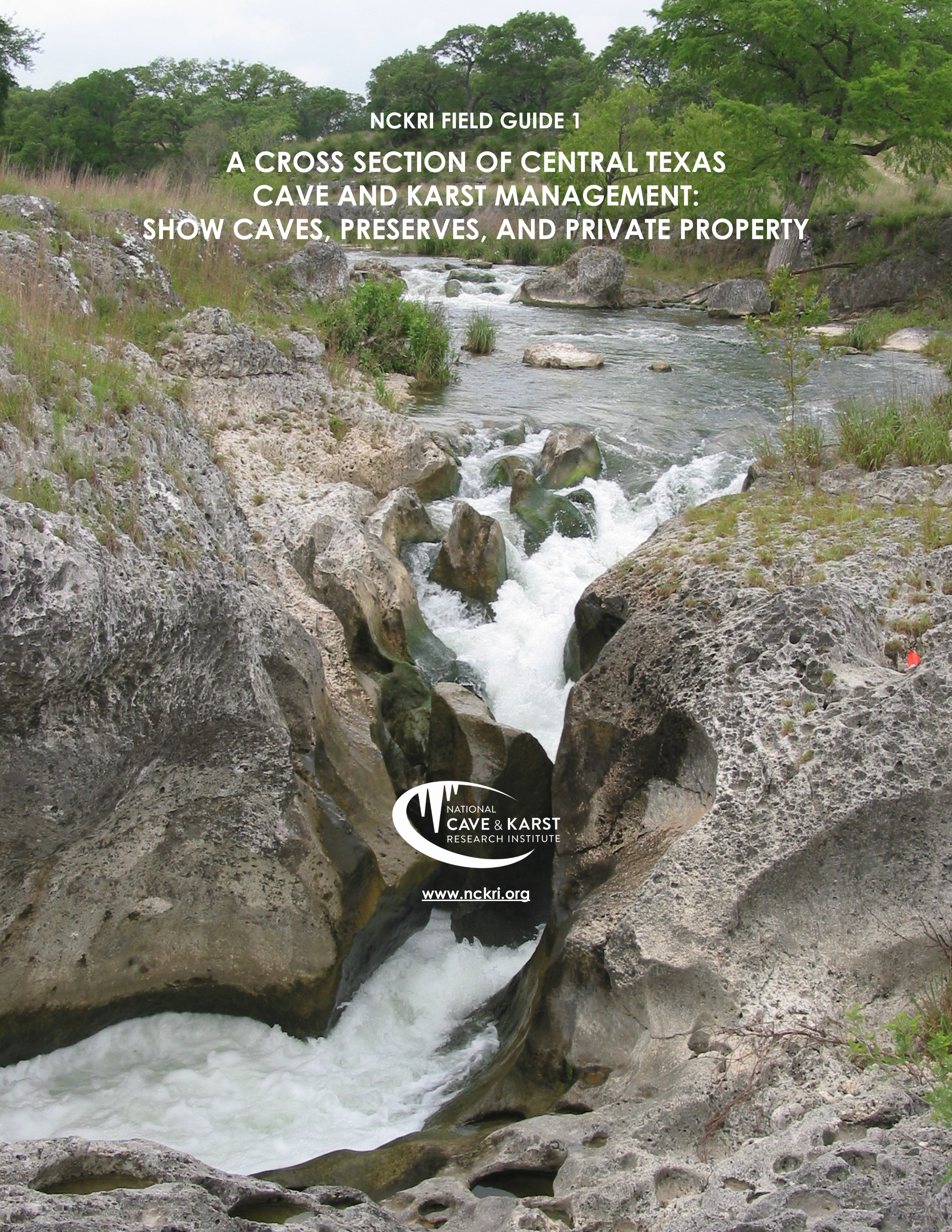

NCKRI FIELD GUIDE 1

A CROSS SECTION OF CENTRAL TEXAS CAVE AND KARST MANAGEMENT: SHOW CAVES, PRESERVES, AND PRIVATE PROPERTY

NATIONAL CAVE & KARST RESEARCH INSTITUTE

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A CROSS SECTION OF CENTRAL TEXAS CAVE AND KARST MANAGEMENT: SHOW CAVES, PRESERVES, AND PRIVATE PROPERTY

George Veni
National Cave and Karst Research Institute
(all text and graphics by the author except where noted)

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Dr. George Veni, Executive Director

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Front cover photo: Herff Falls, Kendall County, Texas, in 2004 before the 2019 opening of Hawkins Swallet that captured all the water (except flood flows) in Cibolo Creek. Hawkins Swallet is located in the creek about 60 m upstream of the falls.

Back cover photo: In contrast to Cibolo Creek that is recharging the regional aquifers in the front cover photo, the Guadalupe River loses little water into the aquifers. Despite the rock often being highly fractured and karstified, the river is mostly at or below the base of limestone throughout of the field trip area, and has little ability to recharge groundwater.

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NCKRI was created by the US Congress in 1998 in partnership with the State of New Mexico and the City of Carlsbad. NCKRI is administered by the New Mexico Institute of Mining and Technology (aka New Mexico Tech or NMT).

NCKRI's enabling legislation, the National Cave and Karst Research Institute Act of 1998, 16 USC, §4310, identifies NCKRI's mission as to:

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2) centralize and standardize speleological information;
3) foster interdisciplinary cooperation in cave and karst research programs;
4) promote public education;
5) promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
6) promote and develop environmentally sound and sustainable resource management practices.

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A Cross Section of Central Texas Cave and Karst Management: Show Caves, Preserves, and Private Property

George Veni
National Cave and Karst Research Institute, Carlsbad, New Mexico

Introduction

Trip Focus and Summary

This trip is designed for the 23rd National Cave and Karst Management Symposium for people interested in contrasting various landscape-wide and site-specific approaches to cave and karst management. Many styles of cave and karst management occur to meet the diversity and needs of each situation and setting. The styles also vary according to the type of ownership and general land use. This trip spotlights three styles of ownership/management. It will first visit Cave Without a Name, a small, lovely, privately owned show cave where management is focused on public access, education, and safety. Next is the non-profit Cibolo Center for Conservation, a nature center focused on Cibolo Creek, an important karst aquifer recharge feature. From there we will visit the adjacent private Cibolo Preserve where natural resource protection is the primary focus, followed by public education/access and research. Afterward is a stop at the entrances of Honey Creek Cave, Texas' longest cave, on a privately owned ranch trying to protect over 150 years of family stewardship from now rapidly encroaching exurban development. The last stop is at Bracken Cave, managed by Bat Conservation International as a biological preserve, educational, and research site.

Sponsors

Many thanks are extended to the owners of Cave Without a Name, the Cibolo Center for Conservation, Cibolo Preserve, and Bat Conservation International for entry without charge, and to the owners of Honey Creek for access to their property. The National Cave and Karst Research Institute is happy to provide this guidebook.

Logistics

To minimize risks to COVID-19, the group will travel in privately owned vehicles and up to two 15-passenger vans. Masks are required in the vans and inside Cave Without a Name. Lunch will be provided at the Cibolo Center for Conservation. No caving equipment is needed. A camera, comfortable hiking shoes, and a reusable water bottle (drinking water will be provided) are suggested. One stop will involve crossing a shallow stream (typically 10-20 cm deep); consider crossing barefoot or in sandals and bringing a small towel. Details are subject to change. Rain is not expected but could require a change in some destinations.

Schedule

8:00 – 9:15 a.m.: Leave San Marcos Activity Center and arrive at Cave Without a Name.

9:15 - 11:30 a.m.: Enter Cave Without a Name to discuss show cave management and methods for trails, lighting, tourist management, public education, and vandalism.

11:30 a.m. – 12:00 p.m.: Leave Cave Without a Name and arrive at the Cibolo Center for Conservation.

12:00 – 1:00 p.m.: Lunch provided at the Cibolo Center for Conservation where its staff will describe public education and natural resource protection challenges.

1:00 – 3:15 p.m.: Tour the adjacent Cibolo Preserve and caves and karst features along Cibolo Creek. Discuss water quality challenges from an upstream sewage treatment plant, neighboring urban developments, and the naturally evolving karst landscape that is capturing the stream and depriving water to the downstream riparian area.

3:15 – 4:00 p.m.: Leave Cibolo Preserve and arrive at Honey Creek Cave.

4:00 – 5:15 p.m.: Visit the natural entrance of Honey Creek Cave, Texas' longest cave, and the headwaters of its namesake Honey Creek. Discuss state and private efforts to protect this pristine riparian area, one of the few remaining in Texas, from proposed exurban development that may degrade water quality of surface runoff and groundwater through the cave.

5:15 - 6:00 p.m.: Leave Honey Creek Cave and arrive at Bracken Cave. There is no set time to return to San Marcos, but the trip there will take about 40 minutes.

Road Log for Figure 1

Total miles	Miles since last landmark	Description
0.0	0.0	Leave San Marcos Activity Center. Turn right (west) on E. Hopkins and drive through downtown San Marcos. Like many communities in semi-arid to arid climates, San Marcos was founded around a spring. The San Marcos Springs are the lowest elevation springs that flow from the San Antonio Segment of the Edwards Aquifer. Native Americans lived around the springs for thousands of years. Historic settlement attempts began in the 1750s, thwarted by Comanche attacks and floods, until permanent settlement began in 1851.
2.4	2.4	Turn right (north) onto Ranch Road 12, we'll be traveling across the Edwards Limestone, the Balcones Fault Zone, and the Edwards Aquifer Recharge Zone. The elevation of the land gently rises as we cross the fault zone. Much of the next 2.5 miles is the Purgatory Creek Natural Area. The Purgatory Creek flood control dam is visible on the left (west) side of the road. The Natural Area was created as part of the re-routing of Ranch Road 12, which formerly extended through a congested part of San Marcos. The Natural Area restricts urban development across parts of Purgatory Creek to limit urbanization of the recharge zone and protect many of the roughly 200 caves and karst features discovered during the environmental impact studies for the road. These features are important recharge sites to the Edwards Aquifer, and some have been dye traced to the San Marcos Springs.
12.6	10.2	Ranch Road 12 turns right (north) to Wimberley. This town began as the site of a grist and saw mill in 1856 along Cypress Creek, whose flow is supplied by the cave spring Jacob's Well. Continue west by veering left onto Ranch Road 32. The karst of central Texas is topographically subdued. Sinkholes are usually less than 2 m in diameter and 0.5 m deep. Soils in the region are thin, typically less than 0.5 m thick, and often patchy or absent.
16.2	3.6	Cross from Hays County into Comal County. The next 1.7 miles are along the Devil's Backbone, a narrow ridge, in some places little wider than the road which follows the drainage divide between the Blanco River drainage basin to the right (north) and the Guadalupe River drainage basin to the left (south). At the west end of the Devil's Backbone we leave the Edwards Limestone and begin driving on the underlying Upper Member of the Glen Rose Limestone, which is not cavernous in this area. About 0.3 mile past a picnic area on the right is a road cut in the Upper Glen Rose. Several small holes are present in the road cut, best seen on the right (north) side of the road if not hidden by vegetation. While some are solutionally formed, the majority are partly or mostly formed by the washing out of clays and marls (clay-rich limestone) below limestone beds with a minor degree of solutional activity. This is a modern process that occurs throughout the Upper Glen Rose in road cuts and cliffs. One way to identify the Upper Glen Rose is to look for "stairstep" topography. It is formed on a sequence of hard limestone beds between soft clay and clay-rich beds. The hard beds form topographic steps, and the soft beds form flat to gently-sloping benches. They are sometimes seen as barren, rocky limestone bands in the hillsides between vegetated bands where soils and greater moisture occur on the clay beds.
24.3	8.1	Cross Farm Road 484. To the right (north) lies the village of Fischer. Established in the 1850s, the Fischer Store was a locally important commercial and postal center through the mid-1900s. The store included a saloon in its early years, which was overlooked by postal inspectors in exchange for "a drink on the house." Continuing on Ranch Road 32, we cross a fault (not easily apparent) and drop stratigraphically from the Upper to the Lower Member of the Glen Rose Limestone, which contains some of the longest caves in Texas. We will visit two.
28.8	4.5	Cross from Comal County into Blanco County (not marked but followed shortly by the crossing of Rocky Creek). The dominant vegetation of the area is a Live Oak-Ashe Juniper forest. This ecosystem is found on the shallow limestone soils of the Edwards Plateau ecological region. The junipers, locally called "cedars," are the bushy dark green trees. Their increased presence on the landscape is due primarily to the past roughly 120 years of fire suppression. The impact of fires on the region's cave ecosystems remains to be studied.
29.4	0.6	Turn left (southwest) onto Farm Road 473 and follow the Little Blanco River, which will be prominent on the left (east) starting after about 3 miles. Situated over the Lower Member of the Glen Rose Limestone, this section of the river is often dry, losing its water into the Lower Glen Rose Aquifer. Most streams we will see are recharging or "losing" streams and are dry except during storms.
35.0	5.6	Turn left (south) on US Highway 281. Over the next several miles, on this and subsequent roads, we will drive either on the Lower Member of the Glen Rose or the Upper Member.
36.8	1.8	Turn right (west) back onto Farm Road 473. We have just crossed from the Blanco River drainage basin into the Guadalupe River's drainage basin.

