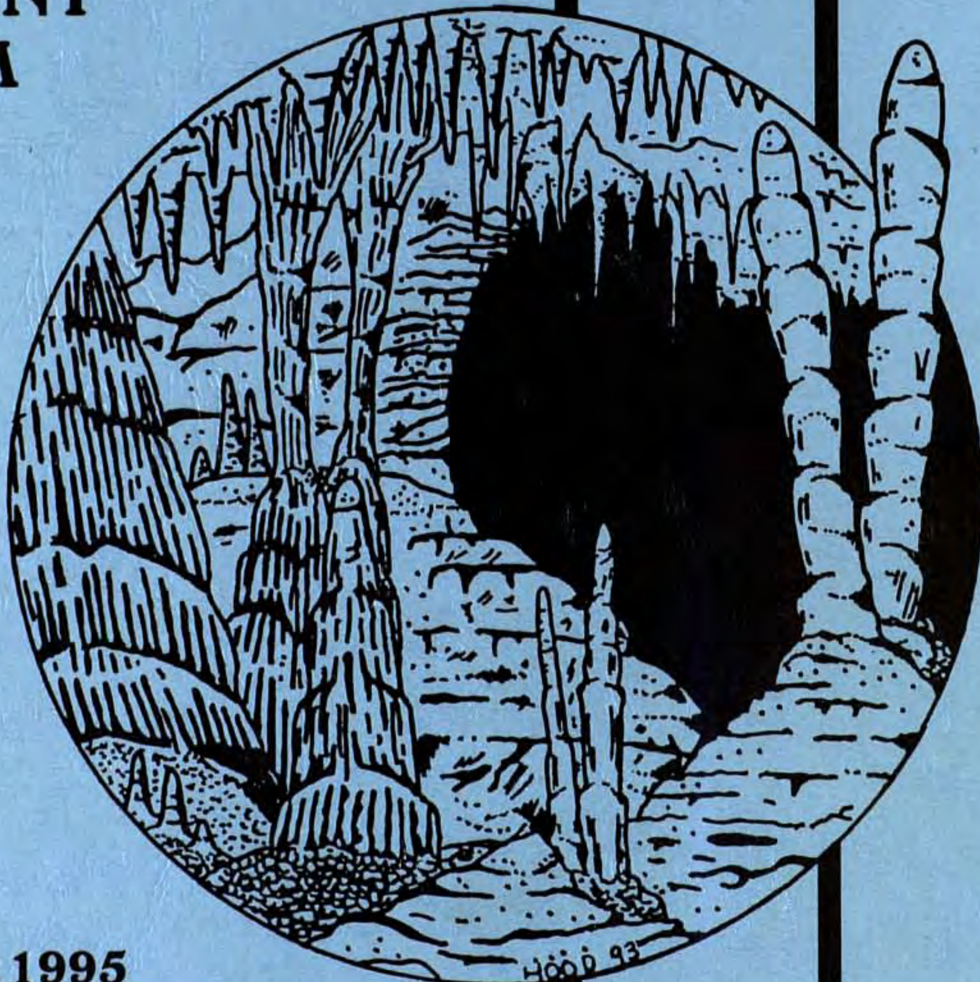
1995 NATIONAL CAVE MANAGEMENT SYMPOSIUM



October 25 - 28, 1995
Spring Mill State Park, Indiana

PROCEEDINGS

Proceedings of the 1995 National Cave Management Symposium

Spring Mill State Park
Mitchell, Indiana

October 25 - 28, 1995

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Layout and Design by
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Produced by
Indiana Karst Conservancy, Inc.
PO Box 2401
Indianapolis, Indiana 46206-2401
USA

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Indiana Department of Natural Resources
Division of Nature Preserves
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Printed in the United States of America

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Opening Remarks

Janet Thorne
Coordinator
NCMS Steering Committee

I welcome everyone to the twelfth National Cave Management Symposium that's been held. We have about 150 people registered, and I think that may be the largest group we've ever had at the symposium. We have people here from California and Washington, from Florida and Pennsylvania, and most of the states in between. We have Alaska and Hawaii represented, we even have people here from Barbados, the Philippines, Canada, and Australia. So I think that the Cave Management Symposia are becoming more widely known and certainly their value has become recognized. The people who are here are here primarily because caves are becoming increasingly recognized as an important natural resource, and one that needs to be managed carefully or it can be damaged forever.

The NCMS started in the mid-1970s, they were run informally by volunteers for many years. Then in the late 1980s we started to feel that they needed more structure so they could grow and be more responsive to the people attending. The organizations which are involved in cave management on a national level got together and created a steering committee for the symposium. Each organization has one representative on the steering committee, and I'd like you to meet those people at this time. If you have any questions later on, please try to find one of these people. From the agency side, the Bureau of Land Management is represented here at this meeting by Jim Goodbar from New Mexico. Fish and Wildlife Service by Bob Currie from North Carolina. The Forest Service of course is represented—I don't know who is going to be proxying at this meeting— by Jim Neiland from Washington State. The National Park Service's representative, Ron Kerbo, is in New Mexico. Those are the agencies that are represented on the steering committee. In the private sector, the American Cave Conservation Association of Kentucky represented by Dave Foster. The Cave Research Foundation—Roger McClure from Ohio is representing them at this meeting. The National Caves Association is represented by Gordon Smith, from Indiana and one of our hosts, the owner of Marengo Cave. The Nature Conservancy is on the steering committee and I'm not sure who might be representing them in our group this week. And finally the National Speleological Society, of course. I am the representative for the NSS, and the NSS representative serves as the coordinator of the steering committee, so that's why I'm up here today.

The symposium provides tremendous opportunities for you to learn about caves and cave management. The other thing that is almost equally important is that it provides an opportunity for the people who attend to meet new people—the other people who are involved in cave management in one way or another. I've seen lots of people come together during the symposium; one has a question on a certain problem or topic and finds just the right person here to ask and to get a solution. So the interaction here is a very important thing, in my mind, that takes place at the symposium. I know a lot of you already know one another; but I hope that everyone will make the effort to meet the other people and talk to them. There are a lot of very interesting people here, and very knowledgeable people, so I think that's a worthwhile thing to make the effort to meet each other.

If you are coming here with a specific cave management problem, and don't see it addressed by one of the topics of the papers, I hope you will come up and ask one of the steering committee people or someone else here that you know. If we don't know the answer, we will try to find out for you or put you in touch with someone who might be able to answer your question. Also during this week, if you see ways in which we can improve the symposium, we certainly want to hear that so that we make progress and each symposium improves over the years.

So, I want to thank you for coming and I hope you have a great time this week.

Wilma Marine
Public Information Officer
Hoosier National Forest

It is a pleasure and an honor for me to welcome all of you to the Hoosier National Forest and to south-central Indiana. Ken Day unfortunately had a conflict and will not be able to attend today, or he would personally have done thisintroduction.

I'd like to start by telling you just a little bit about the Hoosier National Forest. It is the only national forest in Indiana, and it contains about 193,000 acres. Those of you who know your other national forests will say "that is really small for a national forest" and that's true. However, it contains almost half the public lands in the state of Indiana. The other thing about the Hoosier National Forest is that it is not a solid ownership. Unlike many other national forests, particularly west of the Mississippi, sometimes within our proclamation mapping, Forest Service ownership is less than 29%. We don't have very many solid blocks of land. Therefore, as finances allow, acquisition has been the prime emphasis area for us, and in our acquisition work one of the criteria we have selected is protection and management of special features. Caves and karst features are one of those emphasis items.

Within our forest plan, which was released in 1991, we are very proud that caves and karst resources are featured throughout that plan; and indeed, through the effort of folks like Larry Mullins, who is our cave and karst specialist on the Forest, have become integrated into our day-to-day operations. We are very pleased about that. In the last four years of our acquisition program we have purchased about 11 tracts that have significant cave and karst features on them. This totals almost 1,500 acres, and we estimate there are about 12 caves on that. Our most significant acquisition at this time is Gory Hole, which I'm sure you'll learn more about later this week. Another significant feature is Wesley Chapel Gulf, which I know one of your field trips will be visiting this week. That is not a part of the Hoosier National Forest at this time, but is part of a proposed land-for-minerals exchange with U.S. Gypsum; so if the exchange gets approved after the analysis is completed, that feature, which is already a National Natural Landmark, would become part of the national forest.

In addition, we have set aside certain Special Areas, and recognize those features for management and protection; such as Tincher Hollow, Beaver Creek, and Gypsy Bill Allen Cave—these are again examples of cave and karst management being addressed in our forest plan. We also ought to recognize that as a part of our efforts we have had positive and ongoing partnerships and cooperation, both with the caver community and with the Indiana Karst Conservancy; and we could not have accomplished all the things that we have without the assistance and help of those people in managing these features.

In closing I would like to thank all of you for coming and giving me an opportunity to welcome you here. I've looked over your agenda and I know you have a busy, full week ahead; and I'd also like to recognize the excellent efforts of the Indiana Karst Conservancy in putting together this year's symposium.

Gerald Padgett
Director of State Parks
Indiana Department of Natural Resources

I'm happy to welcome you to this fantastic state park—we're very proud of Spring Mill. I like to brag about it when I have a chance to speak to groups out-of-state, especially when I tell them about a really special place where you can have everything you would have in what might be considered a "typical" state park but also a pioneer village; Donaldsons Woods—which is a spectacular, never-cut forest within the park that you all should get a chance to see—and then to top it all off the caves that we have. I'm told that we have more than 15 miles of passage within the park that we have mapped and there's probably a great deal more that is unmapped that is under there somewhere. So it's a very special place and I hope during this week you will have a chance to see all of it that you possibly can.

I want to introduce a couple of people that are important to us and hopefully will be important to you during your stay. Mark Young is the property manager and Brant Baughman is the assistant manager here, they're here to help you out in any way they can; that is, with anything to do with the park. Wilhelmina Robison is the Inn manager, I don't see her in the room right now, but she's here to help as well.

I want to tell you a little bit about some of the things that we're doing in the department that I think are significant in an area that will interest you. Something called a Karst Task Force has been created in the department, thanks to the efforts of Jeff Cummings who's serving as the chair of the group. That group is looking at what our management policies should be in the department when it comes to karst resources. They've been meeting on this for over a year now and we're hoping to have some good things come out of it that will help us manage what we have in the way of cave resources. Here at Spring Mill we have just about completed a mapping project that's taken many, many years. We had a near-catastrophe with two people who were trapped in one of our caves a number of years ago, and when we had that rescue it was pointed out that we really didn't know where our passageways were. So an effort was undertaken totally by volunteers. Steve Collins and a dedicated group of volunteers spent literally years mapping passageways and in the process discovered many, many miles of new passageway. So it was kind of a thrill for them and very good information for us to come out of that effort.

Well, just to be brief, I want to conclude by saying that it is really great to have an opportunity to host a conference like this in our home state and have an opportunity for our people to glean information, establish contacts, and get to know people—establish friendships that will help us, I'm sure, in years to come in better managing our karst resources here in Indiana. With that, I'd just like to again say, welcome to Indiana and to Indiana State Parks, the Department of Natural Resources, and Spring Mill State Park.

Scott Pruitt
Bloomington Field Office
U.S. Fish and Wildlife Service

Welcome to Indiana. I guess you might be getting tired of hearing that, but welcome from the U.S. Fish and Wildlife Service. I come from the Bloomington office which is just up north and we also happen to be within a karst area so this is close to home for us. We are a host, but I think all the credit really should be given to the Indiana Karst Conservancy—to Bruce and to Keith—because they've really done a lot of hard work. We offered several times saying, "what can we do, how can we help," and the response was "don't worry about it, we have it taken care of." So they should be given a lot of credit. Be sure to thank them throughout the week.

The Bloomington Field Office has also has been involved with karst and cave programs and concerns for quite some time; we recognize their value here and I'll just give you a couple of quick examples of two primary areas in which we have been involved: through endangered species and along the regulatory end of things.

As far as endangered species go, we only have two endangered bats—and mammals for that matter—in Indiana, of course they're both very much tied in with cave systems; and that's the Indiana bat and gray bat. It so happens that the only two areas that are designated critical habitat under the Endangered Species Act also happen to be two caves that are Indiana bat hibernacula, so we're very closely tied into that and very interested in cave systems because of that. Also, just recently, I think Indiana can now brag that our caves hold more than 50% of the wintering Indiana bats nationally, so I like to think that through the efforts of a lot of the people in this room and throughout the state that we're doing a good job of taking care of our cave systems. One last thing we are looking at right now is we have just about completed a Northern blind cavefish status survey to try to determine what's going on with our blind cavefish here in Indiana and throughout its range. We are the lead office for that also.

On the regulatory end of things, from time to time—I think you will probably see it in one of your field trips to the Lost River area—various groups and agencies have come forward and either wanted to dam or somehow alter the Lost River system for one reason or another (something I have never really been able to understand). But at any rate, again with the help of a lot of folks here, we've been able to work with agencies such as the Soil Conservation Service and the Corps of Engineers to try to convince them and educate them about the value of that karst system. And again with the efforts of many of the people in this room we've been able to persuade those agencies that it wasn't a great idea and to date the watershed is pretty much intact. One last thing that you'll hear more about today is that we've worked with the Indiana Department of Transportation for several years in locating highways and changing highways and the like in the karst area of Indiana. Through those efforts we're pleased to be part of putting together the karst MOU between the Indiana Department of Transportation, the Indiana Department of Natural Resources, and our agency. I think that it's working quite well; it basically helps us and the Department of Highways route and select alternatives in how they're going to construct highways in karst systems to protect them as much as we can.

So with that, again welcome to Indiana and let's get on with the programs.

Bruce Bowman
President
Indiana Karst Conservancy

Those who know me well know that I tend to stand around meetings and pontificate endlessly on cave conservation, and several of them have come up to me and asked—no, pleaded—that I not do that today. So for the benefit of all concerned I hope to oblige them this time, and as a mnemonic device I've written my entire speech on the back of my program. If it looks like I'm reading it, that's exactly what I'm doing because it's the only way I can keep myself focused here. That's just the kind of person I am, I guess.

Okay, so getting along with the reading here . . .

The Indiana Karst Conservancy came into being in 1985 in response to damage that was occurring to some caves in the Bloomington area, just up State Road 37 near Indiana University. In the following year, the IKC gated several caves in the area, an activity that really was not quite as accepted back then as perhaps it is today. Fortunately, we were able to set some policies that restored some of the trust that we had lost with the local cavers. From this shaky start we have grown in membership and the number of karst resources under our protection, and also have forged a great number of ties with a number of organizations, both in the private and the public sector, state and federal—some of whose representatives have already stood up here and spoken today.

Nonetheless, I think the Indiana Karst Conservancy remains a very grassroots organization. We are totally volunteer. We have no paid staff, largely because we don't have any money, so we can't pay anybody with anything but promises. Although many of the members have other affiliations as well, all the people you see here with pink badges are IKC members, and are here on their own time and for the most part at their own expense as well.

As the IKC starts into its second decade, we hope to acquire more funds through grants and extend our sphere of influence. We also plan to use some of these funds to actually purchase some properties outright, rather than go on with our current property leasing approach; since this is the only way we can ensure the protection of these resource in perpetuity. It is perhaps appropriate that the IKC act as a host at this time; this is pretty much the biggest thing we have ever taken on, and will hopefully be a starting point for even bigger and better things for the IKC.

However, this is really your symposium. With that thought, I just want to thank each of you for your contributions—through your presentations or your attendance—in making the '95 symposium a success. Thank you very much and have a good time.

Adding Cave Ecology to the College Curriculum: A Description of BIO398 at Missouri Western State College

David Ashley, PhD
Missouri Western State College

Abstract

This presentation would introduce a junior-level biology course that deals with the ecology of cave habitats. The course includes information on biotic and abiotic factors affecting cave organisms, cave microhabitats, cave biodiversity, trophic interactions, and evolutionary adaptations. Students are assigned readings from the primary literature of speleology and must complete class mini-projects that relate to cave ecology. These mini-projects have helped to generate a database of information concerning zonation, population density, and growth patterns of cave invertebrates. Students prepare manuscripts of their research projects and are also required to present the results of these mini-projects during a class symposium at the end of the semester. Copies of student manuscripts are provided to state agencies and the managers of those caves where the research projects are conducted.

An Ecologically-Based Approach to Karst and Cave Resource Management

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Abstract

The geologic and climatic setting of southeastern Alaska are particularly favorable for karst development. Extensive areas of very pure carbonate, some 515,000 acres (approximately 805 square miles or 207,690 hectares), are found within the boundaries of the Tongass National Forest. Because of the highly fractured nature of the carbonates, the climatic conditions, and the peatlands proximal to the carbonate bedrock, karst has developed, to one extent or another, within all carbonate blocks. It has been suggested that karst development to the extent found throughout southeastern Alaska is globally rare (Aley *et al*, 1993).

The karst landscape, in southeastern Alaska, can be characterized as an ecological unit found atop carbonate bedrock in which karst has developed and includes the recharge areas on adjacent non-carbonate substrate. A few of the characteristics of this ecological unit include: mature, well-developed spruce and hemlock forests; increased productivity for plant and animal communities; extremely productive aquatic communities; well-developed subsurface drainage; and the underlying unique cave resources. Because of the presence of these well-developed spruce and hemlock forests, much of the past and proposed timber harvest has been or is focused on the karst lands.

Karst lands impose land management liabilities not encountered in non-karst areas because this three-dimensional landform functions differently than other landforms. Recognizing these differences, the Tongass National Forest has begun to change its land management strategies accordingly. The Forest is incorporating karst management standards and guidelines into the current revision of the Tongass Land Management Plan. These standards and guidelines provide for other land uses while taking into account the function and biological significance of the karst and cave resources within the landscape. The Forest is adopting a land management strategy for the karst lands similar to "hazard area mapping" or "risk assessment." Referred to as "vulnerability mapping" or "karst vulnerability," this strategy assesses the susceptibility of the karst resources to any proposed land use. The thesis of this approach recognizes that not all karst development and associated resources are equal. Vulnerability mapping utilizes the fact that some parts of a karst landscape are more sensitive than others to planned land uses. The zonation scheme is intended as a guide for management purposes at the strategic planning level.

Introduction

The Tongass National Forest contains the largest concentration of dissolution caves known in the State of Alaska. The Forest also contains world-class surface or epikarst features particularly in the alpine and sub-alpine zones (Aley et al, 1993). The caves and epikarst features result from chemical weathering of limestone and marble bedrock. The karst and cave features and associated resources are a recently-discovered and recognized attribute of the lands within southeastern Alaska and have been found to be of national and international significance for a wide variety of reasons, including their intensity and diversity of development, the biological, mineralogical, cultural, and paleontological components, and recreational values (Aley *et al*, 1993).

The following are a few key concepts or philosophies of karst management that must be understood to apply any karst management strategy to the land:

- The Federal Cave Resources Protection Act (FCRPA) is the primary U.S. law affecting caves. It requires protection of significant caves on Federal lands. A cave must possess one or more of the criteria outlined in 36 CFR Part 290.3 to be determined "significant." Though "non-significant" caves may exist, most meet the criteria for "significant." The intent of this act is to protect cave resources not karst resources. However, it is important to recognize that caves and associated features and resources are an integral part of the karst landscape. Karst must be managed as an ecological unit to ensure protection of the cave resources (Baichtal; 1994, 1995).
- As a practical matter, all lands underlain by carbonate rocks within southeastern Alaska should be considered a karst landscape. It has been found that, to one extent or another, karst has developed within all carbonate blocks. This approach is appropriate because the climatic circumstances of southeastern Alaska combined with the purity of the carbonates, proximal peatlands, and highly fractured bedrock are particularly favorable for karst development.
- Karst lands add a third dimension to land use planning—a vertical dimension. Karst landscapes function differently than other landscapes. One must recognize these differences and change their management strategies accordingly.
- Subsurface drainage networks generally operate independently of, and with more complexity than, the surface drainage systems above them (Aley *et al*, 1993; Huntoon, 1992a). The watershed characteristics of the surface topography may have little or no relationship to the subsurface karst drainage system. The many solution-widened fissures become injection points into the complex subsurface drainage system. These fissures rapidly move water and sediment vertically downward into the underground lateral systems. Sediment transported from roads and disturbed lands may emerge unexpectedly at one or more distant springs even across surface watershed boundaries.
- A large portion of a particular karst system's vulnerability is that system's openness. The degree to which the surface is connected to the karst system conduits at depth relates directly to the affect of any planned land use. A high density of solution and collapse features indicates the presence of well-developed underground systems. The presence of a single sinkhole demonstrates a direct surface/subsurface connection, even if the sinkhole intermittently retains water.
- It is important to understand the differences in sediment transport mechanisms between karst and non-karst landforms. A particle of soil within deposits atop non-carbonate substrate must be transported by gravity, landslides, and/or surface water flows, sometimes over great distances into a watercourse to become sediment. Atop a karst landform, depending on the openness of the karst system, a soil particle only needs to be transported laterally a few inches or feet before it can be washed vertically through the epikarst into the karst conduits at depth.

Karst Management Goals

The goal of the karst management strategy proposed here is to maintain and protect, to the extent practical, the natural karst processes and the productivity of the karst landscape while providing for other land uses where appropriate. The proposed strategy is designed to assess a karst resource's vulnerability or sensitivity to a proposed land use. The strategy recognizes the differences in intensity of karst development across the karst landscape.

The key elements of the strategy focus on the openness of karst and its ability to transport water, nutrients, soil and debris, and pollutants into the underlying hydrologic systems. The strategy strives to maintain the capability of the karst landscape to regenerate a forest after harvest, to maintain the quality of the waters issuing from the karst hydrologic systems, and protect the many resource values within the underlying cave systems as per the requirements of the Federal Cave Resource Protection Act.

Karst Resource Management Strategy

The following is the karst management strategy being proposed in the current revision of the Tongass Land Management Plan. This strategy has been developed during the last five years combining the most current thinking on karst management issues (Aley and Aley, 1993; Aley *et al*, 1993; Blackwell, 1995; Eberhard, 1994; Griffiths, 1991; Harding and Ford, 1993; Herring, 1995; Huntoon, 1992a and 1992b; Kiernan, 1993; Lichon, 1993; Stringer *et al*, 1991; Tasmania Forestry Commission, 1993) and the results of field studies specific to the Southeast Alaska karstlands (Aley *et al*, 1993; Baichtal, 1993 a, 1993b, 1993c, 1994, 1995; Elliott, 1993; Lewis, 1995; Streveler, 1991; Swanston, 1993). As stated above, the goal of the karst management strategy is to maintain and protect, to the extent practical, the natural karst processes and the productivity of the karst landscape while providing for other land uses where appropriate. The authors feel that the premise of the proposed strategy should be applicable wherever karstlands may be evaluated. The following is the proposed Karst Management Strategy.

Karst Management Program

Forest-wide Direction, Standards, and Guidelines

A) Maintain a karst resource management program that will identify, evaluate, and protect karst resources, managing karst systems as ecological units to ensure protection of these resources and the cave resources within. Karst resources will be evaluated as to their vulnerability to land uses affecting karst systems, as described in the *Karst and Cave Resource Significance Assessment, Ketchikan Area, Tongass National Forest, Alaska* (Aley *et al*, 1993) and as outlined within these directions, standards and guidelines.

B) Seek participation from interested publics, such as caving organizations, scientists, recreationists, and development interests in managing the karst resources.

C) Integrate and coordinate karst management with the management of other resources. Management strategies developed will consider the function and biological significance of the karst landscape. Karst management strategies will be based on system recognition and protection, not solely feature preservation.

D) Develop public education and interpretative programs to insure an increased understanding of the components and function of the karst landscape. Primary research results will be used to foster and promote conservation and further public education of karst resources.

E) Work with universities and other appropriate research facilities to foster partnerships to study and characterize the function and biological significance of karst landscapes. In order to maintain existing aesthetic and future scientific values, non-consumptive research techniques will be used as much as possible. As emphasis items, the Forest will pursue, within available budgets, programs that:

1) study the effects of timber harvest and road construction on karst landscapes.
2) Systematically evaluate the relationship between the degree of karst development; the elevation, slope, and aspect of the karst landscape; and the soil displacement, soil loss, and the forest regeneration rates with various timber harvest methods.
3) Study the relationship of peatlands to karst development.
4) Characterize the contribution of the karst groundwater systems to productivity of aquatic communities.
5) Describe the biospeleology of the karst systems.
6) Characterize the paleoecology and prehistory of southeastern Alaska by studying the sediments, mineral deposits, and paleontological and cultural resources within the karst landscape.
7) Analyze the geochemistry of the karst host rocks to help understand karst development and identify possible areas suitable for mineral development.

Useful Definitions

Due to the uniqueness of the karst landscapes, definition of several terms is needed for a better understanding of the resource. The following terms are used throughout these directions, standards, and guidelines:

- **"Karst"** is a type of topography which develops as the result of the dissolution of soluble rocks, in this case limestones and marbles. Dissolution of the subsurface strata produces a landscape that is characterized by well-developed subsurface drainage—collapse features such as sinkholes, dry valleys, vertical shafts, caves, and fluted rock surfaces (epikarst).
- ***"Karst Landscape"*** in southeastern Alaska can be characterized as a three-dimensional ecological unit found atop and within carbonate bedrock in which karst has developed and in-

cluding the recharge areas on adjacent non-carbonate substrate. A few of the characteristics of this ecological unit include: mature, well-developed spruce and hemlock forests along the valley floors and lower slopes, increased productivity for plant and animal communities, extremely productive aquatic communities, well-developed subsurface drainage, and the underlying unique cave resources.

