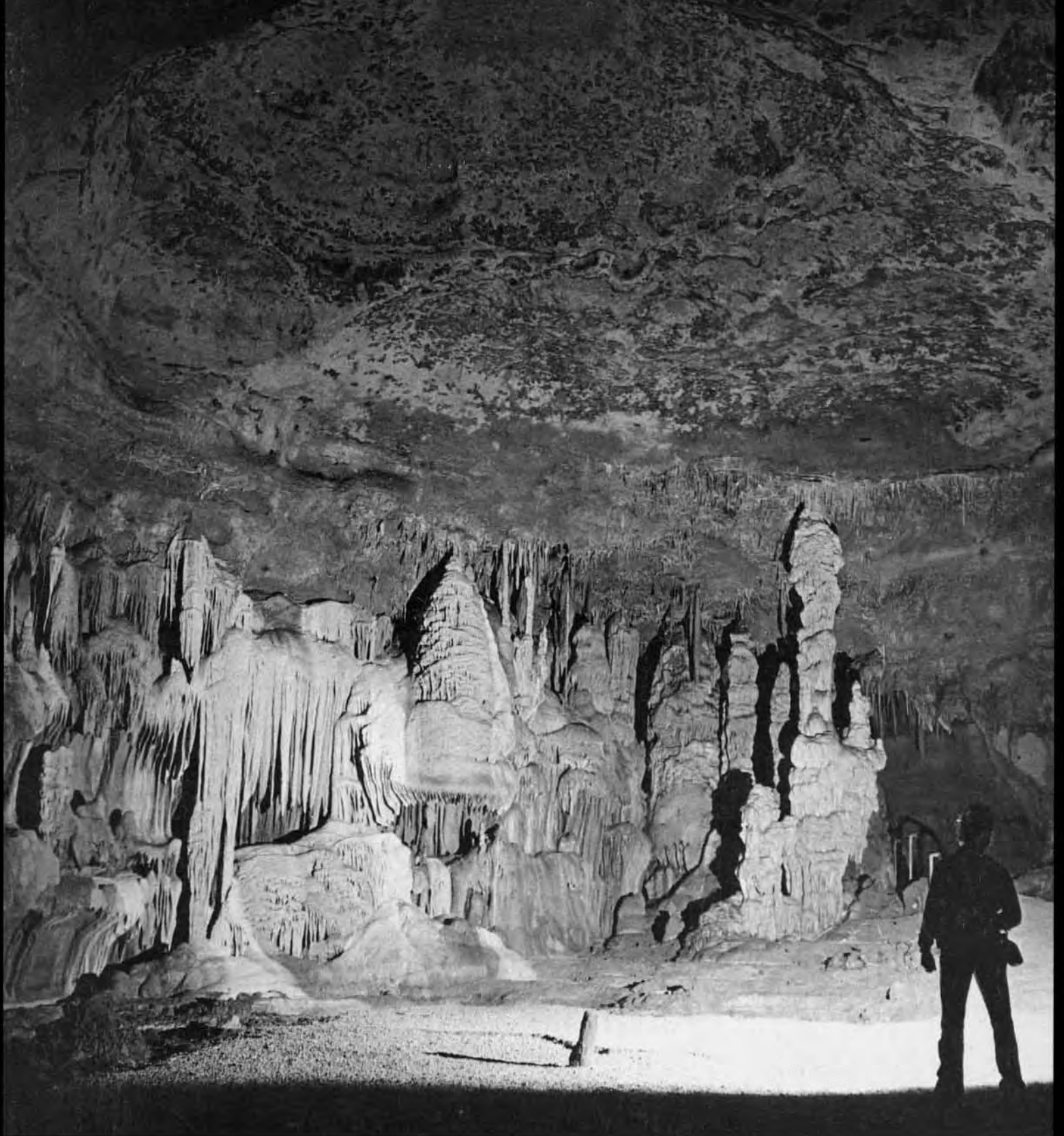


# 1989 NATIONAL CAVE MANAGEMENT SYMPOSIUM PROCEEDINGS

New Braunfels, Texas



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# **Proceedings of the 1989 National Cave Management Symposium**

New Braunfels, Texas U.S.A.

Edited by Jay R. Jorden  
and  
Robert K. Obele

Symposium Hosted by:  
Texas Cave Management Association  
Texas Parks and Wildlife Department

Sponsored by:  
U.S. Bureau of Land Management  
National Park Service  
National Speleological Society  
Texas Speleological Association  
American Cave Conservation Association  
Richmond Area Speleological Society

John M. Walsh, Program Chair

Texas Cave Management Association  
New Braunfels, Texas U.S.A.

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Published by:

Texas Cave Management Association  
P.O. Box 310732  
New Braunfels, Texas 78131  
U.S.A.

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ISBN

Printed in the United States of America

Cover Photo: Cave Without a Name, by James Jasek, Waco, Texas.

Inside Photos: Kickapoo, Old Oriente Mill, Molasses Bat, Barnyard, and Hutto Bat Caves, by James Jasek, Waco, Texas.

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**BANNED IN SALEM**

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## FORWARD

### 1989 National Cave Management Symposium

by Jay Jordan

Night paths winding beneath walls of rock,  
Old winds blowing through halls of stone,  
Water, remembering long dead reflections,  
                    gathers in calm pools ...  
and new light shines toward the unknown.

— Ronal C. Kerbo, 1989

It was with a renewed earnestness that about 50 cavers and friends of caves (scientists, government agency representatives and conservationists) gathered in the Texas Hill Country in the late summer of 1989. Optimism was evident; the Federal Cave Resources Protection Act, for which the National Speleological Society and other groups had lobbied several years, had been enacted, and a movement to try to commercialize a cave in a surface wilderness area on national parkland had been defused, although not entirely. Yet, challenges remained for cave conservation and management. Though lobbying continued for a cave wilderness bill in Congress, previous efforts to establish such a designation had failed. And the cave conservation and management movement itself had lost some momentum. It had been some time since the last National Cave Management Symposium had been held. The organizers of the 1989 Symposium, realizing that, had fashioned a slightly different approach to the Texas event,

mingling field trips and case study (cave study!) approaches to management problems with the usual lecture hall and audiovisual program fare. Participants visited more than a dozen caves in Bexar, Comal, Kendall, Hays and Travis Counties. At these sites, which included commercial and private caves in various types of management environments, experts used case studies to examine specific issues. For instance, cave gating and biology were discussed at the entrance of Ezell's Cave, managed by the Nature Conservancy and its volunteers within the city limits of San Marcos, Texas. There, the Conservancy and volunteers had successfully battled vandals who wrecked a succession of gates to gain entry to a window the aquifer underlying the city.

More than a dozen speakers addressed the four-day Symposium on problems and solutions in managing caves and their contents on government and private lands. About 50 representatives from the Nature Conservancy and government including the National Park Service, United States Geological Survey, Bureau of Land Management, and U.S. Forest Service attended, as well as speleologists and other interested persons.

One of the Symposium's highlights was a field trip to Bracken Bat Cave in South Central Texas, which contains the world's largest population of Mexican free-tailed bats.

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There, technical papers were presented as participants watched the spectacular night bat flight.

The Texas Parks and Wildlife Department and the New Braunfels-based Texas Cave Management Association were pleased to co-sponsor the Symposium. The TPWD, stewards of a park system totaling 434,000 acres in 129 units, are managers of hundreds of caves. With each new acquisition of parkland comes the possibility of new cave management challenges. The state officials were able to share their expertise on the subject and recount their cooperative effort with cave explorers in the state in helping to preserve and protect these subterranean treasures for future generations. From those who volunteered their efforts to plan and execute the programs of the Symposium to those who participated in it, the feeling was universal that the events were a success. A symbiosis of thought and practice developed in cave conservation and management that was carried back to each participant's workplace and hometown. By the Symposium's end, everyone was busily looking forward to the next one and actively planning for it.

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## 1989 National Cave Management Symposium October 3 - 7, 1989 The Natural Heritage of Texas

### Edwards Plateau

- Location: Alkaline soils in limestone in granite areas.
- Flora: Oak savannahs, oak woodlands, juniper breaks, many endemic plants.
- Fauna: Varied mix of native animals.
- Rainfall: From 15 to 33 inches.
- Rarities: Blind catfish, cave salamanders, Clear Creek Gambusia, San Marcos Gambusia, Large Spring Gambusia, Fountain Darter, Golden-cheeked Warbler, Black-capped Vireo, basin bellflower, Texas snowbells, rock quillwort, Edwards Plateau cornsalad, bracted twistflower, Edge Falls anemone, Texas wild rice.

The life of the Edwards Plateau is divided between the daylight and the dark, between the wet and the dry.

The weatherbeaten surface of the Plateau, blistered by drought and cut by flash floods, is one of limestones and granites. It is a land of many rare plants such as Texas snowbells, basin bellflowers and rock quillwort.

And it is a land of many springs, whose sparkling waters are sought by man and animal alike. The purity and constant temperature of the waters are the ideal habitat for specialized spring dwellers such as Clear Creek

Gambusia, the San Marcos Gambusia, the Large-Spring Gambusia, the Fountain Darter and the San Marcos Salamander.

The moist river corridors are lined with cypress, pecan, hackberry and sycamores. Within the rivers can be found the unique Guadalupe Bass and Cagle's Map Turtle. On the slopes above, the Golden-cheeked Warbler, which winters in the tropical forests of Mexico, nests in thickets of Ashe juniper and Texas oak.

The limestones of the Plateau, cut by springs and rent by flash floods, are honey-combed with thousands of caves of all sizes. Many animals, such as cave shrimp and blind salamanders, live only within the confines of these cave systems. Others visit this intermediate world for special purposes, such as nursery colonies of free-tailed bats. Bracken Cave, near San Antonio, contains an estimated 30 million bats during the breeding season.

A wet, dark world lies beneath the western edge of the Plateau. This hidden world of underground lakes is known as the Edwards Aquifer. It is a series of underground reservoirs that is replenished by surface waters that sink through the porous limestone. The Edwards Aquifer is home to a host of curious creatures, including two kinds of blind catfish, a blind salamander and a plethora of invertebrates - all blind and without any pigments to give them color.

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But, while there are many more species remaining to be discovered in this subterranean world, its very existence is being threatened. As cities and towns along the Balcones Fault draw ever increasing amounts of water from the Edwards Aquifer for their domestic and municipal use, they increasingly threaten the existence of the world's most diverse collection of aquifer fauna.

### **New Braunfels**

The host city for the 1989 National Cave Management Symposium is New Braunfels, Texas. Located midway between Austin and San Antonio, this city is on the eastern edge of the Edwards Plateau.

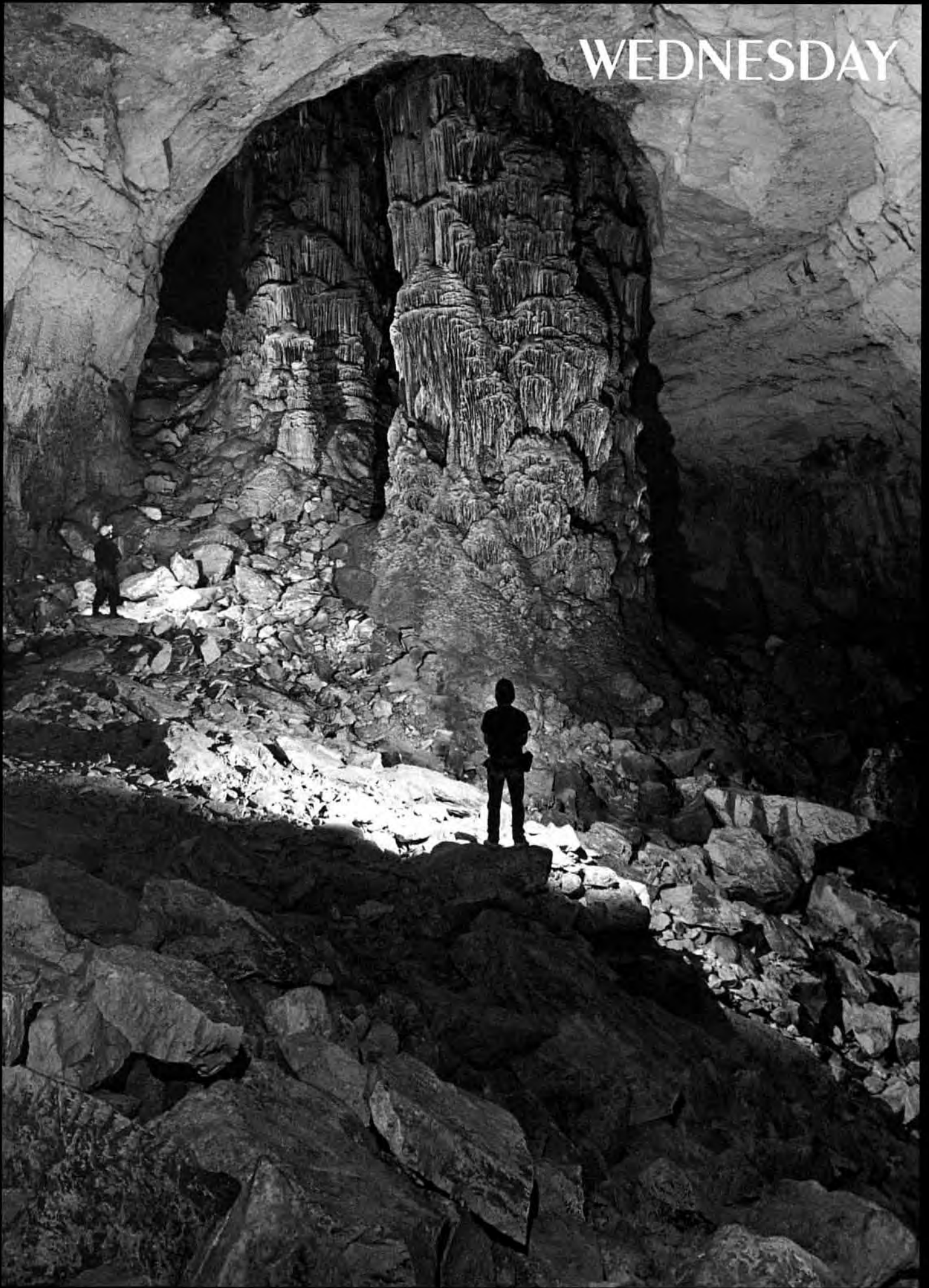
This picturesque community, founded by Prince Carl of Solms-Braunfels in 1845,

takes you on an enchanting trip back to the past.

You'll see dozens of quaint homes, built of the old German fachwerk construction, along with "gingerbread" on the gables and verandas. A number of the homes are designated as official Texas Historic Landmarks, and a few are open to visitors.



WEDNESDAY



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# **Introduction to the Caves and Cave Management Problems of Texas**

**Keynote Address — 1989 National Cave Management  
Symposium, New Braunfels, Texas**

by  
**George Veni**  
**George Veni & Associates**  
**11304 Candle Park**  
**San Antonio, Texas 78247**

## **ABSTRACT**

Texas is a large and diverse state, containing nearly 3000 caves and many varied aspects in their management. Karst groundwater issues are the primary management factors involving Texas caves. These issues include water quality, water quantity and water rights, in both urban and rural settings. Management of cave ecosystems has required habitat study and protection from loss of habitat area, contamination, invasion by non-cave competitive species, and by human visitation. Style and ease of cave ecosystem management varies. Endangered cave species are grudgingly protected by landowners who see little practical benefit from the animals. Bats, however, are more willingly protected as the general public becomes better informed to their many beneficial aspects. Caves' geographic locations also affects management style; urban-avoidance versus rural-exploitive. Special uses of Texas caves include State-owned caves, commercial caves, and caves with archaeologic and paleontologic materials. Texas cave management is in flux and is being influenced from many directions as state and local agencies set new rules and guidelines.

### **Introduction**

Welcome to the great State of Texas! Despite the Hollywood stereotypes, Texas is a land rich in cultural and physiographic diversity. That diversity extends to its caves and

the many ways in which they are managed. Cave management techniques in Texas are developed as a combination of four primary factors: geology, biology, geography and special use. This paper will outline these factors, discuss their pertinence to cave

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management in Texas, and hopefully provide some useful insight for similar situations elsewhere.

### Geology

About 25% of Texas is underlain by karstified rock. Most of this area lies in a 300 km wide belt which extends from east-central Texas almost 1000 km west to El Paso. The Texas karst contains nearly 3000 caves and has been divided into 13 regions based on the geologic conditions which have a distinct effect on cavern development (Figure 1). A detailed description of these regions can be found in Smith (1971) and Fieseler (1978). For a more generalized discussion, however, it is adequate to say Texas contains limestone karst, gypsum karst, and pseudo-karst.

Examples of varied cave development for each karst type can be found among some of Texas' most noted caves: Honey Creek Cave, one of the longest caves in the U.S. with 30 km of limestone stream passages; the Devil's Sinkhole, a tremendous limestone shaft which opens to a chamber nearly 200 m in diameter; River Styx Cave, the state's longest gypsum cave; and Enchanted Rock Cave, possibly the longest granite pseudo-karst cave in the world.

Of these three karst types, however, the limestone karst of Texas contains by far the greatest number of caves, as well as the largest, longest and deepest caves. It occurs over the greatest geographic area and shall be the primary karst type discussed in this paper. Limestone caves have the most significant impact on human activities and are conversely the most significantly impacted by them. The caves' primary importance to Texans are as

sources of water.

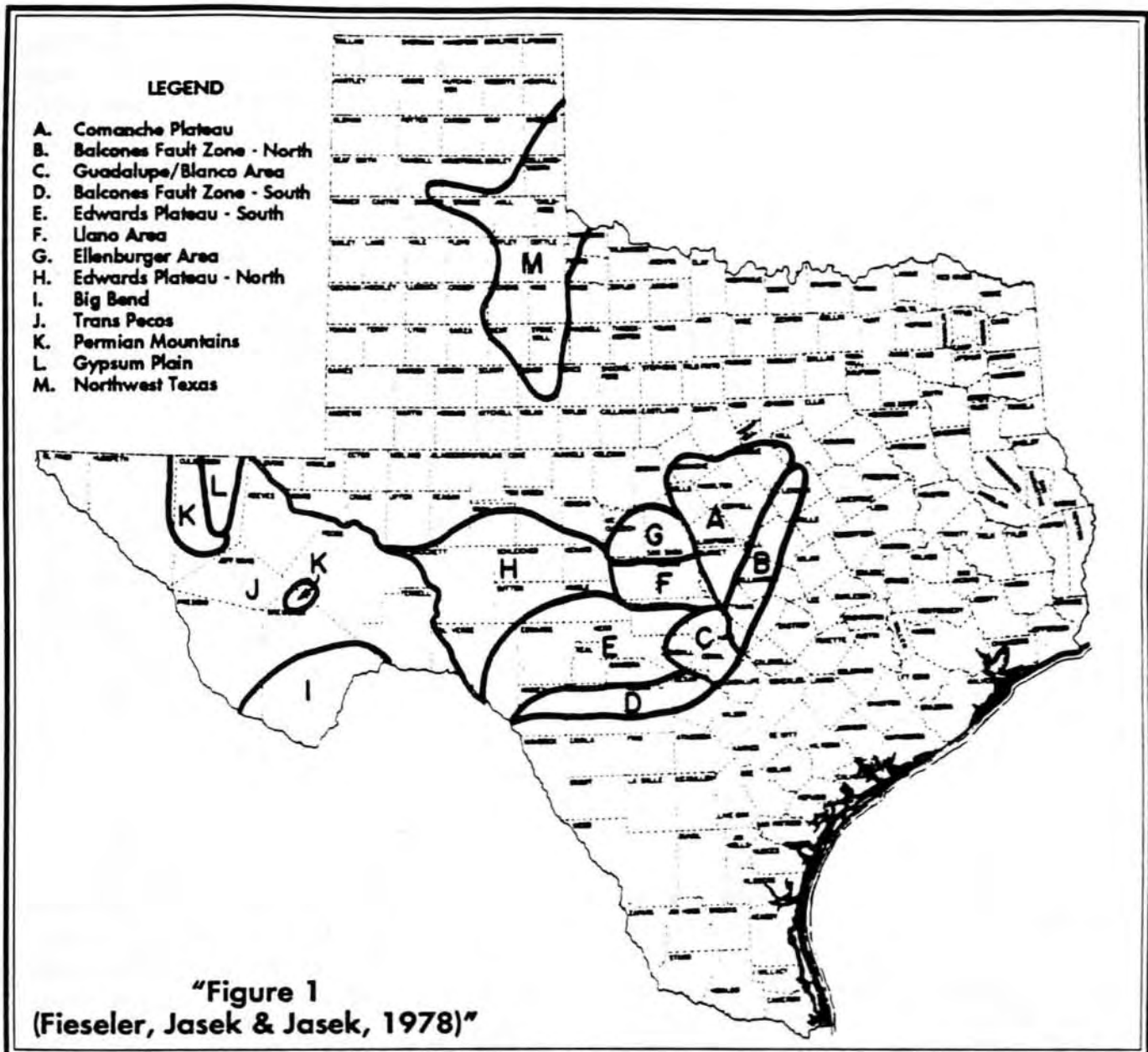
### Karst Groundwater

Most of the Texas karst occurs in a sub-arid climate. Surface water is scarce and groundwater is in constant high demand. Along the southern and eastern boundaries of the karstic Edwards Plateau there are several cities and towns whose sole reason for settlement was location next to the perennial springs which wellup along the plateau's Balcones Escarpment. The city of New Braunfels grew up around the Comal Springs. Austin, the state capitol, has long relied on water from Barton Springs. And in San Antonio more than a million people currently depend on karst groundwater as their sole water supply.

The geologic occurrence of limestone caves as conduits for groundwater gains importance as various private and governmental agencies seek ways to manage these resources. Many of the current karst groundwater problems are arising in San Antonio and Austin where development onto the source areas, or recharge zones, of the aquifers is rapidly occurring. The two primary issues of concern are water quality and water quantity.

### Karst Groundwater Quality

Karst aquifers are notorious for offering little or no purification to groundwater, and then rapidly transmitting that water over large distances. Many of the engineering technologies used to prevent groundwater contamination have often been demonstrated as being ineffective in karst. Landfills, underground storage tanks, sewer lines, septic systems and urban runoff are some of the common factors



contributing to karst groundwater pollution.

In order to minimize contamination, the Texas Water Commission has developed rules for the use and development of groundwater. Of more recent and of greater implications is a new law (effective 9/89) stating that Texas has adopted a non-degradation policy toward

the management of its groundwater. While these are important steps, the real difficulty is in adopting measures which call for the evaluation of karst aquifers with methods best suited to karst. Some progress is being made in this direction, but all too often techniques best suited to sandstone and other non-karst

aquifers are still being used, and caves are usually evaluated only from a look at their entrances. Local geologic factors in the Balcones Escarpment area have often resulted in very significant caves having very "insignificant" entrances (Veni, 1987); this factor has led to the mismanagement and destruction of several important caves.

### **Karst Groundwater Quantity**

The issue of water quantity is much more complex than that of water quality. Groundwater in Texas is subject to "the right of free capture," which is the right to pump virtually unlimited quantities without regard to the consequences. Comanche Springs yielded an average 1200 liters per second and put the West Texas town of Fort Stockton on the map as a pleasant water resort town. However, in the late 1940s, increased pumping of groundwater for irrigation caused the karst springs to cease flowing by 1961 (Brune, 1981).

Similar concerns occur in the Edwards Aquifer area. The communities of New Braunfels and San Marcos fear that overdrafting the aquifer by agricultural activities and by the city of San Antonio may cause the Comal and San Marcos Springs to run dry. Downstream communities which rely on that springflow are also concerned. In response to this concern the Guadalupe-Blanco River Authority (GBRA), whose rivers are largely spring-fed by the Edwards Aquifer, is taking legal action to prove the aquifer is an underground river. Should the GBRA win its case, the aquifer's water will not be subject to the right of free capture, and it will fall under the full jurisdiction of the Texas Water Commission which has control over the surface water of Texas —

the Edwards Aquifer would simply be recognized as a subsurface extension of certain surface rivers. While some Texas caves can be easily defined as underground rivers, it is currently uncertain if the complex Edwards Aquifer will gain such recognition.

Not all karst water quantity issues involve groundwater depletion. In one case, a cave has been used to increase recharge into the Edwards Aquifer. In 1982 a dam was built across Seco Creek by the Edwards Underground Water District, and a diversion channel was cut to drain floodwaters into Valdina Farms Sinkhole. A study following a major flood in 1987 showed the cave was able to efficiently recharge the aquifer, transmitting more than 12 million cubic meters of water underground. More than four months after the flood, water levels in wells 8-14 km away were still rising. Although the hydrologic use of the cave was successful, the cave's biota was desimated and further studies were recommended to determine if and how well the fauna would recover (Veni and Associates, 1988).

In some instances, water quantity issues often overlap issues of water quality. In areas where groundwater pollution through caves is a major concern, it has been easy to recommend sealing a cave or diverting its inflow elsewhere. Yet in areas such as Texas, where another major concern is to maximize the volume of the groundwater reservoir, it is recognized that preventing contaminated streamflow from entering the aquifer is also preventing the replenishment of that water supply. Additionally, sealing of cave entrances or diversion of flow does not assure that significant contamination will not enter the aquifer through solutionally enlarged frac-

tures adjacent to and connected to the cave. While regulations are being enacted to prohibit high contamination risk activities on the recharge zones, the idea of simply staying off the karst and diverting urban expansion to less environmentally sensitive areas does not seem a viable option to most public officials.

In rural areas the water issues surrounding caves are much less complex. For many ranchers, caves serve as water supplies, either through their springflow or by wells placed to intersect underground lakes and streams. The raising of livestock, the most common livelihood in the Texas karst, poses few water quality threats. On occasion, caves and sinkholes are used as trash dumps, but their wide spacing and low toxicity have had little effect on the area's sparse population. Texas caves have served as the primary resource in locating subsurface streams for ranchers, and in educating those cave owners that "out of sight, out of mind" can be a dangerous policy.

### **Biology**

The diversity, richness and range of Texas cave fauna has been well documented, and is nicely summarized by Lundelius and Slaughter (1971). The state's cavernicole fauna represents a major crossroads of geologic processes, climatic changes, animal migration patterns, and troglobite evolution. Many of the cave species are relictual ancestors of climates which no longer exist in Texas and of surface species which may now be extinct.

The management concerns of cave fauna in Texas can be divided into two groups: endangered species and bats. The same set of factors, however, adversely impacts both groups. These factors are: loss of habitat,

contamination, invasion by foreign fauna, and visitation.

### **Loss of Contamination of Cave Habitat**

Of the above four factors, loss of habitat is the most significant. Cave fauna have evolved to survive in a particular type of highly specialized environment. Troglobites, the most highly adapted of all cave fauna, are by definition creatures which must complete their entire life cycles underground and are unable to survive on the surface. The filling and destruction of caves are obvious examples of habitat loss which occur as cities expand onto the Texas karstlands. In San Antonio alone, nearly 50 caves are known to have been destroyed by urban expansion.

Less obvious examples of habitat loss occur when the caves remain intact but the surface significantly changes and no longer supports certain cave life. This was a major point of concern in 1988 when caves harboring endangered species were threatened by the urban expansion of Austin. These species included beetles which depend on cave cricket eggs as their main food source. The crickets' survival, however, depends on the preservation of the surface flora upon which they leave the caves nightly to feed.

Another concern for the Austin endangered cave species was the impact of contamination on the caves. Groundwater is the most effective means of transmitting contaminants into a cave ecosystem, and it will readily enter the cave along zones where the food sources are highest: the entrance, collapse areas, and streams. These areas will also have the highest concentrations of cave fauna. Significant

contamination can also occur by material dumped into a cave or sinkhole, by fumes from nearby roadways, and from pollutants such as pesticides which can be sprayed into caves or carried in through plant root systems.

### **Invasion and Visitation of Cave Habitat**

Urbanization around the caves of San Antonio and Austin has introduced species which are highly adaptive, and are either competitive with or predatory upon cave fauna. Good examples of such invertebrates include cockroaches, sowbugs and fire ants. Fire ant nests have been reported as deep as 15-20 m into some Texas caves. Some of the invaded areas contain or are likely to contain rare and endangered species. A potentially effective treatment for the fire ants, and which might not harm the cave species, is a product called LOGIC. LOGIC is a growth hormone which is consumed by the ants and renders them sterile. Its use in and around caves is currently under experimentation.

Another type of invasion by foreign species is human visitation. Deliberate destruction of bat populations has occurred in some cases, but most visits that are damaging to cave fauna have innocent intentions. Common impacts include disturbing nursing or hibernating bats, trampling of floors to reduce usable habitat for invertebrates and crushing those invertebrates sheltered under small rocks, leaving potentially harmful trash in caves (such as batteries), and leaving other trash which may not be poisonous but may upset the cave's ecologic balance. Examples of these various type of disturbances occur throughout Texas, but the way they are perceived and managed has depended on whether the spe-

cies were endangered or were bats.

### **Endangered Cave Species**

There are currently 5 species of Texas cave invertebrates which are federally listed as endangered. All of these are isolated to the small Jollyville Plateau near Austin. Stream dissection has separated the Jollyville from the parent Edwards Plateau. Genetic isolation of the cave species within the Jollyville has resulted in the speciation which sets them apart from the main Edwards cavernicole fauna. Similar dissection along other parts of the Balcones Escarpment has created many other locations where isolation and speciation of cave fauna may have occurred. These areas, however, lack sufficient study to list any such apparently isolated fauna as endangered.

Endangered designation requires not only a faunal uniqueness, but also entails a potential threat to the species' very limited population. The threat could be from either natural or human origins. The endangered designation is given by federal or state authority and it is those authorities who are responsible for species and habitat management. This management often works jointly with private landowners.

Once the endangered Texas cave invertebrates near Austin became listed and construction was imminent, they received a federally and privately funded study to determine the caves' hydrologic and biologic zones of influence. Much of the projected development near the caves was consequently occupied by these zones, and there has been no further construction on the properties since late 1988. Also as a result of these studies, the U.S. Fish and Wildlife Service required the

landowners to install gates on the caves known to house endangered species, and has recommended limiting development near caves which do not contain such fauna, but which may be important to the endangered caves' ecosystems.

The only other currently listed endangered cave species in Texas is the famous Texas Blind Salamander, Typhlomolge rathbuni, found in Ezell's Cave in San Marcos. Managed by the Texas Nature Conservancy, the cave is gated and its population is stable. Another salamander, Eurycea tridentifera, is more widely spread among several Texas caves and has only a state designation as threatened rather than endangered. As yet there have been no attempts to manage or protect this species, other than to provide it with threatened listing.

For the most part, the listing of a cave species as endangered has provided substantial means of protecting and studying certain caves and their ecosystems. While landowners have cooperated with the management recommendations, they have often done so only under federal pressure and otherwise "wouldn't give a damn about those damn cave bugs." Without this pressure it is doubtful any protection of the cave life would have occurred.

### **Bats**

While still subjects of misinformation and malfeasance, bats have gained a certain level of acceptance among the general public in Texas. Within 150 km of San Antonio three of the world's largest bat populations occur within caves. Although the rabies scare has given bats some bad press, a lot of good press

has been given to the bats' tremendous contribution to insect control. A major factor in Texas contributing to the protection of bats, and to the education of the public about them, has been the establishment of Bat Conservation International's headquarters in Austin. With some of BCI's most active membership consequently occurring in Texas, many bat studies are being done with bat cave owners learning how they benefit from their nocturnal tenants. As a result, protection of bat habitat has proved easier than that of invertebrates which have no direct or appreciable value to practical-minded cave owners.

### **Geography**

The location or geography of caves plays an important role in their use and management. The geographic zones and uses can be classified as: urban-avoidance and rural-exploitive.

Caves are recognized by urban planners, developers and engineers as being important groundwater resources. Yet they consider finding a cave on a piece of property they are developing as finding trouble. Special considerations must be taken for water pollution abatement plans. Extra research is needed. Overall costs increase. And what if endangered species or archaeological materials are found in the cave? The project could be postponed, severely altered or canceled.

With so many potential difficulties surrounding the urbanization of caves and sinkholes, many have been quietly filled and left unreported to avoid potential problems and excess costs. A few hours spent talking with construction crews will reveal the location of many such lost caves. Stricter regulations and caver communication of data to city and state



agencies has resulted in a slight decline in cave destruction. While some developers are reporting caves out of sincere concern, others do so for fear of getting caught violating state water commission regulations. Other incentives for compliance include conservation easements which can be used as tax breaks for landowners who protect their caves. In other cases, as in Austin, not building near a cave may gain a developer some compensation in the form of higher-density construction in less environmentally sensitive parts of their property.

The other geographic zone in cave management is the rural-exploitive. In these areas cave owners have generally been unaffected by the state regulations governing urban developments. Caves have instead been used or exploited for whatever resource they may provide. Groundwater has been the main cave resource exploited, but caves have also been used for commercial tours (discussed further below), mining bat guano, raising mushrooms, disposing of trash, hiding illegal aliens, hiding moonshine stills during prohibition, and mining archaeological artifacts and speleothems (which is illegal in Texas). Most rural caves, however, are simply ignored by their owners.

Rural cave management is at the discretion of the cave owner, and is little impacted by outside influences. Some caves are being managed by cavers who run mapping projects at the caves and screen visitors for the owners. This system has worked very well in Texas where landowners do not want to deal with a hoard of strangers wanting access to their land. These owners are often happy, however, to cooperate with one caver who will manage all matters concerning their caves.

### Special Use

Special use of caves refers to management situations which do not clearly fall into the above discussed categories. These include caves on public lands, commercial caves, and caves containing archaeological/paleontologic materials.

### Caves on Public Lands

Within the past few years the Texas Parks and Wildlife Department (TPWD) has been purchasing substantial tracts of land which contain some of the premier caves in the state. Some of these caves include the Devil's Sinkhole, Kickapoo Cave, Fawcett's Cave, and the Gorman area caves. Prior to these acquisitions TPWD owned few caves and, with the exception of commercial Longhorn Caverns, none were of any major significance. Since the acquisition of these caves, TPWD has actively pursued development of a best-use cave management strategy.

In 1986, a Memorandum of Understanding (MOU) was developed between TPWD and the Texas Speleological Association (TSA). The memorandum recognized "the participatory management contributions of the TSA on... cave resources" and encouraged the continued or increased participation of the TSA in the inventory, management and stewardship of these cave resources" (Walsh, 1986).

Because most of the TPWD lands containing caves had not yet been developed for public use, the MOU allowed cavers access to most of the caves under special use permits. Projects were set up, similar to those of the Cave Research Foundation within National

Park Service lands, for the exploration, survey and inventory of caves and related features. Although some cavers did not like the idea of working within the state bureaucracy, many saw it as an opportunity to visit caves they would not otherwise see and to have some impact on how those caves would be managed. Thus far many caves have been found and surveyed, and TPWD has been very pleased and impressed with TSA efforts and coordination.

In 1989 the Texas Cave Management Association (TCMA), along with the TSA, developed management and use plans for TPWD caves. TCMA and TSA is currently assessing all state caves for placement into management categories. These categories will be used by TPWD personnel as guides to permitting or restricting access to caves when the land is eventually opened to the public.

### **Commercial Caves**

Texas is proud to have 7 of the country's finest commercial caves within its borders. Management of these caves has, of course, been to maintain them as viable business ventures. Some of the caves have recently expanded or are considering expansion of their tours. Recreational caving is not allowed in most of these caves, although access is sometimes allowed for scientific research and cave rescue training sessions. A detailed discussion of the caves' management is beyond the scope of this paper, but their geographic range and geologic variations make them all very difficult so that each cave is a unique experience for the visitor.

### **Cave Archaeology and Paleontology**

Many caves in Texas contain significant archaeological and paleontologic remains. The Texas Antiquities Law provides some degree of protection to these caves, but their ultimate fate rests with their owners. Where significant materials are found, the profit motive spurs many cave owners to discreetly sell either the artifacts, or the "rights of excavation and sale" to someone else. In many rural areas such activities are difficult to monitor, and even more difficult to enforce applicable laws. As with the biologically important caves, some positive influences on owners are made by cavers but their problem remains: "so much karst, so little time."

### **Summary**

The wide expanse of Texas lends itself to an equally wide variety in geologic, climatic and cultural landscapes in which caves occur. Consequently the hydrology, biology, archaeology and paleontology of the state's caves is also incredibly diverse. This paper has touched upon only a few of the many aspects of this diversity, the factors affecting management, and the varied means by which the caves are managed. No attempts have been made here to solve problems or provide new insights, but this paper does illustrate that generalizations can seldom be made in cave management, and that each cave requires its own individual assessment.

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## Texas Cave Management

by John M. Walsh  
P.O. Box 310732  
New Braunfels, Texas 78130

In the early 1980's the Austin-San Antonio area began growing rapidly with the destruction of many caves as a result. The Texas cavers saw the system where the rancher protected the natural resource failing in the urban areas. Over 50 caves were destroyed in Bexar County alone. It was time for a new Texas revolution. In 1985, several Texas cavers spoke with Russell Gurnee concerning the large scale destruction of Texas caves and the need to take action. Acting upon his advise, action was taken in 1986, when the Texas Cave Management Association was created. The TCMA is a non-profit Texas corporation dedicated to the long term protection of caves, cave life, and the aquifer as related to caves. For a group of cavers who had little use for "officials", this amounted to a Texas cave revolution!

The TCMA found that rather than talking to land developers about saving speleological resources, they could save caves by contacting the engineering company on the development. When both caves and money could be saved, they were ready to listen. The TCMA motto, "Solutions to Cave Related Problems", and their desire to work with those in charge of caves, began to make a difference. The TCMA found that among those who must deal with caves, information was eagerly received.

As more and more land management

groups find they must deal with cave resources, the desire for quality information grows. This often presents a problem since cavers are often a closed group. Many cavers consider themselves the cowboys of the 1980's. They are a close group and they are a group dedicated to the protection of caves and cave life. In the past, often they have been viewed by land managers as a nuisance. This has led to problems. Now that the laws, on some occasions, require the consideration of cave resources, the big question is "How to protect an unknown resource?" There are two ways to deal with this situation. The first is to hire cavers to collect the necessary information. Since this could cost thousands of dollars, it may not be an option. In order to map a fairly small cave, many man hours are required. multiply this cost by dozens or perhaps hundreds of caves and the problem becomes apparent.

The best solution to your information problem is to work with the cavers in a volunteer situation. You may discover that they have a great deal of information on the caves under your control. They may have been collecting cave information for the last 30-50 years. How do you make contact with this group of experts? Check first with your own field people. They may know some of the cavers and may even be working with them. Many of the cavers are members of local clubs

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known as "Grottos". The National Speleological Society, Cave Avenue, Huntsville, Alabama, 35810, will assist in contacting local cavers.

What is the best way to deal with cavers? First, realize that they are extremely dedicated to the protection of caves. In order to protect the caves, they are reluctant to discuss caves or their location. Since there has been little or no protection for this valuable natural resource, in one part of the country the cavers are quoted, "Arizona has no caves to speak of". Respect their dedication when you work with them. Write or call and invite them to meet with you to discuss the protection of the caves. Take off your coat and tie and keep the meeting informal. Let them know you would like their assistance and present no pressure. Outline your needs and ask for their opinions. Be prepared to modify your requests as you gain information. Often their input on cave management will prove valuable. Give them time to discuss your requests and to present their views at a future meeting.

If it appears that both parties could work together, a Memorandum of Understanding often assists in the definition of the goals. This may help prevent problems and mis-understanding. You will be most successful if you provide leadership. Appoint one person, who is easily reached, to be their contact. Do what you can to assist them. If possible, provide rest rooms, showers, and camping away from the general public. After a 14 hour cave survey trip, they like to get away from it all and unwind around a campfire. Cavers are usually easy to deal with but nothing will lose their support like broken promises. Recreational cave access is one of their main goals. If this can be worked out, it will make it easier to

reach the understood goals.

To quote Russell and Jeanne Gurnee, "The interior of a cave is perhaps one of nature's most fragile environments. The intrusion of man can tip the balance, causing massive changes in the cave biota, in the growth of formations, and in the very nature of the cave architecture. The continued success and preservation of each cave will depend on the cooperation of the cave owner, as custodian of this fragile landscape..."

## **Texas Parks and Wildlife Cave Management Activities**

by **Mike Herring**  
**Texas Parks and Wildlife Department**  
**4200 Smith School Road**  
**Austin, Texas 78744**

### **ABSTRACT**

The Texas State Park System is comprised of 129 units totaling 434,000 acres. Prior to 1985, the Parks and Wildlife Department's cave management involvement had been limited to the operation of one commercial tour cave. Since 1985, several cave-related park resources have been added to the system and a cooperative agreement has been developed with the Texas Speleological Association to assist with cave inventory and management. Currently under study is a cave classification system and user access procedures.

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## **SYSTEMS FOR MANAGEMENT OF CIVIL LIABILITY FOR CAVE RELATED INJURY**

by Joel Stevenson

### **ABSTRACT**

Before any commitment is made for any specific development proposal, a comprehensive, written management plan for the cave should be devised and adopted. Caves, being unfamiliar and sometimes dark and foreboding, appear to have a high potential for liability, but this is a misconception. With the implementation of reasonable steps to prevent foreseeable injury, cave properties should have no greater liability potential than any other properly managed natural area.

Civil liability for personal injury and wrongful death is a complex subject. This paper attempts only a general discussion of the theory and the application of civil liability in contemporary American law. The discussion is necessarily both general and superficial. It is intended for an audience of non-lawyers spread across the fifty American States, each of which has its own distinct jurisprudence. The law in each of these fifty separate jurisdictions is subject to change, sometimes to drastic change, at each Session of the State Legislature and on each day that the Appellate Courts sit for the dispatch of their business. This paper can, in no way, serve as a substitute for a lawyer or legal advice. It can, only at best, help you recognize situations of potential liability and furnish you with the components of a system to help manage liability situations.

Several forms, including releases, that

can be reproduced and used in attempts to reduce and control potential liability are available. These forms are strongly worded and make their intent as clear as language will allow. They have been adapted from various forms that have been developed and used in various parts of the United States over the past ten years. Although these forms are designed to afford the maximum protection to the caver and to the landowner who seek to avoid liability, you must remember that no legal document is entirely and universally effective and the use of these forms does not guarantee the avoidance of all liability.

Contemporary America is a society that litigates. Our Courts, over the past thirty years, have expanded the scope of civil liability for personal injury and the awards of Juries have increased at least as sharply as has inflation. Although the scope and the cost of

liability has expanded, and despite the fact that there are differences, sometimes substantial differences among the fifty American jurisdictions, the basic principles upon which liability is imposed have remained the same for generations.

The branch of law that deals with claims for wrongful death or for injury to persons or property is called the Law of Tort. The concept of tort is so general that no inclusive definition has ever been successfully fashioned by any court, but, for the purposes of this discussion, a tort can be defined as: A civil wrong, arising from a breach of duty, for which the law will provide a remedy.

In the following pages, we will examine the basic rules of tort liability and will discuss how they can be used as guidelines for the reduction or elimination of civil liability in the context of cave exploration and cave ownership.

Liability in tort can be based either upon intentional acts or omissions or upon negligent acts or omissions. Intentional torts, such as assault or defamation, are outside the scope of this paper which is concerned only with the liability that can be incurred for negligent acts or omissions.

There is no rigid or specific definition of "negligence" in its legal sense. Legal negligence is simply the failure to use reasonable care to avoid causing injury to someone to whom a duty of reasonable care is owed. In any situation, if you can determine what constitutes reasonable care and if you can ascertain to whom a duty of reasonable care is owed, you will have analyzed that situation from a standpoint of potential tort liability and you will have identified those things which you need to do to control or eliminate the potential

for liability.

In order to be fair to all, the law must have consistency from one case to another. This requires a uniform standard which can be applied in any conceivable case and which will produce predictable and replicable results. There is an infinite possibility of different fact situations and a policy of pigeonhole categories and specific rules would be unworkable because of size and complexity.