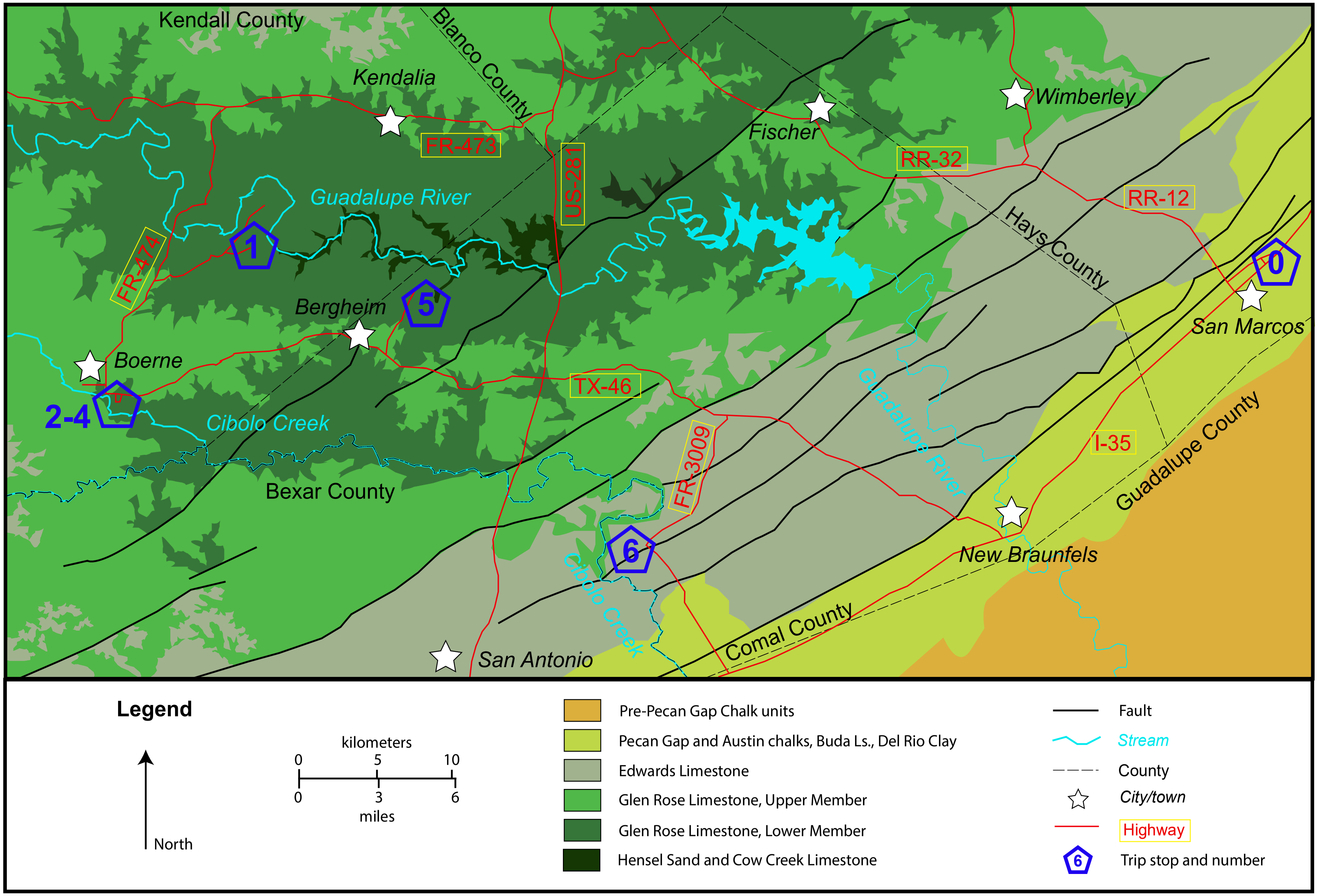

Figure 1. *Simplified geologic and highway map of field trip route and stops (adapted from Barnes, 1983).*

Total miles	Miles since last landmark	Description
38.7	1.9	Cross from Blanco County into Kendall County. Four of our six stops are in Kendall County. As we continue west, we'll cross south-draining tributaries to the Guadalupe River. Along the road, the valleys are in the Lower Member of the Glen Rose and the uplands between them are in the Upper Member. Due to a bias in exploration, few caves are known in the Lower Glen Rose north of the Guadalupe River. The exception is the Spring Branch area due south of this location (see inside back cover photo). Based on the area's hydrogeology, continued exploration should reveal some extensive, linear to meandering caves that drain south to the river. At 5.3 miles, cross through the village of Kendalia, established in 1883. For a great time and great music, visit Kendalia Halle, built in 1903 and one of the oldest dance halls in Texas.
51.4	12.7	Turn left (south) onto Ranch Road 474. At about 4.3 miles, we will cross over the flow path of Prassell Ranch Cave, an exception to the southward-draining expectation for caves in the area. Some caves on both sides of the Guadalupe River, in the Lower Glen Rose, form tapoff passages, which divert groundwater along locally steeper gradients within caves and between caves and streams. In this case, Prassell Ranch Cave formed by water leaking from the river into the limestone to our right (west), to cut under a meander bend to re-emerge on the downstream side of the meander to our left (east).
58.3	6.9	Cross the Guadalupe River, one of the few perennially flowing streams in the area. The riverbed is near the bottom of the Glen Rose Limestone and at the local water table where it is fed by many karst springs. We will visit two—the first one from inside the aquifer.
60.6	2.3	Turn left (east) onto Kreutzberg Road.
62.5	1.9	Pass Camp Alzafar Road on the left (north). A dye trace from a cave to the north was detected at Cave Without a Name.
64.1	1.6	Turn right (east) on Cave Without a Name Road.
65.1	1.0	**STOP 1: Cave Without a Name.**
69.6	4.5	Return the way we came to Ranch Road 474 and turn left (south)
75.0	5.4	Welcome to the Kendall County seat, the town of Boerne (pronounced "burn-ee"). Founded in 1849 as Tusculum by Germans of the Free Thinkers movement, it was renamed three years later in honor of German author and political satirist Karl Ludwig Börne. Ranch Road 474 turns right (west). Continue straight south on Esser Road.
75.7	0.7	Turn left (east) on Texas Highway 46.
75.8	0.1	Turn right (southeast) on City Park Road.
76.2	0.4	Turn right (south) to the Cibolo Center for Conservation.
76.4	0.2	**STOP 2: Cibolo Center for Conservation, and lunch stop.**
--	--	Drive to stops on Cibolo Preserve. For resource protection purposes, directions are not given. **STOP 3: Cibolo Island Cave.** **STOP 4: Hawkins Swallet and Herff Falls,**
76.4	--	Return to the entrance of the Cibolo Center for Conservation. Resume mileage count. Turn north on Charger Boulevard.
76.7	0.3	Turn right (east) on Texas Highway 46. Pass through the community of Bergheim, German for "mountain home," after 8.4 miles. Its store and post office have served the area since 1900.
86.8	10.1	Cross from Kendall County into Comal County. We will have also crossed over the upstream limit of exploration in Honey Creek Cave.
88.3	1.5	Turn left (north) on Park Road 31.
--	--	Drive to entrance of Honey Creek Cave. Directions are not given to protect the privacy of the cave owners. **STOP 5: Honey Creek Cave.**
88.3	--	Return to the intersection of Park Road 31 and Texas Highway 46 and turn right (east) on Texas Highway 46. Resume mileage count.
89.7	1.4	Property to the left (north) is the site of a proposed development that has been the subject of dispute on its potential adverse impact on Honey Creek Cave and Honey Creek. Continuing east, Texas Highway 46 follows the drainage divide between the Guadalupe River drainage basin to the left (north) and the Cibolo Creek drainage basin to the right (south), which recharges the Edwards Aquifer. Most of this section of the highway is along the bottom of the Upper Member of the Glen Rose Limestone.

Total miles	Miles since last landmark	Description
103.9	14.2	Turn right (south) on Farm Road 3009. From here to Bracken Cave we will drive over the upper-most section of the Upper Member of the Glen Rose Limestone in a few places, but mostly on the basal section of the Edwards Limestone. After 6.4 miles is the first of two turn-offs to Natural Bridge Caverns, the largest known cave in Texas by volume and which will be visited by the symposium the previous evening.
110.7	6.8	Turn right (southwest) on a graded road and the Bracken Cave Preserve.
112.3	1.6	**STOP 6: Bracken Cave.** It's only a short walk from the parking area to the cave entrance. You will smell the cave's guano before you see the entrance.
113.9	1.6	Return to Farm Road 3009 and turn right. Drive to Interstate Highway 35. For the first 5.3 miles we will be on the Edwards Aquifer Recharge Zone. At 5.3 miles the road will have descended to the base of the Balcones Escarpment, marked by the intersection with Farm Road 2252 which parallels a major fault. The rest of the trip back to San Marcos will be over the Edwards Aquifer Artesian Zone. The topography is nearly flat, covered in some places with alluvium and gravel washed off the Edwards Plateau, but otherwise underlain by the Cretaceous age Pecan Gap Chalk, which has only a few tiny caves.
121.0	7.1	Turn left (northeast) onto Interstate Highway 35.
133.2	12.2	Cross over the Guadalupe River in central New Braunfels. The river here includes the flow of the Comal River, the shortest river in Texas at only 4 km long, fed by the Comal Springs (Figure 2), the largest springs of the Edwards Aquifer and the largest in Texas. The land in the area was purchased to establish the city in 1845 by German Prince Carl, and named for his hometown, Solms-Braunfels.
142.8	9.6	Cross from Comal County into Hays County. We're nearly back.
150.8	8.0	Exit the Interstate and turn left (northwest) on E. Hopkins Road.
151.6	0.8	Turn right (north) into the parking lot of the San Marcos Activity Center. **End of trip.**

Figure 2. *Spring 1 of the Comal Springs group. These karst springs rise along a fault from the Edwards Aquifer at the base of the Balcones Escarpment. Their combined flow averages 8 m^3/second and is habitat for four endangered species.*

Regional Overview

This field trip loops through the heart of the Texas Hill Country (Figure 1). The Hill Country is as much of a physical region as a cultural one. It is generally defined as the southeastern corner of the Edwards Plateau where it is incised by streams running down to the Gulf Coastal Plain. This stream down-cutting produces the region's namesake rolling to steep hilly topography. To the northwest, the Hill Country levels off up onto the Edwards Plateau. To the southeast, its lower margin is bounded by the Balcones Escarpment.

Culturally, the region has a distinct German heritage which is obvious in the names of some communities we will drive through: Bergheim, Boerne, Kreutzberg, and New Braunfels. The stone architecture of the older buildings in the region also reflects this heritage, as do the stacked stone walls on many ranches which served the dual purpose of free fencing and making fields arable. Given the region was once a Spanish territory, and is located near modern Mexico, Spanish/Mexican culture is also evident, such as in the name of where this 23rd National Cave and Karst Management Symposium is held: San Marcos.

Jordan (2021) provides an on-line summary history of the Hill Country, and several books examine the region's history in detail. The older Native American prehistory of the Hill Country is less studied, and some is found in the region's caves. Bement (1994) gives the most detailed account of archaeological deposits in caves of the region, focused on Bering Sinkhole located about 100 km northwest of this trip's route.

Our route will begin at our lowest elevation of 174 m above mean sea level at the San Marcos Activity Center, located at the base of the Balcones Escarpment. We will reach our high point of 494 m at the northwest corner of our loop on Farm Road 473 where we turn south onto Ranch Road 474. The major streams in the area drain east and turn southeast as they approach the Balcones Escarpment. We will start and end our trip in the Blanco River watershed, and our field trip stops will be in the Cibolo Creek and Guadalupe River watersheds.

Rainfall in the area averages about 76 cm/year. While the topographic rise of the Balcones Escarpment is gentle and low, combined with other local meteorological conditions it results in some of the most intense rainfalls rates in North America. Several storms in the area have dropped the average annual rainfall total in only 1-2 days, producing intense flooding. Slade and Patton (2003) document 215 major and 41 catastrophic storms in Texas from 1853 to 2002, with many occurring in the Hill Country. Local soils are thin to non-existent, and of limited value in slowing floods. The dominant vegetation of the area is a Live Oak-Ashe Juniper forest with interspersed grasslands (the juniper is locally called "cedar"). O'Donnell (2019) provides a detailed historical study of the Hill Country's vegetation.

Historically, the field trip area was ranch land for mostly cattle, with some limited farmland. Over the past 40 years, it has increasingly converted to suburban and exurban housing and "ranchettes," from the spreading growth of San Antonio and its urban corridor along Interstate Highway 35 northeast to New Braunfels, San Marcos, and beyond. This growth has triggered many of the land resource management issues in the area. The most fundamental and contested issues involve water: how to allocate this limited resource and how to safely dispose of wastewater from expanding populations. These issues will serve as the framework for some of the major field trip discussions. Discussion of biological impacts are fewer and secondary in the Hill Country, although federally listed endangered karst invertebrates occur in the Austin and San Antonio portions of the Balcones Fault Zone and are of great significance there.

Regional Karst Hydrogeology

Stratigraphy

Caves and karst form in two Hill Country stratigraphic formations that we will see during this field trip: the Glen Rose Limestone and the Edwards Limestone. Both are Cretaceous in age. The Glen Rose Limestone is exposed throughout about 80% of the field trip area. The Edwards Limestone crops out in the eastern 20% of the trip's area where, even though it is stratigraphically above the Glen Rose, it is at a lower topographic elevation due to downfaulting to the east (Figure 3).

Clark et al. (2016) provide the most recent and detailed geologic mapping of the area, but they only cover the Comal County (southeastern) portion of the trip route and Bexar County to the south which is not visited by this trip. Barnes (1983) maps the geology of the remaining area. Unless otherwise cited, stratigraphic and structure information in this field guide is based on Clark et al. (2016).