- ***"Karst Resources"*** refer to all components of the karst system. These include both the physical and biological components of the karst landscape.
- ***"Epikarst"*** is the surface of the karst. It is an intensely dissolved veneer consisting of an intricate network of intersecting dissolution-widened fissures, cavities, and tubes. It is this network of intersecting fissures which collect and transport surface waters and nutrients vertically to the underlying karst conduits.
- ***"Cave"*** is legally defined under federal law as: ". . . any naturally occurring void, cavity, recess, or system of interconnected passages beneath the surface of the earth or within a cliff or ledge and which is large enough to permit a[n] person to enter, whether the entrance is excavated or naturally formed. Such a term shall include any natural pit, sinkhole, or other opening which is an extension of a cave entrance or which is an integral part of the cave (36 CFR 261.2)."

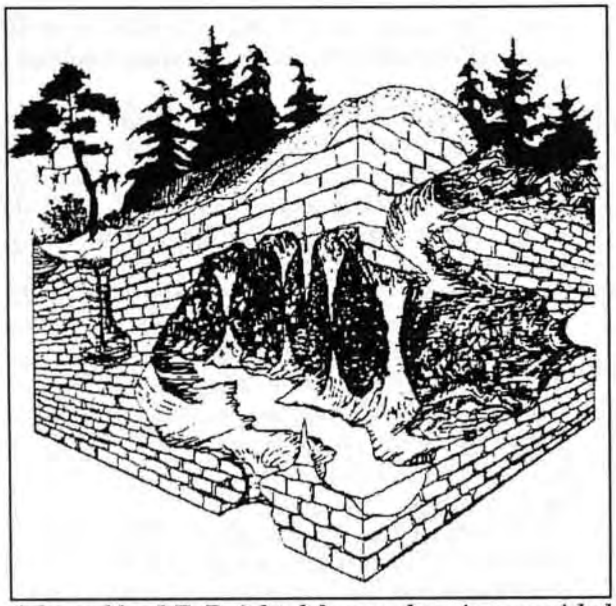
  Speleologists use "cave" to refer to all parts, regardless of size, of an underground system that links openings and chambers and that may connect the system to the surface. The most common type of cave is formed in carbonates by dissolution. Included in the term "caves" are tree molds and lava tubes associated with lava flows, erosional caves, boulder caves, glacier caves, and littoral caves, as well as those formed by dissolution of bedrock.
- ***"FCRPA."*** Federal Cave Resource Protection Act of 1988. This law establishes a Federal mandate to identify, protect, and manage caves on public lands administered by the departments of Agriculture and Interior. It may be referred to as "the Act."
- ***"Cave Resources"*** includes any material or substance occurring in caves including, but not limited to, biological, cultural, mineralogical, paleontological, geological, hydrological, and recreational resources.
- ***"Significant Cave"*** means a cave located on Federal Lands that has been determined to meet the criteria in 36 CFR 290.3.
- ***"Sinkhole"*** or ***"Doline"*** (used interchangeably) are terms used to describe relatively shallow, bowl- or funnel-shaped depressions ranging in diameter from a few feet to more than 3,000 feet. These depressions are generally formed by dissolution of and subsequent settlement of bedrock to form a depression or collapse feature.
- ***"Speleothem"*** means any natural mineral formation or deposit occurring in a cave or lava tube, including but not limited to any stalactite, stalagmite, helictite, cave coral, flowstone, soda straw, drapery, rimstone, or formation of clay, sand, or mud.
- ***"Speleogen"*** refers to relief features on the walls, ceiling, and/or floor of any solution cave or lava tube. Speleogens are part of the surrounding bedrock. They include but are not limited to anastomoses, scallops, meander niches, petromorphs, and rock pendants in solution caves and similar features unique to volcanic caves.
- ***"Vulnerability Mapping"*** or ***"Karst Vulnerability"*** is a management tool used to assess the susceptibility or sensitivity of the karst resources to any proposed land use. This type of approach is similar to "hazard area mapping" or "risk assessment." The thesis of this approach recognizes that not all karst development and associated resources are equal. Vulnerability mapping utilizes the fact that some parts of a karst landscape are more sensitive than others to planned land uses.

Karst Landscape Assessment

Karstlands impose land management challenges not encountered in non-karst areas because this three-dimensional landform functions differently than do other landforms. Evaluate karst resources as to their vulnerability to land uses affecting karst systems. Vulnerability mapping recognizes that some parts of the karst landscape are more sensitive than others to surface activities and groundwater contamination. These differences in vulnerability may be a function of the extent of karst development, the openness of the karst systems, and the sensitivity of other resources that benefit from karst groundwater systems. Assess karst resource vulnerability for both large geographic areas and site-specific projects. Complete vulnerability assessments of large geographic areas for any karst area where activities are planned. Conduct site-specific vulnerability mapping on a project by project basis or as field verification of the larger scale karst vulnerability assessment. Karst lands will be classified as being of low, moderate, and high vulnerability. This is a four-step process:

1) Identify Potential Karst Lands

   Identify those lands underlain by carbonate rocks. As a practical matter, all lands underlain by carbonate rocks within the Forest should be considered a karst landscape.



Adapted by J.F. Baichtal from a drawing provided by the American Cave Conservation Association originally from Indianapolis Newspapers, Inc.

2) Inventory Karst Resources

Prior to the initiation of any land use planning effort, determine the project's proximity to or position on a karst landscape. If it is determined that karst occurs in the project area, a complete inventory is required. Assess the degree of karst development. If karst is present, as a minimum the following information will be recorded:

a) The degree to which karst has developed including the degree of epikarst development, the presence of caves, the presence of insurgences and resurgences, sinkholes, collapse channels, and other karst features.
b) When caves are identified, they will be surveyed and inventoried in accordance with cave management guidelines. To maintain continuity of inventory reports and cave maps, specifications will be addressed prior to commencement of inventory work. During inventory work caving ethics and protection of cave resources will be stressed.
c) The relative position of karst features both within and adjacent to the planned activity.
d) The slope of the land and the depth and nature of soil atop the karst.
e) The presence of any Class I or Class II streams being significantly contributed to from the karst hydrologic systems. It is only intended that streams which have had sufficient residence time or contact with the carbonate bedrock which show appreciable geochemical changes be considered. Temperatures 5°C., pH ranging from 7.5 to 9.0, and specific conductance 120 S/cm would be an indication of the highest-value karst waters. It should be recognized that some normally dry drainage channels in a karst landscape will periodically carry large flows when the capacity of underlying conduits is exceeded during high flow events.
f) Sensitive habitats and features that might be adversely affected by land use changes in the area being investigated. These habitats and features must specifically include, among other things, streams important to fisheries and streams or springs used as domestic water supplies, habitats which support cave adapted organisms, and critical bat winter habitat and/or roosts. When considering karst streams and springs, the inventory work must recognize that many sensitive habitats and features are likely to be located appreciable distances away from points where waters enter the karst groundwater system.
g) The results of the survey shall be documented and digitized onto the Region's GIS data base. The area's geology, location of karst features and caves, and the vulnerability of specific karst areas shall be recorded.

3) Delineate Karst Hydrologic System and Catchment Area

Define, to the extent practical, the karst hydrologic system and the recharge area watershed or catchment area for each karst system. The character of the catchment area—that is the area, slope gradient, vegetation, water quality, soils, and the like—controls the nature of the receiving karst system and defines the volume of runoff available for infiltration into the system. Recharge area delineation is a crucial component of vulnerability mapping; you must know where the water comes from and resurges to credibly assess and characterize possible impacts. At a minimum, the following information will be recorded:

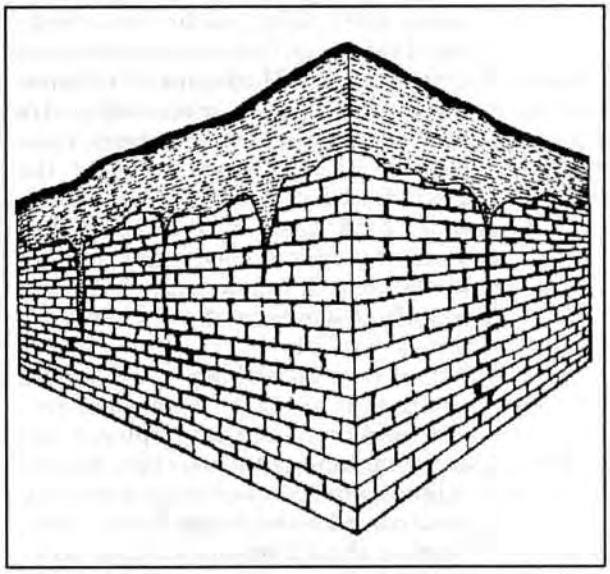
a) During the inventory phase, record the location of all resurgences, insurgences, losing streams, sinkholes, or other features appropriate for injection of tracing dyes. Estimate water volume entering or discharging from the groundwater system at the time of the visit. Describe prevailing weather conditions at the time of the visit.
b) Perform a sufficient number of dye traces to assess the karst hydrologic system or systems within a study area. Conditions on the Forest are such that flow direction of tracer dyes cannot always be predicted. This unpredictability reinforces the need for a thorough area search for all resurgences and accurate estimates of stream and spring flows.
c) Record the results of the dye traces, indicating the relative position of the dye injection

point and the position of the resurgence or spring where the dye was recovered. Record the tracer dye's travel time and concentration if known. Record resurgences and streams that were sampled but no dye was recovered. Document and digitize results onto the Regional GIS data base.

4) Assess Vulnerability of Karst Terrain to Management Activity

The final step is to delineate the land under investigation into various vulnerability categories. An area's vulnerability rating must be sensitive to potential surface management practices based on the extent to which epikarst has developed and the openness of the karst system. The vulnerability categories and their criteria are as follows:

a) Low Vulnerability Karstlands



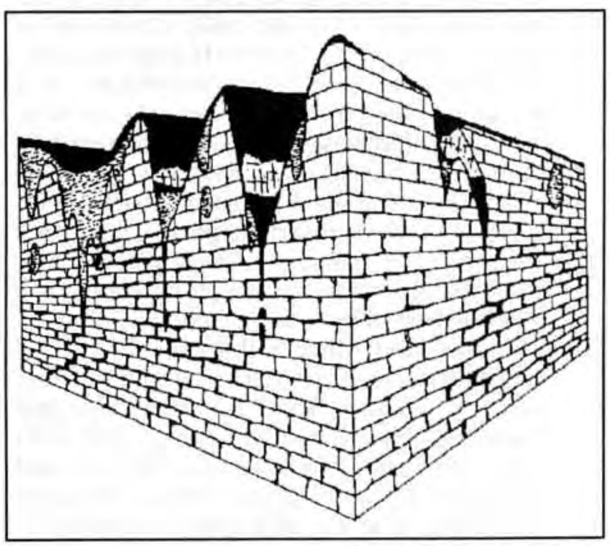
1) Classification Criteria. Low vulnerability karstlands are those areas where resource damage threats associated with land management activities in the areas are not likely to be appreciably greater than those posed by similar activities on non-carbonate substrate. Some characteristics of these lands are:
   - i) Karst development is limited or has been modified by glaciation;
   - ii) Epikarst development is relatively shallow;
   - iii) Solutional karst features are present but not numerous;
   - iv) Soils are primarily mineral, soil depth is shallow to deep, the soils are moderately well to well drained, parent material is the carbonate substrate, glacial till, or volcanic.
   - v) No caves are present;
   - vi) There are no slopes ≥70 percent;
   - vii) The karst hydrologic system does not contribute waters to Class I or Class II streams and/or domestic watersheds;
   - viii) They lie within a watershed which contributes surface waters to a karst area determined to have a low vulnerability.

2) Management Objectives and Appropriate Land Uses.

These are areas of low or negligible vulnerability from a karst management perspective. No special provision for the protection of karst values is considered necessary. Timber harvest and related activities could be conducted in such areas in a similar manner to those normally employed on lands underlain by non-carbonate bedrock. Partial suspension yarding may be required. No quarry shall be developed atop karst without adequate site survey and design. Quarries should be properly closed after abandonment. Recreational development would be appropriate with consideration of karst resource values.

It is possible that within and adjacent to areas found to be of low vulnerability, will be found karst areas with high vulnerability. Along such boundaries or margins guidelines outlined under "Moderate Vulnerability Karstlands" shall apply.

b) Moderate Vulnerability Karstlands



1) Classification Criteria. Moderate vulnerability karstlands are those areas where resource damage threats associated with land management activities in the areas are appreciably greater than those posed by similar activities on low vulnerability karst lands. Some characteristics of these lands are:
   - i) Karst systems are moderately well developed;

ii) Epikarst is up to eight feet in depth;
iii) Solutional karst features are present but not numerous;
iv) Soils are a mosaic of both mineral and organic. Mineral soils vary from shallow to deep, are well drained, and parent material is the carbonate substrate. Organic soils are shallow and well drained. If the soil was displaced from the bedrock, it would be retained in the adjacent solutional channels of the epikarst. The percentage of bare rock would increase but the soils would not be transported beyond the rooting depth of young conifers;
v) No caves are present;
vi) There are no slopes ≥70 percent;
vii) The karst hydrologic system does not contribute waters to Class I or Class II streams and/or domestic watersheds;
viii) They lie within a watershed which contributes surface waters to a karst area determined to have a low vulnerability.

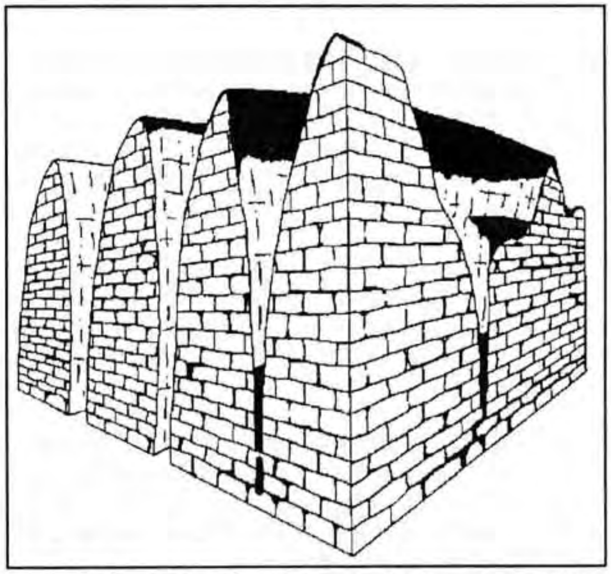
2) Karst Management Objectives and Appropriate Land Uses.

To provide for other land uses taking into account karst management objectives. Timber harvest and related activities could be conducted in such areas under more restrictive guidelines than normally employed on lands underlain by non-carbonate bedrock. To protect the fragile soils found here, as a minimum, the yarding system selected may be required to achieve partial suspension. Longer timber harvest rotational periods may be appropriate. Reduced timber harvest unit size and a greater dispersal of harvest units may be required. Existing roads and quarries will be utilized in preference to the construction of new ones. Roads shall avoid sinkholes and other collapse features and losing streams. At no time shall roads divert water to nor from karst features. Measures shall be taken to reduce erosion and sediment transport from the road surface and cutslopes. Sediment traps, cut and fill slope revegetation, and road closure and revegetation may be appropriate. Because karst development is more intense here, additional design criteria may be required. Such criteria may relate to road construction methods, blasting, culvert placement and density, and sediment retention and erosion prevention. No quarry shall be developed atop karst without adequate site survey and design. Quarries should be properly closed after abandonment. Recreational development would be appropriate with consideration of the karst resource values listed above, particularly with respect to reducing disturbance of sensitive soils and use of construction methods that avoid erosion and diversion of natural and road drainage waters into karst features.

It is probable that within and adjacent to areas found to be of moderate vulnerability, will be karst areas with high vulnerability. Along such boundaries or margins the following guidelines shall apply:

i) No surface disturbing activity such as timber harvest, road construction, and/or quarry development shall occur within a minimum of 100 feet of the edge of a sinkhole, collapse channel, doline field, losing stream, or other collapse karst feature if groundwater dye tracing studies have indicated that such features contribute to Class I or Class II streams or a domestic water supply. If groundwater dye tracing studies have not been completed and it is suspected that the groundwaters contribute to a "significant" cave, Class I or II stream, or domestic water supply, no ground disturbing activity shall occur within 100 feet of *any* above mentioned karst features;
ii) No surface disturbing activity such as timber harvest, road construction, and/or quarry development will occur on lands that overlie a known "significant" cave or contribute waters to any known "significant" cave. Neither should these activities occur on lands that are close enough to the entrance of a significant cave to be capable of altering the microclimate of the cave's entrance and/or cave features within;
iii) When designing buffers to protect karst systems and their features, the buffer should be designed to be windfirm. There is no credible standard buffer distance that will provide the assurance required to protect the systems from blowdown of the forest within a given buffer. Each buffer must be carefully designed considering wind direction patterns, blowdown history, previous adjacent harvest, topography, and stand windfirmness. Delineated lands surrounding such features and systems must be of sufficient size to insure protection even if blowdown occurs.

c) High Vulnerability Karstlands



1) Classification Criteria. High vulnerability karstlands are those areas where resource damage threats associated with land management activities in the areas are appreciably greater than those posed by similar activities on low or moderate vulnerability karst lands. These are the areas contributing to or overlying significant caves and areas containing a high density of karst features. Some characteristics of these lands are:
   i) Karst systems are extremely well developed;
   ii) Epikarst is greater than eight feet in depth and may be open to the lateral karst conduits at depth;
   iii) Solutional karst features are numerous;
   iv) Soils are primarily shallow, well drained organics. Exposed bedrock areas are common to extensive. If the soil is displaced from the bedrock, it may be retained in the adjacent solutional channels of the epikarst, however the percentage of bare rock would greatly increase and the soils most likely would be transported beyond the rooting depth of young conifers. If the karst systems are extremely well developed and open, soils may not be retained within the epikarst channels. They would be rapidly transported to the lateral karst conduits at depth;
   v) Caves may be present;
   vi) Karst areas may contain slopes ≥70 percent;
   vii) The karst hydrologic system may contribute waters to Class I or Class II streams and/or domestic watersheds;
   viii) They lie within a watershed which contributes surface waters to a karst area determined to have a high vulnerability.
2) Karst Management Objectives and Appropriate Land Uses

These areas shall be managed to insure conservation of karst values through the implementation of a high level of protection. Timber management and related activities should be excluded from these lands. Small expanses of these areas may be crossed by roads to access areas where harvest is appropriate, i.e. low or moderate vulnerability karst lands and non-carbonate areas. This would only be allowed if no other route or option was available and karst resource values would not be compromised. No quarry development would be allowed on these lands. Limited recreational development may be appropriate. Roads across such sensitive terrain except as described above, are inappropriate. Recreational facilities and trails would have to consider karst resource values and objectives discussed above, particularly with respect to reducing disturbance of significant epikarst features and sensitive soils and use of construction methods that avoid erosion and diversion of natural drainage waters into karst features.

Karst lands found to be of unquestionably high vulnerability shall be identified and removed from the commercial forest lands suitable land base.

Catchment Area Management

The catchment areas for karst systems, comprised of carbonate or non-carbonate substrate, are an integral portion of those system. These catchment areas must be effectively managed to protect the resource values of the karst systems into which they flow. The higher the resource values found within a particular karst block, the higher the degree of protection which is needed within a contributing catchment area. As a minimum, such things as potential for increased runoff and increased stream velocities, increased sediment transport capability, mass wasting potential of the soils within the watershed, and increased wind-throw potential should be considered when developing management strategies for these catchment areas. During large scale planning efforts, the vulnerability of the karst system's catchment areas should be equal to the highest down-gradient karst vulnerability values. During the site-specific project planning, management strategies developed for the catchment areas should insure protection of the down-gradient karst resource values.

Mineral Development

The chemically pure carbonates of southeastern Alaska have long been considered for their commodity values. Values are not determined solely on chemical purity but on brightness as well. The more pure the carbonate bedrock, the more intense karst development may be. The impacts of any proposed mineral development within the karst landscape can be analyzed through the environmental analysis which is triggered once a Plan of Operation is received. However, on karstlands found to be of unquestionably high vulnerability, mineral development would not be appropriate.

Monitoring

Develop and maintain a monitoring strategy to determine the effects of land uses, specifically timber harvest and road construction on the karst landscape. As a minimum, karst hydrology, soil loss, forest regeneration, sedimentation, and debris transport shall be monitored.

Conclusions

The karst management strategy proposed here works well throughout southeastern Alaska. Similar management strategies have been applied on Vancouver Island, British Columbia, Canada; in the forests of Tasmania; and in select areas within the continental United States. These strategies are focused on the possible effects from surface disturbing activities adjacent to or within a karst landscape associated with timber harvest, forest road construction, and mining. The authors believe that such a karst management strategy is applicable no matter the specific land uses or resource concerns. The strategy proposed here focuses on the extent of the development of the karst topography and systems but most importantly on the openness of that system. It is the openness of a particular karst system which characterizes that systems ability to transport water, nutrients, sediment and debris, and/or pollutants. The more open the karst system the more sensitive the system is or the more vulnerable it is to particular land uses. To fully protect the function and biological significance of the karst landscape and the resource values within the associated caves, one must fully understand how a particular karst system functions and the openness of that system.

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Appendix A

Karst Landscape Overview

This overview is intended to describe to the reader the current understanding of the function and biological significance of the karst landscapes in southeastern Alaska. It is these characteristics and our current understanding of the karst landscape on which the proposed karst management strategy is based. This information is included here so that the current understanding of the characteristics karstlands of Southeastern Alaska are captured for the reader.

The Karst Landscape

In southeastern Alaska the karst landscape can be characterized as an ecological unit found atop carbonate bedrock on which karst features have developed as the result of differential solution by acid groundwaters. These acidic groundwaters are a direct product of abundant precipitation and rapid passage of groundwater through the organic-rich forest soil. Recharge areas may be on carbonate or adjacent non-carbonate substrate. A few of the characteristics of this ecological unit include: mature, well-developed spruce and hemlock forests along valley floors and lower slopes, increased productivity for plant and animal communities, extremely productive aquatic communities, well-developed subsurface drainage, and the underlying unique cave resources. The basic principals of karst development and cave formation documented in Ford and Williams (1994); White (1988); White and White (1989). The rate and processes controlling the aerial extent of karst landscape and cave development along the north pacific coast under the cool, moist, heavily forested conditions are not fully understood. Extensive research is needed to fully understand and describe the characteristics of this ecosystem. The following description of the karst landscape discusses its geologic and hydrologic characteristics, biologic characteristics, and natural history.

Geologic and Hydrogeologic Characteristics

Karst landscape development in southeastern Alaska appears to be controlled by the purity of the calcium carbonate bedrock, the structure of the bedrock (i.e., faulting, fractures, and bedding), occurrence of igneous intrusions, tectonism, proximity of the carbonates to peatlands and other forest vegetation, the development of surface or epikarst, glacial history, precipitation, and temperature.

Karst existed on Prince of Wales Island long before the latest glacial advance. Recent phreatic passages into two pre-Latest Wisconsian caves (44,500 Before Present) have dissolved through Tertiary paleokarst breccias (Aley *et al*, 1993). Older passages have been plugged by debris from past glacial episodes. One small cave has yielded a marmot tooth which has been dated to greater than 44,500 years (Baichtal, 1994b). Most caves pre-date the most recent glaciation based upon the presence of glacial clays, glacial sediments, wood, Pleistocene vertebrate remains, and possibly even ancient ice. Similar features are being found during field reconnaissance on Kuiu and Chichagof Islands and on the islands seaward of Prince of Wales. Such evidence clearly suggests that glaciation modified a pre-existing karst landscape, collapsing some passages and systems, gouging into others, and filling some with sediments. The epikarst, which is exceptionally well developed in higher elevations, has been removed in places at lower elevations by the most recent glaciation. Where low-elevation epikarst is present, primarily on the outer coast of islands seaward of Prince of Wales, vegetation has re-established itself and a forested epikarst developed. Where impermeable compacted glacial till and marine silts are deposited on the karst terrain and poorly-drained lithologies adjacent to karst terrain, peatlands are commonly developed. Many of the glacial deposits overlying karst terrain have filled and modified collapsed karst features. With the development of the forested epikarst and peatlands, and the entrance of associated acidic waters into underground tributaries, a system of enlarged vadose caves and vertical shafts have developed (Baichtal, 1993a).

The rocks most susceptible to karst development are those which are 70 percent calcium carbonate ($CaCO_3$). Well developed karst and cave systems require that the bedrock be 90 percent calcium carbonate or better. Chemical analysis of 67 limestone and marble samples collected from the northern half of Prince of Wales and surrounding islands showed the range of calcium carbonate varied from 91.47 to 99.46 percent. The samples averaged 97.65 percent $CaCO_3$ (Mass *et.al.* 1992).

These very pure carbonate rocks have had a long tortured history. They originated as marine reef and lagoonal deposits near the equator during Silurian time, some 438 to 408 million years ago (Soja, 1990). These deposits were rafted atop spreading oceanic plates until they docked on the ancient shores of southeast Alaska. These rocks are part of what is now recognized as the Alexander terrane, one of five sub-continental blocks of rock which have combined to form the Ketchikan Area. The oblique collision of the Alexander Terrane with North America resulted in the rocks being compressed from east to west and smeared northward along the coast. The Alexander Terrane was spectacularly fractured and then fragmented at all scales as it was rifted apart and smeared northward along the Alaskan coast. This smearing occurred along large, northwest-southeast trending, strike-slip faults. Second order intersecting, north trending strike-slip faults allowed the terranes to break into huge blocks. What makes the picture more interesting is that the granite blocks bounded by the large faults are themselves broken into smaller blocks by smaller faults which mimic their larger counterparts. This same fault pattern can be seen from terrane boundaries to the outcrop and hand specimen scale. The fractures serve two very important functions in the karsts associated with the Alexander Terrane. First, the intra-island and mountain-block scale faults commonly define karst system boundaries. Secondly, cave passages, chains of sinkholes, and many of the other karst features are localized along sets of small to intermediate scale faults. Epikarst development is largely a function of these fractures and faults (Aley *et al*, 1993; Coney *et. al*, 1980; Brown and Yorath, 1989; Brew *et al*, 1992a and 1992b; Gehrels and Berg, 1992).