The solution that has been developed by the Courts is a fictitious standard against which all conduct is measured. This fictitious standard is known as "the Reasonable Man of ordinary prudence". The Reasonable Man has been described as "a model of all proper qualities, with only these human shortcomings and weaknesses which the community will tolerate on occasion". The Reasonable Man is not infallible, but his only errors are those unavoidable by careful planning.

The standard to which each of us is held is simply to act as the Reasonable Man would act under the circumstances as they appear to him at the time. The standard has the flexibility to fit any case which might arise. The conduct of the Reasonable Man will vary with the circumstances with which he is confronted. If the Reasonable Man has superior knowledge or training, he will be required to utilize that superior knowledge or training in conforming his actions to the circumstances. Likewise, if the situation involves increased danger or risk of injury, the Reasonable Man will conform his conduct to that greater risk or danger. If the Reasonable Man is aware of an unguarded elevator shaft he will give warning. If he is involved in blasting operations he will remove people from the area, post lookouts and take other steps to prevent injury or damage. If the



Reasonable Man is aware that children are in an area he will increase his lookout, decrease the speed of his automobile or take other steps to compensate for children's known propensity to not take care of themselves.

If a danger is not reasonably foreseeable, the Reasonable Man is not required to foresee that act or guard against it. For example, the reasonable proprietor of a motel in which there have never been a criminal assault is not required to foresee that there might possibly be one. If, however, the motel had a history of multiple criminal assaults on guests, the Reasonable Man would take steps to increase security.

This does not mean that ignorance of danger is a universal defense. Intentionally remaining ignorant, as, for example, by failing to investigate land for hidden dangers (when there is a duty to warn) would be no defense in an action for failure to warn. In cases involving enhanced risk there is a duty to acquire the knowledge necessary to recognize the dangers involved. It has been held, for example, that the operator of a ferris wheel cannot successfully defend an action brought after the wheel collapsed by pleading that he had no knowledge of the phenomenon of metal fatigue.

It is the duty of the landowner or land manager to provide against dangers which can, in the exercise of reasonable care, be discovered.

The Courts and the commentators speak separately of "duty" and "foreseeability". These are merely components of the Reasonable Man standard, not separate or additional standards to which a manager is held.

Duty can arise in two ways. It may arise by operation of law, that is, through the enactment of statutes or by the decisions of

Courts. Duty can also arise when it is voluntarily assumed. The act of undertaking to fence the edge of a precipice, for example, is the assumption of the duty to provide a reasonably safe and secure fence.

If the duty is discharged with the perfection of the Reasonable Man (nothing else appearing) this will constitute an absolute defense to an action at law.

Foreseeability is sometimes spoken of as that element of tort law which keeps liability within acceptable bounds. In general, if a consequence is not reasonably foreseeable, it does not give rise to liability. In other words, if the Reasonable Man would not foresee injury, there is then no legal duty to provide against such injury. Conversely, if the Reasonable Man could foresee the injury, the fact that a conscientious and competent manager fails to foresee it offers no defense. The caveat here is that Courts, Judges and Juries have twenty-twenty hindsight.

The duty that will be owed will vary with the circumstances. The more important circumstances include the legal status of the person involved, whether or not children are involved, the nature of the danger to be guarded against and what is physically (and to a far lesser extent, economically) reasonable.

We are concerned with three situations, each of which has its own distinctive liability potential. We are concerned with the liability which can arise from cave ownership; that which can result from organized caving activities; and, with our own potential liability as cavers ourselves. The basic concepts discussed in this paper are equally applicable to each situation.

Traditionally, the ownership, use or management of land gives rise to certain

duties that are owed to those who come onto the land. The legal status of the person coming onto the land will define the minimum duty owed by the landowner to that person.

The first classification is that of the trespasser. The duty owed to a trespasser is simply the duty not to willfully injure him. This duty not to willfully injure includes a duty not to set traps which would cause injury to the trespasser. There is no duty to warn the trespasser of dangerous conditions existing on the land and there is no duty to modify the land in order to make it safe for trespassers. There are, of course, exceptions to these broad rules. Frequent known and tolerated trespassers may be owed the same duty as licensees. For example, where trespassers wear a trail across a portion of land and no steps are taken to prevent continued use of the trail by trespassers, some additional duties may become due to them and it would probably be prudent, for planning purposes, to look upon them as licensees. In the states which still recognize the doctrine of attractive nuisance, children attracted onto the land are not, strictly speaking, treated as trespassers.

The second classification of persons entering onto land is that of the licensee. A licensee is one who enters land with permission of the owner but not for benefit of the owner. There is a duty to warn licensees of known dangers on the land. There is no duty on the part of the landowner to inspect the land and discover unknown dangers in order to warn them. There is no duty on the part of the landowner to modify the land and put it in safe condition for the benefit of the visiting licensee. Permission to enter the land can either be direct or by implication.

The third class of persons who enter

onto the land of another are invitees. Invitees are those who enter with the permission of the owner for purposes beneficial to the owner. A paying tourist in a campground would be an invitee as would a customer in the business of a park concessionaire. It is possible that one who enters a cave on park land for the purpose of mapping the cave would be an invitee, if the park authority receives the benefit of the resulting map.

The duties which the landowner owes an invitee include the duty to warn of unsafe conditions, the duty to use reasonable care to inspect and discover dangerous conditions, and the duty to take reasonable steps to put the land in safe condition.

Children, whatever their legal classification while on the land, are owed a higher duty than that which is owed to adults. The reasons for this are twofold and obvious. Children cannot be expected to appreciate danger with the same discernment as adults and children are neither physically nor mentally as able to take care of themselves as are adults.

Because of the special and peculiar circumstances which children present, the Courts developed the doctrine of attractive nuisance. The doctrine was developed to allow recovery by children who were injured while trespassing on the land of another. The theory conclusively presumes that the child is attracted by something on the land. Originally, this had to be something created by the landowner, the classic examples being quarries, railroad turntables and artificial farm ponds.

Most American jurisdictions have abandoned the doctrine of attractive nuisance in favor of an even broader new rule which is based upon foreseeable consequences. Basically, this rule posits that children can be

expected to meddle, to use poor judgment and to explore. The fact that a child is involved in the particular circumstance makes special dangers foreseeable. The standard of the Reasonable Man is then applied and acceptable conduct in which the Reasonable Man would have engaged in similar circumstances involving like children.

The traditional distinctions of trespasser, licensee and invitee are, to some extent, being blurred by the Courts. More and more often, especially in cases where strict application of the traditional approach would lead to a harsh result, Courts are applying the Reasonable Man standard to the acts and omissions of landowners.

As this trend continues, the distinctions of trespasser, licensee and invitee will tend to become more an element of foreseeability rather than the controlling element of the case. The prudent owner or manager can no longer rely solely on the traditional distinctions.

The duties and the potential liability of the owner of an unimproved wild cave for which admission is not charged is sharply different than the liability of a commercial cave operator. The potential liability of show cave operations is beyond the scope of this paper. Duties and liabilities arising from the exploration of the "wild" portions of commercial caves are substantially the same as for unimproved caves.

There is no way that a landowner can totally avoid all possible liability. Even if he simply forbids entry into a cave, a trespasser could enter, receive injury and demand compensation. Blasting the entrance shut, or putting a gate on it does not guarantee that entry will not, nevertheless, be made. It is not

far fetched to imagine a scenario where rescue efforts could be hampered or injury exacerbated by such modifications. Probably the best solution to the liability enigma from the landowners' point of view is a simple management plan which would include some policy for limiting use of the cave, a means of informing cave users of known dangers, and the requirement of the reading and signing of a strongly worded liability release by all visitors.

A release, sometimes called a waiver, is basically a contract where the caver, in exchange for the right to enter the cave, sells to the landowner the caver's right to sue for injury received in the cave. The most important thing to remember about a release is that it is not always effective. As indicated, it is a contract and it must, therefore, have consideration. The consideration should not be money because in most jurisdictions that will constitute the caver an invitee and will place the landowner under a higher duty to him. The consideration, the exchange for which the permission is given, should be the release of the right to sue and nothing more. In some jurisdictions, it may still be necessary to recite a nominal consideration, usually one dollar.

A blanket discharge for any and all negligently inflicted injury would probably not be effective if it was the subject of a Court challenge. It is imperative that the release contain language indicating that the landowner has advised the caver of specific known dangers, that the caver is aware of these dangers and of the general dangers involved in caving, and that he is knowingly exchanging his right to sue for injury for the right to legally enter the cave.

If a release has any significant chance of being enforced by the Courts, it must be

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clearly written and it must appear, from the document itself, that the parties agreed and understood their transaction at the time it was made. The document will be construed against the party drafting it, usually the landowner, and it is to that party's benefit to avoid any ambiguity in the language of the release. At all costs "legalese" should be avoided insofar as possible.

A release is a contract and it can only be effective if it is entered into by a person who is capable of contracting. A release signed by a minor (in most jurisdictions, anyone under 18 years of age), or by one who is mentally incompetent, will have no legal effect. Any time it is necessary to obtain a release from a minor the release should be signed by both parents of the minor or, in appropriate cases, by the guardian of the minor. The signature of one parent may or may not be sufficient to effect a release of possible claims. This will vary from jurisdiction to jurisdiction and will also vary with the facts of the individual case. The better practice therefore, is to require the signatures of both parents when attempting to release the rights of a minor.

In situations involving a minor, the Courts, if they are called upon to construe a release, will view the language of the release very narrowly and will, wherever possible, usually interpret the document to allow recovery by the minor. For this reason, careful draftsmanship, which is always important, is absolutely imperative for documents which may be executed on behalf of a minor.

The signature of the minor should also be required on the release. Although the signature is of no contractual effect, it can be used to show that the minor was actually aware of the risks and dangers involved in cave

exploration and this can, in many cases, furnish a defense - contributory negligence or assumption of the risk - in the event that a claim is made.

It bears repeating that as in the case of any other release, the parents or guardian of a minor and the minor who signs the document, must all be required to read the document they are signing and it is absolutely imperative that the document be drafted so as to be understandable. No release will be legally effective if it is not understood by the parties entering into it.

The effectiveness of any release can be greatly improved by adding additional legal theories. The theory of joint venture has been utilized in the context of caving related releases for a number of years. Members of a joint venture enjoy a degree of immunity from liability to one another. The legal theory is that each member of the joint venture is the agent of the other and that the negligence of each is imputed to each. Four elements are necessary to constitute a joint venture. First, it must arise from a contract. A release, properly worded, would be a sufficient contract. Second, all of the members of the joint venture must have a common purpose. The purpose of exploring a given cave, or engaging in a given caving trip or cave project, would be a sufficient common purpose. Third, there must be what the Courts call a "community of interest". This means that each of the members of the joint venture must have some real stake or interest in the outcome of the joint venture. Fourth, there must be an equal right of control, that is, each member of the joint venture must be given the right, whether it is exercised or not, to have a voice in all decisions.

Clearly, members of a cave trip or of a

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survey project can meet the four requirements of a joint venture. Whether or not a landowner can, unless he becomes a caver, enjoy this additional protection is not as obvious. The requirement of a "community of interest" is where this problem would usually arise. In most instances, the landowner will not engage in the cave exploration and will not have any great interest in the exploration of his cave. If it can be shown that there is a legitimate interest on the part of the landowner, such as an interest in learning about possible water resources, then the "community of interest" requirement could probably be satisfied. It would seem that the requirement of an equal right of control would be met in the average situation where the landowner always has the right to forbid further entry into the cave and where the cavers are not subject to being dispatched into the cave against their will by the landowner.

If it is attempted to include a landowner in the joint venture, it will then be imperative that a clause be drafted into the written document making it clear that the landowner is not to incur liability of any sort for any of the acts of the other members of the joint venture. The drafting of an agreement by which a non-caving landowner would become a member of a joint venture should only be attempted by a qualified attorney.

Another legal doctrine that will afford additional protection against potential liability is a doctrine known as assumption of the risk. The basis of this doctrine is that when someone assumes for himself a specific risk he thereby relieves others of the duty to protect him from that risk and they thereafter will owe him no duty as to the risk that is assumed. In any situation where no duty is owed, there is

no liability consequence because the element of duty is essential to a finding of liability.

The parties must recognize an identifiable risk which is being assumed and the risk must specifically be assumed by the party who undertakes it. The assumption of the risk should be tied to the consideration for the release.

Other principles, which are of lesser value, but which may nevertheless afford some additional protection, include a covenant not to sue and an agreement for indemnification. The covenant not to sue is not a release. It is a contract not to bring an action in the event of injury. It discouraged litigation because the Plaintiff may be liable for the costs of the defense of the liability lawsuit in a separate action for breach of contract. Because the covenant not to sue is a contract, it must have a specific reference to consideration.

The concept of indemnification is also borrowed from the law of contracts. It is a contract to pay damages recovered by a third party. If "A" contracts with "B" to repay "B" whatever amount of damages "C" might recover in a lawsuit, "A" has entered into a contract of indemnification with "B". Like any other contract, a contract of indemnification would require specific consideration. Obviously, a contract of indemnification is of no value if the agreeing party is not solvent.

The documents discussed here can be of great value in managing the risk of liability, but the primary tool of the land owner, manager or caver who wishes to limit liability exposure to acceptable levels must be the implementation of the Reasonable Man standard into the cave management plan. Some specific suggestions follow, but no listing can be complete. In the final analysis the manager and the caver

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must develop the attitude and the outlook of the Reasonable Man in a similar situation.

The landowner should never require the caver to demonstrate his ability, as in requiring him to demonstrate his ability to rappel, or place artificial aid. If the manager engages in judging such demonstrations, he is, in effect, judging the competence of the caver to perform the demonstrated activity and is passing judgement upon whether the demonstrated level of skill is sufficient for safe traverse of the cave. The liability potential of this should be obvious. The prudent manager will require the caver to demonstrate experience and will probably want to take a written history from the caver in order to avoid, as much as possible, passing judgement on skill levels. The manager should adopt written criteria for cavers wishing to enter the cave. These should be simple, non-judgmental and realistic. A manager with responsibility for a vertical cave might develop criteria that would include three years of vertical caving experience and the successful completion of ten vertical caving trips involving pitches of seventy feet or more. If the manager goes beyond a general screening criteria such as this, he runs the risk of beginning to certify the caver.

Likewise, the manager should not give an opinion regarding specific caving gear. A specific brand or generic type of gear should not be recommended or required. At the other extreme, the manager cannot allow a caver to enter the cave with obviously inadequate gear, or with gear that is clearly worn to the point of unreliability. This is an area of fine distinctions and the manager must develop not only a real understanding of the Reasonable Man concept, but also a genuine expertise about technical caving and climbing gear.

The successful manager will know what types of gear are generally accepted in the caving community and what types of equipment are generally considered to be unsafe or inadequate. He will then require those whom he allows to enter the cave to use gear which generally falls within the class of gear that is accepted in the caving community. As in the case of caving skills, the manager should never allow himself to certify the adequacy of cave equipment.

As a general rule, artificial climbing aids should never be provided by the manager or owner. If an artificial anchor or similar aid is provided and if it fails, causing injury, a lawsuit is almost inevitable. For this reason, artificial climbing aids or rigging anchors should only be provided when the risk of injury from not providing them is high. An example of this would be a situation involving a deep pit where there are no good natural anchors and there are numerous unsafe natural anchors. In that situation, the best risk management decision might well be to provide the best possible artificial anchor system, design sufficient redundancy into the system and to inspect it carefully and regularly. Except for such extreme situations, artificial climbing and rope-rigging aids should not be provided. In this respect, when artificial anchors are provided by cavers who are not associated with the cave owner or manager, there is very little risk to the owner until the aid has been in the cave long enough to have become generally accepted by visiting cavers. At that point, the manager may have unwittingly adopted the artificial aid and may be responsible for its maintenance. For this reason, a strict prohibition against the placing of permanent anchors is probably a wise rule.

A landowner, in determining who will be

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allowed to enter his wild cave, should never pass judgment on the question of whether or not the caver is competent. The landowner should not, in any way, indicate that the caver has the ability to attempt the exploration of the cave. Rather, he should require that the caver demonstrate that he has the requisite skill or experience to enter the cave. The landowner should never certify the caver, but should make the caver certify himself to the landowner.

In general, any modification to the entrance or to the passageways of a so-called "wild" or unimproved cave should be avoided. Anytime a modification is undertaken, a duty arises to see that the modification is done with all reasonable care. If a modified entrance collapses causing injury, the liability situation is probably much worse than if an unmodified entrance had collapsed. Any modifications that are done should not be done haphazardly, but with due consideration for the engineering principles that are involved. If the owner or cave manager does not have access to the expertise needed to make modifications in a sound manner, then the modifications should not be attempted.

There are two primary exceptions to the prohibition against modifying the cave. One is for situations where there is obvious danger from the natural situation. If, for example, there is a large unstable boulder over the entrance, prudent management policy would require removal of the boulder. The cautions given in the preceding paragraph to consider the engineering principles involved would, of course, still apply.

The second situation would be modification of the cave entrance, or of a specific passage, by the erection of a gate. A gate,

properly designed, can be an effective tool in limiting liability. Gates present many potential liability problems and no gate should be erected without giving consideration to all of the potential liability problems that can flow from such a modification. The gate must be securely anchored to the cave walls so that it cannot be pulled loose to fall on a trespasser who is trying to breach the gate. The bar spacing must be proper so that the risk of a child becoming stuck in the bars is avoided. The door to the cave gate must be of sufficient dimension to allow passage of a litter in the event of an injury requiring evacuation.

Impediments meant to retard entry must be carefully considered and usually should be avoided altogether. If they are going to be effective, they will probably fall into the category of traps, the liability consequences of which are obvious. For this reason, industrial fences, or fences of any type, should be considered only as a last resort as a means of controlling access to caves. The standard industrial fence has barbed wire at the top to impede entry. The barbed wire can be considered a trap or an instrument intended to injure and can have serious liability consequences. If no barbed wire or other impediment is at the top of the fence, then the fence is so easily breached that its value is questionable. Generally, when access should be restricted, it should be restricted by a full orifice gate. At the present time, state of the art information regarding cave gating practices can be obtained from the American Cave Conservation Association, Post Office Box 409, Horse Cave, Kentucky 42749.

The responsibility borne by cave owners and cave managers in regard to potential liability cannot be delegated or transferred by

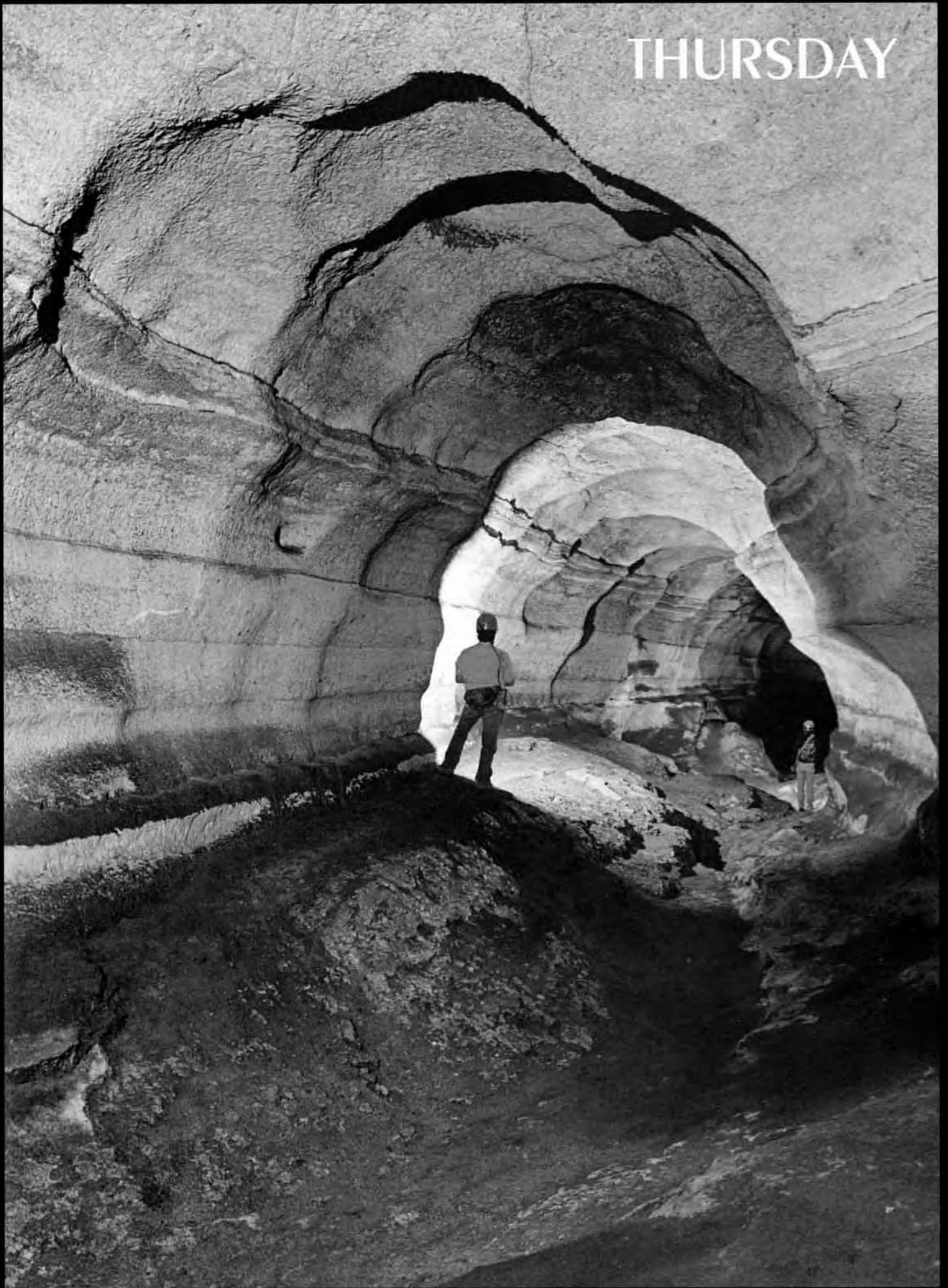
them. If, for example, a cave owner turns over the management of a cave to a group of cavers, he does not thereby escape liability. From a management point of view, there are numerous advantages to including the caving community in the management of wild caves, but from a liability standpoint, the owner or the manager must retain the ultimate direction of the outside group in order to retain control of the risk management duties discussed in this paper.

These concepts of risk management have been employed in industry for decades. Potential liability is an aspect of land ownership that is not unique to cavernous lands. All lands carry the potential for liability, and all lands, including cave and karst lands, can be safely and productively used with a minimum of risk if a comprehensive management plan is used to assess and address situations of potential liability.

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THURSDAY



## **Texas Caver-Cave Owner Cave Management Relations**

By Kurt Menking  
Texas Speleological Association  
San Antonio, Texas

Texas land owners are often extremely protective of their land and, as a result, there are few caves in Texas open to the public. For years, cavers have worked to develop relationships which allow for access to these private caves. As a landowner gets to know one group or individual, it is often easier to have all access go through the cavers. In some cases, the landowner has turned over complete control to the group. Honey Creek Cave is an ongoing work project and all access is arranged through the San Antonio cavers. This system works fairly well as long as most cavers feel they have access through the arrangement. The history of the Honey Creek Cave work will be discussed. The "caver-manager system" will be examined in more detail.

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## Panel Discussion: Government and Private Land Owner Cave Relations

edited by

Jay Jorden

**Editor's Note:** What follows is a transcript of a meeting during the 1989 National Cave Management Symposium at New Braunfels, Texas. On Thursday, Oct. 5, 1989, Ron Kerbo of the National Park Service led the "Panel Discussion: Government and Private Land Owner Cave Relations" following a luncheon at Guadalupe State Park near Boerne.

**Ron C. Kerbo:** Carlsbad Caverns National Park: If you look in your little guidebook here, you'll see that what we're going to discuss is something that's very near and dear to my heart, especially during the last six months. And it is very mildly stated here by saying that from the early problems in the Mammoth Cave, Ky., area up to today, there have historically been problems between federal land management agencies and the private sector, and that sometimes those relationships have been strained. So there are representatives here from three government land use agencies: the Texas Parks and Wildlife Department (TPWD), the American Cave Conservation Association (ACCA), and then there's George Veni. ... So he and Russ and Jeanne Gurnee and Jim Goodbar will participate. And we will try to address some of our concerns and tell you of our experiences. I think the way to start this is by way of introduc-

tion, and then I'll let each of the rest of these people introduce themselves and make a statement. And then we would like to just open it up for general discussion.

Many of you know that at Carlsbad (Caverns National Park) for the past two years, since 1986, there was a cave discovery that has turned out to be a relatively major cave. It is now longer and deeper than Carlsbad Caverns. It is in a corner of the park that contains surface-designated wilderness. The cave comes within 1,200 feet of a common boundary with the Bureau of Land Management. It has also extruded out into a non-wilderness road corridor between two segments of designated wilderness. There is also a little north of the cave and a little west, private land around. We thought — the park service thought — that having that cave designated as wilderness. But as with a lot of good ideas, perhaps we should have thought about it a little more. But in a proposal, we suggested — not an official proposal, just some material that went to our legislative people and to our regional office — that this wilderness would have the opportunity to expand. It would get bigger as the cave was explored. Where else besides underground is it possible for wilderness to get bigger? On the surface, everything seems to be shrinking, getting smaller and impacting the natural en-

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vironment. But in a cave, at least physically, the wilderness had the opportunity to expand. Now, if the surface is designated wilderness, why bother to have the cave designated as wilderness, below the surface wilderness? Well, what if it left the protection of the surface wilderness; would it continue to be wilderness even if it left the protection of the surface wilderness parkland? Those were some of our concerns, but then the local community and business leaders thought that if the cave extruded under their land, would that mean that the surface of their land would be designated as wilderness automatically as this cave came under it? So there arose, as they say, a hue and cry that the park service just wanted to take the land adjacent to it — the BLM land, forest service and us, and private land — by surveying the cave beneath these various lands. Relationships became ... well, it started out with just a few letters in the local paper about those “land grabbing, idiot park service people out there.” And that expanded to some people going through our files, finding what they thought was very incriminating evidence that an NPS official was allegedly a lobbyist, that he had allegedly lied to Congress and was a propogandist ... . So as we try to explain this underground wilderness concept, we just got ourselves into deeper and deeper trouble and it resulted in the formulation of a task force in the local community, appointed by the mayor to examine all the evidence ... and then they would move on from there to grander things, like developing the cave (commercially). So to say that the relationship between the local community and the park was strained was to put it mildly. What we thought that we should have done, and in fact had done, was to go to the local community and its civic clubs and give

talks about the concept of underground wilderness. But what we didn't know, what I didn't know, was the intense reaction to that word, “wilderness.” I had no idea how people would react; had we called it an “area of critical environmental concern,” or had we called it a “primitive area,” or had we called it anything, but when we called it wilderness and when we said it would get bigger — wow! I think that those people must not be from this planet because they so abhor it in a natural state. I think they must come from a place called “Plastic Land.” But I'm digressing from this relationship. Anyway, it has gotten worse and worse and worse. And I will come back a little later and answer any questions about it. But suffice it to say that this task force's findings — and I was a member of the task force, asked to participate in it by the mayor. And I was the only ... no, there were two out of the 10 of us on the task force who said the cave ought to be left alone. And the others reported they thought that we ought to seek appropriate uses for the cave, even if that meant developing it and delegislating the surface as wilderness. So we really opened up a box there, and we opened it up by, I believe, being ignorant of the reaction it would have and not knowing the local community. Ignorance is okay because it can be reviewed by education, but that's one of the biggest problems I see between caves and the private sector understanding them, is that there is no constituency for caves, other than the cavers, most of whom want to keep them a secret and not tell anyone about them. So when you approach someone with a concern about a cave, they don't even know what they are: they think they are nasty, eerie, dirty places under the ground where you ought not to go, or that they

should have trails and lights put in them, and that there's no medium ground for considering the management of that cave.

**Larry Sansom:** U.S. Forest Service: I think Ron put it in very good perspective, that the controversy in Carlsbad really stemmed from the word "wilderness." We have ours, and have had some controversy, before Lechuguilla was discovered, and that was with our wilderness study area. There's a good number of caves in that wilderness study area; offhand, I don't know how many there are that are there. The caves were not a part of the controversy then, not up front at least. The controversy was that the local folks felt that wilderness was a bad word — there'd been enough of it designated throughout the west — so the Forest Service changed its recommendations on wilderness because of the public outcry. We found that wilderness had a bad connotation there. So my recommendation is, that as a result of our experience, as much as I know about Lechuguilla, that you should take wilderness out of consideration up front, and decide if you are talking about a cave or on the surface. You could take that out of consideration up front, and talk about what that resource exactly needs. And then, when you go through all the considerations, wilderness could be the best way to handle it, and that could be the result at the end. And hopefully, that would take out some of the hard feelings that have been in the wilderness battle these days. I think the lines have been drawn so clearly ...

**Mike Herring:** Texas Parks and Wildlife Department: The issue goes beyond caves, really. The issue revolves around two areas. As

a land acquisition person, I've dealt with land acquisition for 15 years. I've dealt with a lot of landowners and sensitive situations. And I've seen a lot of these situations come and go. We can talk about wilderness, but it's not the same in Texas as it is in the west. Take a wild and scenic river; throw that out in Texas and you're dead. The problem is communication and education, and our own planning process. ... Ron, the park service should be learning from their past experiences. ... The department makes the same mistakes. This West Texas situation — there was a situation in West Texas where a bill was passed by a local congressman to do a study of the Davis Mountains area for preservation alternatives. It happened to coincide with the purchase of Big Bend State Natural Area, which was very well politically laid, which absolutely has to be done, especially when working with rural West Texas counties anywhere. You have to lay both the groundwork with your local people so that they understand what you are doing, but more importantly, you have to deal with the local politicians. You have to have the support of that local senator, that local congressman, because those are the people who make the difference.

We had that groundwork laid before we acquired the Big Bend Ranch. There were some deals cut, needless to say. In coming back, the Park Service talked to us. They knew from us the situation they were walking into in West Texas, but did not benefit from past experience and did not take the advice about what they were going into. Hence, that study — that study that was publicly funded — one public hearing, and in defense of the local landowners, those local landowners, regardless of where they are, have a say in what goes

on in their areas. Regardless of whether they represent five or one persons, whatever happens in their area has an impact on them: economically, socially, financially, heritage, tradition. West Texas people turned out in the town of Fort Davis, 500-plus strong. They could not fit into the church. They were standing outside, looking in the windows, and inside testifying. With one public hearing, the next day that appropriation for that Federal study was cancelled, and the Congress reneged, and the money was pulled back and that study was killed. That never entered into acquisition, but was mishandled. The key, in my estimation, is in communication. The state rivers protection bill was introduced this last session. The information, the rumors, the misinformation gets out to the people, to the public, to the potential beneficiaries of the proposal. They develop their own opinions, and their own network, which works much better than any official network. And once those incorrect opinions have been made, amongst the opponents, no matter what you try to do to combat that, they have been made. There's no way to correct that. So the best way to fight that is to get the correct information out. In the case of the wilderness designation, we could use some other word, some other designation and have thought that out so that our information was made before the public made its own opinions. To me, sharing the proper information in as public and as open a forum as possible is the key.

**David Foster:** American Cave Conservation Association: I have to agree with Mike on that. I am not totally well versed on the Lechuguilla situation. But we have problems between the Park Service and the public in the Mammoth

Cave area. In the American Cave Conservation Association, we are typically caught in the middle. We have a lot of friends on both sides and we have to figure out what the best thing to do is. They flirted with the underground wilderness concept out there a number of years ago, but it wouldn't fly because the people were convinced that it would hurt their business, their tourist business. The underground wilderness designation would protect areas of the park, but it wouldn't bring in tourists. Of course, we've got a number of other problems out there. We've got that sewer project, which is making an interesting topic. There's a situation where you've got a lot of sewage that's polluting a national park, and the controls for the project to prevent it are in the hands of local politicians, mostly, with the park service only having one representative, less than one-fourth representation on that. And it's really in the park service's best interest — it's not just the park service we're talking about but a number of agencies — to get out and educate those people and to build bridges — bridges of communication — with these people so that they understand that this is not just somebody who came in from the outside that is giving them a hard time. They have a job to do but they are also interested in the community. So many of these people have an attitude with the parks that they are not really interested in being a part of the community. And there's very much that attitude in the Mammoth Cave Community, and these people can really help you out if you have a problem, if you can build those bridges and get behind that. We recently have had a landfill issue in our county, which threatens Mammoth Cave National Park's water supply, or may threaten it — we don't know yet. Some 800 citizens

came out to protest that landfill. So they're not always going to be screaming about your environmental protection efforts. Sometimes they'll be on the same side of you and if you can use those same things — the groundwater arguments — you can build bridges, start making friends and start educating them about what this groundwater conservation is all about.

**Kerbo:** I think it is really important that everyone up here gets a chance to say something, and then give you the chance to ask questions. So we'll go over here to Jeanne (Gurnee) and then we'll go over to George.

**Jeanne Gurnee:** Cave Management Associates Inc.: It's unfortunate that I don't represent any one group, although I do in the sense that I have been for many years a member of the National Speleological Society in a landowner situation and all these things are well known among us. I have been an environmental commissioner and worked with historians and other figures in government, so that I've gone through those kinds of hearings and know how agonizing they can be. And I've also worked with National Caves Association. Harry and Clara Heideman were some of the founding members of this group that's trying very hard to represent show caves in the best way that they can for business interests. So I feel that I have a perspective and can approach it from the standpoint of some of the things we have been involved in without partisanship or bias. And I think it's very, very hard for anyone in an agency situation to not have bias. I don't mean bias in an unpleasant way, but you know how you feel about it already. But the big challenge is to show that there are a number of ways to go, and that's why I am very much

in favor of what Mike said, that it's a diplomatic job, it's a listening job, and it's an informing job. I see that so many of you have gone through this, that I shouldn't be doing the talking. You should. These are the things that are going to keep a project moving along. It won't happen as fast as we want it to. Cavers particularly can be impatient at times. But from what I've seen, it's a case of moving on, being persistent, with as much background and information as you can bring to it, so I very much support what Mike is saying in tackling these problems.

**Russell Gurnee:** National Speleological Foundation: Ownership is a basis for a lot of the things we've talked about. A number of years ago, I chaired a panel on cave gating, so we had a whole number of people — cavers — talking about gates. And so I said, 'How do you feel about public lands and cave gates? How many feel we ought to have gates on public land caves?' A few hands went up around the room. And so then, I said, 'Okay, now we're going to visualize that everyone in this room has a favorite cave. Okay, now you've won the lottery, and you own it. But you can only go there once a month because it's out of state. Now, how many want to put a gate on that cave?' And everyone's hand went up. So we're talking about whether you own it or someone else owns it. And here, we are talking about ownership that's difficult to comprehend. The government owns it so it's my cave. And that's difficult comprehension. But when you own the cave and you're going to put a gate on it, the difference whether it's on public land or you own it is really the basis of what we're talking about today on public and private lands.

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**Jim Goodbar:** Bureau of Land Management: Well, I think that from the bureau's standpoint, we are a multiple-use agency and there are a lot of competing uses out there. I think, re-emphasizing what Russ has just said and what Mike was saying earlier this morning, we are a family in the United States, and whether you live on the east coast or on the west coast, or right in Carlsbad, New Mexico, that to develop a relationship with the Park Service, the BLM or the National Speleological Society, that the memoranda of understanding are a very good way to do this. It sets out very clearly who is to participate in that memorandum of understanding and, in turn, what each of the participants will provide for that end result. That's where you get down to the specifics of what are we after, who's going to be involved, and then the public participation of how are we going to get together to work on and polish this memorandum of understanding where it's acceptable to everyone?

**Jerry Trout:** U.S. Forest Service: I'm going to admit who I am. I notice these other people haven't introduced themselves. So you'll know who to blame if I say something wrong. I'm Jerry Trout, with the U.S. Forest Service. Someone else had mentioned about experts in the beginning. My title is not expert, it's cave resource technician. I've been to a lot of these meetings where it's one-upmanship and the first questions cavers ask is, 'What caves have you been in?' I'm not here to impress you, but hopefully can share what my experience has been. I have been caving for about 35 years. I was lucky enough and blessed enough to have been caving in the Guadalupe Mountains for about 10 years, before anyone else

discovered it, so I was pretty much on the ground floor there. With the Forest Service, it is more or less mandated by NEPA, National Environmental Protection Act, that we go through a process of involving the public before any decision is made. As I understand it, that has not been the outgrowth of the Forest Service or anyone else making the wrong decisions but making the decisions without looking at other options and without asking the public of the surrounding area about it. So we are mandated at this point to do that with every project we are involved in, whether we are trying to do graffiti removal, or restoration, or whatever. One of the big problems you have here, if you get a big rain and a lot of mud and it's just like a big commode, it washes it out. That's not our situation. People go into our caves and get dusty and dirty and then they go elsewhere and clean themselves off. We have one situation in one cave, near the entrance, where the floor has risen five feet in the last 20 years. They get dirty, they come out and go like this ... and that has created five feet of extra fill. So that's one of our problems. And we would like to have your water.

So what we do — I even brought one of these — we have a calendar like this. We've reached a point where this summer, we had an average of five groups of cavers a day we deal with. Each one of those groups is an average size of about six, so we're dealing with about 30 cavers a day who use our caves. So that's going to be one of our major problems, is spreading that traffic out and being sure that when people do go caving that they have a quality and a safe experience while they are there.

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**George Veni:** San Antonio: I was asked to try to represent the interests of the private landowner. I have worked as a geologist consulting with both private landowners with caves and with the public cave owners as well. And one of the things I see that's a long-term problem that's never been fully resolved, and impacts Lechuguilla going under from one property to another, that impacts the Honey Creek (Water Cave) situation going from private land onto public land, and that's tying together in a legal fashion the relationship between what's going on underground and what's going on above the ground. Who owns the cave? Johnny Goss owns the entrance to Honey Creek Cave. Does that give the (Texas) Parks and Wildlife Department the right to the portion of the cave that goes underneath its property, even though there's no entrance there? Legally, that hasn't been resolved yet. It's an old problem that's been argued out and screamed about, and shotgun battles have been going on for years, but that's not fully resolved. Water rights issues are a very similar thing. And using Honey Creek as an example because it's a very local cave — I don't want to harp on it — but the parks department can be concerned, that if Johnny's pumping water out of the cave, that water's going downstream and so it's affecting us. In Texas, it says that if you're using groundwater, you have the right to pump as much as you please. So that means that at the part of the cave that goes off Johnny's land, they have the right to pump as much as they want, regardless of what happens downstream. And that's the way Texas law is set up. So what happens in New Mexico? Lechuguilla Cave might go under the BLM property, but it doesn't have an entrance there. Of course, in this situation, it might

have another entrance. I understand they're digging in another cave and might, ah, connect into the cave from another entrance. But if they don't have an entrance, does that give them the right to claim this as their cave? How do mineral rights apply to caves? How do water rights apply to caves? These are questions that need to be dealt with in this legal sense. A gentleman here was talking about that small minority that gets very upset when the park service or government wants to do their thing, but oftentimes it's that small minority that's going to be directly or indirectly impacted. We all think it's a good idea when we're stuck in traffic to say, 'Hey, let's put a new highway in here.' But you're mad as hell when they tell you, 'We're going to put this through your living room, so you need to move.' You say, 'Well, this house has been in my family for 150 years.' So when it comes down to a personal level, you tend to get hot about it. And what rights does the state, or government, have in terms of eminent domain, when claiming the property for the public good. So these are a lot of problematic questions that go beyond any individual cave or site, and would have to be worked out by a state-by-state basin on mineral and water rights. When I was working on my bachelor's degree in geology, someone suggested that what would be an excellent field to go into is to go ahead and get your Ph.D. in geology and then become a lawyer. Because groundwater law is this bag of worms that no one has messed with. No one has a good handle on it. We have a lot of lawyers out there trying to work without a good feel for geology. We have a lot of geologists trying to make some kind of legal statements without an understanding of the law. And that's something that's going to take

a lot of work and a lot of time. It's not just a groundwater problem, but our overall problem, whether it's wilderness or not. Once you have an underground wilderness or a stream underground, what effect does that have on the political boundary above it?

**Kerbo:** Let me just say a few things to try to wrap this up so we can get out of here, although I understand we've been given until 2 o'clock. There aren't any good guys or bad guys in all of this, I think. It's more a matter of perception on what you're trying to do. For instance, I wouldn't want it construed that I would apologize for advocating wilderness, because I'm a Federal employee. I didn't see that my status as a Federal employee had anything to do with my freedoms as an American. So, I don't believe we made a mistake in our planning for the cave. We certainly made a mistake in our approach to it, and informing the public about it. But they have economic interests, they have personal interests and biases, and so will people who work for Federal agencies. Whether state agencies or conservation groups, everyone has an idea of the proper way to do it and how to proceed with it. What I try to do, what we all try to do, is the best job that we can. But it seems to me that, upon listening here, that we're supposed to solve these problems. But I think the solution to some of these might be to get rid of the National Park Service and if you find a cave, keep it to yourself. (Laughter). No, that's not what we're going to do. Anyway, does anyone out there have any questions or comments?

(William Elliott of Austin mentions that Roy Davis, a commercial cave owner, advised the mayor's task force in Carlsbad not to commer-

cialize Lechuguilla.)

**Kerbo:** That's exactly right. And what has grown out of this, is that two bills have now been passed by the Senate, one of which is to establish a National Cave Research Institute in the Guadalupe Mountains, in Carlsbad Caverns National Park, and No. 2 is a bill to re-evaluate and to do a new general management plan for Carlsbad Caverns National Park, which it very badly needs. So all of that controversy has led to two very valuable, positive steps.

(An audience member made another comment about Davis saying that Lechuguilla wasn't worth a "plugged nickel" for development.)

**Kerbo:** That's true, but I might also say that that (decision not to proceed) was also the result of everything else that was happening. The task force totally impeached its own witness and went off in its own direction, saying 'fill the cave full of trails' and such. There was no reason to their logic.

(Two other audience members make comments, including details on the Lechuguilla debate and problems with San Antonio urban development in karst regions and pollution at Horse Cave, Ky., with developers having ignored potential problems which later came home to roost.)

**David Foster:** I'm not quite as prepared to go as far as Ron is and abolish the National Parks. I think we need our national parks but we need to quit thinking about our national parks as islands that are separated from the

rest of the world. That's our problem in the Mammoth Cave area, that as far as research funding and everything else goes, that it's been very hard to get government help to do the kinds of things off the park that are necessary to protect the park. If you don't have that kind of thing when you have a natural resource and virtually all of your recharge comes from off the national park, you really have no way of protecting that resource.

**Kerbo:** All right, ... by the way, it's only the battlefields and recreation areas that I don't give a guano about. (Laughter).

(An audience question refers to contingency planning by government agencies.)

**Kerbo:** Yes, each agency has processes — Steps 1, 2 and 3 — but that does not mean that you are not going to run into opposition along the way. But yes indeed, there are processes that they go through.

**Trout:** Just quickly, the NEPA process I mentioned a while ago, Step 1 is the project proposal. Step 2 is the reconnaissance. Go and look at it. Is what you are looking at what you intend to propose? It is possible? Is it reasonable? Take the public with you. What are the issues? What are the options? What are the concerns? What are the opportunities? And it is a ... 13-step process, with Step 13 monitoring what you did. And I think Step 12 is initiate the project. That was what I was addressing a while ago, that we are mandated at this point. (An audience member mentions the Federal Cave Resources Protection Act and land management agencies' role. Closing caves to protect them is not the answer, he said. The public

most often heard from in controversies is that section directly affected by a change. Elliott then mentions the accessibility to Lechuguilla, noting that mostly experienced cavers get access, and adding that allowing members of the general public inside at some point who could relate their experience to other non-cavers would be useful.)