The Glen Rose Limestone is the uppermost formation of the Trinity Group, and locally rests conformably atop the Hensel Sand. It is divided into lower and upper members. The lower member occupies most of the gentler-sloped portions of the area and averages about 70 m thick in this area. It contains abundant fossils, which include gastropods, pelecypods, foraminifera, miliolids, ammonites, and oysters. It is subdivided into

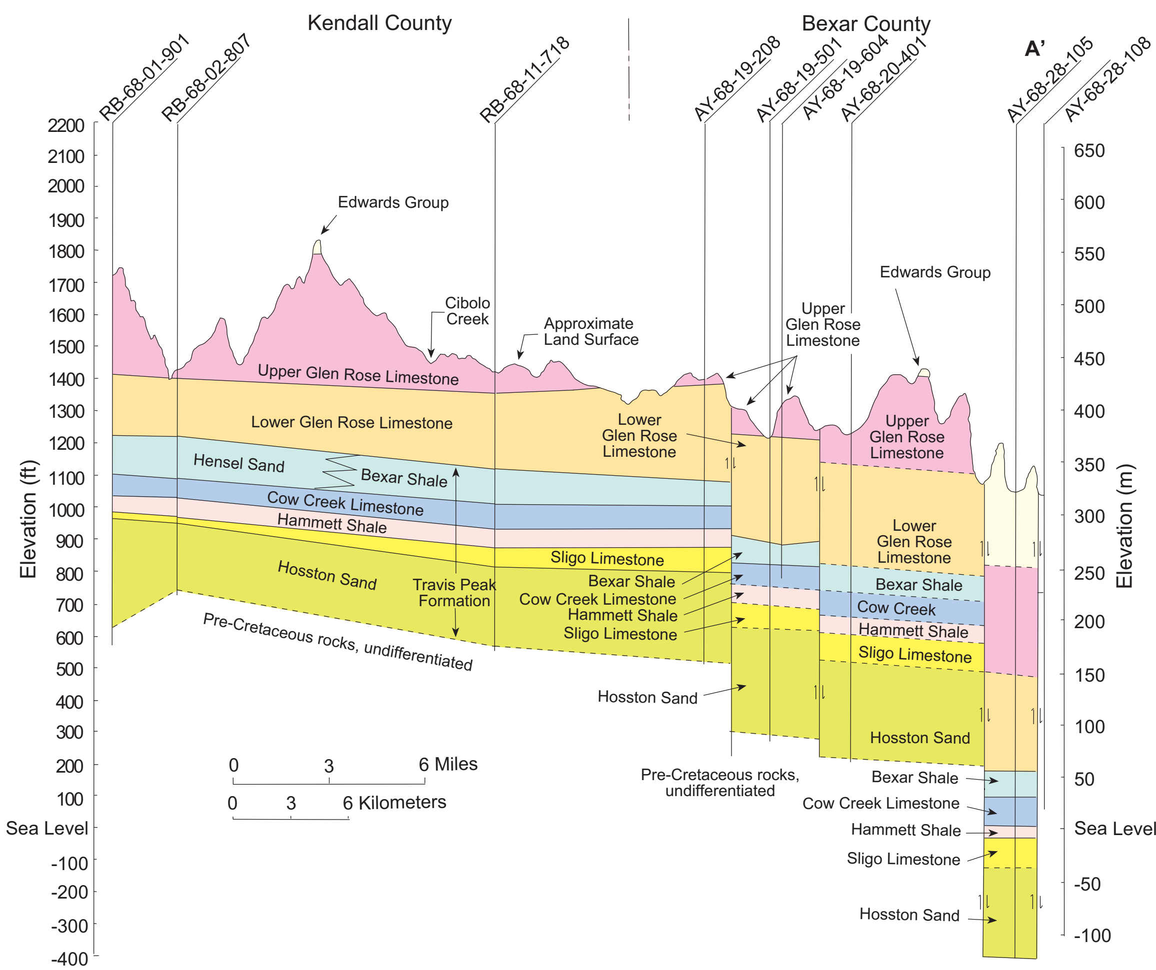

Figure 3. *North-to-south geologic cross section through the Hill Country (north) in western Kendall County into the Balcones Fault Zone in Bexar County (south). From Mace et al. (2000).*

six hydrostratigraphic units. The most cavernous is the basal 17-m thick Honey Creek unit.

The Upper Member of the Glen Rose is locally about 118 m thick and characterized as a fossiliferous sequence of resistant limestones and dolomites alternating with less resistant beds of marl and clay to create a distinctive "stair-step" topography when eroded. It is divided into five hydrostratigraphic units. Historically, the Upper Glen Rose has been considered impermeable and non-cavernous, with many geologists ignoring the fact that Natural Bridge Caverns (not visited during this trip but visited during the symposium's Tuesday evening reception) and adjacent Bracken Cave are large caves formed in that unit.

Following extensive geologic study of caves in Bexar County, especially by Zara Environmental and George Veni and Associates (2011), plus dye tracing from the Upper Glen Rose into the Edwards Limestone (Johnson et al., 2010), the uppermost hydrostratigraphic unit of the upper member is named the Cavernous unit. However, north of Bexar and southeast Comal counties, and west of Bexar County, the Cavernous unit thins, becomes absent, and the Upper Member of the Glen Rose is poorly to non-cavernous.

The Edwards Limestone Group conformably overlies the Glen Rose and is the most cavernous unit in Texas. It was deposited in an area of shallow to tidal marine sedimentation in an open marine environment; lithified mud cracks are well preserved in some areas. Those deposits form a succession of fine to course-grained hard, crystalline, fossiliferous limestone and dolomitic limestone. The Edwards Group is subdivided locally into the Kainer Formation at the base, which averages 73 m thick with four mapped members, and the Person Formation at the top with four additional members and an average thickness of 57 m. A quick way to determine if an outcrop of rock in this area is Edwards or Glen Rose Limestone is to look for *in situ* chert. It only occurs in the Edwards.

Structure

The dominant structural feature of the region is the Balcones Fault Zone. The fault zone is formed along the homoclinal hinge between the relatively flat-lying strata of the Edwards Plateau to the northwest and the more steeply dipping strata in the Gulf of Mexico Basin to the southeast. The fault zone is characterized by a series of *en echelon* (closely-spaced parallel or subparallel) normal faults, mostly downthrown toward the Gulf (Figure 3). The Balcones Escarpment is formed by the Balcones Fault Zone. The escarpment is rarely seen as a cliff, as "escarpment" implies. It is eroded into a usually gentle-to-steep rise in topography—steeper where fault displacement is greater—and linear along the trend of the fault zone.

The Comal Springs Fault in New Braunfels and the San Marcos Springs Fault, adjacent to this symposium's venue, have the greatest displacements along the trip route at 152 m and 143 m respectively (Musgrove and Crow, 2012). Most major fault displacements are about 10 to 15 m and many faults with less than 3 m of throw do not appear on geologic maps due to scale and difficulty in mapping them. Faulting decreases in frequency and amount of displacement from southeast to northwest across the field trip area.

Local researchers often assume that caves in this area form along faults because of the structural prominence of the Balcones Fault Zone. However, Kastning (1977) demonstrates how faults can have positive, negative, or neutral effects on groundwater flow and cave development and illustrates all three processes within Natural Bridge Caverns (Kastning, 1983). Veni (1988) found that even in Bexar County, the most intensely fractured portion of the fault zone, less than 0.5% of the studied caves are formed along faults. The low frequency of fault-guided caves is primarily the result of faults being less common than joints. Additionally, some faults are formed by compression and others are filled with calcite and clay, factors that make such faults less permeable for groundwater flow and thus less likely for enlargement into caves.

Joints are generally of first importance in the area's development of caves and karst recharge features. They are more common and formed by extension, which increases their primary permeability. Most are enlarged parallel to the local direction of Balcones faulting. Except for faults and joints, structural deformation of the area is subdued. Bedding is nearly horizontal, dipping 3–5 m per kilometer (0.17 to 0.29º) to the southeast and striking to the northeast.

Aquifers

Groundwater in the field trip area occurs primarily (from stratigraphically lowest to highest order) in the Middle Trinity Aquifer, Upper Trinity Aquifer, Edwards (Balcones Fault Zone) Aquifer (referred to in this guidebook as the Edwards Aquifer), and in what is informally described as the Edwards-Trinity (Plateau Outlier) Aquifer by Smith and Veni (1994). The general extent of the aquifers is shown by matching the geologic units described below to Figure 1.

The Cow Creek Limestone, Hensel Sand, and the Lower Member of the Glen Rose Limestone comprise the Middle Trinity Aquifer. We will not see the Cow Creek or Hensel during this trip. In this area, the Hensel grades southward into a shale, reducing its permeability and making it the base on which the Lower Glen Rose Aquifer is perched. Some Cow Creek springs and cave streams are likely the result of leakage of Lower Glen Rose water across faults, through the Hensel, into the Cow Creek (Figure 4).

The Lower Glen Rose Aquifer is largely unconfined but has down-faulted confined portions within the Balcones Fault Zone. The aquifer is highly karstified and contains many of the longest caves and underground streams in Texas. It is recharged predominantly from rainfall onto the outcrop of the Lower Glen Rose Limestone. Veni (1997) provides the most detailed hydrogeologic study of the Lower Glen Rose Aquifer to date. He calculates water budgets for the aquifer and estimates recharge as 20.1% of precipitation in the Cibolo Creek and Guadalupe River watersheds. Within the Guadalupe River watershed, the aquifer mostly discharges from springs along the river and its tributaries. The underground stream we will visit in Cave Without a Name feeds one of those springs.

The Honey Creek Cave is a spring that also discharges into a Guadalupe River tributary but is an example of more complex flow paths in the aquifer. The cave formed by capturing groundwater from the higher elevation Cibolo Creek watershed to the south and pirating it northeast to discharge into the Guadalupe River. Meanwhile, part of the cave's flow has since been pirated back into the Cibolo watershed where it joins the Edwards Aquifer (Veni, 1997; Mace et al. (2000).

In 1989, the Middle Trinity Aquifer in the field trip area was listed as a critical water supply area by the state of Texas (Groundwater Protection Unit, 1989). Despite this warning, continued growth in the region is putting considerable stress on the aquifer's water

Figure 4. *Becker Cave is a now-dry spring in the Cow Creek Limestone that was recharged by cross-formational flow from the Lower Glen Rose Aquifer. Honey Creek Cave was the likely source of the groundwater before its namesake creek truncated that cave, separating it from Becker Cave. The orange electrical cord extending down the entrance supported an archaeological excavation of the entrance.*

resources. Mace et al.'s (2000) groundwater modeling study of the Trinity Aquifer shows that the area is projected to have its groundwater depleted by the year 2050 due to increased demand, and earlier if a drought-of-record is repeated.

The Upper Member of the Glen Rose Limestone is the sole unit of the Upper Trinity Aquifer. This aquifer is unconfined and recharged locally. Although the Upper Glen Rose contains enough clay and marl beds to make it the lower aquiclude for much of the Edwards Aquifer, its outcrop exposes enough limestone and dolomite beds to absorb some recharge, which discharges naturally through seeps and minor springs. Regionally, there is little use or demand for the aquifer's groundwater because of its typically low yield and its occasional contact with gypsiferous zones that results in high sulfate concentrations. Many small domestic water wells tap the Upper Glen Rose where other sources are not available, too expensive, and/or where the small yields are adequate for home use. The Cavernous Hydrostratigraphic Unit of the Upper Glen Rose yields the most water to wells and has trans-formational flow into the Edwards Aquifer, primarily in the southern and eastern Cibolo Creek watershed and areas further south and east.

The Edwards Aquifer is a complex hydrologic system within the Edwards Limestone in the Balcones Fault Zone. It is divided into four segments from south to north: San Antonio, Barton Springs, Northern Balcones, and Washita Prairie (Yelderman, 1987). A drainage divide, an incised valley, and a gap of Edwards Limestone outcrop within the fault zone respectively separate the segments. The San Antonio Segment of the Edwards is the largest. The trip extends over its lowest section. All discussion of the aquifer in this report refers to the San Antonio Segment

The Edwards Aquifer is divided into four zones: drainage or contributing zone, recharge zone, artesian or confined zone, and saline zone. The drainage zone is the area upstream of the Balcones Fault Zone from which streams flow onto or cross the recharge zone, where the exposure of Edwards Limestone within the fault zone allows water to enter the aquifer. The artesian zone is the area where the Edwards Limestone is down-faulted into the subsurface, and its groundwater is confined between upper and lower less permeable formations. The aquifer's largest springs occur where groundwater rises along fractures to discharge in valleys that intersect the potentiometric surface. The San Marcos Springs, located 900 m north of this conference's venue in the San Marcos Activity Center, are the aquifer's lowest elevation springs. The aquifer's saline zone is the downgradient low-permeability portion of the Edwards Limestone to the southeast. It is named for its high concentration of total dissolved solids.

The upper end of the Edwards Aquifer begins near Brackettville, where groundwater flows east 180 km to San Antonio, and then follows the bend in the Balcones Fault Zone northeast for 80 km to San Marcos. Following this path, the cities of Uvalde, San Antonio, New Braunfels, and San Marcos were established around Edwards Aquifer karst springs. While the Edwards is the most famous karst aquifer in Texas, it is only marginally a part of this field trip. For more extensive and detailed information, visit the website of the Edwards Aquifer Authority.

The Edwards-Trinity (Plateau) Aquifer is well recognized as one of the more areally extensive karst aquifers in the country, extending west about 600 km from the San Marcos area and 250 km north-to-south. It is an unconfined aquifer capped by Edwards Limestone, where the water discharges from springs along the basal contact with the Glen Rose Limestone. This spring discharge supports the flow of the Guadalupe River and other streams that cross the Hill Country.