Epikarst is exceptionally well developed throughout the karst areas. The alpine epikarst is characterized by deep shafts, crevasse-like dissolved fissures, eroded dissolution rills of all sizes, and spires and spikes of limestone. In the sub-alpine, the epikarst has virtually the same characteristics found in the bare alpine settings except it is vegetated. Typical thicknesses of the epikarst zone range from more than 100 feet in the alpine zone to less than 5 feet along the coast and lower elevations. The epikarst thickness appears to be more a function of glacial history than altitude. The epikarst is extremely important in moving water, nutrients, organic matter, and soil from the land surface and from the rooting zone into the subsurface where these materials can move laterally to seeps and springs or to vertical collector structures which channel them downward into cave networks (Aley *et al* 1993).

Peatlands form atop poorly drained non-carbonate rocks and impermeable compact glacial tills and marine silts that overlie carbonates. Surface waters originating from these poorly drained areas seldom flow more than a few yards onto carbonate substrate before diving below the ground, down vertical shafts or into cave entrances. The highly acidic waters from the peatlands accelerate cave and karst development. pH levels of waters flowing from these sphagnum-dominated wetlands can be as low as 2.4 (Aley *et al*, 1993). Waters flowing from the cave systems that accept these waters commonly show a pH range of 7.5-9.0. The buffering capabilities of the pure carbonates is evident.

Most of the caves studied so far are hydrologically active. Those that carry streams are subject to extreme variations in flows. Rainfall in the areas dominated by karst terrain varies greatly ranging from annual average precipitation of 60 to 250 inches per year. The largest floods occur when heavy rains fall on wet snow packs. These cave systems can best be described as very dynamic. Limited dye tracing work on Prince of Wales Island has demonstrated that karst groundwater systems routinely transport water for several thousands of feet to receiving caves, springs, and surface streams (Aley *et al*, 1993). The limited specific conductance information gathered to date from this same area suggests that values from karst systems in southeast Alaska are about half the mean values typically encountered in most other North American karst areas. However, karst areas in southeastern Alaska yield annual runoff which is typically on the order of 8 to 16 times greater than that found in other American karsts. The net effect is that solution of soluble bedrock occurs on the order of at least four to eight times faster in southeastern Alaska (Aley *et al*, 1993).

Hydrologic models currently used for estimating the cumulative effects of proposed surface management activities are not designed to model the effects of timber harvest on the karst landscapes. Evidence suggests that timber harvest increases available surface waters, thereby increasing sediment and debris transport capabilities and flooding passages which have not flooded for centuries. Observations in some caves suggest that passages which now flood result in fragile ceiling formations becoming tannin-stained and showing signs of dissolution. Many cave entrances are infilled and/or blocked by logging slash, sediment, and debris. Runoff generated from road surfaces commonly is diverted into karst features. It is not known what cumulative effects past timber harvest has had on the epikarst landscape (Baichtal, 1993c).

Biologic Characteristics

Only limited information is available on the importance of the karst landscape to plant and animal life in coastal Alaska. The following characterizes what is known about the vegetation/forest, wildlife, and fisheries components of the karst landscape:

Vegetation/Forest. There is a definite tie between the karst landscape and the productivity of the spruce and hemlock forests found there. The major contributors are believed to be the nutrient rich soils, well developed subsurface drainage, and dissected bedrock surface which allows the tree roots to hold fast and become somewhat more windfirm. The old growth on the karst provides a well structured, multi-layered canopy resulting in important winter habitat. The structure of the forest provides many forbs and shrubs for wildlife. It is possible that the available forage contains, at a minimum, higher calcium levels allowing for better bone, muscle, and antler development. The combination of quality forest structure and abundant nutritional browse could make the karst landscape exceedingly crucial habitat (Gustafson, 1993).

One way of demonstrating the productivity of the karst area is to compare timber volume differences between karst and non-karst areas. Exceptionally dense stands of very large diameter spruce and hemlock at lower elevations are characteristic of many karst landscapes. For example, the Lab Bay Project Area Draft Environmental Impact Statement (US Forest Service, 1995) on north Prince of Wales Island indicates 74% of volume class 7 occurring on karst. Past timber harvest on the karst landscapes has been disproportionately high most likely due to the high percentage of very large, dense forest stands. For instance, in the Central Prince of Wales FEIS analysis, 66 percent of the commercial forest land on known karst has been harvested while only 33 percent of non-karst areas have been cut (Baichtal, 1993c). It has been estimated that in some areas 70 to 80 percent of the commercial forest land within specific karst blocks on the Ketchikan Area has been harvested (Streveler and Brakel, 1993; Baichtal, 1995b). Recent analysis of the karstlands <1,400 feet in elevation and on slopes <60% (27°) on the Thorne Bay Ranger District indicates that 50% of those acres have been harvested.

On karst landscapes worldwide, timber harvest has led to serious, often long-term declines in soil depth and fertility, in some cases culminating in permanent deforestation (Harding and Ford, 1993; Huntoon, 1992a, 1992b; Kiernan, 1993). Trees growing on karst generally have roots extending down into the dissolved cracks in the bedrock. These roots act to pump water and nutrients back up into the forest canopy. Much of the site productivity is tied up in this nutrient cycle and in the forest canopy. When trees are harvested this nutrient cycle is broken. Soils tend to be thin residual soils on these karst areas. The greater the development of the epikarst, the greater the surface/sub-surface connection. The greater the epikarst development, the easier nutrients and soil can be transported vertically beyond the rooting depth of vegetation and into the conduit systems of the karst drainage. Vertical migration of nutrients and soil becomes possible in areas of heavy rainfall and well developed sub-surface drainage once the forest canopy is removed (Harding and Ford, 1993; Gams, 1993; Lichon, 1993). Karst systems are productive but fragile (Huntoon, 1992a and 1992b; Streveler and Brakel, 1993).

Field observations and aerial photo interpretations show strong evidence of greatly increased surface runoff on karst areas after harvest. This increases sediment, nutrient, and debris transport capability of these systems. Transport capability increases both vertically and laterally. Current harvesting techniques leave the slash within the unit, which helps to protect the shallow fragile soils from erosion and drying, Timber regeneration information from the Ketchikan Area, taken on low-elevation, flat-topography karst areas, indicates few regeneration problems. A considerable percentage of the easily accessible low-level karst areas within the area have been harvested. Timber harvest is now moving onto steeper, higher elevation karst areas which are characterized by shallower, better drained soils. Observations suggest that with harvest atop these soils, much of the soil may be removed if adequate log suspension is not achieved. Often, only a thin organic mat covers the karst. The exceedingly shallow soils become excessively dry once the protective forest canopy is removed. The high rainfall of the area can rapidly move these fragile soils into the well developed epikarst. Observations suggest that these steeper, higher elevation karst areas show less than desirable regeneration or remain as bare rock slopes within harvested units.

Wetlands dominate much of the landscape of southeastern Alaska. Calcareous fens have been recently identified on Chichagof and Prince of Wales Island, associated with occurrences of carbonate bedrock (Brock *et al*, 1995). This wetland type is important in other regions because of its rarity, unique water chemistry, and because it frequent harboring of rare plants. The calcareous fens discovered lie at the base of carbonate talus slopes or adjacent to resurgences where calcium-enriched ground waters discharge onto the wetland surface. The pH values of these waters are markedly higher than those found in bogs or other peatlands in southeast Alaska, pH ranging from 6.7 to 7.4 (Brock *et al*, 1995). The vegetation was a lush, species-rich meadow or meadow-shrub complex dominated by herbaceous plants. Common wetland plants such as *Pinus contorta*, *Sphagnum*, and ericaceous shrubs were absent. Specific conductance values for the waters issuing from these fens were much higher than normal peatland water values ranging from 315-380 S/cm (Brock *et al*, 1995). Some of the most productive salmon fisheries on Chichagof Island are fed by the waters from these calcareous fens.

Wildlife. Many wildlife species find the surface karst features and the stable environment and shelter provided within the caves to be valuable habitat (Baichtal, 1995b). Caves have been used as natal den sites for otters, and as resting and denning sites for deer, bear, wolves, and small furbearers. Deer are known to rest around cave entrances both in summer, when the air coming from the caves is cooler and in winter when the cave entrance environment is warmer than elsewhere.

Cave systems are known to provide critical roosting and hibernating habitat for bats (Parker, D.I., 1996). The stable environment within caves can provide roosting habitat both in summer and winter. Bats select cave sites because they fulfill very specific requirements involving cave structure, air circulation patterns, temperature profiles, humidity, and location relative to feeding sites (Hill and Smith, 1992).

Preliminary surveys in southeast Alaska show some bat usage in many of the caves inventoried. Bats have been found within a few caves once temperatures drop below freezing. Roost sites are beyond where freezing air temperatures penetrate from the cave entrance. Southeast Alaska caves appear to be most important to bats during periods of winter torpor. No use of caves by bats as summer roosts or maternity colonies has been noted yet. Much more work remains before the year-around importance of caves to bats is understood. Three species of bats have been reported from caves in the Ketchikan Area: *Myotis luicifugus, M. californicus,* and a possible *Lasionycteris noctivagans (*Parker *et al*, 1995; Parker, 1996). During the summer of 1993 the first specimen of *Myotis volans* has been collected from Prince of Wales Island (Parker, 1996). In December 1991, the first ever recorded hibernating bat in Alaska was described and photographed from within El Capitan Cave. The *Myotis californicus* collected in El Capitan cave in February of 1992 was the first live record of that species in Alaska (Parker, 1996). The first record of *Myotis keenii* from Prince of Wales Island was captured in the proximity of El Capitan Cave during the summer of 1993 (Parker and Cook, 1996).

Cave systems provide habitat for many invertebrate organisms. Preliminary studies conducted during July 1992 identified 77 species from collections made within several caves. Taxonomic identification of these species must be done before further biological correlations or associations can be made. One amphipod has been identified as *Cratigonyx obliquus-richmondensis,* the first ever record of this amphipod's occurrence in a cave in all of northwestern North America (Carlson, 1993a). Field work continued during the 1993 and 1994 field seasons, with collections made from a number of caves. A troglobitic *Stygobromus* amphipod was collected on Heceta Island to the west of Prince of Wales Island (Aley *et al*, 1993, Elliott, 1994). This species is morphologically identical with *Stygobromus quatsinensis* from two caves on Vancouver Island, British Columbia, Canada (Holsinger, 1987, 1993). This discovery is possibly a high-latitude world-record for a cave adapted species (Aley et at., 1993). Similar *Stygobromus* species were discovered in caves and karst springs on the western shore of Dall Island during the summer of 1993 (Carlson, 1994) and on Coronation and Suemez Islands during 1994 and 1995 respectively.

Some bird species—including dippers, thrushes, and swallows—have been known to use cave entrances for nesting and feeding. Rookeries for seabirds including cormorants and pigeon guillemots, and murres and puffins on Coronation Island have been found in some littoral caves (Baichtal, 1995b).

Fisheries. The karst landscape influences productivity of its aquatic habitats in several aspects. The geochemistry associated with karst development contributes to productivity in aquatic environments through its carbonate buffering capacity and carbon input from dissolved limestone bedrock. This has significant downstream effects on the aquatic food chain and biotic community. Preliminary studies (Swanston, personal communication) suggest that aquatic habitats associated with karst landscapes may be eight to ten times more productive than adjacent non-karst dominated aquatic habitats. The karst dominated aquatic habitats support a higher abundance, distribution, density, and variety of invertebrate species than the non-carbonate based systems, have higher growth rates for smolts and resident fish, reflect less variable water temperatures and flow regimes, and contain unique habitat affecting species distribution, abundance, and adaptations (Wissmar *et al*, 1995; Swanston, 1993). It is believed that karst waters have the following connection to fisheries:

- The carbonates have important buffering effects. Very acidic waters flow from the peatlands (pH 2.4 to 5.8) into karst systems, emerging at a slightly basic pH of 7.5 to 9.
- Resident time for groundwater in the karst systems results in cool, even temperature water. Flow rates through karst systems are flashy, however storage capability of the karst systems results in lower peak flows and higher low flows. This helps to moderate the effects of storm events on resurgence streams.

Table 1. Radiocarbon ages of paleontological discoveries from within caves on Prince of Wales, Heceta, and Dall Islands.

AHRS Site Number	Date Number	Sample Identification	$d^{13}C$ %	^{14}C Age (BP)
PET-189	Beta-52709	El Cap, Fish Bone, Steam Room		5,770 ±130
PET-189	AA-10450	River Otter, Archaeological Site, El Cap	-10.0	3,290 ±60
PET-190	AA-10449	ECC-07, Fish Bone Surface	-11.1	6,810 ±65
PET-190	AA-11514	Sediment #123, Fish Bone Deep	-13.2	8,535 ±70
PET-190	AA-10445	ECC-03, Grizzly	-18.3	12,295 ±120
PET-190	AA-7794	ECC-02, El Cap, Giant Grizzly	-18.0	9,760 ±175
PET-190	AA-10448	ECC-06, El Cap, Black Bear (Juvenile Cranium)	-18.7	11,565 ±1115
PET-190	AA-10446	ECC-04, El Cap. Black Bear (Complete Skull)	-20.0	11,540 ±1110
PET-190	AA-07793	ECC-01, El Cap, Black bear, Complete Skeleton	-21.1	10,745 ±175
PET-190	AA-10447	ECC-05, El Cap, Black Bear, fused cranium	-22.1	6,415 ±1130
PET-220	AA-10451	BWI-1, Juvenile Grizzly	-18.5	9,995 ±95
PET-220		BWI-2, Juvenile Grizzly		undatable
PET-407	AA-15222	Bumper Cave, Grizzly, #1 bear, rib fragment	-17.8	11,567 ±82
PET-407	AA-15223	Bumper Cave, Grizzly, #2 bear, humerus	-16.8	11,226 ±109
PET-407	AA-15225	Bumper Cave, Grizzly, Large Molar	-19.5	10,970 ±86
PET-407	AA-15224	Bumper Cave, Grizzly, #3 bear, lower jaw	-17.9	7,205 ±67
PET-407	AA-16553*	Bumper Cave, Grizzly, 1 bear, rib fragment	-17.8	11,727 ±118
PET-407	AA-18449	Bumper Cave, Caribou, metacarpal	-19.1	10,515 ±90
PET-408	AA-16831	On Your Knees Cave, Bear bone, tibia	-20.7	41,600 ±1500
PET-408	AA-15227	On Your Knees Cave, Large Grizzly Femur	-15.9	35,363 ±794
PET-408	AA-18450	On Your Knees Cave, Ring Seal (Ulna)	-14.7	17,565 ±160
CRG-442	AA-15226	Enigma Cave, Grizzly humerus, complete skel	-16.0	11,714 ±118
CRG-462	AA-10574	Nautilus Cave, deer humerus	-25.2	8,180 ±70
PET-410	AA-17415	Kushtaka Cave, Black Bear, femur	-23.2	8,725 ±70
PET-410	CAMS-24378	Kushtaka Cave; Black Bear Rib		8,660 ±70
PET-221	AA-8871A	Devils Canopy Cave, Marmot incisor	-23.7	>44,500

*Note: AA-16553 represents a second date for AA-15222. This sample was mistakenly dated twice.

- The cave systems filter out some debris and sediments, although they do not filter out chemical impurities or microorganisms.
- Smolts and resident trout use the cave systems for protection from predation, for shade, and for a feeding area since many insects utilize the photic zone of the cave system for breeding and shelter. Adult salmon have been seen spawning through some cave systems, and evidence of salmon spawning in the caves has been found. Salmon are reported to spawn within one river cave system on Chichagof Island.
- Karst streams have a much greater and more diverse aquatic insect population, both within the caves and in the streams. There also seems to be greater moss and algae growth within the carbonate dominated systems, most likely reflective of nutrient availability (Swanston, 1993, Wissmar *et al*, 1995).

Natural History and Paleontological and Cultural Resources

The potential cultural and paleontological significance of the caves and karst landscape is high. The Pleistocene paleontology of the area is primarily known from cave and rock shelter deposits, which are often intimately related to archaeological sites. The cool, stable, basic environments in the caves result in exceptionally good preservation of bone and organic materials (Aley *et al*, 1993). Recent paleontological work in caves on Prince of Wales and surrounding islands, along with botanical surveys of alpine areas and genetic studies on chum salmon populations, argue for a well developed coastal refugium along the western coast of southern southeast Alaska. The evidence sheds new light on problems of glacial chronology, climatic change, biogeography, and archaeology along the western margin of North America (Autrey and Baichtal 1992; Heaton and Grady, 1992; Dixon et al, 1992).

To date, significant archaeological and paleontological materials have been discovered in at least thirty caves and rock shelters on the Ketchikan Area (R. Carlson, 1993). During the summers of 1993 and 1994, at least three new bone deposits were located during inventory of caves.

Recently, six black bears (*Ursus americanus*), one of which dates to approximately 11,565 years before present (BP) and sixteen grizzly or brown bears (*Ursus arctos*), now extinct on Prince of Wales Island, ranging in age from 35,363 to 7,205 BP have been discovered. A possible black bear tibia has been dated to 39,100 BP Natal otter (*Luta canadensis*) dens dating to 8535 BP have also been discovered and described (Baichtal, 1993b). Early humans were exploring some caves during the middle Holocene. Evidence of human habitation, the oldest dating to nearly 4,500 BP, has been discovered in several caves on Prince of Wales and seaward islands. The remains of red fox (*Vulpus volpes*), caribou (10,515 BP) (*Rangifer tarandus*), ringed seal (*Pusa hispida*) (17,565 BP), and marmot (*Marmota* sp.), now extinct on the islands, have been recovered (Heaton 1994, 1995a, & 1995b, Baichtal, 1994b, 1995a). The marmot was dated to over 44,500 years BP Botanical studies on Dall and Prince of Wales islands have described plant populations which suggest ancestry from local remnant populations that escaped glaciation (Hulten, 1968; Muller, 1991). Recent research concerned with chum salmon populations from the Queen Charlotte Islands and southeastern Alaska has shown that the greatest genetic variation exists in the fish along the western coastlines of Queen Charlotte and Prince of Wales Islands (Kondzella, 1993). These significant genetic variations suggest longer habitation of streams in these areas, and therefore the possibility of coastal refugia. The occurrence of the *Stygobromus* species on Heceta, Suemez, Dall and Coronation Islands also supports the refugia theory. The apparent lack of troglobites on Prince of Wales Island appears to be correlated with the glacial history of the region (Aley *et al*, 1993). This new information, combined with limited data on raised marine beaches in the area, strengthens the argument for a coastal refugium, along which Pleistocene mammals and humans may have migrated.

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Monitoring Human-Caused Changes With Visitor Impact Mapping

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Abstract

Impact maps are overlays to a standard cave map which indicate the location, extent, and severity of impacts to cave features. Two types of visitor impact maps were developed, one locates and describes impacts and fragile resources at points, and the other classifies and locates impacted areas within the cave. Both types of maps were developed for ceiling features and floor features. Impacted areas are placed into three classes based on severity. The resulting maps provide a quantitative measure of the impacts that can be easily updated to monitor changes in the condition of the cave.

Introduction

Photo monitoring is currently the only method used by most cave managers to monitor nonrenewable resources such as mineral formations, bone deposits, and floor surfaces. Photo monitoring provides the manager with some extremely detailed information. However, it is challenging to establish if the resource to be monitored is expansive or damages to resources need to be quantified. Visitor Impact Mapping can be used as an alternative or to augment photo monitoring.

Visitor Impact Mapping (VIM) involves locating visitor caused damages, or undamaged resources, on a detailed map of the cave. Several different types of Visitor Impact Mapping can be developed to suit a variety of management needs. In this report two types are discused, Visitor Impact Point Mapping and Visitor Impact Area Mapping.

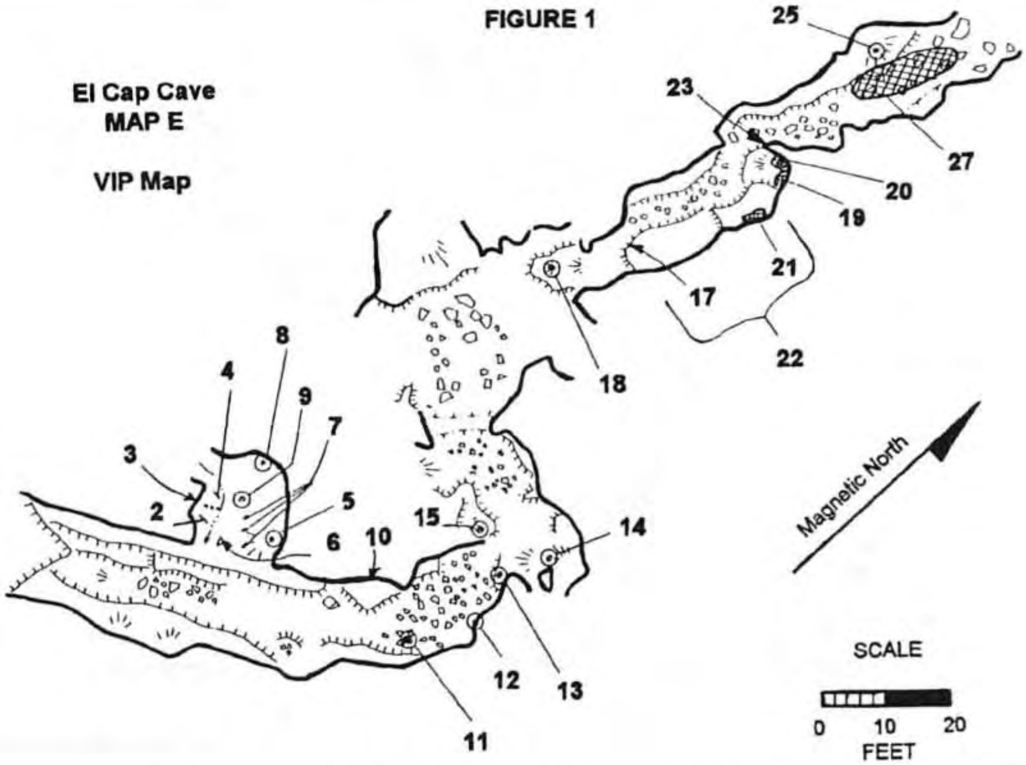
Visitor Impact Point Mapping

Visitor Impact Point (VIP) Mapping locates damaged and fragile resources with numbered points. Each point is drawn onto a map of the cave based on its relative position to mapped features, and a description of the damaged (or fragile) resource is recorded. An example VIP map is presented in Figure 1 and a portion of the corresponding point descriptions are included in Table 1. By studying the VIP map and descriptions it is possible for the cave manager to assess conditions (at the time of mapping) of resources at numerous points throughout the cave.

Visitor Impact Area Mapping

Visitor Impact Area (VIA) Mapping locates areas which have been impacted. These areas are drawn onto the cave map based on their relative position to mapped features and, using coded patterns (or colors), each area is classified according to the severity of impacts within it. An example of a VIA map for floor surfaces is presented in Figure 2. On this VIA map visitor impacts are classified as Pristine, No Observable Impacts, Light Impacts, Heavy Impacts, and Severe Impacts. Areas which are Pristine have floor surfaces which are of such a fragile nature that it is obvious no visitors have ever walked there. Areas which are classified as No Observable Impacts are areas where visitors may have walked (and left impacts), but floor surfaces are of such a nature that impacts can not be detected even under close visual inspection. Areas which are classified as Light, Heavy, and Severely Impacted are defined according to type of floor surface. Table 2 presents an impact classification for several different types of floor surfaces, and Figure 3 shows the type of floor surfaces for the same portion of cave shown in the VIA map in Figure 2.

The VIA Map, Floor Surface Type Map, and Impact Classification Table can be used to give the cave manager an overall feel for the condition of resources throughout the mapped portion of the cave. It can also be used to give the cave manager more specific information concerning the types of impacts within smaller areas.



Point Number	Description
	Table 1 Impact Point Descriptions El Cap Cave Map E
2	Ten mud stalagmites, each about 2 in. in diameter. Five are about 10 in. high and five are about 2 in. high. No signs of any visitor damage.
3	Three mud stalagmites, each is about 1 in. in diameter and 4 in. high. No damage.
4	Five mud stalagmites, each is about 1 in. in diameter and 1 in. high.
5	Beautiful *pristine* mud surface with red-orange coating and white speckles.
6	One boot skid mark in silt surface.
7	Small depressions in silt surface, three sets of closely spaced, ½ in. diameter depresions. Probably finger (or hand) prints.
8	Strange feature—thin, white, irregular coating which covers area less than 1 ft in diameter.
9	Large depression in silt serface (about 2 ft in diameter). May be the result of visitors kneeling, falling, sitting, or placing a pack in this area. Depression may also be natural.
10	Hand traffic on edge of silt deposit has slightly altered the character of the surface. On top of ledge there are three areas with obvious finger drepression marks. Other than these three areas top of ledge is *pristine*.
11	Black-coated rock. Some wear and spalling probably from visitor traffic. Throughout this passage (Map E) these place coated rocks are present in a density of about 5 to 15%. Some seem to have been worn a bit by visitor traffic.
12	Resolutioned flowstone on corner. No damage due to visitors.
13	Pristine silt and cobble deposit in alcove. Deposit has white speckles. No visitor damage to deposit.