**Kerbo:** And we've done that. Understand that we have 75 caves in the park. Two of them are open to anyone. One of them is even open to wheelchairs. Carlsbad Caverns and New Cave. Then we have 10 caves where you can get a permit and go caving. In fact, one of those you can even go caving with scouts in. Then we have Lechuguilla. There is a problem with doing what you said. But we wanted to do what you said. So we sent in a video team. And some of the finest cave photographers in the world have been in the cave. All you have to do to interact with this is to be able to rappel down the drops and have the stamina to stay in the cave. So what did the video concentrate on and what did the still photographers concentrate on? The Chandelier Ballroom. You don't even have to have seen it to imagine that that is some kind of a spectacular place. (Pictures were taken) where all the draperies were, where all the rimstone was, where all the hangy-downs and sticky-ups were. Nobody took pictures of the thousands of feet between there that didn't have anything. So that constituency, as we try to tell them by showing them the beauties, as a non-caver would think ... When people look at that shot of Honey Creek that George took, with all the glistening water and British techniques and bare (flash) bulbs, here's this magnificent passage. But you don't see the person's face. You

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don't see they're ready to fall on their face in the water if that idiot takes one more picture. So we create these beautiful pictures and then we show them to people, but we say you can't go unless you can get in there. So part of the problem with Lechuguilla was concentrating on the aesthetic values in that cave rather than its geologic, mineralogic importance to oil and gas exploration, and the fact that developing the cave would destroy the very things that we ... we have done this to ourselves, cavers, by concentrating on the beauty, by not wanting people to know what's in them, and then when they go to the show caves, and we show them these pretty things in the wild caves, then they think that you can necessarily build a trail into every one of them. And probably someone like Cousteau has done as much to open the eyes of the public to the plight of the seas as any living person. Is there anyone in the caving community who out of selfishness in wanting to keep caves to himself, would want to open them up to the public through a medium like Backpacker magazine? No, because opening them up is going to destroy the cave. So caves are a very unique part of the resource and in any park, state or national or wherever it is, that we have to draw back as a cultural resource, like a pot or an arrow point, or we're going to destroy the thing. So it's difficult to develop that constituency in the broad sense of the word because when you get down to specifics, half the cavers in the world are going to start calling you a heretic. And it's time to cut it off. These are emotionally charged issues and I'm glad we had the opportunity to talk about them today. And I wish we had more time. I'd be glad to talk with anyone further about these. And anyone else up here (panelists) will be glad to discuss this for the

rest of the week that we're going to be here. I wish we had more time, we could then talk more about these things. But we don't have any more time. Just 30 seconds.

**Foster:** Let me take 30 seconds to just mention one thing about that constituency thing. Carlsbad Caverns is unique in that. But a large percentage of the cave areas that we do have also have the opportunity to develop a constituency. That is their relationship with the groundwater. So that is a way that you can develop that public constituency, by convincing them that by protecting the caves, they protect their groundwater.

**Kerbo:** That's all. Thank you. (Applause.)

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## RESTORATION OF SHOW CAVES

by Russell Gurnee

### ABSTRACT

Technology is available to the engineer, designer, and contractor to provide safer and more satisfying conditions for the visitor, but any modifications in the cave must consider the impact on the environment. This requires knowledge outside of the traditional trade skills and engineering handbooks. The decision to modify a cave is sometimes made by managers and administrators without the advice and recommendations of experienced professionals. Careful review of the Design, Construction, and Display aspects of any changes should be made before any work is begun.

**Editor's Note:** Reggie Wuest of Natural Bridge Caverns and Jack Burch of Caverns of Sonora presented talks on commercialization, including trail development. Before a decision is made to convert a natural cave to a show cave, the owner should ask the following questions and be able to answer yes to all of them: Is the cave scenic, superior and safe? Is the location convenient to travelers? Is the site accessible and large enough to accommodate all visitors in comfort? Can I obtain professional advice in the design of trails and lighting in the cave? Am I prepared to provide continuous maintenance, security and control of access for the protection and preservation of the cave? Their oral presentations addressed the questions above as well as discussing the details of engineering, lighting and trail development. What follows is Mr. Gurnee's presentation.

There are hundreds of thousands of natural caves in the land areas of the world, but only about 700 of them have been modified to permit public exhibition as Show Caves. This modification, which provides easy access for the visitor, varies in sophistication from self-guided "spelunking" tours to visits using motorized vehicles and trams.

The selection of caves for public exhibition is generally based upon some significant and outstanding feature within the cave that sets it apart from other caves. The first caves to be "exhibited" were probably the painted caves of prehistory where the use of artificial light permitted artists to mark with natural earth colors the walls and ceilings of deep caves. It is not clear whether the drawings were for exhibition or religious purposes, but it is evident that they were visited by many thousands of persons who left visible trails worn into solid rock.

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The exhibition of caves for the beauty of architecture occurred at the end of the Middle Ages in Europe when caves located on the property of local lords were visited as "curiosities." This led to the popularity of artificial grottoes built in the gardens of castles. These representations of nature were enhanced by actual stalactites and stalagmites taken from natural caves. The practice continued for several hundred years and was unfortunately a factor in the destruction of many fine caves that were stripped of their decorations.

The "developed" caves, exploited by the gentry, were only for the enjoyment of a few. There was no tourism as we know it today. Only the wealthy aristocrats were able to visit and with the exception of caves near the spas, watering places, and stops on the "Grand Tour," these private show places did not provide employment for the local people.

Other caves were opened by the clergy as parishioners made pilgrimages to the sites, but the caves were not open to all people.

It was not until the beginning of the 18th century that a middle-class merchant group arose in Europe and challenged the feudal system of land ownership and church authority. The building of roads, canals, boats, and improved transportation facilities generated a new industry of tourism for a much larger group of people. The advent of the railroad and the subsequent industrial revolution in the 19th century opened new means of travel and created a generation of mobile common people. The most recent advances in this century using automobiles, airplanes, and super highways have made the most remote places in the world accessible. This revolution of mass travel has an impact on natural resources in each country and on every continent.

The study of caves is a comparatively recent science. Early information about the underground came from the mining industry where natural caves were considered worthless as they had little economic value. This negative view changed as public interest in caves grew; and several caves, discovered by mining, were opened as tourist attractions. Blue John Mine in Yorkshire, England, was reportedly mined by Romans two thousand years ago, and three hundred years ago British miners following the same veins discovered the main chambers exhibited today as BLUE JOHN CAVERNS.

Scientific interest in caves was led by naturalists who specialized in geology and archaeology. Mostly "gentlemen" enthusiasts, they stirred up great controversy in the last century with discoveries of early man that predated the concept of the Biblical flood. This heretic discovery was focused on the site of Kents Hole in Torquay, England. Indisputable evidence of man's occupancy of the cave before the last ice age covered the British Isles was found and started a search throughout Europe for other artifacts. Today, KENTS CAVERN is a show cave featuring ancient bones and weapons in situ.

Today speleology is a recognized scientific study that touches all aspects of caves, karst, and cave life; and thousands of papers, books, and photographs have been published around the world. In addition to the scientific aspect, there is a technical area of interest that has attracted thousands of people to map, explore, and photograph caves. This wedding of science/sport interest has resulted in amateur groups springing up in forty-five countries reporting on work done in their local caves. This is serious work, but if all of the dedicated

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speleologists were counted, they would number less than 100,000 in a world of five billion people. The published output of these people and organizations circulates primarily among themselves. Their reports are available to the public but are usually so specialized that they have limited readership.

Some caves are so remarkable that they have become national treasures for the citizens who now take pride in their exhibition. POSTOJNA CAVE, Yugoslavia was first exhibited in 1818 as a show cave and is still respected as one of the great caves of the world. Millions of people have visited this cave in the past 170 years, and the impressions received by those visits have influenced attitudes about caves for generations. MAMMOTH CAVE and CARLSBAD CAVERNS in the United States have been seen by more than forty million people since they were opened. JENOLAN CAVE, Australia; EISRIESENWELT, (Ice Cave), Austria; AVEN D'ORGNAC, France; HOLLOCK CAVE, Switzerland; GUACHARO CAVE, Venezuela; and CACAHUAMILPA, Mexico are all famous caves in countries where they are located. Each of these caves represents to many millions of people an impression of what a cave is and looks like but each is different and features a special aspect of speleology.

The current ability to travel has made natural attractions points of destination for tours and organized outings. Because of the costs and time limitations, only a cursory view is given of the cave's features. It is left to the scientist and naturalist to study, analyze, and public scholarly reports in scientific journals. Unfortunately, these are read by only a small number of people; visitors outnumber scientific readership a thousand-to-one. Four-color

brochures are more attractive than charts and tables; legends and folk tales more interesting than geologic history. A vacationer wants to be entertained, not lectured, so the cave manager concentrates on the pleasurable aspects of the trip.

Show caves are only a miniscule part of the current tourist industry, but they have also been affected by a great surge of visitors. Many show caves have been overwhelmed by numbers of guests in excess of the physical carrying capacity of the tours. This has caused unpleasant personal experiences which destroy an otherwise enjoyable trip.

Most of the major show caves of the world are owned by the state. They usually have park status and are administered by specialists with career incentives and direct authority to protect and preserve the cave. Usually the cave has been an attraction for many years and the modifications made within the cave (lights, trails, and stairways) predate the present administration. The condition of outmoded facilities is present in most show caves today whether private or public. The need for conservation of these caves requires the immediate attention of all concerned if we hope to pass on this natural heritage to our children.

Recent advances in technology provide many more tools for the designer, engineer, and contractor. Periodic reviews of cave lighting, trails, and safety conditions should be made by any show cave management on a regular basis. If any major work is planned within the cave that might change the tour or carrying capacity of the cave the following steps should be taken to avoid damage to the site.

The conservation and preservation of

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any natural public site relies upon maintenance. This maintenance includes administration, security, and protection. This responsibility rests upon three underlying factors that support the conditions necessary for optimum sustained use of the cave by the public.

These factors, like the legs of a three-legged stool, are DESIGN, CONSTRUCTION, AND DISPLAY. They are equally supportive of the whole and must be considered whenever policy decisions are made affecting the cave. If any are neglected; the protection and security of the cave might be jeopardized.

### **1. Design:**

Before changes are made within the cave there should be input and advice of specialists who are knowledgeable of all the conditions affecting the cave. This includes engineering, hydrology, biology, geology, speleology, and environmental impact. Plans, specifications, and cost estimates are part of the design stage and are part of the decision-making process.

### **2. Construction:**

Work within the cave must have careful supervision and be respectful of the environment. Safe working conditions are essential to prevent injury and construction material used must not adversely affect the cave. Only skilled workmen should do electrical and structural work; only experienced artisans should attempt to restore cave features.

### **3. Display:**

Exhibition of a cave requires skills not

used in the first two stages. Interpretative programs, guide training, supervision of personnel, and scheduling are all people-oriented skills necessary to administer a show cave. Marketing, public relations, advertising, and publicity are also essential to a master plan for the guidance of all administrators.

If the management of an existing show cave does not consider all of the above underlying requirements whenever a major revision is made within the cave, there will be an imbalance. All three conditions must be addressed and applied if the administration is to be properly supported.

The logistics of moving thousands of people through a cave requires organizational skill and administrative expertise. The show cave manager becomes expert in handling people and controls the access to the cave. He also decides upon the balance between environmental pressures to limit access and the tourist demands for increased visitation. Left to his own devices a manager can easily rationalize to himself: "If they want to be entertained—provide entertainment.."

This might lead to decisions that are detrimental to the cave, or the quality of the cave experience for the visitor. The "entertainment" quotient is a powerful argument of popular appeal. However, it is the responsibility of a prudent and responsible manager to consider all displays, anecdotes, statements of fact, and information issued by the personnel and literature of the cave to be factual and correct. This will assure that the tour will be informative and "educational" as well as pleasurable.

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### SUMMARY

A show cave is a long-term investment in our natural heritage. We may not see the changes that naturally occur in normal cave growth as they exceed the period of a lifetime; however, changes are possible with our present technology to preserve (or destroy) any of the cave features at will. We can duplicate them but we cannot create them exactly as they occur because we do not control time. Some speleothems require thousands of years to form.

Show cave managers should balance their desire for the public to be "entertained" with a responsibility to "educate" by stressing good conservation practices. A careful periodic review of the cave tour should be made by all show cave owners to see if conditions can be improved. This is an opportunity to promote public awareness of the need for conservation and protection of our natural caves by personal example.

Show caves provide an opportunity for the public to be introduced to an environment that is unusual, mysterious, intricate, and intriguing. It can also be beautiful and awesome. This combination, if presented in a factual and interesting manner will also be educational as well as entertaining. Review of the present conditions within existing show caves and preparing a plan using today's technology would be a good formula to follow to assure that the next generation will be able to enjoy these secret chambers of the underground.

Russell Gurnee,  
231 Irving Ave., Closter, NJ 07624,  
November 3, 1988, (Presented in Postonjna,  
Yugoslavia, November 11, 1988)

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## **Important Mexican Free-tailed Bat Colonies in Texas:**

a summary by

**Rex Wahl**

### **ABSTRACT**

No one has truly sampled Texas caves unless they view one of the most impressive cave sights in the state – a large bat flight. Bracken Bat Cave is a superlative site to view this, since it contains one of the largest colonies of the Mexican Free-tailed bats in the world. It is also historically interesting because since it has been used for guano mining since the Civil War. It is one of the caves used by Dr. Lytle Adams during his Project X-Ray during World War II. Recently, a representative of Bat Conservation International estimated the Bracken bat population at 35 million. Other significant bat caves and details about free-tails are also noted.

A summary of the largest Mexican Free-tailed Bat (*Tadarida brasiliensis mexicana*) colonies in Texas is provided for use in planning conservation of important breeding and roosting locations for this species. This information is compiled from various literature sources, knowledgeable individuals, field work by the Austin Chapter of Bat Conservation International and The Texas Natural Heritage Program. Reported colony sizes are based on the cited source. There is, as yet, no reliable method of estimating large numbers of bats with any confidence. Most of these estimates are based on measures of roost area occupied by bats (Constantine, 1967). These numbers must be regarded as maximum estimates.

The Mexican Free-tailed Bat is one of the

most abundant bats in the southwest, yet there are relatively few large maternity roosts known. One of the functions of large, tightly packed roosts is conservation of energy lost as body heat, and, perhaps, elevation of roost temperatures for nurseries. Caves suitable for large populations, with physical characteristics that are conducive to heat retention may be scarce, and thus, limit the number of bats in an area (Tuttle and Stevenson, 1977).

Texas has the majority of the large free-tailed bat roosts (Eads et. al., 1957 and Davis et. al., 1962). Several well known, and large roosts in other states have suffered marked declines in numbers. Eagle Creek Bat Cave in Arizona declined from an estimated 30 million bats to near zero in the 1970s (McCracken,

1986). Carlsbad Cavern's famed population declined from an estimated 7 million to 200,000 in the mid-1960s (Altenbach, et. al., 1979). McCracken (1986) documents loss of populations in Mexico as well. The only documented colony abandonment in Texas is Valdina Farms Sinkhole, which was modified to provide increased recharge to the Edwards Aquifer through surface water diversion, resulting in the loss of a Mexican Free-tailed Bat colony of an estimated 4 million bats, as well as a colony of Ghost-faced Bats (*Mormoops megalophyla*) (Veni, 1987).

Another large Texas colony, Fern Cave, had an estimated 8 million bats, but the owner states there are far fewer bats present now. A visit to Fern Cave this summer confirmed that there were fewer than a million bats present, and guano deposits do not indicate a large population (Wahl, pers. comm. 1988). Determination of colony decline is complicated by the absence of any reliable estimation method, and lack of confidence in the large population sizes reported in the earlier literature. For instance, the Devil's Sinkhole is reported to house up to 6 million bats, yet there is no statement of how these numbers were determined in reports citing this number (NPS, 1947). Wahl (1988) found that the Devil's Sinkhole

bat colony varied in size from about 750,000 in mid-summer to about 3 million in late summer. It is not known whether this difference represents actual changes in population or errors in earlier population estimation. The Devil's Sinkhole is not a maternity colony. Population estimation is complicated by the

Colony	Size	Date	Source <sup>1</sup>
Bracken Cave	20 million	1957, 1988	1, 2
Rucker Cave	12 million	1958	1
Ney Cave	10 million	1957	1
Fern Cave	8 million < 2 million	1958 1988	1, 4
Beaver Creek Cave	14 million, 6 million	1957 1988	1, 3
Frio Cave	10 million	1958, 1988	1, 2
James River Cave	6 million	1957, 1988	1, 6, 7
Davis Cave	4 million	1957, 1988	1, 5
Devil's Sink-Hole	6 million, < 1 million	1958 1988	1, 4
Valdina Sinkhole	4 million, 0	1958 1988	1, 8
Quarry Colony	4 million	1989	3
Congress Ave. Bridge	<1 million	1988	2, 3

**Table 1.** Mexican Free-tailed Bat population size and status for Texas' largest colonies. Where two numbers are listed, the second is more recent.

swelling of cave populations in late summer by migrant bats from other caves and young-of-the-year recruited into the population.

A reliable method of bat population estimation is being developed by the National Park Service (NPS, 1987), but, is dependent on clear video tapes of the bat's outflight, difficult to obtain in many cases due to characteristics of the cave and outflight (Fletcher, pers. comm., 1988).

All the largest free-tailed bat maternity caves in Texas remain in private ownership. Private owners are usually protective of their bats and cave, often due to the value of guano produced by large numbers of bats in the roost. Carlsbad Caverns is protected by NPS, yet the population still declined. Another large roost in New Mexico (3 million) is "protected" by an agreement (non-binding ?) with The Nature Conservancy. No other large maternity colonies are owned by any conservation agency or organization.

The private owners of the Texas maternity caves are to be commended for their able stewardship of such an important resource. Recently, several conservation organizations have begun to plan for the continued protection of several important large maternity colonies in Texas, in cooperation with the landowners. The occurrence of so many large, and currently occupied, maternity roosts in Texas make possible the ultimate protection of a significant portion of the entire breeding range of a species. Organizations and individuals interested in true protection of an animal community, as well as a major portion of a specie's range, should consider the protection of all large maternity roosts in Texas as an obtainable long-range goal.

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- 1 - Davis, et. al. 1962;
- 2 - Tuttle, pers. comm. 1988;
- 3 - BCI Austin;
- 4 - Wahl, 1988;
- 5 - McCracken, pers. comm. 1988;
- 6 - Kunz, pers. comm. 1988;
- 7 - Elliott, pers. comm. 1988;
- 8 - Veni 1987.

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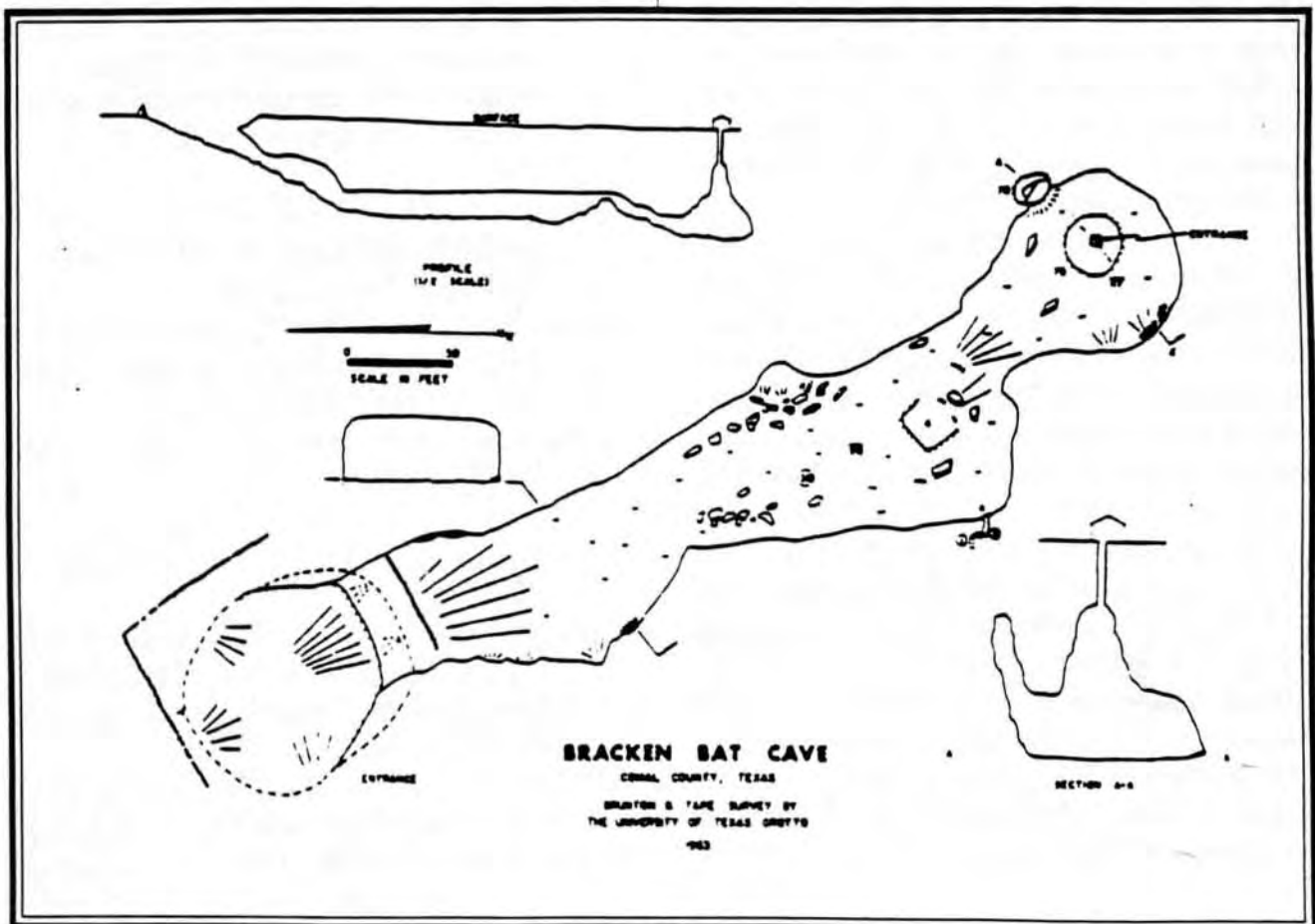
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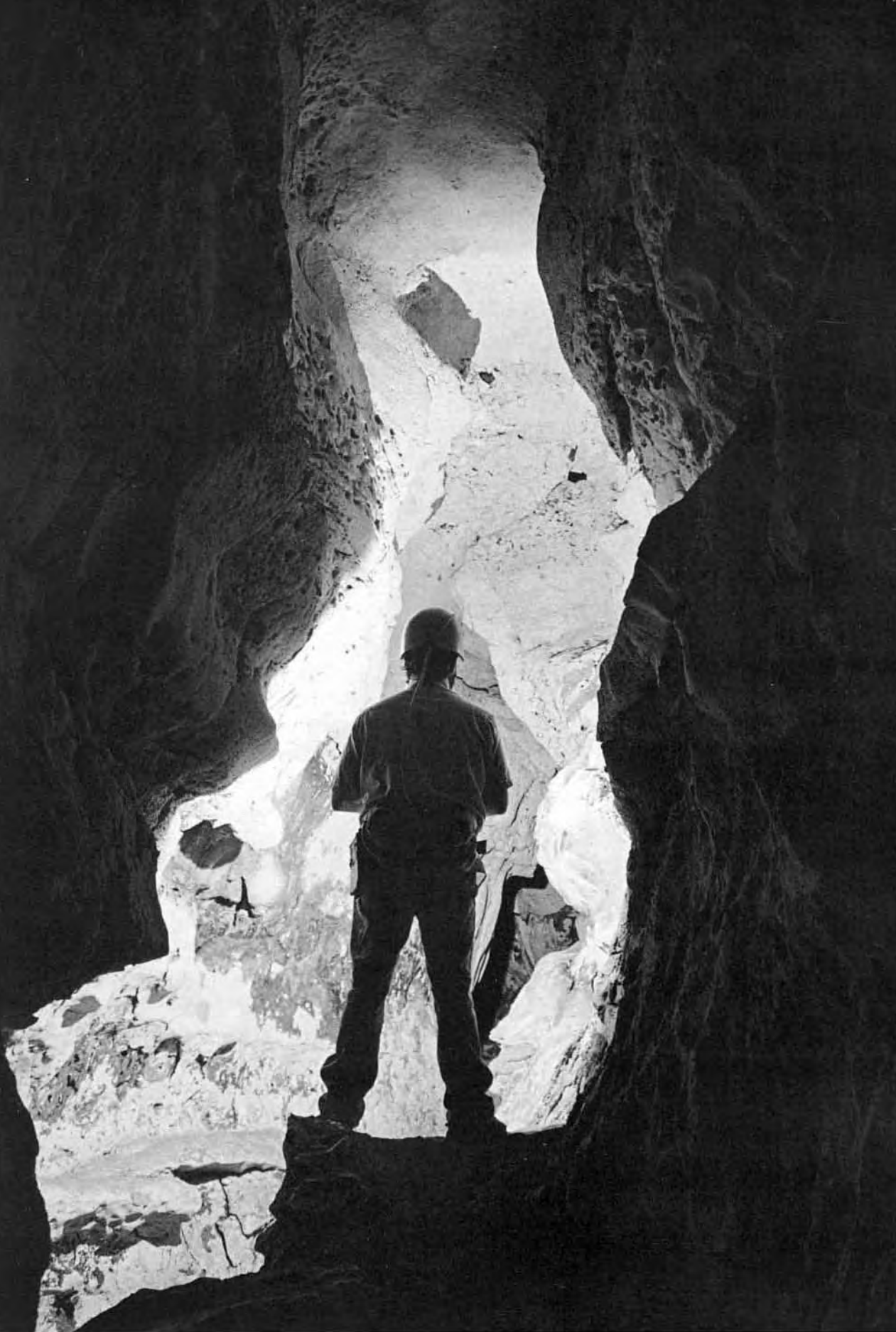
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FRIDAY



## Ezell's Cave

presented by

**Jim Robertson**  
Texas Nature Conservancy

**Ezell's Cave:** Just a hole in the ground of the Texas Hill Country, Ezell's Cave is actually a window into the Edwards Aquifer and home to a group of diverse and highly specialized organisms.

**Location:**

The entrance to Ezell's Cave is located on a 2-acre tract of land in the western part of San Marcos in Hays County. Because of the delicate nature of the cave's ecosystem and the potential danger of personal physical injury, the cave is not open to the public.

**Historical Overview:** The cave was discovered in 1870 by Greenberry B. Ezell on property owned by J.H. Bishop. In 1893, Ezell purchased the cave and less than 1 acre of the land which contained its entrance. He operated it commercially for several years. Truman T. Saltonstall bought the cave and land from Ezell in 1929, believing that the air from it would help his lung condition.

The first Texas blind salamander known to science was reported to have been from Ezell's Cave. Interest in this salamander was shown not only by zoologists, but by enterprising individuals who collected unusual animals for commercial sales. The presence of the salamander and other cave creatures, combined with an urban location, caused an increase in visitation as well as vandalism and over-collecting from the 1930s to the 1950s. In 1955, the Texas Herpetological Society

became so concerned over the decrease in numbers of the salamanders that they purchased an easement to protect the cave and to regulate admission. For 5 years the Society's trustee, William K. Davis, fought a losing battle with the vandals. In 1962, J.T. Mostyn purchased the cave and part of the land for commercial operation, but, since the operation proved unsuccessful, he sealed the entrance and put the cave up for sale. It was purchased by Norman Elder and it was from Elder that the Nature Conservancy bought it in 1967. The cave entrance was then reopened and measures were instituted for the protection of its fauna. In 1972, Ezell's Cave was designated by the National Park Service as a National Natural Landmark.

**Natural History Geology:** The cave is situated at the edge of the San Marcos Springs Fault of the Balcones Escarpment. The Edwards Plateau is to the west; the upper edge of the coastal plain to the east. Ezell's is entirely in Edwards limestone of Lower Cretaceous age, and provides direct access into the San Marcos Pool of the Edwards Aquifer. It was formed as a result of underground solution of blocks of the limestone and the subsequent collapse of various sections of overburden into the solution voids. Enlargement continues to occur as falling rock is dissolved and moved away in the ground water. The narrow entrance is 204.2 meters above sea

level, about 6 meters above the first room and about 15 meters above the second. Water levels in the lower room fluctuate with changing recharge and pumpage. The second room is the first of an interconnected series of chambers, most of which are waterfilled. The full extent of the cave has not yet been mapped.

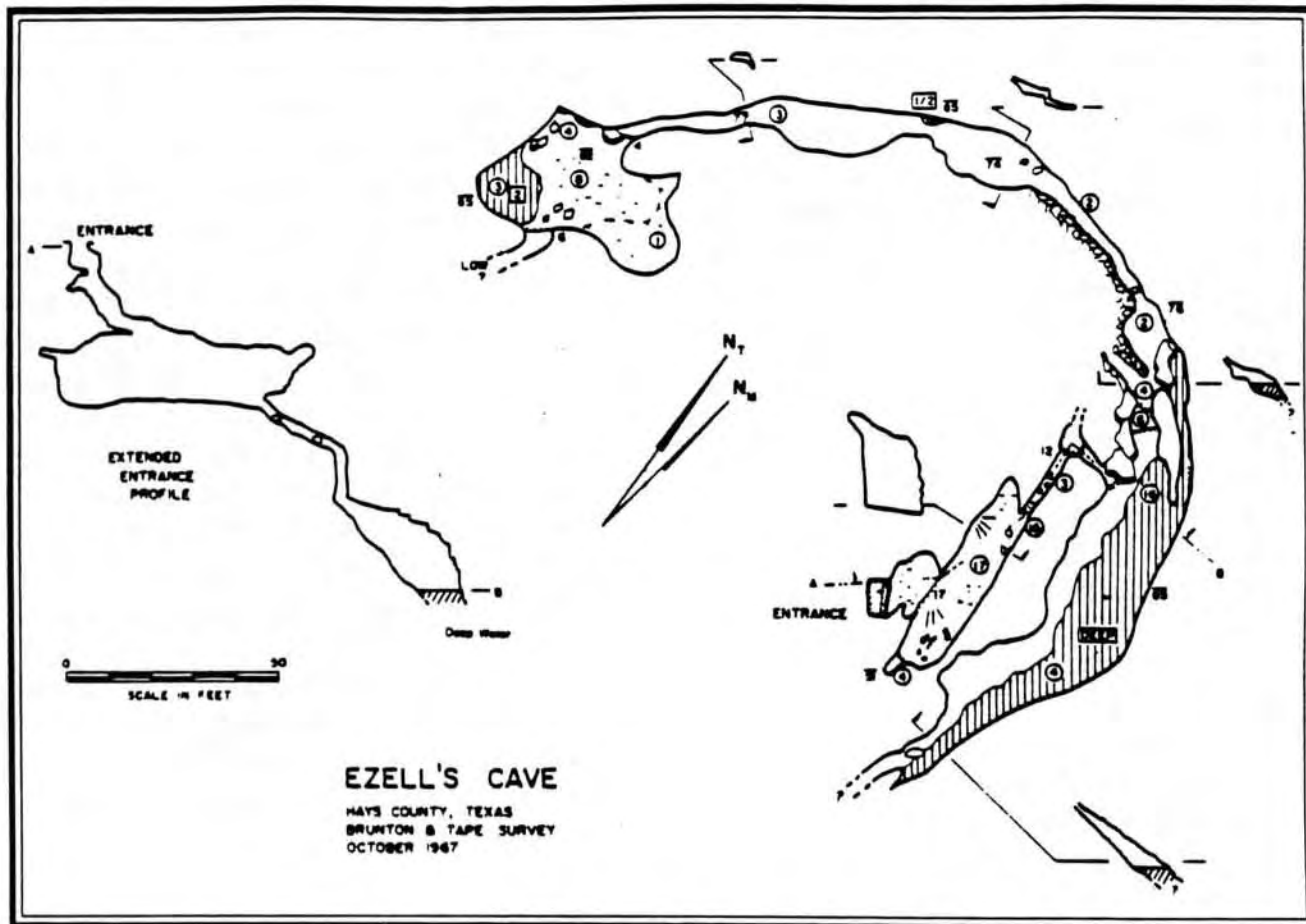
**Flora:** The surface vegetation is typical of the eastern edge of the Edwards Plateau. Clusters of live oaks, Texas persimmon, aromatic sumac, Ashe juniper, sugar hackberry, and hog plum make up the bulk of the woody species. The cleared areas are a riot of bluebonnets and *gaillardia* in the spring. Dove weed, vetch, chili petin, and Englemann daisy are among the other forbs, and, together with three-awn, Johnson grass, burmuda grass and other graminoids, form the herbaceous surface of the cave area.

**Fauna:** Animal species associated with caves are loosely grouped based on their degree of cave adaptation. Troglobites are those cave dwelling organisms which complete their entire life cycle within the cave and cannot survive in surface environments. Troglaphiles generally complete their life cycles within caves but can survive outside of them. Troglaxenes frequent caves, but complete at least some part of their life cycle outside of caves and generally feed in surface habitats. Of the 98 species reported from Ezell's, 16 are troglobites, 22 are troglaphiles, and 25 are troglaxenes. The rest are considered accidental. The troglobites include the well-known Texas blind salamander (*Eurycea rathbuni*), rare, endemic shrimps (*Palaemonetes antrorum*, and *P. holthuisi*), an amphipod (*Stygonectes flagellatus*), a malacostracan (*Mondodella texana*), and an endemic flatworm (*Sphalloplana mohri*). The

troglaphiles include a beetle (*Belonuchus moguinus*), a scorpion (*Vejois* n. sp.), and another salamander (*Plethodon glutinosus*), as well as spiders, isopods, and book lice. Snails, cave crickets, frogs and a toad constitute the troglaxene fauna. This rich endemic fauna is characteristic of, and primarily specific to, the San Marcos Pool of the large and complex Edwards Aquifer. Most of the species of this animal community originated during the Pleistocene, and the present unique ecological assemblage has evolved slowly over thousands of years. Its survival is dependent on the quality and quantity of the water in the Aquifer. The cave itself is one accessing point through which the Aquifer's subterranean inhabitants can be viewed and studied. It is hoped that such an important living barometer to the environmental health of the region will continue to be viable well into the future since the survival of the cave organisms is intimately tied to that of the humans on the surface.

**Texas Nature Conservancy**  
**P.O. Box 1440**  
**San Antonio, Texas 78295**  
**(512) 224-8774**





### EZELL'S CAVE FENCE AND GATE COSTS

#### General Compound Security:

Chain Link Fence, Trespass Warning Signs, Vandal-Proof Mercury Vapor Light

Total Monetary Cost: \$600.00

Total Labor: (volunteer) 50 hours

#### Cave Gate Construction:

Cement, Raw Steel Stock, Locks, Equipment Rental, Galvanization of Gate Components, Welding Supplies, Heat Treating, Misc. Construction Expenses

Total Monetary Cost: \$875.00

Total Labor (volunteer): 325 hours

Total Monetary Cost: \$1,475.00

Total Labor (Volunteer): 375 hours

Gate Fabrication and Construction

Time Span: 11/83 to 02/84

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# Sinkhole Management

by

Ernst H. Kastning and  
Karen M. Kastning

Department of Geology  
Radford University  
Radford, Virginia 24142

## ABSTRACT

Appropriate sinkhole management must include an assessment of the vulnerability of the integrated karst system to changes incurred at sinkholes. Sinkholes serve as discrete points of recharge to the karstic aquifer and care must be taken to prevent the introduction of any toxic substances into them. The most common sources of contamination to caves are dumping of waste into sinkholes, concentrating chemicals from accidental spills of hazardous materials in the vicinity of sinkholes, and by runoff from agricultural land where chemical fertilizers are in heavy use. Cave restoration projects have become increasingly popular among concerned cavers and others. Restoration of sinkholes has also been attempted in recent years. Removal of trash and restoration of original contours around cave entrances have been very successful, but such efforts require considerable effort and in many states, the sheer number of sinkhole dumps is staggering. One of the most effective means to alleviate sinkhole problems is through public education, wherein the sensitivity of the karst environment to sinkhole degradation is strongly emphasized.

## Introduction

Sinkholes (known internationally as *dolines*) are closed depressions on the land surface that are generally conical in shape. They are prevalent in regions of karst where surficial water percolates into the ground and migrates to subsurface drainage paths (see

Monroe, 1970, for definitions of karst terms). Like all karstic landforms, they are formed by the dissolving of rock such as limestone, dolostone, marble and gypsum by mildly acidic groundwater. Sinkholes are typically in hydrologic communication with underground solutional conduits such as caves. These connections may or may not be traversable by

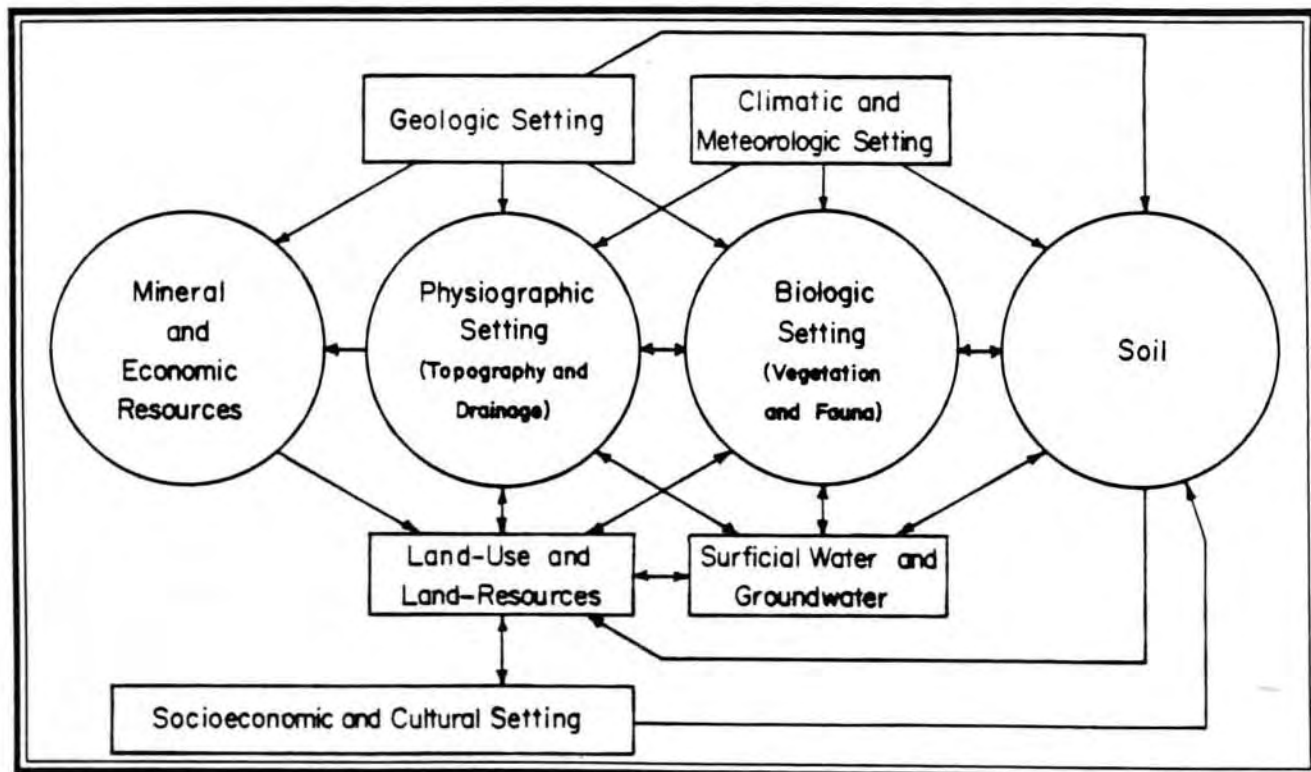
human explorers, but in any case, water infiltrating at sinkholes easily makes its way to the conduits.

Sinkholes pose several types of environmental problems that ultimately affect caves and groundwater in karst terranes. Environmental concerns include: (1) catastrophic collapse and gradual subsidence, (2) introduction of contaminants and pollutants from various sources into sinkholes, (3) flooding during or following intense storms, and (4) modifications to cave entrances that disturb delicate spelean ecosystems. **Proper cave management requires proper sinkhole management, as both features are components of integrated hydrogeomorphic systems.** During cave management, speleological pro-

cesses inherent in caves should not be considered to be isolated from those of the interacting surficial environment.

### The Nature of Karst

Karst is characterized by sinkholes, caves, sinking streams, springs, and solution valleys. The study of karst is a relatively new science that draws largely on the principles of geology and geography. A thorough understanding of the processes that occur both at the surface and underground and appreciation for the total hydrologic system necessitates a global familiarity with scientific karst studies. The level and scope of modern karst studies is demonstrated by the recent proliferation of



**Figure 1:** Cause-and-effect relationships among geologic, biologic, geographic and human factors in karst terranes. Arrows portray directions of effects.

textbooks on the subject (Kastning, 1989a). Recent texts in English include those of Bogli (1978), Dreybrodt (1988), Ford and Cullingford (1976), Ford and Williams (1989), Jennings (1985), Sweeting (1973), Trudgill (1985) and White (1988). Moreover, the number of scientific journal articles and graduate theses on karst is expanding at a phenomenal rate (see for example the bibliographies of Lamoreaux and others [1970, 1975, 1986], White and White [1984], and Huppert [1988]).

### **Environmental Problems**

Karstic landscape is particularly sensitive to environmental degradation (LeGrand, 1973). Stresses induced by mankind in karstic terrane result in environmental problems that are much more acute than those that would occur in terranes underlain by either crystalline (metamorphic or igneous) or klastic (other sedimentary) rock. Problems such as supply and contamination of groundwater and land stability abound, primarily in populated karst regions.

Much of the karstic terrane of the United States lies in rural regions where environmental impacts are generally limited to those imposed by agricultural practices and highways (Davies, 1970). In some cases, karst lies within the confines of public land (parks, forests and the like). However, urbanization is rapidly encroaching in many karst areas and economic development is resulting in severe karst-related environmental problems.

The scope of problems related to the karst environment is large (LeGrand, 1973; White, 1988, pp. 355-405). An appreciation for the complexity of the subject is best gained by consulting proceedings volumes of recent

conferences that have specifically addressed karst-related environmental problems (e.g. Beck, 1984, 1989; Beck and Wilson, 1987; and Dougherty, 1983). The interaction among various natural elements of the karst setting and man's role in the system is illustrated conceptually in Figure 1. Not that the system is far from simplistic and that it consists of a series of nested loops with feedback that represent direct and indirect causes and effects. Making changes in any one element of the system will have consequential impact on the other elements. It is not the intent of this paper to address all of the possible impacts that man and karst have on each other. Rather, it is instructive to select a few situations where karst may be important as an environmental concern. This is perhaps best illustrated by the role of sinkholes in environmental problems.

Among the most severe and immediate environmental problems associated with karst include groundwater supply, groundwater quality and land instability. Karst terrane, particularly that of moderate to high sinkhole density, thus imposes constraints on land use. Mismanagement of karstlands, whether through unsupervised economic development, poor farming practices, improper waste disposal, or other means will often damage groundwater supplies, cave ecosystems, or man-made structures built on karst.

### **Groundwater Supply**

Unlike in other types of terrane, groundwater in karst regions is channelized within a natural underground system of interconnected "pipes" that collectively transmit water from input points (recharge zones) to output points

(discharge points). Recharge in karst terrane occurs in two ways. First, rain water may percolate through the soil and into fractures in the carbonate rock over large areas of the countryside. This is known as *diffuse recharge*. Secondly, surface streams may be entirely swallowed up where they flow into caves or sinkholes. This is called *discrete recharge*. Most karst regions are characterized by both mechanisms occurring simultaneously.

Discharge occurs in several different ways as well. The natural release of karstic groundwater from springs can also be either diffuse or discrete. Diffuse springs are merely places where water seeps from the ground over a wide area. Discrete springs are those where an underground river or cave stream exits from a large opening. Springs may issue anywhere from a few to thousands of gallons per minute. A significant quantity of water is also discharged through man-made wells drilled to obtain water for domestic, commercial, agricultural, or industrial use.

The nature of subsurface flow in carbonate rock can be studied through tracing of water by the injection of harmless fluorescent dyes. The techniques and knowledge gained from various investigations are well-documented in the aforementioned textbooks on karst. Subsurface water tracing has been performed in many large karst groundwater systems.