We will not visit the Edwards-Trinity (Plateau) Aquifer during this field trip, but we will cross portions of the Edwards-Trinity (Plateau Outlier) Aquifer. This informal term refers to the stream-dissected peninsular sections of Edwards Limestone along the plateau margin, and isolated nearby remnants of Edwards Limestone on hilltops (Figure 3). Like the plateau aquifer, these areas function as unconfined aquifers and are gravity-drained to nearby valleys, discharging at the contact with the Upper Glen Rose. They surround the Glen Rose Limestone outcrop by occurring to the northwest along the edge of the Edwards Plateau and to the southeast along the margins of the Edwards Limestone in the Balcones Fault Zone (Figure 1).

Regional Karst Ecology

The Balcones Fault Zone area is one of the world's most biodiverse cavernous regions for terrestrial and aquatic cave-adapted fauna (Culver and Sket, 2000; Culver et al., 2003). Cave organisms are often classified based on their level of adaptation to that environment and range from occasional and non-cave adapted cave users (Figure 5) to obligate cave species (troglobites). Troglobites (or stygobites if living in aquatic environments), due to their narrow ranges of habitat tolerance and high endemicity, dominate the lists of taxa of concern and endangered species.

Seven troglobitic species of karst invertebrates in the Austin region and nine troglobitic species in the San Antonio region are federally listed as endangered by the US Fish and Wildlife Service (USFWS) to insure their survival (USFWS, 1988, 1993, 2000). The listed species are six beetles, three harvestmen, one pseudoscorpion, and six spiders. The reason for this high number of endangered species is that species living in the caves and related voids along the Balcones Fault Zone have become physically isolated from each other through time by streams cutting through the blocks of faulted limestone, resulting in genetic isolation of the populations. This process results in endemism, with the new species known only within small geographic areas that are vulnerable to impact by the region's growing urban centers.

Additionally, 13 aquatic karst species in the Balcones Fault Zone are also listed federally as endangered and threatened with their ranges extending from New Braunfels northeast 120 km to Salado. The species are one amphipod, two beetles, two fish, seven salamanders, and one species of wild rice (USFWS, 2021). While some are aquifer species, most live in the flows of karst springs and commonly recede into groundwater habitat or interstitial spaces during periods of low spring flow.

The number of troglobitic species lessens into the Hill Country due to less fragmented habitat, but the diversity of species types remains high. The only endangered species is the Golden-cheeked warbler (*Dendroica chrysoparia*) which is not truly karst related but breeds in the woody canopy of the Hill Country and adjacent areas. The diversity of karst species results from the area being at an ecological crossroads, and of past climatic and geological changes in the region.

Often overlooked but important components of the region's cave ecosystems are the many species of terrestrial vertebrates. Some of the more common species include:

- Black Vulture (*Coragyps atratus*)
- Cave Myotis Bat (*Myotis velifer*)
- Chirping Cliff Frog (*Syrrhophus marnockii*)
- Coastal Plain Toad (*Incilius nebulifer*)
- Mexican Free-tailed Bat (*Tadarida brasiliensis mexicana*)
- Raccoon (*Procyon lotor*)
- Turkey Vulture (*Cathartes aura*)
- Western Slimy Salamander (*Plethodon albagula*)
- White-footed Mouse (*Peromyscus leucopus*)

These and other vertebrates use caves primarily for shelter, and their scat and carcasses provide vital sources of food energy into cave ecosystems. A recent addition to this list is the porcupine (*Erethizon dorsatum*) which over the past 30 years has expanded its range eastward from west Texas. The most notable of these vertebrates is the Mexican Free-tailed Bat (also known as the Brazilian Free-tailed Bat) which produce the world's densest and largest mammal colonies, including the largest single species colony at Bracken Cave. Salamanders of the genus Eurycea are the most important aquifer vertebrates found in the region's caves.

Figure 5. *Densely-packed colonies of non-troglobitic harvestmen (*Leiobunum townsendii*) commonly cover cave entrance walls in central Texas with a fur-like appearance. Despite being nearly ubiquitous, their relationship to cave ecosystems is largely unstudied.*

Regional Cave and Karst Management

Three major forms of cave and karst management occur in the Hill Country:

1. Show caves
2. Preserves and parks
3. Private

There are certainly subcategories within each and this trip will focus on five specific examples. Below is an overview of all three in the region.

Show Caves

Texas has seven show caves:

1. Cascade Caverns
2. Cave Without a Name
3. Caverns of Sonora
4. Inner Space Caverns
5. Longhorn Caverns
6. Natural Bridge Caverns
7. Wonder Cave

Except for Caverns of Sonora and Inner Space Caverns, all are in or on the margins of the Hill Country. Show caves are developed as for-profit businesses. Historically, show caves globally focused on entertaining the public, emphasizing the sensational over the informational aspect of caves. Many caves suffered damage and degradation as a result. Fortunately, that has been only a small part of Texas show cave history.

Over the past 40 years, increasing numbers of show around the world have changed their business models toward educating the public, as well as entertaining people, with an understanding that cave protection is necessary for business survival. We see this in Texas show caves in various ways, such as: highly restricted groups sizes in Caverns of Sonora, air lock doors in Natural Bridge Caverns, and support for scientific research in several of the caves. This is seen nationally via the National Caves Association (US organization of show caves) and internationally through the International Show Caves Association's strong support of the International Year of Caves and Karst and other public education goals.

We will visit or drive near four show caves during this field trip. Cave Without a Name is one of the stops and discussed at length below. As we start our trip, we will drive near Wonder Cave, now part of the Wonder World complex of family entertainment. It is the longest continuously running show cave in Texas, having opened in 1903. Its urban location and proximity to Interstate Highway 35 gives easy to access to school groups and cross-country tourists. However, its urban location also limits the physical extent of the enterprise and the ability of its owners to manage potential impacts that may occur on the overlying karst.

Our route will next take us near Cascade Caverns, located on the south side of Boerne. It opened to the public in 1932. Surrounded by farmland for most its existence, this cave has seen increased suburban development of the adjacent properties (Figure 6). Located near Interstate Highway 10 and a short drive from San Antonio, it is also easy to access by all groups. However, plans for a bypass road around Boerne raise concern about potential roadway pollutants entering this and other nearby important recharge caves that replenish the Lower Glen Rose Aquifer.

Adjacent to the last stop of the field trip, and where the symposium's Howdy Party will occur, is Natural Bridge Caverns. It is the largest show cave in Texas in both size and business operations. Also well situated near San Antonio and Interstate Highway 35, it is one of the most visited caves in the country. The cave opened to the public in 1964. Nearly centrally located on a large ranch, the cave is protected from immediate adverse impacts. Neighboring properties that are also set aside from urbanization further buffer the cave from impacts. Regional plans to build a dam along Cibolo Creek, which would have increased the frequency and magnitude of flooding in the cave, were abandoned several years ago.

Preserves and Parks

A small number of private nature preserves occur in the Texas Hill Country. Some are private and most not widely publicized. We will visit two that are well known: Cibolo Preserve and the Bracken Cave Preserve. The region also holds a much larger number of community, city, county, and state parks, used for natural resource protection and public recreation. We will visit one, the Cibolo Center for Conservation.

The most notable and best recognized preserves are those owned by The Nature Conservancy (TNC). Their 13 Hill Country preserves are dedicated primarily to ecological protection and restoration, which in turn often benefit surface water, groundwater, and caves. The biodiversity of the region is not limited to caves. The expansion of Austin, San Antonio, and neighboring communities into the Hill Country pose a threat to many species' survival. Primary factors that threaten karst ecosystems include the destruction and

Figure 6. *A dam near the entrance of Cascade Caverns prevents Cibolo Creek floodwaters from entering the cave, but it does not prevent urban runoff from nearby newly established housing developments from flowing into the entrance via other, smaller, channels.*

sealing of caves and karst features, changes in nutrient and moisture input into karst ecosystems, contaminants that enter karst ecosystems, and competition with and predation by non-native species introduced by urbanization (Elliott, 1993 and 2000).

Trust for Public Land (TPL) is another important player in Hill Country preserves and manages several. A pivotal role that TNC and TPL have played regionally is in the identification and occasional brokering for land protection deals either by purchase or easement acquisition. The cities of Austin and San Antonio have raised hundreds of millions of dollars in voter-approved tax bonds to protect aquifer and ecologically important lands. Most of these funds have been spent in the Balcones Fault Zone but some have included the Hill Country.

The Texas Parks and Wildlife Department (TPWD) owns 14 state parks in the Hill Country. While all TPWD properties are generically called "parks," there is an important distinction between two park categories. A "park," such as Guadalupe River State Park located near our stop at Honey Creek Cave, was established primarily for public recreation. Natural resource protection is a highly important consideration, but not the primary purpose of the property. In contrast, a "natural area," such as adjacent Honey Creek State Natural Area, has the primary purpose of protecting the natural resources of that property. Most of the TPWD Hill Country parks contain notable caves and karst. Old Tunnel State Park protects an abandoned railway tunnel that is now occupied by over 3 million Mexican Free-tailed bats.

Private Land Use

Private land ownership yields a patchwork of different management strategies and needs. Historically, Hill Country land ownership was limited primarily to large ranches owned for generations by single families. The impact on caves and karst was minimal to none in most cases. The worst impacts were from the use of some cave entrances as trash dumps.

However, suburban and exurban growth into the Hill Country has raised property values and taxes. Some families sold their land readily for development. Other families that were "land rich but cash poor" were forced by circumstances to sell, despite wanting to maintain their family land and heritage.

One positive aspect of suburban and exurban housing development, at least relative to urban development, is that the lower density housing results in less impact on the karst and its natural systems. Many caves and karst features have been destroyed or buried by roads and homes, but several have been preserved. Some caves have been highlighted by realtors as unique features to attract home buyers. Such owners often see their caves as points of pride and take great care in their management. However, many owners don't know how to protect their caves and are unaware of the potential harm caused by runoff from landscapes treated heavily with fertilizers and a variety of pesticides. Further, most of these homes dispose of their waste through septic systems, and their cumulative impact on karst aquifers has not been studied.

Management Summary and Prospects

The Texas Hill Country is a geologically and biologically complex region interwoven with caves and karst aquifers. Detailed study of these resources is still in its infancy. Cave and karst management is also evolving as ownership changes from large ranches to small suburban and exurban lots, and in some cases to preserves and parks. In general, there is a growing understanding of the importance of this karst environment. New properties are acquired for protection while protests occur about developments proposing environmentally inappropriate plans and activities. Yet, on the personal level, such awareness is often missing. An individual homeowner's impacts are frequently considered insignificant by environmentally aware people who buy suburban and exurban homes.

It is not clear if the low housing densities will be sufficient to protect groundwater quality and the karst ecosystems in the field trip area. Regional karst management has become more complicated with the far greater number of landowners. What remains clear though, are the modeled projections on aquifer use. Each well, for each home, pulls additional water from low storage karst aquifers. Some wells in the region have already gone dry, at least temporarily. Continued suburban and exurban growth, and its demand for water, is projected to result in severe groundwater depletion within the next 30 years (Mace et al., 2000).

Texas has a system of groundwater conservation districts to assure good groundwater management practices, but their effectiveness is hampered by two major problems. First, these districts generally lack sufficient funding to study their aquifers and are not given significant authority to enact and enforce measures needed to use the aquifers equitably and sustainably. Second, the districts are established mostly by county, not the hydrogeologic boundaries which are critical to properly studying and managing their aquifers. My hope is that the groundwater conservation districts are a first step toward regional and hydrogeologically-based sustainable management programs.

Field Trip Stops

Stop 1: Cave Without a Name

Cave Without a Name is a National Natural Landmark. It has operated as a show cave since 1939. Staircases and a sloping trail spiral down the entrance pit to a depth of 24 m and open to a passage averaging 7 m high by 12 m wide. To the northwest, the passage goes 49 m and becomes a clay-floored crawlway that cannot be followed more than 25 m without excavation. To the southeast the passage is decorated with the largest speleothems in the Lower Member of Glen Rose Limestone, prompting the cave's nickname, "Little Carlsbad Cavern." About 140 m from the entrance, the tourist trail ends where the passage intersects a stream passage flowing from the southwest to the southeast (Figure 7).

Downstream (southeast), the stream flows 132 m to a short sump, then flows 675 m to discharge at the Deadman's Cave spring entrance. Spring discharge averages between 2-29 L/s. Upstream beyond the tourist trail, the cave continues nearly 2.7 km southwest, past several sumps and small tributaries. Some of the tributaries are not fully explored or surveyed. A weakly positive dye trace suggests a hydrologic connection to Alzafar Water Cave about 3 km west of the upstream limit of exploration. The total surveyed length of the cave is 5,725 m (Figure 8), placing it as the 8th longest cave in Texas (Texas Speleological Survey, 2021).

For most its existence as a show cave, Cave Without a Name has struggled as a classic "mom and pop" business with little capital to invest in the operation. It is located at the end of a long, small road and not convenient to any major highway. For nearly 60 years, the last mile of road was unpaved, rocky, muddy in places, and difficult to pass with low-clearance vehicles.

With the acquisition of the cave by its current owner in 1998, the road was paved, parking area and gift shop improved, a camping area, pavilion, and an educational "Sinkhole Trail" and other amenities were established. The camping area was extended and 14 RV locations with electric and water hookups were added. An additional restroom near the pavilion is planned for 2021.

