*  
Rha inf = *Rhadine infernalis*  
Rha inf inf = *Rhadine infernalis infernalis*  
Bat ven = *Batrisodes venyivi*  
Tot ES = total endangered species per cave

### **Drainage basin delineation methods**

Water catchment areas for caves containing endangered species are defined in two ways: surface and groundwater drainage basins. Surface drainage refers to water that flows into the caves' entrances or directly associated features, such as sinkholes or fractures known to connect to the caves. For most caves in the area, these areas are small, measured in units of tens of meters or less, and are usually approximated based on visual estimation and pacing the distances in the field. Delineating surface drainage into caves located in streambeds initially seems simple, requiring only tracing the area on a topographic map along the topographic drainage divides. However, in some cases, not all of this water reaches the cave and is recharged via intervening fractures, karst features, and caves. The surface drainage areas are also dynamic, with water from more distant areas reaching a cave as rainfall volume increases. The entire potential surface water drainage basins are delineated in this report, with smaller areas also described as necessary to approximate the area that flows to a cave during a typical 1-year probability storm event of about 5-10 cm of rainfall. Since none of the surface water flowing into the caves is currently gauged, such estimates are rough and based on published and personal knowledge of recharge features and the local geology and hydrology. All surface water basins were drawn in ArcGIS 8.2 and are provided digitally along with this report.

Drainage areas are also delineated for each cave's groundwater basin. These basins delimit the surface areas where water enters the ground and flows into the caves via fractures, conduits, and passages whose connection to the surface is inferred but not observed. Where evidence suggests the likely presence of cave passages beyond the physically explored portion of the cave, and no conditions are known to preclude the presence of the cave's endangered species in those passages, then the groundwater drainage basin includes the areas that likely flow into those passages, even if the groundwater does not flow into the physically explored parts of the cave.

Groundwater drainage basins are determined by hydrogeologic assessment of the caves and karst features, mapping those features' interior conditions and layout of the cave or feature, evaluating the relationship of surface to subsurface features, and measuring and interpreting hydrogeologic features including strata, fractures, flow features (including but not limited to scallops, pitting, ponding, and enlarged bedding planes and fractures), sediments, speleothems, bone distribution, water flow, air flow, air quality, and resolution features. This information is used to determine the probable origin of the cave and karst features in order to gain insight into portions of the karst systems that are inaccessible to human exploration and probing, per the methodology proposed by Veni (1999) as the standard for karst environmental impact assessments. From such an analysis, groundwater basins can be estimated with potentially fair accuracy. In many cases, a cave's end-to-end length is used as a proven measure of conduit development at the site and multiplied by factors such as one, two, or three to establish the probable extent of the drainage basin in a particular direction. The multiplier will depend on the cave's morphology and the presence of fractures, drainage features, airflow, collapse,

sedimentation, and other factors that suggest greater or lesser cave development in a particular direction. If at all possible, tracer testing and geophysical investigation should be used to more accurately delineate groundwater drainage areas, but to date, such methods are not required by regulatory agencies and have rarely been used in the study area.

The above descriptions of surface and groundwater delineation assume access to the caves for field study. Such access is not within the scope of this work. This study relies on published information and personal experience to delineate those areas. With several caves, all of the factors considered in delineating groundwater basins are beyond the scope of inclusion in this report, in which case, the source study is referenced for additional information. All groundwater basins delineate the minimum likely drainage areas; water from additional areas may flow into the caves, but currently, information is insufficient to justify their inclusion in the groundwater drainage basins. Caves that are well studied, and where those data are available, have the best defined basins. Where less information is available, the drainage area sizes are delineated with a tendency to possibly overestimate their sizes in order to err in a fashion that will protect, rather than harm, the species.

The groundwater basins provided digitally with this report were drawn by scanning available maps of the caves or any drawn groundwater basins and inserting them into ArcGIS 8.2. Since the scans were not georeferenced, they were manually oriented to true north, scaled to precisely match the ArcGIS map, and their entrances centered over each cave's location coordinates; for most caves, the locations are probably within 10 m of their true positions. Each cave's location and geologic setting were considered with the factors in the previous paragraphs to determine the size and shape of the groundwater basin. The basins are described as distances from the footprint of each cave, and ArcGIS' measuring tool was used to determine those distances from the footprints drawn on the scanned maps. The basins were generally drawn to within 1 m of their described boundaries.

Analysis of all data used in this report was based on principles of karst hydrogeology, such as in the texts of White (1988), Ford and Williams (1989), and Klimchouk (2000) with consideration of local factors as discussed by Veni (1994). Appendix A is a glossary of geologic, biological, and karst terms used in this report. Appendix B is a conversion index from the International System of Units, used in this report, to English units. Appendix C provides my biography per USFWS guidelines for endangered species research.

Tannika Engelhard of USFWS facilitated this study and provided much needed information. Jenny Wilson of the USFWS and Cecilio Martinez of the USGS provided technical GIS support for this effort. James C. Cokendolpher, of Texas Tech University, and James R. Reddell, of the Texas Memorial Museum, provided important biological data and answered my questions relating to the biology of the study area. Karen Veni proofread the manuscript.

## Karst Zone Delineation

Veni (1994) divided the Bexar County karst into six karst fauna regions defined as:

***Alamo Heights.*** Includes the outcrop of Austin Chalk and Pecan Gap Chalk bounded within the horst beginning near San Pedro Park in San Antonio, and which heads northeast to where it pinches out near O'Conner Road roughly midway between Nacogdoches Road and Interstate Highway 35. Faulting is little to moderate.

***Culebra Anticline.*** Includes the outcrops of the Austin Chalk and Pecan Gap Chalk along the Culebra Anticline, extending west from Culebra Creek to the end of the outcrops about 3 km into Medina County. Faulting is little to moderate.

***Government Canyon.*** Includes the outcrop of the Edwards Limestone and the immediate down-slope outcrop of the upper member of the Glen Rose Formation. Bounded to the north by a major fault, to the east by Los Reyes Creek, to the south by the Haby Crossing Fault, and to the west by San Geronimo Creek. Faulting is moderate.

***Helotes.*** Bounded by the Haby Crossing Fault to the south, Helotes Creek to the east, Los Reyes Creek to the west, and the upper limits of the creeks' watersheds to the north. Includes isolated outcrops of Edwards Limestone on hilltops and outcrops of the upper member of the Glen Rose. Faulting is moderate to intense.

***Stone Oak.*** Includes the outcrops of the Edwards Limestone and the upper member of the Glen Rose Formation. Bounded to the north by Cibolo Creek and the contact with the lower member of the Glen Rose, to the east by Cibolo Creek, to the south by Balcones faults, and to the west by Leon Creek and intense faulting which narrows the Edwards outcrop. Faulting is moderate to intense.

***UTSA.*** Includes the outcrop of the Edwards Limestone, and the immediate down-slope outcrop of the upper member of the Glen Formation where the Edwards-Glen Rose contact is exposed. Bounded to the north by the interstream limit of the outcrops, to the east by Leon Creek and the intense faulting which narrows the Edwards outcrop, to the south by Balcones faults, and to the west by Helotes Creek and the Haby Crossing Fault which narrows the Edwards outcrop. Faulting is intense.

Based on more recent geologic studies and mapping in Bexar County, some of the regions could be slightly redefined but remain generally adequate. Veni, Reddell, and Cokendolpher (2002), following intensive study of Camp Bullis caves, biology, and geology, found justification for subdividing some of those regions according to lesser geologic features and species distribution that have little apparent geologic basis. Such delineation is beyond the scope of this report and is not discussed below. They also suggested modifying the definition of the Stone Oak Karst Fauna Region to include only the physically and hydrologically continuous sections of the outcrops of Edwards Limestone and of the upper 40 m of the upper member of the Glen Rose Formation that abut the Edwards Aquifer recharge zone. That modification is accepted for this report but has little effect on its findings.

Within and between the karst fauna regions, Veni (1994) used the following guidelines in delineating the karst zones in Bexar County. Those guidelines, slightly redefined here in recognition that the species are now listed, are:

**Zone 1.** Areas where listed species are present, and where speleogenetic, hydrologic or stratigraphic factors indicate continuity of the zone's karst and no restrictions to its fauna.

**Zone 2.** Outcrops of the Edwards Limestone, the upper 20 m of the upper Glen Rose east of Leon Creek, the upper 25 m of the upper Glen Rose west of Leon Creek, and the known cavernous areas of the Austin Chalk.

**Zone 3.** Outcrops of the upper Glen Rose from 20-55 m below the Edwards Limestone east of Leon Creek, the upper Glen Rose from 25-55 m below the Edwards Limestone west of Leon Creek, the Buda Limestone, the Pecan Gap Chalk, areas of the Austin Chalk where caves are not known, and alluvium-covered outcrops of the upper Glen Rose, Edwards Limestone, Buda Limestone, Austin Chalk, and Pecan Gap Chalk.

**Zone 4.** Outcrops of the upper Glen Rose stratigraphically more than 55 m below the Edwards Limestone.

**Zone 5.** Outcrops of non-karstic units, and areas where the Uvalde Gravel covers the karstic units.

Zone boundaries inside the Edwards Aquifer recharge zone are more precisely delimited because detailed geologic maps are available. Dashed lines mark approximate or uncertain boundaries and the limits of the study area along San Geronimo and Cibolo creeks where further research is needed to definitively classify those streams as boundaries.

The rationale for defining the specific boundaries of those zones were not defined. The intent of the distinction between Zone 1 and Zone 2 areas was that Zone 2 was where no reason was known to preclude the presence of the listed species, but that the listed species were not known. In most cases, Zone 2 areas were locations where caves were not known and/or biological surveys in the caves had not been conducted. It has since been found that in areas where adequate biological surveys for the species have been conducted in Zone 2, listed species have been found to redesignate them as Zone 1. This does not mean that listed species were found in every cave of a Zone 2 area.

During the general revision of the zone boundaries, taking advantage of precisely overlaying digital geologic maps, some zones were also revised based on more current geologic, karst, and biological information. Zones 1 and 2 remain as described above. Outcrops of the Georgetown Formation, which rarely forms caves and were included as Zone 2 areas by Veni (1994), are designated as Zone 3 in this report because geologic mapping is now available that distinguishes that poorly cavernous unit from the cavernous Person Formation.

Veni (1994) defined Zone 3 as extending 20-25 m below the top of the upper member of the Glen Rose Formation to the top of what Clark (in review) informally named the “fossiliferous zone.” This is informally labeled on the provisional USGS digital map of the upper Glen Rose as the “Lower KGRU” or lower part of the upper Glen Rose. Detailed surveys for caves and karst features in the fossiliferous zone at Camp Bullis, and biological studies of those caves (Veni et al. 2000; Veni, Glinn et al., 2002; Veni, Hammond et al., 2002) demonstrate they are biologically distinct from the areas where the listed species occur. Those areas, many of which had been designated Zone 4 where their status relative to the presence of listed species was uncertain, are now designated as Zone 5. This change in Zone 4 applies only to the area east of Leon Creek where the karst geology and biology of the fossiliferous zone has been well studied.

Zone 4 was eliminated east of Leon Creek as described above, and no changes were made in the unit west of Leon Creek, except where it is better defined by more recent geologic mapping and as discussed below in changes that extend into Medina County. The Zone 4 area west of Leon Creek not only has not been studied, but lithologic changes occur westward in the fossiliferous zone that have uncertain implications on endangered species distribution.

The delineation of Zone 5 was not fully described above by Veni (1994). It should have also included cavernous areas geologically separated from the areas where the listed species occur and which have been sufficiently studied biologically to demonstrate they contain a different suite of species.

Some zone boundaries were changed along floodplains. Zones were reassigned accordingly where topographic maps, geologic maps, aerial photographs, and/or personal experience indicate that the limestone is covered with a thick enough deposit of alluvium to reduce or eliminate the likely presence of listed species.

Veni (1994) noted that the Government Canyon Karst Fauna Region probably extended west from San Geronimo Creek and Bexar County to the Medina River in Medina County, but did not map karst zones for that area since no caves were known there. One cave is now known in that portion of Medina County, but it floods regularly, and large deposits of organic debris produce habitat not conducive to troglobites and the listed species. However, since the 1994 zone mapping, over 50 caves have been found in the Government Canyon Karst Fauna Region, whereas only one had been known. Seventeen of these caves contain listed species and demonstrate the likelihood that several caves, some with listed species, will occur in the largely unexamined karst west of San Geronimo Creek. As a result, karst zones have been drawn west to the Medina River. The boundaries of these zones are more approximate than in Bexar County due to the little speleological and biological information available for that area. This is reflected by the inclusion a large Zone 4 area where cavernous limestone is apparently present, but its potential to contain listed species is unknown.

It is beyond the scope of this report to describe the rationale for each zone boundary. However, the scope does call for a description of and explanation for the Zone 1 boundaries in each of the karst fauna regions, which are described below. Each Zone 1 area is named for a major cave or feature to make its identity more intuitively obvious, rather than assigning a random number or letter designation.

### **Zone 1 in the Alamo Heights Karst Fauna Region**

**Robber Baron Cave Zone 1.** Robber Baron Cave is the only known cave in the Robber Baron Cave Zone 1 area. Delineation of the zone boundaries is limited by several factors:

- 1) the coarse geologic mapping of the Austin Chalk in which the cave is formed;
- 2) its occurrence in a highly urbanized section of San Antonio which covers almost all potentially relevant features plus other reported but now sealed caves; and
- 3) other caves are consequently not available for geological and biological comparison.

With the little information available, the boundaries for the zone are delimited as extending 200 m from the cave's groundwater drainage basin as estimated later in this report. The 200-m distance represents twice the mean end-to-end length of the currently mapped portion of the cave.

### **Zone 1 Areas in the Culebra Anticline Karst Fauna Region**

**Caracol Creek Coon Cave Zone 1.** Caracol Creek Coon Cave is the only known cave in the Caracol Creek Coon Cave Zone 1 area and the only cave known to be biologically investigated in the Culebra Anticline Karst Fauna Region east of Medio Creek. The cave is formed in the Austin Chalk. Veni (1997a) found that the Austin's lithology was an important factor in cave development, but since the unit is poorly mapped locally, the distribution of its effects is poorly understood. The area around Caracol Creek Coon Cave has not been searched for possibly related caves and karst features.

Given the limited information available, the Caracol Creek Coon Cave Zone 1 eastern, western, and southern boundaries are delimited by the base of Caracol Creek for 1.1 km south of the cave to the confluence with an unnamed tributary from the east that cuts nearly as deep into the Austin Chalk. Both creeks cut below the level of the cave's main passage, but only Caracol Creek cuts below the cave's estimated deepest known point. To the north, the east and west boundaries follow the base of progressively shallower creeks for 1.95 km to where they join across a narrow upland drainage divide. This location also approximately marks the location of a possibly locally significant fault as mapped by Pinkley (1996) which might have some affect on species distribution.

**Southwest Zone 1.** Seven caves with listed species are known from this Zone 1 area: Braken Bat Cave, Game Pasture Cave No. 1, Isopit, King Toad Cave, Obvious Little Cave, Stevens Ranch Trash Hole Cave, and Wurzbach Bat Cave. *Rhadine infernalis* n. sp. has been found in all of the caves except Braken Bat Cave, which is the only confirmed locality for *Cicurina venii*; immature blind spiders collected from some of the other caves may be *Cicurina venii*.

The caves occur in two clusters located about 2.7 km apart. There is no intervening valley or geologic restriction between the groups to limit the distribution of their fauna, which is supported by the presence of *Rhadine infernalis* n. sp. in three caves in each cluster. Although there has been no reported survey for caves in this area, several have been found over the years and reported to the TSS. The caves may occur in clusters for geologic reasons not yet understood or simply be clustered by virtual of cave explorers' access to certain properties. Thirteen and 14 caves are known in the respective vicinity of Wurzbach Bat Cave and the Stevens Ranch that are not known to contain listed species; however, most have not been biologically investigated.

The western half of the Southwest Zone 1 boundaries is delimited primarily by the edge of the Austin Chalk outcrop. Caves in that area occur within 50 m of the contact with less cavernous rock and extend lower in elevation than all local outcrops of the Austin Chalk. The far western end of the

Austin Chalk outcrop is excluded due to its probably thin exposure and occurrence beyond a fault mapped by Pinkley (1996) that might mark the edge of that thin outcrop.

The eastern half of the Southwest Zone 1 boundaries is delimited primarily by the beds of Medio Creek and Potranco Creek or where their floodplain alluvium covers the Austin Chalk. Both creeks extend below the elevation of all known cave development in this zone. The southeastern part of the zone is also defined by the limits of the Austin Chalk outcrop between the creeks.

### **Zone 1 in the Government Canyon Karst Fauna Region**

**West Helotes Zone 1.** Fifteen caves with listed species are known from this Zone 1 area: Bone Pile Cave, Canyon Ranch Pit, Continental Cave, Creek Bank Cave, Dancing Rattler Cave, Fat Man's Nightmare Cave, Government Canyon Bat Cave, Hackberry Sink, Lithic Ridge Cave, Lost Pothole, Pig Cave, San Antonio Ranch Pit, Scenic Overlook Cave, Surprise Sink, and Tight Cave. Three caves in this Zone 1 area are reported to contain listed species, but have not been confirmed: 10-K Cave and two unnamed caves on the Iron Horse Ranch housing development property. *Rhadine infernalis* is the most widely distributed listed species within these caves, followed by *Rhadine exilis*, *Batrissodes ventyvi*, *Cicurina madla*, *Cicurina vespera*, and *Neoleptoneta microps*.

The West Helotes Zone 1 area encompasses the eastern half of the Government Canyon Karst Fauna Region. It is a faulted and stream-dissected block of predominantly Kainer Formation limestone, with some limestone from the Person Formation capping Black Hill and Clark's (in review) informally named "cavernous zone" of the upper member of the Glen Rose Formation in some valleys and along the eastern margin near Los Reyes Creek. Despite the faulting and incising of the limestone, the continuous occurrence of cavernous limestone throughout these units, the presence of known caves from high to low elevations, and the distribution of groups of similar listed and non-listed species in many of the caves demonstrate that the area functions as one faunal zone.

The northern and northeastern boundaries for the West Helotes Zone 1 area are established by the absence of geologic restrictions on species distribution from the known localities further to the south. Most of this area has not been examined for caves, but many and significant caves are known in geologically similar to identical settings to the south and east. The northern boundary is delimited by a major fault that juxtaposes the Kainer Formation against poorly cavernous units.

The northeastern boundary and the entire eastern boundary of the West Helotes Zone 1 area is delimited by the base of the upper 25 m of the upper member of the Glen Rose Formation or where it is covered by floodplain alluvium. Six caves with listed species occur near the central section of the eastern boundary. The extension of Zone 1 to the southeastern boundary is supported by sight records of *Rhadine infernalis* in 10K Cave (Miller, 2000b) and especially by the recent report of two caves with unspecified listed species on the Iron Horse Canyon property (Tannika Engelhard, USFWS, personal communication, 2002).

The southern boundary of the West Helotes Zone 1 area is delimited by the Haby Crossing Fault. This fault has the greatest displacement in Bexar County with 180 m of throw down to the south, juxtaposing poorly cavernous rocks against the zone's cavernous rock. Some of the downthrown units include the Austin Chalk, which is highly cavernous in some parts of the county but has not been found cavernous along the fault.

The main channel of Government Canyon marks most of the western boundary of the West Helotes Zone 1, either along its creekbed or where the canyon floor is covered in floodplain alluvium. The boundary extends west of the creekbed to encompass Government Canyon Bat Cave and Surprise Sink. The latter cave's fauna is very similar to other caves in that Zone 1 area east of Government Canyon and clearly belongs with that group. However, it also contains *Neoleptoneta microps*, which is otherwise known only from Government Canyon Bat Cave.

In contrast, Government Canyon Bat Cave lacks some of the species common to several of the advanced troglobite faunas east of Government Canyon (i.e. *Hoplobunus madla*, *Texella* sp., *Texoreddellia texensis*). This could be due to the cave's bat population producing an ecological community based largely on guano, and the guanophiles residing in the ecological niche that those troglobites would otherwise normally occupy. On the other hand, Government Canyon Bat Cave contains one endemic species (*Cicurina vespera*) and one nearly endemic species (*Neoleptoneta microps*), suggesting an ecological distinctiveness independent of the bat colony. However, a sight record of a *Rhadine* beetle in Sure Sink, located near Wildcat Canyon, plus the confirmed records in Lithic Ridge Cave of both *Rhadine* species known in Government Canyon Bat Cave strongly suggest that at least some of the listed species in the southwest end of the West Helotes Zone 1 area are distributed west of Government Canyon. The lack of other biologically studied caves west of Government Canyon makes the Zone 1 boundaries around Government Canyon Bat Cave and Surprise Sink conservative estimates until more information is available.

### **Zone 1 Areas in the Helotes Karst Fauna Region**

**Christmas Cave Zone 1.** Only Christmas Cave is known to contain listed species in this Zone 1 area. The cave provides habitat to *Rhadine exilis*, *Rhadine infernalis infernalis*, *Cicurina madla*, and *Batrissodes ventyivi*. It is located at the base of a partly isolated hill between Helotes Creek and its tributary, Chiminea Creek. The cave formed in the less cavernous lower 14 m of what Clark (in review) described informally as the cavernous zone of the upper member of the Glen Rose Formation and extends at least 32 m below the top of the Glen Rose. The boundaries for this Zone 1 area are drawn around the hill containing the cave and the adjoining hill to the northeast. They are delimited by the mapped base of the cavernous zone, which generally occurs 39 m below the top of the Glen Rose, or the nearest valley floor between these two hills and adjoining hills. No other caves are known or reported between Helotes Creek and Chiminea Creek for at least 1.9 km from Christmas Cave, no cave between those creeks beyond 1.9 km has been biologically investigated, and the area has not been searched for additional caves.