Obtaining usable amounts of water from karstic aquifers is often a "hit-or-miss" operation. Water is highly localized because it is flowing through solutionally enlarged fractures and partings between beds of rock. In contrast to sandstone and other porous-media aquifers where flow is diffuse throughout,

karstic groundwater is coursing mainly through a system of natural pipes. Obtaining water in a porous-media aquifer is usually no more complicated than drilling a well wherever one is desired; in karst, however, wells may often not yield sufficient water unless a solutional conduit is intersected.

Springs and wells in karst are highly sensitive to changing weather patterns such as wet periods and draught. The response to weather trends is rapid because water is quickly conveyed along the solutional conduits. Karstic groundwater supplies are flashy and allowances must be made for this erratic behavior in the allocation of water derived from springs or wells.

Man-made changes to the surficial drainage and to sinkholes may easily alter the *rate* at which the underlying aquifer receives its normal recharge. Vegetation and soil cover slow the runoff and absorb some moisture, providing a slower rate of runoff than impermeable materials would (e.g. cement drains, asphalt roads or parking lots, and roofs of structures). Sinkholes that are infilled become less efficient or blocked inputs. An increase in the rate of runoff and/or the blocking of input points may cause surficial water to pond or backflow, unless it is diverted away from its natural sinkpoint (thereby altering the recharge at yet another sinkpoint). This may drastically affect the amount of groundwater available for use in the immediate vicinity.

### Groundwater Quality

If there is one single environmental issue that stands out in karst, it would have to be the sensitivity of the karst aquifers to groundwater contamination. The effect of man on karst is

most severe in cases where polluted surface waters enter karst aquifers. This problem is universal among all karst regions in the United States that underlie areas of economic growth. The good news, relative to the karst of the United States, is that most of it lies in rural areas. The bad news is that the country's karstic groundwater problems are accelerating with the advent of (1) expanding urbanization, (2) increased production of environmentally unacceptable artificial chemicals, (3) shortage of repositories for hazardous wastes (both household and industrial), and (4) ineffective public education on waste disposal and the sensitivity of the karstic groundwater system. Before any further comment, please consider this excerpt from a recent newspaper story regarding a toxic chemical spill on Interstate 81 near Salem, Va., on 1988:

*More than 3,000 gallons of diesel fuel spilled near Salem Wednesday when a tanker truck flipped onto its top and split open on Interstate 81. Hours after the spill, the fuel had not contaminated any streams or water supplies, but Roanoke County and Salem hazardous materials workers said they could not find where it had gone.*

**"It flowed about 50 feet and then it disappeared,"** said Larry Logan, emergency services officer for Roanoke County. "In the 20 years I've been in it, I've never seen anything like this." Logan said **it was possible that a hidden cavern absorbed the material.** A private company will clean up the spill and hazardous materials workers will continue to try to find the fuel.

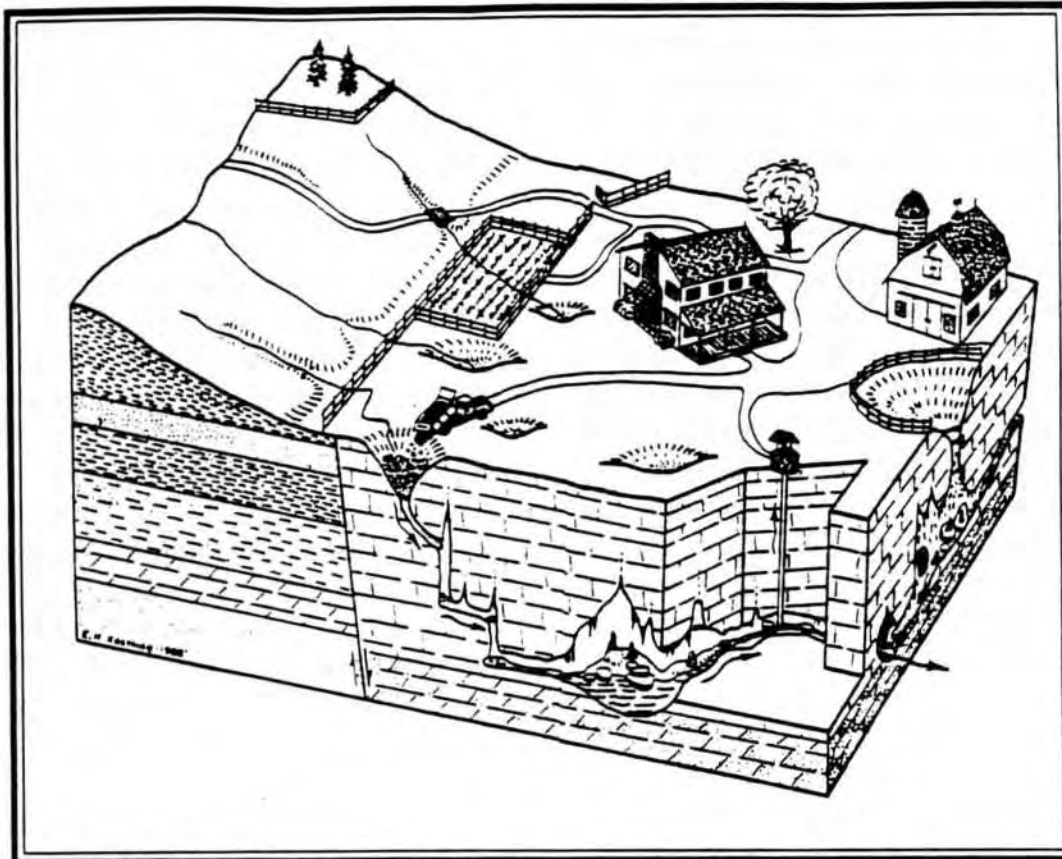
**The amount that escaped was enough to cause a "bad situation" if the spill had been near a stream, river**

**or major water supply,** Logan said.

*Any diesel spill of more than 50 gallons is considered a potential major problem, he said. (Lovegrove, 1988. Article continues. **Bold emphasis is mine.**)*

This quotation makes two important points. First, even in rural areas, karst can easily be contaminated by accidental spills of toxic substances. Secondly, there is a general lack of public understanding of groundwater behavior, particularly in karst. Karst aquifers cannot filter contaminated groundwater sufficiently to render it potable at the discharge sites. As discussed above, water travels rapidly through solutional conduits because recharge points are directly connected to discharge points by a natural system of pipes (Figure 2). Not only does the "garbage in, garbage out" principle apply to karst groundwater, but the conveyance of contamination is highly efficient in this type of terrane.

Because sinkholes are natural holes in the ground surface, they have been inviting sites for dumping of trash, a procedure practiced for a long time by landowners and passers by. The presence of a sinkhole obviates the need to dig a pit in which refuse can be dumped. The number of active and inactive sinkhole dumps in karst regions is staggering. For example, over 260 such illegal dumps have been inventoried for Rockbridge and Botetourt counties, alone (Slifer, 1987; Slifer and Erchul, 1989). It is conceivable that each county with karst in the Valley and Ridge province has hundreds of such sinkhole dumps. The profusion of these dumps is the result of (1) a lack of a refuse removal service in rural areas and the expense and inconvenience of trash haulage on the part of the landowner, (2) the convenient proximity of sinkholes, and (3)



**Figure 2:** Groundwater contamination in limestone terrane. Pollutants enter the karst system through improper waste disposal and from surface runoff through fertilized cropland.

ignorance of the karst groundwater system on the part of the landowner.

Sinkholes are natural funnels that convey toxic substances directly into the karstic plumbing system (Kastning and Kastning, 1990). In many cases, chemicals may be transmitted directly to domestic wells, in a matter of a few hours and without filtration. A farmer who places a carcass of a deceased farm animal into a sinkhole (a common procedure) may very well be drinking water from that sinkhole! Or, his neighbors may be.

Sinkhole dumping is only one way of contaminating a karstic groundwater supply

(Aley, 1972; Aley and others, 1972). Chemical fertilizers applied to fields overlying carbonate rock will enter the aquifer through diffuse infiltration and contaminate springs and wells. Runoff from feed lots will also. Improper siting of municipal landfills on or near karst causes leakage or runoff from these landfills to easily contaminate karst waters. Chemicals introduced in this fashion may include many of the most hazardous, including hydrocarbons, heavy metals, and others. Additionally, leaky septic systems, sewage lines, or effluent from faulty sewage-treatment facilities introduce coliforms and other disease-

bearing organisms into the karst system.

Many of today's streams, including those in rural areas, are polluted. Many of the surface streams in karst terrane readily lose water to their beds (e.g. Sinking Creek in Giles County, Virginia — see Saunders and others, 1981 and Kastning and Lenhart, 1989). Contaminated surface waters entering carbonate rocks introduce toxic substances to subsurface streams. The only difference between surface and underground waters in karst is that the latter is out of sight (and out of mind!) Chemically, they may be identical. Accidental spills, such as the Salem, Virginia example above, and runoff from highways salted in winter to prevent freezing are just two examples of contamination along transportation corridors (Werner, 1983). Effluent from commercial and industrial operations along such corridors is also a problem.

Caves contain fragile organisms that have evolved in the natural cave environment. There are many inhabitants of caves. Most people think of bats as the most common creature of caves. On the contrary, there is an amazing number of cave-adapted organisms. Because these animals are highly adapted to their constant ecological surroundings, they are particularly sensitive to disturbances. Foremost of these is the introduction of foreign substances into the groundwater flowing through the caves. Even "clean" fill, such as brush, hay, sawdust, or dirt may lead to chemical imbalances in the karstic groundwater and adversely affect biological ecosystems. This is largely due to the rapid decay of the vegetative matter and consumption of oxygen. It is in the interest of conservation of species endemic to caves, rare or otherwise, that man be concerned with maintaining clean groundwater in

karst regions.

Caves are esthetically pleasing and wondrous places to visit (provided proper knowledge and techniques of cave exploration are acquired first). Many who visit caves on commercial tours or on caving trips to wild caves are intrigued by the myriad of cave formations. Most common among these are stalactites, stalagmites, columns, draperies, and flowstone. There are, however, many unusual, fragile, and often rare formations in caves (Hill and Forti, 1986). Cave formations are highly susceptible to contamination and derangement of groundwater flow. It is important that formations that take centuries to form be protected in their natural setting from man's influence.

### **Subsidence and Ground Instability**

The potential for the surface in karst regions to give way in collapse is brought home from time to time in the media. Massive collapses in which homes or businesses are swallowed by newly formed sinkholes make exciting news. In some states, such as Florida, Alabama, Texas, and Pennsylvania, such occurrences are somewhat frequent. Most of these events are triggered by man's intervention with the karstic environment (Waltham, 1989). The most common cause for catastrophic sinkhole collapse is an overpumping of groundwater from karstic aquifers, resulting in a relatively sudden loss of buoyant forces that uphold roofs of cavernous openings. A second cause of collapse occurs in response to changes in the position of the water table due to modifications to surficial runoff and infiltration to the karstic groundwater system. Fortu-



nately, not all karst areas have problems with sinkhole collapse, because in many cases the bedrock overlying caves is highly competent and can withstand the stresses.

Sinkholes pose another instability problem, however. Sinkholes have sloping walls and like valley slopes, they are prone to slides and creep of surficial materials that can ultimately cause damage to structures built on the slopes. Although seldom having a catastrophic effect, the long-term damage can be quite costly.

In areas undergoing development, sinkholes are viewed as unwanted holes in the ground. Consequently, there is a great desire to fill them in. The potential for ensuing environmental problems is twofold: First, naturally developed paths of infiltration are often blocked, leading to potential ponding and flooding on the fill. Secondly, over the long run, fill materials will be sapped into the subsurface and settling may occur. These disturbances easily impact any structures built on the fill. Additionally, the increased weight of water, fill and structures upon the cavernous bedrock could cause catastrophic collapse in the future.

### **Management of Sinkholes**

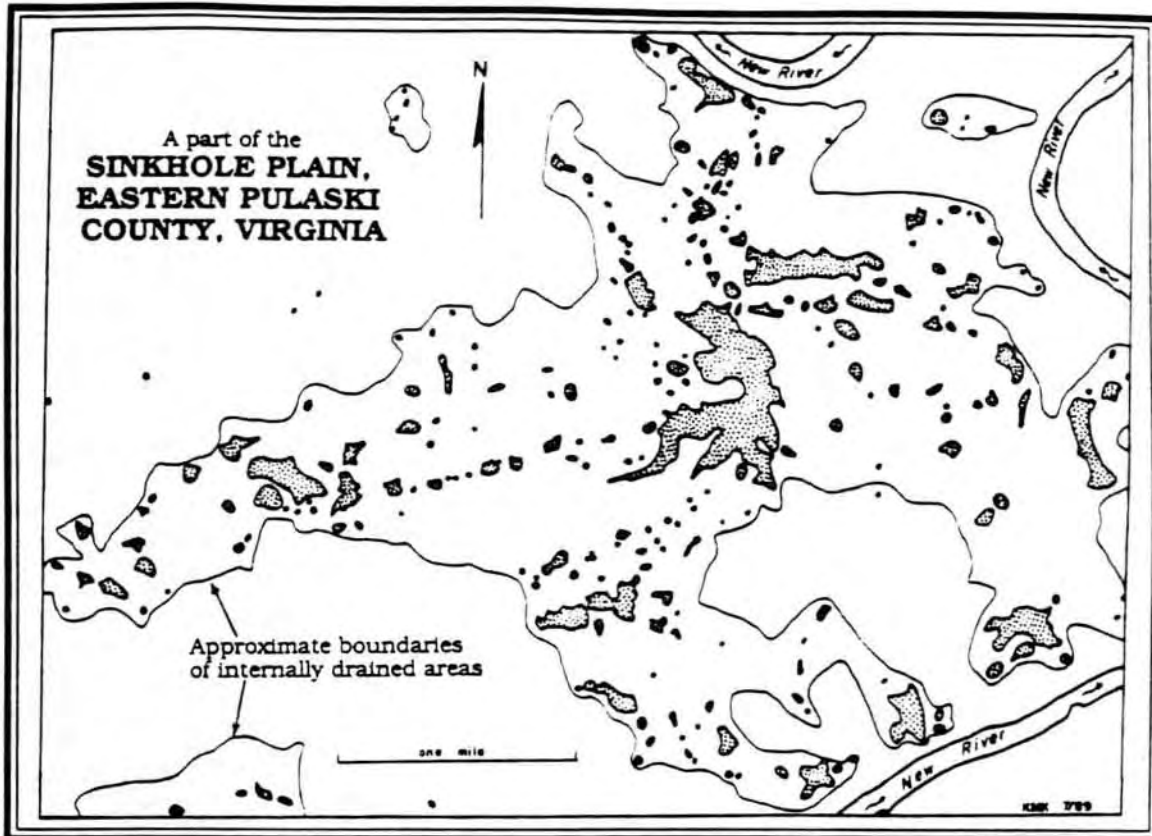
Appropriate sinkhole management must include an assessment of the vulnerability of the integrated karst system to changes incurred at sinkholes. Sinkholes serve as discrete points of recharge to the karstic aquifer and care must be taken to prevent the introduction of any toxic substances into them. The most common sources of contamination to caves are through dumping of waste into sinkholes, concentrating chemicals from acci-

dental spills of hazardous materials in the vicinity of sinkholes, and by runoff from agricultural land where chemical fertilizers are in heavy use.

### **Inventorying Sinkholes in Karst Management**

Large sinkholes are readily identifiable on standard U.S. Geological Survey 7.5-minute topographic maps (scale 1:24,000). It is a simple matter to locate sites of potential contamination prior to economic development of these regions. However, not all sinkholes appear on topographic maps; many are simply too shallow to be represented within the contour interval used on a particular map, or in some cases sinkholes have simply been overlooked in the surveying or cartographic process. Precise inventory of sinkholes necessitates additional work, including use of low-altitude aerial photography and surface reconnaissance by vehicle or on foot. To date, there are very few areas of the country where systematic inventories of sinkholes and other karstic features have been made. A notable effort in accomplishing such a task includes recent surveying both on a statewide and countywide level in the Commonwealth of Virginia (see discussion that follows).

Delineation of sinkholes on a map may readily indicate potential subsurficial flowpaths (Kastning, 1984, 1989b). In many situations, sinkholes are aligned as lineaments in the topography (Figure 3). This indicates a structural or stratigraphic control in the hydrogeologic setting wherein groundwater moves along straight flowpath segments formed along bedding planes and fractures.



**Figure 3:** Inventory of sinkholes in a part of Pulaski County, southwestern Virginia. Only those sinkholes visible on the 7.5-minute USGS topographic quadrangle are shown. Note the alignments of sinkholes in various places on the map. This suggests that groundwater moves along well-integrated, dendritic flowpaths.

The implication then is that infiltration entering an aquifer through such sinkholes contributes water to an integrated flow system. The surface arrangement of sinkholes thereby provides a hint of the configuration of the underground drainage.

### Cave and Sinkhole Restoration

Cave restoration projects have become increasingly popular among concerned cavers and others. Restoration of sinkholes has also been attempted in recent years. Removal of

trash and restoration of original contours around cave entrances have been very successful, but such efforts require considerable effort and in many states the sheer number of sinkhole dumps is staggering.

It is very important that the land immediately surrounding sinkholes be designated as zones to be left in a natural state. This provides a buffer zone protecting the quantity and quality of recharge entering the aquifer at that locale. The recommended size for a buffer zone would vary from sinkhole to sinkhole and would have to be determined for each particu-

lar case.

### **Karst and Public Education**

It is impossible for those concerned with preserving the karst to single-handedly confront all of these problems through remedial action, including cleanups of caves and sinkholes, legal action to prevent development or to seek restitution from violators of environmental law, or other reactionary measures. Although these efforts will help on a case by case basis, they will not keep pace with the impact of *progress*.

Perhaps the single most effective program to prevent the abuse of karst and promote sound environmental awareness is within the context of primary and secondary education. The characteristics and mechanisms of karst and how they differ from other terranes must be made graphically clear in the classroom, particularly in counties or cities that lie within karst areas or are in close proximity to them. Another avenue for contact within this age group is through youth programs including scouts, 4-H Clubs, high school science clubs, and other outdoor-oriented organizations.

Secondly, the news media can be effectively employed in carrying environmental messages to the public at large. Graphic explanations of active karst processes in layman's terms can go a long way toward conveying the need to preserve fragile karst features, water supplies, and cave ecosystems. The use of photography, video recordings, graphic arts, and writing, especially in conjunction with case histories, has been shown to be effective in reaching citizens living on karst. Distribution of this information can be in various

forms, including presentations of papers or multimedia programs at local, regional or national meetings, posters (e.g. the recent cave conservation poster published by the Virginia Cave Board), local cleanup and fundraising events with attendant publicity in the media, exhibits at commercial caves, museums, scout shows and other community events, and literature for distribution to the public and to landowners.

### **The Virginias' Example**

The karst of Virginia and West Virginia lies largely within the Valley and Ridge and Appalachian Plateau physiographic provinces and is characterized by a high density of sinkholes (Herak and Stringfield, 1972; Hubbard, 1984; Kastning, 1986, 1988). The distribution of large sinkholes is evident on 7.5-minute USGS topographic maps. A series of three maps showing exposures of soluble rock and the distribution of sinkholes and caves is being published for the state of Virginia (Hubbard, 1983, 1988). The data is derived from topographic maps, aerial photography, and the speleological literature. Karst maps for two of the counties in this karst region have recently been published (Miller and Hubbard, 1986; Hubbard, 1990). Karst terrane occasionally appears as a mapped environmental unit in local geological mapping as well (e.g. Schultz, 1981). Recent efforts by the Virginia Cave Board and the Virginia Speleological Survey have identified caves considered to be highly significant based on geologic, biologic, hydrologic, archeologic, and historic criteria (Holsinger, 1985).

Inventories of caves and other significant karst features are being maintained by pri-

vately operated speleological surveys in both states. These surveys have been in operation for some times (Davies, 1958; Douglas, 1964; Holsinger 1975; Virginia Speleological Survey, 1987-present). Significant caves (those having unique attributes, contents or value) are being identified (Holsinger, 1985; Gulden, 1989). Karst is being mapped as an environmental unit (e.g. Hubbard, 1983, 1988; Miller and Hubbard, 1986). These sources of data should help planners and managers in assessing environmental impacts of projects in karst regions.

The inhabitants of caves of West Virginia and Virginia have been investigated and documented (Holsinger and others, 1976; Holsinger and Culver, 1988). Additionally, newly discovered species are being added at a regular rate. Research and publication on cave habitats and ecosystems should be among the first steps in the conservation and management of karst regions.

Fortunately, steps are being taken to protect the karstic environment in the Appalachian Region. Both West Virginia and Virginia have enacted state laws that protect caves and their natural contents from vandalism and contamination. Chapters of the National Speleological Society in the Virginias have placed special metallic signs inside the cave entrances informing the visitor of the laws and penalties for violations. The Commonwealth of Virginia has established the Virginia Cave Board as part of the Department of Conservation and Recreation to take up matters relating to caves in the Commonwealth, to advise other agencies, and to participate in education related to caves, cave science and cave conservation.

The geology and hydrology of the karst

of Virginia and West Virginia is being systematically studied. Determination of groundwater flowpaths at specific sites has been under way for some time. Several important groundwater tracings have been made in each state (e.g. Jones, 1973, 1983; Saunders and others, 1981; Ogden, 1976; Werner, 1981). As more of this data becomes available, local communities will be better able to make decisions on land use and economic development.

Local chapters of the NSS in conjunction with other groups (e.g. Boy Scouts and local waste disposal agencies) have been actively cleaning trash-filled sinkholes. Of course, this task is monumental given that thousands of contaminated sinkholes exist in the region (Slifer, 1987; Slifer and Erchul, 1989). Nevertheless, public awareness of the problem is heightened by these efforts and any ensuing publicity.

Problems of sinkhole contamination and efforts at remediation have recently caught the attention of the press in Virginia (Slifer, 1987; Kittredge, 1989). This has led to numerous contacts with landowners who are concerned with properly maintaining their water supplies. Local chapters of the NSS regularly clean caves and sinkholes, leading to favorable publicity in the press (e.g. Farrar, 1989). The Commonwealth of Virginia, through the Virginia Cave Board, produced a large, full-color poster on karst groundwater protection that was distributed to all ninth-grade Earth Science classes in the Commonwealth (Kastning and Kastning, 1990). The Virginia Division of Mineral Resources has likewise published materials on karst designed to educate the public and provide basic data for local communities (Hubbard, 1988, 1989, 1990; Miller and Hubbard, 1986).

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# **PUBLIC RELATIONS AND CAVE CONSERVATION**

by Jay R. Jordan

**Public Relations Committee Chairman  
The National Speleological Society  
1518 Devon Circle  
Dallas, Texas 75217-1205**

## **ABSTRACT**

In an era of increased awareness concerning natural resource conservation, public relations and all of its roles in publicity and helping an organization and its publics accommodate to each other has an important role. Although environmentalists have realized for some time that the earth and treasures within it represent nonrenewable resources, only recently has the general public become aware of the need for cave conservation. Publicity in the form of newspaper and magazine articles and television and radio stories has surrounded efforts to save a number of caves, and at times, the organisms that live within them. These efforts and the publicity they generate are raising the cave conservation awareness of the general public at a time when the future of many caves in urban areas is threatened. Publicity has also surrounded passage of the Federal Cave Resource Protection Act and a proposal to create a cave wilderness designation by congressional act.

### **I. Environmental Awareness**

It's perhaps hard to find anyone who, when questioned, would not want to save the earth's resources for use and enjoyment of future generations. However, it remains a fact that general public awareness on the environment is somewhat limited, and certainly in the case of caves and karst resources. The beginnings of the cave conservation ethic can be traced to the well-publicized environmental

reform movement that began in the 1960s and swelled to a crescendo by the early 1970s. However, some researchers would put the origin of environmental concern much earlier, to the 1930s and 1940s. In 1941, the National Speleological Society was organized for the purpose of advancing the study, conservation, exploration and knowledge of caves. So, too, the NSS was caught up in an environmental movement that has grown since the 60s from a small group of conservationists,

scientists and government officials to a worldwide consciousness. Activities of both business and industry have been impacted by passage of far-reaching state and federal legislation and local laws regulating air and water pollution, solid waste disposal, land use, hazardous substances and noise, among other environmental problems.

The official NSS policy on conservation states: "Caves have unique scientific, recreational and scenic values. These values are endangered by both carelessness and intentional vandalism. These values, once gone, cannot be recovered. The responsibility for protecting caves must be assumed by those who study and enjoy them.

"Accordingly, the intention of the Society is to work for the preservation of caves with a realistic policy supported by effective programs for: the encouragement of self-discipline among cavers; education and research concerning the causes and prevention of cave damage; and special projects, including cooperation with other groups similarly dedicated to the conservation of natural areas."

The Society believes, specifically, that a cave's contents — formations, life and deposits — are crucial to its interpretation and enjoyment. Cavers, therefore, should leave a cave as it was found. The Society motto is, "Take nothing but pictures, leave nothing but footprints, kill nothing but time." (Some cavers have, tongue-in-cheek, proposed that the word "vandals" be substituted for "time".) Cavers should provide means for waste removal; limit marking to a few, small, removable signs as needed for surveying; and exercise extreme care against accidentally breaking or soiling formations, disturbing life forms or unnecessarily increasing the number

of unsightly paths through a cave room or passage. Further, scientific collection should be minimal, professional and selective. It is not justifiable to collect mineral or biological material for display, including previously broken or dead specimens, since others are encouraged to collect and the cave's interest is thereby destroyed.

Over the years, the NSS has encouraged conservation projects, such as creating cave preserves; gating entrances; opposing speleothem sales; restoring and cleaning vandalized or "trashed" caves and backing effective protection laws and other measures. The Society also urges cooperation with private landowners by providing knowledge about their cave and aiding them in protecting it and other property from damage during visits, and encourages commercial cave owners to help educate the public to understand caves and the need to conserve them. The organization has traditionally opposed publication of cave locations where there is reason to suspect that it could lead to vandalism before adequate protections can be put in place.

Surveys over the years have indicated that many people have discovered the needs of the environment, and want to "save" it. But few have knowledge of specific resources or the information on how to go about the task of conservation. For example, in 1971, air pollution was considered a problem by 41 percent of the general public. By 1975, that number had dropped to 25 percent, along with a corresponding decrease in the number of people concerned about water pollution. In the early 70s, a number of challenges in air and water pollution were met and great efforts made to overcome them. Figures show that industry expenditures to clean up air and

water exceeded \$1.5 billion in 1975 alone. So, interest in conservation appears to be cyclical and dependent upon success of efforts. Another, later study showed that 75 percent of those surveyed adopted a pro-environment attitude and believed that more efforts should be expended.

Cave conservation efforts have, to a limited extent, been pulled along by the bootstraps of larger environmental issues. Concern over groundwater pollution, for example, has spilled over and into cavers' efforts to educate landowners about dumping of refuse into sinkholes and other problems. A brochure, "You and Your Cave," explored some of these concerns. Worries about pollution and recharge in the Edwards Aquifer, which provides drinking water to a Texas metropolitan area of more than 1 million people, and in caves near Pindall, Ark., which form part of a recharge zone into the Buffalo National River have generated regional and national publicity in the last three years. A plan in 1989 for a government agency to detonate explosive charges in the Del Rio, Texas area to test methods of withstanding nuclear attack prompted a petition drive by residents and debate on Capitol Hill that resulted in the project's abandonment. Another possible controversy looms in the form of a plan to locate a toxic waste dump in the area of one of Texas' deepest caves near the state's far western mountainous region.

## **II. Public Relations and Cave Conservation Problems**

Public relations practitioner Edward L. Bernays, in his "The Engineering of Consent", wrote, "Public relations is the attempt, by

information, persuasion and adjustment, to engineer public support for an activity, cause, movement or institution." In this decade, cavers on local, regional and national levels have been using PR to mold public opinion on cave conservation issues. As with other environmental problems, reactions of business and government officials to cave resource threats runs the gamut, from a total denial that a problem exists to a partial admission and agreement with conservationists. Taking a middle ground, though, many leaders confronted with cave conservation threats are reluctant to immediately admit a problem exists but, in the event it can be proven by clear and convincing evidence, are willing to work to solve it.

This was the case in the Del Rio blasting plan, where federal officials were reluctant to face the problem until it was shown a strong likelihood existed that explosive charges would fracture rock layers that could alter or stop the flow of large springs that supply municipal drinking water to the community. And, in the case of the Buffalo National River, Tom Aley of the Ozark Underground Laboratory was instrumental in mounting a publicity campaign against the proposed toxic waste dump, including completion of dye tracing that showed water from caves near the site flowed into the waterway.

The policies of organizations that have coped successfully with environmental challenges, when reviewed, show that upper managers, in nearly every instance, have placed a high priority on environmental considerations. A ranking of the successful organizations' priorities shows conservation goals get top billing along with profits, capital equipment, manpower, raw materials, sales

and taxes. Other organizations, less successful at dealing with environmental threats, may focus on the costs associated with meeting them. With the profit motive one of the foremost considerations in a free-market economy, some companies take a balanced approach, weighing the need for continued economic development with improvement and preservation of the natural environment. Today, many confronted with global environmental issues—the greenhouse effect, global warming, ozone layer depletion, etc.—realize we indeed live on a fragile space ship and that, eventually, it may be shown that no cost is too great to preserve life on earth.

In public relations, environmental issues are considered difficult because they have many ramifications and are often intertwined with additional socioeconomic problems. Because of this fact, some of the standard “textbook” PR techniques and procedures don’t always work. Practitioners have had to devise new approaches to some of these problems and adapt other, time-tested communications techniques. Even more complicated are cave conservation issues, because they are often comprised of other, distinct environmental problems. In cave conservation, a problem may involve any or all of the following: vandalism, water pollution, solid waste disposal, land use, pesticides, toxic wastes and other substances, air pollution and others.

Like target markets in advertising, the publics or audiences that conservation publicists hope to reach are many. They include specialized and general media organizations, business management, corporate stockholders, employees, governmental officials, community leaders, citizens’ and environmental groups,

and even academic and scientific groups.

To tackle a cave conservation problem, the issues must, of course, be identified. All of the available facts on the situation must be assembled, preferably through a “public relations environmental inventory.” It becomes a specific checklist for developing cave conservation PR. It’s also a good idea to prepare “backgrounders” in depth on every aspect of the conservation problem. Hopefully, some sort of an “early warning system” is already in place so that cavers are not caught by surprise when a cave is threatened by developers or some other problem arises. In Austin, some of the local grotto members have established contacts with municipal agencies and others who inform them when a cave is in danger of being bulldozed in a new housing development or some other threat appears. It also helps that the city has a watershed ordinance that protects caves and recharge zones to some extent.

That said, the establishment of contacts with appropriate governmental, environmental, scientific and academic groups is important. The NSS is affiliated with the American Association for the Advancement of Science and, as such, possesses potential resources in the scientific and academic areas. Also, many cavers are professionals in various scientific and academic roles and their expertise can be brought to bear in many cases.

Cavers must be prepared to meet threats and criticism promptly and forcefully. Media organizations often have tight deadlines, and news releases that arrive too late simply have no impact. In light of that, cavers seized the opportunity for some positive publicity this year when a member of the Carlsbad, N.M. mayor’s task force on Lechuguilla Cave accused

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cave explorers of cutting a deal with government agencies and obtaining their own "private Disneyland" through the Lechuguilla Cave Project Inc. An NSS news release, mailed and faxed promptly to all appropriate New Mexico media groups, knocked down these allegations and quoted a respected New Mexico geologist who, as it happened, planned to address the city panel the next week. So the release contained another good news angle as a bonus! Preparation of news releases goes beyond the course and scope of this paper, but the techniques of these PR tools lend themselves quite well to cave conservation.

Using the "no brag, just fact" approach, it's a good idea for cavers to publicize any successes in gating projects, vandalism deterrence, etc. early and often through every available means. Daily and weekly newspapers, magazines, electronic media (television and radio stations), wire services and other media are hungry for news. Caves, and especially emergencies involving them, have good news value as a general rule.

Organizations that lead in cave conservation have discovered that, through many methods, it's wise to have an ongoing environmental inventory. In the NSS, an active Conservation Committee oversees a Cave Wilderness Subcommittee, concerned with passage of legislation to create such a designation. Lobbying, a PR tool, is used in this regard, as it was with passage of the Federal Cave Resource Protection Act. The NSS created a professional multimedia show on underground wilderness and presented it to members of Congress and others. Society members testified in hearings on Capitol Hill and aided in the legislation's passage. The NSS Conservation and Management Section

and its members have also been instrumental in this and other environmental efforts. Members try to keep abreast of every major development in the cave conservation scene and anticipate changes that may affect the Society and cavers.

As was mentioned earlier, the NSS has promulgated a conservation policy statement. This helped its members as a whole set priorities in conservation. The Conservation Committee has also designed and printed two sets of cave brochures, one for cavers and another for non-cavers. They contain strong cave conservation messages. To help in assembling, analyzing and interpreting data on the cave environment, the Conservation and Management Section publishes a newsletter, *The Cave Conservationist*. It has a mailing list of hundreds and is also distributed frequently to grottos and other NSS internal organizations. Other informational materials on cave and bat conservation are also available from the NSS, including the "Bats Need Friends" series. It includes brochures, T-shirts and other promotional items. The Society strives through various publications, including *The Conservationist*, to keep members informed of cave conservation programs and plans, and especially of their roles in such projects.

Many experts are available both from NSS membership and allied groups to help in cave conservation. One task of public relations is to communicate technical information to laypersons. Geologists, biologists, hydrologists and others may mean what they say but they can't always say that they mean so that the general public can comprehend it. In communicating with the scientific community, cavers can use (1) publication of scientific materials in appropriate journals, (2) letters to

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the editors of such journals, (3) journal advertisements, (4) articles in the semiprofessional press, (5) direct mail to well-targeted groups, (6) seminars, symposia and other scientific meetings and (7) personal visits to selected scientific leaders.

Through all the publicity, tools available, the NSS and cavers can do a lot to establish their reputation for credibility in the conservation area, by acts as well as words. One byword in public relations is to demand strict accuracy in all materials relating to cave conservation. It is important that every major point in cave conservation communication be supported by scientific documentation. That makes it much easier to fend off sensationalized attacks in the press and to maintain good will.

Cave publicists dealing with the environmental press confront special problems. Several rules are kept by successful PR people in such dealings. First is the old adage, "Know your editor and know his book." Publicists should take time to read up on the publication and its writer so that there won't be any surprises. Secondly, conservationists must know their subject matter well.

Some have been left feeling stupid by sharp-witted and quick-tongued reporters and editors. And, finally, look for news angles that the pros may not have thought of. The news can be how dirty, polluted or vandalized the cave is. But a more far-reaching story is what are the clean-up costs and methods, what is effective and what isn't and who will pay for it. Asking more questions than you answer to a reporter is a good guideline for how things are going.

In this decade of renewed environmental activism, there are more controversial tactics in cave conservation. Surprisingly, some

beleaguered caves have their own champions, akin to the Greenpeace organization. In Austin, Texas, when Tooth Cave and other nearby caves were threatened by development for a shopping center, members of Earth First! staged a sit-in of sorts at the caves in protest. The move was effective in that it did grab headlines and publicize the problem, in much the same way that Greenpeace has gotten international attention — and results — by storming illegal fishing vessels and confronting baby seal clubbers. But there are dangers from this technique. On the down side, it is very confrontational and can create its own crisis. In the case of Greenpeace, ships can be blown up. In the Earth First! instance, members were jailed on criminal complaints. Also, better coordination with caving groups could have ensured that the activists were better versed on the issues involved in saving the caves. At the time, one Austin caver publicly criticized the activists' methods, saying a more toned-down approach might have worked. In this regard, publicity is sometimes a gamble. Cavers and friends of caves have to decide whether the benefits are worth the risk. As it happened, one outcome of the Tooth Cave controversy was that cave gating projects were started and a government-backed project to identify any rare species of organisms within the caves was begun.

### III. Conclusion

Over the past decade, cave conservation has progressed from a little-known offshoot of the environmental movement to attain a place of its own, with the attendant publicity which that position generates. Perhaps the best examples of this phenomenon have occurred over the last three years, initially with national news coverage of a small Arkansas community's efforts to fight a toxic waste dump's placement in a caving area. More recently, at least two of the three national television networks carried enterprise stories about Lechuguilla Cave in New Mexico and cavers' efforts both to save it from commercialization and also to help create an underground wilderness within. Garnering national publicity for a cause is crucial to molding public opinion. From that, practices and laws can be conformed with conservation goals. Cavers and their organizations, with the help of business and government, are making these changes with a campaign that comes, literally, from below the grassroots.

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## ENDANGERED FROM CAVES NEAR AUSTIN, TEXAS

by William R. Elliott, Ph.D.  
Texas Speleological Survey  
12102 Grimsley Drive  
Austin, Texas 78759

### ABSTRACT

Five troglobitic species from the Austin, Texas region were listed as endangered in 1988. Subsequent field studies have expanded the known ranges of some of the species, but most are very limited in distribution and vulnerable to numerous threats. Karst preserves may be set aside to protect the species.

A study was conducted of 32 caves in the Austin, Texas, area to clarify the status and range of five endangered arthropod species. The study was supported by the Texas Parks and Wildlife Department and the Texas Nature

Conservancy as part of a group of endangered species studies for the Austin Regional Habitat Conservation Plan, now called the Balcones Canyonlands Conservation Plan (BCCP). The BCCP is a committee of state and local agencies, developers, and conservation groups begun on the recommendation of the U.S. Fish and Wildlife Service (Elliott and Reddell, 1989).

The five species of endangered cave arthropods are: *Texella reddelli* Goodnight and Goodnight (1967), the Bee Creek Cave Harvestman; *Microcreagris texana* Muchmore (1969), the Tooth Cave Pseudoscorpion; *Neoleptoneta myopica* (Gertsch) (1974), the Tooth Cave Spider; *Rhadine*

*persephone* Barr (1974), the Tooth Cave Ground Beetle; and *Texamaurops reddelli* Barr and Steeves (1963), the Kretschmarr Cave Mold Beetle. These species had long been known and studied by a number of researchers under the auspices of the Texas System of Natural Laboratories (Reddell, 1984). The species were listed by USFWS in response to a petition initiated in 1986 by the Travis Audubon Society (Chambers and Jahrsdoerfer, 1988). Since the listing, several hydrogeological and biological studies have been commissioned in the Austin area (Veni, 1988b,c; Reddell, 1989).

Texas has a diverse cave fauna with over 900 species recorded (Elliott, 1978a; Reddell, 1965, 1966, 1970, 1971). About 210 species are troglobites, but only 102 of these troglobites are described. Tooth Cave has the most diverse cave fauna in the Southwest U.S. and contains four of the endangered species under study. The known distribution of most

of the five species seems to be limited to a portion of the Jollyville Plateau. The Jollyville Plateau is an irregularly shaped outcrop of Edwards Limestone, about 5 miles in diameter, located just northeast of the Colorado River and Lake Travis in northwestern Travis County.

Based on the Texas Speleological Survey database and Veni (1988a), at least 5% of the approximately 2,500 known caves in Texas have been destroyed or filled. However, in the areas around San Antonio and Austin, intense urbanization has resulted in a 20% loss of known caves in the last 20 years. A projection of this 20-year destruction rate for Travis County indicates there may be only 73% of the caves left in the year 2000. By the year 2010 there may be about 66% left. By the year 2100 there may be only 7% (12 caves) remaining.

The restricted distribution of many troglobites results in their extreme vulnerability to extinction. Physical destruction of the cave, pollution by pesticides and other substances, introduction of foreign species such as fire ants, disruption of groundwater, and loss of habitat for species such as bats and cave crickets which provide food for the ecosystem may all play important roles in the extirpation of the cave fauna. Habitat protection and land use planning are much more effective methods of conserving arthropod species than are last-ditch rescue efforts. (Elliott, 1978b, 1981).

Results of the study are as follows:

1. The range of one species of beetle (*Rhadine persephone*) was found to extend beyond the area of The Parke subdivision on

the Jollyville Plateau to three caves near Cedar Park, about 6 miles north. However, these caves are imminently threatened by land development.

2. The range of one species of spider (*Neoleptoneta myopica*) was extended to a cave about one mile south of The Parke. However, this cave is threatened by its proximity to a new highway under construction.

3. The range of the harvestman species (*Texella reddelli*) has been tentatively revised by recent taxonomic study of old and new material, which indicate that this species is actually limited to three caves south of the Colorado River. One of these caves is under secure protection and one is moderately well protected. The status of the third is uncertain. *Texella reddelli* does not occur in the Tooth Cave area as previously thought. There appear to be other, as yet undescribed *Texella* species in the Austin area. The Tooth Cave harvestman is a new species that appears to range from The Parke area to West Austin to near Round Rock in perhaps nine caves. Few of these caves are protected from land development and human disturbance.

4. No individuals could be found of the pseudoscorpion *Microcreagris texana* and the mold beetle *Texamaurops reddelli*. These species are typically rare in numbers and therefore difficult to study. However, it is possible that unfavorable ecological conditions have already affected their abundance, or else they are actually limited to only a few caves.

5. Several possible new species were revealed during the study: six new species of *Cicurina* (*Cicurella*) spider, one new *Microcreagris* pseudoscorpion, and a cave-adapted *Eurycea* salamander.

6. The study increased the understanding of Texas cave biogeography, which has had a long and complex evolutionary history.

7. A number of different habitat management remedies are proposed and their relative merits considered. The proposed remedies will be further considered by the BCCP. Actions could include negotiating the donation or purchase of land for small preserves around some of the caves, fencing and berming these preserves and protecting the native vegetation, gating some entrances, public education and cave stewardship programs supported by the City of Austin and the Texas Nature Conservancy, and long term ecological studies of some of the caves.

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## **West Cave: Management, Problems and Solutions**

by **John Ahrns**  
**West Cave Preserve**

### **Abstract**

A deep, cool canyon with a cave and waterfall cuts into the oak and cedar grasslands of the Hill Country. West Cave Preserve, a moist sanctuary for cypress, moss and ferns that line spring-fed pools, seems out of place in the drier surrounding land. Left undeveloped through the years, West Cave acquired a reputation among campers who crept in, sometimes illegally. Also known as Hammett's Cave, it was rapidly vandalized. In 1974, John Watson bought the cave and founded West Cave Preserve. Due to funding problems, the land had to be sold in 1981 to the Lower Colorado River Authority, who then leased it back to the corporation for 99 years.

Starting in 1974, when West Cave was purchased, funding has been a problem for this private cave preserve. The land would have to be restored before it could be open to the public. Under the caretakers' supervision, volunteers carried out trash and built and maintained trails. During John Ahrns' stewardship, the preserve became more beautiful each year. Dedication alone was not enough to prevent the land from being sold to the Lower Colorado River Authority, who leased it back. Problems and low-cost solutions are part of the West Cave heritage.