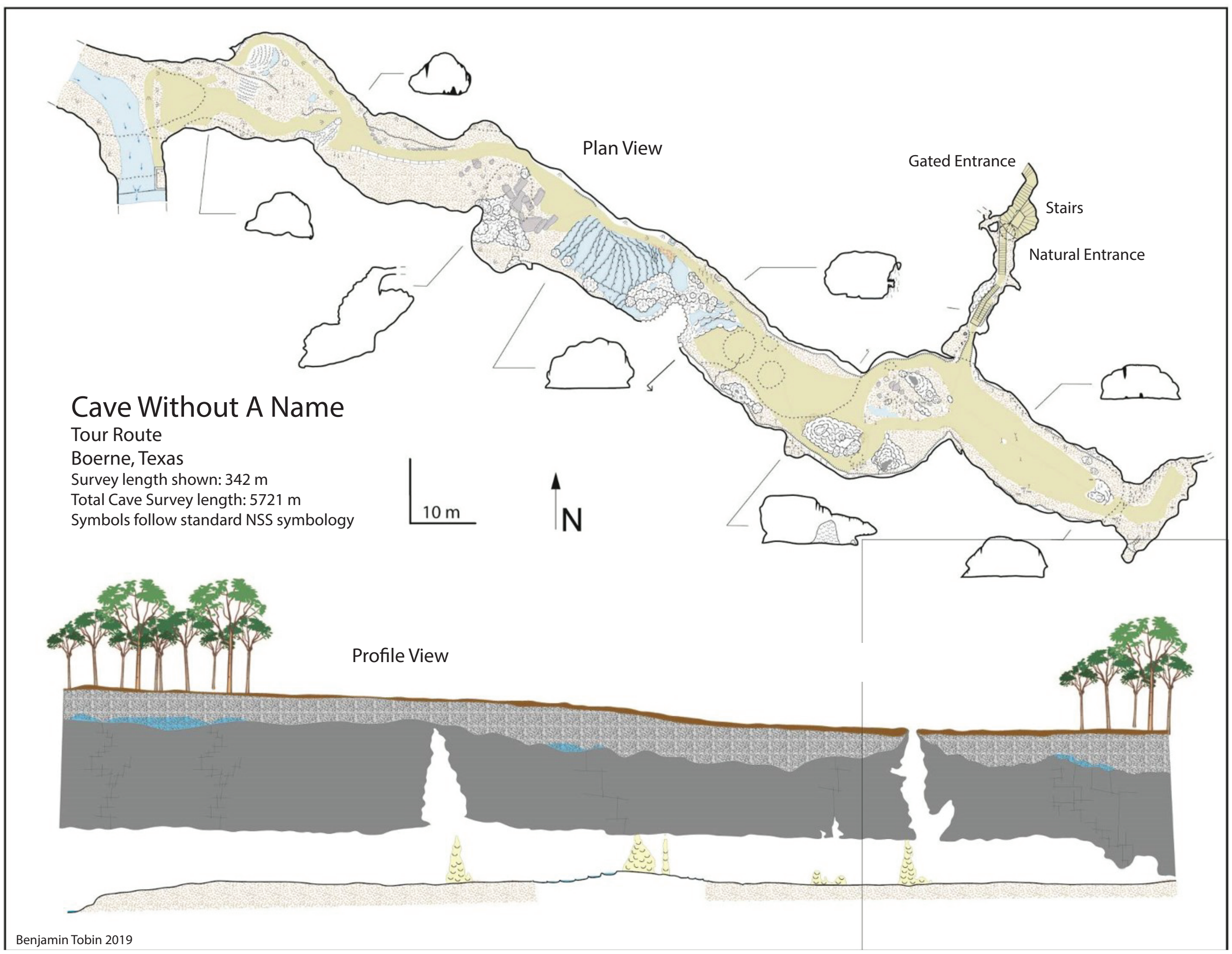

Figure 7. *Map of tour route in Cave Without A Name (map courtesy of Ben Tobin).*

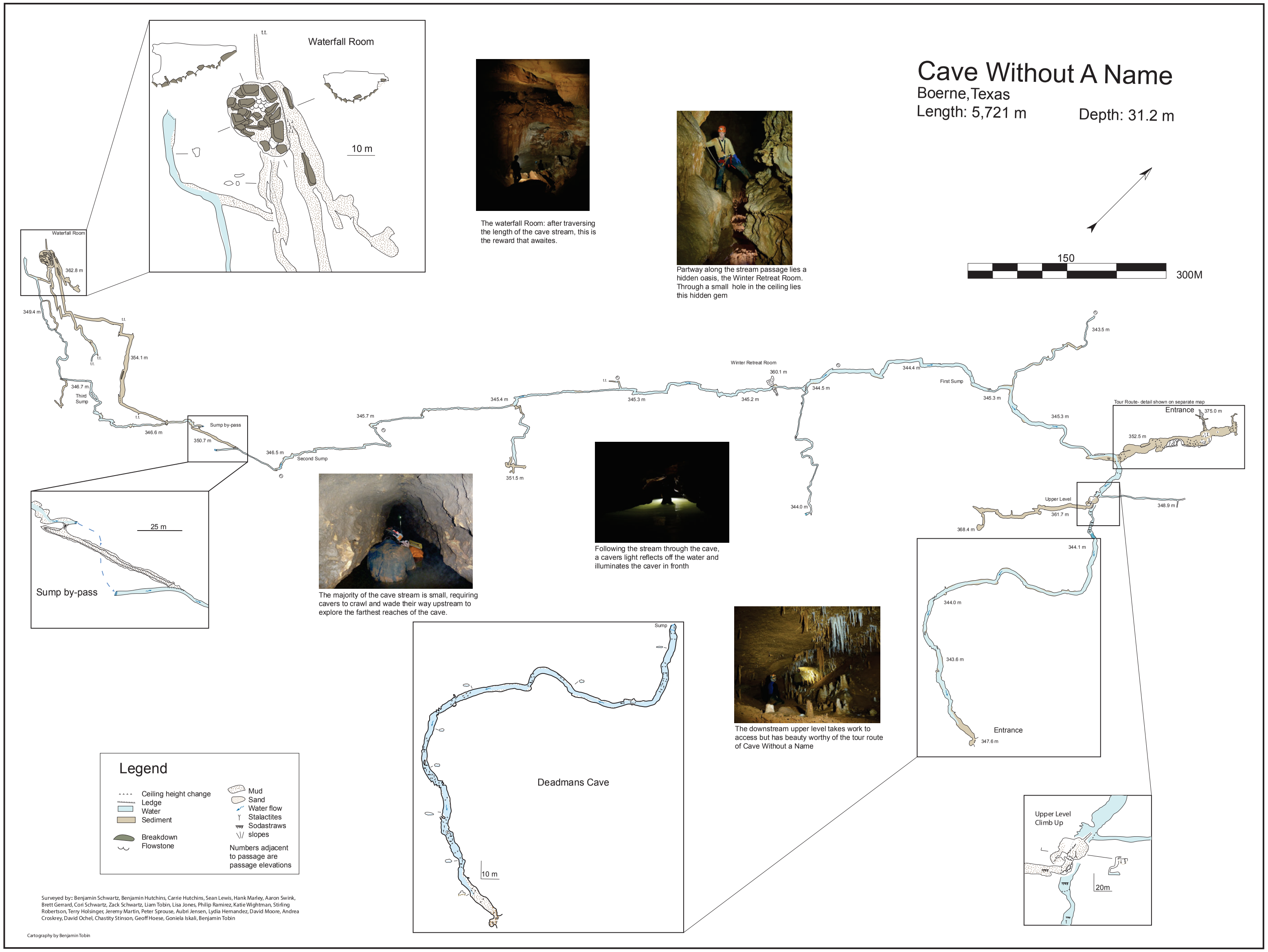

Figure 8. *Map of Cave Without A Name (map courtesy of Ben Tobin).*

In 2020, the "McGrath Room" was added to the Visitor Center. Named in honor of the three children involved with the cave's discovery, it is a multi-purpose room for education, scouting, meetings, and events.

Inside the cave, the electrical system was upgraded to LED lighting. The gravel trails were initially retained and upgraded, but during the COVID-19 pandemic the conversion process to concrete trails began. It may be completed by the time of this field trip. The concrete trails include curbs to contain lint falling from tourists and which also conceal electrical wiring and water lines. Trampled surfaces adjacent to the former gravel trails were cleaned and restored. *Music in the Cave*, an ongoing concert series utilizing the cave's fine acoustics, is performed on a stage built in the cave. Special events, including weddings and meetings, also utilize the stage frequently. Cave and karst educational information is now emphasized during the tours, and scientific research and educational projects are frequently supported, including free access for this field trip and for the annual Texas HydroGeo Workshop since 2013.

Common show cave issues at Cave Without a Name include tourist and trail management, lampenflora growth, and off-trail access. In 2020, with the start of the COVID-19 pandemic, it was necessary to establish a reservations system for guests. The system worked well to level off each day's visits and is continuing forward. Tours depart at the top of the hour with an optimal maximum of 25 guests. On busier days, tours on the half-hour are added as needed. Off-trail tours are not offered, although special off-trail access is granted occasionally to local caving clubs. The new concrete trails are washed as needed, with the drainage absorbed by the clay floor. Lampenflora is kept well under control, treated as needed with a dilute bleach solution, although some legacy lampenflora from the cave's early days of operation has been incorporated by calcite deposition into some speleothems.

Issues specific to the cave involve security, and water quantity and quality. Of these, security seems resolved. The cave was breached twice in the 1990s and vandalized. No break-ins have occurred during the current ownership and its additional security measures.

Water problems at the cave involve both too much and too little water. About every 30-50 years, flooding covers part of the tourist trail near the cave stream (flooding at its worst only shallowly covers the trail and does not fill the passage in the tourist section of the cave). At such times, groundwater seepage from above also covers the floor of the main passage near the base of the entrance pit with up to 0.5 m of water, leaving a muddy deposit on all surfaces that needs to be cleaned. Former floor-level lighting has recently been raised to minimize maintenance problems associated with flooding of electrical fixtures. A sump pump drains ponding at a low point in this section of the cave during normal wet periods, but has not been used yet during major floods. While periods of high rainfall can result in minor problems, more often it fills the cave's many rimstone pools, enhancing their beauty.

During droughts, the cave stream diminishes but hasn't gone dry, though that concern grows with increased exurban development around the cave. The ability for the public to see the actual aquifer is a high point of the tours, which would be lost if stream flow ceased.

Water quality concerns with exurban development are also increasing. There is no local community-wide sewage collection system. The cave's drainage basin is not delineated precisely, but based on December 2020 Google Earth imagery and its minimum likely drainage area, over 30 septic systems are present in that area assuming one per home. One well intersects the cave near the stream and pumps water to the surface. This water is considered non-potable, although allowed for cooking if boiled and for some cleaning.

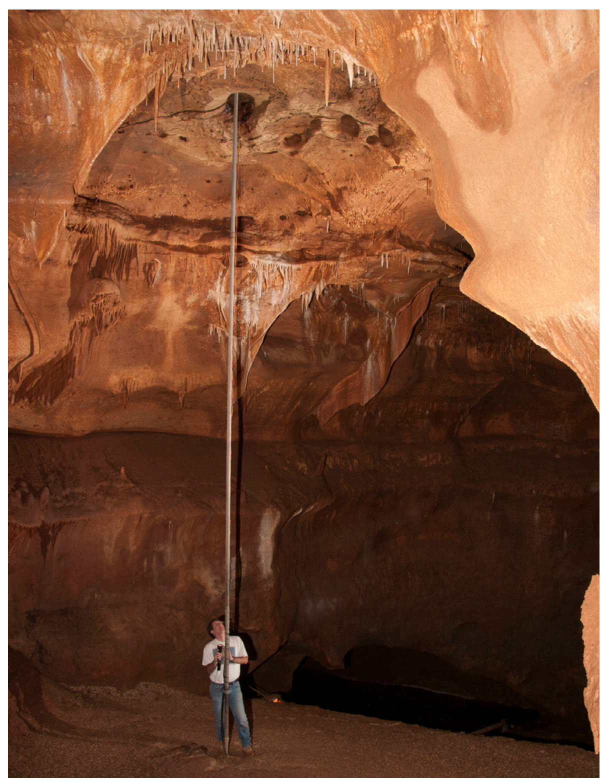

Figure 9. *A water well extends into the floor of Cave Without A Name and runs under the trail to draw water from the cave stream in the background.*

Stop 2: Cibolo Center for Conservation, written by Donna Taylor and Carolyn Chipman Evans

The Cibolo Center for Conservation is widely considered a premiere example of what a community can do when hearts and minds come together. For more than 32 years, the Cibolo Center has deepened the regional community's connection to its land and water and has become a model of conservation education throughout the state.

It started in 1988 with a handful of friends whose goal was to clean up and protect a stretch of the Cibolo Creek, a life source of their community. They set up what was then known as the Cibolo Wilderness Trail. As time went by, they realized that the land and water they protected was really a part of something much larger and greater, and their goals grew. In 1992, with the City of Boerne's support, they built their first building on 0.4 km^2 of city-owned land to establish the Cibolo Nature Center, operated by the nonprofit Friends of Cibolo Wilderness, and started education programs, citizen science research, and stewardship of Cibolo lands.

Learning that water really does flow downstream, they understood that to preserve Cibolo Creek they must connect their efforts to the much larger watershed. Over time, the Cibolo Nature Center became a primary steward of the Upper Cibolo Watershed, spanning more than 32 km of waterways which provide over 3,800 m^3/day of critical aquifer recharge to the Lower Glen Rose and Edwards aquifers.

On the south side of Cibolo Creek, the historic 0.24-km^2 Herff Farm was purchased in 2007 to further protect this fragile watershed, and the name changed to the Cibolo Nature Center & Farm. Settled by Europeans in the mid-1800s, the old, abandoned farm is now a vibrant public space that builds community through the Nest Nature Preschool, special events, research, nature trails, sustainable living education programs, community gardens, and a weekly Farmer's Market.