**Helotes Hilltop Zone 1.** Two caves with listed species are known from this Zone 1 area: Helotes Blowhole and Helotes Hilltop Cave. *Rhadine exilis* is known in both caves and *Rhadine infernalis infernalis* is known from Helotes Blowhole. *Cicurina madla* is also known from Helotes Blowhole and suspected to occur in Helotes Hilltop Cave, which also contains *Batrissodes ventyivi*.

The caves occur in an isolated hill between and north of the confluence of Helotes Creek and Los Reyes Creek. The boundaries for the Helotes Hilltop Zone 1 area are delimited by the base of the upper 25 m of the upper member of the Glen Rose Formation or where it is covered by floodplain alluvium. Helotes Hilltop Cave occurs near the top of the hill, and Helotes Blowhole occurs near the base, 25 m below the top of the upper Glen Rose, demonstrating cave development throughout the hill's vertical extent.

**North Helotes Zone 1.** Three caves are known to contain listed species in this Zone 1 area: Logan's Cave, Madla's Cave, and Madla's Drop Cave. *Rhadine infernalis infernalis* is known from all three caves, *Cicurina madla* is known in the two Madla caves and suspected to occur in Logan's Cave, and *Rhadine exilis* is known from Logan's Cave. The caves occur in an isolated line of hills between Chiminea Creek and Los Reyes Creek.

Part of the northern boundary for this Zone 1 area is delimited by a fault that juxtaposes cavernous limestone with poorly cavernous limestone. The remaining boundaries are generally delimited by the base of the upper 25 m of the upper member of the Glen Rose Formation, except where it is covered by floodplain alluvium, or where the Glen Rose or Kainer formations extend under Chiminea Creek. The known portions of caves approach, but do not extend, more than 25 m into the Glen Rose. These caves are some of the largest in western Bexar County. Their concentration in these hills suggests that other extensive caves may exist; small parts of the hills have been searched for additional caves, but only cursorily. Two small caves are known in this Zone 1 area but have not been biologically investigated. The presence of similar groups of listed and non-listed species in the three studied caves indicates the caves occur within the same Zone 1 area.

### **Zone 1 Areas in the Stone Oak Karst Fauna Region**

**Stone Oak Zone 1.** This Zone 1 area is the largest in Bexar County. Veni (1994) drew a conservatively small Zone 1 area around both Black Cat Cave and Genesis Cave. Their boundaries were assumed to extend further due to lack of significant geologic barriers to species distribution, but the lack of detailed biological and geological studies on caves in that area made it technically indefensible to draw larger zones. That is no longer the case.

In addition to Black Cat Cave and Genesis Cave, listed species are now known from this redrawn zone in Hairy Tooth Cave, Hornet's Last Laugh Pit, Kick Start Cave, Ragin' Cajun Cave, and Springtail Crevice within the Stone Oak housing development. Additionally, 20 of the 23 caves with listed species on Camp Bullis occur in the southeastern corner of Camp Bullis adjacent to the housing project and are included in the Stone Oak Zone 1: B-52 Cave, Backhole, Boneyard Pit, Bunny Hole, Cross the Creek Cave, Dos Viboras Cave, Eagles Nest Cave, 40mm Cave, Hilger Hole, Hold Me Back Cave, Isocow Cave, MARS Pit, MARS Shaft, Pain in the Glass Cave, Platypus Pit, Poor Boy Baculum Cave, Root Canal Cave, Root Toupee Cave, Strange Little Cave, and Up the Creek Cave.

Of these 20 caves on Camp Bullis, 15 were opened by excavation and the known extents of two were significantly expanded by excavation. This demonstrates that caves with listed species are far more prevalent in this area than indicated by surveys where minor or no excavations were conducted. Combined, the following factors are clear evidence that the above 27 caves occur in the same Zone 1 area:

- 1) proximity of the 27 caves to each other, especially the close proximity of caves in the well-studied portion of Camp Bullis;
- 2) similar suite of species in the caves;
- 3) the same listed species occur in the caves;
- 4) identical to similar hydrogeologic settings for all of the caves;
- 5) many of the caves extend well below the elevations of creek beds in the area and have listed species at those lower elevations;

- 6) at least nine known, biologically unstudied caves in the Zone 1 area demonstrate the presence of caves and potential habitat for the listed species;
- 7) no geologic, hydrologic, or biological barriers to the species' distribution are apparent.

The northern boundary of Stone Oak Zone 1 is delimited by faults. On Camp Bullis, the northern boundary is marked by the northeast-trending fault north of Ailor Hill and Papke Hill. It significantly displaces the cavernous units and juxtaposes them against less cavernous units and smaller outcrops of cavernous units. The area north of the fault has not been surveyed for caves but will be surveyed by the spring of 2003. East of Camp Bullis, a fault ranging from about 800 m to 1,800 m to the south of the one on Camp Bullis was selected as the Zone 1 boundary. It has less effect in the distribution of cavernous rock but is based largely on the observation of a *Rhadine* beetle in Tick 'n Delight Cave. The species I saw, but was unable to collect, was too robust to be *R. exilis*, the listed species common to all of the Stone Oak Zone 1 caves. It resembled *Rhadine* sp. 1, an undescribed species known only to date from caves mostly in the northeast portion of Camp Bullis (Veni, Reddell, and Cokendolpher, 1999) and could represent an eastward extension of that group. However, its presence would not necessarily preclude the occurrence of *R. exilis*, since both slender and robust *Rhadine* occasionally occur in the same cave.

The eastern Stone Oak Zone 1 boundary follows the bed of Elm Waterhole Creek and one fault. This boundary is an approximation for lack of any other notable features that might affect species distribution. The stream cuts through part of the limestone but its effect, and that of the fault, on species distribution is uncertain. Further east, an unlisted species of *Rhadine* was found in Poison Ivy Pit near Cibolo Creek. Biological study of caves between Black Cat Cave and Poison Ivy Pit would help better delineate the eastern Zone 1 boundary.

The northern third of the western Stone Oak Zone 1 boundary is marked where the base of the upper 20 m of the upper member of the Glen Rose Formation is exposed. Below this level the strata are less cavernous. The southern two thirds of the western boundary follows the bed of Salado Creek. The stream cuts through part of the limestone, and a fault runs roughly parallel to the overall trend of the meandering creek in the middle third of this boundary. The creek and fault probably have little effect on species distribution but are used for lack of any other notable features that might affect species distribution.

West of the Stone Oak Zone 1 boundary, the same fault block that contains the Kainer Formation limestone and most of the Stone Oak Zone 1 area extends west into the UTSA Karst Fauna Region and the La Cantera Zone 1. Even though *Rhadine exilis* occurs in the La Cantera caves, there is currently insufficient information to connect the Stone Oak Zone 1 to the La Cantera Zone 1. No caves are known within the fault block between the two Zone 1 areas, and the currently known distribution of troglobite species still supports the findings of Veni (1994) that Leon Creek and associated geologic factors in its vicinity significantly restrict the distribution of the listed species.

The southern Stone Oak Zone 1 boundary is defined primary by faults that mark the southern limit of the Kainer Formation. Black Cat Cave is the only cave with listed species in Stone Oak Zone 1 that occurs in the Person Formation. It is highly unlikely that the fault and minor lithologic difference between the Kainer and Person constitutes a significant barrier to the distribution of the listed species. The observed species distribution is almost certainly an inadvertent collection bias caused by access to

and study of caves mostly in the Kainer Formation. In the area of Black Cat Cave, the outcrop of the Regional Dense Member of the Person Formation, which is the least cavernous member in the formation, is primarily used as the Zone 1 boundary.

The southwest boundary of Zone 1, while approximate, may reflect an area where *Rhadine exilis* occurs poorly or is absent. In 1978, in the Woods of Shavano housing development, I found blind *Rhadine* in Cave of the Woods (Veni, 1988). While I did not collect any, they were too robust to be *R. exilis*, and their gross morphology was consistent with *R. infernalis*. About 2.5 km to the southwest, in the southwest corner of the Stone Oak Karst Fauna Region, a blind *Rhadine* was collected from Here Today Gone Tomorrow Cave in 1994. James Reddell (personal communication, Texas Memorial Museum, 2002) suspects it could be a new species but would need more specimens to be certain and to describe it. Both caves have since been sealed by urban development. However, several other caves remain open in the Shavano Park area, and their biological study would be important to better define the distribution of the listed *Rhadine* species.

**Eisenhower Park Zone 1.** Three caves with listed species are known in this Zone 1 area: Flying Buzzworm Cave, Headquarters Cave, and Low Priority Cave. All of the caves are located in the southwest corner of Camp Bullis, but the zone includes most of the City of San Antonio's Eisenhower Park which offers a more recognizable name to the zone. These caves provide the only known localities for *Rhadine infernalis ewersi*; Headquarters Cave also contains *Rhadine exilis* and the spider *Cicurina madla*.

This Zone 1 area is delimited to the north, east, and west by where the base of the upper 20 m of the upper member of the Glen Rose Formation is exposed. That lithologic horizon is almost exposed to the south but instead is truncated by a fault that serves as the southern boundary. Poorly cavernous horizons of the upper Glen Rose crop out to the east and west beyond the boundaries, severely limiting distribution of the listed species in those directions. The boundaries to the north and south offer lesser constraints on the species. Both present exposures of less cavernous limestone but no test on their actual effects on limiting the species' ranges. Two caves are known within 2 km of the northern boundary but have poor conditions for troglobites (Veni et al., 2000); no caves have been reported beyond the southern boundary for almost 3 km.

### **Zone 1 in the UTSA Karst Fauna Region**

**UTSA Zone 1.** This Zone 1 area covers most of the UTSA Karst Fauna Region. Veni (1994) drew conservatively small Zone 1 areas around John Wagner Ranch Cave No. 3, Kamikazi Cricket Cave, Mastodon Pit, Mattke Cave, Robber's Cave, Scorpion Cave, Three Fingers Cave, and Young Cave No. 1. Their boundaries were assumed to extend further due to lack of significant geologic barriers to species distribution, but the lack of detailed biological and geological studies on caves in that area made it technically indefensible to draw larger zones. That is no longer the case.

Listed species are now known from this redrawn zone in Crownridge Canyon Cave, Hills and Dales Pit, La Cantera Cave No. 1, La Cantera Cave No. 2, and the unnamed cave 8 km northeast of Helotes, and are reported in Porcupine Squeeze Cave and Sunray Cave. Continued geological and biological study of the area demonstrates that caves with listed species are more prevalent than previously known, especially in areas where minor or no excavations of karst features

have been conducted. Combined, the following factors are strong evidence that the above 14 caves occur in the same Zone 1 area:

- 1) proximity of the 14 caves to each other;
- 2) similar suite of species in the caves despite presence of potential geologic restrictions to species distribution, including similar to identical groups of listed species;
- 3) the presence of listed species in caves from high to low topographic elevations and formed by identical to dissimilar hydrogeologic processes;
- 4) three of the caves with listed species have not had adequate biological surveys and may contain species that further demonstrate biological affinity to the other caves;
- 5) at least 16 known, biologically unstudied caves in the Zone 1 area demonstrate the presence of caves and potential additional habitat for the listed species;
- 6) geologic, hydrologic, or biological barriers to the species' distribution do not occur in some areas and potential barriers in other areas have no apparent effect on observed species distribution.

Most of the boundaries for this Zone 1 area are delimited by the base of the upper 25 m of the Glen Rose either along Leon Creek and its tributaries to the east or Helotes Creek and its tributaries to the west. These stream systems curve toward each other to define part of the Zone 1 area's northern boundary. The rest of the northern boundary is defined along a fault north of Young Cave No. 1 that follows two valleys where cavernous limestone is locally thinnest. It is likely that listed species occur north of the fault, but only two caves are currently known in that area and neither has been biologically investigated.

The southern UTSA Zone 1 boundary is defined by faults that mark the southern limit of the Kainer Formation, since all of the caves with listed species known in the UTSA Karst Fauna Region are developed in the Kainer. It is highly unlikely that the fault and minor lithologic difference between the Kainer and adjacent Person Formation constitute a significant barrier to the distribution of the listed species. The observed species distribution is almost certainly an inadvertent collection bias caused by access to and study of caves mostly in the Kainer Formation.

## **Cave Drainage Basin Delineation**

### **Caves in the Alamo Heights Karst Fauna Region**

**Robber Baron Cave.** Veni (1997a) hydrogeologically evaluated this cave and delineated its drainage basins. The surface water drainage area for the cave includes the entrance sinkhole and its roughly 5-m-radius watershed. In late 1995, this drainage area was decreased to a radius of 2-3 m by a berm constructed to minimize visitors' chances of stepping dangerously close to the edge of the sinkhole. It was also meant to deflect possible overflow from a sanitary sewer located 5 m east of the sinkhole.

Delineating the groundwater drainage basin for water infiltrating down fractures into the cave is more problematic. Reliable reports indicate the cave extends as a maze well beyond its known location. However, that portion of the cave has not been mapped, studied, or well or recently explored. Defining a drainage basin on such minimal information can only be done in the gross terms of the area above the probable extent of the cave. That extent would be a 100-m-wide band (the width of the known portion of the cave) to Holmgreen's Hole, a now-sealed extensive maze cave located about 600 m to the southwest, and to two wells accessed underground via the Robber Baron entrance. One well was located approximately 100 m east of Nacogdoches Road and the other about 1.2 km southwest of the cave. The basin could also reasonably include Oak Park Mall Cave, an apparently large cave discovered and covered during the mall's construction, and located roughly in line toward Holmgreen's Hole about 220 m south to southeast of Robber Baron's entrance.

Defining a groundwater drainage basin for only the currently known and mapped portion of Robber Baron Cave is also difficult. Unlike caves in the Edwards Limestone, for example, where observations of a sufficiently large number of similar caves can be used to estimate probable drainage areas based on surface and subsurface features, no such comparison is available for Robber Baron, which occurs in the Austin Chalk and in an unusual hydrogeologic setting. Additionally, nearly all relevant surface features have long since been covered or disturbed. The distribution of damp and wet areas in the cave under areas of impermeable cover on the surface demonstrates that infiltration can flow at least 7 m laterally during its vertical flow underground. Solutionally enlarged bedding plane conduits, including those dug open off the Domed Passage, extend up to 16 m from the known cave. Based on summing these two distances and on the examination of these features and the cave's development a conservative estimate of the known cave's drainage basin is a 30-m-radius from its footprint.

One area beyond Robber Baron's known sections that is given special consideration for inclusion within the groundwater drainage basin relative to the cave's known passages is the area along the cave's eastern margin. Air photo lineaments in that area line up with known passages and probably reflect the continuation of those passages beyond their artificially induced collapse. Passages in that area include those reported to extend to the water well east of Nacogdoches Road. Given these coinciding reports and observations, that area of lineaments with a 30-m-wide infiltration zone, is included as part of the cave's groundwater drainage basin.

### **Caves in the Culebra Anticline Karst Fauna Region**

**Braken Bat Cave.** Veni (1997a) hydrogeologically evaluated this Austin Chalk cave and delineated its drainage basins. The surface drainage area for the cave is delimited by the sinkhole and

associated drainage surrounding the cave's entrance. The surface drainage basin captures runoff from an area approximately 60 m long by 46 m wide. The cave's groundwater drainage basin likely follows the cave's 55° fracture trend, and probably captures infiltration along that axis from at least 30 m in either direction from the footprint of the cave, and for a width of 20 m from each side of the cave. However, this groundwater basin was determined by Veni (1997a) without conducting a hydrogeologic evaluation inside the cave, because the cave's entrance had been filled with rocks a couple of years earlier.

**Caracol Creek Coon Cave.** Unpublished information was gathered from the TSS files and examined for this report on Caracol Creek Coon Cave. The cave is partly mapped, and excavation will likely extend the cave's known extent. An investigation for potentially related karst features and a detailed hydrogeologic study has not been performed for the cave. I wrote much of the geologic information in the following paragraph for the TSS files.

The cave is formed in a relatively flat upland, interstream area in the Austin Chalk. It is on the south limb of the Culebra Anticline, 2 km south of the anticlinal axis, and trends subparallel to the axis along an 80°-bearing joint set. A secondary joint trend of 39°, dipping 84°W, is prominent in some sections of the cave. The cave drains a broad elongate area through a series of domes; the largest one having developed into the cave's entrance. Drainage within the cave moves to the area of lowest floor elevation, southwest of the entrance, then flows downward through a series of shafts. Most of the shafts are narrow, shallow and end in dirt fill, but the major drain point is a 6.6-m-deep pit which eventually leads down to water. It is unclear if this water represents the true water table in the Austin Chalk or if the water is perched. Its approximate elevation is the same as the base of Caracol Creek, and the cave water may enter the creek as underflow. However, there is some speculation that Austin groundwater in the Culebra Anticline may actually drain into the underlying Edwards Aquifer, in which case, the cave water would be perched and not reflect the water table to which it finally drains. A few features in the cave walls may be poorly-developed scallops. Further study is needed, but they were about 17 cm long and their asymmetry suggests groundwater flow to the northeast, opposite the direction of modern flow in the cave.

Based on my recollection, the surface water drainage area for the cave is about 10 m in diameter, centered on the 4-m-diameter sinkhole that contains the cave's entrance. The footprint of the cave extends about 25 m northeast of the cave's entrance and 50 m southwest of the entrance, and averages a width of about 3 m. Like Isopit and other caves in the Culebra Anticline region that are often strongly guided by fractures, Caracol Creek Coon Cave's groundwater drainage basin is also probably structurally guided. Using the groundwater drainage area for Isopit as a guide, the width of Caracol Creek Coon Cave's groundwater drainage basin is approximated as extending 50 m from the cave's footprint. The basin is also estimated to extend at least 150 m (twice the cave's length) from the footprint to the northeast and southwest along the cave's axis.

**Game Pasture Cave No. 1.** Unpublished information was gathered from the TSS files and examined for this report on Game Pasture Cave No. 1. An investigation for potentially related karst features and a detailed hydrogeologic study has not been performed for the cave. I wrote much of the geologic information in the following paragraph for the TSS files.

The cave is vadosely developed in the Austin Chalk. The main passages are developed along near parallel joints bearing 25° and dipping 89°E, and the connecting cross-joint passages are formed along joints bearing 117° and dipping 82°N. Surface water runoff within a 10-20 m radius of the entrance flows into the cave through its 4-m-diameter sinkhole and may sometimes fill nearly all the passages. Bottles floated up to high ledges mark the degree of flooding. The flood levels are inconsistent with the estimated size of the surface drainage area and suggest inflow from a larger groundwater drainage basin. That basin is estimated as extending for 80 m, about twice the end-to-end length of the cave, along the cave's axis from its footprint and for 40 m from the footprint perpendicular to the axis.

**Isopit.** Veni (1997a) hydrogeologically evaluated this cave and delineated its drainage basins. The surface drainage basin for the cave is approximately 25 m long by 18 m wide where sheetwash flows into the sinkhole that surrounds the cave's entrance.

The cave's groundwater basin is complex. Isopit shows a higher degree of conduit development in the Austin Chalk than most caves in the area. Domes and solutionally enlarged cross joints frequently intersect Isopit, and the multi-stage development of Wurzbach Bat Cave has created a complex group of conduits that surround that cave. Consequently, the width of the groundwater drainage basin is approximated as a minimum 50-m-radius from the footprint of both caves and the likely courses of its passages. The basin extends 300 m upstream of Isopit to include Wurzbach Bat Cave, almost certainly the upstream end of Isopit, and a sinkhole beneath which the caves probably connect. The downstream limit of the basin extends 180 m northeast of Isopit to a sinkhole formed along a fracture aligned with the cave; excavation of the sinkhole would almost certainly open a cave. While the stream passage doubtless extends much farther to the northeast, there is too much uncertainty to estimate its course beyond this sinkhole until the sinkhole is excavated and evaluated.

**King Toad Cave.** Unpublished information was gathered from the TSS files and examined for this report on King Toad Cave. An investigation for potentially related karst features and a detailed hydrogeologic study has not been performed for the cave. Unlike most caves described in this report, I have not entered this cave, although I did briefly see its entrance in 1993. I vaguely recall it capturing sheetwash from a small area, probably no more than 20 m long by 5 m wide

Rough survey notes in the TSS files illustrate the cave as a 9-m-deep pit leading to passages that total 34 m in length. Most of the length is in a single passage about 20 m long and probably formed along a fracture that bears about 30°. The cave is vadosely developed in the Austin Chalk, just below the contact with the Pecan Gap Chalk. Given the little information available on the cave, its groundwater drainage basin is estimated to extend 60 m from the footprint of the cave in all directions (triple the length of the longest passage). The distance is similar to that of the better studied Austin Chalk caves, and the lack of a preferential direction relates to the uncertainty in the interpretation of the rough survey notes.

**Obvious Little Cave.** Veni (1997a) first reported this cave but did not conduct a detailed hydrogeologic evaluation. It was discovered in the middle of a 30-m-diameter sinkhole that probably captures surface water from a 50-m-diameter area.