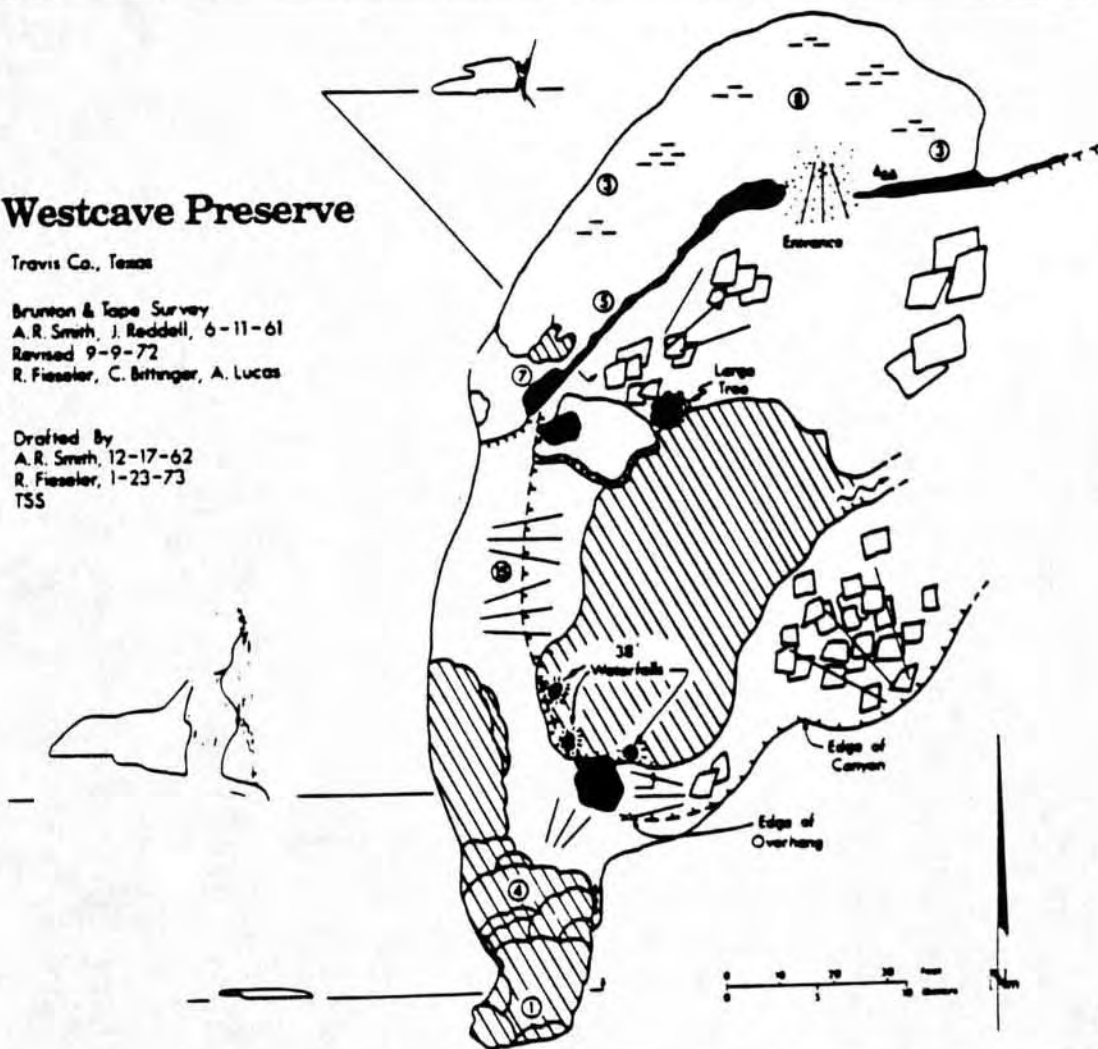
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## Westcave Preserve

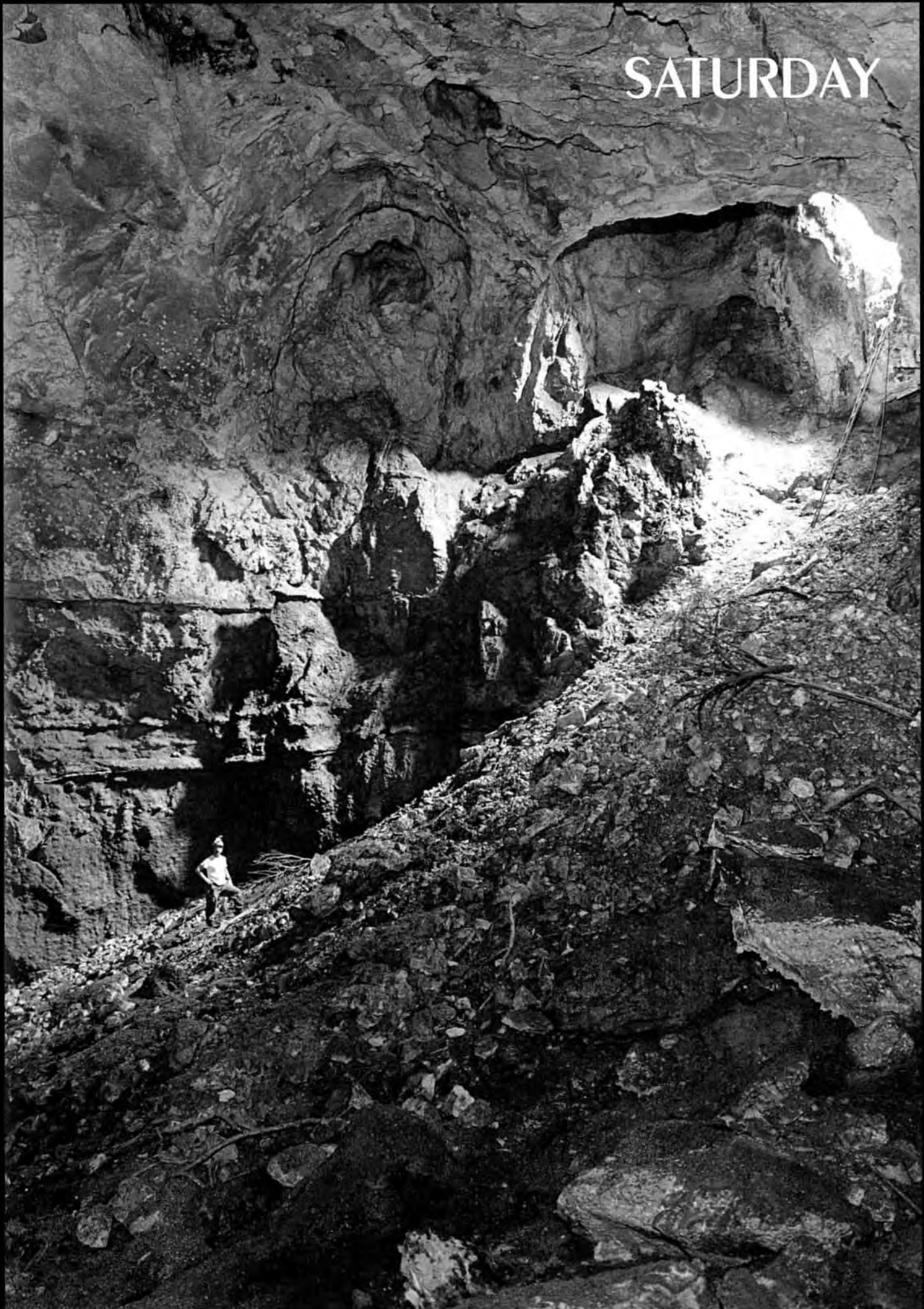
Travis Co., Texas

Brunton & Tape Survey  
 A. R. Smith, J. Reddell, 6-11-61  
 Revised 9-9-72  
 R. Fieseler, C. Bettinger, A. Lucas

Drafted By  
 A. R. Smith, 12-17-62  
 R. Fieseler, 1-23-73  
 TSS



SATURDAY



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## **The Overused or Abused Cave Resource: Problems and Solutions**

by David G. Foster  
American Cave Conservation  
Association  
Horse Cave, Kentucky

### **Abstract**

The overused and abused cave resource is a reflection of the way the American society views cave resources. For most Americans, caves are a recreational resource. The public does not relate caves with anything relevant in their own lives. A small percentage of the nation's caves are plagued by overuse. Some are developed as publicly or privately operated show caves. Most major karst regions have a few wild caves, such as Virginia's New River Cave, which have become popular among the locals. High numbers of visitors to these caves make adequate protection of the resource difficult. An even larger percentage of the nation's caves are being abused by actions occurring on the surface. Poor land management above a cave system often equates with destruction of the underlying resource. These two areas of overuse and abuse are examined.

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An even larger percentage of the nation's caves are being abused by actions occurring on the surface. Poor land management above a cave system often equates with destruction of the underlying resource. It is these two areas of overuse and abuse which will be examined in this paper.

The damage done by actual visitors to cave systems includes everything from intentional vandalism to lent left from the visitors clothing. It includes algal damage from poor lighting systems in show caves. It includes the three men who killed several hundred bats in a Kentucky cave several years ago. It includes National Park tours which run a hundred visitor per tour into the cave. It includes the fellow who writes his name on the wall and the adventurer who leaves the first footprint in an unexplored area.

Many of these problems can be addressed by increasing our educational efforts. Human nature makes it unlikely that we can ever completely stop vandalism from occurring nor will we stop cavers from being curious. The best we can do is create an environment that discourages vandalism and makes it harder to do actual damage.

In some places protective gates must be constructed. We must actively manage highly visited developed and undeveloped caves, discourage overvisitation of undeveloped caves, and encourage the establishment of low impact trails. Conservation should be a main

theme of any novice trip.

The same considerations apply to public and private show caves. The show caves must promote visitation to survive, however, there is much they can do to protect their investment by developing lighting systems which reduce algal growth, incorporating conservation into their public message, and basically generating an atmosphere that gives the public the impression that they are in a preserve or a museum, not an amusement park.

Our nation's most highly visible national parks should be encouraged to take a radical step. Caves such as Mammoth and Carlsbad Caverns are under a congressional mandate to promote and regulate their use...by such means and measures as conform to the fundamental purpose of said parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations. (16 USC 1)

Some of our national parks apparently interpret the use of the word "promote" to mean running as many people through a cave tour as can be convinced to go! This cave management strategy leads to a low quality cave experience by thousands of people each year. To the American mind, importance is often assigned to an object based on its rarity and its ability to entertain. The Macdonalds approach used by the National Park service contributes greatly to the devaluation of caves in the public perception. This perception should be altered.

A larger problem affecting many caves is the impact of surface activities which ignore underlying geologic conditions. In rural

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America dumping in sinkholes is a major problem and one which is often compounded by well meaning solutions.

One of the best known examples of a polluted cave system is Hidden River Cave in the City of Horse Cave, Kentucky. Both the cave and the City's water supply were threatened by numerous sewage discharges in sinkholes and rock fissures by local households and businesses in the 1930's and 1940's.

The solution: The town built a wastewater treatment plant in 1964 and began disposing all of the "treated sewage" into one big hole in the ground...upstream from Hidden River Cave. Over 10 million dollars and 25 years later the problem is still being corrected and citizens of Horse Cave live with the odor of sewage in the downtown air.

Hidden River Cave should be viewed in a similar manner as the canary in the mine. The canary that dies when the air goes bad serves as a visible example that something bad is occurring in the mine. Hidden River Cave serves as a visible example that something bad is happening to groundwater in America's karst regions. The canary died in Hidden River Cave more than 40 years ago. The locals are just now beginning to see the light. The difficult job is to convince those that don't live within smelling distance.

A similar mistake is often made in the name of solutions to solid waste disposal problems. In Hart County we are asking citizens to stop dumping in sinkholes, yet our only legal landfill serves as recharge for a significant karst area.

Thousands of communities across the nation are under pressure to find an adequate sit to dispose of garbage. Rather than pay the

cost of recycling, most would rather dispose of waste in a dump, preferably in someone else's backyard.

Karst regions are poor places to put solid waste dumps. Soils are usually thin and good sites are hard to find. To those unfamiliar with karst it seems natural to dump in a sinkhole, after all, they are found and deep like a trashcan.

Recently a proposed landfill was nearly sited which threatened the Buffalo National River. The landfill was defeated in a court battle with the help of the ACCA, NSS, the National Park service and the Ozark Underground Lab.

The case should never have come to court. Despite strong scientific evidence showing the landfill to be poorly sited, and strong opposition by locals and the aforementioned groups, the Arkansas Department of Pollution and Ecology approved the permit.

The American Cave Conservation Association is now involved with a similar situation in Hart County, Kentucky. A landfill permit in an area pockmarked by caves, sinkholes and sinking streams is under review by the State of Kentucky. This landfill may affect the main water supply for 6 counties and Mammoth Cave National Park.

Green River Environmental, the firm developing the landfill, insists that the site is not located in a karst terrain. Situations such as this are likely to become more commonplace as available landfill sites become filled, unless we can mount a major public awareness effort against the siting of landfills in porous karst terrains.

A variety of other problems relating to surface use continue to beset cave systems in highly populated areas. Change the surface runoff by constructing a parking lot and you

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change the conditions that created the underlying cave. Fill in sinkholes for development and you not only change the cave environment, you create a potential flooding or subsidence problem.

Clearly it is in the nation's best interest to understand the nature of karst terrains and land use problems in these areas. By helping the public to prevent karst related mistakes, we can inadvertently protect the caves as well.

In conclusion, significant progress has been made since the 1980 National Cave Management Symposium highlighted groundwater problems in the central Kentucky karstlands. Since that time there has been a big increase in cooperative efforts among cavers and federal agencies.

Numerous caves have been acquired by the Nature Conservancy, NSS Grottos, and various individuals for the purpose of preserving their environmental and recreational value. The American Cave Conservation Association was established in this decade as a new voice in cave conservation. The United States Congress recently signed federal cave legislation into law. Much has been happening ... but not enough!

Despite the major increases in available cave management information and expertise, the American public for the most part remains ignorant of caves and problems associated with caves. The maxim, "out of sight, out of mind" applies practically without exception to caves in the public perception.

If it is true that scientists talk mostly to other scientists, the same can be said for resource managers. Twice a year we meet at the National Cave Management Symposium to present our "solutions" to cave management problems. If we are going to solve the

problems of the next century the public must be involved. Essentially, we the "technicrats" must become the "communicators". Likewise, America's communicators must become better informed.

This theme was recently addressed by Tom Aley at the 1989 convention of the National Cave Association, representing the nation's show cave operators. The NCA as a whole reaches over 8 million tourists each year, yet there is little contact between these professional cave communicators and scientists, federal and nonprofit cave managers, and cavers. The show cave industry could help us build the bridges we need to reach the public with our message.

Additionally we need to focus more effort on improving the quality of earth science teaching in our nation's school systems. In many schools earth science is taught only at the Jr. High level and is given little emphasis. Perhaps every student doesn't need to know how to build a rocket engine, but everyone should understand the nature of the land upon which they live.

Anything less implies more than scientific illiteracy, it implies a basic lack of skills necessary for survival in a world of finite and abused resources. I won't begin to address the needs for updating our schools here, however, I suggest that this is an area where most of us can easily have a big local impact. Education is at best a long term solution which does not provide easily documented results. It is, however, the direction we must go to protect caves. The public doesn't give a damn about anything that it doesn't understand and value.

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## MANAGING BAT CAVES

by

**Matthew Stafford**  
**U.S. Bureau of Land Management**  
**Carlsbad, N.M.**

### ABSTRACT

While the primary management concern for a known bat cave may be protection of the resident bat colony, carefully regulated recreation and scientific use can be allowed. Restrictions on the level or seasons of use can mitigate impacts on the colony. Several bat caves on public lands in sotheast New Mexico have been the subject of bat population studies. These caves are used as examples of managing caves for protection as well as public use.

### Need for Special Management

Bats are highly beneficial to mankind and fill a vital ecological niche. A large colony of bats can consume tons of night-flying insect pests each summer night. The bats themselves often act as primary energy producers for an entire spelean ecosystem. The guano they produce and the bodies of dead bats provide a habitat and food source for hundreds or thousands of insects which, in turn, are food for higher level consumers.

Caves that provide habitat for cave-dwelling bats need special management attention. Many species of bats will abandon a roost site if unduly disturbed and may not be able to find another suitable one. Hibernating bats will burn up important fat reserves if disturbed enough to cause arousal from hibernation and may not survive the winter.

Species such as the Indiana Gray Bat, and subspecies of the Big-Eared Bat are listed as threatened or endangered by the U.S. Fish and Wildlife Service. Several other species have been placed in Category 2, which means that they are currently under study for listing. In many cases, habitat disturbance or destruction is listed as a factor in the declining population numbers. Thus, it is extremely important to address an indigenous bat colony in any cave management plans.

### Use of Caves by Bats

Bats will use a cave for the following reasons: 1) As a **hibernaculum**. Bats that hibernate will choose a fairly cold cave as a winter roost. In the Southwest, they will begin entering the cave in late fall, gradually increasing in numbers up to a peak count in mid to

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late January. Then the population will decrease until they have all left by the end of April.

2) As a **nursery site**. Nursery caves or rooms are generally warmer and may contain a high ceiling or dome. Males will roost in another room of the cave or a completely different location. The young are usually born by the middle of June. 3) As a **transient or temporary roost**. Migrating bats will occasionally 'stop off' at a cave along their migration route to spend a few days before moving on. This occurs in the migration seasons and is the reason why late spring and early fall populations are larger than mid-summer. Some bats will use a cave as a temporary night roost during their feeding forays.

Hibernating bats are sensitive to the environmental factors of their roost site. Temperature, humidity and airflow all must fall within a narrow range to be acceptable. In Fort Stanton Cave, New Mexico, the bats will move from location to location in the early part of the season to find a suitable microclimate. During deep hibernation, the bat's body temperature drops to within a few degrees of the surrounding temperature. All metabolic functions will slow tremendously. When a bat is disturbed enough to cause arousal from this state, significant quantities of stored fat are used to facilitate arousal. Awakening from and returning to hibernation over a several hour period uses as much fat energy as staying in hibernation for 2 to 3 weeks (Poulson, 1975). There are no insects about to feed on so the fat reserves cannot be replenished and the bat may starve before spring.

Another critical period in the bat's lives

is the time just before, during and after the young of the year are born. Human disturbance then may cause the colony to leave the nursery site or abandon the young.

Bats may be observed in some manner without negative effects. Hundreds of park visitors watch the bats fly out of Carlsbad Cavern each summer evening. This has been going on for sixty years but the population is stable and may be increasing. Summer bat counts are most easily conducted by counting the bats as they leave a cave.

### Use of Caves by Humans

Recreational use is the most common use of caves in the United States. There are four active Grottos and a Region of the National Speleological Society in the vicinity of Southeast New Mexico. Several hundred people a year enter each of the more popular caves managed by Bureau of Land Management (BLM). Some of these caves also contain bat colonies at certain times of the year.

Other reasons people visit BLM caves are for educational or scientific purposes. The science of speleology is still a young one and growing rapidly, so there is much to be learned about the world below. Researchers and educational groups visit caves as part of their studies. Studies of bat populations and their habitats are included.

### Management Strategies

A management strategy, or plan, will prescribe the management actions for a cave for several years. The advantage of having a written plan of action is to provide a consistent management policy in the event of personnel

changes.

A first step in developing a management strategy for a cave is to evaluate the need for regulation of use. Current levels of use, future potential and the sensitivity of the resource (bats) to disturbance need to be assessed. The more valuable a cave is in terms of its scenic, scientific and recreational opportunities and the more vulnerable it is to damage, the higher the need for active use regulation. The higher the level of public awareness of the cave and its location, the greater the need for regulation (Thornton, 1986).

If a management plan is written, it should contain a section on acceptable levels of change to the resources and the consequent actions to take place if the levels are exceeded. An adopted management strategy should be dynamic and subject to modification to meet any new situations which might arise.

Several strategies have been used by BLM to protect bat roosts: Spatial Restrictions - Closing off a room or passage to protect a nursery site. This will work if the nursery site is situated away from the primary travel routes. The closed areas are marked by flagging or explanatory signs. Seasonal Restrictions - Recreational use is limited to the times of year that bats are not in the cave. For example, use is allowed during the middle of the year for winter roost caves and in the winter for summer roosts. Cavers are directed to other caves during the closed season. Another type of restriction based on time is to allow caving trips in only at night after the bats have left the cave for their nightly feeding flights. Guided Trips - Having a caving trip led by a BLM employee or volunteer provides some control over the group's activities. This includes

avoiding undue disturbance and entrance to closed areas. Cave Gates - To impose the restrictions stated above it is usually necessary to install a gate. Great care should be used in the design of the gate. A poor design can defeat the purpose of such a protective structure. It may cause alterations in the cave environment by interrupting or changing air and water flow and by interfering or blocking the movement of wildlife such as bats to and from the cave (Thornton 1986). In one cave that acts as a nursery roost, BLM has tried leaving the gate door open when the bats are absent and locking it when the bats return in the spring. This is one form of a seasonal restriction. Interpretation - Interpretive talks, guided tours, literature and displays can help to improve the public's appreciation of bats. If the public appreciates bats, then they will be more likely to abide by any restrictions enacted to protect them. An agency's role in the protection of endangered or threatened species of bats can be the basis for an admission of pride in its program (Mohr, 1975). All personnel that come into contact with the caving public should be informed about bats and cave management.

### **Monitoring**

Monitoring the status of the bat colony and the level of use is important in evaluating the effectiveness of any management strategy. The population should be censused periodically to determine its stability. If a decline is occurring, possible measures to rectify the situation need to be developed. These may include additional restrictions on use, modification of existing gates, restoration of excavated entrances or other methods

depending on the situation.

If a management plan is written, the section on acceptable levels of change should describe the consequent actions to take place if the levels are exceeded.

### Bat Population Studies

I have been conducting hibernating bat population studies in Crystal Caverns, Crockett's Torgac and Ft. Stanton caves. The species of bats involved were Western Big-Eared (*Plecotus townsendii*), Cave Myotis (*Myotis velifer*) and Small-Footed Myotis (*Myotis subulatus*). The studies were conducted by entering the caves during the hibernation season (October-April) and manually counting the bats. In the case of the Cave Myotis, the bats were often too closely packed together to obtain an accurate count, so an estimate of the ceiling space covered by bats was multiplied by a conversion factor of 158 bats per square foot (Barbour and Davis). Temperatures were measured for each hibernaculum area.

### Fort Stanton Cave

Fort Stanton Cave is a winter roost only, and counts have been taken here since 1977. The resulting eleven years of data are presented in Figure 1 (two species added together). These results seem to show a five-year cycle of high and low population numbers. High peak counts were recorded in the 77/78 season, five years later in the 82/83 season and again five years after that in the 87/88 season. Low counts were recorded in the 79/80 season and in 85/86 (the low may have been in 84/85, but data is missing). If this pattern continues without extreme troughs

(less than 450 bats) then the population would be considered stable.

During the entire study, recreational cave trips were allowed. The limits were established at one trip per month during the hibernating season, and guided tours only. The purpose of having a guide is to make sure that the party moves through the hibernating area quickly and quietly, so as not to disturb the bats.

### Torgac Cave

Torgac Cave is unusual because it acts as both a hibernaculum and a summer nursery site. A warmer, remote room in the cave provides a nursery for about 2,000 Cave Myotis. The nursery is closed to visitors and is far enough from the primary travel routes that disturbance is avoided. In winter, Cave Myotis, Western Big-Eared and Small-Footed Myotis are found hibernating in almost all accessible passages. The Cave Myotis seem the most easily disturbed, so the areas of the cave that they prefer are avoided by the BLM-led trips. Visitation is restricted during the hibernating season.

### Summer Roost Sites

Summer censuses are being conducted at several caves in the Carlsbad area. The counts are taken by observing the bats as they exit the caves. Cave Myotis and Mexican Free-Tailed (*Tadarida brasiliensis*) are the primary species here. The summer roosts in these caves are generally in isolated cave passages or rooms away from the main travel routes. They are closed to visitation and roped off. If the cave specialist determines that disturbance of the nurseries is occurring, fur-

ther protection measures will be imposed.

In summary, protection of a resident bat colony and its cave habitat is highly important and should be addressed in any cave management activities. Some type of plan or management strategy should be prepared to set policy for a particular cave. While many protection actions require closing the cave to visitation, some carefully monitored recreational use may be allowed. BLM in southeast New Mexico has managed caves containing bat colonies for several years and has conducted studies to determine when the bats are in the cave, how they are using it and what disturbs them. Information gathered from these studies is used to formulate cave-specific management plans for future guidance.

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## Radio Surveillance of Cave Resources

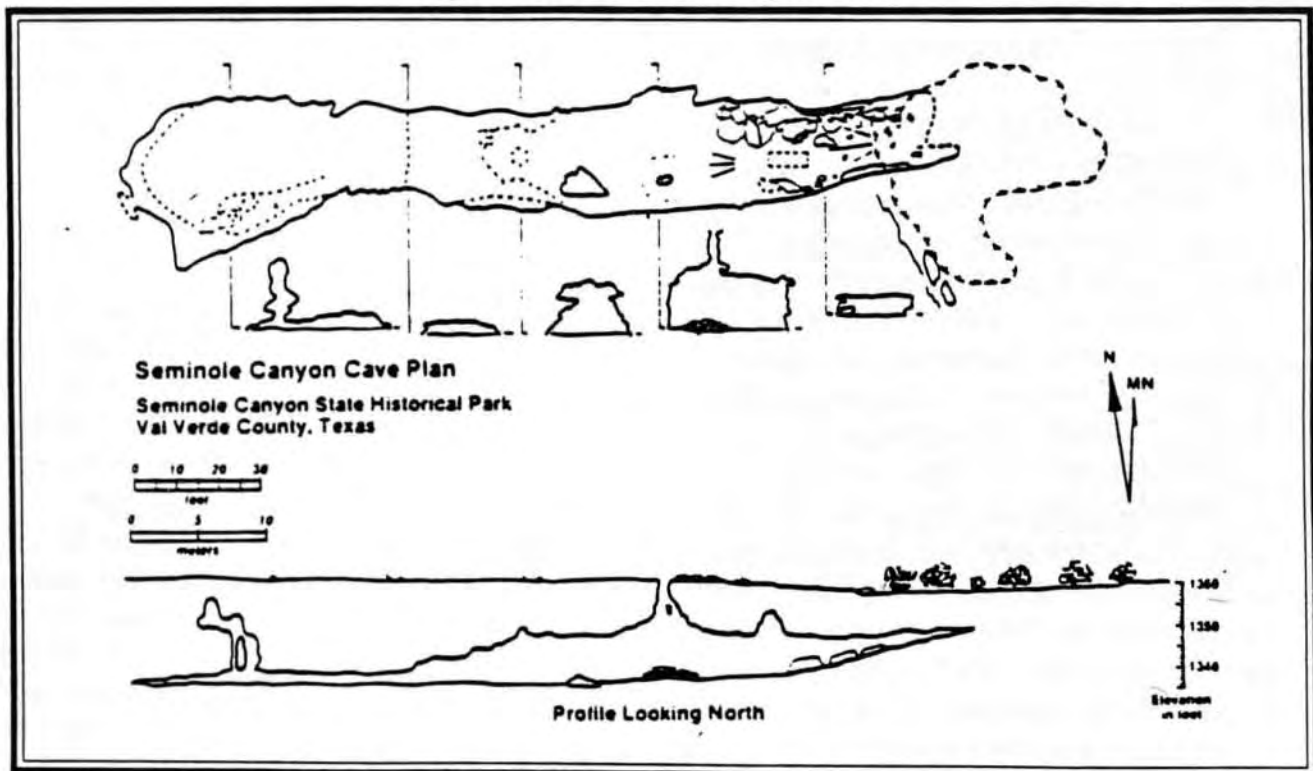
by

**Barry Bennett**  
Texas Parks and Wildlife Department  
Del Rio, Texas

### Abstract

Because of remotely located shelter cave rock art at Seminole Canyon State Historical Park, the Texas Parks and Wildlife Department installed surveillance devices. This case study discusses the system's detection and remote alerting of park staff of intruders in restricted areas of the park, which is rich in prehistoric rock art and artifacts.

**Figure 1. Seminole Canyon Cave**



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## **BLM — Solving Cave Management Problems Through the Planning System**

by

**James R. Goodbar - BLM Cave Specialist  
Carlsbad, New Mexico**

### **ABSTRACT**

The primary method for solving major issue related, problems within the Bureau of Land Management is its planning system. The Bureau is directed to initiate a planning process by the Federal Land Policy and Management Act of 1976. The Federal Cave Resources Protection Act of 1988 requires that caves are considered in that planning process. The Bureau uses a Resource Management Plan and an Activity Plan to address the issues surrounding resource management conflicts and provide solutions in a multiple use agency. This paper discusses the process and components of the Resource Management Plan and the Activity Plan.

One of the primary problem solving mechanisms used by the Bureau of Land Management (BLM) is its' planning system. The precepts of this system are outlined in Section 202 of the Federal Land Policy and Management Act (FLPMA) of 1976. The basic foundation of the BLM planning system takes into consideration several different concepts and principles in order to develop a coordinated plan. These include: 1) the principles of multiple use and sustained yield, 2) a systematic interdisciplinary approach, 3) protection of areas of critical environmental concern, 4) consideration of present and potential uses of public lands, 5) consideration of

the relative scarcity of the values involved, 6) long-term versus short-term benefits, and 7) coordination with other federal, state, and local governments. Another vitally important component to the planning process is public involvement. The Federal Cave Resources Protection Act of 1988 identifies the planning system as a major management action. These two laws along with other appropriate laws and regulations provide a framework to determine the compatibility between identified resources and accomplishment of the BLM mission.

The currently used BLM planning document is the Resource Management Plan (RMP).

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The RMP uses a cross-program or trans-disciplinary approach to interfacing various programs and solve complex resource management conflicts. The basic RMP process is as follows: 1) identify the resources through an inventory of resource components, 2) analyze the current situation, 3) evaluate the situation and identify the issues or conflicts between the various resource program, 4) determine the importance of the competing resources, 5) develop a set of preferred actions and alternatives, and, 6) approval of the plan via a Record of Decision. This decision set administrative policy for the allocation of resources.

Once the RMP is approved, the next step in the planning process is to write an activity plan. The activity plan addresses, in detail, the site specific actions to protect the resource. Criteria for development of cave related activity plans are outlined in the District Cave Resource Management Plan. This criteria provides a framework for development of management decisions of specific caves. The District Cave Resource Management Plan ensures consistency within the decision making process for all caves in the district.

Throughout the entire planning process there are many opportunities for public input and involvement. This is accomplished through public hearings and comment periods which are required by the National Environmental Policy Act (NEPA). In many cases the public identifies the physical resources and the conflicts between competing resource programs. There are four points in the RMP process for public input. The first point is the scoping and issue identification conducted at the beginning of the process and accomplished through

public hearings. The second is the public review of planning criteria. The third point is a review of the draft proposal alternatives and environmental impact statement (EIS). The final point is the final plan and EIS.

The following is an example which will help illustrate how the planning system functions: the study area is a real karst area with real management problems. For the purposes of this paper a few hypothetical variables have been added. The setting is a sensitive hydrologic karst area with many shallow caves. The caves are located in an important ground water recharge zone. The largest cave in the area contains a permanent source of water which provides habitat for a suspected endangered species of fish.

The first action of the overall planning process is to determine if a management plan is needed to protect this karst area. Within the BLM Section 202 of the FLPMA requires development of land use plans for public lands. The Federal Cave Resources Protection Act requires consideration of caves in land use plans.

The next action is to begin moving the issue through the RMP process.

Step 1 of the RMP process is to identify the resources. This includes the physical setting, relative importance of caves and other resources. This has been done over a period of several years in this year. The resource information has come from a variety of sources ranging from university researchers and studies of regional geology and hydrology to the local caving club which has provided cave surveys and topographic map overlays and on the ground cave locations.

Step 2: analyze the current situation. The current situation is one of expanding explora-

tion and development of oil and gas fields. This includes applications for permit to drill, applications for rights-of-way for roads, powerlines, and pipelines. The drilling activity itself can cause problems for both the oil companies and the karst area due to loss of circulation and drilling fluid into down hole voids, pollution of the ground water system, and collapse of drilling rigs, access roads and pipelines into underlying cave systems. Other situations seen as posing a threat to the cave systems are increased sulfur prospecting, historical over grazing, and increased recreational use.

Step 3: evaluate the situation and identify issues of conflict. The issues of conflict with oil and gas are basically the potential pollution of karst ground waters and possible destruction of cave passages due to collapse. For sulfur prospecting the conflicts are much the same. The conflict with over grazing is that over grazing removes too much vegetation. This in turn decreases filtration of rain water and increases run off, soil erosion, and siltation within the cave. The documented increase in recreational use is possibly detrimental to the aesthetics of the cave, but may have a greater impact on the cave life and on the recreational experience of other users if there are too many people in the cave at one time. All of the above actions could have a detrimental effect on the endangered species of fish, which is also protected under separate state and federal laws.

Step 4: ascertain resource allocation using resource values. Basically what this means is determining the threshold of impairment of a resource, or another way to say it could be to determine the limits of acceptable change. Just how important, how sensitive, or how

rare are the resources involved? Sometimes there are other existing laws, regulations, or policies that set guidelines to help make those determinations such as the Threatened and Endangered Species Act or The Antiquities Act. Other times it may be simply a matter of assigning a level of high, medium, or low. In any case, there should be a definite management goal established for the resources being managed. What follows is a conscientious decision. Is it possible to allow the competing resources uses? If the answer is no, that requires one set of management prescriptions. If the answer is yes, then the next question is how and what will the tradeoffs be? A set of management prescriptions can then be developed such as protecting important ground water recharge areas, providing protection for sensitive karst features and resources, and managing cave resources to provide a quality recreation experience.

Step 5: develop a set of preferred actions and alternatives. These preferred actions are developed by the multi-disciplinary team so the solution to one specific problem won't create three or four more problems in other programs. Each conflict or issue is looked at by a team of program specialists. The specialists usually involved are the wildlife biologist, archeologist, conservationist, and oil, gas, and mining engineers. Each specialist looks at the particular issue or problem and at a variety of possible solutions. Then they determine what kind of impacts a proposed solution, or any viable solution, may have on their specific program. Another consideration is whether the proposed solution is acceptable to the reviewing specialist's program. Management actions should avoid any irreversible or irretrievable commitment of resources. Some of

the management actions which could be proposed in order to protect the karst area are:

1. Designate the karst as an Area of Critical Environmental Concern (ACEC),
2. Designate as a right-of-way avoidance area,
3. No Surface Occupancy for all future oil and gas leases,
4. Close to mineral material sales,
5. Withdraw the area from the Mining Laws,
6. Close the area to solid mineral leasing,
7. Restrict off-road-vehicle use and other surface disturbing activities to minimize erosion and impacts to the cave and hydrologic resources.

When a draft plan is complete, it is put out for a public review and comment period. This provides the public the opportunity to study the management prescription and point out any discrepancies or deficiencies. At the end of the comment period all the public comments are reviewed and appropriate corrections and additions are made to the plan. A final plan is then prepared and another review period is provided. If there are no substantive comments the Resource Management Plan is approved.

The next level of planning is the preparation of an activity plan. The purpose of an activity plan is to clearly state the specific management direction, goals, and objectives for an area. The plan should describe in detail how the management prescriptions developed in the RMP are to be implemented. The basic components of the activity plan should include: 1) a description of the resources and setting (this section should describe the geol-

ogy, hydrology, biology, archeology, surface use, and discuss the resource conflicts and need for protection as pertains to the stated goals and objectives), and 3) a section on management actions. This section should outline the management prescriptions developed in the RMP and state the management actions necessary to accomplish it. For example, if the management prescription was "apply no surface occupancy (NSO) stipulations to future oil and gas leases" then the management action could be, review all new leases or expiring leases subject to re-issuance and the NSO stipulation. If the management prescriptions were, regulate visitor use to enhance the recreation experience and protect the endangered cave fish, the management action could be, limits of acceptable use will be set, cave entry will be regulated by use of an entry permit system.

The last part of the plan should be the Implementation and Monitoring section. This section should outline an implementation strategy. It should state whether the plan will be implemented in phases and if so, how the priorities of implementation will be determined. For example, phase one might be to initiate those actions which are directed towards the most threatening of the resource conflicts. Other considerations to determine the phasing of project implementation might be the amount of manpower and budget available. Another aspect of the implementation plan is to identify the priority of implementation of the management actions. This can be set up by fiscal year or by available funding. Additionally, the cost in manpower and in dollars can be estimated for the accomplishment of each management action or phase of implementation. This gives the

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resource manager definite items to use in the preparation of the budget in the coming years.

A monitoring plan is then developed to determine the success of the management actions. This plan should set out the specifics as to what is to be monitored, how the resources will be monitored, how often monitoring activities are to occur, and what kind of manpower and budget will be needed to accomplish the monitoring. For instance, if it is determined that photo monitoring is to be one type of resource monitoring used, the plan should describe what is to be photo monitored, i.e. fragile formation areas and heavy traffic areas. Frequency of monitoring might be once or twice per year or every two years. The amount of money necessary for film, processing, and filing binders for each year should be calculated in addition to how much time will be necessary for personnel to complete the year's photo monitoring. This amount of money can then be added into the annual

budget as part of the base program needs.

In summary, the BLM is directed to initiate a multiple use planning process by the Federal Land Policy and Management Act. The Federal Cave Resources Protection Act requires that caves be considered in that planning process. The BLM uses a Resource Management Plan as its primary planning document to solve a wide range of complex issue related problems. Then problems or resource conflicts are addressed by an interdisciplinary team. Basic resource management prescriptions are developed through the RMP process.

The next level of planning is the Activity Plan. The Activity Plan outlines specific management goals and objects and how they are to be implemented. This is accomplished by developing a set of management actions, an implementation plan, and a monitoring plan.

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# **A PRELIMINARY REPORT ON HYDROGEOLOGICAL STUDIES AT KARTCHNER CAVERNS STATE PARK**

by

**Charles G. Graf**  
**2624 North Evergreen Street, Phoenix, AZ 85006**

## **Abstract**

With the signing of a bill by Governor Rose Mofford on April 27, 1988, Kartchner Caverns became a state park, ending a remarkable 14-year period of secrecy following the discovery of the cave by Tucson cavers Gary Tenen and Randy Tufts. The meteorological, geological, hydrological and biological aspects of the cave are currently being studied under contract for Arizona State Parks by Arizona Conservation Projects, Inc. These environmental studies will provide Arizona State Parks with the information necessary to develop the cave for public visitation and education while preserving the cave in as pristine a condition as possible. Kartchner Caverns is located within a low hill of Paleozoic limestone at the base of the east flank of the Whetstone Mountains 10 miles south-southwest of Benson and 21 miles north-northwest of Sierra Vista. Although 12,594 feet of passage have been mapped in the cave, the entire cave lies within a rectangular area of 1300 feet by 1600 feet. Each of the three main chambers of the cave is more than 400 feet long, and the widest, the Big Room, is more than 200 feet wide. The vertical extent of the cave is 102 feet, and the greatest ceiling heights are about 50 feet. The profile of Kartchner Caverns is nearly horizontal, reflecting its development under shallow phreatic conditions. The cave cuts impressively across steeply dipping (up to 30°) limestone beds. The bedding planes appear to have had negligible influence on the solution of the cave. Instead, many of the cave passages, including the three large well-decorated chambers of the cave, are oriented along northeast-trending faults. Ceiling collapse and the development of in-cave drainages have subsequently modified the original phreatic passages. The cave is replete with a dazzling

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array of calcite speleothems including stalactites, stalagmites, columns, draperies, flowstone, coralloid, boxwork, cave pearls, and soda straws. Especially impressive are the large number of shields and the spectacular display of helictites. A variety of sediments are exposed in the cave including massive breakdown, finely-laminated clays, and deposits of allocthonous granitic detritus containing granite cobbles up to one foot in diameter. In addition, the cave contains a system of intermittent channels which have flowed twice during the last 15 years. Observations of the cave passages, sediments, speleothems and other features indicate that Kartchner Caverns possesses a complex solutional and depositional history. A progress report on the surface and subsurface geology and hydrology studies are presented in this paper. Brief summaries of work on other aspects of the investigation, including mapping, cave meteorology, and cave biology are also included. A tentative outline of the speleogenesis of Kartchner Caverns is offered.

### **Introduction**

Fourteen years of secrecy ended on April 27, 1988, when Governor Rose Mofford signed a bill declaring Kartchner Caverns Arizona's newest State Park. Mofford's signature capped a remarkable series of events which began with the discovery of the cave by Tucson cavers Gary Tenen and Randy Tufts in 1974. To prepare for the public opening of Kartchner Caverns in an environmentally sensitive manner, Arizona State Parks has contracted for a two-year long pre-development study of the meteorological, geological, hydrological and biological aspects of the cave. This paper previews these studies, describes the cave and its history of exploration, presents some preliminary results, and proposes a tentative outline of the speleogenesis of the cave. This paper is not a treatise of the results compiled to date. Those results will be reported later by the specialists working in each discipline.

Instead, this paper is intended as an introduction to the ongoing studies of the cave, and to the cave itself.

### **Setting**

Kartchner Caverns is located beneath a low hill of Paleozoic limestone at the base of the east flank of the Whetstone Mountains 10 miles south-southwest of Benson and 21 miles north-northwest of Sierra Vista (Figure 1). The state park embraces 550 acres of limestone hills and adjacent alluvial slopes. As Figure 2 shows, the park occupies the E1/2 of Sec. 25, T 18 S, R 19 E, and most of the W1/2 of Sec. 30, T 18 S, R20E., all within Cochise County.

The Coronado National Forest bounds Kartchner Caverns State Park to the west. From this boundary, the Whetstone Mountains steepen rapidly, cresting three miles distant at an elevation of 7388 feet. The



highest point within the park itself, at 5078 feet, is the summit of a limestone hill located in the northeast corner of the property. An alluvial pediment occupies the southern part of the site, sloping gradually down to the San Pedro River eight miles away. Picturesque Guindani Canyon, incised deeply into the Whetstones behind the park, is the source of the only major drainage (intermittent) traversing the park. The only significant prior use of the land has been for cattle grazing.

### History

The discovery and exploration of Kartchner Caverns and its eventual addition to the Arizona State Parks system is a remarkable story of secrecy spanning fourteen years. The cave was discovered in 1974 by Tucson cavers Randy Tufts and Gary Tenen. Actually, Tufts found the small opening seven years earlier in 1967, but did not pursue it as the crevice appeared awkward and seemed to lead nowhere. Returning to the area with Tenen in 1974, they rechecked the hole and this time pushed through. Enticed onward by blowing air, they reached another small hole which they had to enlarge with hammer and chisel. After an extremely tight squeeze through, the passage began to open up, beckoning the cavers further into the cavern. The cave did not disappoint them, for in the Big Room they marvelled at the kind of discovery that many a caver only dreams about. Little did Tufts and Tenen imagine, climbing down into the sinkhole on that eventful day in 1974, that their lives and most of their spare time for the next fourteen years would be tied to that auspicious spot of hillside.

Early during the many explorations fol-

lowing their discovery, Tufts and Tenen recognized the fragile nature of their spectacular find and realized how vulnerable it would be to those less careful. Sadly, most publically known caves in Arizona have been defaced, stripped of formations, and littered with trash. Because of the cave's location within sight and strolling distance of State Highway 90, and because they knew how easy it would be for someone else to stumble upon the entrance sinkhole, the two cavers determined that further action was necessary to protect the cave.

Therefore, in 1978, they approached the owner of the land, James Kartchner, of St. David, with an offer to buy the 550-acre parcel containing the cave. When the offer was rejected, Tufts and Tenen divulged the secret of the cave. Thus began a long and supportive exploration, mapping, and caretaking relationship with the Kartchner family. Eventually, Tufts, Tenen, and the Kartchners realized the need for full-time protection of the cave by a modern and well-equipped resource management agency. Several agencies were contacted including Arizona State Parks. State Parks was interested but lacked the statutory tools to effect acquisition of the property. Undeterred, the group arranged a trip into the cave for then-governor Bruce Babbitt, requiring an oath of secrecy from him as they had from all others involved in the project. Babbitt provided renewed impetus to the project by suggesting that they work with The Nature Conservancy, a conservation organization which buys up land to preserve critical habitats for rare and endangered species.

The Nature Conservancy, under Arizona Director Dan Campbell, surveyed the cave but found no rare or endangered species on which

to justify their purchase and permanent stewardship. However, Campbell contacted Ken Travous, the new Director of Arizona State Parks, and after a trip into the cave, Campbell and an enthusiastic Travous began devising a plan to acquire the cave for Arizona State Parks. With The Nature Conservancy arranging to buy the cave in the interim, Tufts, Tenen, Campbell, Travous and others now involved in the project began the complex negotiations needed to enable State Parks to fund the purchase of the cave. A major difficulty was the lack of a permanent funding mechanism for land purchases by Arizona State Parks; all park revenues from entrance fees went into the State general fund.