FIGURE 2

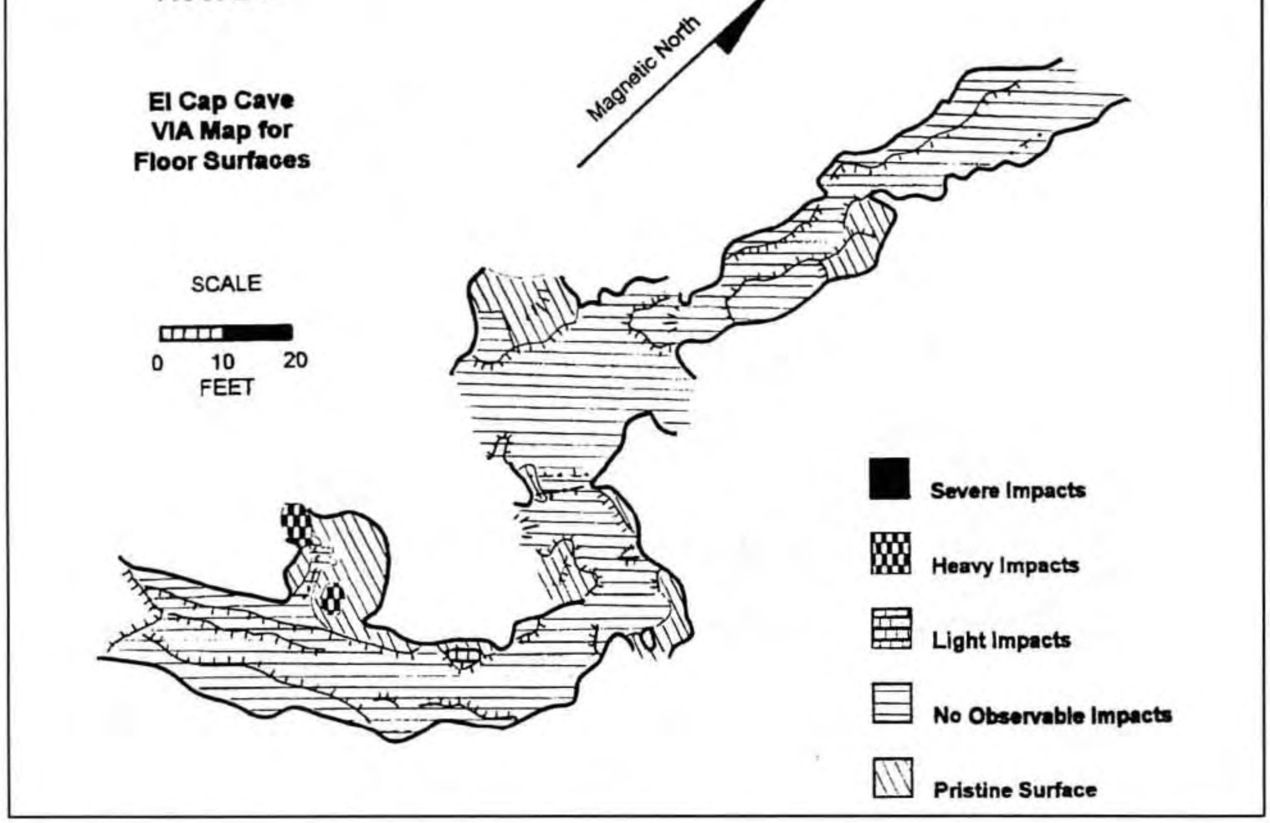


FIGURE 3

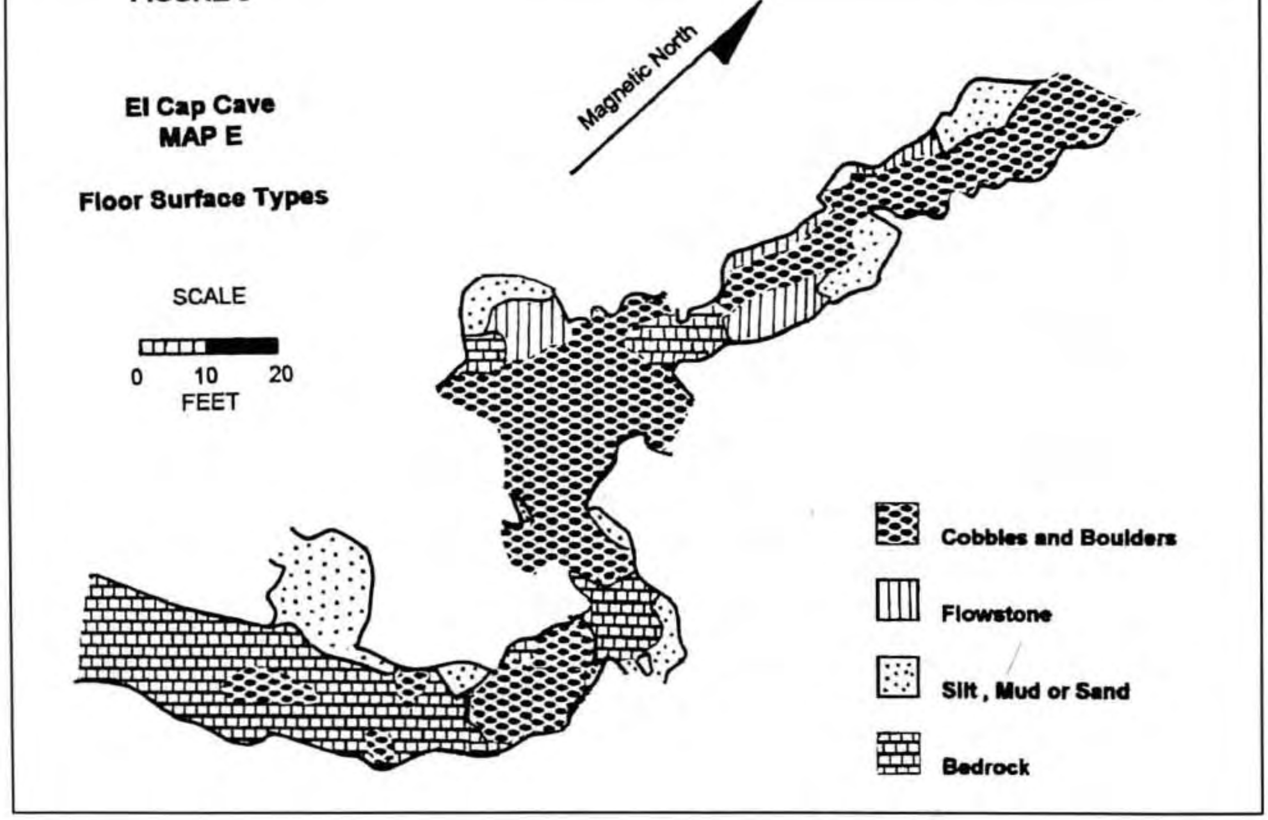


Table 2
Explanation of Impact Classes for Different Types of Floor Surfaces

	Types of Floor Surfaces			
Impact Class	**Silt, Mud, or Sand**	**Rounded Cobbles or Angular Rock**	**Bedrock or Flowstone**	**All Types of Floor Surfaces**
Light	Light brushing of surface covering less than 25% Faint depressions covering less than 25%	Mud smears cover less than 50% of tops	Mud smears cover less than 25%	¼ in. or less debris layer rolled onto surface
Heavy	Trenching less than ½ in. deep Brushing of more than 25% Noticable depressions covering 25 to 50%	Mud smears cover 50 to 100% of tops	Mud smears cover 25 to 50%	¼ in. to 1 in. debris layer rolled onto surface
Severe	Trenching greater than½ in. deep Depressions ½ in. or greater cover 50 to 100%	Mud is deposited in layers ¼ in. or greater Cobbles (or Rocks) are rolled to side to form trench	Mud smears cover 50 to 100% Mud is deposited in thick layers ¼ in. or greater Surface has been chipped or broken	Greater than 1 in. debris layer rolled onto surface

Using Visitor Impact Mapping to Evaluate and Compare Caves within a Region

Visitor Impact Mapping can be used to evaluate and compare resource conditions of different caves within a region. Figures 4, 5, and 6 show VIA maps for floor surfaces in the entrance portion of three caves in the Grand Canyon of northern Arizona. The floor within each cave consists of thick deposits of pollen and powdered sulfate minerals. The presence of extinct animal bones on the floor surface suggests it may be up to 8,000 years old.

Rex Cave, represented in Figure 4, has received a cumulative visitation of about 500 people. Most of these were recreationists. Severe impacts, which are shown in black, are limited to a small area along the north wall, about 40 feet from the entrance. These impacts were the result of visitors digging a pattern into the floor sediments by dragging their feet. Heavy Impacts (which are shown in the dark checkered pattern) cover the largest portion of floor surface and only a few small areas with No Observable Impacts. These are near walls and under low ceilings.

Kappen Cave, represented in Figure 5, has an access and visibility similar to Rex Cave. Cumulative visitation is also similar at about 300 visitors. However, about 25% of these visitors were affiliated with research activities. The amount of floor surface which has been Heavily Impacted, and the amount of floor surface which has No Observable Impacts is proportionally about the same as seen in Rex Cave, but unlike Rex Cave, Severe Impacts are more extensive and well defined. Severe impacts are the result of excavation pits which have been left uncovered. Of special note are the doubled circles. These represent prehistoric artifacts which have been left in the cave but are not in their original context.

Matts Cave, represented in Figure 6, has a similar access as Kappen and Rex Cave, but its entrance is much more obscured. Cumulative visitation is only about ten people. There are no Severe or Heavy Impacts in the cave. It seems all visitors have remained on the Lightly Impacted trail which traverses the middle of the passage. Of

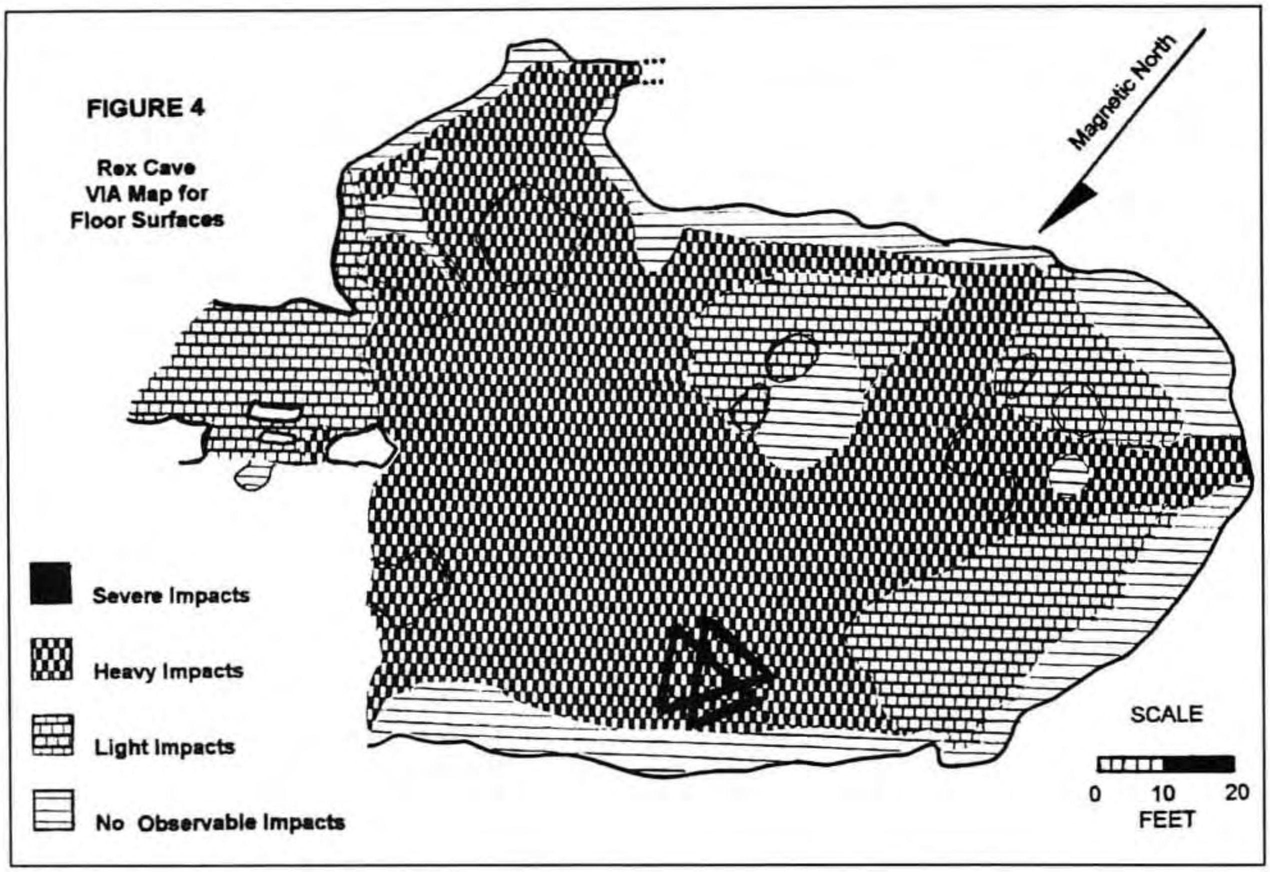


FIGURE 4
Rex Cave
VIA Map for
Floor Surfaces
Magnetic North
Severe Impacts
Heavy Impacts
Light Impacts
No Observable Impacts
SCALE
0
10
20
FEET

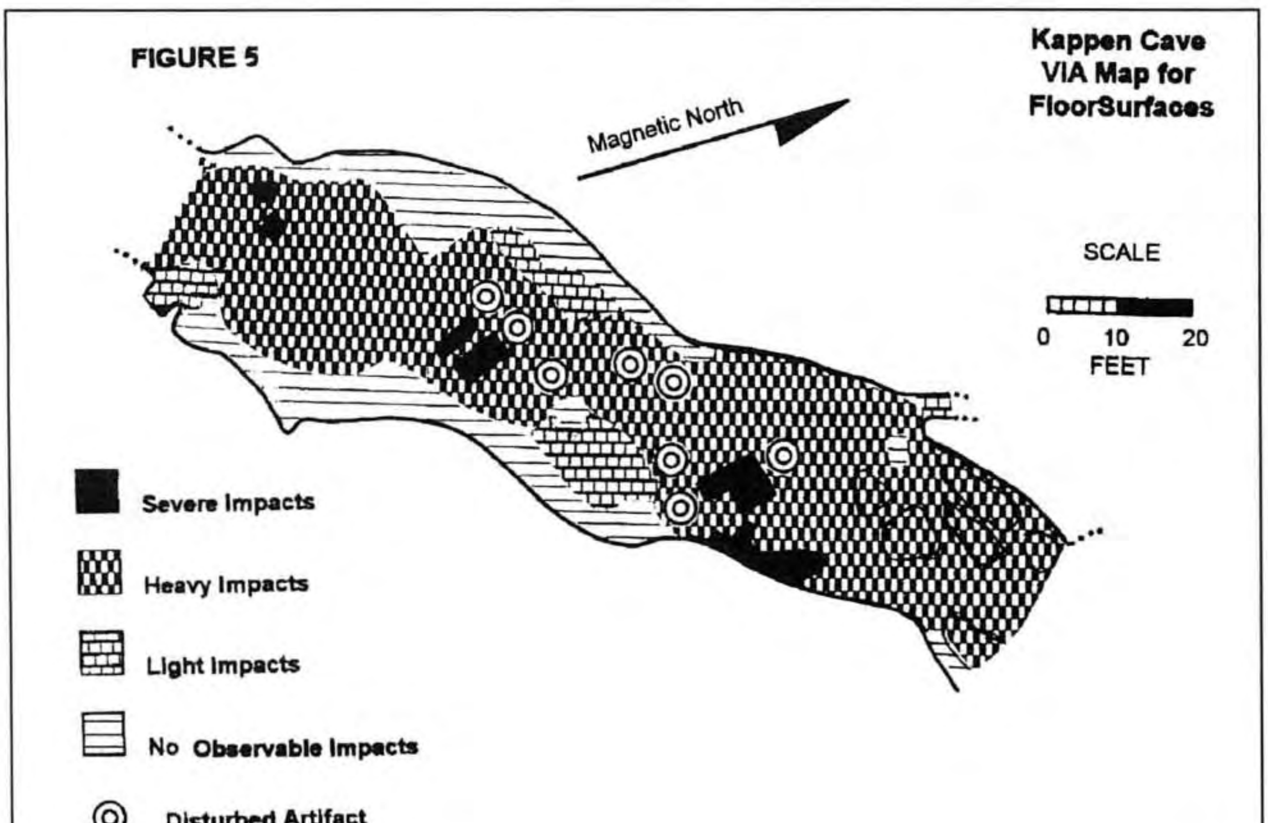
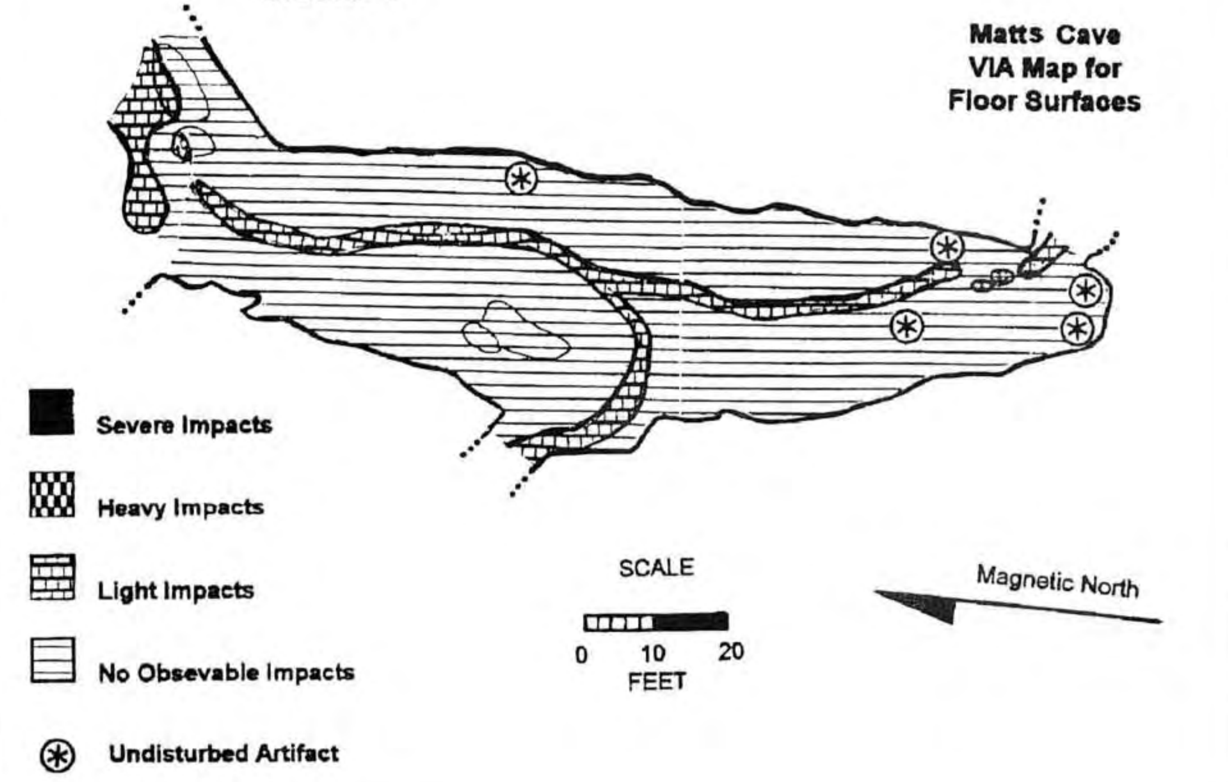


FIGURE 5
Kappen Cave
VIA Map for
FloorSurfaces
Magnetic North
SCALE
0
10
20
FEET
Severe Impacts
Heavy Impacts
Light Impacts
No Observable Impacts
Disturbed Artifact

FIGURE 6



interest are the circled asterisks which represent prehistoric artifacts that are in their original context and have not been touched in modern times.

The cave manager is given a very graphic impression of resource conditions within each cave by studying and comparing the three previous Visitor Impact Area maps. If resource conditions are related to use patterns and other factors it is possible for the manager to extrapolate the condition of these caves to other caves throughout the region. As a matter of example these three maps were selected to represent conditions to be expected within all known caves along the South Rim of the Grand Canyon.

Using Visitor Impact Mapping for Long-Term Monitoring

Visitor Impact Mapping can also be used for long-term monitoring. Figure 7 presents a VIP Map for a portion of SP Cave. Point numbers and descriptors have been omitted for clarity. Points are coded according to how they have been impacted over a four year period (from June 1991 to July 1995). Points marked with a "Happy Face" have remained unchanged. Points marked with an "Unhappy Face" have become more severely impacted. About half of the points reinspected in 1995 had become more severely impacted. This mostly involved breakage of additional stalactites and smearing of mud onto previously pristine flowstone.

As another example of long-term monitoring with VIM, Visitor Impact Area maps for floor surfaces within a portion of SP Cave are also presented. Floor surfaces throughout most of the portion of this cave consist of pristine mud-cracks. Figure 8 shows the original VIA map of the floor surfaces. Figure 9 shows the remapped portion as it appeared four years later. Close study of the two maps will reveal that a few trails have become wider and more severely impacted. Figure 10 combines the two maps to graphically emphasize changes to resources which were detected as a result of VIA mapping. Table 3 further emphasizes changes by calculating the change in area for each class of impact. The table provides a very quantitative and tangible look at how resources have changed.

Using Visitor Impact Mapping for Short-Term Monitoring

Visitor Impact Mapping also can be used to determine the effects of one-time, special events. Figure 11 shows the floor surfaces of the entrance portion of El Cap Cave before and after a rescue practice was conducted. An increase in Heavily Impacted area and a new Severely Impacted area are noticeable at

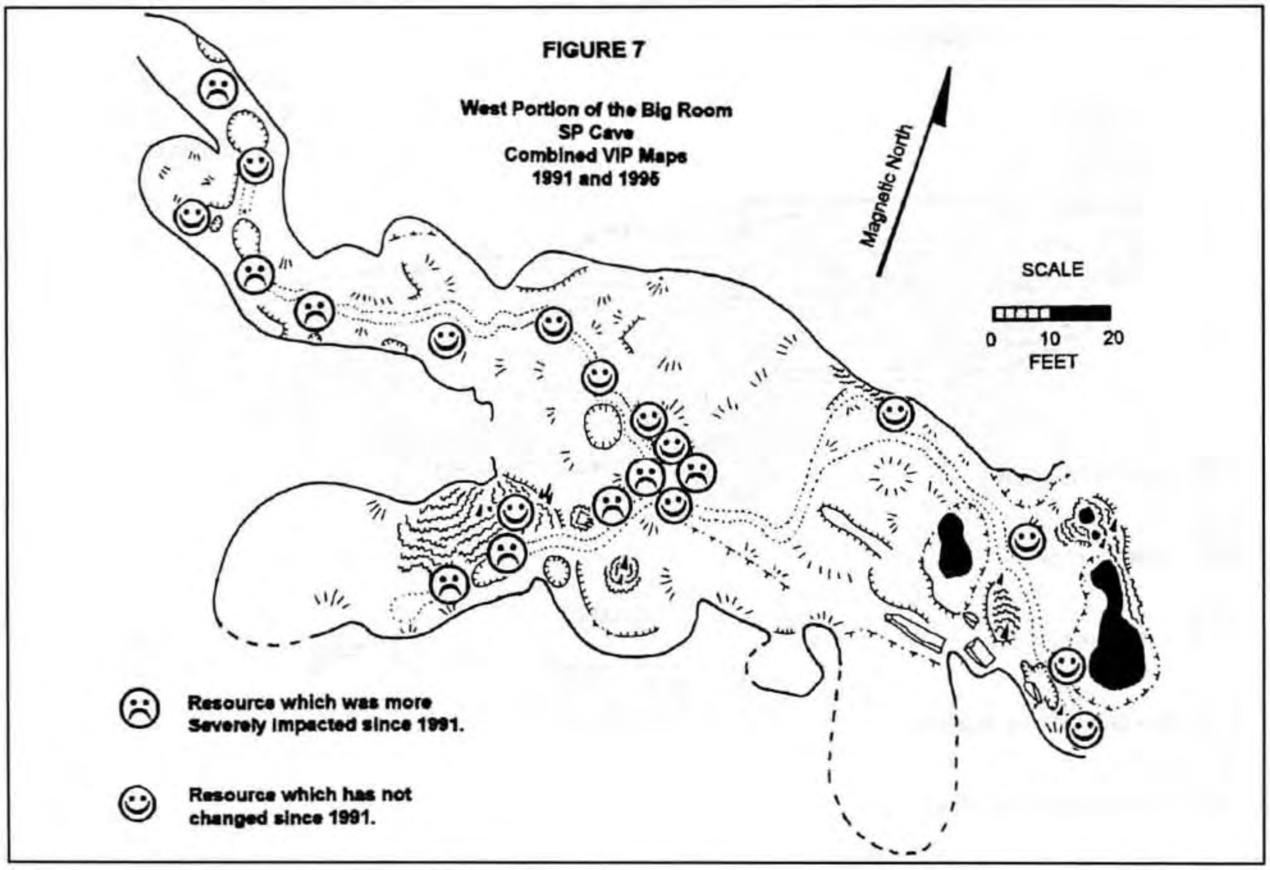


FIGURE 7
West Portion of the Big Room
SP Cave
Combined VIP Maps
1991 and 1995
Magnetic North
SCALE
0 10 20
FEET
Resource which was more Severely impacted since 1991.
Resource which has not changed since 1991.