The cave is formed in the Austin Chalk along a fault that strikes 109° and has an estimated dip

of 50-60°S. Displacement along the fault could not be measured, but gouge was observed along the fault plane. The cave alternately follows the fault's strike and dip, with its length predominantly following the strike to the east. The cave has not been mapped, and the constriction at its base has not been excavated to reach what may be a humanly accessible continuation of the passage. Based on observations in nearby Isopit and Wurzbach Bat Cave, its groundwater drainage basin is estimated to extend 50 m from the footprint of the cave, except in the easterly direction along the fault's strike where it is estimated to extend at least 100 m.

**Stevens Ranch Trash Hole Cave.** Unpublished information was gathered from the TSS files and examined for this report on Steven Ranch Trash Hole Cave. An investigation for potentially related karst features and a detailed hydrogeologic study have not been performed for the cave. I have not seen or visited this cave, unlike most caves described in this report. The surface water drainage area for the cave has not been described. A large sinkhole, perhaps 10 m in diameter, is reported near the cave, but apparently does not drain into the cave's entrance. Based on caves in the area and the topographic map, the cave's entrance probably captures sheetwash from an area no larger than 200 m long by 140 m wide.

A preliminary map in the TSS files illustrates the cave as a 3-m-deep pit that slopes steeply down into a 25-m-long passage. Domes at the end of the passage suggest they transmit water into that distal part of the cave. The mapped morphology of the cave indicates that it probably formed along a fracture that bears approximately 45° for the first half of the cave, then a fracture that bears approximately 90° for the second half. A passage needing excavation for exploration extends north of the cave's mid-point. The cave vadosely developed in the Austin Chalk. Given the little information available on the cave, its groundwater drainage basin is estimated to extend 75 m from the footprint of the cave to the north and along its trend to the southwest and east (triple the length of the longest passage), and 50 m to south.

**Wurzbach Bat Cave.** This cave is the largest and longest, with 600 m of mapped passages, of those known in the Austin Chalk on the Culebra Anticline. Veni (1997a) hydrogeologically evaluated this cave and delineated its drainage basins. The cave has five entrances and one sinkhole that drains into a dome over the entrance to The Death Crawl, the deepest passage in the cave. Drainage into all of these features is within an approximately 230-m-diameter surface water drainage area. The cave's entrances occur in the eastern half of the surface drainage basin. See the discussion of Isopit for a description of the cave's groundwater basin.

### **Caves in the Government Canyon Karst Fauna Region**

**Bone Pile Cave.** Veni (1996b) described this cave but did not conduct a detailed hydrogeologic evaluation. The following paragraph is adapted from that report. Miller (1999) provided a map of the cave (which inadvertently shows the north arrow pointing east), which is located in a cliff wall and captures no surface water.

Bone Pile Cave is a phreatically formed conduit along Government Canyon that developed in the upper member of the Glen Rose Formation. It formed below the canyon floor, when the floor was at a higher elevation. Assuming that Government Canyon has down-cut at a similar rate to what Veni (1994) determined for nearby Helotes Creek, the cave was intersected by the canyon about 450,000 years ago. As the canyon was incised below the level of the cave, the water table in

the area dropped, and water ceased flowing through it. In most cases, such caves first discharged groundwater to the surface stream, then, following stream incision, became small, dry, dead-end crawlways that quickly become too small to explore. What makes Bone Pile Cave unusual is that the tight crawl near the back is one of the rarely seen diversions of vadose groundwater from the phreatic passage down to the lowered water table. Further, backflooding from the canyon has cut a channel in the cave floor which also drains to that crawl. This backflooding decreased in frequency as the canyon floor cut to lower elevations. Based on the type of sediments found in the cave, the last flooding episode probably occurred about 5,000-10,000 years ago.

The cave's groundwater drainage basin is defined by the flowpaths that fed the cave's main passage when it was both a phreatic and vadose conduit, plus the area contributing water to the vadose crawlway. However, the explored extent of this passage extends west and perpendicular to the trend of the main passage, so some of its drainage area is probably not encompassed by the drainage area for the main passage. The linear and well-defined nature of the main passage suggests it was a significant groundwater flow path, the southern end of which is currently obstructed by sediment. Scallop studies or analysis of other flow features have not been conducted to estimate the volume, velocity, or direction of flow; the cave could have formed either to discharge water to Government Canyon or transmit recharge away from Government Canyon. The survey data suggest flow toward the canyon but lack sufficient precision to be conclusive for the low gradient indicated. Based on observations and information currently available, the cave's groundwater drainage area is estimated to extend at least 150 m south (triple the end-to-end length of the cave) along its axis, to include areas currently inaccessible due to sediment fill, for 50 m perpendicular to that axis to the east, and for 75 m perpendicular to the axis to the west.

**Canyon Ranch Pit.** SWCA (2000a, 2000b, 2001a) described this cave and provided a map and a geologic description. SWCA (2000a) mapped its surface water drainage area as potentially extending 120 m up the hillside but noted it was probably smaller based on drainage features observed. However, that mapped location of the cave does not coincide with two independent sets of GPS (global positioning system) coordinates in the TSS files, which place the cave about 50 m further north. The TSS locations are assumed correct and used in this report to evaluate the cave. Based on the cave's hillside location and the size of the cave entrance, the basin is probably no larger than 20 m long by 2 m wide.

The cave is developed in the Grainstone Member of the Kainer Formation. SWCA (2001a) describes Canyon Ranch Pit as a collapsed phreatic chamber. The profile of the map shows upper and lower sections of the cave that are not shown in the plan view and reported as part of the collapsed area. Speleothems were described as hydrologically active. What seem to be solutionally enlarged bedding planes were also described in the report. No fractures were reported, but unpublished data in the TSS files provided by Horizon Environmental Services, Inc., report the entrance is formed along a fracture that bears 120° and the underlying passage and bulk of the cave is believed to follow a set of fractures bearing 60°.

SWCA (2000a) proposed a groundwater drainage basin for the cave that extends 26 m from the cave's footprint, equal to the distance of nearby Scenic Overlook Cave's end-to-end length. However, this does not consider the effects of fractures on cave development, proximity to the two nearby caves, the probable extent of the cave beyond its mapped portions, or observed morphology

and hydrology in other Grainstone caves. Given the information available, the groundwater drainage area for Canyon Ranch Pit is estimated to extend a uniform distance of 60 m, approximately triple the end-to-end length of the cave, or to the limits of the Grainstone Member, whichever is nearer. However, since this partly overlaps with the estimated groundwater basins of Scenic Overlook Cave to the east and Fat Man's Nightmare Cave to the west, the three basins are merged as a single basin that is indistinguishable with the information and methods available to this study.

**Continental Cave.** SWCA (2001b) briefly described this cave and its geology. It is not known if the cave has been mapped or if other pertinent information exists; only a few pages of the report were provided to the USFWS. Its surface water drainage area was not described, but given the cave's hillside location and the size of the cave entrance, the basin is probably no larger than 40 m long by 3 m wide.

Detailed geologic mapping by the USGS (Stein and Ozuna, 1995) shows that the cave occurs in the top of the Kirschberg Member of the Kainer Formation; SWCA (2001b) erroneously described it as within the Dolomitic Member. SWCA (2001b) described Continental Cave as a pit that was excavated 2 m down into a 9-m-long by 6-m-wide by 0.3 to 1-m-high room. The cave is postulated to be a phreatically-formed chamber. Based on its description and knowledge of other caves in the area of similar hydrogeologic occurrence, the room is probably the top of a deeper, solutionally formed collapsed phreatic chamber. The cave entrance is described as a solutionally-enlarged fracture, and the room is said to be formed along a joint that may guide its drainage to deeper levels. However, SWCA did not present information on the orientation of the fractures and drainage.

The Kirschberg Member of the Kainer Formation is poorly exposed in Bexar County. Few caves in this unit have been studied in detail, increasing the difficulty in predicting typical behavior for its caves. Several relatively large, broad rooms are known from the Kirschberg in Travis County. Most of the few Bexar County caves in the Kirschberg exhibit similar behavior. Based on this limited information about caves in the Kirschberg and the minimal information provided for the cave by SWCA (2001b), the groundwater drainage area for Continental Cave is estimated to extend a uniform distance of 70 m from the cave's footprint, equal in total area to that of Lithic Ridge Cave which has the largest known groundwater drainage basin of Kirschberg caves in the Government Canyon Karst Fauna Region.

**Creek Bank Cave.** Information provided by SWCA, Inc. to USFWS indicates the cave is at least 9 m long and extends at least 6 m further north. No map, physical description, or geologic description is available to better assess this cave and its drainage basins. USFWS attempted but was unable to obtain this information (Tannika Engelhard, USFWS, personal communication, 2002). The cave is near an unnamed streambed, but it is not known if it receives water from the stream. Its location suggests a possibly 40-m-long by 2-m-wide surface water drainage basin. Given the unknown nature of the cave and its relationship to two nearby caves, one of which is Tight Cave, known to contain listed species, its groundwater drainage basin is estimated to extend 225 m uniformly from the caves' entrances. This distance is triple the long-axis radius of Surprise Sink, located in a similar geologic setting, but not as extensive as the basin around Government Canyon Bat Cave.

**Dancing Rattler Cave and Hackberry Sink.** Unpublished information and survey data were gathered from Marvin Miller (personal communication, 2002) and the TSS files on Dancing Rattler Cave, Hackberry Sink, and nearby Blacktail Cave and Dancing Fern Cave. The origins and relationship of the latter two caves are important in delineating the drainage basins of Dancing Rattler Cave and Hackberry Sink. Additionally, biological collections have not been made in the Blacktail and Dancing Fern caves, but they may contain suitable habitat for the listed species. A detailed hydrogeologic study has not been performed for any of these caves. Information on the size of Dancing Rattler Cave's and Hackberry Sink's surface water drainage basins has not been recorded. Based on recollection, Dancing Rattler probably captures sheetwash from an area no more than 10 m long by 3 m wide. Based on its topographic position and survey notes, Hackberry Sink probably captures sheetwash from an area no larger than 30 m long by 10 m wide.

This group of four caves appears to be phreatically formed and later modified by vadose entrenchment of the floors, followed by a period of sediment deposition. While this process is not unusual, these are four of the six caves known to be formed in the Grainstone Member of the Kainer Formation in Bexar County. This does not include some caves in Bexar County where pits extend vertically through the Grainstone but have no passages horizontally extending into the unit. Like the other members of the Edwards Limestone Group, the Grainstone might be characterized by a distinctive style of cave development, assuming the observations in these four caves are not limited to their immediate area.

Combined, the four caves have a maximum elevation range of about 3 m and seem perched on a less permeable horizon near the base of the Grainstone Member. Airflow is common in the caves, suggesting the presence of additional passages and possible connections between them. Three of the four caves were opened by excavation, and constrictions within the caves are common and have often led to additional passages when enlarged. Dancing Rattler Cave and Dancing Fern Cave appear strongly fracture controlled toward the southeast and south; Blacktail Cave is oriented to the northeast and Hackberry Sink has an indistinct pattern except for a 30-m-long south-bound passage that aligns with and extends to within 8 m of connecting to Dancing Fern Cave. Fractures have been observed but not measured in these caves, located 90-200 m south of a normal fault that bears 90°, has 21 m of drop to the south (Stein and Ozuna, 1995), with no apparent effect on the development of the caves. Some of the caves' orientations are roughly down the current topographic gradient and may indicate former potentiometric gradients when the valleys were at elevations equal to or above the levels of the caves.

Given the caves' airflow, their general morphology of often enlarging beyond constrictions, the presence of listed *Rhadine* in two of the caves with entrances about 100 m apart with passages that come to within 30 m of connecting, and the general uncertainty about the geologic setting, the subsurface drainage basin for Dancing Rattler Cave and Hackberry Sink is assumed to include the other three caves plus a 100-m radius from their footprints, or to the limits of the Grainstone Member, whichever is nearer. While all of this area does not drain into the known parts of Dancing Rattler and Hackberry, most of it probably drains into the caves' probable extensions to include the other two caves. The 100-m-radius is roughly equal to the maximum distance between the four caves and covers almost all of the Grainstone Member on the hilltop where they are located. Even though caves are known to occur in the underlying Kirschberg Member, none are known within this particular hill, and these caves appear perched within the Grainstone, making it a logical lower

elevation limit for their distribution.

**Fat Man's Nightmare Cave.** SWCA (2000a, 2000b, 2001a) described this cave and provided a map and a geologic description. SWCA (2000a) mapped its surface water drainage area as potentially extending 200 m to the hilltop but noted it was probably smaller based on drainage features observed. However, that mapped location of the cave does not coincide with two independent sets of GPS coordinates in the TSS files, which place the cave about 90 m to the northwest. The TSS locations are assumed correct and used in this report to evaluate the cave. Based on the cave's hillside location and the size of the cave entrance, the basin is probably no larger than 20 m long by 2 m wide.

The cave is developed in the Grainstone Member of the Kainer Formation. SWCA (2001a) described Fat Man's Nightmare Cave as a collapsed phreatic chamber that has divided the cave into multiple small rooms and passages. The passages occur at two primary levels. It is not evident from the map or description if the cave walls are of intact limestone and/or collapsed bedrock. Few speleothems were found in the cave. Unpublished data in the TSS files provided by Horizon Environmental Services, Inc. report at least one passage formed mainly in breakdown and also airflow in some breakdown areas. The cave's entrance was described as formed along a fracture that bears 120°. Based on the cave's morphology, the fracture may guide the southern portion of the cave. Horizon reported a solutionally enlarged fracture bearing 30° and extending at least 5 m from the entrance room, plus a fracture-controlled northeast-trending passage.

The Grainstone Member of the Kainer Formation is poorly exposed in Bexar County. Few caves are known in this unit, and none have been studied in detail, increasing the difficulty in predicting behavior typical for its caves. Dancing Rattler Cave and associated caves suggest that extensive horizontal passages develop near the base of the Grainstone, possibly perched on a horizon of lower permeability. It is not clear if that is typical of the Grainstone or can be applied to Fat Man's Nightmare Cave.

SWCA (2000a) proposed a groundwater drainage basin for the cave that extends 26 m from the cave's footprint, equal to the distance of nearby Scenic Overlook Cave's end-to-end length. However, this does not consider the effects of fractures on cave development, proximity to the two nearby caves, the probable extent of the cave beyond its mapped portions, the cave's airflow, or observed morphology and hydrology in other Grainstone caves. Given the information available, the groundwater drainage area for Scenic Overview Cave is estimated to extend a distance of 75 m along the cave's axis in the general northeast-southwest direction where solutionally enlarged fractures and airflow were noted, approximately triple the end-to-end length of the cave, 50 m perpendicular to the axis, or to the limits of the Grainstone Member, whichever is nearer. However, since this partly overlaps with the estimated groundwater basin of Canyon Ranch Pit, which partly overlaps the groundwater basin of Scenic Overlook Cave, the three basins are merged as a single basin indistinguishable with the information and methods available to this study.

**Government Canyon Bat Cave.** Veni (1988) provided a brief description of the cave and the original map. Veni (1996c, 1996d) and Miller (2000a) discussed the status of cave exploration at Government Canyon State Natural Area and included a more detailed map of the cave. No geologic investigation of the cave has been performed. Its surface water drainage area has not been delineated,

but based on the topography, the size of the entrance and associated collapse area, and observations of the site, it captures sheetwash from an area probably no larger than 30 m long by 4 m wide.

The cave is by far the largest room in Bexar County. My preliminary observations at the cave suggest it formed in the Basal Nodular Member of the Kainer Formation and the upper member of the Glen Rose Formation. Mapping by Stein and Ozuna (1995) place it within the upper Glen Rose. In either case, both units are known to form large room and passages. The entire cave is a solutional, phreatically-formed room, except for the entrance area, where erosion of the hillside has truncated and collapsed the room. The room is probably a large passage, although its one end is collapsed and mostly removed by erosion, and the other end is filled with sediment which precludes a complete hydrogeologic assessment. No fractures have been noted as guiding the cave's development, although its northwest to southeast trend suggests fracture control, as often occurs along that orientation in the basal Kainer and the uppermost Glen Rose. No features have been found to account for the cave's unusually large size. It is certainly a hydrologic relict that pre-dates the modern Edwards Aquifer and the existence of Government Canyon. Some dripwater enters the cave as well as surface runoff, and evidence of occasional sheetflow is visible on the sediment floor. Its water flows into the back wall of the cave and suggests the cave's continuation beyond the sediment fill. Based on these factors and the uncertainty of the cave's origin and extent, the groundwater basin is estimated to extend 200 m (twice the cave's length) from the cave's footprint along its axis and 100 m from the footprint in all other directions. Parts of this area include the Government Canyon creekbed, since the cave extends below that elevation. A southeast-flowing tributary to Government Canyon 80 m north of the cave's entrance might be partly formed and guided by collapse of the cave. Intact portions of the cave may exist in or extend northwest from that area.

#### **Hackberry Sink (see Dancing Rattler Cave).**

**Lithic Ridge Cave.** Unpublished information was gathered from the TSS files, and a map prepared by Miller (2002) was examined for this report on Lithic Ridge Cave. A detailed hydrogeologic study has not been performed. Information on the size of its surface water drainage has not been recorded, but based on recollection, it probably captures sheetwash from an area no more than 10 m long by 3 m wide. About 15 m south of the entrance is a sinkhole with an inaccessibly small passage at its base that almost certainly connects to the cave (see next paragraph). Based on recollection, sheetwash from a roughly 10-m-long by 2-m-wide area drains into this sinkhole and should be considered part of the surface water drainage area for the cave.

Lithic Ridge Cave appears to be a phreatically formed room roughly 30 m in diameter, divided by collapse and speleothem growth into smaller rooms and passages. Several inaccessibly low passages continue to the north, west, and south. The low passages to the south almost certainly connect to the sinkhole described above. Fractures have not been noted to guide the development of the cave, which is slightly elongated along a north-south orientation. The cave is developed in the Kirschberg Member of the Kainer Formation, which is poorly exposed in Bexar County. Few caves in this unit have been studied in detail, increasing the difficulty in predicting typical behavior for its caves. Several relatively large, broad rooms are known from the Kirschberg in Travis County. Most of the few Bexar County caves in the Kirschberg exhibit similar behavior. Based on this limited information, the groundwater drainage area for Lithic Ridge Cave is estimated to extend a distance of 60 m from the footprint of the cave, approximately the diameter of the cave.

**Lost Pothole.** Unpublished information was gathered from the TSS files and examined for this report on Lost Pothole. A detailed hydrogeologic study has not been performed for the cave. Information on the size of its surface water drainage has not been recorded, but based on recollection, it probably captures sheetwash from an area no more than 10 m long by 2 m wide.

The cave is a series of vadosely developed pits that descend through the Dolomitic Member of the Kainer Formation and probably extend into the underlying Basal Nodular Member. It appears to be an excellent example of a cave formed along highly permeable fractures and which probably had no humanly passable entrance until it was unroofed by hillside erosion per the model of Veni (1987). No fractures have been reported in the cave, although the narrow passage at the bottom has been described in ways that suggest fracture control. Unfortunately, that passage has not been surveyed, and its orientation is unknown. Some airflow has been reported from this passage, indicating that a significant portion of the cave has yet to be entered. Based on this limited information and comparison with similar caves in the area, the groundwater drainage area for Lost Pothole is estimated to extend a distance of 40 m from the footprint of the cave.

**Pig Cave.** Information provided by SWCA, Inc. to USFWS indicates this cave has listed species, but no map, physical description, or geologic description is available to assess it and its drainage basins. USFWS attempted but was unable to obtain this information (Tannika Engelhard, USFWS, personal communication, 2002). The cave's location suggests a possibly 60-m-long by 3-m-wide surface water drainage basin. Given the unknown nature of the cave, its groundwater drainage basin is estimated to extend 150 m uniformly from the cave's entrance. This distance is double that of Continental Cave, located in a similar geologic setting but not as extensive as the combined basins around Canyon Ranch Pit, Fat Man's Nightmare Cave, and Scenic Overlook Cave.

**San Antonio Ranch Pit.** Unpublished data in the TSS files provided by Horizon Environmental Services, Inc. provide a map and description of the cave. Its entrance was described as having a surface water drainage basin of "less than 1 acre," but my recollection and the cave's location on a nearly level section of a saddle between two valleys suggest that it probably captures sheetwash from an area perhaps 20 m long by 2 m wide.

The cave is developed near the top of the Dolomitic Member of the Kainer Formation. Based on its map, the cave's morphology suggests it formed vadosely along at least one vertical joint shown on the map; the joint's bearing was not included but measured on the map as 49°. The passage meanders to form an elongated omega-shape in plan view, with the joint guiding the linear basal segments. Cross joints may guide the development of the passage's meander. Flowstone blocks both ends of the passage, which seems to drain to the central section below the 13-m-deep entrance pit.

Most caves in the Dolomitic Member of the Kainer are shafts with little horizontal extent. This cave's 19-m end-to-end length is relatively extensive compared to its depth. The cave probably continues significantly deeper, but human access is blocked by rocks that cover the floor. Given the lack of geologic information on the cave's origin, its groundwater drainage basin is estimated to extend 60 m from the footprint of the cave, about triple its end-to-end length.

**Scenic Overlook Cave.** SWCA (2000a, 2000b, 2001a) described this cave and provided a map and a geologic description. SWCA (2000a) mapped its surface water drainage area as potentially extending 85 m to the hilltop but noted it was probably smaller based on drainage features observed. However, that mapped location of the cave does not coincide with two independent sets of GPS coordinates in the TSS files, which place the cave about 50 m further north. The TSS locations are assumed correct and used in this report to evaluate the cave. Based on the cave's hillside location and the size of the cave entrance, the basin is probably no larger than 20 m long by 2 m wide. What appear to be inaccessibly small passages on the cave map trending toward the cave's entrance may reflect a collapse area at the entrance that captures more surface drainage than is indicated based only on the size of the entrance.