The group worked over a two year period with a few supportive key legislators, particularly Senators John Hays and Greg Lunn (both of whom had personally seen the splendors of the cave) and Representatives Larry Hawke and Joe Lane. This alliance resulted in legislation setting up a permanent acquisition and development fund for State Parks that finally received the support of the full House and Senate. With Governor Rose Mofford informed and ready to sign the bill, the legislators added amendments on the floor to make Kartchner Caverns the first State Parks acquisition with the new fund, thus lifting the 14-year veil of secrecy and surprising the rest of the Legislature, the news media, and the public alike.

Because of the care of the original explorers, the cave is in remarkably pristine condition. For example, Tufts and Tenen marked all routes in order to keep visitors to one path, with the result that 95% of the cave floor remains untrud. Arizona State Parks now has the challenging task, one they look

forward to with enthusiasm and sensitivity, of developing Kartchner Caverns for public visitation and education while preserving the cave in as pristine a condition as possible.

### **Pre-Development Studies**

The purpose of the pre-development studies now being conducted is to provide a framework of basic knowledge about the geologic and environmental conditions of Kartchner Caverns. The studies will document existing conditions and yield information critical to the sound development and management of the cave for public viewing. The studies focus on four main aspects of the cave environment: (1) cave climate and meteorology, (2) geology, (3) hydrology, and (4) biology.

The geological studies include investigations of the surface geology, subsurface geology, speleothems (cave decorations), mineralogy, and speleogenesis. A geophysical survey is being conducted, primarily to determine if other large voids exist in the vicinity of the known cave and to avoid siting surface facilities where they may adversely affect the cave. The hydrological studies, like the geological studies, include both surface and in-cave aspects. This set of studies will be useful for guiding engineering and construction planning, as well as for developing visitor interpretation strategies.

Of all the studies, cave microclimate and meteorology will probably be the most critical in designing an environmentally sound cave development and management plan. Arizona State Parks intends to maintain humidity, temperature, and air flow in the cave in order to preserve the unique features of the cave. Other parameters being investigated in this

study include evaporation rates, air quality, drip rates, and surface meteorology.

The most visible biological activity in the cave are the bats, which spend summer in the cave to bear young. Bats occupy a vital niche in the cave ecosystem, therefore, much effort is being devoted to understanding their habits and requirements. Other small vertebrates, as well as invertebrates, are also being studied. Lastly, the potential of the cave to support algae and moss growth is being studied. Such growth is a common problem in electrically lighted caves.

### Cave Description

Not long after the summer sun sets, bats begin spiraling out of the sinkhole entrance to Kartchner Caverns. This depression, located near the base of an ocotillo-dotted slope of limestone, leads into one of the most beautiful and pristine caves in Arizona. The sinkhole itself drops vertically about 15 feet and measures 25-feet long by 10-feet wide. A few feet above the bottom of the sinkhole, a crevice penetrates the wall, leading down through small chambers, a few squeezes, and some low crawls to Grand Central Station, a delightful gallery and corridor that foretells the truly marvelous parts of the cave ahead. (Cave place names are generally christened by the explorers and provide a road map for locating features and describing the cave.)

From Grand Central Station, a 200-foot amble in walking passage leads to the base of a huge breakdown pile at the south end of the Big Room. Beyond that, in the vaulted expanse of the main part of the chamber, a profusion of stalactites, stalagmites, columns, and flowstone greets the visitor. (See the glossary at

the end of this paper for brief descriptions of the speleothem names used in this paper). These formations cover nearly an acre of floor area and are one of the highlights of the cave. Returning to the breakdown pile, a trail branches west to the top of the breakdown, meandering between boulders almost underneath the roosts of a summer maternity colony of about one thousand Cave bats (*Myotis velifer*). The trail continues down the other side of the breakdown, past two fine stalagmites named Kartchner Towers, to a short, tight downclimb that marks the beginning of the River Passage.

The River Passage is a series of rooms originally formed below the water table which have been modified and integrated by solution and erosion from in-cave stream flows. A somewhat arduous trip leads down this passage through Lover's Leap, the Bathtub Room, the Thunder Room, the Shelf Passage, the Grand Canyon to the Pyramid Room. Several reaches of stream channel (which have contained flowing water only twice since 1974) emerge into this section of passage, only to disappear into sumps a short distance further. Particularly noteworthy along the River Passage are the helictites, flowstone, cave pearls and other speleothems adorning the Shelf Passage.

Beyond the Pyramid Room, the arduous becomes downright nasty! In order to reach the Rotunda Room-Throne Room and the Subway Tunnel-Pirates Den, the other two main chambers of the cave (in addition to the Big Room), the Triangle Passage must be traversed. The Triangle Passage is a 100-foot long, low muddy crawl on belly and hands and knees. Unfortunately, the worst is still ahead: The Trench, a 70-foot long exhausting struggle through thigh-deep mud. Beyond The Trench,

the route becomes easier and leads to The Doorway, a vertical slit cutting through a foot-thick wall of quartz. The Quartz Divide, as this feature is called, is the insoluble vestige of siliceous infilling along a fault. Boxwork has formed on the limestone ceiling bordering this quartz dike, one of the few places in the cave where this speleothem is found.

Once through The Doorway, the cave changes in aspect to very wide, often low but walkable mud-floored passages. The passages are attractive for their sweeping curves, scallop-shaped solution features, and the fossil crinoids and horn corals etched in relief on the walls. Speleothems, though not abundant, have typically formed at the ends of passages. The Pirates Den and Sue's Room both have good displays, and a fine example of a shield is found at The Angels Wing.

Back outside The Doorway, a trail branches off to the Rotunda Room. The Rotunda Room was named for the limestone beds arching dramatically across the passage. A myriad of beautiful helictites and barbed soda straws hang from the roof near the trail. Several of these, The Fallen straws, have dropped from the roof and now stand upright in the mud floor (see the Speleogenesis section of this paper for further discussion). From The Fallen Straws the trail ascends a huge breakdown pile to the highest point in the cave, an overlook above the Throne Room, the most significantly decorated room of the cave. This room contains the giant column, Kubla Khan, and the towering stalagmite, Nefertiti. Kubla Khan is the largest known column in an Airzona cave. Surrounding these two giants is a forest of stalactites and stalagmites. The room also houses an abundance of soda straw, including a 20-foot long

specimen that ranks among the longer ones known in the world. Helictites the thickness of spaghetti also grow from the ceiling and walls of the Throne Room, curving and twisting delicately through the air in apparent defiance of gravity.

The total length of surveyed passage in Kartchner Caverns stands at 12,594 feet (2.39 miles). Surprisingly, the entire cave lies within a rectangular area of 1600 feet by 1300 feet. Each of the three main chambers of the cave is more than 400 feet long, and the widest, the Big Room, is more than 200 feet wide. The vertical extent of the cave is 102 feet, and the greatest ceiling heights, about 50 feet, are found in the Big Room and the Throne Room. The terminal sump of Red River, located off the Big Room in the Red River Room, is the deepest point in the cave, at an elevation of 4592.7 feet. At a few points in the cave, roots are visible where the roof thickness is small. The greatest thickness of limestone overburden, about 260 feet, occurs where the Mushroom Passage crosses under the summit ridge of the limestone hill containing the cave.

### Geology Synopsis

The surface geology of the Benson Quadrangle, which includes the Kartchner Caverns area, was mapped by Creasey (1967). The map reproduced as Figure 4 of this paper came from a study by Wrucke and Armstrong (1984) which utilized the 1967 map compiled by Creasey. Other recent studies in the area include a map showing mineral resource potential (Wrucke, et al., 1983) and a map showing the results of aeromagnetic and gravity surveys (Bankey and Kleinkopf, 1985).

The rocks of the limestone hill overlying Kartchner Caverns have been mapped by Creasey as mainly Escabrosa Limestone of Mississippian age, with a small outcrop in the south of Horquilla Limestone of Pennsylvanian age. According to the map, the entrance to Kartchner Caverns would be through Horquilla Limestone (Figure 4). However, the limestone hill is more disrupted than shown by Creasey, and a reconnaissance of the lithologic composition, bedding thicknesses, and fossil assemblages indicates that not all of the exposed limestone may be correctly identified (Scott Gibson, personal communication). In fact, a study of conodonts from the limestone at the entrance to the cave positively identified this outcrop as Escabrosa Limestone, rather than the Horquilla Limestone as the map by Creasey shows (Robert Buecher, personal communication).

The limestones of the hill overlying Kartchner Caverns dip westward of southwestward at angles generally between  $10^{\circ}$  and  $40^{\circ}$ . Kartchner Caverns cuts impressively across these steeply dipping beds, which appear to have had negligible influence on the solution of the cave. A series of faults of apparent small offset trend  $N30^{\circ}E$  across the hill (the sense of movement along these faults has not yet been mapped). The three main chambers of the cave are clearly aligned along these northeast trending faults, however the faults themselves probably were not the primary weakness controlling limestone dissolution (see the Speleogenesis section of this paper for further discussion). Development of the three chambers toward the northeast was apparently stopped by a fault (visible on the surface) trending approximately  $N45^{\circ}W$ . No extensions to the cave have been found beyond this

structure. The most spectacular fault visible in the cave is the one oriented along the Throne Room and Rotunda Room, where brown recrystallized dolomite (?) is juxtaposed against light gray limestone (Scott Gibson, personal communication).

Near the west boundary of the park, the limestone hills are in fault contact with Precambrian Pinal Schist. A few hundred yards further to the west, another fault places the Pinal Schist in contact with Precambrian alaskite. The Whetstone Mountains rise steeply at this location and are mainly composed of alaskite. Further up the mountain, Precambrian quartz monzonite becomes the dominant rock type exposed at the surface. Mines and prospects for bull quartz, fluorite, uranium and tungsten are located in Precambrian rocks within 1-1/2 miles of Kartchner Caverns (Wrucke, et al., 1983).

At the crest of the Whetstone Mountains, Paleozoic sedimentary rocks rest unconformably on the Precambrian intrusive and metamorphic rocks. The Paleozoic rocks dip southwesterly at angles of  $20^{\circ}$  to  $35^{\circ}$ , and resemble in outward appearance the relationships present at Kartchner Caverns, except on a much larger scale. However, the rocks at the crest of the Whetstones are broken by only a few minor faults (Wrucke and Armstrong, 1987). The Escabrosa Limestone outcropping in the hills at Kartchner Caverns has been dropped about 2000 vertical feet relative to the exposures near the top of the Whetstones.

The southern part of Kartchner Caverns State Park is occupied by an alluvial pediment which extends out into the San Pedro Valley about four miles (where it is truncated by a lower surface). This upper pediment surface was named the Whetstone Surface and mapped

by Bryan (1926). The Speleogenesis section of this paper provides further information about this and lower surfaces. In the park area, the Whetstone Surface consists of an undetermined thickness of gravel wash (nomenclature first used by Gray, 1965 and 1967) overlying a surface of Pinal Schist. The thickness of the granite wash probably varies, but is not believed to be great (as suggested by the predominance of schist cuttings found beside water wells penetrating the granite wash in the western part of the park).

West of the Highway Well (see Figure 2 for locations of wells mentioned in this paper, and Table 1 for cadastral identifications) just west of State Highway 90, a major north-trending basin and range bounding fault is postulated to exist beneath the cover of granite wash. The Highway Well bottomed without hitting bedrock at 790 feet in "fairly well cemented alluvial materials consisting of fragments of decomposed granite, limestone, and quartz," according to the driller (Don Weber, personal communication). Water levels in the Middle Canyon and Kartchner Wells are also consistent with such a major fault. A projection of the water table between these two wells would intersect the land surface near Highway 90, which suggests that the surface of Pinal Schist supporting the water table must terminate west of that location.

As noted previously, the block of Paleozoic sedimentary rocks cropping out in the Kartchner hills lies about 2000 feet lower in elevation than the same rocks in the upper Whetstones. The structural features responsible for this relationship are unclear. The map and cross-sections of Creasey (1967) indicate that this Paleozoic block is bounded by deep-seated, high-angle normal faults

(probably associated with basin and range faulting). If this scenario is true, a major E-W trending fault must bound the south side of the limestone hills in order for the Paleozoic rocks to extend deeper than the adjacent Pinal Schist underlying the gravel wash.

Alternatively, Davis (1979) proposed a thin-skinned gravity glide mechanism for this "anomalously highly faulted and folded isolated block of Paleozoic strata" (p. 551). In the gravity glide scenario, the Paleozoic rocks would have come to rest on a platform of Pinal Schist underlying the sedimentary block at relatively shallow depth. Additionally, the western bounding fault of the limestones would be low angle rather than high angle as shown by Creasey. These two alternative hypotheses account for the queried contact shown between the limestones and the Pinal Schist in the hydrogeological cross-section (Figure 6). Knowledge of the true structural relationship in this area is important for understanding the speleogenesis of the cave. On a more practical basis, such knowledge is important for understanding the occurrence and movement of groundwater in the park for possible future utilization as a park water supply.

### Hydrology Synopsis

The unusually large number of wells (Table 1) located in the vicinity of Kartchner Caverns is fortuitous, considering the general lack of development along the east side of the Whetstone Mountains. Although many questions remain about the hydrogeology, particularly with respect to the Paleozoic block itself, the information derived from these wells permits the presentation of a relatively unspeculative synopsis of the hydrology.

Available well data for these wells is listed in Table 1; the well locations are shown on Figure 2.

The North and South Wells (dug) and the Middle Canyon and Kartchner Wells (drilled) penetrate the gravel wash covering the Pinal Schist. It is not known whether the North Well (34 feet deep) penetrates the entire thickness of gravel wash, but the other wells certainly do, based on cuttings or dug material still remaining at the well sites. No drillers logs have yet been located for any of these wells, so the actual thickness of the granite wash is now known. However, the thickness is believed to be small based on the preponderance of schist cuttings at the drill sites and the gradually sloping schist surface exposed at the upper edge of the granite wash just west of the state park boundary. The Middle Canyon and Kartchner Wells were drilled to 205 feet and 220 feet, respectively. The South Well was dug to a 58-foot depth, encountering schist within this distance.

Water table elevations (calculated from June 1989 measurements, but similar for other dates) indicate that the water table may not be continuous over the area covered by these wells. The water table elevation at the North Well, 4696 feet, is approximately 50 feet higher than the water table at the Middle Canyon and Kartchner Wells; the water table at the South Well is about 12 feet higher than the water table in the latter two wells. Based on these measurements, groundwater appears to occupy (at least in part) old channels eroded into the surface of the Pinal Schist; the individual bodies or shoestring occurrences of groundwater may lack significant continuity over the area. It is also possible that the water level in the Middle Canyon and Kartchner

Wells may lie below the base of the granite wash, possibly in a fractured or weathered zone in the schist. The specific conductance of water samples collected from the wells also indicates a possible independence: 393, 318, and 859  $\mu\text{S}/\text{cm}$  at  $25^\circ\text{C}$  for the North, Middle Canyon, and South Wells, respectively.

Groundwater flow in the granite wash is generally easterly toward the San Pedro Valley. As discussed in the previous section, a major north-trending basin and range fault is postulated to exist beneath the granite wash at a location west of the Highway Well. East of this fault, within the San Pedro basin, a great thickness of alluvial sediments has been deposited. The bulk of these are Pliocene and Pleistocene fine-grained fluvial and lacustrine sediments named the St. David Formation by Gray (1965, 1967). The St. David sediments were deposited in a mildly subsiding trough as indicated by a monoclinical fold traversing the formation west of the present San Pedro River (Gray, 1965). This sequence of fine-grained deposits is overlain by younger deposits of gravel wash, and Holocene alluvial deposits. The thickness of the St. David Formation is not known, but wells over 1000 feet in depth near St. David bottom in sediments similar to those observed in the overlying St. David Formation (Gray, 1965). The sediments penetrated by the Highway Well near the eastern edge of Kartchner Caverns State Park probably represent a coarser, more cemented facies of the St. David Formation. These latter sediments were probably deposited at the margins of the basin contemporaneously with the fine-grained sediments. The relationships between the basin sediments, the pediment surfaces, the limestone hills, and Kartchner Caverns are shown on the hydrogeological

cross-section (Figure 6).

Water levels have been measured in the Highway Well (741 feet below land surface) and the Black Well, located 2-1/2 miles basinward (518 feet below land surface). These water level measurements define a low gradient piezometric surface that probably represents the mountainward extension of the artesian aquifer underlying the San Pedro River near St. David. Within the gravel wash resting on the surface of Pinal Schist in the southern portion of Kartchner Caverns State Park, groundwater moves easterly to the edge of the buried fault scarp, then descends to the lower aquifer marked by the water level in the Highway Well. This lower water level lies about 765 feet below the lowest measured point within Kartchner Caverns.

An entirely different situation exists at North Well. North Well was dug less than 100 feet from the limestone hill containing Kartchner Caverns, yet the water level within the well is 70 feet higher in elevation than the bottom of the passage leading into Sue's Room. The horizontal distance between North Well and Sue's Room is only 700 feet. The groundwater surface measured at the North Well is hypothesized to extend to the nearby limestone, where the groundwater drains readily down through the limestone to a level below the present accessible level of the cave. The water level in the North Well has fluctuated over a greater range than the level in the South Well (Figure 5). During the one year cycle over which measurements have been taken, the water level in the North Well has varied 4.5 feet. In the South Well, a dug well located in a setting very similar to the North Well (but not near limestone), the fluctuation was only 2.1 feet.

One of the most interesting questions remains unanswered: Where is the water table in the Paleozoic block? The answer appears to depend on which structural scenario for the emplacement of the Paleozoic block is correct. If the block was dropped by deep-seated basin and range faults, the water level within the block is probably an extension of the water table within the San Pedro basin to the east (or roughly 740 feet below land surface as measured in the Highway Well). This scenario, however, would not rule out the possibility of a perched water level within the Paleozoic block, considering the complex structure and presence of dipping beds within the block.

If the second scenario is correct and the block is a thin-skinned gravity glide overlying Pinal Schist, a much higher water table, supported by the surface of Pinal Schist, would have formed. If the Paleozoic block had glided down and come to rest on a low area of the Pinal Schist, groundwater recharge moving into the block) likely to be enhanced due to the permeable nature of the limestone) may be significantly channelized in this depression before spilling over the bounding basin and range fault. Under this scenario, a well tapping this hypothetical low area just west of the fault might yield good quantities of water from reasonable depth. Should a well be considered at this location, a determination would have to be made on whether withdrawals could adversely affect conditions in the cave (which depend on the maintenance of high humidity).

Guindani Canyon is the surface drainage with greatest potential to affect the hydrologic regime within the limestone block. Guindani Canyon heads at the crest of the Whetstones and descends through a rugged, oak-lined



gorge. However, at the point where it crosses the eastern boundary into the park, Guindani Canyon is more aptly described as an arroyo. Most of the canyon is cut into impermeable scribed as an arroyo. Most of the canyon is cut into impermeable alaskite and quartz monzonite, so prodigious floods can be expected. In August and September of 1988, during a 30-day period over which a total of 6.23 inches of rain fell into the Park's rain gage, the arroyo through the park flowed almost continuously. Despite the impingement of Guindani Canyon directly against the limestone at several locations, no flows or ponding of water were noted afterward in any part of the cave.

On the other hand, water has ponded in a few low parts of the cave twice since 1974 (most notably in The Trench and Subway Tunnel). Water began entering the cave and ponding in December 1978 and in March 1985. Rather than correlating with intense summer thunderstorm activity, the ponding appears to result from prolonged flows due to snowmelt runoff. Although low areas of the cave apparently do not pond often on a human time scale (especially reflecting that the last fourteen years have been among the wettest of record), the great thickness (six feet or more) of laminated muds in these areas attests to the frequency of ponding in the recent geologic past.

Although mud is abundant in certain parts of Kartchner Caverns (and a bane to keeping notes and instruments clean), no permanent water exists except for a few small drip pools. Intermittent stream channels are present in some rooms and passages, however. Typically, these channels emerge into a passage or room through breakdown or a small hole; flow a short distance; than disappear

into a sand or gravel filled sump, a small hole in the limestone floor, or into breakdown. The in-cave stream flows and the ponding of water in low areas are part of a sequence of events that is not entirely clear. Water first enters the cave in upstream passages heading near Guindani Canyon (such as Granite Dells). The stream flow disappears into a hole or sump, than apparently begins rising upward into some of the nearby low areas (parts of the Water Room and Subway Tunnel, for instance). The ponding apparently represents the rise of a water table of limited extent, because some very low passages, such as the Cul-De-Sac Passage, do not fill. As the water level continues to rise, some previously dry streams become activated. The stream in the Thunder Room (named for the roar a five-foot cascade makes as the stream emerges into the room) is one example. Channels in the Big Room then begin carrying water. These streams coalesce, then flow down the Red River Passage before finally disappearing into a sump in Red River Room, the lowest point in the cave.

The rather complicated flow system described above is controlled by a combination of structural, stratigraphic, and solutional features, many of which are hidden from view below the present level of the cave. Once the program of precise leveling in the cave is completed, parts of the flow system will become better understood. However, without actually being present during a stream flow episode and carefully observing the progression of events, measuring discharges, conducting dye traces, and performing other relevant studies, any conclusions about the cave hydrology will be partly conjecture. Considering the rarity of flow in Kartchner Caverns, such observation

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may not occur for some time.

### **Speleogenesis**

Kartchner Caverns began forming several hundred thousand years ago and has developed since then in response to a complex interplay of geological and hydrological factors. The outline presented below of the speleogenetic history must be considered tentative—to be tested and modified by observations and results from the detailed hydrogeological studies now in progress.

#### **1. Initiation and enlargement of the cave under shallow phreatic (water table) conditions.**

Shallow phreatic genesis (as opposed to either a vadose or deep phreatic mechanism) is evident in the predominance of rounded passages and rooms and the extremely flat profile of the cave, which cuts dramatically across steeply dipping strata. The three main passages (Big Room, Rotunda Room-Throne Room, and Subway Tunnel-Pirates Den) are aligned along faults that trend parallel or sub-parallel to the strike of the beds.

Closer examination, however, reveals that the faults probably only indirectly influenced the formation of these main cave passages. The fault planes often coincide with passage walls rather than the axes of the passages, suggesting that the faults did not act as the primary weaknesses through which groundwater flow and resultant limestone dissolution occurred. Instead, groundwater appears to have flowed more readily along fractures or joints located within the crest of narrow anticlinal flexures which lie adjacent to

the fault surfaces. These shallow flexures appear to be drag features produced during faulting.

A water table high enough to initiate solution of Kartchner Caverns could not have been sustained until the San Pedro basin had filled with sediments to a level at least as high as the cave. Alternatively, a localized water table perched in the Paleozoic block could explain the initial solutional episode, but this possibility is considered less likely. For a localized perched water table to remain stable, recharge must remain relatively constant. However, the Paleozoic block is located so close to the base of the Whetstones that it must have been subject to great precipitation extremes (from a single storm, annually, or over longer periods of geologic time). It is difficult to imagine that recharge into the block from runoff and infiltration would be moderated enough to avoid producing significant fluctuations in the water table. Although some caves appear to have originated by this mechanism, the phreatic features displayed in Kartchner Caverns appear more consistent with a much longer period of stability in the water table.

The existence of a regional water table in the San Pedro basin (which extends mountainward into the limestone block) is proposed to explain the initial solution of Kartchner Caverns. In order for a regional water table to have formed, alluvium must have been deposited in the San Pedro basin to a level at least as high as the limestone block. Such a condition apparently did not exist earlier than the end of deposition of the St. David Formation. Paleomagnetic dating of the uppermost remaining St. David sediments indicates that they were probably

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deposited soon after the Matuyama-Brunhes paleomagnetic chron boundary (Johnson, et al., 1975) dated about 730,000 years ago (Harland, et al., 1982). However, these uppermost sediments are separated by an erosional unconformity from the granite wash, signifying that deposition continued for some time later and at a higher level than the dated sediments. If the St. David sediments were deposited high enough, a regional water table extending to Kartchner Caverns could have developed. Although the water table would have formed later than 730,000 years ago, this paleomagnetic date establishes a maximum age for the onset of cave formation.

Alternatively, a water table high enough to initiate cave formation may not have existed until later, when the granite wash was deposited on top of the St. David Formation. The granite wash, which blankets much of the alluvial slope on both sides of the San Pedro Valley, nearly surrounds the limestone hill containing Kartchner Caverns. At the very upstream end of the Granite Dells passage, the cave is separated from surface deposits of granite wash by a horizontal distance of less than 100 feet. At this location, the surface of the granite wash lies about 50 feet in elevation above the level of the cave. In fact, the entire profile of the cave lies below the adjacent surface of the granite wash (Figure 6).

While no evidence has been discovered to indicate that St. David sediments were ever deposited high enough for a water table to form at cave level, the requisite height certainly was achieved after deposition of the granite wash. The age of the granite wash is not well known. Melton (1965) suggests an Illinoian age based on stratigraphic relationships. If the deposits are Illinoian, an age of between

about 120,000 and 170,000 years old is indicated (Van Eysinga, 1983).

## **2. Lowering of water table.**

After a long period of relative water table stability, during which most of the phreatic solution of the cave was completed, the water table began dropping. A decline in the water table could be due to a reduction in recharge (drier climate) or a drop in the base level (downcutting in the San Pedro basin), or a combination of the two. Except for a shorter period of phreatic activity described later, vadose processes henceforth became the predominant factors in the further evolution of the cave.

## **3. Breakdown and passage enlargement.**

Passage enlargement in caves typically occurs as water levels fall below passage ceilings. Buoyant support is lost, and over time ceilings collapse until a stable ceiling configuration is reached (White, 1988; Bogli, 1980). As water levels slowly lower, breakdown may remain on the floor, depending on the rate of solution and the length of time groundwater actively circulated through the breakdown. Huge piles of breakdown in the Big Room, Rotunda Room, and Throne Room are evidence of this enlargement process. In other areas, such as the Grand Canyon, most of the breakdown blocks have been removed.

## **4. Speleothem formation.**

The first speleothems in the cave would

have started forming as the water table fell. Some of the large stalactites, stalagmites, and columns located in parts of the Big Room and Throne Room probably began forming at this time.

### **5. Further lowering of the water table to below the present level of the cave.**

Evidence for this includes some relic vadose modification features, such as an abandoned stream channel in the southwest end of the Cul-De-Sac Passage that appears to have once connected to the Thunder Room.

### **6. Water table rise followed by a period of stability.**

This time interval is strikingly evidenced by the Mushroom, a seven-foot high stalagmite in the Back Section of the cave which has been undercut by re-solution at the level of an ancient water table. Surveys show that the undercut shelf, about half way down the stalagmite, lies at the same level as low horizontal ceilings in the Triangle Passage and the passage connecting the Water Room to Granite Dells. These ceilings are immaculate, phreatically-formed planes that cut across dipping limestone beds. This period of water table rise and renewed limestone solution appears to have integrated the major rooms of the cave into a single, connected system.

The rise in water table may have been due to wetter conditions in southeast Arizona or to a rising base level, perhaps caused by downstream damming of the ancient San Pedro River. In any event, the water table stabilized at a level slightly lower than halfway between the present high and low points of

the cave. The age of this water table rise is problematical. The rise might have followed the preceding drop relatively quickly (although considerable intervening time must have passed for the Mushroom to form) or it might have come much later. Except for the initial solutional episode, this is the only phreatic water level recognized in the cave to date. As further observations are made and spirit leveling data becomes available, additional sub-ter paleo water levels may be revealed.

Figure 6, the hydrogeological cross section, provides one clue to the minimum age for this stage of phreatic activity. The cave profile (and, hence the slope of the water table that produced it) is much flatter than the existing topographic surface, so it must be older than that surface. Two geomorphic surfaces relevant to this discussion have been identified, the Tombstone Surface and the Whetstone Surface.

The Tombstone and Whetstone Surfaces (as well as a lower Aravaipa Surface) are pediment surfaces mapped by Kirk Bryan between 1922-24 (Bryan, 1926; Plate 10 in Gilluly, 1956). Both the Tombstone and Whetstone Surfaces truncate the granite wash and the St. David Formation, but are in turn truncated by the inner valley of the San Pedro River. These surfaces once extended across the valley and therefore reflect periods of significantly higher base levels, but as Figure 6 shows, not high enough to correspond to the gradient evident in the cave.

The Tombstone Surface is the highest surface. This surface surrounds much of the Whetstone Mountains, but is not present on the northern and northeastern alluvial slopes (including the area where Kartchner Caverns is located). This surface probably once existed

in the area, but was destroyed during bevelling of the later Whetstone Surface (Gilluly, 1956).

The Whetstone Surface slopes down from the mountain in the vicinity of Kartchner Caverns and represents a period of climatic stability (Gray, 1965). During this time, a deep, mature red soil formed on the Whetstone Surface (Melton, 1965). A red soil also formed on the Tombstone Surface (Haynes, 1967). The difference in age between the Tombstone and Whetstone Surfaces is not clear, but the formation of the red soil on both surfaces apparently occurred during the same interval of geologic time. Melton (1965) proposes that this occurred largely during Sangamon time. This would place the age of the red soil in the interval between 120,000 and 70,000 years ago (Van Eysinga, 1983). Sangamon time in southeast Arizona was characterized by a "warm and considerably more humid climate than now" (Melton, 1965, p. 14). Thus, although the last episode of phreatic development in Kartchner Caverns must have preceded the cutting of the Tombstone and Whetstone Surfaces, the age of the red soil establishes a definite younger bound.

#### **7. The phreatic surface of the regional aquifer drops for the last time in the vicinity of Kartchner Caverns.**

#### **8. Vadose modification.**

The drop in water table brought on a new cycle of vadose modification, which continues to this day. Stream flows within the cave have become better integrated. The stream courses in Granite Dells and other areas of the cave appear to coalesce and flow out of the cave

(downward through a gravel sump) at the end of Red River Passage, the lowest point in the cave. However, it is not clear that all cave flows combine into one flow at Red River Passage, as significant lengths of the stream channels pass under breakdown, where they are inaccessible. In addition, small drains (a few inches to a foot in diameter) have formed near stream level in several areas. Some of the water entering these drains may discharge back into known parts of the cave at lower elevations, but significant deeper losses also probably occur.

Despite some integration of flow paths as a result of vadose modification, the process of drainage integration is still at an immature stage. As mentioned, disconnected reaches of stream channel occur throughout the cave. Also, when flows in the cave do occur, water backs up and ponds in the Subway Passage and other areas, where it takes many months to drain.

Although the drop of the regional water table ended phreatic development of Kartchner Caverns, later geoclimatic events in the San Pedro Valley have influenced vadose processes. Speleothem formation, cave sediment deposition and erosion, and in-cave stream flows and ponding are all related to these external geologic, hydrologic and climatic circumstances. Two of the significant external events are outlined below. These events provide perspective for reflecting on the later history of the cave; they are also probably recorded in the cave in clastic and carbonate deposits.

At the end of the last interglacial (Sangamon), the Whetstone Surface extended across the entire San Pedro Valley. In early or pre-Wisconsin time (ca. 70,000 years ago),

the San Pedro River cut down through this surface (Haynes, 1967). This entrenchment amounted to about 200 or more feet (Wrucke and Armstrong, 1984). The base level was lowered and the water table in the regional aquifer further declined. The current water level in Black Well, 518 feet below land surface, probably reflects the additive effects of this early Wisconsin base level lowering, the more recent reduction in aquifer recharge due to the drier climate prevailing in the last several thousand years, and pumping of the artesian aquifer in the St. David area in the last hundred years.

Haynes (1967) has proposed that, after entrenchment of the San Pedro River, a large late Pleistocene lake occupied the San Pedro Valley. The lake may have reached an elevation of 2800 to 2900 feet in the San Pedro Valley below Kartchner Caverns. Haynes associates this lake with an intermediate surface lying between Bryan's Whetstone and Aravaipa Surfaces. However, he suggests that this intermediate surface actually correlates with the Whetstone Surface further upstream in the San Pedro Valley. He believes that the Whetstone Surface mapped by Bryan in the vicinity of St. David is actually an older surface. In this paper Bryan's older nomenclature is used, but the intermediate surface described by Haynes is identified on Figure 6. Marls associated with the intermediate surface and ascribed to the late Pleistocene lake have been dated from 30,000 to 12,000 years before present (Haynes, 1967). Around 12,000 years ago the lake had disappeared, according to Haynes.

## 9. Renewal of speleothem deposition.

As the water table dropped, speleothem formation began anew in previously flooded sections. In parts of the cave unaffected by the water table rise, deposition of calcium carbonate no doubt continued unabated, perhaps explaining the great size and abundance of formations in such areas as the Throne Room.

## 10. Deposition of a sequence of cave sediments.

After vadose processes had enlarged the cave passages to essentially their present size, a sequence of cave sediments was deposited. Although some of the deposits look alike, it is not clear whether deposits found in different parts of the cave are strictly contemporaneous. The sequence listed below (in ascending order) was deposited in the Bathtub Room in the River Passage:

a. Small breakdown chips and cobble-sized breakdown fragments embedded in the finer-grained detrital matrix. The matrix is probably composed of insoluble residue left from the dissolved limestone. This lithological unit is about six inches thick at the observed location.

b. Laminated clays (the total thickness of about three feet includes at least four subunits distinguishable by color). These clays record a long interval of periodic (yearly?) low-velocity flows in the cave. These clays are clearly older than the laminated silts and clays described earlier which are still being deposited in the Subway Tunnel.

c. Granitic detritus. A six-inch layer of granitic sand and gravel has been deposited above the laminated clays. This material looks

very similar to the granite wash outside the cave and represents reworked material. The presence of granite wash in the cave indicates the opening of a significant hydraulic connection to the surface. The effect of this hydraulic connection is dramatically visible in the upstream end of the cave at Granite Dells, where granitic material composed of sand, gravel, and cobbles up to a foot across is found in deposits as much as eight feet thick.

d. Flowstone. Over the granitic detritus, a flowstone deposit 1/4-inch to one-inch thick was deposited. This suggests the existence of a more quiescent, wet period in the late history of the cave. Such a climate existed between about 9,000 and 10,000 years ago when cienegas and marshes proliferated along the San Pedro River, and followed a period when Clovis hunters camped and butchered Late Pleistocene mammoths and other mammals at many locations within the San Pedro Valley (Haynes, 1981).

e. Speleothems. Speleothems were also actively forming during this time, as evidenced by the picturesque display of decorations deposited on top of the flowstone in the Shelf Passage. This period may have corresponded to the last episode of vigorous growth of speleothems in the cave. Although speleothem formation is still active today, conditions are certainly drier than they have been in the past, and the total volume of speleothem growth must be significantly decreased.

11. Renewed stream flow in vadose passages. Renewed stream flow eroded through the deposits described above. In the Shelf Passage, the sediments below the flowstone were washed out, leaving the flowstone shelf and associated formations bridging the top half of the passage. In some areas, such as in the

Grand Canyon passage, coralloid and other speleothems have already formed on the eroded surfaces of the sediments.

12. Fallen soda straws. In the Rotunda Room, soda straws have fallen like a row into the mud. Except for ponding which has occurred in the Subway Passage twice during the last 15 years, this is the last geologic event recognizable in the history of the cave. It is suggested that the straws were detached from the roof during the Great Sonoran earthquake of 1887. This quake unloosed a rock slide in the Whetstones which ignited a forest fire, and damaged and destroyed buildings in nearby Benson and St. David (DuBois and Smith, 1980). In addition to events discussed in the preceding tentative chronology, several events of uncertain chronology have been identified. These are briefly described below:

1. The opening of an entrance to the Throne and Rotunda Rooms, and use of these rooms by bats. The Throne Room and Rotunda Room are now inaccessible to bats, but fossil deposits of guano occur at several locations. Later, at some unknown time, this entrance closed, ending use by bats.

2. A ponding event in the Rotunda Room and the Cul-De-Sac. This exceptional event in the geologic past left a line of remnant bat guano flotsam adhering to breakdown boulders in these two rooms. The level is far higher than any recent ponding. The ponding obviously occurred after use of the Throne Room by bats, and must represent an uncommon period of sustained precipitation outside the cave.

3. Collapse of the entrance sinkhole and opening of the present entrance into the cave. Several related events must be placed into this part of the chronology. Some time

after the sinkhole formed, it partially filled with sediments. These sediments were later washed out, leaving the marks that are visible today. It is not known whether the cave was accessible both before and after this deposition, or only after. It is also now known how long bats have used this entrance to access their present roosts in the Big Room.

4. Drying out of formations in the Big Room. Very large stalagmites, stalactites, and columns have formed in the Big Room but many of them are now dry, their growth ended. It is not known whether this is a relatively recent or very old event.

5. Helictites. A exceptional array of helictites festoon the Rotunda and Throne Rooms. The delicacy of many of them would suggest they are relatively young, but this is conjecture.

6. Deposition of a bone tentatively identified as a bison bone, in the Bison Burial Ground off the Echo Passage. The speleogenetic history presented above is tentative. Many questions about the chronology remain that will be answered by the studies in progress. Detailed investigation of the key speleogenetic events, combined with dating of critical material, will substantially improve the chronology. Radiocarbon dating of fossil guano and other suitable material, paleomagnetic dating of cave sediments, and uranium/thorium series dating and oxygen isotope studies of speleothems will be particularly useful. In the end, not only will the speleogenesis of Kartchner Caverns be better defined relative to the late Quaternary history of the San Pedro Valley, but our knowledge of the late Quaternary history will

benefit as well.

### Studies in Progress

Precise survey. Although an excellent map of the cave has been produced, the key to understanding many aspects of the geology, hydrology, and speleogenesis of the cave hinges on obtaining precise leveling and traverse data. Cave surveys with compass, clinometer, and tape are typically accurate to one part in one hundred, even for careful work. Carrying a more accurate theodolite and spirit level survey through any cave is a formidable task owing to often tight and muddy conditions and short sights. Kartchner Caverns will be no exception. This phase of the project is scheduled to begin once the bat colony has moved out for the summer.

Geophysics. The primary purpose of the geophysics is to determine if additional large cave chambers have been carved within the limestone block. Another objective is to aid in the placement of surface facilities to minimize impact on the cave. Three methods will be applied over known parts of the cave: (1) microgravity, (2) electrical resistivity, and (3) natural potential.

Based on the results, the two most promising methods will be applied. These methods will be applied over the entire park on both limestone and alluvial surfaces. By including the pediment area in the study, the structural relationship between the pediment and the Paleozoic block should be better elucidated. The traverse lines and levels for the geophysics



are currently being surveyed.

### **Surface Geology and Subsurface Geology**

The objectives of the surface and subsurface geological investigations are twofold: (1) To provide a detailed understanding of the geological setting and speleogenesis of the cave and (2) to provide geological engineering information critical to the evaluation of potential visitor access points. The studies include identification and mapping of the lithologic and stratigraphic units, strike and dip of beds, faults, folds, and joints. The relationship of these features to passage formation, cave sediments, breakdown, speleothems, and air and water flows is being noted. Careful study of the details of faulting and folding, both on the surface and underground, should shed considerable light on the mode of emplacement of the Paleozoic block. Surface and subsurface geological reconnaissances have been completed; subsurface work will recommence after the bats have migrated from their summer maternity roosts.

Cave sediments. The clastic sediments deposited within a cave provide a unique record to understanding the cave's speleogenetic history. Autochthonous deposits present within Kartchner Caverns include the insoluble residue left by the dissolution of the limestone bedrock; breakdown; and organic deposits of guano (relatively minor compared to some caves). The allochthonous deposits in Kartchner Caverns, described in the preceding Speleogenesis section, promise to be especially useful for interpreting the cave's history. The distribution, mineralogical composition, characteristics, thickness, stratigraphy

and probable source of the cave sediments are being studied. In addition, the age of suitable deposits will be determined through paleomagnetic dating.

### **Speleothems and Mineralogy.**

Secondary mineral deposits within Kartchner Caverns give it much of its beauty. The speleothems decorating the cave are composed primarily of calcite, although some aragonite (a polymorphic form of calcium carbonate) is present. Speleothem formation occurs when calcite-saturated water infiltrates into the cave and comes in contact with the cave atmosphere. The high dissolved carbon dioxide concentration in the percolating water is not in equilibrium with much lower concentrations in the cave atmosphere, resulting in degassing from the water. This shifts the equilibrium in the water, causing calcite to precipitate (and explains why speleothems can be deposited in cave atmospheres of 100% relative humidity).

Other cave minerals of more limited distribution and prominence may also occur in Kartchner Caverns. For example, whitish crusts of unknown mineralogy coat the surface of some breakdown blocks in the Rotunda and Throne Rooms; some secondary silicate minerals could also be present. On the other hand, gypsum speleothems or deposits, common in some caves, have not yet been found in Kartchner Caverns.

Once underground field work begins again in September, the speleothem types will be inventoried. Mineralogical composition of selected speleothems will be identified by X-ray diffraction and petrographic methods. Trace element analysis will be used to deter-

mine the cause of speleothem coloration, and uranium series dating of speleogenetically important speleothems will be performed. These studies, like the others, will assist in developing interpretive and educational materials for park visitors.

### **Hydrology and Hydrochemistry.**

Much of the hydrology work in progress has been described in preceding sections. Among work items not mentioned are the calculation of the 100-year runoff in each watershed in the park and the determination of the 100-year floodplain. Inside the cave, "bugs" (detectors made of cotton and activated charcoal) have been placed in the bottom of some stream channels, waiting in readiness for in-cave flows should any occur during the study period. The bugs would allow fluorescent dyes and optical brighteners to be used to trace surface-subsurface stream flow relationships and underground flow paths.

Although standing water in the cave is scarce, water samples will be collected from some of the small pools. Some samples of drip water will also be collected. If an episode of flow does occur in the cave during the study period, additional sampling will be done. Finally, water chemistry samples will be collected from the wells and from stream flows in Guindani Canyon. Concentrations of major cations and anions, trace metals, and radiochemical constituents will be determined. Alkalinity and pH will be measured with particular care in order to obtain precise values of the saturation indices. In clarifying the hydrochemistry, insight will be provided into the surface-subsurface hydrologic relationships and flow patterns within Kartchner Caverns

State Park. On a more practical basis, the data will indicate whether groundwater meets drinking water standards, which would allow it to be developed as a park water supply if withdrawal does not adversely affect conditions in the cave.

### **Cave Meterology.**

The cave meterology study will be of key importance in guiding the planning and development of Kartchner Caverns. Large parts of the cave are still live. In the live areas, calcite is still depositing and speleothems are forming. Changes in airflow, temperature, or humidity caused by improper development could quickly dry out the cave, halt speleothem growth, and diminish the cave's beauty.

Among the meterological variables being studied are temperature (both air and soil), humidity, evaporation rates, drip rates, air flow, and barometric changes. As Figure 3 shows, a total of 22 micrometeorological stations have been installed in the cave (plus seven additional air temperature-only stations). At each station, electronic temperature sensors record maximum and minimum air and soil temperatures. Stations in the Back Section of the cave are read at least once monthly, while ten of the Front Section stations are cabled to a data logger for hourly readings. The coldest temperature recorded in the cave is 65.6°F at Pirate's Den; the warmest temperature is 69.4°F at the Overlook in the Big Room. Temperatures are virtually constant at all stations within the cave. The only exception is the air temperature station at the Babbitt Hole, a construction near the entrance which funnels air, where a 5°F annual fluctuation in temperature has been recorded.

Eight-inch diameter evaporation pans (protected by canopies to ward off overhead drips) have been installed at each micrometeorological station to determine evaporation rates. Exactly 750 milliliters of water are added to each pan using a volumetric flask. Once a month, the volume is remeasured to determine loss, then topped off again at 750 milliliters. As expected, evaporation rates are extremely low, varying from 0.1 to 1.3 milliliters per day, equivalent to a depth of evaporation of 1.1 to 13.8 millimeters per year. By comparison, evaporation from a pail kept indoors at the project office in Tucson is 100 times as much.