In recent years, it became clear that the organization is much more than a nature center or a farm, and a new name was needed. The organization's research is recognized internationally, educational programming reaches tens of thousands of children and adults each year, regional conservation efforts are known statewide, and civic engagement is making a significant impact on the future landscape of the growing community. To reflect these many roles, they chose the new name, Cibolo Center for Conservation, and launched it in early 2021. Much of their work is still taking place on the two campuses, The Cibolo Nature Center and Herff Farm. Meanwhile, their mission remains the same—to promote the conservation of natural resources through education and stewardship.

With two campuses encompassing over 0.65 km^2 in the heart of Boerne, Texas, (Figure 10) the Cibolo Nature Center offers miles of trails through four distinct ecosystems; prairie, woodland, marsh, and riparian that offer the visitor a small glimpse into the varied landscapes of the southern Edwards Plateau. Along the riparian trail an outcrop of the Glen Rose Limestone is easily observed to where it transitions into a Pleistocene conglomerate. Near the pavilion, the replica of 100-million-year-old tracks of an Acrocanthosaurus are found for visitors of all ages to enjoy (Figure 11). The tracks were exposed during a 1997 flood at Boerne City Lake.

The Cibolo Center for Conservation campuses are in Kendall County, one of the fastest growing counties in the United States. With population growth and the increased need for accessible open space during the COVID-19 pandemic, the Cibolo Center has had growing pains on scales previously unforeseen. Issues related to urbanization including trash, animal waste, trail cutting, surface compaction, and motor vehicle use in unauthorized areas have all stressed the limited staff and budget. The research program which conducts long-term monitoring of key habitat indicators has found slow but continuous degradation of water quality

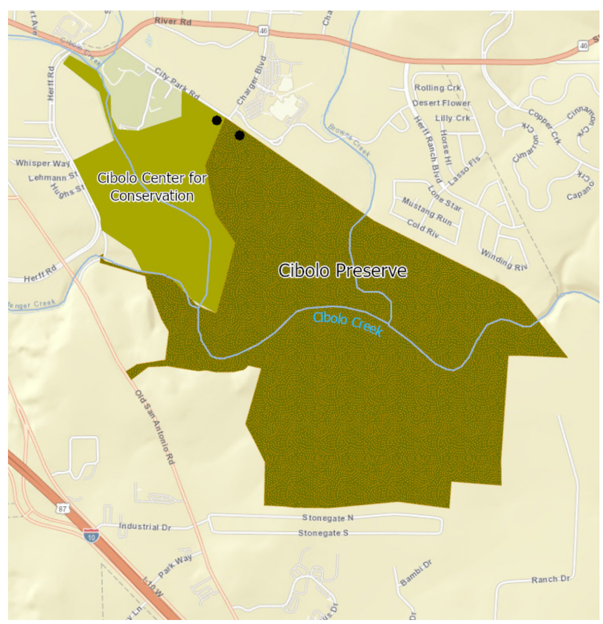

Figure 10. Map of Cibolo Center for Conservation and Cibolo Preserve (map courtesy of Donna Taylor).

Figure 11. *Replica of Acrocanthosaurus tracks at the Cibolo Center for Conservation (photo courtesy of Donna Taylor).*

in Cibolo Creek as well as impairments to ecosystem function due to many of the issues noted above. The Cibolo Center for Conservation works tirelessly to guide the community to more sustainable policies in the areas of water and land (habitat) conservation by hosting numerous workshops and courses year-round.

Stop 3a: Cibolo Preserve, written by Donna Taylor.

Bill Lende had the foresight to establish the Cibolo Preserve in 2008 as a 501(c)(3) non-profit organization. It protects and preserves his former ranch, now 0.65 km^2 in size, with 2.4 km of Cibolo Creek flowing through it (Figure 12).

When Mr. Lende first acquired this Kendall County property in 1981, dead cypress trees lined the creek and Ashe Juniper covered most of the rest. Through Mr. Lende's stewardship, the ranch activities evolved over time from initial cattle raising, to a vineyard, to axis deer harvesting, and finally to plant nurturing. When a wildlife biologist told Bill that he had no tree regrowth in 25 years, he realized something had to change. Now the Cibolo Preserve is a place that truly protects nature through research. It is a model for how private land can be protected and preserved.

Set aside for research projects on nature, the Cibolo Preserve has seen more than 55 projects successfully conducted since its creation. One of the major research partners is The University of Texas at San Antonio (UTSA) College of Sciences. UTSA graduate students have conducted studies in geology, botany, water quality, small mammals, and aquatic wildlife. Other environmental research partners include the San Antonio River Authority, Texas Parks and Wildlife Department, Texas Commission on Environmental Quality, US Geological Survey, and the Cibolo Center for Conservation.

The Cibolo Preserve's land stewardship goal is to manage the land utilizing a science-based ecosystem management approach. Healthy ecosystems are the basis for vigorous wildlife populations and diverse native plant communities. Healthy ecosystems result in watersheds that are resilient and produce abundant and high-quality water.

Land management activities support research and employ those findings in ways that continually improve management and stewardship. Through sound management, the preserve facilitates the education of the community and future land stewards. By integrating both professional and community scientists into its research program, Cibolo Preserve simultaneously has a robust

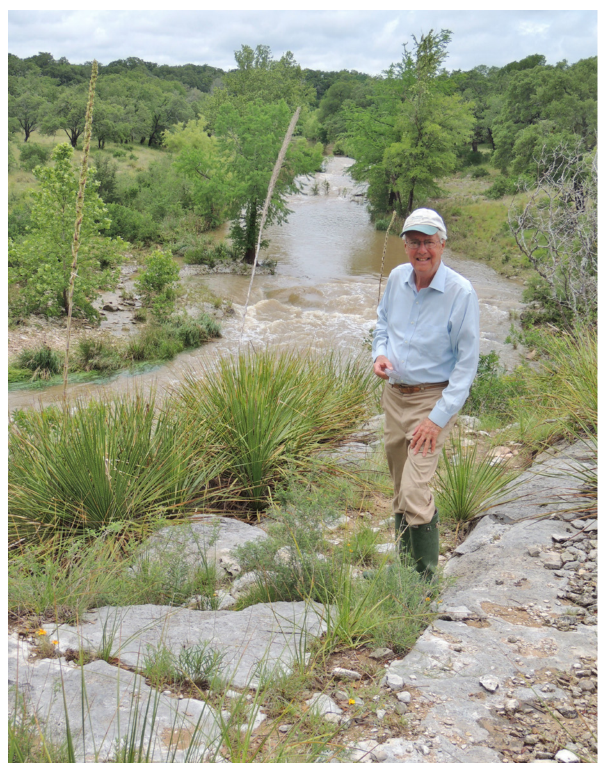

Figure 12. *Cibolo Preserve founder Bill Lende at Horseshoe Falls (photo courtesy of Donna Taylor).*

research and teaching model that provides feedback for refinement of its land stewardship approaches. This model also allows scientists to take this information to landowners in the local community based on their experiences.

The mission of the Cibolo Preserve is to own, maintain, and preserve the preserve's real property in its natural habitat as part of the Cibolo Creek watershed for educational, scientific, and charitable purposes. It is a 0.65-km^2 natural habitat laboratory and groundwater recharge area that supports a unique plant and animal environment. So that the human footprint is minimized, access to the Cibolo Preserve is restricted to research partners and volunteers actively involved in approved projects during limited time frames. This allows nature to thrive and is an excellent comparison to the neighboring Cibolo Center for Conservation which is open to the public.

Stop 3b: Cibolo Preserve, Cibolo Island Cave

This section of Cibolo Creek is a losing stream. Stream loss begins 4.3 km upstream, at least theoretically, at the dam in Boerne, where the Lower Member of the Glen Rose Limestone is first exposed in the creek bed. No measurable loss of water to the Lower Glen Rose Aquifer is observed there, nor is any loss noticed down to this point of the cave.

Flowing streams typically indicate that the water table of the local aquifer is at the land surface. With losing streams, the water table is below the surface, allowing recharge to occur, causing streamflow to diminish downstream. Cibolo Island Cave is an excellent site to observe recharge along fractures from inside the aquifer. As you wade across the creek to reach the island where the cave entrance is located, you will not observe any eddies or other indications of water loss to the subsurface. However, at the 0.5-m diameter concrete culvert that surrounds the cave's entrance, it is often possible to hear dripping as water is lost from the creek into the cave. Inside the cave, which is a 19-m deep pit into a passage formed along a northwest-to-southeast trending joint (Figure 13), the dripping and dribbling of water is often intense. A small stream at the bottom of the cave sumps immediately and is perched; the actual water table is probably about 10 m deeper during base ("normal") flow conditions.

The rate of base flow recharge into Cibolo Island Cave is not significant, but its continuous recharge makes its volume over time a significant input to the aquifer. And, this does not include times when the creek rises high enough to pour down the cave's entrance. The cave demonstrates the high permeability of karst aquifers where water easily and quickly flows to the water table, even in places where recharge is not observed such as where you crossed Cibolo Creek to reach the cave. Geophysical surveys around the cave by students from The University of Texas at San Antonio identify likely continuations of the cave beyond the limit of exploration, as well as other cave passages.

One of the concerns of recharge along fractures into Cibolo Island Cave is aquifer water quality. Commonly in Texas and many karst areas, fractured bedrock is observed. However, unless a "karst feature" such as a cave, sinkhole, or notably solutionally enlarged fracture is present, few or no restrictions are placed on the activities that can occur on the fractured surface. As a result, instead of clean creek water steadily recharging the aquifer through such fractures, effluent from a sewer line or gasoline from a leaking storage tank could be entering the aquifer. Cibolo Island Cave illustrates the vulnerability of karst aquifers to contamination. It highlights the fact that the entire karst aquifer recharge zone is highly vulnerable, and not just through the larger, obvious individual karst features.

While activities on the Cibolo Preserve pose no water quality concerns, the water flowing onto the property is of degraded quality. Cibolo Island Cave is about 4 km downstream of the Boerne Wastewater Treatment Plant. Although the effluent is treated to state standards, elevated nutrients levels persist, and algal blooms are common along the creek. Additionally, Boerne's urban runoff flows into the creek, which includes oils, grease, and heavy metals from roads, and chemicals and fecal bacteria (from pet waste) from lawns. Most recently, urban development adjacent to the property is resulting in soil erosion from the construction and increased rates of runoff. The Cibolo Preserve Board works with the City of Boerne and neighboring landowners to minimize adverse impacts as much as possible from activities off the Preserve.

If Cibolo Island Cave were not in the creek, its stream passage would be a likely locale for stygobitic *Eurycea* sp. salamanders, which are found in several caves in the Cibolo Creek area. However, the high influx of organic debris and epigean (surface) species through the cave's entrance during floods has kept them from being discovered. Stygobite species are found in more food-poor areas of the aquifer, which lack the large volume of washed in organic material, and where they do not compete with surface species brought into the cave by flooding.

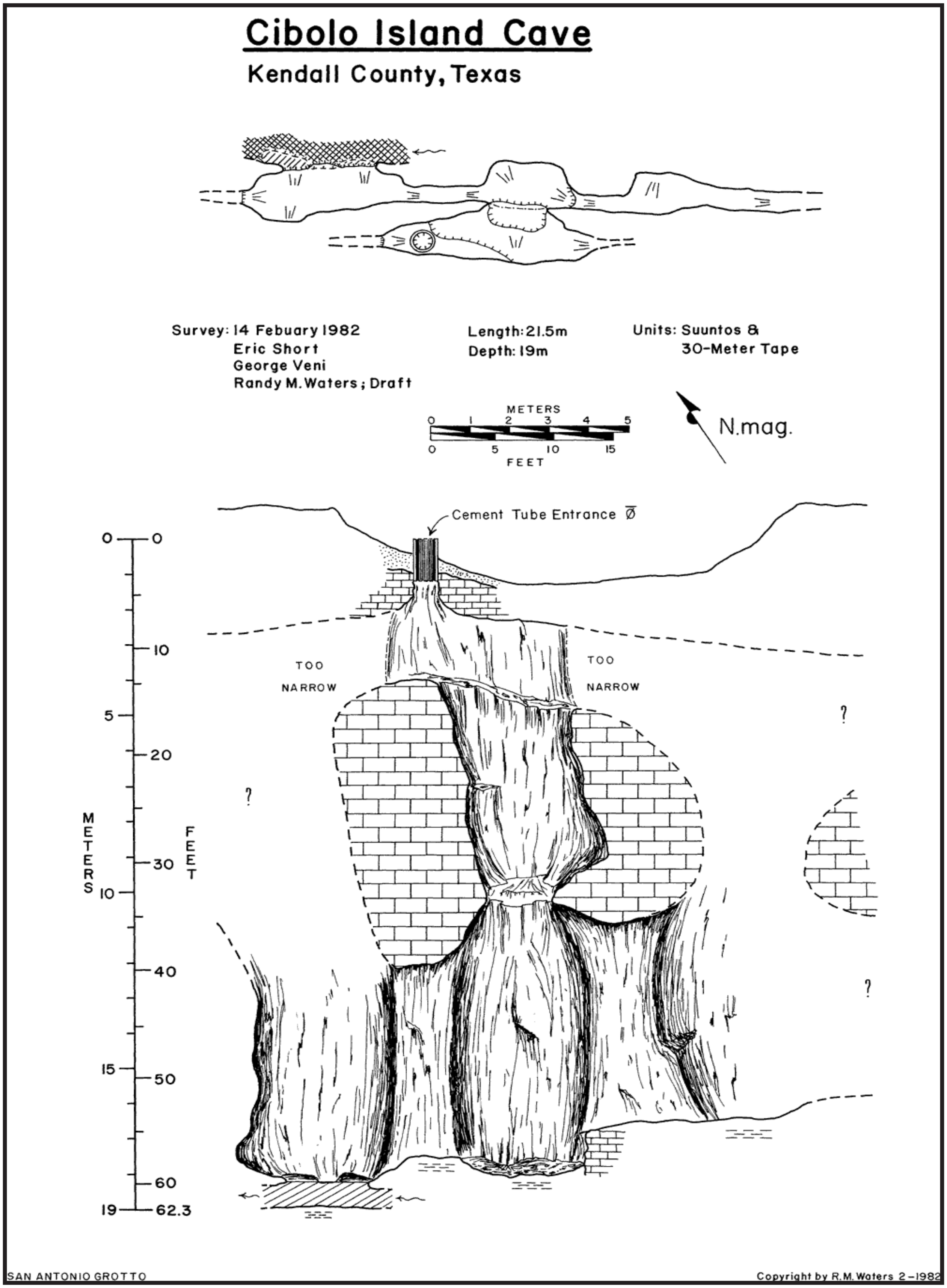

Figure 13. *Map of Cibolo Island Cave (from Waters, 1982).*

Stop 4: Cibolo Preserve, Hawkins Swallet and Herff Falls, written by Donna Taylor and George Veni

About 450 m downstream of Cibolo Island Cave is Hawkins Swallet. Found in March 2019, it was 1 m in diameter along a fracture, and as its name indicates, it swallowed all water when Cibolo Creek flowed less than 0.3 m^3/second. The swallet is now about 2.3 m across and its capacity for intake continues to increase with time. The depth of the swallet is not known.