The cave is developed in the Grainstone Member of the Kainer Formation. SWCA (2000a, 2001a) described Scenic Overlook Cave as a collapsed phreatic chamber. Except for the entrance, the room occurs on one primary level about 5-6 m below the surface. It is not evident from the map or description if the cave walls are of intact limestone and/or collapsed bedrock. The cave has a strong east-west trend. The entrance was described as formed along a fracture that bears 140°. Based on the cave's morphology, the fracture might slightly guide the western, enlarged portion of the cave. Speleothems were described as having little recent hydrologic activity.

The Grainstone Member of the Kainer Formation is poorly exposed in Bexar County. Few caves are known in this unit, and none have been studied in detail, increasing the difficulty in predicting behavior typical for its caves. Dancing Rattler Cave and associated caves suggest that extensive horizontal passages develop near the base of the Grainstone, possibly perched on a horizon of lower permeability. It is not clear if that is typical of the Grainstone or can be applied to Scenic Overlook Cave.

SWCA (2000a) proposed a groundwater drainage basin for the cave that extends 26 m from the cave's footprint, equal to the distance of the cave's end-to-end length. However, this does not consider the effects of fractures on cave development, proximity to the two nearby caves, the probable extent of the cave beyond its mapped portions, or observed morphology and hydrology in other Grainstone caves. Given the information available, the groundwater drainage area for Scenic Overview Cave is estimated to extend a distance of 75 m along the cave's axis, approximately triple the end-to-end length of the cave, and 50 m perpendicular to the axis, or to the limits of the Grainstone Member, whichever is nearer. However, since this partly overlaps with the estimated groundwater basin of Canyon Ranch Pit, which partly overlaps the groundwater basin of Fat Man's Nightmare Cave, the three basins are merged as a single basin indistinguishable with the information and methods available to this study.

**Surprise Sink.** Veni (1997b) discussed the status of cave exploration at Government Canyon State Natural Area and included a detailed map of the cave. No geologic investigation of the cave has been performed. Its surface water drainage area has not been delineated, but based on the topography, the size of the entrance, associated collapse areas, and observations of the site, it is probably no larger than 10 m long by 5 m wide.

The entrance to the cave is in a meter-diameter sinkhole with a narrow pit at the bottom that opens into the larger of the cave's two rooms. Two similarly sized sinkholes filled with soil and rocks

almost certainly lead into that room as well. The cave is in the Basal Nodular Member of the Kainer Formation and the upper member of the Glen Rose Formation; the contact occurs about 3 m below the entrance. The rooms are roughly square, connecting to form an overall southeast-trending alignment. No fractures were noted along this orientation, although it often occurs in caves within the Basal Nodular and upper Glen Rose. Both rooms are collapsed, but washed-in soil obscures some of the breakdown in the first room. Collapse in the northeast section of the first room indicates that the cave may be turning in that direction. Abundant coralloid speleothems in the cave suggest higher humidity levels that probably existed prior to the natural opening of the entrance. Based on this limited information and the possible deviation from its axis, the groundwater drainage area for Surprise Sink is estimated to extend a distance of 60 m from the cave's footprint.

**Tight Cave.** Information provided by SWCA, Inc. to USFWS indicates this cave has listed species, but no map, physical description, or geologic description is available to assess it and its drainage basins. USFWS attempted but was unable to obtain this information (Tannika Engelhard, USFWS, personal communication, 2002). The cave's approximate location is known but not precisely enough to estimate the size of its surface water drainage basin, although the steep topography indicates it will probably cover only a few dozen square meters. Given the unknown nature of the cave and its relationship to two nearby caves, one of which is Creek Bank Cave, known to contain listed species, its groundwater drainage basin is estimated to extend 225 m uniformly from the caves' entrances. This distance is triple the long-axis radius of Surprise Sink, located in a similar geologic setting but not as extensive as the basin around Government Canyon Bat Cave.

**Unnamed caves in Iron Horse Canyon.** USFWS has learned from SWCA, Inc. that two caves with endangered species occur in the Iron Horse Canyon property, which is under construction as a housing development. Additional information on these caves is being sought by USFWS (Tannika Engelhard, USFWS, personal communication, 2002). Without locations or descriptions, surface and groundwater drainage basins cannot be estimated for the caves.

### **Caves in the Helotes Karst Fauna Region**

**Christmas Cave.** Veni (1996a) hydrogeologically evaluated this cave and delineated its drainage basins. Its entrance captures sheetwash runoff from a surface drainage area approximately 8 m long by 6 m wide. The cave is formed in the cavernous zone of the upper member of the Glen Rose Formation, and its groundwater drainage is delimited to the north and east by east-flowing and south-flowing creeks. They define the area which contributes most water to the cave, and include the likely discharge sites for the cave's original and current flow paths. The western groundwater basin boundary marks the probable limit of groundwater capture for the side passage in the cave's south wall. The cave's southern groundwater basin boundary is marked by the southern limit of the cave. The cave formed by draining to the south, and there is no indication of northward flow from south of the entrance into the cave's southern end.

**Helotes Blowhole.** Veni (1988) provided a brief description of the cave and a map. Located at the base of a cliff above Helotes Creek, it captures no surface water during normal storm events. Pape-Dawson (2000) reported that the cave is located within the 500-year probability flood plain of Helotes Creek and possibly within the 100-year floodplain but that a detailed floodplain survey would be needed to confirm or refute that possibility.

The cave is a 117-m-long passage in the upper member of the Glen Rose Formation. Veni (1988) hypothesized that it was a resurgence for groundwater recharged higher up the hill at Helotes Hilltop Cave and other associated caves and karst features. However, a more accurate plot of the caves' locations (SWCA, 2001a) casts some doubt on this theory. The cave does not trend toward Helotes Hilltop Cave as once believed, but about 215 m to the southeast. This does not rule out a possible hydrogeologic connection, only makes it a little less likely. Factors that favor the possibility is that Helotes Hilltop Cave is formed along the north-south set of fractures and seems to drain to the south, down the dip of the beds, toward Helotes Blowhole along slightly southeast-bearing fractures. Also, other than Helotes Hilltop Cave and possibly nearby (now sealed) Spider Cave, there is no other known significant source of groundwater to account for the cave's origin, nor is another site known that could account for the discharge of that water.

Pape-Dawson (2000) performed a hydrogeologic investigation of Helotes Blowhole and supported the hypothesis proposed by Veni (1998). They noted the cave is formed along a set of fractures with an approximate orientation of 60°; one fracture with flowing water located about 20 m from the entrance was noted to strike 80° and dip 55°N. Pape-Dawson also measured fractures in the cliff near the cave to range in orientation from 50-70°, with a subset bearing 165°, and most dipping about 65°N. They reported bedding to dip about 3° to the south.

The cave's name suggests airflow, but none has ever been reported. It shows no evidence of significant recent hydrologic activity, at least relative to transmitting a flowing stream, but the cave is seldom visited, and evidence of such flows could have been erased or not noticed. Pape-Dawson (2000) observed drips and seeps in the cave and noted that water sank into the floor rather than running over the floor for substantial distances. The map of the cave shows several domes, but it is not known if they formed under phreatic or vadose conditions.

Pape-Dawson (2000) estimated the cave's groundwater drainage basin extended a uniform 26 m from the footprint of the cave. This was based in part on information by Veni (1996a) relating to John Wagner Ranch Cave No. 3 and Madla's Cave but which is not an appropriate comparison given significant differences in the caves' origins. Additionally, it does not consider the cave's possible relationship to Helotes Hilltop Cave, which they supported. Based on these factors and this report's intent to include probable continuations of the cave beyond its mapped footprint, Helotes Blowhole's groundwater basin is estimated to extend 200 m (twice the cave's end-to-end length) southwest of the cave's footprint along its axis, 50 m perpendicular from the footprint southeast of the cave, and as a 100-m-wide band northwest, updip and perpendicular to the footprint, to include the groundwater basin of Helotes Hilltop Cave as described below.

**Helotes Hilltop Cave.** Veni (1988) provided a description of the cave and three maps. Pape-Dawson (2000) reported that the cave may theoretically capture surface water from a 60-m-long by 12-m-wide area but admit this is probably an overestimate. My recollection and a photograph in Veni (1988) show the cave probably captures sheetwash from no more than a 5-m-long by 1-m-wide area. However, since Pape-Dawson felt the larger area is justifiable, that area is adopted for this report.

The cave is developed primarily along a series of joints oriented approximately north-south in the Basal Nodular Member of the Kainer Formation. The cave's entrance occurs at the top of the unit, along a fracture set bearing approximately 10° (Pape-Dawson, 2000), and the bottom of the cave

extends about 3 m into the upper member of the Glen Rose Formation. The configuration of the cave's entrance suggests that parts of the cave extended higher in elevation but were truncated by the erosion of the hillside. The cave's north-south orientation is unusual for the Bexar County area. It may reflect drainage to the south along a locally steep gradient and downdip toward Helotes Blowhole. The two lowest points in the cave are at its north and south ends, and flow directions have not been determined. The southern end of the cave follows fractures trending about 100°. The three maps of the cave are basically correct, yet show different information and scales. The end-to-end lengths of the cave per these maps are 29 m, 42 m, and 66 m. These differences decrease the certainty of any hydrogeologic interpretation.

Pape-Dawson (2000) conducted a hydrogeologic assessment of the cave and assumed the north end was hydrologically more significant than the south end based on the greater presence of moisture and dripping water. However, they did not explore the cave southward beyond Ivan's Squeeze into an area that is as wet or wetter than the cave's north end. They also estimated the cave's groundwater drainage area to extend a maximum of 26 m from the footprint based on the extent of passages extending from the cave's main room on the map that shows the median extent. That is an inappropriate figure, since it ignores the extent of the room and its associated passages.

For this study, given the uncertainty with some factors and accounting for the cave's possible relationship to Helotes Blowhole, the groundwater basin of Helotes Hilltop Cave is estimated to extend 130 m (twice the cave's maximum surveyed end-to-end length) from the cave's footprint along its axis, and 50 m perpendicular to the axis from the footprint. The groundwater drainage basin joins to the southeast with the groundwater basin of Helotes Blowhole as described above. The combined basin is wider between the two caves than indicated above to include the area down the steepest hydrologic gradient between them where groundwater flow and conduits are likely to occur.

**Logan's Cave.** Unpublished information was gathered from the TSS files and examined for this report on Logan's Cave. A detailed hydrogeologic study has not been performed for the cave. Information on the size of its surface water drainage has not been recorded. The cave has two entrances that capture sheetwash. Based on recollection, the main entrance probably drains surface water from an area no more than 10 m long by 2 m wide. Information is not available for the second entrance, but a similar sized surface water drainage area would be typical for the area.

A few survey notes and a partial map of the cave are in the TSS files, but most of cave is unsurveyed and poorly defined. Data for about 500 m of passages are contained in the TSS files and possibly as much as an estimated 1,500 m of passages have been explored. The quality of the survey notes vary but seem to show the cave extending primarily in an east-to-west direction for at least 200 m, with the cave's main entrance roughly in the middle. The north-south surveyed extent of the cave covers a width of about 60 m. The cave extends at least 30 m below the elevation of the main entrance, with much of the surveyed portion apparently occurring at elevations of 10-15 m below the entrance.

Logan's Cave is located in a hill with an isolated cap of Edwards Limestone. Its entrance is at the base of the Dolomitic Member of the Edwards' Kainer Formation. The bulk of the cave is in the Kainer's Basal Nodular Member, and some of the deeper passages extend into the upper member of the Glen Rose Formation. The cave is geologically complex. The upper rooms are the tops of collapses into pre-existing lower rooms which are obscured, so interpretation is difficult. Completion of the cave

map will assist in understanding Logan's origin and development. The Fissure Passage, which extends off the Mud Room, is solutionally enlarged along the margin of a huge collapse block which has dropped about 0.3 m. Tectonic fractures do not seem to control the cave's morphology and orientation. The predominant fracture along the Fissure Passage trends 102°, and a second fracture runs roughly 12°. However, it is not yet clear if these trends are localized to the collapse or reflect a general fracture pattern for the entire cave. A red clay-filled, 0.8 m high by 1.2 m wide phreatic tube occurs at the base of the Mud Room and is intercepted by a vadose canyon over 10 m tall. Leaf litter suggests a probably inaccessibly small connection with the surface. Tall, fluted domes in the cave are other features of recent vadose inflow.

Given the cave's reported size, partial survey and exploration, and incompletely understood geology, its groundwater drainage basin is estimated to extend 350 m, twice the surveyed end-to-end length of the cave from the footprint of the cave along the cave's axis, and at least equal to the 175-m-length from the cave's footprint perpendicular to the cave's axis. This area is truncated where the hillside intersects the basin boundary at an elevation 7 m below the lowest known levels of the cave. Veni (1994) found this horizon was a downward limit for much cave development in the Helotes area.

**Madla's Cave.** Veni (1996a) hydrogeologically evaluated this cave and delineated its drainage basins. The cave's surface water drainage basin includes sheetwash from an area about 5 m long by 1 m wide that drains to the cave's entrance, but it is mostly comprised of sheetwash into a collapsed part of the cave that drains a 34-m-long area for about 28 m to the hilltop drainage divide. This area is smaller than that shown by Veni (1996a) based on a more accurate location of the cave's entrance relative to the topography. The lack of solution features for guidance on the probable extent of the cave's groundwater basin requires consideration of the probable extent of conduits in other phreatically formed caves in the upper member of the Glen Rose Formation in the Helotes area. Based on that information, the groundwater basin boundary should extend at least 30 m from the footprint of Madla's Cave. This is probably the likely groundwater drainage area since infeeding conduits and passages in other caves seldom reach greater distances from their main phreatic voids.

**Madla's Drop Cave.** Unpublished information was gathered from the TSS files and examined for this report on Madla's Drop Cave. Veni (1988) published a brief description and rough sketch of the cave, which has yet to be surveyed or subjected to a detailed hydrogeologic study. The TSS data record the cave's surface water drainage basin as capturing sheetwash and channelized flow from an area about 85 m long by 12 m wide based on the cave's location on a 7.5' topographic map.

The cave is a 9.4-m-deep pit into a room about 17 m long, 7 m wide, and 5-8 m high. It is located in a hill with an isolated cap of Edwards Limestone. According to the geologic map of Stein and Ozuna (1995), the cave is formed entirely within the Dolomitic Member of the Edwards' Kainer Formation, which is unusual because the Dolomitic is otherwise not known to form large rooms. Also, my recollection of the limestone forming the cave walls is more consistent with the underlying Basal Nodular Member of the Kainer. The cave is located at the fringe of Stein and Ozuna's study area which may not be as well mapped.

Preliminary observations indicate the cave was formed on two levels, one at a depth of 5-7 m and the other below 17 m. Collapse of the intermediate zone created one large room and the rumble-strewn floor. Fractures do not seem to control the cave's morphology and orientation. The

predominant fractures are diagonal to the approximate north-south trend of the cave, with average bearings of 44° and dips of about 45° to both the east and west. The cave probably had a phreatic origin and has some vadose modifications including dripstone and domes. The capture of a small surface stream has filled the lowest levels with soil and organic debris. The water probably drains to springs on the south side of the hill. Based on the available information, the groundwater drainage basin of Madla's Drop Cave is estimated to extend 60 m from its footprint, about triple its end-to-end length, in all directions, except to the south where it is extended along the cave's trend to merge with the groundwater drainage basin of Logan's Cave. The boundaries of these two adjacent basins are indistinguishable with the information and methods available to this study. Although the explored portion of the cave does not seem guided by fractures, the presence of cross-fractures in the cave may indicate conduit development in other directions than along the cave's axis.

**Unnamed cave 800 m north of Helotes.** The exact location of this cave is not known. James Reddell (personal communication, 2002) has discussed its location with Dr. Thomas Barr, who collected *Rhadine exilis* beetles from the cave in 1959. Dr. Barr has no specific recollections of its location and character. Given the large number of known caves in that area, several of which contain *Rhadine exilis*, it is likely that this cave is already listed in this report, but under a different name.

### **Caves in the Stone Oak Karst Fauna Region**

**B-52 Cave.** Veni et al. (1999) hydrogeologically evaluated this cave and delineated the surface water drainage basin as a 60 m by 40 m area where sheetwash enters the cave via its entrance and Charley's Annex, a nearby pit that drops into the cave but is humanly impassible due to sediment. This drainage area covers the footprint of the cave and includes areas that drain into the cave's underlying domes and inaccessible passages. However, it focused on slightly channelized sheetwash that could be readily observed to flow into the cave and did not include sheetwash in an ever-narrowing area that extends another 120 m up the hillside as shown on the 7.5' topographic map.

B-52 Cave is one of the most complexly developed caves known in Bexar County. It is formed in the recharge zone of the Edwards Aquifer. The cave's entrance and upper 12 m are within the Dolomitic Member of the Kainer Formation. Passages, pits, and rooms between depths of 12 m and about 27 m are in the Kainer's Basal Nodular Member; the cave's lower half is in the upper member of the Glen Rose Formation. It has a surveyed length of 344 m and a depth of 59 m.

The earliest and least well understood period of the cave's history most likely involved the development of a room below the current position of Cataract Chamber. This room collapsed, and some of the bedrock formed subsidence fractures which were later solutionally enlarged to form a maze of pits and passages that extend off and under Cataract Chamber. The walls of passages that occur more than 35 m below the level of the entrance appear as intact bedrock, demonstrating that they formed below the room and its subsequent overlying collapse zone.

A second early-formed room is also critical to the development of the cave. It occurred southeast of the first and extended under the present location of the Gordian Room. No clear evidence suggests the relationship of the second room to the first, but based on the most likely scenario of the cave's origin, it was probably an extension off the first. It likely continued to grow after the collapse of the first room, so that its collapse was not a gentle subsidence. The cause of each collapse is unknown;

the small focus and degree of subsidence of the first room's collapse is unusual. It probably reflects a drop in the water table combined with some structurally incompetent beds in the upper Glen Rose and closely spaced vadose solution of overlying fractures.

Small vadose passages began to form and extend down to the water table as the early rooms grew and collapsed. These passages continued to grow with time and fed more vadose water through the cave. The size and position of Bone Lake Passage, bottoming out at the probable level of the early rooms, indicate it has been carrying water deep into the cave throughout much of the cave's history. The dome at the south end of the Gordian Room is not currently as hydrologically active as that over Bone Lake Passage but appears to have contributed water for a long time to the early room that collapsed to form the Gordian Room. The passages at the top of Lollypop Dome are mostly hydrologically inactive at present and have a complicated history of development and groundwater diversion. Soil and some water flows down through a dome 2.5 m northeast of the Texella Room. The cave entrance itself is a fairly recent feature, although it probably existed in a different form in the past. The rocks that filled the entrance when first discovered were probably derived from the collapse of an older, now erosionally removed passage that once extended above the modern land surface. Given the concentration of recharge into the opposite northwest and southeast ends of the cave, separate drainage routes to the Edwards Aquifer probably exist under the collapses. The northwest drain has been discovered and surveyed.

Veni et al. (1999) delineated the cave's groundwater basin as within 50 m of its mapped footprint. This was in part due to that area being contained within a 50-m-diameter cricket foraging area that was recommended as a minimum management boundary. Airflow from one passage, As Goo As It Gets, suggests that its exploration may significantly alter the cave's footprint and drainage area. However, the excavation needed to allow exploration would be a significant effort. While most drainage will preferentially flow vertically through the limestone in this area, the cave's depth allows it to capture water from a larger area than caves of lesser depth. The recommended 50 m radius from the cave's footprint will include most of the cave's groundwater drainage basin but should be extended an additional 30 m southwest along the trend of the Bone Lake Passage and an additional 50 m to the northeast along the trend of As Goo As It Gets. Both passages are aligned along the predominant fracture trend of the Balcones Fault Zone, and airflow from As Goo As it Gets suggests it has the greater extent.

**Backhole.** Veni et al. (1995) hydrogeologically evaluated this cave, a significant recharge site into the Edwards Aquifer, with a topographic surface drainage area of 0.73 km<sup>2</sup>. However, much of this flow is captured by other caves and karst features, especially Eagles Nest Cave, and an area within about 700 m of the entrance is estimated to primarily drain into the cave.

The entrance to the cave is in the Dolomitic Member of the Kainer Formation. About 8 m below the entrance, the pit enlarges in diameter as it descends into the Basal Nodular Member. The base of the pit is at the contact with the upper member of the Glen Rose Formation. Beds in the southern half of the cave strike 145° and dip 6°S, most likely the result of a subsidence into a large, undiscovered chamber. Fractures known to intersect the cave play only minor roles in the cave's development, but the attitude of two prominent fractures suggests subsidence of the beds toward the southern portion of the cave. One is a joint bearing 117° near the cave's mid-point that dips 68°N down toward the breakdown pit where the cave drains. The other is a joint that bears 57° in the

entrance pit and dips 32°N. Beds to the north of these fractures are nearly horizontal. The fracture in the entrance pit and the dip of the beds to its south become less prominent with increased elevation, behavior expected in subsidence and collapse structures.

Backhole vadosely developed in the Edwards Aquifer's recharge zone by capturing the overlying stream. Before the cave's entrance was dug open, some streamflow went past the cave. Now all streamflow enters the pit. The excavation slightly accelerated the rate of stream capture because the cave would soon have naturally opened without digging. Flooding during the spring of 1994 washed in large amounts of sediment and organic debris, little of which can be found in the cave. The majority was carried below the humanly accessible portion of the cave. No water ponded in the cave, suggesting either the sediments did not occlude conduits leading into the aquifer, and/or considerable conduit storage capacity lies between the bottom of the cave and the water table. Air flow from the newly opened crawl indicates the latter is true.