In June 1989, matric suctions were measured in several locations in the cave using a dew point microvoltmeter (Rasmussen, 1989). Matric suctions can be directly converted to relative humidities, which allows relative humidities greater than 95% to be accurately determined (in contrast to wet and dry bulb psychrometric measurements which become decreasingly useful above this range). In Grand Central Station, free atmosphere matric suctions varied between 20 and 30 bars (equivalent to a relative humidity of between 97.7 and 96.0 percent). Deeper in the cave, at Lover's Leap and the Pyramid Room, free atmosphere suctions varied between 10 and 15 bars (99.2 and 98.7 percent relative humidities, respectively). Readings with the probe embedded within sediments in the Pyramid Room indicated matric suctions between 4 and 8 bars (equivalent to soil pore relative humidities varying between 99.70 and 99.35 percent). Based on these data, a moisture gradient exists between cave soil water and the cave atmosphere. In addition, an atmospheric moisture gradient exists from

the rear of the cave to the front. Net movement of moisture out of the cave through the entrance is therefore inferred (Rasmussen, 1989). These measurements compare favorably with the evaporation pan data, which indicate greater evaporation rates near the entrance.

A surface meteorological station has been installed which includes a recording thermograph for monitoring temperatures, a recording microbarograph for monitoring air pressure changes, a recording hygrothermograph for monitoring relative humidity, and a recording weighing-bucket rain gage. One of the objectives of the cave meteorology study is to determine whether air flow in and out of the cave entrance is due to barometric, chimney, or gravity effects. To determine this, barometric changes will be recorded simultaneously inside the cave, and a highly sensitive hot-wire anemometer to measure air movement will be installed at a passage constriction near the entrance. When these results are combined with other hydrometeorological information collected during the study, a cave water budget can be determined. This will be helpful in assessing the vulnerability of the cave microenvironment to determine construction and development options which may be considered for visitor access.

### **Air Quality.**

The air quality studies will involve measurements of carbon dioxide, methane, and hydrogen sulfide gases; alpha radiation (radon and thoron daughters); and viable airborne moss and algal spores. Methane and hydrogen sulfide concentrations are usually negligible in caves with little decomposing organic

matter (like the situation at Kartchner). Carbon dioxide concentrations are commonly elevated in cave atmospheres because of exsolution of carbon dioxide from CO<sub>2</sub>-saturated water infiltrating into the cave. However, concentrations are typically far below levels of concern if little decomposing organic matter is present (again, like the situation at Kartchner Caverns).

Monitoring of natural alpha radiation will be conducted to characterize typical concentrations and to help in understanding air flow patterns in the cave. In addition, background levels of viable moss and algae in the cave atmosphere will be determined. Exotic plant growth in electrically lighted caves is often a major problem that can damage cave features and detract from the natural beauty of the cave. Understanding airborne transport of plant material will assist in the design of cave protection measures and will provide background data to assess the effectiveness of those measures.

### Bats

Kartchner Caverns is the summer migratory and maternity home for about one thousand Cave bats (*Myotis velifer*). The bats begin arriving from their winter range in Mexico in May, have young about the third week of June (which begin flying the first week of August), and leave by mid-September. In their nightly forays for insects, the bats navigate deftly through the tortuous series of small rooms and passages connecting the Big Room to the entrance sinkhole, threading through an eight-inch diameter constriction along the way. (Humans bypass this obstacle through a nearby artificially enlarged passage, replacing

a plywood cover behind them to maintain the natural meteorological conditions of the cave).

The bat flights begin about 20 minutes after sundown and last 25 to 35 minutes. In 1988, about 650 bats flew nightly from the cave, growing to 1300 bats after the babies began flying. In 1989, pre-maternity numbers started higher, about 1000 individuals, and the total population after the young began flying peaked at about 1800 (Deborah Buecher, personal communication). Because of the configuration of the entrance sinkhole, the bats can be counted with unusual accuracy. The investigators sit quietly, backs against the wall in the bottom of the sinkhole, and count the bats as they fly out of the sinkhole highlighted against the twilight sky. As each bat exits the sinkhole, the investigators press the space bar on their portable computers, automatically recording the exit time. The data can later be dumped out to yield graphs of the bat flight.

Inside the cave, the locations of former and current bat roosts have been mapped. Bat bones have also been noted in several areas. A sampling of the bones will be examined to identify species, and if suitable old material is found, absolute dating will be attempted. Remains from the Throne Room are of particular interest, because this area is now unused by bats due to its remoteness from the entrance. No other species of bats are presently known to use the cave, except for occasional individuals of Townsend's big-eared bat (*Plecotus townsendii*), which roost in the entrance.

Outside of the cave, investigators have periodically set up mist nets to survey the bats indigenous to the area. The mist nets are usually erected at the water tank near the

southwest corner of the property where the bats swoop down and skim the water to drink. Captured bats are identified by species and usually further examined to determine sex, age, and maternity status. Weight and size measurements are then commonly taken before the bats are released. To date, seven species have been captured, all of which are typical of this range and habitat (Deborah Buecher, personal communication):

Cave bat	<i>Myotis velifer</i>
California myotis	<i>Myotis californicus</i>
Fringed myotis	<i>Myotis thysanodes</i>
Big brown bat	<i>Eptesicus fuscus</i>
Pallid bat	<i>Antrozous pallidus</i>
Sanborn's long-nosed bat	
<i>Leptonycteris sanbornii</i>	
Mexican long-tongued bat	
<i>Choeronycteris mexicana</i>	

Invertebrates and Small Vertebrates. Invertebrates make up the majority of all known cave organisms, but tend to be overlooked during cave inventories. The dark, generally nutrient poor habitat of caves gives rise to interesting invertebrate dominated ecosystems and unique cave-limited species. In Kartchner Caverns, the bat guano, although limited in extent and quantity, is a major nutrient source in the underground food web. Mites forage in the guano for mold and are themselves eaten by other predatory species of mites. Isopods, spiders, ants, and pseudoscorpions have been observed in Kartchner Caverns. A cave-adapted silverfish also has been found; this silverfish has been tentatively identified as a species previously known no closer than from caves in Texas and Central America. Cave crickets, exhibiting some characteristics of

cave adaptation, have been found throughout the Front Section of Kartchner Caverns and as far back as Grand Canyon and the Granite Dells. The small vertebrates, such as mice and lizards, have been seen only in the entrance sinkhole and nearby connecting passages. Two types of rattlesnake, the Western Diamondback and the Blacktailed, are also frequently observed on ledges or in crevices within the entrance sinkhole.

### Summary

In a few years, the wonders discovered by two cavers in 1974 and kept secret for so long will be open for all to view. The baseline information gained during the current geology, hydrology, meteorology, and biology studies will allow Arizona State Parks to develop Kartchner Caverns as a premier park for visitation and education. Arizona State Park's commitment to develop the cave only after performing thorough studies of the cave environment will assure that the quiet beauty and nearly mint condition of Kartchner Caverns will awe visitors for years to come.

### Acknowledgements and Disclaimer

The author gratefully acknowledges the assistance of Robert H. Buecher, Project Manager for Arizona Conservation Projects, Inc., the not-for-profit organization conducting the pre-development studies at Kartchner Caverns for Arizona State Parks. Many of the ideas presented in this paper evolved during cave trip discussions with Mr. Buecher. I also thank Deborah Buecher for her help, most notably for discussions on the bat and invertebrate studies and for her preparation of base maps used in several of the figures. Randy

Tufts is thanked for his assistance with the history section of this paper and Mike Darr is thanked for his help in drafting the hydrographs and hydrogeological cross-section.

While acknowledging the assistance of those named above, the author remains solely responsible for any factual errors or imperfect interpretations presented in this paper. The voluntary work on which this paper was based was conducted during the author's spare time and is not connected with his official duties at the Arizona Department of Environmental Quality.

### Glossary

For brevity, speleothem types were not defined in the main text of his paper. The short definitions presented below capsule a large body of literature dealing with the unusual forms and growth mechanisms of speleothems. The authoritative work by Carol Hill and Paolo Forti (1986), Cave Minerals of the World, discusses these topics in considerable detail. The definitions presented below are largely borrowed from this book.

**Boxwork**—intersection mineral blades, usually calcite, projecting from the walls or ceiling of a cave.

**Column**—a speleothem formed by the joining of a stalactite and a stalagmite.

**Coralloid**—any of a number of nodular, globular, or coral-like speleothems.

**Drapery**—a folded or furled speleothem which hangs down from inclined walls or ceilings with a curtain-like appearance.

**Dripstone**—any sort of speleothem formed by dripping water (e.g. stalactites and stalagmites).

**Flowstone**—a smooth, sheet-like speleothem formed by films of flowing water.

**Helictite**—a twisted, usually worm-like speleothem which grows via a small capillary channel.

**Pearl, Cave**—a spheroidal, polished carbonate concretion which forms in shallow cave pools.

**Shield, Cave**—a disc-shaped speleothem composed of two parallel hemispherical plates separated by a medial crack. Like the helictite, it is believed to have formed under capillary pressure.

**Soda Straw**—a tubular stalactite which resembles a drinking straw.

**Speleothem**—a secondary mineral deposit formed in caves.

**Stalactite**—a vertically-hanging speleothem formed by dripping water and generally having a tube or remnant of a tube at its center.

**Stalagmite**—a vertically-oriented convex floor deposit formed by water dripping down from above.

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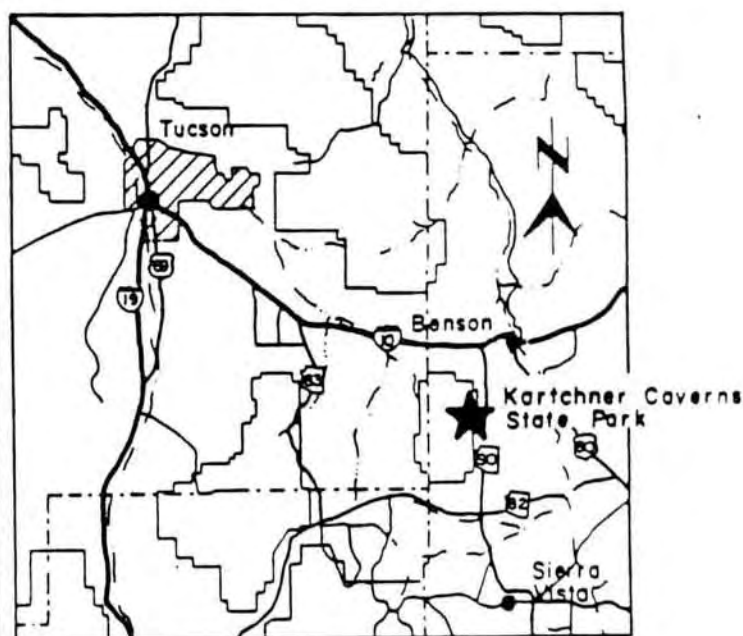
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### Biographical Sketch

Charles G. Graf received a BSE degree in Engineering Science from Arizona State University in 1972. He has caved since 1969 and has been a member of the National Speleological Society since 1980. He has attended courses on karst hydrogeology given by Western Kentucky University and the National Water Well Association.

On many weekends, Mr. Graf can be found "firing up" his carbide lamp at the entrance to Kartchner Caverns, volunteering time in support of the Kartchner studies. During the week, he is employed by the Arizona Department of Environmental Quality as a Hydrologist, where he currently manages the Superfund Hydrology Unit. Prior to coming to ADEQ, he worked as a Hydrogeologist for Tetra Tech International, where he supervised and conducted water resource studies in the Sultanate of Oman.



Scale: 1 Inch Equals Approximately 22 Miles

FIGURE 1  
LOCATION MAP



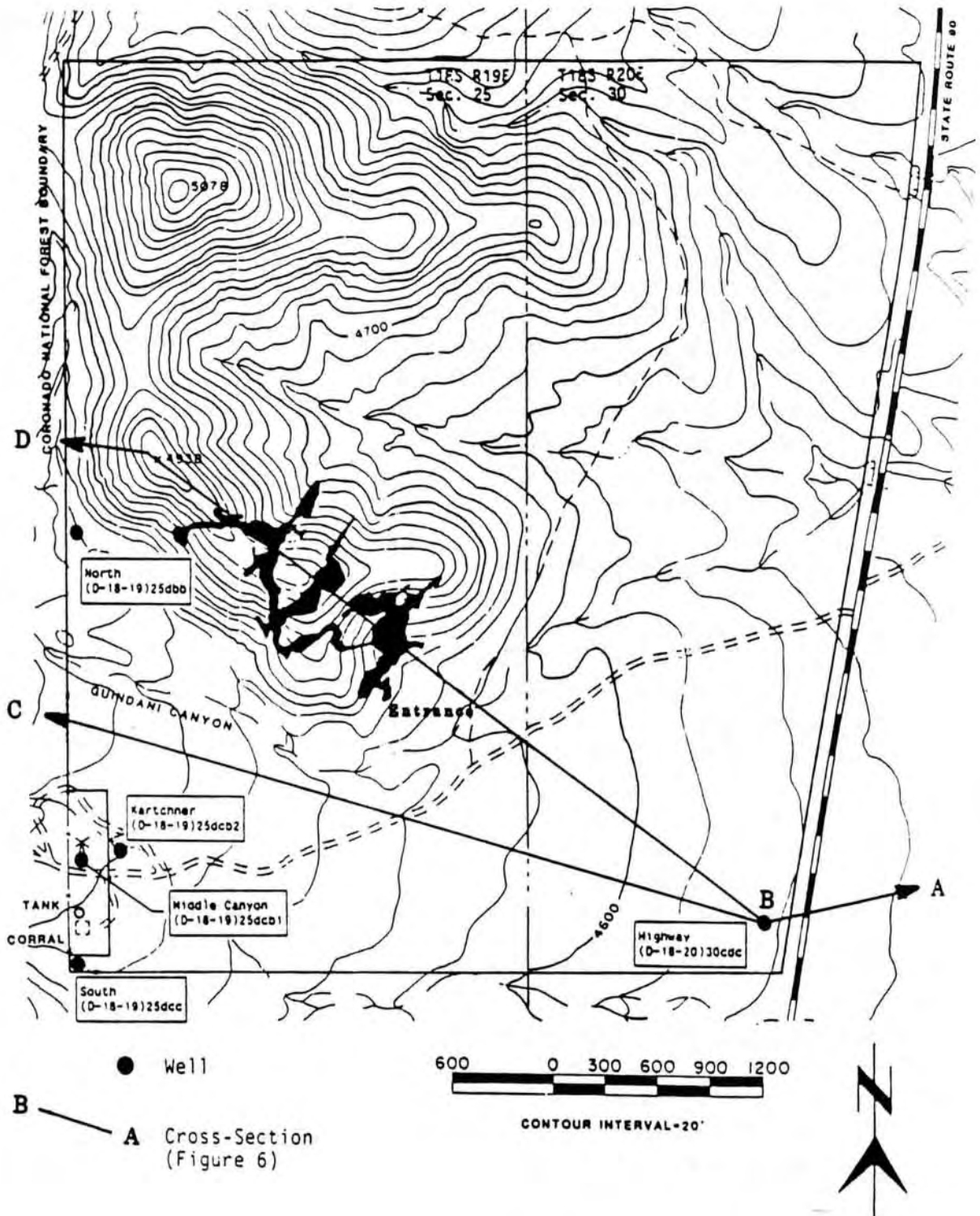
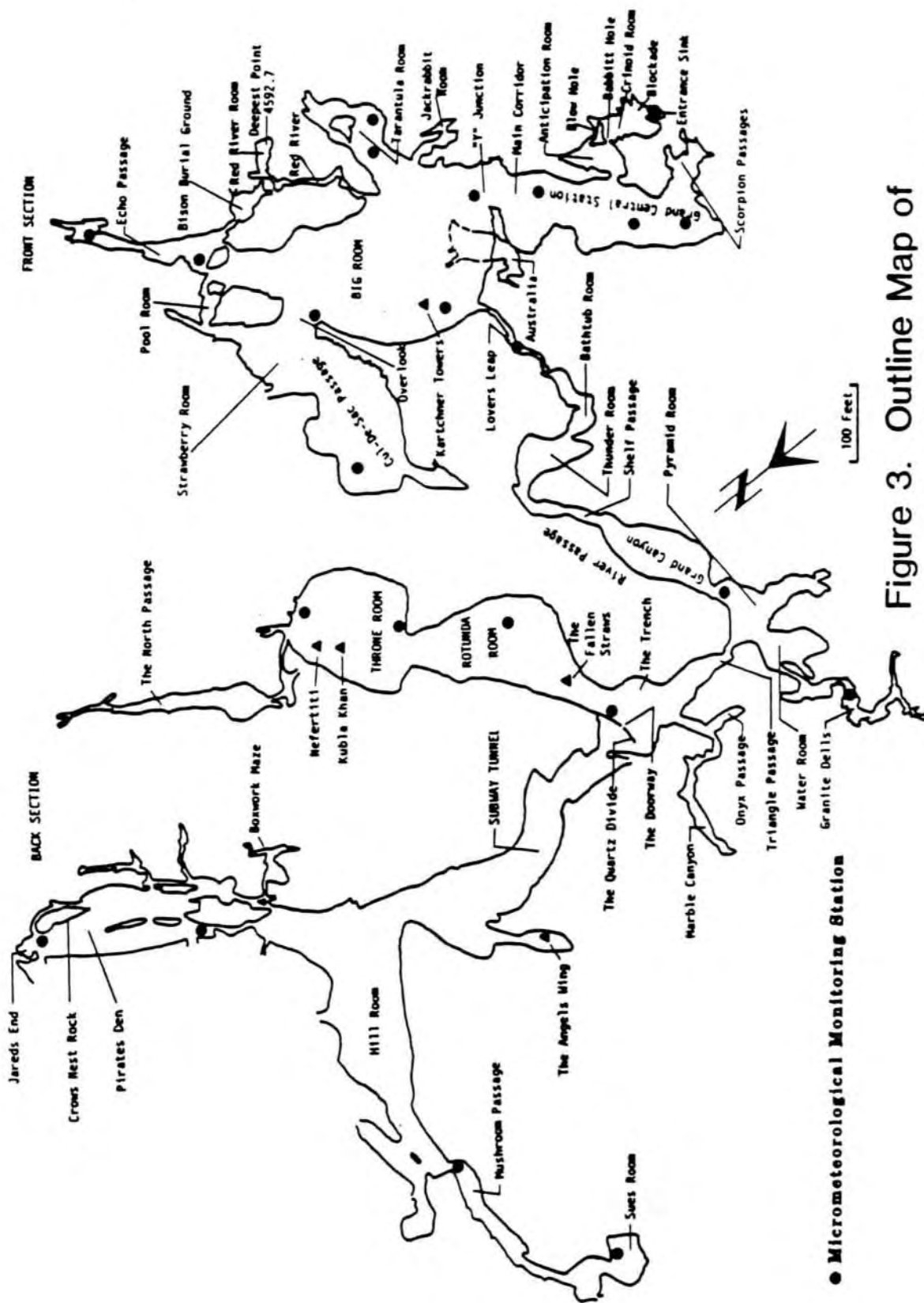


Figure 2. SiteMap, Kartchner Caverns State Park



● Micrometeorological Monitoring Station

Figure 3. Outline Map of Kartchner Caverns

# Preliminary Geology of Kartchner Caverns State Park

<b>QTg</b> Gravel Deposits	<b>Me</b> Escabrosa Limestone	<b>€b</b> Bolsa Quartzite
<b>PHI</b> Horquilla Limestone (lower)	<b>Dm</b> Martin Formation	<b>Pa</b> Alaskite
<b>Pb</b> Black Prince Limestone	<b>€a</b> Abrigo Limestone	<b>Ep</b> Pinal Schist

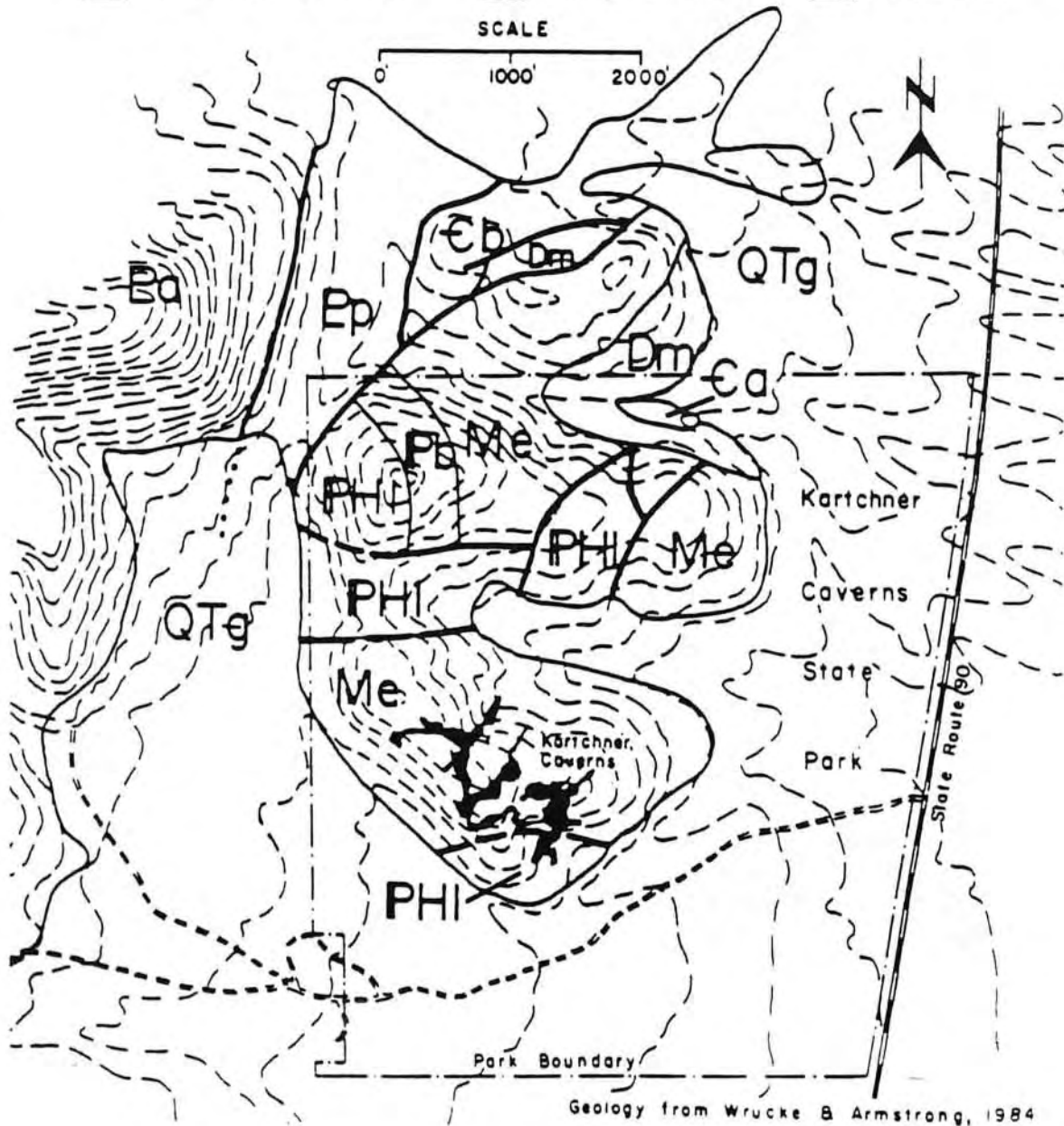


Figure 4. Surface Geology

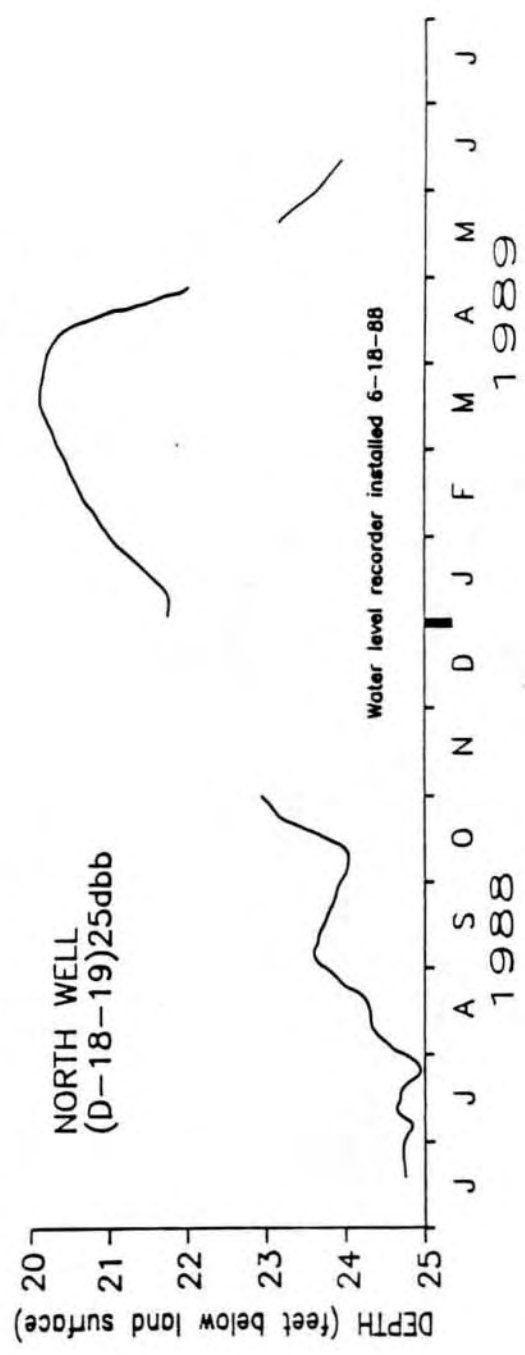
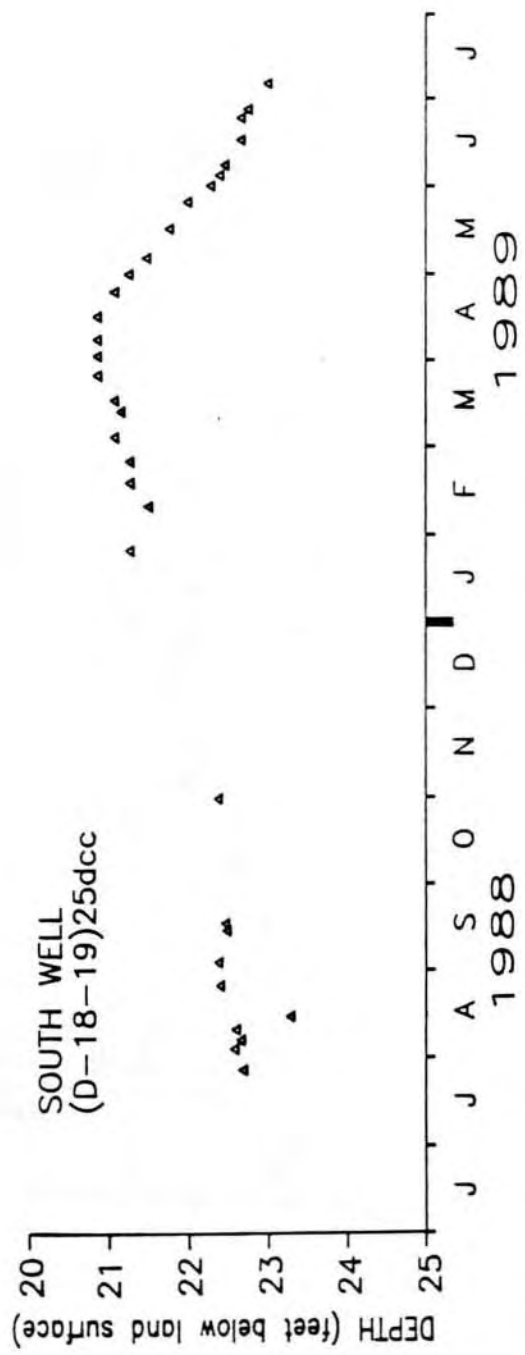


FIGURE 5. SELECTED WELL HYDROGRAPHS



## **State-Owned Show Caves: Should They Be Self-Supporting?**

by **Russell Gurnee**

### **ABSTRACT**

About 700 caves throughout the world have been modified and made accessible to visitors as show caves. Some are privately owned; some are maintained as religious shrines; but most are state owned and operated. State-owned caves are administered by public officials and dependent upon government appropriation for their protection. All are valuable natural attractions and often points-of-destination for citizens and tourists. Their value (private, religious, or public) is dependent upon continued protection and sustained maintenance. Their success can influence the economy of an entire region.

Management of public show caves requires the same skills and expertise as a private business enterprise. However, public caves do not have to make a profit to survive, but most outstanding show caves are self-supporting and generate more revenue than they require for maintenance and upkeep. The exhibition of caves requires major modifications to the natural conditions and constant attention to the environment if the public experience is to be safe, educational, and pleasurable. Publicly owned show caves, developed using tax dollars and later charging admission for visitors, are in competition with private enterprises. The administration should provide for depreciation, maintenance, and replacement of capital investments from the revenue generated-before the generated income is returned to the state for budget assignment.

Examples of management plans of state-owned show caves of several countries are given. Recommendations are made for cooperation with citizen/speleological/scientific organizations to monitor the impact on the cave by visitors. The recognition by the government of the unique needs of the cave environment and the long-range consequences of neglect of maintenance is the first step for sustained conservation of this resource. Investment of income generated by cave admissions should be allocated to the preservation of the cave. State-owned caves can, and should, be self-supporting.

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Approximately 700 caves throughout the world have been modified and made accessible to visitors as show caves. Some are privately owned, some are maintained as religious shrines; but most are state owned and operated. State-owned caves are administered by public officials and are dependent upon government appropriation for their protection. All these selected caves are valuable natural attractions and often points-of-destination for citizens and tourists. The value of caves, whether under private, religious, or public ownership, is dependent upon continued protection and sustained maintenance. The success of their attracting visitors can influence the economy of an entire region.

Most public national parks and preserves are evenly supported by the largess of government appropriations even though a small number can provide for their own upkeep. The policy of evenhandedness is understandable and because the value of a natural resource is generally measured in human viewpoint terms, it is logical and simple to justify. Unfortunately, in the United States, public Show Caves (the one segment of the park service which usually returns more money than it costs) are treated equally in the budget and often they suffer through inadequate funding. "Why should caves be treated any differently than other natural features in the park service?"

It is true that all of the property set aside as public domain is equally deserving and important. However caves have characteristics that set them apart.

Caves require controlled access, usually by a gate, because they can be dangerous and are often fragile and subject to damage. Safety of visitors usually requires guides for protec-

tion, and for this service an admission is usually charged. Unlike most natural attractions (such as waterfalls, mountains, and beautiful scenery), caves have a mystery about them that piques the curiosity of visitors. A well-known publicly owned cave will automatically attract visitors and require services beyond the usual requirements of an average park.

However, no matter how attractive, caves are not unique. There are many show caves around the world which have set the standard for comparison, and a publicly owned cave must "compete" with others. Many caves, in the United States for example, are privately owned businesses and operate as profit-making enterprises. The owners must pay taxes, provide maintenance costs, allow for depreciation, and still return a profit. It is unfair to these private endeavors for government-owned caves to exhibit caves without charge. For this reason the state usually charges a fee and sets its costs to be comparable to the private sector. Ordinarily the admission fee (usually arbitrarily set) does not return directly to the management of the cave. It goes into the general fund for the whole park, and a budget set by the administration determines the necessary maintenance and operation costs. This may not provide sufficient income to protect and exhibit the cave.

In those areas where a government-owned cave is in competition with private enterprise, government should play by the same rules required of the private owner; and if there is a profit after meeting all of the general maintenance expenses these funds should be applied to long range investments directly related to the protection of the cave. Any income above that provision could then revert to the general fund. Foregoing the

"profit" from a public show cave means that the individual taxpayer who does not use the service or attraction is forced to contribute to the upkeep of the cave.

## **MANAGEMENT SYSTEMS**

### **National Ownership**

In the United States, the policy for the National Forest Service differs from the National Park Service in that the Forest Service has a husbanding role in maintaining and monitoring a renewable resource; primarily trees. However, they also control mineral rights and mining leases on public land. This raises "value" questions sometimes in conflict with the National Park Service. The National Park Service maintains areas for the enjoyment of the public and the protection of the wildlife and environment. Both positions are defensible as good and worthy human causes, but they conflict when it comes to allotment of budgets. Serious consideration should be given to the revision of budgets for state-owned show caves to provide for the adequate protection, security, and preservation of those caves that are now under the supervision of the government.

In the U.S.A. there are a number of world-class show caves that are points-of-destination for visitors from all over the world. Mammoth Cave, Kentucky; Carlsbad Caverns, New Mexico; Blanchard Springs, Arkansas; Wind Cave and Jewel Cave, South Dakota are managed by the United States government and provide an outstanding experience for the public. Great capital investments have been made in these properties by taxpayers to present them as the principal attraction to

each park. However, in every case, after the initial development expense, the major outlays of their yearly budgets have gone to surface development. Maintenance within the cave and improvement of the experience of visitors has not kept up with the available technologies or the demands of the public. Volunteer projects are launched to "clean-up" some of these caves by dedicated volunteers because the budgets do not allow for the investment of public funds even though the admission money is adequate to cover this expenditure. It is like having theater-buffs clean the theater while the management enlarges the ticket office.

## **MANAGEMENT RESPONSIBILITY**

In the public sector a Show Cave manager might be an administrator from the Federal, State, or local municipality who is appointed to provide supervision and protection. His principal duties are related to the administrative and operational aspects of the site. In the National Park Service it is a policy to rotate Superintendents throughout the Park system, regardless of the main theme of the park, in order to permit broad personal organizational skills to develop. A Superintendent's function is in the short-range management of the facility. The long-range goals are set by administrators (usually not on site) who prepare programs for the entire Park System.

Private, not-for-profit groups such as religious or cultural organizations do not have the organizational structure to choose administrators to operate their public caves. They operate in the manner of private cave owners and appoint a manager who has control of the



access to their caves and are responsible for their upkeep. Few of these managers have any expertise in cave operation as tourist attractions. Most of them are experienced in business management and concentrate their efforts on surface development and improvement. Decisions regarding changes within the cave are generally made on site and the committee of the not-for-profit owner has little input in the actual work done in the cave.

Both of these methods of public show cave management exist and with most well known caves their efforts have been very successful.

"Then why change a system that is working?"

Sometimes the system has been too successful, and has brought a show cave to a point beyond its carrying capacity. Today, in most of the developed countries, the historic world-class caves that are in good condition are suffering from over-visitation.

In England, the caves of the Cheddar Gorge have overflow crowds in summer and in the French caves of prehistory they limit public access because of the fragile nature of the cave paintings. Too many people can cause a change in cave temperature simply by their presence. In Spain, Portugal, Yugoslavia, and Italy the attendance to show caves has exceeded the facilities and capacity of the caves during the vacation season.

In the United States many of the National Park Caves limit the number of people by admitting them on a first-come, first-serve basis. When a predetermined quota is reached the administrators close the cave. Puerto Rico and Barbados, in the Caribbean, have show caves where appointments are made for visitation. All these caves, wherever located, are

attractive, exotic, and interesting and present visitors with a unique natural experience. This makes them a point-of-destination for travelers. The caves are responsible for the attendance at many parks and while many changes are made to the surface facilities, little is done to enhance and safeguard the one feature that has attracted the public—the cave.

### **DEFINING THE PROBLEM**

Policy seems to be the principal stumbling block in finding a solution to the over-crowding in public show caves. Without a clear-cut policy regarding the conservation of the cave and the responsibility of public management, there is little hope of improving the situation. Until a balance is achieved, permitting the optimum sustained public use of the cave, based upon improved facilities to accept them, the goal will not be reached without deterioration of the cave environment. At this time the decision of when this balance is achieved is being made at various levels of authority and by people of different degrees of expertise. By definition, a show cave is set aside for the benefit of man, unless the presence of some other organism or life within the cave is hazardous to him. The conservation of the cave then becomes a matter of self-interest to man and the policy to protect the cave is to enhance the experience for visitors by maintaining the natural conditions that are the basis for the visit. Conservation then becomes not altruistic but realistic and can be measured in dollars.

### **SEEKING A SOLUTION**

Reducing this complicated subject to

dollars permits decisions by committees and local managers regarding important necessary conservation programs by the simple expedient. "We don't have the money."

Some conservation needs cannot be measured in money. The preservation of Lascaux Cave in France, endangered by over-visitation, defied scientific solution even after 10 years of study. Only by building a duplicate cave nearby, to fulfill the demands of the public, was the pressure on the original cave relaxed.

The sustained continued enjoyment of natural caves throughout the world is well within professional expertise available today. We can train guides, administrators, engineers, and artists to maintain the conditions that created these caves in the first place. The caves can be self-supporting by the visitors and attendees if provisions are made to include in long-range plans the resources for the preservation of the sites.

### CONCLUSIONS

The redevelopment of a show cave is required only once or twice in a generation and should not be a practice carried on by the day-to-day managers of the operation. Monitoring of conditions within the cave should be the responsibility of management, but the decision to make changes must come from specialists who can analyze the data, project the consequences of change, and prepare a program for maintenance to sustain the results. This analysis is a limited specialty that does not provide an opportunity for many careers. However, the knowledge and skills are available today. With a worldwide economy providing sophisticated and critical visitors and

tourists in the most obscure places, a government that exhibits a public show cave should take advantage of current technology in presenting their caves.

A search should be made for experienced and capable experts in the design and presentation of these specialized areas. Speleological organizations can aid in the search for persons with background and experience as prospective consultants. A thorough knowledge of the environment, esthetic sensitivity, and an awareness of the effect on the cave life, structure, and human safety are all ingredients required to prepare a plan or modification within the cave. The most important ingredient required by the designer is the ability to work with the natural conditions with the least impact on the cave. (Don't call in a house painter to redo the ceiling of the Sistine Chapel.)

Authorities who control access to public show caves should provide for the contingency money, with income from admissions, to pay for the monitoring of conditions within the cave, examining the need for extensive surface development, and maintaining the natural integrity of the site. All these costs should be part of the budget and only after this expense is met should the surplus revert to the general fund.

Russell Gurnee  
231 Irving Avenue  
Closter, NJ 07624

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## **Cave Conservation: Special Problems of Bats**

by **Gary F. McCracken**  
**Department of Zoology and Graduate Programs**  
**in Ecology and Ethology**  
**University of Tennessee, Knoxville**  
**Knoxville, Tennessee 37916**

### **Abstract**

Ignorance as to the real status of populations of almost all bat species is a major problem for their conservation. This ignorance is reflected in the IUCN "red list" of threatened species, which is both minimalist and biased. The recent proposition that we should construct "green lists" of species known to be secure, rather than red lists, is extended to bats. Available information regarding the status of the five species of North American bats listed as endangered is reviewed, and these species are used to illustrate major problems encountered by bat populations. All of these species rely on cave roosts. Their habit of roosting in large aggregations during hibernation and/or reproduction make these and other cave dwelling bats particularly vulnerable to disturbances which can reduce populations. Types of disturbances and their likely effects are discussed. The long-life spans and low reproductive rates of bats mandate that they will recover slowly following population reductions. Habitat alteration and destruction outside of roosts and poisoning from pesticides also have impacted negatively on bat populations; however roost site disturbance and habitat destruction have probably had much greater negative effects than has pesticide poisoning. Because disturbance within their cave roosts is a major problem in bat conservation, constructing lists of "green caves" (those which can be visited) and "red caves" (those which must be avoided) is encouraged. Criteria for constructing these lists of caves are discussed.

### **Red Books, Green Lists, and a Lack of Information**

Each year, the International Union for the Conservation of Nature (IUCN) updates

the Red Data Book which lists plant and animal species known to be endangered, vulnerable or rare. The 1988 Red Data Book places 33 bat species in these categories. As there are approximately 900 species of bats in

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the world (nearly one-fourth of all mammal species), this "red list" of threatened species includes less than four percent of the world's bats. This disproportionately small number should lead anyone with even remote awareness of the worldwide extinction crisis to question whether this list reflects reality with regard to bat species that are threatened. In reality, the red list does not come close to giving an accurate picture of the problem.

First, consider that the red list has a substantial geographical bias toward North American species. The standard reference on North American bats (Barbour and Davis, 1969) lists 39 species of bats in North America, north of Mexico. These 39 species comprise about five percent of the worldwide bat species diversity. However, of the 33 threatened bat species on the IUCN list, five are native to North America. So, a fauna comprising five percent of total bat species diversity accounts for 15 percent of the species considered as threatened. I argue that this bias does not reflect reality with regard to species management. Rather, this bias reflects our ignorance regarding the status of most bat populations. We simply know the status of bats in North America better than for other parts of the world. I also argue that our degree of ignorance is even more frightening when you recognize that we are not even certain how accurate the IUCN red list is for bat species in North America. This is so because for most bat species in North America, much less for those elsewhere (particularly in the tropics), we simply do not have the information to determine whether overall population sizes are stable, decreasing, or if they are decreasing, at what rates? So our ignorance on the status of bats is extreme. Given this ignorance, the IUCN

red list gives a highly inaccurate and minimal assessment of our current extinction crisis.

Recognizing this, prominent conservation biologists recently have suggested that the construction of red lists has been a major tactical error by those who wish to preserve the world's biota (Imboden, 1987; Diamond, 1988). Red lists are thought to be a tactical error because the existence of such a list may lead to the assumption that if a species is not on the list, that species is not in jeopardy. This, of course, is not how the list should be interpreted. Many species that are not on the list should be, but are not, simply because we don't know enough about them. To correct this tactical error, it has been suggested that rather than constructing red lists, we should construct "green lists". Green lists would include species that we know are secure. To be on the green list, a species should meet the criterion of "known not to be declining in numbers now, and unlikely to decline in the next decade" (Diamond, 1988). With a green list, it is argued, the burden of proof is shifted to those who wish to maintain that all is well with a species.

Those proposing green lists have been concerned with birds, not with bats. Certainly, much more is known about the status of birds than of bats. However, it is estimated that fewer than one-third of the world's bird species would qualify for inclusion on a green list. This being the case with birds, I also suspect that fewer than one-third of the world's bats likewise would qualify for such a list.

### **Some Things That We Do Know**

With our ignorance as a perspective, I wish to consider some of what we do know

about the status of bats, particularly cave bats. This requires going back to the red list. Of the 39 bat species in North America, north of Mexico, 18 rely substantially on caves for roosting sites. Some of the remaining 21 species also are occasionally found in caves, but caves evidently are not absolutely essential to them. Of the 18 species for which caves are essential, 13 species utilize caves year-round, both for reproduction and as winter roosts. The remaining five species rely on caves as hibernating sites, but roost elsewhere during reproduction. Four of the five North American species on the red list require caves year round (Table 1), and one species (the Indiana bat) requires caves for hibernation, but roosts elsewhere during the summer. So all North American bats listed as threatened are cave-dwelling; there appears to be a correlation with cave-dwelling and species jeopardy. However, to hearken briefly back to our ignorance, it is easier (not easy, just easier) to assess the status of cave dwelling bats than the status of bats that are more dispersed in their roosting habits, and thus more difficult to find and monitor. The bias toward cave-dwelling bats being on the threatened list may in part be a result of relative ease of censusing.

#### **Life History Traits Predisposing Bats to Extinction**

Unlike most small mammals, bats have extremely long life spans. Even the smallest bat typically has a life expectancy on the order of 10 years, and individuals are known to live much longer than this. Wild little brown bats, for example, are known to survive as long as 30 years (Keen and Hitchcock, 1980). In addition to long life expectancies, bats have

very low rates of reproduction. Many female bats do not reproduce until their second year and, after reaching maturity, females usually produce only a single pup each year. Consequently, bats have far lower potential rates of population growth than are typical of most small mammals. Although bats are often perceived of as similar to rats or mice, the reproductive rates of bats are, in contrast, more similar to those of antelopes or primates. If a bat population is decreased in size, it can recover only slowly.

Bats have other characteristics which contribute to their vulnerability. Among the most significant is their habit of roosting together in large aggregations. The fact that large numbers of individuals often are concentrated into only a few specific roost sites results in high potential for disturbance. Because of their aggressive roosting habits, species that are very common actually can be vulnerable because they are in only a limited number of roosts. Mexican free-tailed bats (*Tadarida brasiliensis mexicana*) are an excellent example. Single cave roosts of these bats can contain tens of millions of individuals, and the loss of even one such roost would mean the loss of a significant portion of the entire species population.