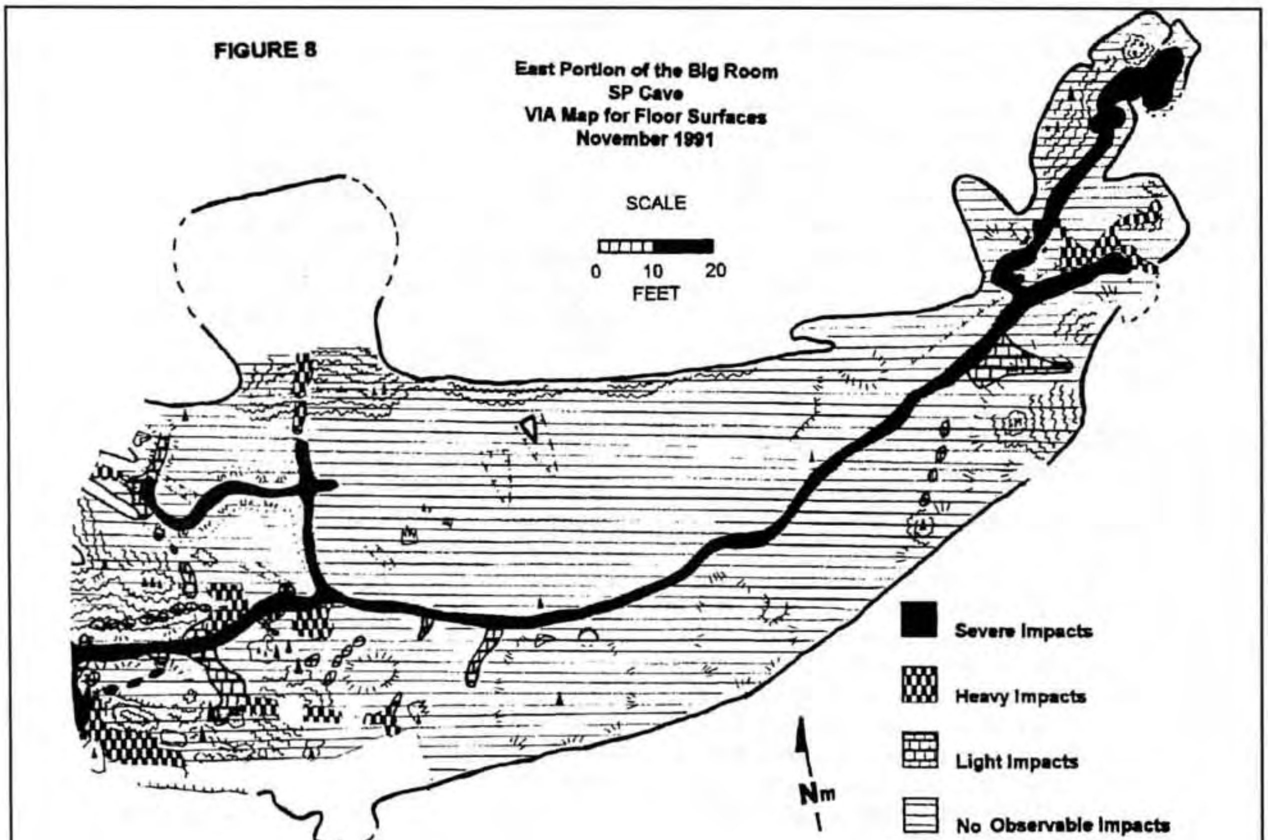


FIGURE 8
East Portion of the Big Room
SP Cave
VIA Map for Floor Surfaces
November 1991
SCALE
0 10 20
FEET
Nm
Severe Impacts
Heavy Impacts
Light Impacts
No Observable Impacts

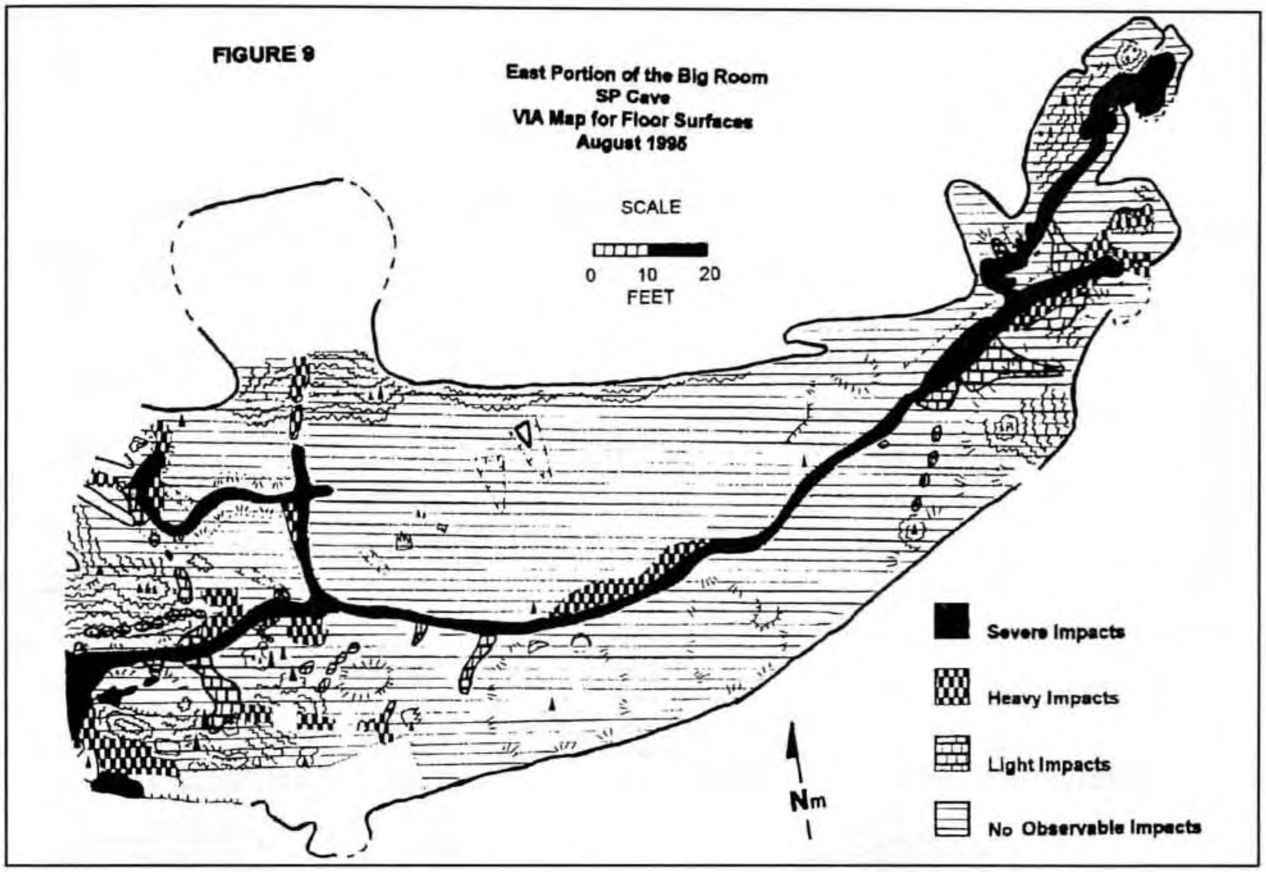


FIGURE 9
East Portion of the Big Room
SP Cave
VIA Map for Floor Surfaces
August 1995
SCALE
0 10 20
FEET
Nm
Severe Impacts
Heavy Impacts
Light Impacts
No Observable Impacts

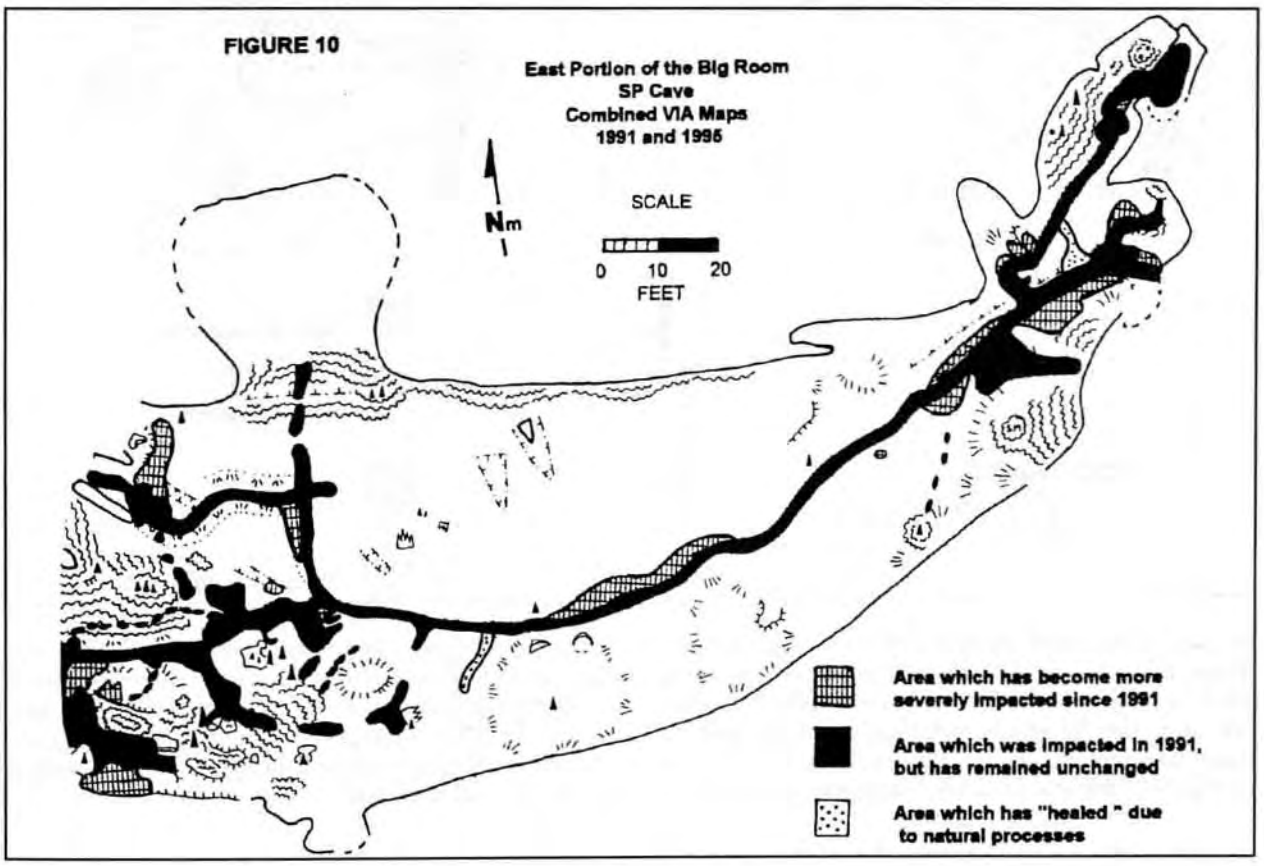
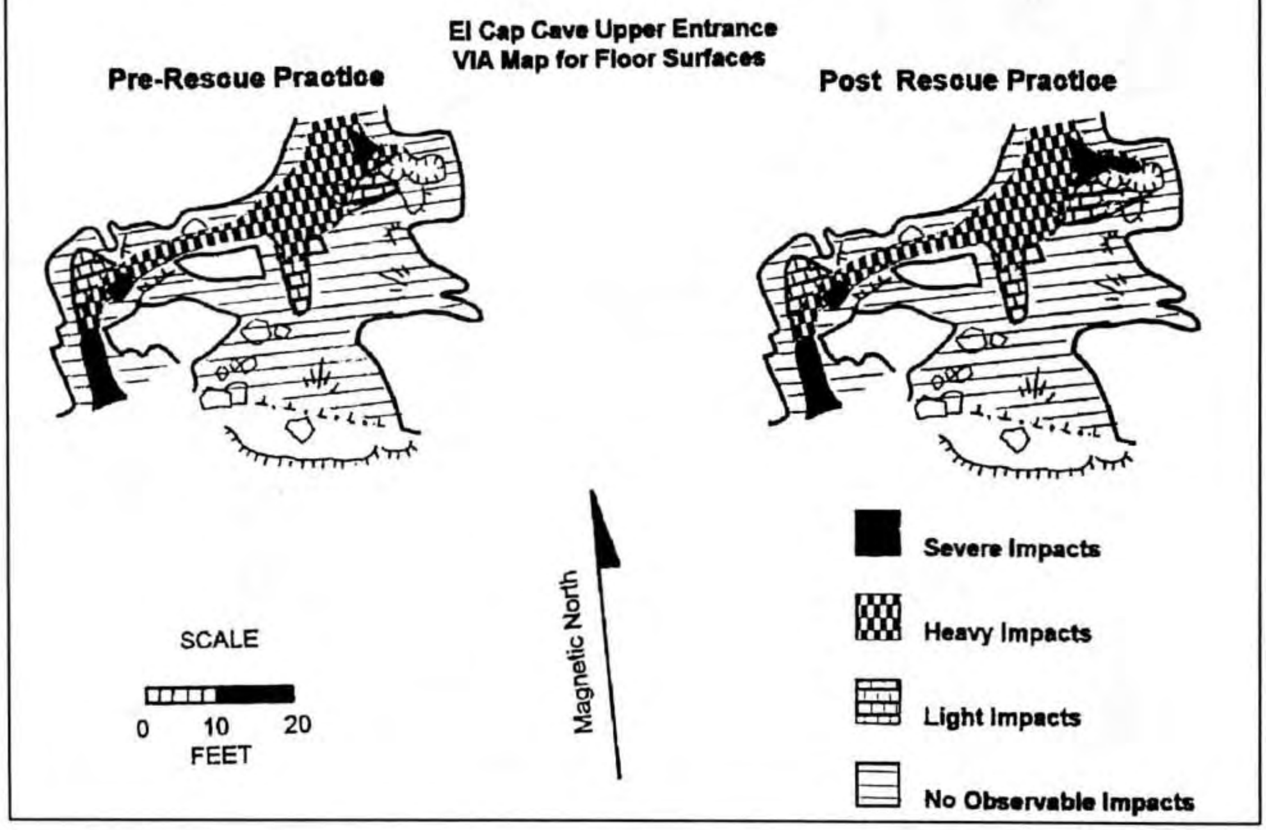


FIGURE 10
East Portion of the Big Room
SP Cave
Combined VIA Maps
1991 and 1995
Nm
SCALE
0 10 20
FEET
Area which has become more severely impacted since 1991
Area which was impacted in 1991, but has remained unchanged
Area which has "healed " due to natural processes

Table 3
East Portion of the Big Room
SP Cave
VIA Map Surface Areas

	November 1991		August 1995		Change	
Impact Class	Floor Area (sq ft)	Percent of Total Area	Floor Area (sq ft)	Percent of Total Area	Floor Area (sq ft)	Percent of Total Area
No Impacts	9,696	87.7%	9,497	85.4%	-199	-1.8%
Light Impacts	211.5	2.0%	274.5	2.5%	+63	+0.5%
Heavy Impacts	304.5	2.7%	368.5	3.3%	+64	+0.6%
Severe Impacts	904.0	8.1%	976.0	8.8%	+72	+0.7%
Totals	11,116	100%	11,116	100%	—	—

FIGURE 11



the top of the small pit about 40 feet into the cave. These impacts are the result of rescuers hauling a stretcher up the pit. The rescuers walked further out onto the lip of the pit than previous visitors had, and the stretcher scrapped and broke-off chunks of bedrock as it was dragged over the lip.

Interestingly, photo monitoring was also repeated before and after the rescue practice. Photo monitoring detected *more* impacts than VIM. Impacts detected with photo monitoring mostly include small mud smears on previously pristine bedrock wall surfaces.

Visitor Impact Mapping versus Photo Monitoring

In comparison, both Visitor Impact Mapping and photo monitoring have advantages and disadvantages. VIM seems to be better at detecting and quantifying large scale and/or isolated impacts in an expansive area; Whereas Photo monitoring seems better at detecting detailed changes in a small area. For example, a large area of pristine floor surface may be better monitored with VIM. Trails and offtrail footprints throughout the area could be located and most changes would be easy to detect. However, an articulated skeleton of a squirrel may be better monitored with a photo. VIM could be used to tell if visitors have stepped on or near the skeleton, but in order to determine if visitors are actually picking up and moving individual bones a photo would clearly be more informative. Prudent cave managers should probably develop, experiment with, and adapt both VIM and photo monitoring to best fit their management needs.

Closing Comments

In closing, the author would like to add two points. The first is in regard to time. Often when people first view Visitor Impact Maps their impression is that the process must be very tedious and time consuming. In actuality it seems to take about the same amount of time to establish VIM as it does to establish a good photo transect, but unlike photo monitoring, repeating VIM usually goes more quickly. The one aspect required for VIM that does seem to take a lot of time is developing detailed base maps. Good VIM requires a scale of about 1 inch = 20 feet, and detail should be such that an isolated foot print in a an area about three feet in diameter can be located and drawn. Fortunately there are a lot of cave mapping enthusiasts and these folks are likely to volunteer for a project that would generate a detailed base map. Perhaps such enthusiasts would also be interested in developing Visitor Impact Maps.

As a last comment I would like to emphasize that in establishing and repeating VIM (in addition to developing detailed base maps) it is very important to drastically limit additional impacts which may result from the monitoring. My policy when conducting VIM is to stay on well-established, designated trails. In order to see impacts and fragile resources which are off trail I use a *very* bright light. Hand-held, self-contained spot lights which are suitable for VIM are available through various outdoor sports retailers. If there are areas off-trail which I can not see, even using a bright light, I simply don't map them. In almost all cases, the type of monitoring information which is generated by staying on trails will be more than adequate to detect resource changes and direct management decisions.

Systematic Winter Population Census of the Indiana Bat Within Indiana

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Keith Dunlap, Indiana Karst Conservancy
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Karen Tyrell, PhD, 3D/Environmental

Abstract

Use of Indiana Caves by bats was established by Blatchley before the turn of the century. Over the years, the caves and the bats within have too often suffered abuse. On March 11, 1967, the Indiana bat (*Myotis sodalis*) was listed as endangered by the U.S. Fish and Wildlife Service. Since listing, Indiana bats and their hibernacula have been studied in an effort to identify population declines and reasons for declines. Throughout its range, the species is restricted to a few caves during the winter. There are large numbers of Indiana bats in a small number of these caves; most hibernacula contain only a few bats. Some of the larger hibernacula in Indiana were censused occasionally during the 1950s, 1960s, and 1970s. Regular biennial surveys began in 1981. Winter surveys provide a unique and inexpensive opportunity to regularly census essentially all bats, and to monitor population gains and losses. In Indiana, *M. sodalis* has been found hibernating in 23 caves. During the 1995 census, 14 of these caves contained at least 100 bats. Seventy-four percent of the bats in the state hibernate in just four caves and 97% of the bats were in six caves. Disturbance at the hibernacula adversely affects survival of the bats. Human activities at several hibernacula is monitored with electronic *speloggers* that record the date and time of each disturbance.

Reassessing Cave Significance

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Abstract

Cave significance can sometimes be a difficult characteristic to measure. Most will agree that large and/or beautifully decorated caves are significant and worth protection. However, care should be taken during the inventory process to assess even the small, superficially insignificant caves to ascertain their true value. Many times paleontological, historical, invertebrate, or microbial evidence is commonly overlooked by the unpracticed eye. A cave in Arizona provides an example where a small, one-room cave has significant value which should be considered when developing a management plan.

Since the passage of the Federal Cave Resources Protection Act, there has been an increased effort by Federal land managers to inventory their caves and develop cave management plans for the resource. In many instances they have depended on cavers to inform them of the known caves on Federal land. It has also been the cavers who have, for the most part, submitted caves for significance status and protection under the Federal Cave Resources Protection Act. This process is more straight forward for those caves that are of great length, are extremely well decorated, or have rare endemic species of organisms living in them. However, this leaves many more caves, probably the greater proportion of caves, in a "gray area" of significance. Cave inventories are an ideal tool to assess the significance of the caves' resources and how much protection should be afforded by the cave management plan. It is during this process that care should be taken to ascertain the true significance of a cave. Recreational cavers may not be the best group to identify some of the more obscure, yet greatly significant value of some caves. Paleontological, historical, invertebrate, and microbial evidence requires a trained eye to pick out and is many times overlooked by sport cavers.

A small cave in southern Arizona is an excellent example where many of these elements come into play. Deadman Cave is a small (100-foot-diameter) one-room cave that is well known by locals. Recreational cavers do not often visit this cave because it is small, heavily visited and trampled, and, although once well decorated, now has broken, desiccated formations. Although perceived as a "sacrificial cave" by cavers, this cave has many features which should actually elevate it into a more significant category.

During the end of the last century, prospectors wandered southern Arizona in search of valuable minerals. Many small mines were dug in the mountainsides, especially along faults where mineralization would occur. Some of these mines would intersect small caves. In the case of Deadman Cave, miners dug a shaft in the back of a natural cave, excavating along a fault and through a layer of travertine on the floor. This exposed approximately 6.5 feet of cemented rubble and bone material. In the 1970s this was identified by researchers as an incredibly rich assemblage of fossilized bones of 64 different species of vertebrates from the Late Pleistocene-Early Holocene Period. These bones date from 12000 to 8000 Before Present (BP) and included three extinct species of large Pleistocene mammals. This deposit of bones, however, has even greater significance beyond the examples of extinct species. It has enabled scientists to reconstruct climate in the area of Deadman Cave during a period of time little known before (Mead *et al*, 1984). This bone material, in some cases, is so broken and calcified that it can be overlooked as bits of broken speleothem. Sometimes the older the bones the more weathered it becomes and the harder it is to identify as bone material. Here is where the trained personnel performing an inventory will be better able to pick out material from debris.

Graffiti is one of the great evils humans have done to caves through the ages. It seems universal that mankind has wanted to leave his "mark" on cave walls to prove he was there. Even cave paintings at famous Lascaux Cave in France, one of the early man sites, could be described as graffiti. In the last 30 years the National Speleological Society has had an aggressive educational message that spelunkers should sign the cave registers—not the cave walls. Caving groups have had projects where they clean up caves, repair speleothems, and remove graffiti as a conservation activity. This is an excellent educational project for club members, especially beginners, but care must be taken not to remove what is actually of historical significance. Before a graffiti removal activity, a thorough inventory should be made of the signatures with photomonitoring documentation to preserve them (Bilbo and Bilbo, 1993). Then only recent signatures should be scrubbed off the walls. Signatures of "historical" value, which is generally accepted as older than 50 years, should be preserved. Signatures which are more recent than 50 years old may also be protected if they hold special local historic value. In Deadman Cave, mixed in with the recent 1990s graffiti are signatures dating back to the original ranchers and miners in the area in the 1880s. Some of the signatures are ornately penned and one in particular has a nostalgic verse included. This is still graffiti, and yet it seems less obnoxious when one considers that the U.S. Cavalry was still pursuing Geronimo through the region and the overall remoteness of the area made life more tenuous. If an unsupervised cleanup of the cave walls were to occur, even in an attitude of conservation, a part of history would be lost.

Another area in which a trained eye helps in the basic inventory of a cave is in the search for organisms using the cave. Because of the paucity of past work done in the field of cave invertebrates, new cave adapted species are still being identified from caves. Many times, especially in a heavily traveled cave, these invertebrates seek remote, more protected areas to live. A careful search under pieces of wood and under rocks in the moister areas of the cave floor will yield collembola, isopods, millipede, mites, pseudoscorpions, and other small (1- to 2-millimeter) invertebrates. It is a slow process which requires careful search using magnification to properly complete. Invertebrates will also show a seasonal abundance in caves. When drier conditions occur or when there is less food available, these organisms will retreat into cracks and become dormant to survive the harsher period. It is therefore important to inventory caves for invertebrates during the different seasons to get a complete picture of the cave's inhabitants (Northup and Welbourn, 1993). A single inventory during the wrong time of year might report no organisms using the cave and would cause the cave to be listed incorrectly on a significance rating. As long as there are even brief periods of moisture and some food input (guano, rotting wood, leaf litter, etc.) there is a good chance that there will be an ecosystem for the cave invertebrates.

In addition to the generally overlooked inventory criteria mentioned previously, there exists the whole area of the cave microbial ecosystem that has been, until recently, overlooked. These organisms are even more difficult for the recreational caver to "see" as there is nothing to observe. Until recently, cave adapted bacteria and fungi were overlooked in cave inventories because of the difficulty in identifying them properly. There is a new group of researchers beginning to develop techniques to study how these organisms can exist in such extremely-low-nutrient environments (Rusterholtz and Mallory, 1994). A cave like Deadman Cave, heavily traveled and contaminated by the surface, has little to offer this new field of research. Yet, there are many caves which could provide additional information in this new area that have not been assessed. Care should be taken in newly-discovered portions of caves, especially those that have pools of water, not to contaminate the area before work can be done to assess their potential for new undescribed strains of bacteria. There is the potential for these bacteria to have a benefit to man and promises to be an exciting field of work that will no doubt continue to see great advances.

Deadman Cave was used as an example of a small cave that would be easily overlooked in a management plan which in fact has significant importance in a number of fields of cave science. However, there are many caves throughout the United States that probably fall into this category of cave more than in the group of caves that immediately demand significance and protection. It will be the responsibility of the resource managers to acquire sufficient information from experienced researchers to assess the value of their caves and not rely entirely upon the recreational caving community for nomination of significant caves.