The strongly indicated presence of a large room underlying the cave and the lack of structural or morphologic features to indicate any preferred direction of cave development require a uniform-distance groundwater drainage area be estimated. Since a large room under a creekbed is likely to have multiple domes, conduits, and fractures capturing water from the surface, a distance of 70 m from the cave's footprint is estimated as the cave's groundwater drainage basin.

**Black Cat Cave.** Veni (1988) described and provided a map and brief geologic report on this cave. An investigation for potentially related karst features and a detailed hydrogeologic study has not been performed. Veni (1988) reported that the area draining into the sinkhole entrance was not large, but that report predated the clearing of dense vegetation surrounding the cave. Veni and Associates (1989) estimated that an area perhaps more than 100 m in diameter drained into the cave from the east side of Bulverde Road, located about 4 m west of the cave's entrance. Using the Bulverde 7.5' topographic map and recollection of the area, the surface water drainage basin is estimated as 125 m long by about 53 m wide.

Black Cat Cave is developed in the Leached and Collapsed members of the Person Formation, 110 m southeast of a major normal fault that bears 34° with 65 m of through down to the southeast (Stein and Ozuna, 1995). It shows vadose and phreatically formed features, and trends west toward and is probably related to Encino Park Cave, a now-sealed cave 220 m away, formed at about the same elevation and stratigraphic horizon. That cave was hydrogeologically examined prior to being sealed; the summary results are discussed in correspondence of the Texas Water Commission on file with the TSS but provide few hydrogeologic insights. It was described as a crescent-shaped room about 23 m long by 15 m wide. Only one cave cricket was reported by cavers, but a biological study was not performed.

The lack of ponding in Black Cat Cave indicates efficient drainage into underlying conduits. The linear morphology of the cave suggests strong structural control over its 54-m end-to-end length but is apparently unrelated to the nearby fault. Its groundwater drainage basin is roughly estimated to extend east along the cave's axis and north and south from the axis for 54 m, and west along the axis for a more than triple its end-to-end length for 206 m from its footprint, to include Encino Park Cave. The western half of the groundwater basin includes portions of an urban neighborhood.

**Boneyard Pit.** Veni et al. (1996a) hydrogeologically evaluated this cave. Boneyard Pit is a significant recharge site into the Edwards Aquifer, with a drainage area that extends 730 m north with a width of 210-450 m. The creek must rise about 40 cm to pour into the cave's entrance. However, many humanly impassable conduits enter the cave at all levels. A few are hydrologically inactive or of reduced activity, but most show evidence of carrying considerable recent recharge.

The cave is formed in the Kainer and Glen Rose formations. The section from the entrance to 9 m down the cave's 15.3-m-deep pit extends through the Kainer's Dolomitic Member, from there to the ceiling of The Ossuary is within the Kainer's Basal Nodular Member, and The Ossuary is within the upper member of the Glen Rose. Several joints guide the orientation of the cave, with northeast trending joints being the preferred avenues of cave development in the Dolomitic Member, and southeast trending joints being dominant in the Basal Nodular and the Glen Rose. The northeast joints range from 68° to 72° and may relate to a major fault which is 280 m to the north and curves from a 53° to a 57° trend. The cave developed vadosely under a creekbed to recharge the Edwards Aquifer and had reached its current dimensions before the opening of its modern entrance. At least one other entrance is known to have once opened to the cave, located about 2 m north of the current entrance and connected to the top of the cave's 6.4-m-high dome. Light brown clayey sediment is distributed from the dome down to The Ossuary, where it bears numerous bones, and likely originated from this entrance. When the entrance finally sealed and prevented the entry of additional sediment, The Ossuary contained brown sediment fill at least 2.7 m deep. Similar sediment also appears to have entered The Ossuary from the passages and domes extending upward from the room's east end. The walls and floors of this area are thickly lined with the silty clay and probably represent what the other parts of the cave looked like before the current entrance formed and washed away much of the sediment.

The cave's groundwater basin was tentatively delineated as within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. Additional exploration of one pit was recommended before establishing firm groundwater boundaries. Since its upper portion is developed along southwest to northeast fractures and its lower sections along northwest to southeast fractures, and given the cave's depth, the uniform 50-m radius from the cave's footprint is still estimated as its groundwater drainage area.

**Bunny Hole.** Veni et al. (1996a) hydrogeologically evaluated this cave and described its surface water drainage basin as an area approximately 60 m long along the cave's axis, by 50 m wide extending up a gently sloping hillside to the southeast. A more precise plotting of the cave on the topographic map for this report finds the drainage area to extend 110 m up the hillside. This area drains into the cave's entrance, plus into five sinkholes that drain directly into the cave.

The cave is a rarely found phreatic conduit system developed in the Dolomitic Member of the Kainer Formation. The braided nature of the passages, as well as their lack of scallops and other high-flow features, is evidence of development by low-velocity groundwater. Flow features and the dip of the passages suggest that the phreatic downgradient end of the cave was to the southwest, and that vadose water also flowed in this direction. The cave's general 55° trend is almost certainly joint controlled. However, this influence is inferred from linear passage morphology and the passages' parallel trend to major Balcones faulting. Little dissolution along the joint planes has been observed, possibly due to low hydrostatic pressure during the cave's phreatic development, and by later speleothem development and case hardening of the walls and ceiling which hid the fractures. When

vadose conditions first occurred, the floors of some passages were incised as water flowed down to the water table. Some collapse occurred at this time, rerouting some vadose streams; the breakdown was later partially covered by speleothem deposits. At least three collapses breached the surface, probably because underlying passages extended higher than in other parts of the cave. Three solution sinkholes also breach the cave.

Veni et al. (1996) recommended a management area for the cave that extended 90 m north, 80 m east and west, and 40 m south of the cave's footprint, based on a combination of surface, groundwater, and biological factors. The groundwater basin alone is estimated as twice the cave's length along its axis, or 80 m, 40 m perpendicular to the axis to the south, and 60 m perpendicular to the axis to the north where a set of parallel passages are hypothesized to occur.

**Cross the Creek Cave.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 30 m long by 16 m wide.

The cave's entrance pit is developed in the Dolomitic Member of the Kainer Formation, and its lower sections are within the Kainer's Basal Nodular Member. The cave vadosely formed along a 77° stress-release fracture slumping toward the nearby valley and its intersection with a 173° joint. The bottom room probably pre-dates the entrance; its thick sedimentation certainly post-dates the entrance, and may result in part from creek inflows along its several small, infeeding conduits. While the cave certainly drains to passages and rooms at even deeper levels, there is insufficient information to postulate their probable groundwater drainage area. Groundwater drainage for the known parts of the cave is estimated to originate from within 20 m of the footprint of the cave.

**Dos Viboras Cave.** Veni et al. (1999) hydrogeologically evaluated this cave and delineated the cave's groundwater basin as within 50 m of its mapped footprint, in part due to that area being contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. Its surface water drainage basin was described as an area approximately 7 m long by 2 m wide, including two 10-cm-diameter solution pits that probably drain into the crawlway at the bottom of the entrance pit.

The cave is developed within the Dolomitic Member of the Kainer Formation which typically forms deep shafts with comparatively minor horizontal extent. At distances of 3 m and 12 m north of the entrance are sinkholes that probably contribute recharge into a deeper section of the cave than has currently been explored, although the nearer sinkhole may drain into an impassable conduit that extends east from the top of Backbender Pit. The entrance is oriented along a 90° joint that dips 68°S. The next pit is formed at the intersection of three minor joints, the most prominent of which bears 57°. A 73° joint guides the steeply sloping passage to Backbender Pit. Airflow at the bottom of the cave suggests that much of the cave has yet to be explored and almost certainly captures more groundwater flow than the currently known portion of the cave. Based on the hydrogeology of similar, more fully explored and studied caves in the area, Dos Viboras Cave's groundwater drainage basin is conservatively estimated as extending 40 m from the cave's footprint.

**Eagles Nest Cave.** Veni and Elliott (1994a) hydrogeologically evaluated this cave and delineated its surface water drainage basin along topographically mapped drainage divides as an area of 0.10 km<sup>2</sup> where sheetwash and a small channel flow to the cave's entrance. However, some of this flow is captured by Hanging Rock Cave and other karst features.

The cave is a phreatically-formed chamber in the middle portion of the Dolomitic Member of the Kainer Formation. Collapse occurred when water drained out of the cave and was followed by a period of speleothem deposition. Stratified clay-rich sediments were deposited in the cave at this time. Downcutting of a small creek later intersected the cave and washed open the current entrance. The cave developed lower level conduits to transmit water captured from the creek into the Edwards Aquifer. Organic debris on the walls and ceiling indicate the lower portion of the cave floods when the volume of recharge surpasses the rate of transmission into the aquifer.

Two areas of the cave need to be accounted for in delineating its groundwater drainage basin. The first is the collapsed portion of the cave and any uncollapsed areas beyond the limits of exploration. This area is estimated to extend about twice the 16-m-width of the known cave to the southeast as a probable cave footprint. The second area is the inaccessibly narrow passage where the cave drains its flow into the aquifer. It probably leads to a series of pits that have only moderate horizontal extent. Given the uncertainty in defining that area, it is assumed to be at least partly encompassed by the known and probable cave footprint. The collapsed nature of the cave obscures its full extent and any features that indicated probable areas of greater passage development and groundwater flow. The drain suggests that such an area extends from the cave's south end. Based on this information, the cave's groundwater drainage basin is estimated to extend 40 m (the end-to-end length of the cave) from the cave's footprint and probable footprint plus an additional 40 m to the south to account for the drain.

**Flying Buzzworm Cave.** Veni et al. (1998) hydrogeologically evaluated this cave and delineated its surface drainage basin. Its groundwater basin was not delineated because the cave is not fully explored, and the basin was probably contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an approximate area of 20 m by 3 m.

The cave is developed in the Dolomitic Member of the Kainer Formation within the Edwards Aquifer recharge zone. The entrance is formed on a 61° joint and is the remnant section of a passage where the cave once continued upward before truncated by erosion of the hillside. A 49° joint guides the orientation of the cave's middle level, and some weak fractures may guide the middle level passages along the north side of the pit. The 61° joint at the entrance extends vertically down to also guide the development of the cave's bottom room. Soil erosion in the area has recently deposited a considerable amount of sediment into the cave, especially when the small size of its surface water drainage area is considered. The passage extending southwest from the bottom room is at the top of a meter-high cutback of sediments that may be as much as 4 m thick. Cobbles over the main pit floor area are probably lag deposits and may partially armor the floor from erosion. The substantial airflow from both ends of the bottom room strongly indicates the presence of significant additional passages below the current bottom level of the cave.

Based on the geological study of the known portion of the cave and study of similar caves in the area, its groundwater drainage basin is estimated as extending 50 m from the cave's footprint along the axis of the 61° joint and 25 m from the footprint perpendicular to that trend. Excavation of the passages at the bottom of the cave will likely require revision of the groundwater drainage basin based on their strong airflow.

**40mm Cave.** Veni and Elliott (1994a) hydrogeologically evaluated this cave but did not delineate its surface water drainage basin given its small area. Based on recollection, it is estimated to be no larger than about 10 m long by 1 m wide.

The cave's entrance is near the top of the Basal Nodular Member of the Kainer Formation. The cave is a phreatically-formed chamber developed along bedding planes and only weakly aligned along intersecting and curving fractures. A well-cemented breccia along the pit wall is probably fill from a paleo-entrance. After phreatic water drained from the cave, much of the room's walls were case-hardened and covered with a calcite crust up to 3 cm thick. Chemically aggressive vadose water later removed most of these crusts and developed the cave's domes, one of which enlarged to form the modern entrance. Airflow corrosion in the other domes indicates air movement through small holes at the top to a connection with the surface; the presence of passages buried under sediment fill is also suggested since the current airflow is probably inadequate to result in the corrosion features. Vadose flow later formed small speleothems. The cave's larger breakdown fell with the development of the domes; small rocks below the entrance were recently washed into the cave along with substantial soil from the surface, probably when the area was grazed near the beginning of the 20<sup>th</sup> Century and again when it was bulldozed in the 1970s. Its groundwater drainage basin is related to that of nearby Strange Little Cave and is described later in this report.

**Genesis Cave.** Veni (1988) described and provided a map and brief geologic report on this cave. An investigation for potentially related karst features and a detailed hydrogeologic study has not been performed. Veni and Associates (1989) estimated that surface water drainage area of about 10,000 m<sup>2</sup> flows into the cave from the north based on a roughly estimated topographic position for the cave on the Longhorn 7.5' U.S. Geological Survey topographic quadrangle. Far more precise GPS coordinates now place the cave where it would naturally capture water from an area no larger than about 250 m long by 75 m wide. However, construction in the area has diverted most of the flow, so that currently only about a 90-m-long by 75-m-wide area drains into the cave.

The cave is the deepest known in Bexar County. Its geology needs to be carefully reexamined. Based on preliminary geologic mapping of the Person and Kainer formations in the area, Veni (1988) placed the cave entrance in the Marine Member of the Person Formation with the bottom of the cave extending into the Kirschberg Member of the Kainer Formation. This is consistent with features observed in the cave. However, geologic mapping by Stein and Ozuna (1995) place the cave's entrance in the Dolomitic Member of the Kainer Formation, which would extend it well into the upper member of the Glen Rose Formation. While several caves in Bexar County occur in these latter units, lithologic features observed in the cave are inconsistent with this interpretation. The cave is located within a mapped 400-m-wide fault block (Stein and Ozuna, 1995) and may occur within an even smaller fault block of different lithology consistent with the features reported in the cave.

Genesis Cave is vadosely developed to recharge the Edwards Aquifer. Several of its passages are guided by fractures. The 30-m-long “Walkway” is developed along a fault which trends approximately 30° and has a 1 m vertical displacement downthrown to the east. Infeeding conduits along fractures throughout the cave have also been observed to transmit surface water into the cave within 20-30 minutes of rainfall.

The cave has an end-to-end length of about 80 m, extending 62 m east and 35 m north toward Godchildren’s Sink, located 180 m east and 50 m north of the entrance of Genesis Cave. Godchildren’s Sink is an incomplete explored, trash-filled cave, partly excavated in 1985 (Veni, 1988) and filled with rocks circa 2000 when preserved in a 3-m-wide vegetated road median. It may potentially account for and drain to the large dome near the east end of Genesis Cave. The trend of Genesis’s passages toward Godchildren’s and the direction of Godchildren’s Sink relative to Genesis Cave are similar in orientation to the 50-60° azimuths of the faults on either side of the fault block and suggest a common structural guiding force between the caves. Based on measured fractures within Genesis Cave, its morphology, and its potential relationship with Godchildren’s Sink, its groundwater drainage basin is estimated as extending 50 m west of the cave’s footprint along the cave’s axis, 60 m from the cave’s footprint perpendicular to the cave’s axis, and a little more than twice the end-to-end length of the cave along its axis to include Godchildren’s Sink and a 60-m-radius area around Godchildren’s Sink.

**Hairy Tooth Cave.** Veni and Elliott (1994b) hydrogeologically evaluated this cave. Its surface water drainage basin was not delineated, but based on my recollection and photographs, is estimated to capture sheetwash from an area of less than 20 m long by 10 m wide. Its groundwater basin was delineated in combination within a 50-m-diameter cricket foraging area recommended as part of a minimum management boundary.

The entrance to Hairy Tooth Cave is formed in the Kirschberg Member of the Kainer Formation. Most of the cave is formed within the Dolomitic Member of the Kainer, and the base of the cave is probably near the contact with the Basal Nodular Member. The exact stratigraphy of the cave cannot be determined without additional study.

The low precision in determining the cave’s stratigraphy results from Hairy Tooth’s development down three fault planes. Additionally, speleothems and calcite crusts cover much of the walls, limiting the amount of available exposed bedrock for correlating beds on opposite sides of the faults in order to measure fault displacement. Fault #1 crosses Hairy Tooth Pit at a strike of 39.5° and a dip of 66°N. Fault #2 strikes 51.5° and dips 69°S with probably about 3 m of displacement. The Formation Crevasse and most of Yahoo Pit are formed along this fault. Fault #3 marks the drop in ceiling near Last Drop from Pendulum Pit into The Final Room. It strikes 40.5° and dips 57°S. This is probably the fault that Stein and Ozuna (1995) mapped 30 m northwest of the cave with a bearing of 40° and 4 m of throw down to the south.

The presence of faults in the cave is unusual. Only about 2% of the caves in Bexar County are intersected by faults; most form along joints. Many faults in the area are filled with calcite or fault gouge, which lessen their permeability and thus decrease groundwater flow which would develop caves along those planes. In contrast, the faults through Hairy Tooth Cave are permeable enough to dominate its development and to channel most recharge into it. Little water enters the cave through its

entrance. From 1987 when the cave was dug open until the time of Veni and Elliott's (1994b) study, little of the loose rock and dirt on the entrance slope had washed down the first pit. Nonetheless, flooding at least 1.5 m deep had occurred at the bottom of the cave and washed open a conduit to the Edwards Aquifer. Morphologic and hydrologic features in the cave indicate the majority of the water entered the cave along the faults. The thick mud deposits and seasonal ponding of water at the bottom of the cave suggest perching on the Basal Nodular Member. The local water table is not encountered for at least another 30 m deeper, so Hairy Tooth Cave should extend considerably further past its current depth.

Due to the cave's strong development along faults and observed flow features along faults, the cave's groundwater drainage basin was estimated by Veni and Elliott (1994b) to extend as a 60-m-wide band along the cave's axis for 50 m southwest of the cave's footprint and 120 m northeast of the footprint to include two karst features near Fault #3. Subsequent development of the surrounding area did not protect this drainage basin as recommended by Veni and Elliott (1994b). The entrance of the cave has been preserved and gated, but only an area estimated from aerial photographs as 20 m long and wide is currently preserved around the entrance.

**Headquarters Cave.** Veni and Elliott (1994a) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was probably contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. Its surface water drainage basin was delineated as an area less than 10 m long and wide.

The entrance of the cave is below the contact of the Dolomitic Member with the Basal Nodular Member of the Kainer Formation, with the cave formed entirely within the Basal Nodular. Much of the cave is modified by collapse; uncollapsed segments are probably hidden by the breakdown. Drainage enters the lower end of the cave through solutionally enlarged fractures. All recharge sinks into the cave floor, and its route to the water table is not apparent; it may travel through the humanly inaccessible uncollapsed passages. No structural control is apparent in the cave's development. The area over the cave is covered by a contiguous soil that obscures any fractures or karst features that might be present.

The cave has an end-to-end length of 49 m and its arc-shape extends over a width of 28 m. Given the little information available to evaluate its groundwater drainage basin, it is estimated to extend at least 50 m from the footprint of the cave per that originally proposed for the cricket foraging area by Veni and Elliott (1994a).

**Hilger Hole.** Veni et al. (1998) hydrogeologically evaluated this cave and delineated its surface drainage basin. Its groundwater basin was not delineated because it was probably contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 2 m long by 1 m wide.

Hilger Hole is one of the more geologically unusual caves known in the study area. The cave's entrance is developed in the Basal Nodular Member of the Kainer Formation, and it appears that the ceiling of the second room is along the contact between the Kainer and the underlying upper member

of the Glen Rose Formation; extensive speleothem crusts and other related growths cover much of the walls so the contact is not well exposed. A 152° joint guides the development of a dome and the back half of the cave, and the beds along the east wall in that area dip 9°E and strike 160°. This tilting could be tectonic or subsidence into an underlying void.

What makes the cave unusual is its abundance of coralloid speleothems, airflow corrosion features, and brecciated wall rock. The second room and lower portion of the entrance room are covered with coralloid speleothems. These formed by condensation, as indicated by their presence on surfaces like breakdown and even roots, where seepage from the walls is not possible, and from the decrease in coralloid density with increased elevation to where corrosion features occur. Small condensation-corrosion rims with evaporation-formed acicular tips (probably aragonite) are present in the entrance room. Wall crusts in the entrance room display soft inner cores beneath hard, crystalline outer layers; the inner material could be aragonite or moonmilk formed by air corrosion. The upper 3 m of the entrance room, increasing with elevation, show air corrosion down to bedrock walls which are formed of brecciated limestone and megacrystalline flowstone.

The cave is probably a segment of an old phreatic passage that pre-dates most caves in the area. It likely had an upper level near the modern entrance which collapsed and was recemented along with flowstone fragments and orange sediment that occurred in that passage. Because the cave's origin did not involve local recharge, few solutionally enlarged fractures developed between the surface and the cave after the potentiometric surface dropped and placed the cave in the vadose zone. Some probably formed where massive flowstone deposits occurred and which eventually blocked off the north and south ends of the cave. In the intervening area, the currently accessible part of the cave, moisture transmitted through the limestone matrix reached saturation and was convectively deposited on cave surfaces. The convection probably occurred along a small but consistent geothermal temperature gradient, where slightly warmer air in voids below the cave slowly rose, corroded the cave ceiling, cooled, sank, and deposited condensation coralloids from the calcite obtained from corroding the ceiling, and reheated at depth to begin the cycle anew. Humidity and carbon dioxide also affected the process. Either because of greater solubility, fractures, and/or dissolution from moisture descending from the surface, corrosion was concentrated in one area of the ceiling until it breached the surface (probably with a little help in the final stages from bulldozing) to form the cave's entrance.