#### **Disturbance of Roosts by Humans**

Aggregations of bats are vulnerable to a variety of human-caused disturbances. At least three North American endangered species (Indiana, gray and Sanborn's long-nosed bats) are known to have abandoned traditional roost sites because of commercial cave development (Humphrey, 1978; Tuttle, 1979;

Wilson, 1985a). An important hibernaculum for endangered big-eared bats has been threatened by quarrying (Hall and Harvey, 1976), and I personally have observed numerous examples of vandalism such as burning old tires, or shooting guns inside bat cave roosts. Although intentional disturbance of roosts is well documented, unintentional disturbance often poses an even greater threat. In the temperature zone, aggregations of bats which cavers typically encounter are either hibernating groups that occur in late fall, winter or early spring, or maternity colonies that occur in late spring or summer. There is no question that disturbances as seemingly trivial as merely entering a roost area, or shining a light on hibernating bats or on a maternity group of females and their pups, can result in decreased survival, perhaps outright death, and possible abandonment of the roost site. Although there is some controversy about the significance of this apparently "innocent" disturbance, my own experience and reading of the literature lead me to the opinion that it can be extremely significant. However, there is no question that the impact of such disturbances are somewhat species-specific, and that the timing of the disturbance is very important.

The results of "innocent" disturbance of a maternity colony can include the following: (1) It can cause individuals to abandon roost sites, particularly early in the reproductive season when females are pregnant. This may result in females moving to other, perhaps less ideal, roosts where their success at reproducing is reduced. (2) Disturbance raises the general level of activity within roosts. This may result in greater expenditure of energy and less efficient transfer of energy to nursing

young. This, in turn, may cause slower growth of young and increase the foraging demands on females, thus increasing the time females are outside of the roost and vulnerable to predation. (3) Disturbance can cause outright death of young that lose their roost-hold and fall to the cave floor. (4) Maternity aggregations often result in thermoregulatory benefits. Clustering bats gain thermal benefits from being surrounded by other warm bodies. However, individuals also may receive thermal benefit because the accumulated body heat of all individuals present serves to raise temperatures within the roost area. Therefore, if the size of a colony decreases, the accumulated thermal advantages to the individuals in that colony may likewise decrease, and it may become energetically less advantageous, or perhaps even energetically impossible for females to raise pups in that roost. Thus, there may be a "threshold", where after a population reaches a certain lower size, roost temperatures cannot be raised sufficiently for rearing young and that roost must be abandoned as a maternity site.

Problems caused by disturbing hibernating bats also relate to their energy requirements. During winter, temperate zone bats go long periods without eating, and allow their body temperatures to drop, often to near freezing. The energy reserves that bats accumulate prior to hibernation are often close to what is needed to survive the winter. Disturbance during hibernation may cause bats to arouse prematurely, elevating their body temperatures and utilizing stored energy reserves which should not be spared. The bats may go back into torpor after the disturbance, but then they may not have sufficient energy to

survive the rest of winter. This may not be apparent to the person causing the disturbance.

Roost site disturbance also can seriously impact bats which do not form large aggregations. This is undoubtedly so for many tropical bats which roost in mature, hollow trees, which are being cut as more tropical forest goes into cultivation. To my knowledge, we don't know the trajectories of populations of any of these tree-roosting bats. As an example closer to home, it seems probable that the decline of the Indiana bat may be attributed in part to the loss of roost sites other than caves. Indiana bats hibernate in caves and there is no question that disturbance of hibernacula has contributed to their decline. However, in the midwestern United States, several large hibernacula of Indiana bats are protected from disturbance, yet these cave populations continue to decline (Clawson, 1987). We can only speculate on the reasons for this continued decline, and this again points to our ignorance. However, while Indiana bats hibernate in caves, in summer they roost and give birth in three hollows and under the loose bark of trees. The loss of tree roosts may very well be a serious factor in the continuing decline of the Indiana bat in the Midwest. That the decline of the Indiana bat may be due in part to factors outside of their hibernacula in no way implies that disturbances at hibernacula are unimportant. Rather, it emphasizes the importance of protecting hibernacula so as not to add additional stresses to these populations.

### **Habitat Degradation Outside of Roosts**

Man also has impacted negatively on bat populations by causing habitat alteration and degradation outside of their roost sites. For example, two species of North American bats on the red list are endangered, in large part, because man's activities have decreased their food resources. Both species of long-nosed bats inhabit desert regions of the southwestern U.S. and Mexico, and both feed on the nectar and pollen of desert flowers (Wilson, 1985a, b; Anonymous, 1988). Wild agave is a major food source of both species. Wild agaves have been severely reduced because they interfere with cattle grazing and because they are harvested by moonshiners for making tequila. Although long-nosed bat populations also have been affected by interference with their cave roosts (Wilson, 1985a, Anonymous, 1988), the reduction in agaves is clearly important in their decline. Long-nosed bats also are major pollinators of both organ pipe and giant suaguaro cacti. The well-known decline of these cacti also is evidently directly attributable to the decline of long-nosed bats (Wilson, 1985a, b; Anonymous, 1988).

### **The Role of Pesticides**

Pesticides used to control insect populations have negatively impacted populations of many bats (Clark, 1981). Two effects seem likely: (1) direct poisoning of bats, and (2) reduction in the resource base of bats which eat insects. At present, we know little regarding the effects caused by pesticides reducing the insect prey of bats. However, direct poisoning by DDT (now banned for use in the U.S.) and other organochlorine pesticides have been widely implicated in the decline of many bats (reviewed in Clark, 1981). While pesticide poi-

soning clearly has caused the decline of local populations of many bats, there has been a tendency to over-emphasize the importance of pesticide poisoning as one of the major factors in the decline of bats (Clark, 1981; McCracken, 1986). In fact, I question whether the general decline of any bat species can be attributed solely or even largely to the toxic effects of pesticides. This is not to exonerate pesticides, but rather to point more strongly at what are the major causes of bat population declines: i.e. roost site interference and the reduction of resources. I suspect that overemphasis of the importance of pesticide poisoning serves to draw attention away from these other causes.

How do I justify these statements? First, the belief that bats are unusually sensitive to pesticides dates from an early paper which purported to document their extreme susceptibility to DDT poisoning (Luckens and Davis, 1964). It is now established that the susceptibility of bats to DDT is in general no greater than that of other similar sized animals (Clark, 1981). Second, there have been many observed, dramatic declines of bat populations that have been attributed to DDT poisoning, without strong data to support these attributions. The most spectacular of these occurred in Eagle Creek Cave, Arizona, where the population of Mexican free-tailed bats declined from an estimated 30 million to an estimated 30 thousand individuals. While other toxins, such as methyl parathion (Clark, 1986), may have contributed to this decline, and human disturbance also seems a likely culprit, there is no evidence that DDT poisoning was a major cause of the loss of this population

(Clark, 1981; McCracken, 1986). Again, this is not to say that DDT or other toxins have not directly killed bats. It is well documented, for example, that young Mexican free-tailed bats from Carlsbad Caverns have had potentially lethal pesticide concentrations. However, this is evidently a local problem that has not been reported in other colonies of this species (Geluso et al., 1981). Finally, a natural "experiment" on DDT poisoning has been done for us. In the early 1960s, Cave Springs Cave in Alabama housed a major maternity colony of gray bats. This cave was heavily disturbed by humans and by the early 1970s, all its gray bats were gone. However, Cave Springs Cave was then protected by fencing and its gray bat population began recovering to the point that it now houses an estimated 50,000 individuals. Cave Springs Cave is near a former DDT processing plant which also was a major toxic waste dumping site. At present, the bats and bat guano within this cave are substantially polluted with a variety of toxic chemicals including DDE (derived from DDT) and PCBs. Although this bat colony experiences occasional dieoffs resulting from these toxins, the colony has nonetheless continued to recover in the face of these pollutants; this recovery dating from when the cave was protected (Tuttle, 1986).

#### **Red Caves/Green Caves**

From what we know about human-caused impacts on bat populations, there is little question that roost-site disturbance, vandalism, and habitat destruction have had severe effects. This is particularly so for cave-dwelling bats. My opinion that these impacts are likely to have had greater negative effects than



pesticide poisoning is shared by other researchers (Clark, 1981; Tuttle, 1985). People who visit caves, both professionally and for sport, must be acutely aware of the potential damage they can do to resident bats. To minimize such damage, we should recognize that there are caves ("Red Caves") which should not be visited by humans at any time, or only visited during certain times of the year, and other caves ("Green Caves") which are not important to bats or other threatened species and can be open to visitation. Bats select caves as hibernacula or as maternity sites because they fulfill very specific requirements. Fulfilling these requirements depends on cave structure, air circulation patterns, temperature profiles, and the cave's location relative to foraging sites (Tuttle and Stevenson, 1978; Tuttle, 1979). Because the requirements of bats are highly specific, those caves which do fulfill them will be relatively rare and may be absolutely essential to the bats. There may simply be no acceptable, alternative roost sites available. These caves must be placed on our red list. Conversely, most caves will not satisfy these requirements and will not be important as bat roosts. These can be placed on a green list. It seems likely that the vast majority of caves would go on the green list. For example, less than five percent of caves surveyed in the southeastern U.S. were found to be physically suitable as gray bat maternity or hibernating roost sites (Tuttle, 1979).

A major problem, of course, will be deciding whether a cave belongs on the green versus the red list. One obvious criterion is that major hibernacula and maternity roosts of threatened and or declining bats should be

red-listed, at least during the seasons when bats are present. Conversely, caves which are not occupied by bats and for which there is no evidence of prior occupancy should be green-listed. But, obviously, judgements will have to be made, often with only limited information. For example, it can be argued that historically important roosting sites that are now abandoned should be red-listed, at least temporarily, in the hope that they will be reoccupied. It also can be argued that caves with only small colonies should be red-listed, possibly for gene pool conservation, or that caves important to transients during seasonal movements should be red-listed during the relevant seasons. On the other hand, there may be no harm in green-listing some cave roosts of abundant, widely dispersed species (e.g. those of eastern pipistrelles), particularly if those caves have inherent interest to cavers.

Although listing caves for no or restricted access because of their use by roosting bats is likely to be controversial, these listings are necessary to preserve bat populations. Individuals who explore caves for sport or scientific study have a high probability of encountering roosting bats. The NSS, as the largest single organization of cavers, has the opportunity to provide education regarding potential impacts on bat populations to large numbers of people who are likely to encounter bats. In addition, cavers often have knowledge of bat roosting sites, and this knowledge is essential to informed and responsible listing of caves on red or green lists. Opportunities are abundant for cavers to cooperate with state, national and private conservation agencies in identifying and preserving sensitive cave habi-

tat. Several NSS grottos have taken the initiative themselves to construct, or are in the process of constructing, red and green lists of caves. These people should be supported in their efforts. Efforts to construct these lists should be expanded.

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**Table 1:** Officially endangered North American bats\* and their use of cave roosts.

<b>Species</b>	<b>Cave Roost Requirements</b>
Indiana Bat <i>Myotis sodalis</i>	Winter Hibernacula
Gray Bat <i>Myotis grisecens</i>	Year-round
Big-Eared Bat** <i>Plecotus townsendii</i>	Year-round
Sanborn's Long-nosed Bat <i>Leptonycteris sanborni</i>	Year-round
Mexican Long-nosed Bat <i>Leptonycteris nivalis</i>	Year-round

\* These species are listed on both the IUCN Endangered Species List.

\*\* Two subspecies of big-eared bats are listed. These are the Ozark big-eared bat (*P. t. ingens*) and the Virginia big-eared bat (*P. t. virginianus*)

and are listed on the IUCN Red List and the U.S. Fish and Wildlife Service

Endangered Species List. These are the Ozark big-eared bat (*P. t. ingens*)

## **Mystery Cave Trails: Past, Present and Future**

by **Warren Netherton**  
**Forestville State Park**  
**RR 2, Box 128**  
**Preston, Minnesota 55965**

### **Abstract**

Mystery Cave is a show cave in southeastern Minnesota. It was privately operated until 1988, when it was purchased by the state of Minnesota and included in Forestville State Park. The current development work is based on the premise to re-establish the passages to what existed when the cave was discovered. The much needed trail renovation currently under way is progressing as a result of planning which gives equal consideration to future interpretive possibilities, resource management concerns, and the historical record. Oral history interviews provide an important background which trail modifications are based on. Early photographs have provided documentation of cave alterations. Test pits excavated in the floor identified areas where speleothems are buried from development work 40 or more years ago. The Minnesota Conservation Corps (MCC) is found advantageous to use for the variety of preparation and excavation projects under way. The MCC identifies areas where contractors can remove material in less sensitive zones. Excavation techniques incorporate shovels, picks, wheelbarrows, rope, garden hand trowels, hand pressure sprayers, and plastic putty knives. Refractive seismic survey techniques are used to map potential safety problems near the tour route. Other caves and materials are being examined by park personnel for possible application in the Mystery Cave development.

**Editor's note:** Paper presented at the 1989 National Cave Management Symposium, New Braunfels, Texas, 3-7 October 1989.

Mystery Cave is located in southeast Minne-

sota near the town of Spring Valley. The 12.7-mile maze of joint controlled passages are developed on two levels under about a half square mile. The cave is a stream piracy route on a meander loop of the South Branch Root

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River. Two separate sections of tour routes are accessed at opposite ends of the cave system (the historical entrance and the Minnesota Caverns entrance).

The historic tour route is currently undergoing development work. In the past, this is where most of the visitors toured the cave. It is expected this trend will continue with the addition of a new lighting system and trail modifications. The purpose of the present efforts is to restore the cave to as close to the natural conditions which existed when discovered and maintain easy accessibility for visitors. It is an opportunity to redevelop a representative portion of the cave and its features for the public to view. At the same time, some of the resource problems can be addressed.

### **History of Development**

Discovered in 1937, Mystery Cave was immediately developed as a show cave. The development involved enlargement of passages by excavation of sediment and flowstone, bridge and stair construction, and stringing of bare light bulbs. Crawlways were dug out so visitors could walk through upright. This initial trail work was done largely with pick, shovel, and a mule which hauled excavated material loaded onto a two-wheeled cart.

Tours were offered from 1937 until 1942, when torrential rains flooded the cave. The flood damage coupled with difficult economic times dissuaded the lessees to terminate tour operations and blast the entrance closed. In 1947, new entrepreneurs leased the cave. They opened the entrance and began

removing the flood deposits with shovel, wheelbarrow and water hose. Additional excavation of material from one location in the cave and filling of passages in another location eliminated at least one of the previous bridges. By cutting the high spots and filling the low areas, the tour paths were transformed to relatively level, broad walking surfaces which often span the width of the passages. Pea gravel spread on the paths provided a mud-free trail surface. In 1958, a new entrance was dug at the eastern end of the cave and more tour routes established.

Tours were offered under these conditions up to 1988 when Mystery Cave was acquired by the state of Minnesota and made an addition to Forestville State Park. One hundred sixty thousand dollars was appropriated for new wiring and other improvements. Park officials are mandated to continue cave tour operations during the summer season.

It was determined the historical entrance to the cave is unsafe for the general public; the antiquated lighting system includes deteriorating insulation on undersized wiring within easy reach of the trails. This route is now undergoing development. Tour operations have continued at the Minnesota Caverns entrance for the past two summers despite somewhat clumsy logistics. Liability concerns at this entrance have heightened pressure to open the historical entrance as soon as possible.

The trail development work on the historical entrance goes beyond simply a new lighting system. The work is based on the premise to re-establish the cave passages to as near a condition as possible to what existed at

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the time of discovery in 1937. Well illuminated walking surfaces are to be provided which are easily accessible to the public, including wheelchairs for a portion of the route.

The previous cut and fill development served its purpose well. Present management finds several problems with the previous improvements, however, and steps are being taken to rectify these with the present development efforts.

### Interpretive Problems

From the interpretive perspective, visitors receive a distorted view of the cave on the historical entrance tour route. Numerous speleothems, in particular flowstone along the walls, are covered with fill material. Some of the better examples of draperies, flowstone and stalagmites are buried. This is in a show cave which does not have many speleothems. These are some of the features unique to the underground which visitors pay to see.

Flowstone cascades appear to stop abruptly at trail surfaces to the uninitiated. It is obvious to one familiar with caves what is occurring; however, the general public would never recognize the condition and leaves the cave with a false impression.

Besides covered speleothems giving the visitor an erroneous view of Mystery Cave, the cut and fill methods have altered the passage shapes considerably in at least four areas. For example, in one room (the Devil's Kitchen) the 20-foot-high room appears rather interesting. What one does not recognize upon entering this chamber is that the original floor surface

lies beneath 20 feet of fill underfoot. By removal of this fill, the character of this room will change from interesting to spectacular when put in context with the rest of the tour route.

### Resource Degradation

From the resource standpoint, the existing trail situation has serious problems. The result of thousands of visitors through the cave is that the pea gravel trail surface has been kicked, tossed or in some manner transported atop flowstone, sediments and wall crevices. In numerous places, pebbles are cemented to the travertine. The choice is to allow the gravel to remain in place or remove it. Either way, the surface is marred. The remarkably rapid rates of deposition along some portions of the tour route has compounded this problem.

The fill material discussed above has obviously choked off speleothems and altered water drainage, while in the trenched out portions of the cave, flowstone is now being deposited upon sediments which were previously buried. It is cementing loose gravel which tends to dislodge and roll off on the trail.

When the passages were cut larger, tons of layered poolstone deposits were removed and used as fill elsewhere. The trail trenching through these areas provided standing room five and a half to six feet high. This is an improvement from taking the general public through a crawlway, but wasn't enough to keep soda straws intact on the ceiling. The soda straws are long gone and streaks from visitors' heads mar the natural texture of the mud coated ceiling.

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Several primary sources of information were tapped to help determine the extent of cave alterations mentioned above. They are:

1. Oral history interviews
2. Photographs
3. Test pits.

### **Oral History Interviews**

Fortunately, several key individuals are still living who were intimately involved with the original development work at Mystery Cave. By tape recording interviews with these people, insight was gained about the early development. Interviews reveal the cave changes made from the unique perspective of the interviewee. They not only provide information on what was done, but also help explain the reasons behind the actions; information that a set of dry facts don't uncover.

### **Photographs**

Early photographs of the entrance and cave features document the trail facilities, passage alteration, speleothem conditions, and above-ground land use. Although early photo coverage in the cave is limited to the showier features, it serves as tangible evidence present development work is based on. Old brochures, postcards and personal black and white photographs serve as source material.

### **Test Pits**

Simply by examining the walls and floors, it is possible for a person familiar with caves to recognize alterations. With the assistance of

local volunteer cavers, a series of preliminary test pits were dug in selected areas. These holes uncovered speleothems beneath the floor which have been covered for 40 or 50 years.

By considering the historical, interpretive and resource impacts of previous Mystery Cave development, it is estimated that approximately 600 cubic yards of fill material requires removal from the tour routes to re-establish the natural floors of 1937. Additionally, some portions of the route necessitate excavation beyond the natural floors to provide protection of the resource by incorporating seven-foot ceiling heights and making grades suitable to accommodate the general public.

### **The Workers**

Excavation work began in May of this year (1989) and has continued for the past four months. It is proceeding with the use of two different types of crews, a Minnesota Conservation Corps (MCC) crew and a contractor. The MCC is a youth program modeled after the Young Adult Conservation Corps (YACC). The MCC performs the excavation along the walls and speleothems. The contractor is used to remove the bulk of the material between the MCC excavated portions, the so-called grunt work.

The MCC was selected to work on the cave project for several reasons. The results of their work have been quite satisfactory.

(1) Close quality control over their work (park personnel supervise the crew. The non-re-

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newable resources of the cave do not allow for mistakes. The measure of production for the MCC crew is quality, not quantity.)

(2) Inexpensive. (Pay per hour is slightly above minimum wage. The cost of the MCC performing comparable work is 24 percent below contractor costs.)

(3) Public relations (The intangible public relations benefits of an impressionable, young (ages 18 to 26) crew working on a physically challenging and unique project will last for years and has been well demonstrated by former Civilian Conservation Corps workers at Wind Cave National Park and Jewel Cave National Monument. In a sense, the MCC-Mystery Cave project, if managed correctly, will yield perhaps 50 years of free advertising.)

(4) Flexibility (the workers can be used on a diversity of tasks which are sometimes difficult to write or pay for on a contract basis. During the course of a day, a crew member may perform heavy labor, shovelling mud and gravel, lifting rocks, and hauling wheelbarrows, then switch to carefully exposing flowstone a fraction of an inch at a time with a water sprayer and putty knife.)

Disadvantages of such a crew include:

- (1) Supervision time.
- (2) Difficulty in securing workers during the school year.
- (3) In Mystery Cave, workers' radon exposure must be monitored and limited.

The success of the MCC crew at Mystery Cave is a function of two key elements, training and

a good crew supervisor. Considerable time has been spent training the crew members and supervisor on how to do the work. Fortunately, for this project, a natural leader was selected who appreciates the significance of the task at hand and is a hard worker.

The MCC crews accomplished a number of preparation projects which had to precede most of the excavation work. The entrance to the cave is at the base of a cliff face. Tons of talus on a poorly engineered 15-foot entrance tunnel was removed by hand and new shoring installed to protect workers from potential rock falls. The inner and outer doorways and steps of the entrance building prevented use of wheelbarrows so the concrete steps were jackhammered out and replaced with a ramp while the doors were eliminated completely. A vapor barrier replacement restricted air flow. Approximately 100 feet inside the cave, a temporary door and wall was installed to provide security.

To protect speleothems and walls of the cave during development work, heavy guard structures of plywood were erected around the features. The structures are designed to withstand the impact of a fully loaded wheelbarrow.

All of this work required its own on-the-spot customizing. Plans and designs changes as problems were encountered. For example, the massive security door had to be relocated three times due to irregular cave wall shapes and buried crevices.

### **Special Excavation Techniques**



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Flowstone is the main indicator used to arrive at the natural floors. By carefully removing the gravel, silt, and rock from the floor, the former air filled portion of the passage is exposed, having been buried 40 or 50 years. Following the flowstone downward is not a foolproof method of arriving at the discovery year's floors, but overall the most reliable one.

Upon reaching undisturbed sediments, the stratification of the material is an indication of surfaces unaltered by man. Much of the floor surface, however, consists of poorly sorted gravel with indistinct layering. It takes a fairly large exposure to see what is occurring. These layers indicate that the natural floors have already been surpassed. Occasionally, masses of layered silt and clay are exposed, but closer inspection has proved it to be large clods cut from other sections of the cave and used as fill. In practice, this method has helped minimally.

Another indicator is foreign debris which is deposited in the fill. Finding these items is a clear marker not of where naturally deposited material is, but where it is not. When digging through a couple feet of material with no clear indicators to demonstrate if it is fill or natural sediments, it is a relief to encounter a coin, shovel handle, board or broken pop bottle among the muck.

For the heavier removal of fill material, shovels and picks are used. To move large rocks, a rope is tied around it. The rope serves as hand holds so workers can lift or drag the rock to a wheelbarrow for transport out of the cave. Removing fine silt offers some difficulty. The mud adheres so tightly to the shovel

blades that the shovel must be stuck sharply against the wheelbarrow or scraped off the shovel with another tool. Buckets are often used to lift and carry mud from the dig site to wheelbarrows. Work crews quickly learned not to leave tools, buckets or wheelbarrows filled or muddy at the end of the day, as the material begins to set up like glue overnight.

Fine work is accomplished by means of garden hand trowels, plastic putty knives, and a hand pump sprayer. The plastic putty knives work well. The idea behind these is that the plastic is softer than calcite. If a scratch appears from exhuming the speleothems, hopefully it will be on the putty knife and not the travertine. Of course, care must be taken, as the material being scraped or pulled away can easily act as an abrasive against the flowstone. Sometimes a hand pump sprayer is used in conjunction with the putty knife work for satisfactory results. Garden hand trowels are used for courser work away from the flowstone. Putty knife work follows.

The fine work of material removal to expose speleothems is some of the most rewarding job experiences for the workers. It is somewhat analogous to an archeological dig. It is exciting to follow a thin crust of flowstone downward along the wall, only to have it continue to expose a drapery which has been buried for years.

The character of the tour route is changing, not only from the unearthing of speleothems, but also from the sheer change in size of the corridors. The most dramatic change thus far is the addition of an entrance room. Previously, this section of cave was a

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passage approximately six feet wide and six feet high. One wall of this passage consisted of rocks stacked to the ceiling, with trail fill debris behind. After the contractor wheelbarrowed this material out of the cave, a room about 30 feet long, 6 feet high and 12 feet wide was exposed.

Digging out this room has saved considerable expense to the project by eliminating the need for a man-made entrance building. The room will function as an initial staging area for tour groups.

The material excavated from the cave is stockpiled a couple hundred feet from the entrance. Most of this was removed by the contractor who hauled it out of the cave by wheelbarrow to a contractor who hauled it out of the cave by wheelbarrow to a tractor with a bucket and then transported it to the pile. The contractor was to be paid on the basis of loose fill in the stockpile, but shrinkage and settling reduced volumes significantly. In order to account for this, a 20 percent shrinkage adjustment was made.

### **Other Concerns**

The largest room in the cave is part of the historic tour route. There are two structural concerns in this room which are intimately related. Breakdown blocks and sediments are sloughing off an embankment onto the stairway which enters this room. Dripping water is washing away the small material in this sediment which holds it together. A large mass of material is undercut. When it falls, this mass will land directly on the tour route.

Portions of the ceiling and walls of the room are in the Dubuque and Maquoketa formations, a portion of which are remarkably consistent alterations of limestone and shale beds. The constantly dripping water is gradually eroding the shale and encouraging separation of the beds. Concern exists for the integrity of the ceiling.

To investigate the situation further, a refractive seismic survey was performed on the surface above the room. The mapped results indicate the soil covered limestone forms a depression above the room and is acting as a basin which is the source of the dripping water. The final analysis and solution to this situation is pending.

Another application of the refractive seismic techniques is scheduled to be done along the tour route. A characteristic of many Mystery Cave passages is their keyhole shapes. Often, the crevice at the bottom is filled with sediment of breakdown, either naturally or by previous cave developers. Two times, these crevices have been accidentally and unexpectedly breached during trail work. One of the crevices extended six feet deep. A refractive seismic survey can identify these passage situations and are scheduled in the future.

### **The Future**

Plans call for a new lighting system and concrete trails. Bridges will span areas where floor gradients are excessive. Other show caves are being examined by the Division of Parks personnel to identify materials and construction techniques which may be appropriate for Mystery Cave.

The development work at Mystery Cave is continuing. Due to the particular nature of previous trail development, the present excavation is actually a restoration based on resource concerns, historical information and interpretive potential. The overall goal is to return the cave to as natural a condition as possible and easily accommodate visitors. It is anticipated these portions of trail will handle the bulk of the tour business in the future. Hopefully, the work done currently will provide a sound foundation for the developments to come. It is a step toward eliminating resource problems and providing visitors an accurate view of the speleothems and passages of the historical portions of Mystery Cave.

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## Some High Tech Answers to Cave Management Problems

by Jim Pisarowicz  
Forestville State Park  
RR 2, Box 128  
Preston, Minn. 55965

### ABSTRACT

In 1988, Mystery Cave became a part of Forestville State Park. Is the first developed cave in a state park in Minnesota. One of the first tasks of the park's management team was to generate a map of Mystery Cave for resource management and interpretive uses. To this end, caver's surveys were used in conjunction with cave radios to pinpoint positions in the cave on the surface. Aerial photography and high precision surface surveys indicated the locations of these points and computers were used to tie all the loose ends together. Using computer cartography linked with cave resource inventory databases provides a means of supplying cave managers with better information for decision making.

**Editor's Note:** Paper presented at the 1989 National Cave Management Symposium, New Braunfels, Texas, 3-7 October 1989.

Caves are an interesting and important aspect of the natural environment, yet unlike many major geological features remain hidden from view. The original entrance to the Mystery Cave System in southeastern Minnesota was discovered in 1937 despite beginning its speleogenesis millions of years ago. Like many aspects of the natural world, caves, once discovered attract explorers who scrutinize and map those areas that are not known. For many years, cavers have reached into the unknown, worming their way down narrow

cracks and fissures, discovering large trunk passages, underground lakes and rivers, and ultimately surveying their discoveries in Mystery Cave.

Mystery Cave became a part of Forestville State Park in 1988. It is the first show cave in a state park in Minnesota. Managing and understanding this important natural resource is part of the duty of the park managers at the park. Yet to accomplish this goal, the extent and the resources of this underground world have to be recorded.

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## Line Plots

One of the first tasks of the park's management team was to generate a map of Mystery Cave for resource management and interpretative uses. Fortunately for the park managers, cavers have spent literally thousands of hours underground in Mystery Cave surveying the over 20 km of passages we now know comprise the Mystery Cave System. Using compasses (to record direction), clinometer (to record slope or dip) and measuring tape (to record distance) these explorers have charted hundreds of passages, rooms and features under the rolling countryside of southeastern Minnesota.

Using the data collected from these many trips into Mystery Cave, these cavers have generated a line plot of the survey traverse through the cave. Such a "map" provides general orientation and distance underground and a crude notion of connectivity between passages and regions of the cave. Missing from this "map" is the sense of relative space: the size of passages, their shapes, what lies on their floors, where the water flows, etc. (Ganter, 1989).

### A Better Line Plot

Although a line plot is not a map in the true sense of the word, it is a very useful tool in determining where Mystery Cave is located. On the one hand, visitors typically ask questions such as: "When we were crossing the underground lake, where would we have been if we were on the surface?" and "How deep are we here in the cave?", and on the other hand, park managers wonder whether the cave ex-

tends beyond the boundaries of the park or whether roads, buildings, etc., go over portions of the cave. These are related questions which may be answered by having a "better" line plot — one upon which users can feel confident that the plot represents where the cave actually is underground.

Because of the difficulties in surveying cave passages (reading instruments in passages barely large enough for people to get through, having everything coated with mud, etc.) cave surveys will typically have larger errors associated with them than surveys run by land surveyors.

To compensate for these errors, statistical procedures called loop closure is used to distribute survey errors if a survey can form a loop in the cave. A loop is formed when a survey begins and ends at the same location. Even with these procedures, occasionally one cave passage will go off in a trend without looping back into itself and only one survey runs down that passage. If any errors occurred along that survey, the actual position in the cave and position shown on a line plot or map of the cave can be very different. To correct for these errors (usually related to the incorrect reading or recording of survey instrument readings or distance measurements) a special kind of underground survey called a cave radio survey was done at Mystery Cave to pinpoint locations in the cave onto the surface to correct for cave survey errors.

In a cave radio survey, a special device called a cave radio is carried to different locations in the cave. This "radio" is actually a low-frequency magnetic induction device and special antennae. Once the antennae is leveled in the cave and the transmitter turned on,

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a signal can be received on the surface by a special receiver and antennae combination. This sort of equipment can accurately locate positions directly above points in the cave to within several centimeters on the surface. In addition to finding the geographic location of the cave point on the surface, by using the magnetic properties of the electromagnetic waves of the transmitter, depths in the cave can be determined to a high degree of accuracy.

These techniques were used at Mystery Cave to locate 22 points in the cave up to the surface. High precision land surveying techniques using laser electronic distance measuring (EDM) devices then located a number of these surface points. Coupling these coordinates with depth reading from the cave radio work, provided accurate assessments of the locations of the passages in the cave relative to surface features above the cave.

Because of the expense of employing a survey crew, the additional cave radio points were tied into the survey network using aerial photographs. This technique not only saved substantial money in terms of salary for these professional employees but also tied into other resource needs being addressed in the park. This component of the project is discussed below.

Another problem that plagues long term cave projects is that over long periods of time, the drift of magnetic north must be taken into consideration. In the Mystery Cave area, the drift is approximately 8 minutes per year. Using cave surveys going back twenty years or longer, these differences in magnetic instrument readings can significantly effect the line plot of the cave.

Using the cave survey reduction program SMAPS, constraints were placed upon the survey data based upon the two entrance locations and the 22 cave radio points. By entering data by survey year, shifts in magnetic pole drift were compensated for in the data. Once these constraints were placed upon the data, loop closure algorithms were used to statistically adjust for survey errors. Basically, the passage locations were allowed to "vibrate" around fixed points in the cave as new survey loops are added by new explorations. By using such highly constrained data, the amount of vibration that could occur was minimized. The resulting coordinates for the cave survey points were thus located as accurately as were possible given the original data and the number of cave radio points set.

### Aerial Photography

To really make the connection between the surface and the underground worlds, aerial photographs were taken of the land above Mystery Cave. Before the aerial flyover, large "X"s constructed out of rolls of white plastic were put out at each of the cave radio locations. These "X"s, each one meter wide and eight meters across, could easily be seen in photographs of the area taken by airplane.

The aerial photographs, combined with land, cave and radio surveys allows both park managers and visitors a first glimpse of the exact relationship between Mystery Cave, the surrounding topography and identifiable surface features. Cave passages and features can be directly compared and contrasted to surface features. Not only can questions about where certain features in the cave area located be answered, but these sorts of graphic aids

allows geologists and interested lay persons to begin to answer questions about why certain features developed where they did in Mystery Cave.

### **Putting It All Together**

From the aerial photos, high precision topographic maps above the cave were produced. By using electronic stereoscopic plotting equipment, land contours were determined and these data were put into digital form so that they could be processed by computer-aided drafting programs (CAD). Contour intervals of 1.3 m were obtained using these techniques. Digital contouring at this precision over a large area was both faster and less expensive than using survey crews to do the same work. Line plots and eventually the actual passage contours of the cave itself were then merged with the digital surface topography maps.

Using the CAD program, AutoCAD, to draw both cave and surface features simultaneously and interacting those programs with collections of information in computer database files via dBASE III+ provides park managers, scientists and the interested park visitors an unprecedented view of Mystery Cave and its relationship to its surroundings. The cave and surface can be literally turned upside down to get a better view of the cave and the surface topography. Virtually all the data that has been collected about Mystery Cave can be directly accessed and compared in real time with a computer.

### **Geographic Information System**

A system such as the one described above for

Mystery Cave is referred to as a Geographic Information System (GIS). An important aspect of this GIS is that each of the components of the system is a commercially available product. The survey reduction is via SMAPS, the database dBASE III+ and the drawing engine AutoCAD.

Each of these programs have relatively user-friendly interfaces which make data entry and manipulation by the system relatively easy and straightforward. In addition to this important feature, these programs (especially dBASE III+ and AutoCAD) are widely distributed commercial software that many people know how to use. This is a critical consideration to park management who may have turnover of park staff and who do not want to be constantly training new staff in the peculiar aspects of a totally custom designed cave GIS.

By using AutoCAD for the drawing engine, drawing files may be easily transferred into GIS formats. Although standard GIS programs such as ARC/INFO, EPPL7, GRASS, etc. cannot handle three-dimensional geographic objects such as caves; two-dimensional cave representations can be transferred to all the standard GIS packages through the AutoCAD file format (DXF). Thus, cave drawings and associated resource inventories (in dBASE III+ files) will interface with GIS systems that other agencies associated with land management are probably using. This is a critical aspect of the system used at Mystery Cave because it allows the park to fit into the larger resources inventories generated by other Minnesota state agencies or even federal land management databases and vice versa. Thus the Mystery Cave GIS can accommodate the unique three-dimensional problems of handling a cave resource and at the same time be

compatible with the statewide GIS's used by other agencies.

For the park management team, this system provides a powerful land management tool allowing them to make decisions about the welfare of the park based on the most accurate and up-to-date information available. Park structures and roads can be seen in direct relation to the cave passages below the earth (see Figure labeled "Mystery Cave Area"). Planning of development can take into consideration the delicacies of the cave either directly under the planned development site or those parts of the cave nearby the planned development and land uses above or near the cave (see Figure labeled "Picnic Grounds Area Mystery Cave"). The relationship of the cave to adjoining properties can be accurately plotted and kept up-to-date as land around the park and over the cave may change ownership (see Figure labeled "Property Boundaries" — state park land is shaded.)

For the park visitors, this system provides a means to "see" what cannot ordinarily be seen. The land surface with its rolling hills,

streams, and valleys can be made transparent so that the cave can be viewed right through the ground. The important connection between the surface, the cave and ultimately the water that shapes each of these features and our lives can be recognized and perhaps better understood and appreciated. Park visitors now leave Forestville State Park/Mystery Cave with more than just having had a cool hour underground away from the heat of the summer sun. They leave the park looking at the countryside, visualizing more than just what they see, and hopefully take that attitude with them everywhere they may go.

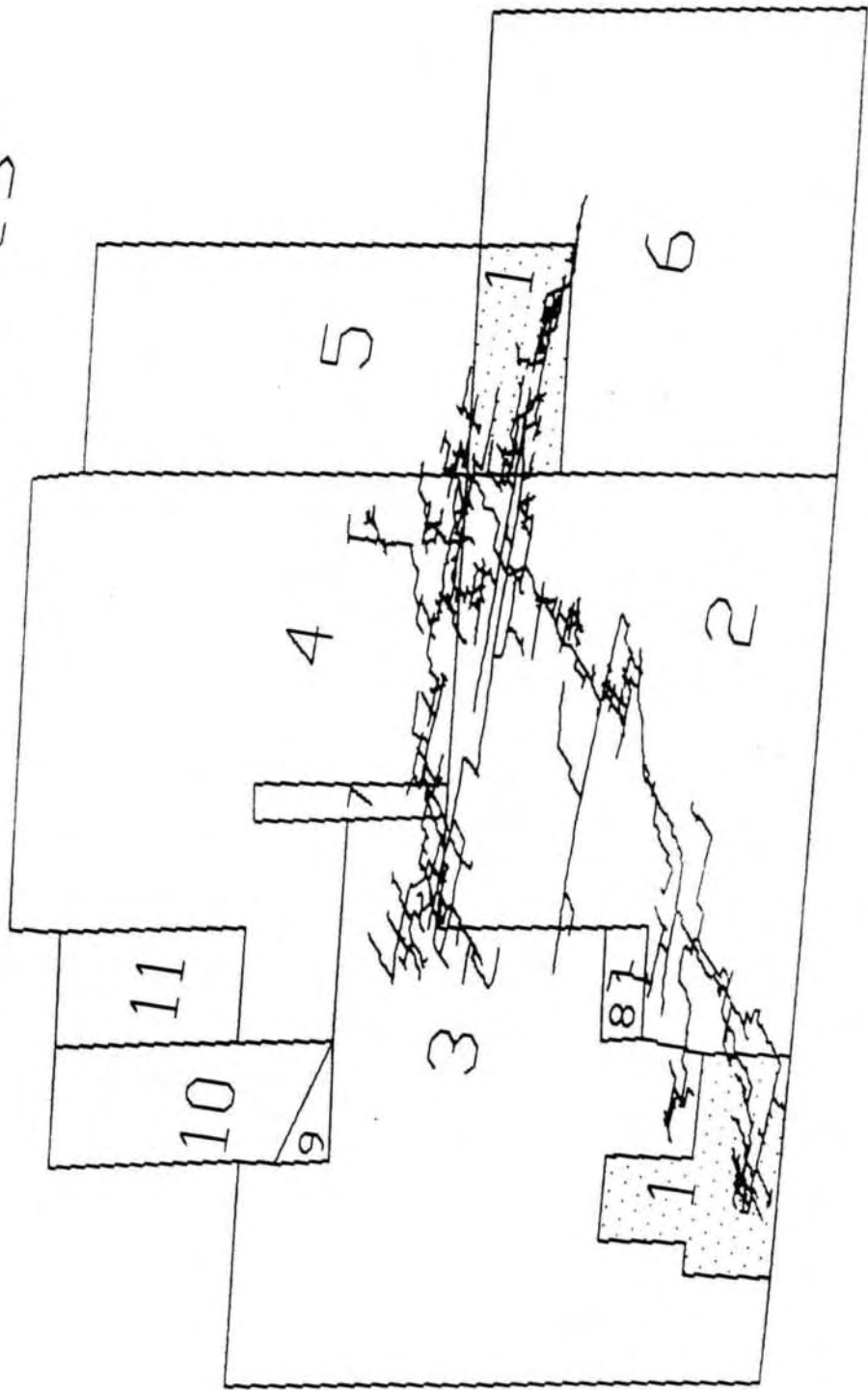
### References

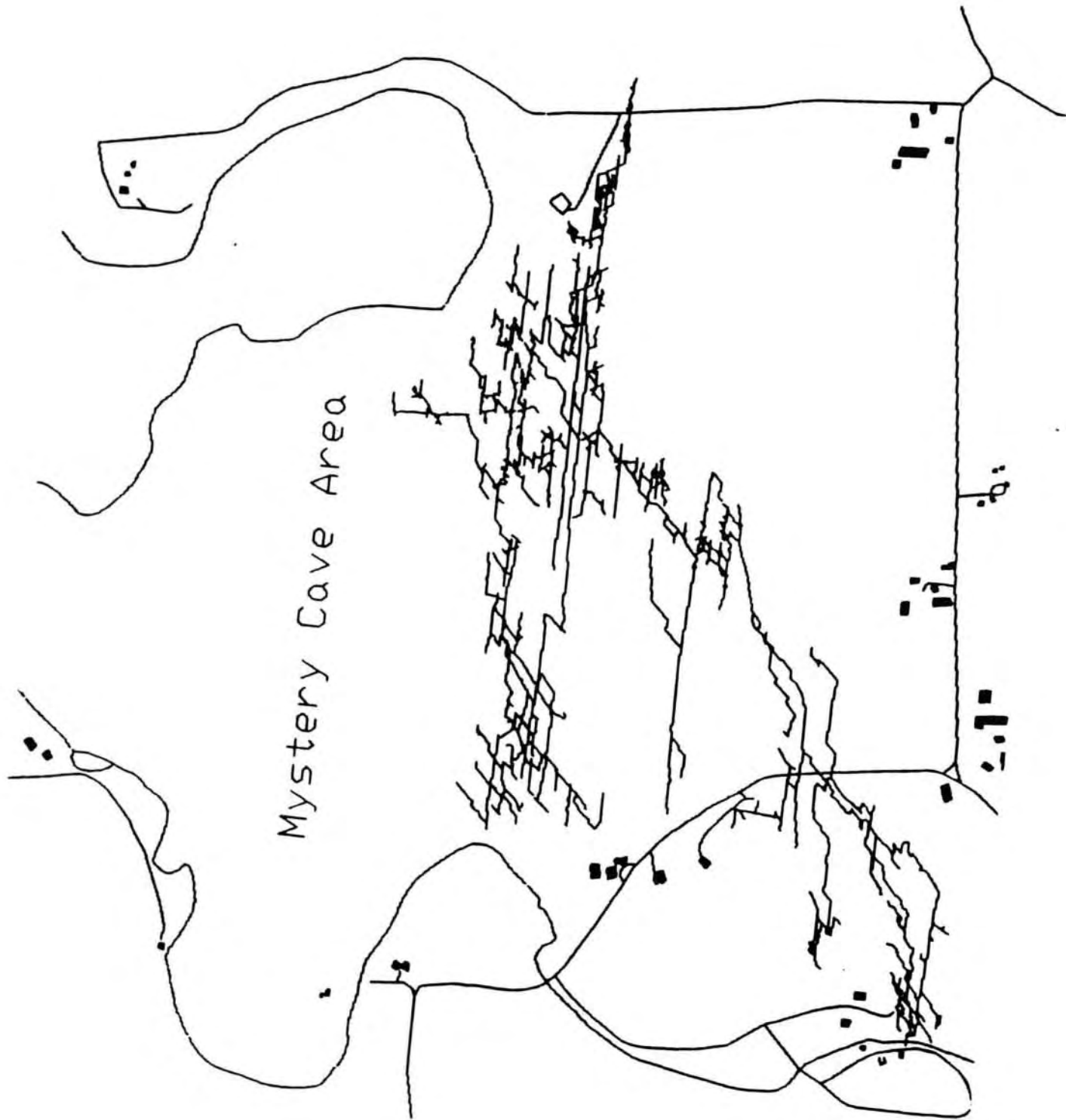
Ganter, John. "Will we map as we survey?", NSS News 47 (6), p. 143-144, June 1989.

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# Property Boundaries





PICNIC GROUNDS AREA  
MYSTERY CAVE