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Monitoring the Cave Environment

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Abstract

A basic understanding of the mechanisms that control the microclimate of a cave can be a valuable tool in managing a cave. In many cases simple observations and measurements can be used to identify the general operation of the cave microclimate. Some types of cave microclimate are more susceptible to man-caused changes. In most cases a simple baseline study should be performed before and after any modifications, such as gates, are made to a cave. Various instruments that can be used are reviewed, including simple $25 thermometers and inexpensive data loggers.

With increased emphasis on cave management, resource managers are often called upon to make decisions that can have profound impacts on the climate and ecosystem. This paper presents a brief overview of cave climate and outlines simple methods and equipment for making rapid assessments of cave climate. Being able to recognize the basic controls on the climate of a cave or portion of a cave allows the resource manager to make better decisions.

Resource managers should be aware of activities that can change the cave environment. The most common cause is modifications to the entrance of a cave. This can include installation of gates, physical changes to cave passages, creation of new entrances, and blocking of existing entrances.

Caves are relatively static environments protected from the extremes of surface weather by relatively small entrances and insulated by thick layers of rock and soil. In caves where there is no large influx of surface water into the cave, temperature and relative humidity reach stable values within a few hundred feet of the entrance. In cave systems that contain flowing streams, the influence of surface temperatures can extend for many thousands of feet into the cave.

It is generally true that the temperature of a cave is the same as the mean annual surface temperature. This is a good starting point for any investigation of a particular cave's microclimate. Is it warmer or colder than would be expected based on the mean surface temperature? Figure 1 shows the correlation between mean surface temperature and elevation in Arizona. Plotted on the same graph is the temperature of many caves. A brief look shows that caves temperatures have a wide variation from the mean surface temperature. While caves are, on the average, at the mean surface temperature there are individual caves that are up to 15°F warmer or colder than expected.

By collecting temperatures from many caves in an area, one can construct a similar graph that is useful in picking out caves with unusual tempera-

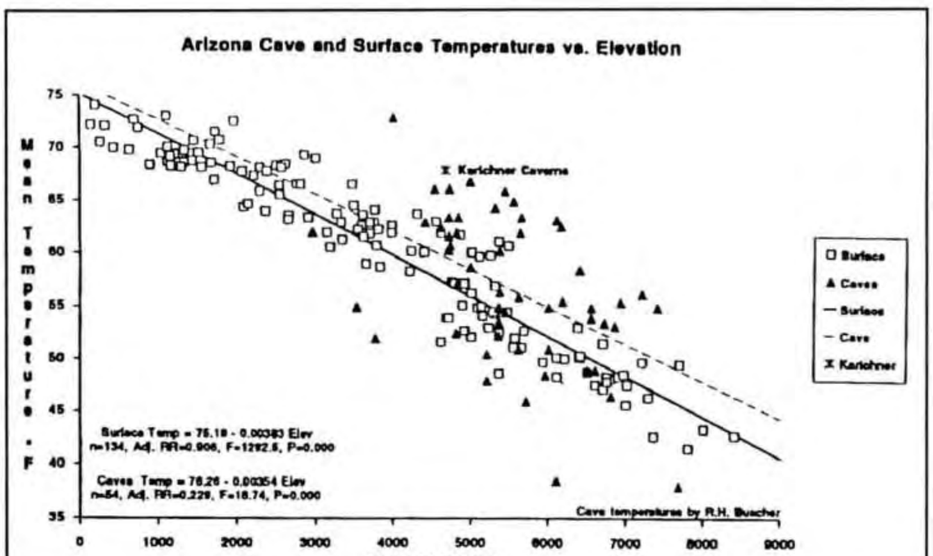

Figure 1. *Arizona surface and cave temperatures versus elevation.*

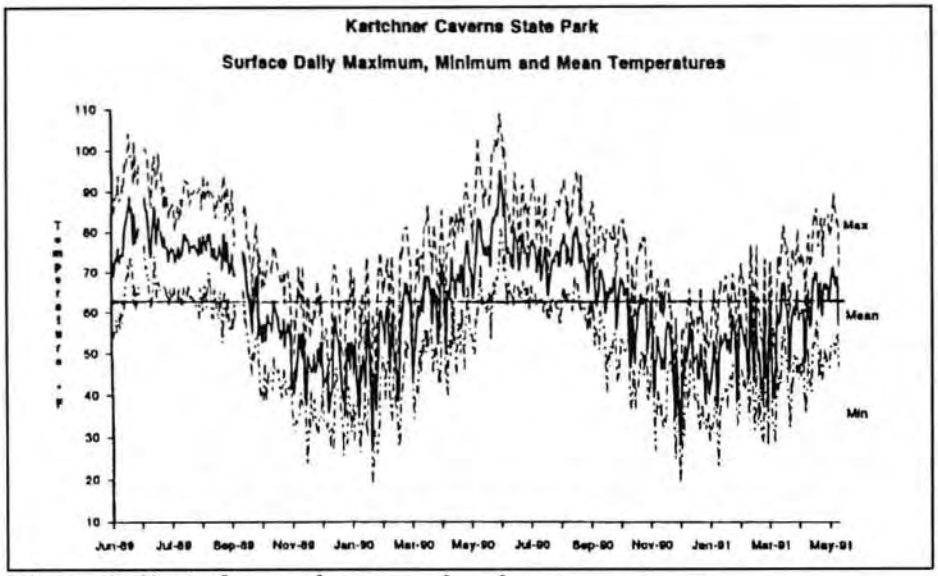

Figure 2. *Typical annual pattern of surface temperatures.*

tures. A similar graph of cave temperatures for a given area allows one to quickly determine which caves appear to have significantly warmer or colder temperatures. These are caves where the microclimate is most likely being dominated by other factors.

Based on this information, one can also make some generalizations about what to expect. For instance, caves which are unusually cold might be good places to look for bat hibernacula.

Almost all caves respond to surface temperatures to a certain degree and follow a muted pattern of seasonal changes. If we look at a graph of surface temperatures we see that there is also a considerable amount of variation in the temperature throughout the year and also on a daily basis. Figure 2 plots the daily maximum, mean, and minimum temperatures at Kartchner Caverns State Park. The mean surface temperature is 62.5°F but the daily temperature fluctuates over a range of 30°F. The yearly cycle of temperature can be roughly broken up into three phases. From May to September the outside temperature is almost always above the mean temperature, even during the coldest part of the night. From December through January the outside temperature is almost always colder than the mean, even during the warmest parts of the day. The remaining months, September through November and February through April, are transition periods when the daily range of temperatures can be above or below the mean surface temperature. Caves will show a more general response based on these three phases than to daily variations.

Cave-adapted organisms can be a very sensitive indicator of the microclimate. These organisms have evolved in the stable cave environment. A study by David M. Griffith shows how sensitive a species of cave-adapted beetle and cave cricket eggs are to the relative humidity of the soil.

Figure 3 is modified from a paper by Griffith ("The Effects Of Substrate Moisture On Survival of Adult Cave Beetles (*Neapha-enops Tellkempfi*) and Cave Cricket Eggs (*Hadenoecus Subterraneus*) In a Sandy Deep Cave Site," *NSS Bulletin*, V53, #2, Dec 1991). This illustrates the importance of substrate moisture can have on the mortality of cave-adapted invertebrates. As soil dries from 100% relative humidity to 99% the mortality increases from near zero to almost 100%. For these animals a change of 1% in relativehumidityiscatastrophic.Otherorganisms using caves have not been as well studied but may be similarly adapted to very narrow ranges in relativehumidityortemperature.

The typical methods of measuring relative humidity have a resolution of 0.5% to 2.5%. Such methods are incapable of accurately assessing changes that would affect such organisms. In fact a biologic survey of the species using a cave may be one of the most sensitive methods for monitoring the cave climate.

Figure 4 shows how relative humidity can be roughly correlated to the observable conditions in the cave. At relative humidifies below 97% to 98%

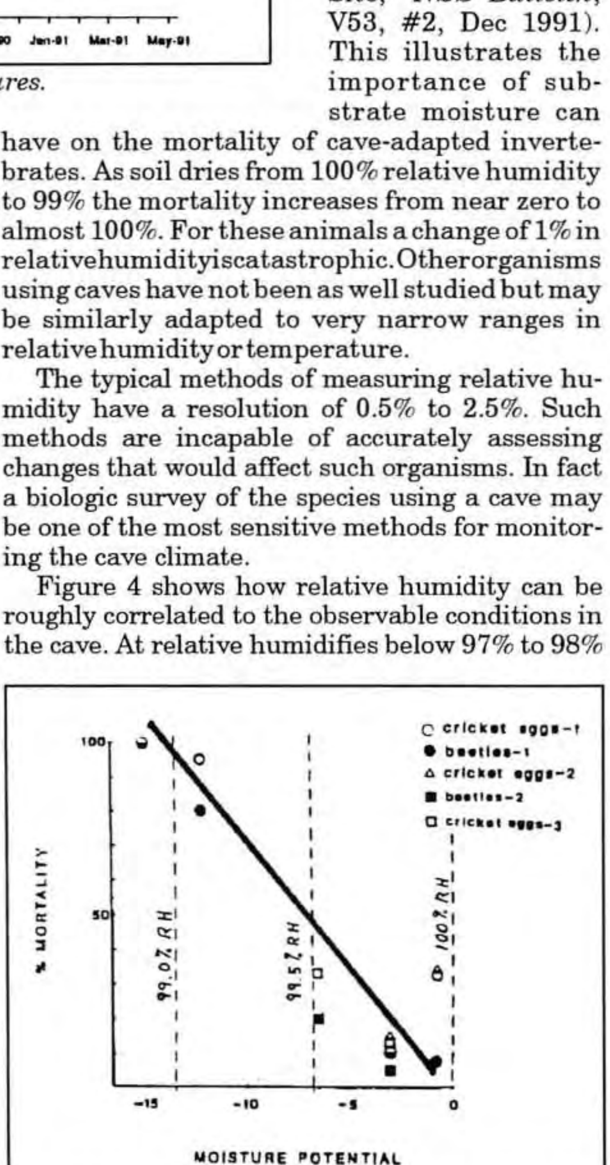

Figure 3. *Mortality of cave invertebrates as a function of soil moisture.*

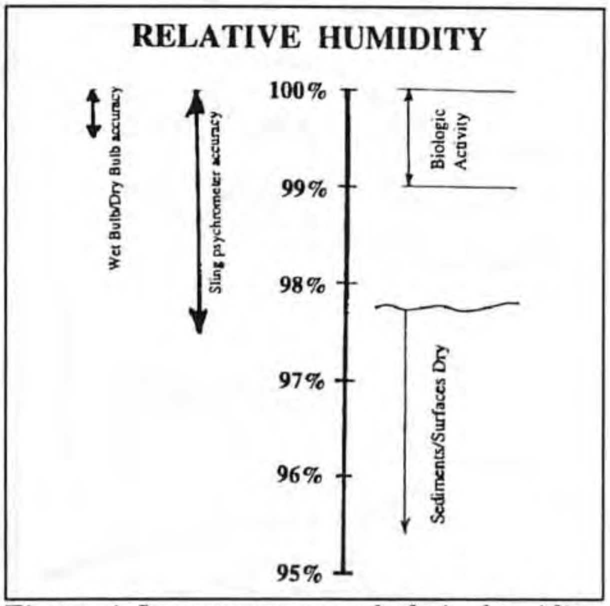

Figure 4. *Important ranges of relative humidity.*

rock surfaces and sediments exposed in the cave will begin to appear dry. Also plotted on the same figure are the range of accuracy that can be expected using a sling psychrometer reading to 0.5°F and using a wet bulb-dry bulb pair reading to 0.1°F. The range of humidity which is important for cave-adapted organisms is also shown. As can be seen, the available methods for monitoring moisture in the cave can give only a crude indication of this important variable. For most conditions where the cave surfaces are moist, the use of instruments for measuring relative humidity has very little benefit.

In order to anticipate the likely impacts of changes to the cave on the microclimate of the cave, we must first have a rudimentary understanding of the basic processes which influence cave microclimate. Knowing how the cave microclimate operates will aid in predicting the likely effects of changes to the cave.

Four basic types of airflow patterns found in caves are shown in Figure 5. Each pattern is determined largely by the geometry of the cave passages and the number of entrances. Simple inspection of a cave or even a cave map can allow one to make a reasonable decision as to what type of airflow pattern is likely to be dominant. Larger and more complex caves can be broken up into segments where each of these basic mechanisms is the dominant mode.

Chimney caves are caves with two or more entrances which lie at different elevations. During the year two patterns of steady airflow can develop due to the differences in air density between the two entrances and the air in the cave. The greater the elevation difference the more pronounced the air flow will be.

During the winter, cool air entering the lower entrance is warmed and rises to the top of the cave and exits as a plume of warm air at the upper entrance. During the summer, the air inside the cave is cooler and more dense than outside air and it flows out the lower entrance.

Cold-air-trap caves selectively capture and hold cold air. Typically these caves have entrances and initial passages which slope downward from the entrance. Usually there is only a single entrance and the cave volume is relatively small. At night or during the winter months, air that is colder and of greater density will flow into the cave, filling the areas lower than the entrance with cold air. During the warmer months of the year, a pool of colder dense air remains. The volume of cold air stored must be large enough to keep the area cool for several months.

Warm-air traps selectively capture and hold warm air. Warm air is less dense and will rise to the top of the passage or ceiling of a room. Caves that slope upward or have extensive areas lying above the elevation of the entrance are potential warm-air traps.

The fourth type of airflow is a barometric or wind driven resonance. Given a sufficiently large cave volume, small changes in air pressure due to wind gusts or approaching weather disturbances can cause the cave to breath in or out in order to come to equilibrium. This effect is more pronounced for very large cave volumes.

Caves may not be one simple form but rather a complex combination of several different types. Various passages and rooms may have separate airflow-dominated mechanisms. Small and moderately large caves usually have a single dominant control of the airflow pattern. Larger caves are more likely to have more complex behavior because of the increased likelihood of multiple entrances and larger volumes.

A comprehensive mathematical model of the temperature and relative humidity profiles at the entrances of caves was developed by Wigley and Brown ("Geophysical Applications of Heat and Mass Transfer In Turbulent Pipe Flows," *Boundary-Layer Meteorology*, 1971). An important aspect of the model is the concept of the "relaxation length (X_0)" as applied to the temperature and relative humidity profiles.

Relaxation length (feet) $X_0 = 63\ R^{1.2}\ V^{0.2}$
where R = passage radius in feet and
V = air velocity in feet per minute

the relaxation length is a measure of the rate of exponential damping of temperature differences as one proceeds deeper into the cave. At a distance into the cave of four or five times the relaxation length, temperatures remain constant year-round.

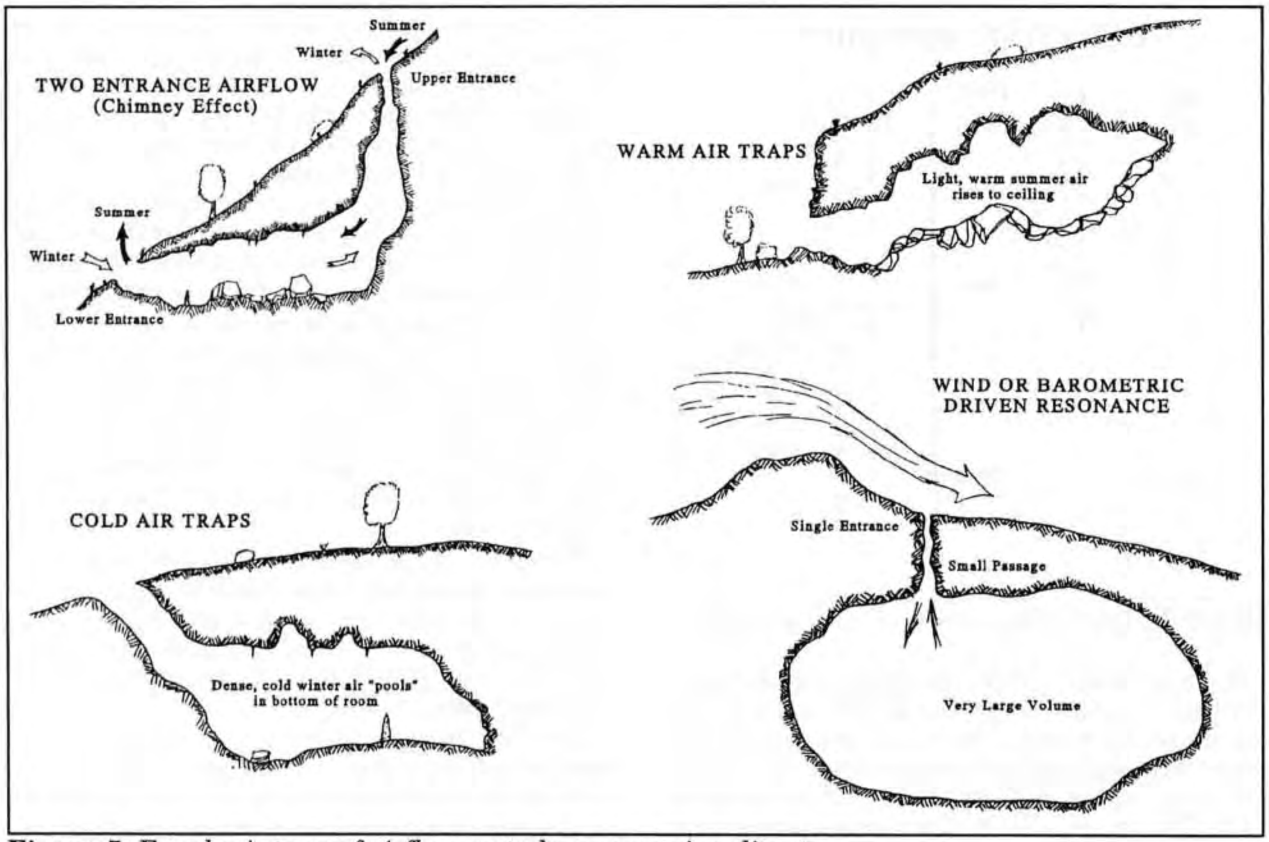

Figure 5. *Four basic types of airflow controls on cave microclimate.*

The model predicts the relaxation length based on air velocity and passage geometry. Passages are considered to be essentially circular pipes with moist walls. Air entering the cave gradually comes to thermal equilibrium with the walls through conduction with the walls and the gain or loss of water by evaporation or condensation.

Figure 6 is a graphical representation of the types of temperature profiles predicted by the Wigley-Brown equation. Several types of temperature profiles are possible and generally correspond with seasons on the surface.

The Wigley-Brown theory is very insensitive to changes in airflow, changing airflow velocity by a factor of two would change the relaxation length by only 15%. Changes in passage dimensions have a much greater influence. Here doubling the passage radius would increase the relaxation length by a factor of 2.3.

This equation allows us to make at least qualitative predictions about how changes in passage size and airflow will affect the cave environment. We can calculate that the relaxation length of a gravel plug is on the order of two to three feet. Digging out the plug to create a small human-sized entrance will increase the relaxation length to several hundred feet. For a small cave this may mean a total disruption of the cave climate.

Another important aspect of the Wigley-Brown equation is that the distance into the cave that surface conditions penetrate is described by a sin-

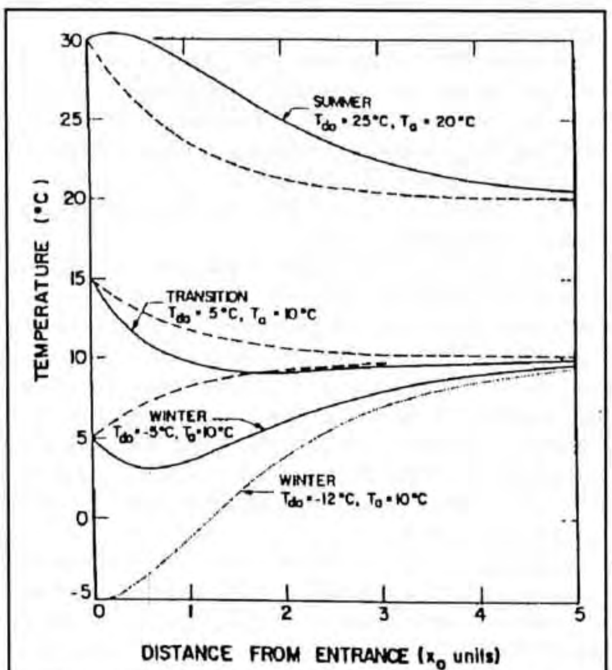

Figure 6. *Theoretical temperature profiles near cave entrances.*

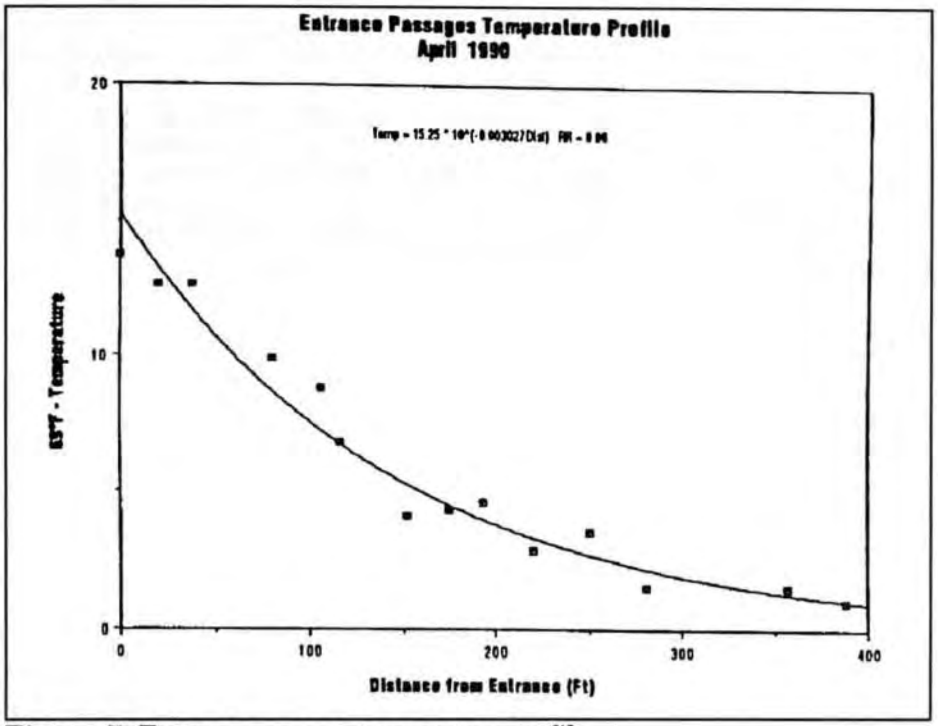

Figure 7. *Entrance passage temperature profile.*

gle number, the relaxation length. It is relatively easy to measure the relaxation length based on a simple temperature profile.

Figure 7 is a temperature profile taken of the entrance passages of Kartchner Caverns. The temperatures were taken in April during a transitional time of the year. The figure shows that temperatures steadily warm from the entrance into the cave. At a distance of 400 feet a stable temperature is being reached.

From this graph we can determine the relaxation length X_0 predicted by Wigley. For this example the relaxation length is 100 feet. This one number describes the distance over which the entrance influences the cave temperature. If changes were made to the entrance we would expect that the value of X_0 would also change. A follow-up temperature profile would show the effect of any modifications. This provides a simple descriptor and means of assessing entrance changes from a simple temperature profile.

The basic equipment needed to make a quick assessment of the microclimate is readily available. A simple but reliable thermometer is needed. A particularly good thermometer for use in caves is manufactured by Taylor, as a 1° digital stem thermometer. The cost is approximately $25. These thermometers have a temperature resolution of 0.1°F and remain stable over long periods of time. A poor choice is the max/min indoor/outdoor thermometer sold by Radio Shack. The chief drawback of this thermometer is a lack of stability which makes it impossible to obtain consistent results. There are also a range of good hand-held thermometers available at costs of $100 to $500. Of these, the best for cave use are thermister thermometers. Avoid using a thermocouple thermometer. Thermocouple thermometers are a universal type of thermometer for measuring a wide range of temperatures. This makes them less suitable for the narrow range encountered in cave studies.

Relative humidity is difficult to measure accurately in most caves. As we have seen, much of what we are interested in occurs at very high relative humidities, 95% and above.

Generally the least suitable instrument for measuring relative humidity is one of the newer, inexpensive hygrometers. Most are accurate only up to 90 to 95% relative humidity and so are useless in the high humidities encountered in caves. These types of sensors are also subject to large amounts of drift over time.

A simple sling psychrometer is suitable for general relative humidity measurements. A number of models are available such as Taylor or Bacharach. The Taylor stem thermometer can also be used to measure relative humidity by using a tubular wick and recording both a wet bulb and dry bulb temperature. It is still difficult to obtain relative humidity measurements with these methods that are accurate enough. Psychrometers with a temperature reading to 0.5°F have an accuracy of only 3% relative humidity. More accurate assessment of long-term relative humidity trends can be made with simple devices such as an evaporation pan or Piche evaporimeter.

The prices of data loggers has now reached the point where suitable inexpensive models are available for $100 to $200. The newest data loggers will operate for six months to one year on a single nine-volt battery. Temperature resolution should be at least 0.5°F and preferably better than 0.1°F. (See Dunlap 1996, this publication.) Unfortunately there are no models available with relative humidity sensors suitable for cave use. If relative humidity is to be measured, a better choice is to construct a wet bulb/dry bulb data-logger probe.