The cave's shallow depth and lack of vadose conduit development suggest the presence of a relatively narrow groundwater basin. However, the cave's unusual north-south orientation is probably only a localized portion of the phreatically formed passage and not representative of the passage's overall orientation. Without clear evidence of that orientation, a preferred orientation for the cave's drainage basin cannot be accurately determined and a wider basin must be defined to increase the likelihood of capturing all the probable drainage. A minimum radius of 30 m from the footprint of the cave is recommended as the groundwater basin.

**Hold Me Back Cave.** Veni et al. (1995) hydrogeologically evaluated this cave. Its sinkhole entrance and Karst Feature 11A-11, 16 m to the southeast, currently capture little overland flow and thus bring little water into the cave. Karst Feature 11A-10, 22 m northeast of the entrance, accounts for most recharge. Within 30 minutes of a brief storm on 18 October 1994, recharge was observed entering the cave's Entrance Room. Roughly 10% of the estimated flow of 12 L/min. came through the entrance, 60% through Karst Feature 11A-10, and 30% through fractures in the ceiling. Based on

these observations and the topography, the cave's surface water drainage basin is approximately 160 m long, partly along the axis between the entrance and Karst Feature 11A-10, by 60 m wide. This area includes Karst Feature 11A-11. Bulldozing of the land surface has altered the natural drainage patterns near the cave; the original patterns are not known.

The entrance to Hold Me Back Cave is developed in the Dolomitic Member of the Kainer Formation. The contact with the Kainer's Basal Nodular Member occurs at the top of the Main Pit. The contact between the Kainer and the upper member of the Glen Rose Formation is situated 4 m below where the Parallel Shaft divides from the Main Pit. A normal fault bearing 67°, dipping 55°S, and with 0.9 m of displacement crosses the cave at the pits' junction. The fault extends to within 2 m of the breakdown area near the bottom of the cave and may be related to that collapse. Extensive breakdown hides faults that may exist in that zone. Hold Me Back Cave is vadosely developed within the recharge zone of the Edwards Aquifer with much of the cave's development occurring along or because of the fault.

Veni et al. (1995) estimated the groundwater drainage basin for the cave as the area that includes the observed trace of the fault on the surface, proximal karst features, and surface drainage into that fault trace. The dimensions extended along the trace of the fault for 130 m west and 100 m east of the footprint of the cave, and 50 m north and 60 m south of the cave's footprint.

**Hornet's Last Laugh Pit.** Veni and Reddell (2002b) have conducted a biological investigation of this cave, but it has not been surveyed or subjected to a detailed hydrogeologic study. Its surface water drainage basin captures sheetwash from an area about 20 m long by 2 m wide, but it is also in the uppermost elevation to capture floodwaters within the reservoir of San Antonio River Authority Flood Control Dam No.8.

The cave is a 6-m-deep shaft followed by two shorter pits that extend to a depth of about 12 m. Vadosely developed in the Basal Nodular Member of the Kainer Formation in the recharge zone of the Edwards Aquifer, it may reach into the underlying upper member of the Glen Rose Formation. The cave's entrance pit is formed along a normal fault that strikes 49°, dips 74°E, and has 15 cm of throw down to the east. Based on the preliminary information available, the cave's groundwater drainage basin is estimated to extend 50 m from its footprint along the strike of the fault and 30 m from its footprint perpendicular to the strike. Since the cave has not been mapped, its footprint is approximated based on its description.

**Isocow Cave.** Veni et al. (1995) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 3 m long by 2 m wide.

The cave is developed in the Dolomitic and Basal Nodular members of the Kainer Formation and within the upper member of the Glen Rose Formation. The contact between the Dolomitic and Basal Nodular members is about a meter down the 8.2-m-deep pit, and the Basal Nodular-upper Glen Rose contact occurs 3.7 m above the base of the last pit. Isocow Cave is vadosely formed in the Edwards Aquifer recharge zone. Additional recharge occurs through solutioned fractures which are

soil-covered and not generally apparent at the surface. Like many caves in the lower Kainer and in the upper Glen Rose, fractures guide the development of passages but are often not obvious. One notable 89° joint guides the 4-m-long passage at the top of the 8.2-m-pit. This passage probably leads to an old entrance that has since plugged with red clay and flowstone. Another source of the red clay at the base of the 8.2-m-pit is the small, clay-floored passage in the wall of the 4.6-m-deep pit. The cave originally formed along two series of pits which joined at the top of the 8.2-m-pit. The 3.4-m-long passage near the entrance originally extended farther west, past the now-present flowstone plug, to a previous entrance, sinkhole, or set of fractures which transmitted recharge into the cave.

Most of the cave walls are clean-washed of the abundant sediments that occur in a couple of short passages along several ledges, demonstrating considerable inflow of water into the cave that does not enter through the soil-floored entrance. However, there is little direct information from which to estimate the size and configuration of the cave's groundwater drainage basin. Based on observations in similar but better studied caves, the basin is estimated to extend at least 35 m from the footprint of the cave. However, since this partly overlaps with the estimated groundwater basin of Root Canal Cave, which has passages that extend to within 75 m of Isocow Cave, the two basins are merged as a single basin indistinguishable with the information and methods available to this study. The groundwater drainage basin for Isocow Cave should be reassessed when the exploration and study of Root Canal Cave is complete.

**Kick Start Cave.** Veni and Reddell (2002b) have conducted a biological investigation of this cave, but it has not been surveyed or subjected to a detailed hydrogeologic study. Its surface water drainage basin captures sheetwash from an area about 15 m long by 2 m wide.

This newly discovered cave has not been surveyed, but it is basically a 2-m-deep pit to a 4-m-deep pit that leads to a passage and small room and reaches an estimated total depth of about 12 m. It is formed in the Basal Nodular Member of the Kainer Formation in the Edwards Aquifer recharge zone and may reach into the underlying upper member of the Glen Rose Formation. The cave generally trends to the northeast, but it is not known if it is guided by fractures. Its groundwater drainage basin is preliminarily estimated to extend 50 m from its footprint along its axis and 30 m from its footprint perpendicular to the axis, as at nearby Hornet's Last Laugh Pit. Since the cave has not been mapped, its footprint is approximated based on its description.

**Low Priority Cave.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 10 m long by 2 m wide.

The cave is formed at the top of Basal Nodular Member of the Kainer Formation. It is phreatic in origin and modified by vadose flows and collapse. The current entrance is the second to develop for the cave. The first was about 2-5 m to the south and eventually filled with sediment. A dome in the entrance passage later breached the surface to become the modern entrance. The cave exhibits considerable collapse for its relatively small size. Both open and closed stress fractures run along the axis of the passage and suggest ongoing collapse which will drop some limestone beds to the cave floor but is unlikely to reach to the surface within the foreseeable future. Beds in the walls of the eastern half

of the cave dip  $10^\circ$  to the southwest and probably reflect subsidence into a larger, undiscovered, underlying chamber whose existence is further supported by airflow from the floor of the cave.

The cave's southeastward trend probably follows unobserved fractures. While that trend is not along the dominant Balcones Fault Zone alignment, it has been observed to guide the development of other caves in the Basal Nodular Member of the Kainer and suggests that such might be the case here. Low Priority Cave's shallow depth limits its potential groundwater drainage area, but its underlying unexplored portions have a greater probable drainage area. The cave's groundwater basin is estimated as an area extending at least 40 m from the footprint of the cave along the cave's axis and for 30 m from the footprint perpendicular to that axis.

**MARS Pit.** Veni et al. (1999) hydrogeologically evaluated this cave. Its surface water basin drains sheetwash into its entrance and two adjacent sinkholes from an area roughly 40 m long by 15 m wide. The cave probably once captured water from a larger area. The flat surface area where the cave is located suggests planing by stream erosion. The dry, shallow, creekbed now located 90 m south of the cave may once have been over the cave and provided substantial recharge; the cave shows no evidence of recent flooding through the entrance and sinkholes. Flooding of the lower levels in November 1998 was due mainly to a rise in the aquifer's water table rather than increased recharge through the entrance.

MARS Pit is developed in the recharge zone of the Edwards Aquifer within the Dolomitic and Basal Nodular members of the Kainer Formation and the upper member of the Glen Rose Formation. The entrance is formed in a solutioned fracture zone that measures at least 33 m long by up to 2 m wide and 0.4 m deep. The zone is aligned along two main fracture trends, with the cave entrance being the point of intersection. Northeast of the entrance along a  $55^\circ$  fracture trend are rock-filled sinkholes at distances of 6.5 m and 20 m. The fracture trace is distinct for about 90 m farther on the surface, with a possible small sinkhole occurring 54 m out. Southwest of the cave's entrance, two sinkholes are aligned along a  $24^\circ$  fracture trend at distances of 5 m and 13.5 m. The fracture is not apparent on the surface beyond the more distant sinkhole. The cave entrance and the two sinkholes closest to it on either side essentially form one long collapse feature, with short spans of uncollapsed bedrock. The northeast sinkhole is the head of the rock-choked passage extending off the entrance crawl, and the passage in the wall of the cave's 13-m-deep pit likely originates in the southwest sinkhole.

Seven normal faults cross the inside of the cave. In addition to the faults, at least seven prominent joints cross the cave. Six of the seven faults and four of the seven joints in MARS Pit are similar in orientation and are probably related to a major fault 45 m northwest of the cave's entrance that strikes  $46.5^\circ$  through this area. The cave has complexly developed with phreatic stages developing rooms that were later modified and enlarged during vadose conditions. Its air flow, hydrology, and structurally favorable location indicate that significant passages exist to the southwest and northeast along the major fracture trend. Veni et al. (1999) used these factors to delineate the cave's groundwater basin as extending 50 m from the footprint of the cave and the notable fracture exposed on the surface that roughly parallels those fractures in the cave.

**MARS Shaft.** Veni and Elliott (1994a) hydrogeologically evaluated this cave, a significant recharge site into the Edwards Aquifer with a topographic surface drainage area of 2.8 km<sup>2</sup>. However, much of this flow is captured by other caves and karst features, especially Boneyard Pit, and

approximately the nearest 1 km<sup>2</sup> to MARS Shaft are estimated to drain into it. Water in the creekbed adjacent to the cave entrance must be at least 0.9 m deep for it to flow down the hole. Substantial water also recharges the aquifer via the cave by way of the humanly impassable conduits that capture flow through the many solutionally enlarged fractures under the creek.

The entrance to the cave is at the top of the Basal Nodular Member of the Kainer Formation, and the ledge about halfway down the pit is near the contact of the Kainer with the upper member of the Glen Rose Formation. No fractures dominate the cave's development, although some of the short passages at the bottom have trends similar to joints measured nearby on the surface. The cave vadosely formed as a recharge site within the Edwards Aquifer recharge zone. The lower portion of the cave formed as two parallel shafts now interconnected with natural bridges marking the former intervening wall. Flood debris at the base of the cave is no more than 1.5 m above the main floor, indicating efficient transmission of recharge into the aquifer.

Inaccessibly small passages extend east, west, and southeast from the cave. The position and orientation of these passages suggest development along northwest to southeast and northeast to southwest trending fractures. The passages to the east and southeast seem more hydrologically significant and more likely to open into currently known passages if excavated. Based on these observations, the cave's groundwater drainage basin is estimated to extend at least 30 m from the cave's footprint.

**Pain in the Glass Cave.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 50 m long by 30 m wide. The incised top meter of the entrance pit may indicate that the cave once captured water from a larger area, and that the flow was more channelized prior to the terrain's disturbance by bulldozing and military training activities.

The cave is developed in the recharge zone of the Edwards Aquifer within the Kainer and Glen Rose formations. The upper 5 m of the entrance pit are formed in the Dolomitic Member of the Kainer Formation. The contact with the Kainer's underlying Basal Nodular Member is covered by flowstone and unexcavated rock-soil fill. The lowermost 10 m of the cave are within the upper member of the Glen Rose Formation. Ninety meters northwest of the cave, at a bearing of 330°, is a major fault that has an overall trend of 53°, and near the cave, it is oriented 57° and has 26 m of displacement. No fractures in the cave are clearly related to the fault, but the main room's trend of 45° may be evidence of such fractures, covered by extensive speleothem deposits. Like other caves in the area, Pain in the Glass may have had an entrance that is now closed and not apparent on the surface. In the east wall, within the upper 5 m of the 14-m-deep pit, is what appears to be a 2.5-m-high by 1-m-wide passage entirely filled with red-brown clay and that may have led to a now-filled entrance. The modern entrance was probably a dome which later opened to the surface, as indicated by the incised flowstone in the walls of the entrance pit.

Delineation of the cave's groundwater basin is complicated by extensive speleothem deposits that cover many of the walls and surfaces, obscuring fractures and other geologic features. Most flow into the cave is from the entrance, but some water enters through other routes. Since the cave

seems developed along southwest to northeast fractures and northwest to southeast fractures, a uniform 30-m-radius from the cave's footprint is estimated as its groundwater drainage area.

**Platypus Pit.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 10 m long by 5 m wide.

The cave is developed within the Kainer and Glen Rose formations. The cave's entrance to the floor of the 7-m-long passage is within the Kainer's Dolomitic Member. From there to the ceiling of the bottom room, the cave is developed within the Kainer's Basal Nodular Member. The bottom room is formed in the upper member of the Glen Rose. While prominent joints which follow the region's predominant Balcones Fault trend cross the cave, they do not significantly guide the cave's development. The upper sections of the cave seem formed along a steep hydraulic gradient. The bottom room could have provided that gradient if it predates the development of the upper sections, as is suggested by morphologic evidence such as the size disparity between the upper passages and the room, and the room's lack of significant development or modification relative to the entry of the upper passages. An enlarged bedding plane below the entrance and other flow features within the cave indicate that additional recharge enters from other openings to the surface. No obvious openings were noted on the surface within a 50-m-radius of the cave, although much of the terrain is covered by rocks and thin soils which may hide such features.

Morphological evidence suggests that the upper portion of the cave, above the bottom room, captures relatively little groundwater from the surrounding area. Its groundwater drainage area is estimated as 20 m from that portion of the cave's footprint. However, the room at the bottom of the cave captures water from multiple domes and fractures not accounted for by the cave's known upper levels. The groundwater basin for this part of Platypus Pit is estimated to extend 40 m from the footprint of the bottom room. This figure is based on the 20-m length of the cave's known upper level plus its 20-m-wide groundwater drainage area. Where the 40 and 20-m radii overlap, the boundary furthest from the cave is used.

**Poor Boy Baculum Cave.** Veni et al. (1995) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 25 m long by 15 m wide.

The cave is vadosely developed in the recharge zone of the Edwards Aquifer. Its entrance down to the upper 12 m of The Nevada Shaft is formed within the Dolomitic Member of the Kainer Formation. The Kainer's Basal Nodular Member extends from there down to the ceiling of the room at the bottom of the cave. The ceiling marks the contact with the underlying upper member of the Glen Rose Formation. The cave shows four distinct periods of development. The first was the development of the shafts and passages. The second was characterized by macrocrystalline speleothem growth throughout the cave, indicating an environment high in humidity and carbon dioxide, and suggesting the entrance was not open or developed at that time. The third period saw deposition of red

and brown clays in the cave, which have a probable age range of 15,000 to 5,000 years B.P. The lack of bones in these sediments supports the hypothesis that an entrance did not yet exist for the cave. The clays were likely washed in along small solutionally enlarged fractures that extended into the epikarst. The fourth and current period began with the development of the cave entrance, which changed atmospheric conditions to form microcrystalline speleothems, and which increased recharge to dissolve many older speleothems, erode older sediments, and wash in recent sediments, including bones.

A vertical joint that bears 122° is the only fracture measured in the cave. The plan view of the cave is linear and subparallel to the joint, suggesting that the development of the cave is structurally guided. Abundant calcite speleothem deposition along the walls, especially in the lower half of the cave, may obscure other guiding fractures. A relatively contiguous soil obscures fractures and karst features that drain into the cave. Based on this information and examination of similar caves in the area, Poor Boy Baculum Cave's groundwater drainage basin is estimated as extending 40 m from the cave's footprint, twice the linear extent of the cave, along its axis and 20 m from the cave's footprint perpendicular to the axis.

**Ragin' Cajun Cave.** Veni and Elliott (1994b) hydrogeologically evaluated this cave. Its surface water drainage basin was estimated to capture sheetwash from an area of about 30 m<sup>2</sup>. Its groundwater basin was delineated in combination within a 50-m-diameter cricket foraging area that was recommended as part of a minimum management boundary.

Ragin' Cajun's entrance is formed in the Dolomitic Member of the Kainer Formation. The contact with the Basal Nodular Member occurs 1.5 m above the floor of the cave's 20-m-deep pit. The passages from the base of that pit to about 4 m down the 19-m-deep pit into the Gumbo Room are formed in the Basal Nodular. Below that level, the cave is in the upper member of the Glen Rose Formation.

The cave's entrance passage and underlying 8.5 and 20-m-deep pits are developed along a joint trending 98.5° and dipping 69°S. Crawdad Crawl probably follows a similar joint trend, but the fracture is not as evident. A joint bearing approximately 133° changes the orientation of the cave in the Gumbo Room, and another joint bearing roughly 95° leads to the Bayou Room. Significant drainage into the cave easily occurs through solutionally enlarged fractures. In January 1987, a day after a rain storm, water from the fractures was observed in the cave to coalesce into a flowing stream at the bottom of the 20-m-deep pit. The stream gained in volume from other infeeders as it flowed rapidly through the cave and drained through the breakdown in the Gumbo Room down to recharge the Edwards Aquifer.

Due to the cave's development along fractures and observed flow features along faults, the cave's groundwater drainage basin was estimated by Veni and Elliott (1994b) to extend as a 75-m-wide band along the cave's axis for 45 m northwest and southeast of the cave's footprint. Aerial photographs taken in 2000 show the immediate area around the cave has been bulldozed and prepared for the construction of homes. Rumors reported to the TSS suggest the cave entrance was filled with concrete in mid to late 1990s while other rumors refute that assertion. Neither of these rumors have been confirmed.

**Root Canal Cave.** Veni et al. (1999) hydrogeologically evaluated this cave. Its entrance is in a roughly level area near a paved road. Natural surface water drainage patterns at the cave have been disturbed by road-building and other activities. Currently, no appreciable surface water enters the cave beyond a 2 m radius of its entrance.

Veni et al. (1996) roughly delineated the cave's groundwater basin as within 50 m of its mapped footprint, in part due to incomplete study of the cave but also because it matched a cricket foraging area recommended as a minimum management boundary. Although further exploration and study has been conducted, notable airflow from several locations strongly indicates that a considerable volume of cave remains to be discovered.

Root Canal Cave is developed in the recharge zone of the Edwards Aquifer within the Dolomitic and Basal Nodular members of the Kainer Formation. The contact between the members has not been precisely determined in the cave, but it probably occurs 20-25 m below the entrance. The cave has a surveyed length of 115 m and depth of 38 m. Many fractures criss-cross the uppermost portion of the cave; most are less than 2 m in length. Fractures at depths greater than 3 m have a stronger influence on the orientation of passages, although no single orientation predominates. The main factors affecting the cave's morphology are the changes in hydrologic conditions during its development.

The entrance room appears phreatically formed. The pits are more recently formed vadose features that did not carry substantial phreatic flows. A passage may extend northeast from the entrance pit, currently obscured by fill. The lowering of the water table was abrupt at the cave. The upper passages were only slightly entrenched as waters drained to the developing series of pits. Clean-washed walls of the Third Pit Series indicate that most flow presently entering the cave comes from the passage to the south and flows into this section. Considerable airflow blows from the cave, and its airflow corrosion features are well developed. The proximity of the cave to the underlying upper member of the Glen Rose Formation, which often forms large chambers, suggests that many of the passages and pits interconnect and probably drain to a single room of considerable size. The cave has a depth potential of an additional 30-40 m.

The approximate groundwater basin delineated by Veni et al. (1996), as described above, is retained for this study. No doubt the cave continues beyond its mapped portions, based on geologic observations and the presence of unexplored passages that would require little effort to enter. These deeper passages will invariably capture drainage from fractures and passages currently unknown. Additionally, the cave's entrance room has formed at the same lithologic horizon and potentially under similar conditions to that of Bunny Hole, with 50 m of end-to-end extent. However, since the basin delineated by Veni et al. (1996) partly overlaps with the estimated groundwater basin of Isocow Cave, which has passages extending to within 75 m of Root Canal Cave, the two basins are merged as a single basin indistinguishable with the information and methods available to this study.

**Root Toupee Cave.** Veni et al. (1999) hydrogeologically evaluated this cave and delineated its surface drainage basin. Its groundwater basin was not delineated because it was contained in a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an approximate area of 20 m by 5 m.

Root Toupee Cave is vadosely developed in the recharge zone of the Edwards Aquifer within the Dolomitic Member of the Kainer Formation. Alternating fractures guide its development, with most of the cave formed along a vertical joint that bears 73°. Conduits contributing water into the cave are small and do not appear to extend far from the cave, consistent with the Dolomitic Member which typically forms deep shafts with comparatively minor horizontal extent. Other karst features have been surveyed in the vicinity of the cave but seem too far away to likely contribute water into the cave's known sections. Its groundwater drainage basin is estimated here as extending 20 m from the footprint of the cave along the 73° bearing of its dominant joint, and 10 m from the footprint of the cave perpendicular to that trend.