About 60 m downstream of Hawkins Swallet is Herff Falls. Prior to the opening of Hawkins Swallet, Herff Falls flowed and roared continuously as water from the creek was channeled down and through the narrow, 12-m deep canyon (see front cover photo). The falls cut through a rudist-reef bioherm, the best exposure of such a mound among the many that occur in this part of the Lower Member of the Glen Rose Limestone.

A review of Google Earth imagery from 1985 through 2018 shows that except for floods, Cibolo Creek below Herff Falls flowed either 460 m or 1.3 km downstream before going dry. Presumably, those locations along the creek have greater permeability; no faults are indicated on the geologic map and those areas have not been examined for karst features. Starting in 2019, after Hawkins Swallet opened, water is seen to extend only about 120 m downstream from Herff Falls.

Hawkins Swallet is an excellent example of karst landscape evolution. The water-filled pit that presumably exists beneath the in-flooding water formed along a joint and in March 2019, the roof fell in to capture the flow of the creek. Herff Falls are now dry as nearly all flow from Cibolo Creek enters Hawkins Swallet, except during brief times of high flow after storm events. Over the next several millennia, Hawkins Swallet will probably become part of the Herff Falls canyon, contributing to the headward erosion of Cibolo Creek.

The water that flows down Hawkins Swallet does not reappear at the base of Herff Falls and thus must recharge the Lower Glen Rose Aquifer. The roughly 75% reduction in flow distance below the falls suggested by Google Earth imagery, supports this premise that most of the flow in Cibolo Creek is now recharging the aquifer through Hawkins Swallet. In several thousand years, or maybe in the near future (if a major flood washes away Cibolo Island Cave's island), Cibolo Island Cave will become a swallet to leave Hawkins Swallet and the section of the Cibolo Creek between them dry. Several other swallets are known downstream along Cibolo Creek, dry except during floods, demonstrating the opening of Hawkins Swallet is the most recent of a long history of swallet development.

These changes in the karst landscape require an evolving land management strategy. As natural and inevitable changes, they should go unaltered. However, at a minimum, the impacts on the diminishing downstream perennial riparian habitat needs to be studied. Unlike the Endangered Species Act, which is triggered by human-induced environmental changes, this natural situation raises philosophical as well as legal questions. If rare species occur in that diminished riparian area, should they be transplanted above Herff Falls where the creek still flows perennially? And for humans in such situations, what water rights are lost and retained in such natural losses of surface water?

Stop 5: Honey Creek Cave

Honey Creek Cave is the longest cave in Texas. Nearly its entire mapped length of 33,295 m (Texas Speleological Survey, 2021) is an angular dendritic underground stream system (Figure 14). It is formed in the Honey Creek Hydrostratigraphic Unit at the base of the Lower Member of the Glen Rose Limestone. We will visit the cave's two natural entrances in the cliff wall of a surface valley also known as Honey Creek. Rockfall has dammed the natural entrances and the cave's baseflow of 40-50 L/s discharges only from the northern "spring" or "wet" entrance except during major floods. The cave also has a centrally located artificial 42-m deep shaft entrance located almost 3 km to the west. Without the shaft, the cave's furthest reaches would have been beyond the endurance limits of exploration.

For the first 2.7 km, the cave's main passage averages 4-5 m wide by 3-5 m high but with 1-2 m of average air space above water level (Figure 15). The passage diminishes gradually in size upstream after each tributary. After 5.3 km, the passage is about 2 m wide and no more than 0.5 m high where something unusual is reached—a conduit groundwater divide.

One of the more unusual hydrologic features of karst aquifers are conduit groundwater divides, where water flows out from one passage into another, and flows downstream in two different directions. Often the two streams will not rejoin but go to different destinations. Unlike underwater conduit bifurcations or high-level conduits which allow floodwaters to rise and spill into adjacent drainage basins, these drainage divides occur during vadose (above the water table) base flow conditions. Five are known in Honey Creek Cave and are important in understanding and managing this groundwater system. Veni (1997) describes the process.

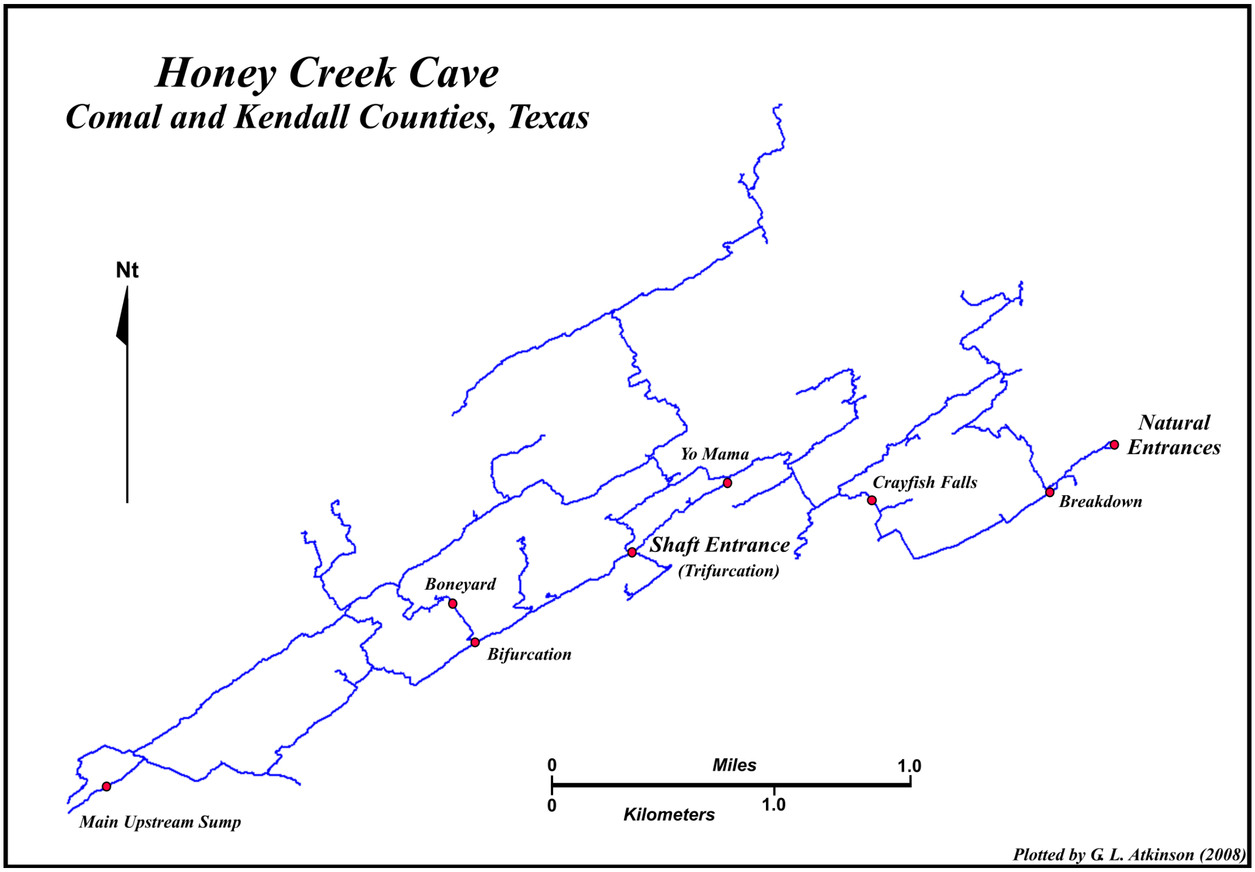

Figure 14. *Map of Honey Creek Cave (map courtesy of the Texas Speleological Survey).*

The divides are related to tapoff passages, which are relatively newly formed and short, locally high-gradient cave stream passages that pirate flow from high elevation streams to lower elevation streams. Tapoffs can form between any combination of surface and subsurface streams, are usually small relative to the surrounding passages, and have few or no tributaries (Veni, 2005). They are also critically important to the origin and management of many karst aquifers.

Honey Creek Cave formed as a tapoff passage, pirating water from the larger, longer, and higher elevation Cibolo Creek about 1 million years ago to the Guadalupe River. Within the past 170 thousand years, a new tapoff passage was created, capturing that water from the current upper end of the cave and transmitting it southeast into the Edwards Aquifer. This piracy created the conditions for the groundwater divide in the main passage to form. Part of that water flows to and out of the cave entrance into Honey Creek, and from there to the Guadalupe River. The rest of the water flows to the tapoff passage and into the Edwards Aquifer. During major floods along Cibolo Creek, the tapoff passage is too small to accept the extra volume, which overflows the divide and pours down to the cave spring.

The exploration and protection of Honey Creek Cave was facilitated greatly by the family which owns the property. Their historic ranch use and small farm had no measurable impact on the cave's water quality or its ecosystem. As cavers discovered more of the cave and physical limits of exploration approached, the owners offered to drill an entrance to support further exploration and research, while giving the owners a well into the cave. The cavers agreed after discussion and assurance that only small amounts of water would be removed for livestock and related needs. This intermittent pumping has proved sustainable with no observable impacts on the cave's discharge or ecosystem.

Until recently, there was no management concern about the cave or its groundwater. In 2019, a nearby ranch bought for exurban development proposed a community sewage collection system where sewage overflows would run down Honey Creek, which is one of the few remaining pristine riparian areas in Texas. Following broad public protest, the Texas Commission on Environmental Quality rejected that proposal and a wastewater irrigation system was instead proposed. This action was also contested by affected landowners as harmful to the creek, cave, and aquifer.

Figure 15. *Caver swimming through a typical downsteam section of Honey Creek Cave.*

A settlement agreement was reached where the effluent volume was reduced, treatment method improved, and surface and groundwater monitoring systems enhanced to what is hoped to result in no adverse impacts. However, if impacts do occur the State's response is to impose fines, and it is not clear how far remediation can be required. Could homes be removed and the land restored to a natural state if the number of homes is proven unsustainable to meet agreed upon clean water standards? This question applies to other properties as well, but no precedent is known, and it has yet to be answered.

While the proposed development ended with an accepted resolution, a school for the growing population is planned nearby, as are other homes and businesses. The expense of maintaining the Honey Creek Cave ranch as a business, plus as a groundwater and ecological haven, will likely continue to increase. The family which owns the cave is dedicated to the property, but it is not certain how long they can continue to afford to keep the land.

[As this field guide is going to press, the Texas Parks and Wildlife Department is proposing to purchase the property targeted for development and add it to Honey Creek State Natural Area.]

Stop 6: Bracken Cave

[Most of the following is abbreviated from Veni and Green, (2017), with minor updates.]

Bracken Cave holds the world's largest colony of bats. Each spring, millions of pregnant Mexican Free-tailed bats (also called Brazilian Free-tailed bats), *Tadarida brasiliensis mexicana*, return from their winter migration to Mexico and give birth to an average one pup each, doubling the population by early summer. Bat Conservation International (BCI), which owns the cave, estimates the maximum summer population at about 15 million (Mylea Bayless, BCI, personal communication, 2016). The cloud of bats that exits the cave nightly appears on the radar of airport and Doppler weather radar (Figure 16).