I generally recommend taking soil temperatures rather than air temperatures. In my experience it is very difficult to take air temperatures that are more accurate than ±0.25°F.

It takes over five minutes for most thermometers to come to thermal equilibrium and the presence of a person quickly elevates the local air temperature. Soil temperatures are much quicker to take and less disturbed by the observer.

A brief report of the environmental conditions should be made for each cave. This should include the date and outside weather conditions. Even simple observations made without any sort of instruments can provide useful information. Features of particular significance include entrance size, type, airflow direction, condensation on walls, presence of dry surfaces, and whether cave-adapted organisms are present.

Footprints, Routes, and Trails

Methods for Managing Pathways In the Cave Environment

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Abstract

Much of the damage to cave features is caused by careless foot traffic which tramples delicate features, transports mud, and compacts the sediments. Many of these problems can be minimized by delineating trails or pathways through the cave. The type of delineation used depends upon the anticipated volume of traffic and nature of the cave. Examples are shown of different types of delineation which have been successful in several caves. This includes types of markers, placement, and identification of problem areas.

The use of marked trails should be a carefully-considered management decision. A well-marked and placed trail can aid in protecting fragile cave resources and contribute to a visitor's enjoyment of the cave. Properly placed, a trail will guide visitors through the cave in a manner that will minimize the area disturbed and call attention to features that may have gone unnoticed. Trails also allow for more efficient travel through the cave and reduce the burden of route finding. This increased ease of travel can also mean that there will be less accidental damage caused by weary cavers becoming careless. Good trails discourage indiscriminate wandering and encourage visitors to follow a predetermined pattern of travel.

The notion of marked trails within the cave environment is at odds with many of the reasons that attract us to caves—the alien environment, sense of mystery, and freedom to explore are all compromised and intruded upon by the presence of a trail. We should perhaps regard artificially-marked trails in caves as a necessary evil at best.

It is also not axiomatic that placing a trail will insure greater protection for cave features. A poorly-placed trail may direct visitors into inadvertent damage. A poorly-maintained trail can give the impression that there is little real interest in protecting cave resources. An overly-prominent trail can be counterproductive, creating resentment among the caving community.

If everyone understood all about caves to the fullest extent, a trail would simply be a path through the cave. People would walk over this trail with understanding, care, and appreciation. Everyone would know where to look and how to act and all would know the meaning of what they saw. Unfortunately, there are an increasing number of people who, from the lack of experience, do not know how to understand and protect many of the unique features found in caves. The trail, therefore, should put into practice various methods of stimulating a visitor's interest and pointing out things for him to see.

The degree to which trails should be developed should correspond to the anticipated level of visitation and abilities of the visitor. Every trail should have a purpose. In cases where a larger number of people come as visitors, it is important to carefully plan trails. In some cases this will mean rethinking the placement of trails and the elimination of unneeded trails. Routes which were suitable for small groups of experienced cavers may not be suitable for less experienced groups or larger party sizes. Exploration trails are generally very inefficient and can set a poor foundation for later management trails. Initially all areas are explored as the explorer looks into each nook and cranny, hoping to find additional cave passages. Much of the passage traversed ends up being a dead end or contains little of further interest, but the initial foot path will remain and can encourage others into the same dead ends.

Most caves do not require any form of formalized trail delineation. Generally these are caves that are either too small, have an simple layout, or the number of visitors remains low.

Not all types of caves lend themselves to delineated trails. Stream caves, caves subject to flooding, crawling caves, and very muddy caves are usually not suitable for delineated trails. Caves with delicate features, confusing mazes, or breakdown areas are more suitable.

Trails also have an educational element. One important function is to train visitors how to behave underground. The very presence of a trail indicates that there is a reason for limiting unrestricted wandering. The manner in which various features are emphasized can also call attention to delicate formations or deposits that could be easily destroyed without being seen or appreciated.

On the most basic level there should be a notice at the entrance, in the register, or on a permit that informs visitors that there are marked trails and that they should stay on the trails.

Remember that the function of trail markers may not be familiar to many visitors. It is not always initially obvious whether flagging marks the trail or is meant to protect an area from traffic.

A poorly-maintained trail gives the perception that there is little ongoing commitment to the management of the cave. Plastic flagging can become broken, fall out of position, and accumulate to the point of becoming an eyesore. It is also unlikely that the first attempt at delineating a trail will be completely successful. Some portions of the trail will be subjected to unanticipated damage that will need to be rectified.

Suitable markers would seem to last indefinitely in the cave environment but proper placement will determine if they are useful travel aids or if they become an accumulation of trash. There will always be the need for a certain amount of maintenance when the occasional caver catches a piece of flagging and tears out a section of trail. Individual strips of flagging will also become dislodged and either be hidden from view or fall into a misleading position. It should be the responsibility of each party of visitors to repair trail markers or report damage to the managers. There should be an constant program of trail maintenance and improvement. Ultimately a steady state should be reached where old flagging is removed and replaced with new.

The ideal trail delineator should have an appearance that indicates its function to the most inexperienced visitor but the devices should not intrude into the scene.

Marking methods and devices should have the following qualities: They should be highly visible and contrast with the cave background. They should not degrade in the cave environment and should be made of inert, non-corroding, and non-biodegradable materials. They should be neither brittle nor too small.

Rocks can be used to build cairns or used to delineate the edges of trails. This makes for an aesthetically pleasing trail that is acceptable to almost all visitors. It also can be quite permanent.

String has been the historic choice of novice cavers but it also has a place in delineating trails. Types of synthetic fishing line, nylon cord, and plastic "weed eater" line can be used to mark trails.

Plastic (vinyl) flagging has been widely accepted for marking trails in caves. It has many advantages. It is cheap, about $2 for a 300-foot roll, and very compact to carry. Flagging is also readily available at most hardware stores and construction suppliers. There is an almost limitless range of available colors and patterns and custom printed flagging is also available. Some of the disadvantages of vinyl flagging is that it can be dislodged easily, its function in the cave is not always obvious to beginners, it is glaringly artificial in a natural environment, and it is chewed on by rodents near entrances and by crickets deeper in the cave.

Reflective tape can be used to add additional emphasis to other types of markers. Different colors can be used to indicate different trails or features. Highly visible colors, white and yellow, are frequently used on trail markers. Red reflective tape can be used to indicate caution or end of trail. Other colors, such as blue or green, are less suitable. They reflect less light and so are less visible and all types of reflective tape slowly lose their reflective properties in the cave. Plastic reflectors can also be used instead of tape. These are brighter and do not dull with age. Some come with an adhesive backing which can be used to attach them to signs and plastic stakes. Reflective markers can be very effective when used like highway delineators to mark each side of a trail. Reflective markers can also be one of the most objectionable markers because of their high visibility and unnatural appearance. This is particularly true in areas that are frequently photographed.

Popsicle sticks have been used in the past for survey markers and with reflective tape as trail markers. Unfortunately wood will rapidly rot in the cave leaving an unsightly residue. A better choice is plastic coffee stirrers, short pieces of PVC pipe, or plastic spoons. The round surfaces allow reflective tape to be seen over a wider viewing angle.

PVC plant stakes also make suitable markers. These come in a variety of sizes and can be ordered from plant nursery suppliers with custom printing. Cost is approximately two cents per marker for one- by four-inch size. Reflective tape and a marking pen allow custom markers to be created.

Plastic tent stakes and nylon construction stakes can also be used where the ground is soft or in small breakdown areas.

PVC flags similar to the wire and plastic flags used for marking utilities in construction sites make simple, long-lasting markers. Additional visibility can be gained by a ring of reflective tape around the shaft of the flag.

PVC Pipe of ½-inch diameter can be used as a stake. Short, one-inch-long sections can be wrapped with reflective tape and used as small trail markers.

Types of Flagged Trails

Intermittent route flagging—short strips of flagging, 8 to 12 inches long, are used to mark the route at frequent intervals. The exact location of the route on each side of the flagging and in-between flagging is left to the cavers judgment. From a users perspective this is the least objectionable form of permanent marking.

Intermittent trail flagging—short strips placed on either side of trail at frequent intervals. Two strips of flagging bracket the trail, each caver must determine the way between each set of markers.

Continuous double side flagging—continuous flagging along each side of the trail. This leaves no doubt as to the location of the trail but the amount needed can be aesthetically objectionable.

Elevated Continuous flagging—continuous flagging elevated off the floor forms an obvious trail corridor.

Coded flagging—use of special color or patterns on flagging tape to highlight special features.

Combinations of the above types of marking to emphasize the proper actions. For passages with an obvious route an occasional strip of flagging may be sufficient. In unusually delicate areas continuous flagging and narrow trails highlight the need for additional care.

Written signs can be a significant addition to a trail system but should be used sparingly. Signs are appropriate at the entrance to caves where regulations and general instructions are needed. Otherwise signs should be used only at important or confusing trail junctions or to protect unusual features.

Most signs can be simply made on the spot by writing on short strips of flagging with a waterproof marking pen. Using a different color of flagging, such as white, for all signs helps to attract attention to them.

More obvious and official-looking signs can be made from sheets of rigid PVC plastic. These can be cut with scissors and written on with waterproof marking pen. Paper signs can be laminated in plastic and last surprisingly well.

Frequent Mistakes and Problem Areas

Trails should be marked widely enough to avoid flagging being snagged and pulled out of position. The width should allow areas where two people can pass but not be wide enough to encourage walking two abreast. A frequent mistake is to make trails too narrow. This will only lead to flagging being pulled out of position and require unnecessary additional maintenance. Trails should include rest areas and gathering areas.

Long runs of continuous flagging should be avoided. Where necessary they should be frequently tied off to keep it in position and limit the amount that can be pulled out of position. Care should also be taken to ensure that long runs of flagging follow easy routes of travel. The most important aspect of a trail is the ease of use. Flagging that makes travel slower and more difficult will quickly be ignored by cavers.

Realize that any delicate features within the trail corridor will eventually be destroyed. A decision to route a trail through an area is in reality a decision to allow all features in that corridor to be trampled.

Flagging can be tied to or hung near stalactites in low passages to alert passing cavers, who frequently are concentrating on the floor, to the hazard above.

Steep terrain can be broken by the use of steps or zigzagging the trail. Steps carved into clay banks can be used to create a route that will keep features on the walls from being used as handholds.

The end of a trail should be clearly marked in a manner that indicates that this is the end of acceptable travel. There should also be a large enough area to allow the group to gather and turn around.

Where a passage or route is being eliminated or blocked off with flagging it is helpful to place a message on a piece of flagging explaining the reason for closing the old trail.

Active Trail Markers

A new generation of exceedingly low-power electronic devices has opened up the possibility of constructing active marking systems. The simplest of these is a blinking light emitting diode (LED). These small, solid-state lights can be coupled with an LM3809 flashing chip to make a low-power flashing beacon. Typically a single 1.5 volt AA battery will power the flasher for three to six months, a "D" cell can last up to two years. The parts for this type of flasher are readily available at Radio Shack for a total cost of less than $3.50.

A second approach is to use LED markers that are triggered by a caver's light, remain lit for several minutes, and then turn themselves off when darkness resumes. This would provide additional battery life and the active nature would attract additional attention.

While it is exciting to consider the possible uses such as highlighting emergency supplies or calling attention to a register, these devices may not be suitable for long-term use in a cave. The ability to construct a suitable device that will keep the battery from corroding should be given high priority. Another drawback will be theft of the flashers.

Another use of modern electronics is building inexpensive caver counters. Ian Drummond has published the design of a simple caver counter in the April 1992 issue of Speleonics. More sophisticated (and expensive) counters can be constructed using the "Basic Stamp" computer module. These counters can store the number of times that they were turned on by a caver's light and, with the addition of a clock, the time and date. The small size and low power requirements allow them to be easily hidden and require servicing once or twice a year.

This type of counter can be used to determine patterns of use, determine which caves are the most popular, and to determine if off-limits or closed areas are being honored.

The thought that their actions are under some sort of surveillance is likely to be met with a great deal of resistance by most cavers. Cavers are likely to believe that this is a sign of profound distrust on the part of cave managers.

Summary

The use of delineated trails is useful only for a small category of caves. It is only one of a broad spectrum of management options. Caves with moderately high visitor volume and caves with increasing popularity or delicate features are the ones most likely to benefit from a managed trail system. There is a significant and often-overlooked maintenance requirement for all trail markers.

Users will determine how successful a trail system will be and there will always be cases where it is impossible to modify existing patterns of use. Most cave trips are by unsupervised groups; no amount of trail delineation can force people to remain on the trail but proper design can result in wider acceptance. The use and acceptance of trails is a cooperative effort between cave visitors and resource managers.

In order to be successful, trails should provide a subtle message to guide cavers. What is the best route? Where should one be careful? What features are important?

Ingredients for Successful Wild Cave Tours

As Provided In The Devils Icebox Cave at Rock Bridge Memorial State Park Near Columbia, Missouri

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Abstract

For 15 years, participants have enjoyed wild cave tours led into the Devils Icebox Cave at Rock Bridge Memorial State Park, Columbia, Missouri. The wild cave tours are four to eight hours in duration and explore portions of the sixth longest cave in Missouri. Ingredients to providing successful wild cave tours include: designing and enforcing policies, promotional and post-registration literature, registration procedures, equipment, and training and management of volunteers and employees of co-sponsors. All are essential in efforts to create a high-quality recreational and interpretive experience for participants. What it takes to accomplish these goals effectively and efficiently is shared in this paper. Of particular interest may be recent improvements in volunteer management and leader training.

Introduction

The Missouri Department of Natural Resources manages Rock Bridge Memorial State Park. The park receives about one quarter of a million visits each year. About 180,000 people a year take the self-guiding Devils Icebox Trail. About 7,000 people a year participate in naturalist-led interpretive programs, many of which take people through the natural rock bridge and to the karst window of the sinkhole entrance to the Devils Icebox Cave. But most people stop there and never go any further. However, every year, about 300 to 500 brave souls do go further. They enter the Devils Icebox Cave on wild cave tours.

The Devils Icebox Cave is significant for several reasons. It is the sixth-longest cave in Missouri with over seven miles of passages. These passages contain speleothems such as the 20-foot-high, pure-white Waterfall and colorful curtains and rimstone dams of the Chocolate-Vanilla Room. The cave is very important to about 10,000 gray bats. In the summer months, a maternal colony is actively raising its young in the cave. There are no wild cave tours from April 1 to August 31 in order to protect this endangered species.

Our goals reflect a philosophy that if we give people an experience in which they enjoy and learn about the cave, it will create feelings and thoughts of appreciation that will motivate them to act to protect the cave. Thus, there are three key words that summarize our goals. They are preservation, interpretation, and recreation.

The implementation of the wild cave tour program involves numerous topics such as policies, procedures, equipment, volunteer leaders, safety, protection of the cave, and interpretation. Scott Schulte, Park Superintendent, has guided the development of the wild cave tour program as it has evolved over the last 15 years. Described below is how we currently manage the wild cave tour program. Other methods may be just as successful in different circumstances.

Scheduling and Promotional Literature

We maintain a mailing list of those interested in a wild cave tour. After we schedule trip dates, we publish a brochure which is sent to everyone on the mailing list. We publish one brochure for the fall, September through December, and another brochure for the winter, January through March. Co-sponsors have their own means of advertising, so the brochure lists only the wild cave tours for which a person would register through the park.

One wild cave tour is scheduled on each Saturday and Sunday throughout the seven-month season except for those dates near major holidays or those in conflict with major park events. In addition, some co-sponsors arrange to have wild cave tours on weekdays. About 60 to 70 wild cave tours are scheduled each year.

The demand for wild cave tours is much greater than the supply. People usually sign up right away after receiving the brochure. Most trips are booked up two or three months in advance even though people are only required to sign up at least two weeks in advance.

Devil's Icebox Cave is one of the largest caves in Missouri. In order to protect a maternal colony of gray bats, the Devil's Icebox is closed from April 1 to August 31. Wild Cave Tours are available from September 1 to March 31.

General Wild Cave Tour Information
Going on a Devil's Icebox Wild Cave Tour (WCT) is truly quite an adventure. It takes a great deal of physical energy and is not for everyone. Many people love the challenge and find it to be a memorable learning and recreational experience.

A pre-trip orientation at the park office is the first part of a WCT and takes about 30-45 minutes. During the orientation you will meet your leader and be issued caving equipment. The park will provide caving equipment, but participants must have appropriate clothing and footgear. You will then drive to the Devil's Icebox parking lot. From the parking lot we carry the cave canoes about 1/4 mile to the cave entrance.

Once underground we spend three to eight hours exploring a portion of the Devil's Icebox cave. The first half mile of the Devil's Icebox is a water passage, interrupted by several portages. In the water passage, we will be alternately paddling and portaging canoes. Lunch is carried in and eaten during a break in the exploration. The majority of the WCT will be spent walking through spacious passages involving slippery mud, steep banks, rocky surfaces and wading across streams. Some areas require stooping, crawling, crawling in water, climbing and very small passages. There is a great variety in the type of WCT you can experience. The WCTs take different routes within the Devil's Icebox and vary in their difficulty and duration. These variations are explained under "Explanation of Codes on Schedule."

After leaving the cave, boats are carried to the parking lot, and everyone returns to the shop where all park equipment is cleaned by the trip participants. This usually takes about an hour. Once the park equipment is cleaned and stored, you are free to clean yourselves and change into something dry and clean. The entire WCT experience takes from 6 to 12 hours. Please schedule accordingly.

Fees / Age Restrictions / Other Considerations
The fee for WCT trips is $25 per person. In addition, we require an equipment damage deposit of $20 per person. Fees are payable in advance (see registration information). Damage deposits are payable in CASH the day of the trip and, if all equipment is returned in good condition, will be returned after the trip.

WCTs are designed to be ADULT experiences. Participants must be at least 14 years old, unless otherwise specified. Participants under age 18 are required to have a parental consent form signed by their parents/guardian. A photo ID may be required to establish age. All participants will be required to sign a "Release–Covenant Not to Sue" agreement, acknowledging the potential hazards in a WCT.

Each WCT will consist of a minimum of six and a maximum of ten participants.

We will cancel WCTs for the following four reasons:

1. Threat of flooding
2. Cold weather (less than 30° forecast for exit time)
3. Too few participants (less than six)
4. Leader unavailability (illness, etc.)

No Make-Up trips. Trip fees will be refunded if WE cancel a WCT.

Registration Procedures
You MUST make a reservation by visiting the park office or by calling (314) 449-7402 AT LEAST TWO (2) WEEKS PRIOR to the date of the trip. Individual registration only. You can only register yourself and one other (exception–spouse & children in same household). After making your reservation, you MUST confirm your reservation by paying the trip fee within SEVEN DAYS of making the reservation. Once the reservation is confirmed with the receipt of the trip fee, we will send a confirmation packet with complete information regarding preparation for your trip.

Make check payable to Rock Bridge Memorial State Park and send trip fee to:

Wild Cave Tour Reservation
Rock Bridge Memorial State Park
5901 S. Hwy 163
Columbia, MO 65203

NOTE: POLICIES AND FEES ARE SUBJECT TO CHANGE WITHOUT NOTICE.

Experienced Caver Trips
Experienced cavers MAY qualify for a self-led trip into the Devil's Icebox. Groups must have their own equipment including helmets and three sources of non-carbide light. The park will furnish boats and life jackets and a park-certified caver to protect the cave and to provide information as requested. The fee for these trips is $15.00 per person. **Reservations must be made at least two months in advance of expected trip date.** In order to qualify as an experienced caver group at least half of the people going into the cave MUST be NSS members for at least three years. All members of the group also MUST be at least 18 years and MUST be in good standing with the Missouri Division of State Parks. Failure to comply with park or division caving policies may jeopardize the status for a Caver Trip. When registering for an Experienced Caver Trip, each caver's name must be submitted along with the $15.00 fee. No substitutions will be allowed. Contact the Park Superintendent for further information.

Explanation of Codes on Schedule

These codes explain the difficulty level, duration of trip, previous experience requirements and other information.

A	Designed for first time trips. Three to four hours underground. Stay in main passage. No crawling. Combined with an above ground hike of sinkholes.
B	Moderate level but challenging for beginning cavers. Four to six hours underground. Variety of destinations. Information for all "B" trips will provide the core elements of several subjects about caves such as geology, hydrology, speleothems, stream life and bats.
C	Strenuous trips–six to eight hours underground. Fast walking. Plus much of trip involves stooping, climbing and crawling, often in water. Requires one previous WCT or prior wild caving experience and being in good physical condition. Each trip will emphasize one particular subject.
D	Arduous. Stamina a must. Special preparation and extra supplies required. Requires one previous WCT of C level or be a NSS member with a membership number lower than 36,000 and have comparable caving experience.

Figure 1. *The inside panels of the winter 1996 brochure for the wild cave trips.*

Difficulty Levels

Most participants are novices and this is their first experience in a wild cave. A variety of difficulty levels of wild cave tours are offered. Most wild cave tours are B level trips which take four to six hours underground. C level trips take from six to eight hours underground and involve more difficult areas of the cave. To go on a C level trip, it is required that participants have already gone on a B trip or that they have prior wild caving experience and be in good physical condition. Only three to four hours are necessary for an A level tour, which stays in walking passage. D level trips are arduous and require special preparations in addition to either prior participation on a C level tour or be a NSS member with a membership number lower than 36000 with comparable caving experience. D level trips often qualify as DI-50 wild cave tours. Those who participate in a DI-50 wild cave tour, receive certificates indicating that they are among the first 50 people to visit that particular place.

Permit Trips and Caver Groups

We no longer authorize permit trips where cavers explore on their own. Some problems were experienced with damage to the cave and poorly prepared cavers. Our current policy for caver groups allows them to go on a cave trip, but requires that one of our wild-cave-tour leaders accompany them. The leader allows them to go wherever they would like in the cave while seeing that the cave is protected. They must contact us at least two months in advance with their request and possible trip dates. Then we contact our leaders to try to find one available on one of the possible trip dates. All members of the caver group must be at least 18 years old and half of the group must be NSS members with membership numbers lower than 38000. Since implementing this policy in the fall of 1993, only a few caver groups have requested trips.

Fees and Equipment

The cost for caver groups is $15 per person. For this fee, they receive a guide and use of boats and personal flotation devices. They must supply their own non-carbide lighting system and other caving gear.

The cost for those participating in regular wild cave tours is $25 per person. In this case, participants are also supplied with a head lamp, two batteries, helmet and pack (if they don't have their own).

Wild cave tours for co-sponsors who provide a leader are charged $15 per person. The park provides all equipment for participants on these tours.

Group Size

On regular wild cave tours, the group size is limited to 10 participants. We found 12 to be too large due to the accordion effect as the group gets strung out in the cave and then comes back together again. However, sometimes an assistant leader (often in-training) or two may go in addition to the 10 participants. Wild cave tours may be canceled if there is not a minimum of six participants.

Registration and Policies

Our registration list is computerized in an Info Select program. For each wild cave tour date, a computer page with ten spaces is made up ahead of time. Individuals may call and register themselves and one other person or members of their families. We do not allow someone to reserve several spaces. In the past when this was allowed, problems were encountered with members of the group not being well informed or some members not showing up due to lack of interest. Group leaders did not prove to be reliable. Therefore, we get each person's address and mail the Post-Registration packet of information directly to them.

Once registered, a person has exactly seven days to get the fee in to us. Once payment is received, the reservation is secured. However, if the fee is not received within seven days and someone calls and requests that space, the first caller loses the space and it is given to the second caller.

It would be a difficult task to keep a waiting list and manage it fairly, so we do not keep one. When people call and find the wild cave tour dates they were interested in are booked up, we suggest that they call back to see if openings are created due to non-payment.

We do not allow another person to substitute for a registered person. The main reason is because of the time it takes for us to get post-registration information out and for people to make adequate preparations. These are important measures for having a safe wild cave tour.

Enforcement of Policies and Staff Time

Occasionally, someone complains about the no-substitutions policy, especially if the proposed substitute already has the post-registration information and what they think are adequate preparations. We've tried to think of alternative policies, but all our ideas are problematic. One alternative that we considered would require additional staff time to ensure that substitutes are adequately prepared. Sometimes, we are challenged to justify why we spend a large amount of time on wild cave tours when they meet the needs of a very small percentage of park visitors. Our other duties would suffer if we did not try to avoid creating policies that would increase the time commitment of staff members. To date, we have not found an acceptable alternative to the no-substitutions policy. We have found it necessary to be firm on our policies. In years past, when exceptions were allowed, we found ourselves dealing with numerous requests. When it occurs often, it is too time consuming to discuss the request with the person on the phone, to confer with other staff members, make a decision, and make a return call.

We've had to discipline ourselves to say "no." One advantage of a no-exceptions policy is that you can at least say that it's fair. We recognized that it was more difficult to maintain a no-exceptions policy when it might be one of several employees who handle the requests. It has been easier since we have told employees and volunteers to pass policy exception requests on to one of two designated employees. Those two deal with the wild cave tour program policies regularly. This strategy has made the park more efficient and has provided consistent responses to the public.