**Springtail Crevice.** Veni and Reddell (2002b) have conducted a biological investigation of this cave, but it has not been surveyed or subjected to a detailed hydrogeologic study. Located in the bed of Mud Creek, the cave's potential drainage basin is an area of about 28 km<sup>2</sup>, based on tracing the drainage divide on a topographic map. However, during typical storm events, the cave probably captures streamflow from an area within about 2 km upstream.

The cave is a 2-m-deep pit into a low passage about 10 m long that continues inaccessibly small at either end. It seems to be oriented along a northeast-southwest trend, but this has not been confirmed with a compass. Springtail Crevice is developed in the Basal Nodular Member of the Kainer Formation. It is not clear if it formed as a phreatic or vadose conduit and whether or not it is guided by a fracture. This cave regularly floods, so the presence of *Rhadine exilis* seems unusual. However, about 20 m north of the cave is a cliff along the creek bed. This abrupt rise in topography may provide a haven for the listed species, from which the cave's population may be reestablished following impacts from flooding. The cave's groundwater drainage basin is preliminarily estimated to extend 100 m from its footprint along its axis and 50 m from its footprint perpendicular to the axis, to include some of the area beyond the cliff. Since the cave has not been mapped, its footprint is approximated based on its description.

**Strange Little Cave.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave's surface water drainage basin captures sheetwash from an area approximately 10 m long by 6 m wide.

The cave is developed in the Basal Nodular Member of the Kainer Formation. Stein and Ozuna (1995) mapped a major normal fault that plots over the cave but is not seen in the cave, suggesting it is within a few meters. Veni and Elliott (1994a) estimated its position as 24.5 m southeast of the cave's entrance. The fault locally bears 47° and has about 12 m of displacement down to the southeast. The fault does not appear to have any effect on the orientation of the known section of the cave. Strange Little Cave is phreatically formed with modifications from several small vadose inflows. It trends southeast, weakly following a joint that strikes roughly perpendicular to the fault at 142° and which dips 75.5°S. The cave's name in part reflects its features which do not distinctly define the cave's origin. Some features are probably buried by washed-in soil eroded from the surface by turn-of-the-century grazing, as well as by later bulldozing. The strong airflow from the back of the cave, as well as its varied fauna, suggests that a significant volume of passage lies beyond, possibly in the form of

relatively large rooms which the Basal Nodular and the underlying upper member of the Glen Rose Formation tend to produce.

Groundwater drainage into the known part of the cave is probably derived from a relatively small area. However, given the cave's strong airflow, proximity to the major fault, trend toward 40mm Cave about 30 m away, and the proximity of Karst Feature 9-24 (shown by Veni and Elliott [1994a] with its earlier designation of 9-1) located roughly between the caves but 60 m south and which will almost certainly open to a cave if excavated, it is highly likely that all three karst features are hydrogeologically and biologically related. Therefore the cave's groundwater drainage area must include both caves and the karst feature. 40mm Cave does not display any strong structural alignment, but Strange Little Cave follows a southeast trend common in upper Glen Rose caves in that area. Until these features are excavated and better studied, their drainage area is estimated as a 30-m-radius from the footprint of both caves and Karst Feature 9-24, plus an additional 25-m-wide area west of Karst Feature 9-24 to include the nearby major fault.

**Up the Creek Cave.** Veni et al. (1996) hydrogeologically evaluated this cave but did not delineate its groundwater basin because it was contained within a 50-m-diameter cricket foraging area recommended as a minimum management boundary. It is defined here based on the results of that study. The cave is defined as having no surface water drainage basin. It is located in a short bluff above a shallow creek. Flow in the creek is rarely high enough to enter the cave; the creek is not gauged, but based on sediment depositional patterns, it probably reaches the cave no more than once every 10-20 years. At the location of the cave, the creek has a surface drainage area of 0.86 km<sup>2</sup>.

The cave is developed in the Basal Nodular Member of the Kainer Formation, with parts of its ceiling reaching the contact with the Kainer's Dolomitic Member. Much of the small collapse in the back half of the cave is from solution along the contact, although in some areas calcite deposition has cemented small, previously destabilized sections of the ceiling. Up the Creek Cave developed as a phreatic chamber that formed independently of the creek outside its entrance. Valley downcutting intersected one of the many small conduits extending from the chamber, and flooding enlarged it to form the cave's entrance. Flooding also deposited large amounts of sediment in the cave, burying its original floor and any off-going passages. Continued incision of the creekbed has resulted in less frequent flooding of the cave.

Much of the cave's probable extent and geologic features are obscured by sediments, making it difficult to accurately estimate its groundwater drainage basin. The cave has a general north-south trend and numerous infeeding conduits along northeast to southwest trends that suggest development along Balcones Fault Zone fractures. Its occurrence within the Basal Nodular Member of the Kainer Formation suggest the presence of a large underlying chamber, although how much of it is filled with sediment is unknown. In consideration of these factors, and in an attempt to include some of the drainage into the probable underlying chamber, the cave's groundwater drainage area is estimated as extending at least 30 m from the footprint of the cave.

### **Caves in the UTSA Karst Fauna Region**

**Crownridge Canyon Cave.** Veni and Reddell (2002a) described this cave as roughly a 5-m-deep sloping pit along a solutionally enlarged fracture that intersects a solutionally enlarged bedding plane. Much of the cave's humanly accessible volume was created by excavation. A hydrogeologic

evaluation of the cave has not been performed, but it was reported to capture surface water from an approximately 3-m-long by 1-m-wide area.

Airflow from the cave suggests it is considerably more extensive than currently known. However, the preliminary geologic assessment conducted to date is insufficient to accurately estimate its extent or groundwater drainage basin. The cave is formed near the base of the Basal Nodular Member of the Kainer Formation. Both this unit and the underlying upper member of the Glen Rose Formation tend to form large rooms. Based on the limited available information and comparison with other potentially similar caves in the area, the groundwater drainage basin of Crownridge Canyon Cave is estimated here as a 150-m-long by 100-m-wide area centered on the cave and with its long axis aligned north-to-south along the approximate direction of the cave's fracture.

**Hills and Dales Pit.** Veni (1988) published a description and map of this cave, located in the bed of an unnamed creek. Its surface water drainage basin is delineated directly from the Helotes 7.5' topographic quadrangle as capturing sheetwash and channelized flow from a 133,000-m<sup>2</sup>-area. Prior to the installation of a gate, which sometimes clogs with flood debris, water in the creek was never observed to flow past the cave's entrance; soil and vegetation that cover the creek floor downstream of the cave demonstrate that such an occurrence is exceedingly rare.

The cave is an 18-m-deep pit into a room about 27 m long by 10 m wide. Breakdown divides the room into smaller segments. The room's ceiling height is often 2-3 m high but less than 1 m high in several areas and up to 12 m high in domes that reach to within 3-7 m of the surface. The entrance pit is formed within the Dolomitic Member of the Kainer Formation, and the underlying room is within the Basal Nodular Member. The entrance occurs about 25 m south of a normal fault that locally bears 75° and has about 30 m throw down to the south (Stein and Ozuna, 1995). Pape-Dawson (2000) mapped several fractures in and near the cave that are nearly parallel to the fault. One near-perpendicular fracture was measured at the cave's northeast end. They found the beds in the cave strike 78° and dip 5°S.

The cave originally developed as a phreatic chamber. When vadose conditions developed and the creekbed concentrated water directly overhead, water recharged through the creek floor to create the cave's domes until one extended to the surface and captured the stream. I've observed up to an estimated 114 L/sec of water entering the cave during a declining flood pulse. Despite this and higher recharge rates, water levels in the lowest parts of the cave, based on "bathtub rings" of sediments and organic debris, have never been noted to exceed a depth of about 1.4 m. Although conduits to the Edwards Aquifer are not humanly accessible without excavation, this hydrologic behavior demonstrates that they are highly efficient at transmitting water away from the known part of the cave.

The cave's domes demonstrate that water entering the known part of the cave primarily originates over the cave's footprint. However, significant additional parts of the cave are indicated by the hydrology and must be considered in delineating its groundwater drainage basin. Most water seems to drain into conduits at the south end of the cave, consistent with the dip of the beds, the presence of a notable fracture in that part of the cave, and the direction of the mean potentiometric gradient. Some water also seems to drain into a fracture-guided conduit extending west from the breakdown. Neither of these conduits appear on the cave map.

Pape-Dawson (2000) proposed a groundwater drainage basin that extends about 46 m north of the cave's footprint and 9 m to the south based on fractures observed to the north and probable downdip flow of water. However, the morphologic and hydrologic features in the cave indicate more localized recharge. Also, that study did not consider the probable downgradient extent of the cave in delineating the basin. Based on the available information, the groundwater drainage basin of Hills and Dales Pit is estimated here to extend 30 m, about its end-to-end length, from its footprint to the north and east, and 60 m west and 90 m south along the probable drainage routes. The lower portion of the cave is in the Basal Nodular Member of the Kainer Formation and may extend into the upper member of the Glen Rose Formation. Horizontally extensive passages are common in both units.

**John Wagner Ranch Cave No. 3.** Veni (1996a) hydrogeologically evaluated this cave and delineated its drainage basins. Its surface water drainage is a slightly oval, 52-m-long by 43-m-wide area that drains sheetwash into the cave's entrance.

The lack of solution features for guidance on the probable extent of the cave's groundwater basin requires consideration of the probable extent of conduits in other phreatically formed caves in the upper member of the Glen Rose Formation in the Helotes area. In the direction perpendicular to the axis of the cave, the groundwater basin boundary should extend 20 m from the footprint of John Wagner Ranch Cave No. 3, plus an additional 10 m to include a probable collapse area at the cave's northeast end. This is the likely groundwater drainage area since infeeding conduits and passages in other caves seldom reach greater distances from their main phreatic voids. However, in the direction of the cave's axis, the cave may feasibly capture drainage from an area at least twice its known length. The collapsed valley to the south is no longer a physical part of John Wagner Ranch Cave No. 3, and its main passage is obliterated. However, conduits probably exist off that former passage and radiate outward from the valley so a groundwater drainage basin should also extend at least 20 m from the edge of the valley.

**Kamikazi Cricket Cave.** Veni (1988) published a description and map of this cave, which has yet to be subjected to a detailed hydrogeologic study. Its surface water drainage basin has not been measured, but based on my recollection, it probably captures sheetwash from no more than a 10-m-long by 2-m-wide area.

The cave contains four levels of passages connected by pits ranging from 2 to 6.3 m in depth. From the entrance to a depth of about 4-6 m, the cave is developed in the Dolomitic Member of the Kainer Formation. Below that level to the bottom of the cave at a depth of 16 m, the cave occurs in the Kainer's Basal Nodular Member. The entrance occurs about 110 m south of a normal fault that locally bears 62° and has about 15 m throw down to the south (Stein and Ozuna, 1995). Fractures in the cave have not been mapped but guide the cave's passages along approximate east-west trends. Veni (1994) found that this and other caves in the steep terrain of the area are formed along fractures aligned down the locally steepest hydraulic gradient rather than on the most prominent fractures.

The cave developed by capturing surface water from several fractures and small pits and converging it to form a passage and a drain. One upper level drain extended to the north, but the now central part of the cave became the dominant drain and currently captures most of the flow. As the drain deepened, infeeding passages developed at progressively deeper levels to transmit recharge down the steeper gradient. Some of the recharge originates not only along the main fracture trend but

perpendicular to that trend, probably along roughly north-south fractures. The small drain at the bottom of the cave may suggest that recharge has diminished with time, but it may instead represent a newly forming drain to replace one that is possibly plugged by flowstone and sediment.

Based on the available information, the groundwater drainage basin of Kamikazi Cricket Cave is estimated to extend 50 m, about twice its end-to-end length, from its footprint to the east and west and 25 m from the footprint to the north and south.

**La Cantera Cave No. 1.** Pape-Dawson (1999) and SWCA (2000b, 2001a) described this cave and provided a map and geologic description. Its surface water drainage area was mapped as 170 m long by about 50 m wide.

Detailed geologic mapping by the USGS (Stein and Ozuna, 1995) shows that the cave's entrance occurs in the Dolomitic Member of the Kainer Formation, about 150 m west of a normal fault that locally bears about 45° and has at least 65 m of throw down to the south. Pape-Dawson (1999) and SWCA (2001a) erroneously described the cave respectively as within the undivided Cyclic, Marine, Leached, and Collapsed members of the Person Formation and the Leached and Collapsed members of the Person Formation. The cave map shows La Cantera Cave No. 1 as a 7-m-deep pit below a 3 to 4-m-diameter sinkhole. A second pit follows and reaches a depth of about 12 m and the explored end of the cave. An inaccessibly low passage extends at least 3 m from the base of the cave. Water that enters the cave drains down into the Edwards Aquifer through breakdown in the floor of the second pit. Pape-Dawson (1999) suggests that "vertical development has ceased" at this level of the cave, but that is highly unlikely. Breakdown, vertical drainage through the breakdown, and the cave's position about 80 m above the water table (see discussion below for La Cantera Cave No. 2) strongly indicate continued vertical development beyond the limits of exploration.

SWCA (2001a) described the cave as a "fracture-oriented vadose shaft," but they and Pape-Dawson (1999) did not describe any fractures or their orientations. The map of the cave does not exhibit a preferential direction of development, but it is roughly drawn and some details are not clear. Domes and flowstone in the Cricket Room and Formation Alcove demonstrate recharge along pathways other than from the entrance. The low passage at the bottom of the cave may reflect recharge into the cave from a more distant source. The cave map also suggests other possible routes for recharge. The bottom of the cave is roughly at the contact with the Basal Nodular Member of the Kainer Formation. Locally, this unit often produces relatively large rooms and more horizontally extensive passages.

Pape-Dawson (1999) estimated the cave's groundwater drainage basin extended a maximum 20 m from the footprint of the cave. This was based on information by Veni (1996a) relating to John Wagner Ranch Cave No. 3 and Madla's Cave, but it is not an appropriate comparison given significant differences in the caves' origins. Based on the information available, the probable greater extent of the cave at deeper levels, and the unavailable information on fractures that guide the cave's development, the groundwater drainage area for La Cantera Cave No. 1 is estimated to extend 30 m from the footprint of the cave, almost triple its 11.4-m end-to-end length.

**La Cantera Cave No. 2.** Pape-Dawson (1999) and SWCA (2000b, 2001a) described this cave and provided a map and geologic description. Its surface water drainage area was mapped as 110 m long by as much as about 80 m wide.

Detailed geologic mapping by the USGS (Stein and Ozuna, 1995) shows that the cave's entrance occurs in the Dolomitic Member of the Kainer Formation, about 80 m northwest of a normal fault that locally bears 50° and has at least 65 m of throw down to the south. Pape-Dawson (1999) and SWCA (2001a) erroneously described the cave as occurring within the undivided Cyclic, Marine, Leached, and Collapsed members of the Person Formation. Pape-Dawson (1999) reported several fractures in the cave that guide the development of passages and pits. Most bear about 70°, which follows the cave's general trend.

SWCA (2001a) provided a map that shows the cave as a series of pits that extend to a depth of 35 m. At the base of the cave is an inaccessibly small, partly water-filled passage. An unpublished map of the cave in the TSS files shows the passage to head north for 2 m then turn northwest for at least 4 m. Water level elevations in nearby wells were not examined, but regional potentiometric maps of the Edwards Aquifer (e.g. Maclay and Small, 1984) show the water table occurs about 50 m below the bottom of the cave, demonstrating that the cave's water is perched within the upper member of the Glen Rose Formation. Mud and flood debris on the walls of the lower 5 m of the cave demonstrate that La Cantera Cave No. 2 recharges faster than its lower portions drain into the aquifer. Neither rate has been gauged, but observations of similar flood levels in other caves in the area suggest the water usually drains within a week, possibly in less than a couple of days.

Pape-Dawson (1999) proposed a groundwater drainage basin that extended no more than 20 m from the footprint of the cave. This was based on information by Veni (1996a) relating to John Wagner Ranch Cave No. 3 and Madla's Cave, but it is not an appropriate comparison given significant differences in the caves' origins. It is also does not account for the cave's strong fracture control, depth, probable extent of the water crawl, and cluster of two, possibly three, karst features nearby that may have formed to drain into the cave. Based on the information available and observations in other, similar caves, the groundwater drainage area for La Cantera Cave No. 2 is estimated to extend 50 m from the footprint of the cave along its axis to the northeast in the immediate downgradient direction, to include Karst Feature 4-2 shown on Pape-Dawson's (1999) map of drainage around the cave, and 30 m, a little less than triple its end-to-end length, perpendicular to the axis and to the southwest along the axis.

**Mastodon Pit.** No published information is available for this cave. Its description is based on unpublished reports and data in the TSS files. No hydrogeologic investigation of Mastodon Pit has been performed. Its surface water drainage basin has not been measured, but based on my recollection, it probably captures sheetwash from no more than a 20-m-long by 5-m-wide area.

The cave consists of two pits. The first is the entrance pit, which is 1 m in diameter at the top and enlarges to 3 m long by 1.3 m wide at its floor, which occurs 8.1 m below the surface. The floor steeply slopes about 3 m to a constriction that opens to the top of the second pit, which is 8.2 m deep and 3 m long by 2 m wide at its floor.

The cave is vadosely developed in the Dolomitic Member of the Kainer Formation. Detailed geologic mapping by the USGS (Stein and Ozuna, 1995) shows a major normal fault about 45 m southeast of the cave that locally bears 50° and has at least 65 m of throw down to the south. The sketch of the cave in the TSS files suggests that the entrance pit may be formed along a north-south trending fracture, but this is not clear. The sketch of the lower pit clearly suggests development along a fracture that bears approximately 40°. This orientation is consistent with the range of fractures that guide most cave development in Bexar County. Slight airflow at the bottom of the cave suggests that additional passages will likely be found if the rocks and soil of the cave floor were excavated. These would lead into the Kainer's Basal Nodular Member and from there into the upper member of the Glen Rose Formation. These units often form relatively large rooms in the study area and capture recharge from multiple sources.

Lost Mine Trail Cave, a short cave that seems likely to lead into a significant cave if excavated, plus an unnamed sinkhole that also seems likely to lead into a cave, are located an estimated 25 m and 45 m to the north. Their proximity to each other and Mastodon Pit, plus their alignment with a possible north-south fracture in the upper part of the cave, suggest that they may all be physically, if not hydrologically and biologically, related. Based on these factors and hypotheses, the groundwater basin of Mastodon Pit is estimated to extend from its footprint for 75 m to the north to encompass the other cave and sinkhole (or if they are further than estimated in this report, their actual distance plus an additional 30 m) and 75 m northeast and southwest along the axis of the cave's lower pit, and 50 m perpendicular to the axis from the footprint. Since the cave has not been mapped, its footprint is approximated based on its description.

**Mattke Cave.** Veni (1988) published a description and map of this cave, which has yet to be subjected to a detailed hydrogeologic study. Its surface water drainage basin has not been measured, but based on its location along a steep hillside, it probably captures sheetwash from no more than a 10-m-long by 2-m-wide area.

The cave is a 2.8-m-deep pit into a 10-m-long by 5-m-wide room that is divided into two rooms by sediment. It is developed in the upper member of the Glen Rose Formation about 47 m northwest of a normal fault that locally bears 53° and has about 30 m throw down to the south (Stein and Ozuna, 1995). Fractures have not been reported in the cave, but the morphology of the entrance and north end of the cave suggests development, at least in that area, along an east-west fracture. Three conduits drain into the cave from the north, and the cave continues inaccessibly small to the south.

The cave probably developed as a phreatic chamber that formed a vadose shaft entrance during the down-cutting of the Helotes Creek Valley. Sediments that washed into the cave filled much of the room and blocked human access to its southward continuation. The cave is aligned with the trend of Scorpion Cave, located 53 m to the southeast, and may be the lower continuation of that cave. Based on the little available information and knowledge of somewhat geologically similar area caves, the groundwater drainage basin of Mattke Cave is estimated to extend 30 m from its footprint, about triple its end-to-end length. It also merges with the groundwater basin of Scorpion Cave, since the two are probably hydrologically connected or at least indistinguishable with the information and methods available to this study. The basin is truncated to the west by the cliff that drops to Helotes Creek.

**Porcupine Squeeze Cave.** Unpublished data in the TSS files suggest this cave contains *Rhadine exilis*. This has not been confirmed. USFWS is seeking to confirm the report and obtain a location and other information so its surface and groundwater drainage basins can be estimated (Tannika Engelhard, USFWS, personal communication, 2002).

**Robber's Cave.** Veni (1988) published a description and map of this cave, which has yet to be subjected to a detailed hydrogeologic study. Its surface water drainage basin has not been measured, but based on my recollection and photographs, it probably captures sheetwash from no more than a 30-m-long by 6-m-wide area.

The cave is an 8.2-m-deep pit in a 17-m-diameter room. The upper portion of the pit is developed in the Basal Nodular Member of the Kainer Formation, and the room is formed in the upper member of the Glen Rose Formation. It is located about 60 m north of a normal fault that locally bears 63° and has about 15 m of throw down to the south (Stein and Ozuna, 1995). Fractures have not been reported in the cave, and its morphology does not suggest preferential development along fractures.

The cave developed as a phreatic chamber that experienced substantial collapse with the onset of vadose conditions. No portion of the original solutionally formed chamber is visible. Since collapses decrease in diameter with height, this suggests the original room and any associated passages are larger, possibly substantially larger, than the known extent of the cave. Based on the little available information and knowledge of geologically similar caves, the groundwater drainage basin of Robber's Cave is estimated to extend 60 m from its footprint, about triple its diameter.