In 1992, the cave was acquired by BCI to protect the bats, conduct research, and promote public education on bats. The initial purchase was for 0.3 km^2, which was expanded a few years later to 2.8 km^2. However, in the spring of 2013 the integrity of the preserve was threatened by a proposed housing development on an adjacent 6.2-km^2 property. Following an outcry from local citizens and a massive fundraising drive, $20.5 million were raised, with substantial portions coming from the City of San Antonio and The Nature Conser-

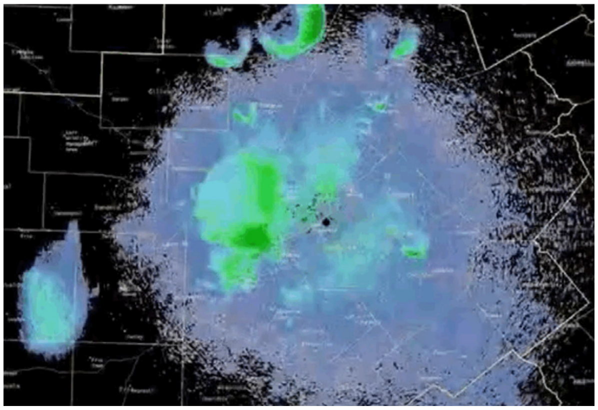

Figure 16. *Mexican Free-tailed bats emerge from central Texas caves and appear as blue-green areas on this 320-km wide Doppler radar image; the bats from Bracken Cave are the mostly green area just left of center (from https://www.kut.org/science/2017-08-17/is-that-some-weird-storm-on-the-radar-nope-its-bats).*

vancy. On 31 October 2014, BCI bought the property and expanded the preserve to 9.0 km^2.

The cave's entrance is impressive, at 20 m wide by 7 m high at the base of a 30-m diameter by 13-m deep collapse sinkhole. The size of the cave's single passage averages 15–20 m wide by 10–15 m high. It descends steeply 12 m down a bat guano-covered rubble slope, then continues south along a roughly level guano floor to where the ceiling abruptly lowers at a horizontal distance of about 130 m from the entrance. The passage beyond is filled with guano (Figure 17). A shaft for guano mining pierces the cave ceiling in this area.

It is not known when the cave was discovered, but it was almost certainly located due to its impressive evening bat flights, as large clouds of bats emerge nightly during the spring through fall months. The cave was named for the nearby town of Bracken. Guano mining began in 1856, with most of the guano used as fertilizer. The cave yielded up to 70 metric tons of guano annually. Mining was usually done in the winter when the bats were absent. Shipments went by rail to the west and east coasts. During the Civil War, the guano was leached for saltpeter used in Confederate gunpowder. Mining continued sporadically until 2009 when it ceased as a precaution to prevent the spread *Pseudogymnoascus destructans*, the fungus responsible for White-nose Syndrome. While the fungus was not known in the cave at that time, it has since been found in Bracken and several other central Texas caves.

Probably the most curious aspect of Bracken Cave's history was when Dr. Lytle Adams used it in Project X-Ray. This formerly top-secret World War II project proposed attaching incendiary bombs to bats, releasing them, and when the bats would roost in buildings the bombs would ignite to raze the cities. The project was abandoned abruptly when atomic bombs were used to end the war. Extensive ecological data were gathered during Adam's research, most of which became classified military information for some time.

Working in Bracken poses challenges not found in most caves. During the months when large numbers of bats are present, their body heat raises the cave's temperature to over 40 °C, while the guano and urine create hazardous atmospheric ammonia levels as high as 55 ppm. Meanwhile, the floor literally moves due to the probably millions of dermestid beetles feeding on dead bats on the floor. The cave is rarely entered and usually only in the winter to not disturb the bats, that's also when temperature and ammonia levels are at their lowest. Masks with filters are necessary at all times, if only to prevent inhalation of the cave's fine guano dust that pervades the air.

For more general information on the cave, see Elliott (1994). Couffer (1992) offers a detailed and engaging account of Project X-Ray. For the most recent news on the cave, including a web cam to watch the evening flights live, visit BCI's website page on Bracken Cave.

Bracken Cave is formed in the Kainer Formation of the Edwards Limestone Group and in the underlying Upper Member of the Glen Rose Limestone (Figure 17). The Dolomitic Member of the Kainer Formation extends from the surface down 9 m to the dripline of the cave's entrance. This thick-bedded, structurally competent unit forms the roof of many large cave chambers in the area, as well as the namesake bridge of Natural Bridge Caverns 1.1 km to the northeast.

The humanly accessible portion of Bracken Cave is mostly within the 15-m thick Basal Nodular Member of the Kainer Formation, previously designated as the Walnut Formation when Figure 17 was drafted. Large solutionally formed chambers and passages are often present in the Basal Nodular Member in Bexar County to the east and in this part of southeastern Comal County, but the currently accessible portion of Bracken Cave is not formed by solution but by collapse into a deeper solutionally-formed passage.

Bracken Cave's deepest 7 m are formed in the Cavernous Hydrostratigraphic Unit of the Upper Glen Rose. This unit contains most of the largest solutionally formed cave chambers and passages in the area. Like the Basal Nodular exposure in the cave, its humanly accessible section in the cave is not

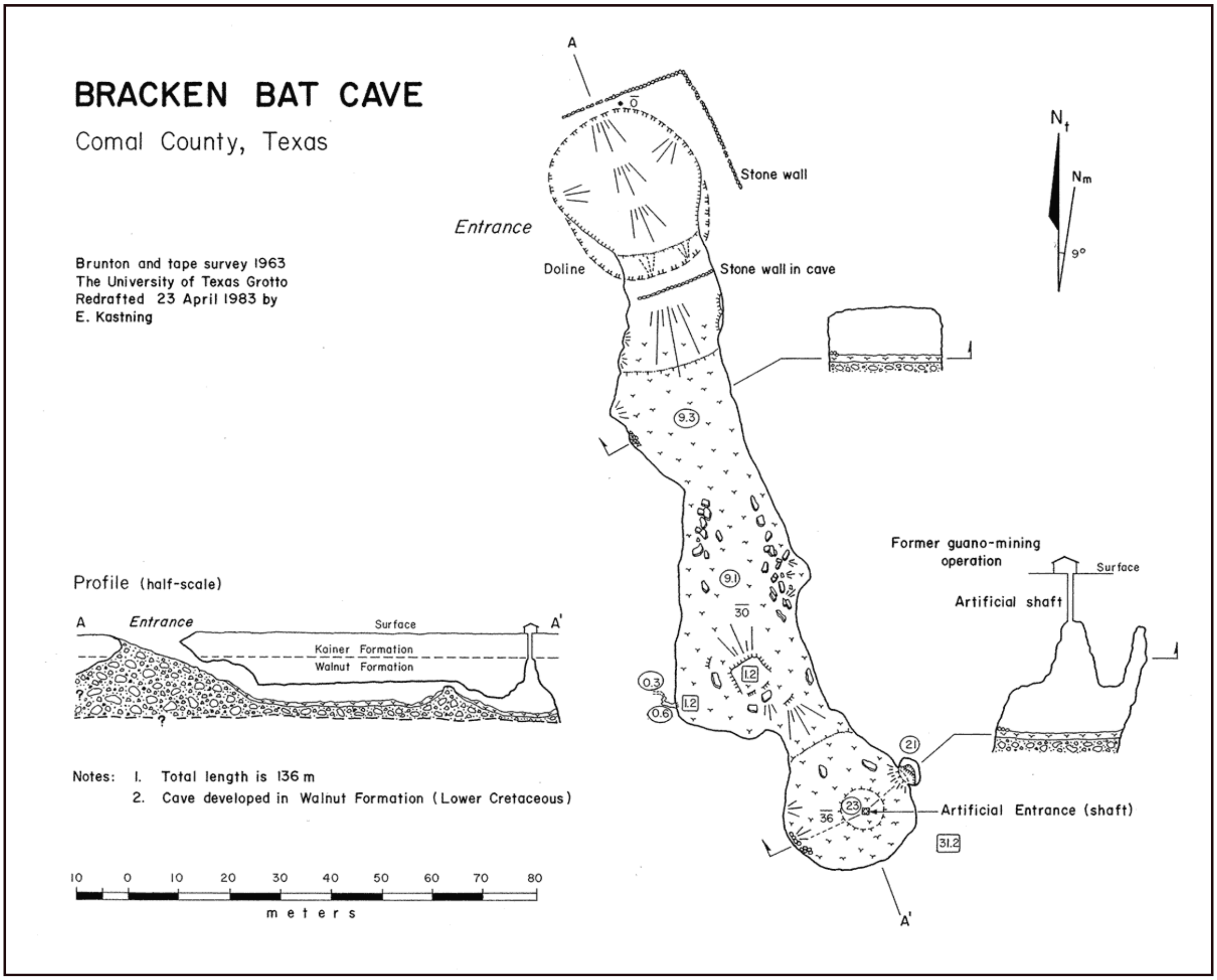

Figure 17. *Map of Bracken Cave (from Kastning, 1983).*

formed by solution but by collapse into an underlying solutionally-formed passage. Work by Kastning (1983) suggests the cave is far more extensive and likely similar to Natural Bridge Caverns if it could be explored beyond the collapse and guano.

Veni and Green (2017) propose that Bracken Cave and Natural Bridge Caverns formed as tapoff passages. The caves are parallel and located across a meander of Cibolo Creek, which reverses its west-to-east flow by flowing south, then west 1.6 km north of the caves, then south 2.2 km west of Bracken Cave (Figure 1). Where the seasonally active creek turns west, north of the caves, it forms a steep hydraulic gradient with the Edwards Aquifer to the south; tapoff passages form along such gradients. They typical have no side passages, or few and hydrologically under-fit side passages as seen in Natural Bridge Caverns. The caves' large sizes are consistent with the large volume of typically chemically aggressive surface water recharging Cibolo Creek to the north, which can be seen in Natural Bridge Caverns when the creek floods.

In 2013, a drilling company offered its services to BCI. BCI then contacted the National Cave and Karst Research Institute (NCKRI) to use the drilling services to core the guano in Bracken Cave and analyze it for paleoenvironmental and paleoecological data. But first, it was necessary to find the best place to drill. NCKRI organized a team of specialists to work on the study. Working with a team of BCI volunteers, NCKRI conducted three sets of electrical resistivity surveys in the cave in the winters of 2014, 2016, and 2017 (Figure 18). The wintertime study periods coincided with the time when most of the bats were in Mexico, resulting in minimal disturbance and also better working conditions.

Having no idea how deep the guano might be, the first surveys determined a minimum depth of 18 m. Veni (2014) provides a description of the methods and results from those first surveys. Continued surveys identified a depth of 36 m, as shown in Figure 19,

Figure 18. *The first electrical resistivity surveys in Bracken Cave in 2014. The yellow cable identifies the first survey line. The pink flags mark the electrode locations (NCKRI photo courtesy of Allan Cobb).*

which has since been revised to 31 m following a high-precision elevation survey of the location of the resistivity array in the cave. Based on interpretation of geophysical data (the drilling offer fell through), the guano ends on breakdown, which according to known cave development in the deeper strata is estimated to continue at least 20 m deeper. The original, solutionally formed cave floor does not appear in the imagery, and another trip is planned to look deeper with the geophysics and image the passage's full vertical extent and its deposits.

Since the bats spend nearly half the year in Mexico, much of their management is beyond BCI's control. Additionally, BCI has no ability to control nor jurisdiction over where the bats fly to in the evenings when they exit the cave to feed. However, these are reasons why BCI focuses much of its efforts on public education programs at the cave, online, and in activities nationally and abroad, to help protect these bats (as well as all bats) when away from Bracken Cave.

A key part of the education programs conducted at Bracken Cave is information so visitors do not disturb the bats. Most educational trips to the cave watch the nightly emergence of bats as they exit to feed. Loud talking and other noises, camera flashes, and bright lights interrupt the emergence. Access inside the cave is limited to research.

With the acquisition of the proposed adjacent housing development in 2014, the cave is well buffered by nature preserves. The nearest housing is a small, low-density neighborhood 2 km to the southeast. Trespassing is minimal, as is trash, though a few small items are carried onto the property by wind. All uphill areas are clean and undeveloped so there are no water quality problems with stormwater runoff.

General land management on the Bracken Cave Preserve strives to maintain the natural environment, which includes occasional removal of Ashe Juniper that can dominate the landscape when not controlled by natural grass fires. Any tree removal is monitored to not disturb known or potential habitat for the endangered Golden-cheeked warbler. No endangered cave species are known on the property and are unlikely to occur.

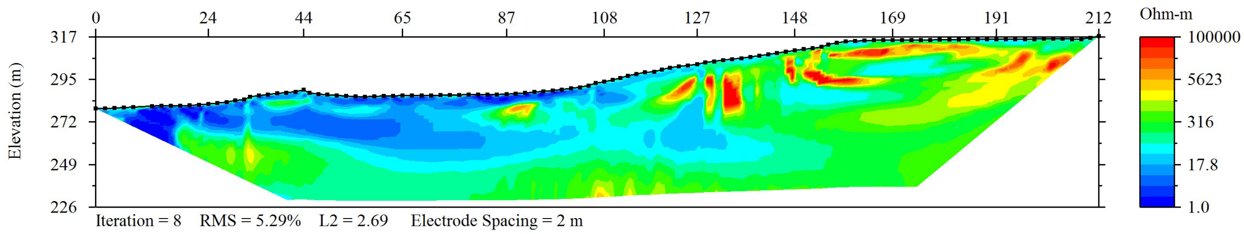

Figure 19. *Electrical resistivity profile of Bracken Cave. The scale the top is in meters. The end of the cave is at 0 and the entrance is near 127. The slope to 154 is the entrance sinkhole and the land surface is the flat area to 212. The blue and blue-green areas are interpreted as predominantly guano on breakdown (yellow-orange in color); the red areas are almost certainly voids in the breakdown formed by the entrance collapse.*

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This trip and symposium are part of the celebration of the International Year of Caves and Karst.

Entrance to the Spring Branch-CM Cave System in Comal County, Texas. This is the most extensive cave known on the north side of the Guadalupe River's watershed. While the entrance of this cave is on a currently protected property, like many stream caves in the area, its water quality may be threatened by increasing exurban housing in its drainage basin.

**National Cave
and Karst Research Institute**

**400-1 Cascades Avenue
Carlsbad, New Mexico 88220 USA**

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