**Scorpion Cave.** Veni (1988) published a description and map of this cave, which has yet to be subjected to a detailed hydrogeologic study. Its surface water drainage basin has not been measured, but based on my recollection, it probably captures sheetwash from no more than a 5-m-long by 1-m-wide area.

The cave is a 3.8-m-deep pit in a 12-m-long by 3-m-wide by 3-m-high room. Water in the cave drains west into a small passage that ends at a 3.5-m-deep pit. The cave is developed in the Basal Nodular Member of the Kainer Formation. Geologic mapping by Stein and Ozuna (1995) places a normal fault along the northwest end of the cave. The fault has not been noted in the cave. It locally bears 53° and has about 30 m of throw down to the south. Fractures have not been reported in the cave, but its morphology suggests development along a northwest to southeast trending fracture. Veni (1994) found that caves in the steep terrain of the area are formed along fractures aligned down the locally steepest hydraulic gradient rather than on the most prominent fractures.

The cave developed as a phreatic chamber and has undergone some vadose modifications, such as the pit at its lower end. The cave is aligned with the trend of Mattke Cave, located 53 m to the northwest, and may feed groundwater into that cave. Based on the little available information and knowledge of geologically similar caves, its proximity to the major fault, and its perpendicular trend, the groundwater drainage basin of Scorpion Cave is estimated to extend 25 m from its footprint, about double its end-to-end length. It also merges with the groundwater basin of Mattke Cave, since the two are probably hydrologically connected or at least indistinguishable with the information and methods available to this study.

**Sunray Cave.** Unpublished data in the TSS files suggest this cave contains *Rhadine exilis*. This has not been confirmed. USFWS is seeking to confirm the report and obtain a location and other information so its surface and groundwater drainage basins can be estimated (Tannika Engelhard, USFWS, personal communication, 2002).

**Three-Fingers Cave.** No published information is available for this cave. Its description is based on unpublished reports and data in the TSS files. No hydrogeologic investigation of Three-Fingers Cave has been performed. Its entrance is located at the base of a short cliff and captures no appreciable surface water drainage.

The cave begins as a single passage but soon branches and rejoins on different levels as it heads 50 m northwest and to a depth of 12.4 m. One hundred and sixty meters of passages have been surveyed in the cave. Airflow from impassibly small areas indicates that the cave has considerably greater extent, but substantial excavation will be needed to breach the current constrictions and blockages to human exploration.

The geology of the cave is difficult to evaluate without a field study. The cave is developed either in the Dolomitic Member or Basal Nodular Member of the Kainer Formation. It is located next to a normal fault that locally bears about 85° and has about 15 m throw down to the south (Stein and Ozuna, 1995), but it is not clear if the cave occurs on the up or down thrown side. Since horizontally extensive caves are more common in the Basal Nodular Member, it is more likely on the upthrown side of the fault. The cave probably developed as a large phreatic chamber, the full extent of which is not represented by the known parts of the cave. Following the onset of vadose conditions, substantial collapse occurred in the chamber, dividing it into several passages. This was enhanced by the down-cutting of an unnamed valley that truncated the cave. Concentrated recharge enlarged and solutionally modified some of the breakdown-formed passages, and substantial volumes of sediment were washed in and deposited. As the valley cut below the level of the cave and soil and rocks fell down the steep hillside in front of the cave's entrance, recharge via the creek ceased. However, recharge still continues through domes and fractures.

Based on the little available information, the above hypothesis of the cave's origin, and knowledge of geologically similar caves, the groundwater drainage basin of Three-Fingers Cave is estimated to extend 100 m from its footprint along its axis to the northwest, double its end-to-end length, and 50 m from its footprint in all other directions. It almost certainly captures water recharged into a nearby creek that runs roughly parallel to the cave.

**Unnamed cave 8 km NE of Helotes (Cave 23).** Unpublished data in the TSS files suggest this cave is La Cantera Cave No. 3, but this has not been confirmed. SWCA (2001a) reported no endangered species in the La Cantera Cave No. 3 which has been sealed as a result of their report. However, USFWS has been unable to obtain additional information on this cave (Tannika Engelhard, USFWS, personal communication, 2002), which was identified as containing endangered invertebrate species apparently from an earlier SWCA investigation.

**Young Cave No. 1.** Veni (1988) published a description and map of this cave, which has yet to be subjected to a detailed hydrogeologic study. Its surface water drainage basin has not been

measured, but based on my recollection, it probably captures sheetwash from no more than a 10-m-long by 2-m-wide area.

The cave is essentially a single 52-m-long passage divided into separate, smaller passages by breakdown, sediment, and speleothems. About 7 m from its southwest end is Young Cave No. 2, a low, 6-m-diameter room that extends to the southwest. The cave developed as a phreatic chamber or passage in the Basal Nodular Member of the Kainer Formation or the underlying upper member of the Glen Rose Formation. No portion of the original, solutionally formed chamber is visible. Since collapses decrease in diameter with height, this suggests the original room and any associated passages are larger, possibly substantially larger, than the known extent of the cave. This is supported by the presence of Young Cave No. 2, which is part of that same collapse but separated by breakdown.

The cave has a strong northeast-southwest trend that is probably related to some unidentified fractures. Based on the little available information and knowledge of geologically similar caves, the groundwater drainage basin of Young Cave No. 1 is estimated to extend 130 m along its axis from its footprint and the footprint of Young Cave No. 2, about double their end-to-end length, and 50 m from their footprint perpendicular to the axis.

## **Critical Habitat Comments and Recommendations**

USFWS (2002) has proposed critical habitat for the listed karst invertebrates in Bexar County. To assist in that effort, the following comments and recommendations are based on the findings of this report. These comments also stand as this report's conclusions and recommendations.

1) Page 55,065 of the proposal indicates that "over 400 caves" were known in Bexar County by 2000. As manager of the TSS database for Bexar County, I can provide more up to date figures. As of 23 December 2002, 475 caves are known in the county. It is important to note that of those caves, at least 97 are sealed or destroyed. Several more are rumored as sealed or destroyed but remain to be confirmed. Very few of those were biologically investigated. Listed species were possibly known in three sealed caves: Cave of the Woods, Here Today Gone Tomorrow Cave, and La Cantera Cave No. 3.

2) In Tables 1 and 2 of the proposal, change "Eagle's Nest Cave" to "Eagles Nest Cave" and "Hold-Me-Back Cave" to "Hold Me Back Cave."

3) The proposal does not define critical habitat for Crownridge Canyon Cave, Dancing Rattler Cave and Hackberry Sink. The presence of listed species in these caves was established after the proposal was submitted for publication. Critical habitat for these caves needs to be defined.

4) The proposal does not define critical habitat for the following caves: Porcupine Squeeze Cave, Sunray Cave, the unnamed cave 8 km northeast of Helotes, and the unnamed two caves on Iron Horse Canyon. Information on these caves is needed to delineate critical habitat. The information is also needed to accurately delimit the surface and groundwater drainage basins for these caves, as well as for Continental Cave, Creek Bank Cave, Pig Cave, and Tight Cave.

5) The surface water drainage area delineated in this report for Springtail Crevice extends more than 6 km outside of its proposed critical habitat area. All or at least a significantly greater percentage of the lower drainage area within about 2 km of the cave should be included within the critical habitat area to better protect the cave from degradation of water quality due to urbanization. Maintaining impervious cover to less than 15% of the drainage area should generally protect water quality (Schueler, 1994), except from large storms that transmit water from further up the valley or in the event of a hazardous materials spill.

6) The groundwater drainage basin for Black Cat Cave and Logan's Cave extend beyond the boundaries of their proposed critical habitat areas. The Black Cat basin extends into a housing development and encompasses Encino Park Cave. That cave is sealed and within a vacant lot, preserved as a small neighborhood park. Critical habitat for Black Cat Cave should extend at least to the neighborhood and include the lot with Encino Park Cave. Only a small edge of the groundwater drainage basin for Logan's Cave is excluded from critical habitat and should be included if possible.

7) The following proposed critical habitat areas, as numbered by USFWS (2002), do not include at least half of their Zone 1 areas: 1(a-e), 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 21. As much of the Zone 1 areas as possible should be included. The major difference in the Zone 1 boundaries delineated in this report versus those proposed by Veni (1994) is that increasing data show

that many caves with listed species can be found in Bexar County if adequate surveys are conducted. While this could be interpreted as rationale for more lax protection, it demonstrates, along with detailed biological surveys that find many new species rarer than those listed (e.g. Veni, Reddell, and Cokendolpher, 2002), how little is known of the karst ecosystem and that extra steps should be taken to protect it.

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## APPENDIX A

### Glossary of Geologic, Karst, and Biological Terminology

This glossary is broad in scope to assist nonspecialists reviewing this report, but is not meant to cover all possible terms. Additional karst definitions and geologic terms can be found in the geologic dictionary of Jackson (1997); for biospeleological terms see Culver (1982).

**Aggradation:** The process of building up a surface, such as a stream channel or cave floor, by deposition.

**Alluvium:** Stream-deposited sediments, usually restricted to channels, floodplains, and alluvial fans.

**Anastomoses:** Small interconnecting conduits that fork and rejoin, usually along bedding planes and joints.

**Aquifer:** Rocks or sediments, such as cavernous limestone and unconsolidated sand, which store, conduct, and yield water in significant quantities for human use.

**Base level:** The level to which drainage gradients (surface and subsurface) are adjusted, usually a surface stream, relatively impermeable bedrock, or water table. Sea level is the ultimate base level.

**Baseflow:** The “normal” discharge of stream when unaffected by surface runoff; derived from groundwater flowing into the stream channel.

**Bearing:** The azimuthal direction of a linear geologic feature, such as the axis of a fold or the orientation of a fracture; commonly used to denote specific orientations rather than average or general orientations. See trend for comparison.

**Beds:** See strata.

**Bedding plane:** A plane that divides two distinct bedrock layers.

**Breakdown:** Rubble and boulders in a cave resulting from collapse of the cave ceiling.

**Cave:** A naturally occurring, humanly enterable cavity in the earth, at least 5 m in length and/or depth, in which no dimension of the entrance exceeds the length or depth of the cavity (definition of the Texas Speleological Survey).

**Conduit:** A subsurface bedrock channel formed by groundwater solution to transmit groundwater; often synonymous with cave and passage, but generally refers to channels either too small for human entry, or of explorable size but inaccessible. When used to describe a type of cave, it refers to base level passages that were formed to transmit groundwater from the influent, upgradient end of the aquifer to the effluent, downgradient end.

**Cretaceous:** A period of the geologic time scale that began 135 million years ago and ended 65 million

years ago.

**Depth:** In relation to the dimensions of a cave or karst feature, it refers to the vertical distance from the elevation of the entrance of the cave or feature to the elevation of its lowest point. See vertical extent for comparison.

**Dip:** The angle that joints, faults or beds of rock make with the horizontal; colloquially described as the “slope” of the fractures or beds. “Updip” and “downdip” refer to direction or movement relative to that slope.

**Discharge:** The water exiting an aquifer, usually through springs or wells; also the amount of water flowing in a stream.

**Drainage basin:** A watershed; the area from which a stream, spring, or conduit derives its water.

**Drainage divide:** Location where water diverges into different streams or watersheds. On the surface they usually occur along ridges or elevated areas. In aquifers, they occur along highs in the potentiometric surface between groundwater basins.

**Endemic:** Biologically, refers to an organism that only occurs within a particular locale.

**Epigeal:** Pertaining to species living on the surface of the earth.

**Epikarst:** The highly solutioned zone in karst areas between the land surface and the predominantly unweathered bedrock.

**Fault:** Fracture in bedrock along which one side has moved with respect to the other.

**Floodplain:** The flat surface that is adjacent and slightly higher in elevation to a stream channel, and which floods periodically when the stream overflows its banks.

**Footprint:** The outline of a structure or cave in plan view; generally refers to defining the horizontal limits as they relate to the land surface.

**Fracture:** A break in bedrock that is not distinguished as to the type of break (usually a fault or joint).

**Geomorphology:** The branch of geology that studies the shape and origin of landforms.

**Gouge:** The finely ground material that forms along some fault planes by the grinding of one plane against the other.

**Graben:** A section of rock between faults that has dropped downward relative to strata on the opposite side of the faults.

**Grade:** The continuous descending profile of a stream; graded streams are stable and at equilibrium, allowing transport of sediments while providing relatively equal erosion and sedimentation. A graded

profile generally has a steep slope in its upper reaches and a low slope in its lower reaches.

**Groundwater trough:** A steep furrow-shaped feature in the potentiometric surface, usually indicative of high groundwater transmissivity through an underlying conduit.

**Head:** The difference in water level elevations that creates the pressure for water movement down a gradient.

**Headward:** In the direction of greater elevation; typically refers to upstream or up a hydraulic gradient.

**Homogeneous:** Condition where an aquifer's hydraulic properties are the same in all locations.

**Honeycomb:** An interconnected series of small voids in rock, commonly formed in karst by near-surface (epikarstic) solution, or by phreatic groundwater flow.

**Horst:** A section of rock between faults that has been raised relative to strata on the opposite side of the faults.

**Hydrogeology:** The study of water movement through the earth, and the geologic factors that affect it.

**Hydrology:** The study of water and its origin and movement in atmosphere, surface, and subsurface.

**Impermeable:** Does not allow the significant transmission of fluids.

**Joint:** Fracture in bedrock exhibiting little or no relative movement of the two sides.

**Karst:** A terrain characterized by landforms and subsurface features, such as sinkholes and caves, which are produced by solution of bedrock. Karst areas commonly have few surface streams; most water moves through cavities underground.

**Karst feature:** Generally, a geologic feature formed directly or indirectly by solution, including caves; often used to describe features that are not large enough to be considered caves, but have some probable relation to subsurface drainage or groundwater movement. These features typically include but are not limited to sinkholes, enlarged fractures, noncavernous springs and seeps, soil pipes, and epikarstic solution cavities.

**Length:** In relation to the dimensions of a cave or karst feature, it refers to the summed true horizontal extent of the cave's passages or the feature's extent.

**Lithology:** The description or physical characteristics of a rock.

**Marl:** Rock composed of a predominant mixture of clay and limestone.

**Nodular:** Composed of nodules (rounded mineral aggregates).

**Normal fault:** A fault where strata underlying the fault plane are higher in elevation than the same

strata on the other side of the fault plane.

***Paleodrainage:*** An earlier pattern or condition of surface or groundwater flow.

***Passage:*** An elongate, roofed portion of a cave or karst feature; usually a conduit for groundwater flow.

***Perched groundwater:*** Relatively small body of groundwater at a level above the water table; downward flow is impeded within the area, usually by impermeable strata.

***Permeable:*** Allows the significant transmission of fluids.

***Permeability:*** Measure of the ability of rocks or sediments to transmit fluids.

***Phreatic:*** The area below the water table, where all voids are normally filled with water.

***Pit:*** A vertical cavity extending down into the bedrock; usually a site for recharge, but sometimes associated with collapse.

***Porosity:*** Measure of the volume of pore space in rocks or sediments as a percentage of the total rock or sediment volume.

***Potentiometric surface:*** A surface representing the level to which underground water confined in pores and conduits would rise if intersected by a borehole. See water table.

***Reach:*** The length of a stream or stream segment; often used to denote similar physical characteristics.

***Recharge:*** Natural or artificially induced flow of surface water to an aquifer.

***Room:*** An exceptionally wide portion of a cave, often at the junction of passages; commonly indicative of either the confluence of groundwater flowpaths or of slow, nearly ponded, groundwater flow. Generally synonymous with chamber, except that chamber is usually reserved for relatively large rooms.

***Shaft:*** See pit.

***Sheetwash:*** Surface water runoff that is not confined to channels but moves across broad, relatively smooth surfaces as thin sheets of water.

***Sink:*** See sinkhole.

***Sinkhole:*** A natural indentation in the earth's surface related to solution processes, including features formed by concave solution of the bedrock, and/or by collapse or subsidence of bedrock or soil into underlying solutionally formed cavities.

***Solution:*** The process of dissolving; dissolution.

**sp.:** Taxonomic abbreviation for “species;” when following a genus name, it indicates lack of identification to species level. Plural is spp.

**Speleothem:** A chemically precipitated secondary mineral deposit (e.g., stalactites and stalagmites) in a cave; usually calcite but can form from gypsum and other minerals.

**Strata:** Layers of sedimentary rocks; usually visually distinguishable. Often called beds. The plural of stratum.

**Stratigraphic:** Pertaining to the characteristics of a unit of rock or sediment.

**Stratigraphy:** Pertaining to or the study of rock and sediment strata, their composition and sequence of deposition.

**Strike:** The direction of a horizontal line on a fracture surface or on a bed of rock; perpendicular to dip.

**Structure:** The study of and pertaining to the attitude and deformation of rock masses. Attitude is commonly measured by strike and dip; deformational features commonly include folds, joints, and faults.

**Taxa:** Taxonomic categories, such as species, genus, etc.; taxon is a singular category.

**Taxonomy:** A system for classifying organisms into related groups and in descending order.

**Terrace:** A relatively narrow, flat topographic surface; with reference to streams it usually marks the elevation of a former, higher, water level, and is composed of and formed by the deposition of unconsolidated sand, gravel, and related alluvial material.

**Trend:** The azimuthal direction of a linear geologic feature, such as the axis of a fold or the orientation of a fracture; commonly used to denote average or general orientations rather than specific orientations.

**Troglobite:** A species of animal that is restricted to the subterranean environment and which typically exhibits morphological adaptations to that environment, such as elongated appendages and loss or reduction of eyes and pigment.

**Troglophile:** A species of animal that may complete its life cycle in the subterranean environment but which may also be found on the surface.

**Trogloxene:** A species of animal that inhabits caves but which must return to the surface for food or other necessities.

**Type locality:** The location or area from which a species is first found and described, or where a section or unit of bedrock is described as the typical example; more commonly called type area or type

section when used in a geologic context.

**Vadose:** Pertaining to the zone above the water table where all cavities are generally air-filled, except during temporary flooding.

**Vertical extent:** In relation to the dimensions of a cave, refers to the vertical distance from the highest elevation to the lowest elevation of the cave. Generally used when a portion of a cave extends above its entrance. See depth for comparison.

**Water table:** The boundary of the phreatic and vadose zones. A potentiometric surface but the term is used only in unconfined aquifers.

## APPENDIX B

### Conversions: International System of Units to English Units

| MULTIPLY                                    | BY                             | TO GET                          |
|---|--------------------------------|---------------------------------|
| <b><i>Length</i></b>                        |                                |                                 |
| centimeters (cm)                            | 0.3937                         | inches (in)                     |
| meters (m)                                  | 3.281                          | feet (ft)                       |
| kilometers (km)                             | 0.621                          | miles (mi)                      |
| <b><i>Area</i></b>                          |                                |                                 |
| square meters (m <sup>2</sup> )             | 10.76                          | square feet (ft <sup>2</sup> )  |
| square kilometers (km <sup>2</sup> )        | 0.3861                         | square miles (mi <sup>2</sup> ) |
| square kilometers (km <sup>2</sup> )        | 247.1                          | acres (ac)                      |
| <b><i>Volume</i></b>                        |                                |                                 |
| liters (L)                                  | 0.264                          | gallons (gal)                   |
| cubic meters (m <sup>3</sup> )              | 264.17                         | gallons (gal)                   |
| cubic meters (m <sup>3</sup> )              | 0.00081                        | acre-feet (a-f)                 |
| <b><i>Flow</i></b>                          |                                |                                 |
| liters per second (L/s)                     | 0.0353                         | cubic feet per second (cfs)     |
| liters per second (L/s)                     | 15.85                          | gallons per minute (gpm)        |
| cubic meters per second (m <sup>3</sup> /s) | 35.31                          | cubic feet per second (cfs)     |
| cubic meters per second (m <sup>3</sup> /s) | 1,585                          | gallons per minute (gpm)        |
| cubic meters per second (m <sup>3</sup> /s) | 70.05                          | acre-feet per day (a-f/d)       |
| <b><i>Temperature</i></b>                   |                                |                                 |
| degrees Celsius                             | multiply by 1.8<br>then add 32 | degrees Fahrenheit              |

## APPENDIX C

### Biographies of Key Research Personnel

The appendix provides brief biographical information on the personnel who conducted the fieldwork for this investigation or wrote or conducted key research for the report. This appendix also meets the U.S. Fish and Wildlife Service guidelines for biographical data on personnel associated with the collection, study, and related research on the endangered karst invertebrates that occur in the study area (USFWS, 2000a, 2000b, 2000c). In meeting with those guidelines, the author of this report certifies direct responsibility for this report, that it is true, complete, and accurate to the best of his knowledge.

**Dr. George Veni** is an internationally recognized hydrogeologist specializing in caves and karst terrains. He received his Master's degree from Western Kentucky University in 1985 and his Ph.D. from the Pennsylvania State University in 1994. Since 1987 he has owned and served as principal investigator of George Veni and Associates. Much of his work has been in central Texas, but he has also conducted extensive karst research throughout the United States and in several other countries. He serves as a doctoral committee advisor for geological and biological dissertations at The University of Texas and teaches karst geoscience courses as an adjunct professor for Western Kentucky University. He has taken college level biology courses, including Karst Ecology at Western Kentucky University, and has been collecting cave species and assisting in the study of cave ecosystems since 1976. Three cave-dwelling species have been named in his honor. He has published and presented over 80 papers, including four books, on hydrogeology, biology, and environmental management in karst terrains. He holds U.S. Fish and Wildlife Service Permit TE026436-0 (expires 31 August 2005) to collect and study federally listed endangered Texas karst invertebrate species.