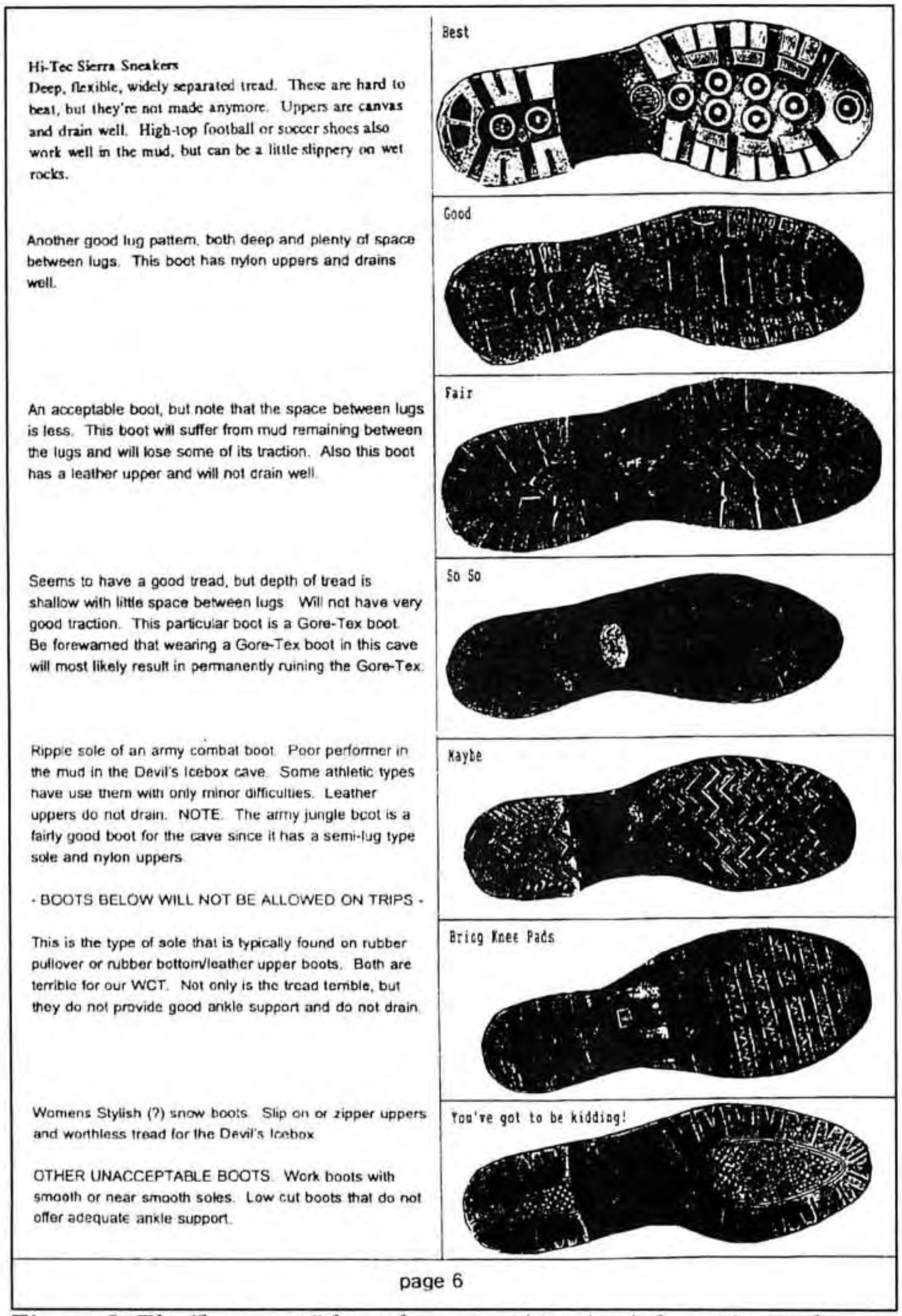
Staff efficiency has also been increased by answering inquiries by giving the person a piece of literature instead of giving an explanation several minutes long. We created a wild cave tour brochure and post-registration information packet to fill this need.

Post-Registration Information

After a person has registered and paid the fee, the applicant is given a packet of post-registration information. It has everything a person needs to know about preparing for a wild cave tour. It includes a reminder of the date and time, a map showing the meeting location, what the park will provide, what the participant must provide, additional recommendations, criteria for canceling the wild cave tour and refunding fees, and illustrations of appropriate footwear.

Participants are admonished that they must provide appropriate footwear and clothing. Wild cave tour leaders are told to refuse participation to anyone who shows up without them. Without them, participants could endanger themselves and members of the group or, at the least, could slow down the progress of the group. The packet describes and illustrates that appropriate footwear should have good traction, good ankle support, and good water drainage.

Due to cool temperatures and wet conditions, clothing recommendations include fabrics such as polypropylene, wool, and polyester. Cotton garments are discouraged.



Best

Hi-Tec Sierra Sneakers
Deep, flexible, widely separated tread. These are hard to beat, but they're not made anymore. Uppers are canvas and drain well. High-top football or soccer shoes also work well in the mud, but can be a little slippery on wet rocks.

Good

Another good lug pattern, both deep and plenty of space between lugs. This boot has nylon uppers and drains well.

Fair

An acceptable boot, but note that the space between lugs is less. This boot will suffer from mud remaining between the lugs and will lose some of its traction. Also this boot has a leather upper and will not drain well.

So So

Seems to have a good tread, but depth of tread is shallow with little space between lugs. Will not have very good traction. This particular boot is a Gore-Tex boot. Be forewarned that wearing a Gore-Tex boot in this cave will most likely result in permanently ruining the Gore-Tex.

Maybe

Ripple sole of an army combat boot. Poor performer in the mud in the Devil's Icebox cave. Some athletic types have use them with only minor difficulties. Leather uppers do not drain. NOTE: The army jungle boot is a fairly good boot for the cave since it has a semi-lug type sole and nylon uppers.

- BOOTS BELOW WILL NOT BE ALLOWED ON TRIPS -

Bring Knee Pads

This is the type of sole that is typically found on rubber pullover or rubber bottom/leather upper boots. Both are terrible for our WCT. Not only is the tread terrible, but they do not provide good ankle support and do not drain.

You've got to be kidding!

Womens Stylish (?) snow boots. Slip on or zipper uppers and worthless tread for the Devil's Icebox.

OTHER UNACCEPTABLE BOOTS: Work boots with smooth or near smooth soles. Low cut boots that do not offer adequate ankle support.

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Figure 2. *The "boot page" from the post-registration information package.*

Participants are asked to bring a lunch, drink, and pack and are told to leave tobacco products, alcohol, and glass containers at home. Plastic bags are recommended in the event of needing to carry out solid human waste.

Conditions Under Which Fees Will be Refunded

Fees will be refunded if the participant cancels at least two weeks prior to the wild cave tour date or if the park cancels the wild cave tour. Fees will not be refunded if the participant does not have proper footwear, proper clothing, suitable proof of age, and the signed release form. Also, fees will not be refunded if the tour is terminated early for any reason, including inappropriate conduct by members of the group.

Age

The packet informs participants that they must provide a proof of age with an identification card having a photo and date of birth. Only rarely do we feel the need to check for identification.

We have established a minimum age requirement of 14 years. For a number of years there was no age restriction except that those under 16 years of age were required to be accompanied by a parent or legal guardian. More often than not, parents came reluctantly and had more problems than the kids. It was decided that the nature of wild cave tours is not appropriate for young children. Teenagers, on the other hand, are usually mature enough to handle the experience. By setting a minimum age requirement of 14 years, we felt comfortable dropping the requirement that a parent accompany the child. In the two years that this policy has been in effect, it has worked well.

Release and Covenant Not to Sue

A guardian release form is used for those under 18 years of age. Those 18 years or older sign a release and covenant not to sue form. A copy of the release form or guardian release form is given to participants along with the post-registration packet. Participants are asked to bring the form with them on the day of the wild cave tour. If they forget it, they can fill out a new form when they arrive. Our fax machine has been used on a few occasions to obtain the signatures of guardians who were not present. Those without a properly signed release form will not be allowed to participate on wild cave tours. While many release forms are available as samples, no one should use similar language without seeking the advice of an attorney. Thus far, no one has sued, so our form has not been tested in court.

Cancellation of Wild Cave Tours

A wild cave tour may be canceled for one of several reasons. The wild cave tour will be canceled if fewer than six people register. This is the rate at which we think we can justify the use of our time and resources. While it rarely happens, we withhold the right to cancel for reasons beyond our control such as illness of the leader or equipment problems.

Usually the reasons for canceling wild cave tours are due to the weather. One staff member is given the primary responsibility of making cancellation decisions, but others may make those decisions as well, depending upon work schedules. Wild cave tours are canceled if the forecasted temperature at the time of exiting the cave is below 30°F. Cold temperatures pose a danger because of the quarter of a mile walk to the parking lot and the need to clean equipment outdoors. Due to the danger of a passage becoming flooded, wild cave tours are also canceled if the current water level in the cave is too high for safe passage or if the weather forecast calls for a good chance of rain. A general guideline is to cancel is there is a 40% or greater chance of rain or any chance of thunderstorms. It's not that clear cut. Several factors and their combined effects must all be considered. These factors are: current water level, soil moisture, amount of precipitation expected, timing of precipitation, time it takes water to enter and travel through the cave, and destination of the group in the cave. Time and again, we gain renewed understanding of the cave's hydrology by observing these factors and their interaction.

When people register, we ask for the phone number where they can be reached on the day before the wild cave tour. We use these numbers if it is necessary to notify people of wild cave tour cancellations. We usually make the decision the day before because the weather forecasts become more reliable the closer it is to the day in question, yet this is enough notice that people can make other plans. Rarely, we will wait as late as the morning of the tour to decide. In this case, the likelihood of being able to hold the trip is high enough to offset the possible inconvenience of people arriving and then still not being able to go on a tour.

The percentage of wild cave tours canceled ranges from about 5% in dry and lucky years to 40% in wet and unlucky years with about 25% being the norm. It takes some time to check the water level and the weather forecasts for each wild cave tour and to call participants when the decision is to cancel.

The Low Spot and Water Passage

The location of concern about high water in the cave is the infamous "Low Spot" which has about 2.5 feet of air space between the water and the ceiling during normal flow. Should it rain while participants are in the cave, they may have to stay in the main passage until the water level drops in order to exit safely. The Low Spot is near the sole entrance to the cave. Boats are used in this area which is part of the half-mile "Water Passage." Thus, it is necessary for participants to lie down in the boat to squeeze through the Low Spot. Participants find it challenging but bearable since it continues for only 15 feet.

The water flow is calm and the depth varies, with the deepest measurement to date being nine feet. The Water Passage has many sharp turns to negotiate due to solution joints in the rock. Most of it has ample air space. Many participants find the water passage to be a unique, relaxing, and awe-inspiring experience. Three portages make it plenty of work, too.

Boats

Down-sized plastic boats have served well. We remove the seats that come with them and replace them with wooden seats. A wooden yoke is also attached to the center of the boat. The boats must be carried a quarter of a mile from the parking lot to the cave entrance and back when the trip is over. We recommend that one of the pair of participants carry the boat on his/her shoulders using the yoke. Personal flotation devices help to cushion the load. Each boat weighs about 50 pounds. The tips are cut off to allow water to be drained out by standing the boat on end. Often, water accumulates due to getting in and out at the portages. It's not uncommon for a pair of participants to swamp their boat. We also have longer ABS (plastic) and aluminum boats which are sometimes used, especially if there is an odd number of participants or if a boat is needed that can handle a greater weight.

Leaders use a one-person ABS boat so they can to respond quickly to anyone in need should there be an emergency. Also, it is a perk of being a leader since leader boats weigh only about 30 pounds.

Other Equipment

Leaders are encouraged to have their own lighting equipment because it increases the participants' impression of the leader's interest and expertise level. However, most use what the park provides.

The park purchases Panasonic brand batteries from Stark Electronics, Inc, 401 Royalston Ave N, Minneapolis, MN 55405, telephone (800) 334-6154. Our cost has been $8.75 each. These batteries are rechargeable lead-acid batteries that last six to eight hours on one charge. It does not hurt them to be immersed. Each battery measures 4.5 by 2.5 by 1.25 inches. We customize the batteries with connector cables that we purchase from the Nite Lite company. These connectors are a heavy-duty version of the automobile light connectors that can be purchased from any hardware store. We've experimented with different lengths and arrangements of connector cords to prevent two batteries from being plugged together. This can cause a short circuit which usually ruins both batteries.

It takes several hours a month of staff time to make repairs to the batteries and head lamps. We use "The Head" lamp sold by Nite Lite Co, PO Box 8210, Little Rock, Arkansas 72221, telephone (501) 227-9050. They cost $32.95 each. It has a bracket for attaching to a helmet. We have obtained a basic construction type helmet for $12 each from Summit Rescue Group, Richard Crabb, telephone (816) 231-8015. Local construction supply stores have been comparable. We cut off the bills for better visibility. Summit also supplies chin straps ($3.30 each), brackets, and leather snaps for holding cords.

The packs we provide were obtained from a federal surplus property store which is available to us since we are a state agency. The public can purchase from surplus property when they hold auctions. We customized the packs with wiring and find that once people learn how to put them on, they work well.

Participants are required to leave a $20 cash damage deposit with us on the morning of the wild cave tour. If all equipment is returned in usable condition, the deposit is returned. Only rarely have we needed to keep a deposit. One recent occasion when we did, was when a participant lost the batteries in the water passage and did not report it until later.

To help keep track of the equipment, each piece is numbered and is stored in designated areas. Batteries and head lamps are kept in bins on a shelf where it is readily apparent when any are missing. Also, it's handy for handing out equipment since each bin holds the proper amount for two participants. Electrical outlet strips make it possible to have chargers in each bin. Periodically, all equipment is inventoried and recorded in a notebook.

The Wild Cave Tour Experience

Having a reliable electrical lighting system allows participants to focus their attention on enjoying the cave. But before getting into the cave, participants need to learn how to use the equipment properly. This instruction is given by the leader as part of the orientation given at the park office. A good orientation is important for preparing participants both physically and mentally for what lies ahead. It takes about 1.5 hours for the orientation and carrying boats and gear to the cave entrance. It takes about three quarters of an hour to paddle through the water passage.

Beyond the Water Passage, boats are parked and the group continues on foot through spacious walking passage. Numerous side passages provide opportunities for climbing or crawling. Most wild cave tours go to at least one well-decorated area such as the Chocolate-Vanilla Room, Waterfall, and Dripstone Cascade. In addition to these, the cave has numerous, smaller, unnamed speleothems of interest. The Devils Icebox Cave is known more for its long and spacious passages than for spectacular speleothems.

Participants get to see 1.5 to 2 miles of wild cave which has been well protected. This cave has more animal life than many. little brown, Eastern pipistrelle and big brown bats hibernate in the Devils Icebox. The number of hibernating bats has been estimated to be 2,000. While the vast majority of the Gray bats (9,000) hibernate elsewhere, a few hundred remain through the winter. Also common are aquatic invertebrates such as isopods and amphipods. Some insects exist in small numbers. Troglobitic species are the pink planarian, *Kenkia glandulosa*, and monorail worm, larval stage of the fungus gnat, *Macrocera nobilis*. Participants almost always get to see bats, invertebrates, crayfish, and Pickerel frogs. Occasionally, participants will see a troglobitic species or one or more salamanders (species include slimy, dark-sided, small-mouth, and cave). Because of the many sinkholes-dome combinations, surface species often find their way into the cave. Some of those seen include: creek chub, bluegill, northern spring peeper, prairie kingsnake, rat (found skeleton) and racoons (have seen tracks and scat).

The wild cave tour leader stops the group occasionally and shares information about points of interest whether it be animals, speleothems, geologic features, or hydrologic features. The cave's many domes are wonderful tools for educating people about the intimate relationship that exists between the land and cave via water flow. There are a multitude of opportunities to see exposures of crinoid fossils in the Burlington Limestone and to talk about how caves form. There are two major breakdown rooms. Layers of chert in the limestone have formed impressive chert bridges in certain areas of the cave.

Participants get a workout walking up and down slippery mud embankments along the cave stream. They also get wet up to at least thigh deep while frequently wading across the stream. Participants walk a total of about two miles in the cave with a break for lunch. How much difficulty participants have depends upon their physical abilities and the quality of their boots. However, even those in good condition and with good boots find the wild cave tour to be strenuous. The majority of wild cave tours are B level tours which keep participants in the cave for about five hours. Some participants are getting pretty tired on the way out. For those who still want more, we usually offer the option of exploring a more-challenging side passage such as the Cloaca, Devils Roost, or Rollercoaster, all aptly named. Most really enjoy the chance to simply have some fun getting wet and muddy while taking on physical challenges. It's almost like being a kid again. It seems to be therapeutic. By the time participants exit the Water Passage, carry boats the quarter of a mile back to the parking lot, and help clean the gear, most are exhausted but happy.

When the wild cave tour is over, desire runs high for restrooms, food, and hot showers. Before leaving to seek the food and hot showers, participants usually give heartfelt thanks to the leader and hand shakes of friendship to fellow participants.

Leaders and Co-Sponsors

A great deal of the success of the wild cave tour depends upon the leader. Currently, our leaders consist of four staff members, five co-sponsoring agency employees, and eight volunteers for a total of 17. Currently, an additional five volunteers are in training. When wild cave tours were first offered at the park, it was feasible because of the help of a co-sponsor—Columbia Area Adult Education. They already had the infrastructure to hire a leader, advertise wild cave tours, take registrations, and provide meeting space for a pre-trip meeting. In years since, several other co-sponsors were added despite the fact that the park became fully capable of conducting wild cave tours independently. Currently, we are not taking additional co-sponsors because co-sponsors were requesting too many of the available trip dates. That is undesirable because co-sponsors cater to a limited clientele. Our co-sponsors are: Hannibal High School, Johnson County Parks and Recreation, University of Nebraska at Lincoln, Columbia Parks and Recreation, and Columbia College. Co-sponsors handle advertising, registration, transportation, and provide a leader who has completed our training. That means less work for park staff. Usually, co-sponsors' employees are very responsible and motivated leaders who continue for several years.

Past Leader Training

It seems that most of our leaders are motivated primarily by their personal enjoyment of the cave. To be successful, leaders must also have an interest in and ability to be in a leadership role and be an interpreter. These abilities can be nurtured through training.

Until two years ago, training consisted of arranging for individuals to go on several wild cave tours to learn from observation how to lead the group and how to find their way in the cave. When the people felt ready, they led wild cave tours with Scott Schulte or me along acting as a back-up leader and evaluating their abilities. Also, there was a one-day training each September at the beginning of the season. On the training day leaders were given an update on any new information or methods and they went as a group into the cave. To provide added incentive to attend, the cave trip usually took leaders to an area which was rarely visited.

Scott observed that one shortcoming some wild cave tour leaders had was not knowing how to answer questions about other aspects of the park. This observation coincided with a desire to develop a stronger volunteer program for the park as a whole. As a result, new volunteer policies and plans were developed about two years ago. In the past, staff members tried to work with volunteers whenever they would express interest. They found themselves pulling away from work duties to guide the volunteers and then getting busy and neglecting to provide the volunteers all that they needed to be successful.

Present Volunteer Program

Currently, when someone expresses interest in volunteering, we inform them of the next opportunity to begin training and explain what's required. We established three levels of volunteering. Park Stewards are those who wish to volunteer for a one-time project or on a short-term basis. Park Specialists are those with an area of expertise who volunteer on a limited basis. Park Aides are those who wish to volunteer on a long-term basis and who can commit to volunteering at least 50 hours a year. Park Aides are required to complete extensive training.

Park Aide training is offered twice a year when we take a class of new volunteers. We actively recruit at that time by placing advertisements in local newspapers and by creating flyers. By taking a group at one time rather than individuals at various times, we ensure that we give the new volunteers adequate attention and make doing so more efficient for staff members.

Before volunteers are allowed to work in the office, conduct historic research, or help with special events, they must complete Park Aide training. Some activities require training above and beyond Park Aide training. These include presenting naturalist programs, leading a fire crew involved in controlled burns, serving on our Trail Patrol, or becoming a wild cave tour leader. Once volunteers have completed Park Aide training, they can choose to obtain additional training in one of these specialty areas. Patches are awarded for each level obtained. Thus, volunteers interested in becoming wild cave tour leaders are required to complete Park Aide training and wild cave tour leader training.

Park Aide training involves about 30 hours of training on topics such as park rules, policies and procedures, agency information, map reading, park familiarity, and information on the park's natural and cultural features. Requiring wild cave tour leaders to go through Park Aide training should ensure that they are well-rounded and able to represent what the park as a whole is all about.

Training for Wild Cave Tour Leader

Once Park Aide training is completed, further training is provided for Wild Cave Tour Leaders in Training. Further training is in two broad categories of interpretation and leadership.

Interpretation training involves the following. As part of their Park Aide training, volunteers learned about the geology, hydrology, and biology of the Devils Icebox Cave. Leaders in Training are given more information about these topics and are asked to do research on their own to learn more. Leaders in Training are given a good example of an interpretive wild cave tour while in the cave with me, the park's naturalist. On the other hand, we want leaders to develop a unique interpretive program that matches their personal interests and abilities. Leaders in Training are required to attend a one-day training provided for Park Aides interested in the Naturalist specialty. Naturalist training defines interpretation and describes how to accomplish it. It also gives them the practice of developing and presenting their own programs.

Leadership training involves instruction on safety, cave protection, group dynamics, care of equipment, and group management. A wild cave tour Leader Manual was written in September 1995 which explains in detail how the park expects leaders to care for equipment, handle an injury, and the like. It has been helpful to have this information down in black and white. It makes the instructions seem more official and, of course, provides a handy reference to augment the leader's memory. The manual includes a cave map and note cards to follow when leading wild cave tours.

Leaders in Training are led on cave trips designed to make them more familiar with parts of the cave. Previous Leaders in Training have told us that they learned to find their way in the cave best when they were in front leading the group, so on these wild cave tours, the Leaders in Training take turns navigating in the cave.

Leaders in Training obtain training in both interpretation and leadership by serving as assistant leaders on regular wild cave tours. In this situation, they can observe the interaction of leader and participants. Usually, the leader allows the assistant leader to navigate for the group which gives them further practice at finding their way in the cave. It takes several trips before most feel confident that they will not get lost.

As in the past, when individuals feel ready, they will be scheduled to lead wild cave tours. Scott or I will accompany the leaders to evaluate their performance and to serve as a back-up leader if necessary. If they do a satisfactory job of leading their first wild cave tour, and if they pass a written test over the wild cave tour Leader Manual, then they officially become wild cave tour leaders. A certificate is awarded to each one at the monthly Park Aide meeting.

To remain in good standing, wild cave tour leaders must commit to lead at least five wild cave tours per caving season and attend the September refresher training at least every other year. The service of wild cave tour leaders can be ended if inappropriate behavior occurs several times.

Volunteer wild cave tour leaders who began service prior to 1995, are being "grandfathered" until January 1, 1997, at which time they must be in compliance with the current volunteer policy. They can become in compliance by either completing Park Aide training or passing the Park Aide final exam.

September Refresher Training

We tried something new and different with our September refresher training in 1995. It was akin to a "road rally" or "scavenger hunt" without really being either. We were very pleased with the results. Leaders enjoyed the challenge and learned something and it demonstrated their abilities to us.

We asked leaders to travel through the cave alone, find locations, write answers to laminated questions posted at those locations, and manage their time well. This tested their self-sufficiency in the cave. A crisis could require a leader to be alone in the cave. It tested their ability to find their way in the cave including points of interest which are difficult to find. By answering the questions, they demonstrated to us how they interpret different subjects. For example, one question asked was, "How would you describe the role crinoids played in how this cave was formed?" The question was posted at a location with particularly well-displayed fossils which the leader may want to remember in order to show them to participants on future wild cave tours. Other questions such as, "What do you do when a participant is injured and cannot exit the cave without help?" serve to mentally prepare them for that possibility. It was a good opportunity for a leader to evaluate the time it takes to travel from one point to another in the cave. This may be helpful in managing future wild cave tours.

After the cave trip, we discussed the best responses to the questions and situations given. This was a competitive event with prizes going to those who scored highest on a combination of locations found, answers to questions, time management, and cleanliness of notebooks. Since two forks of the cave were used to spread everyone out, we thought it only fair to give two prizes.

To mitigate concerns about safety, several staff members were stationed in different sections of cave to be available should anyone have problems. Also, each staff member had a copy of the routes given to each leader so we would know about where each person should be at any given time. This would help in case we needed to do a search and rescue. We placed "stop" signs ahead of time to prevent leaders from going farther than planned in any of the passages. We did not have any safety mishaps even though a couple of leaders had some difficulty finding their way.

We had a second motive in placing staff members throughout the cave. Staff members were charged with recording the time that leaders arrived at the locations. Staff records were used in evaluating scores for time management. One staff member asked leaders to fix a broken head lamp at one location.

It was a complicated task to figure out the timing and routes so each leader would remain alone at all times. We wanted each of them to find the same ten location points sometime during the cave trip. We wanted to avoid very much backtracking so that everyone would get done and be ready to exit the Water Passage at the same time. Figuring out routes and timing will be easier in future years now that we have some experience with it. It was also necessary to make up and laminate the questions and signs and to make a special cave trip to place them.

This new way of conducting September Refresher Training takes more preparation, but was well worth it. We intend to do September Refresher Training this way again next year. The way leaders handled themselves, found their locations, and answered questions assured us that our confidence in them is well founded. The leaders enjoyed the challenge and competition. The response from leaders was very favorable. They especially thought the "going solo" experience was neat. Some learned the importance of having a second light source handy for those moments of darkness while switching batteries or bulbs.

However training is accomplished, it must result in leaders being successful at protecting the safety of participants, protecting cave resources, interpreting the cave to participants, and providing a fun and challenging experience. These are the main goals leaders need to keep in mind. The park has provided the framework, but it is up to leaders to make it happen—to paint the canvas.

Safety of Participants

The Leader Manual indicates what leaders should do to protect the safety of participants. There are two large sections that go into detail about how to deal with an injury and with waiting in the cave in the event that the water level prevents exiting. Several canisters of survival and first aid supplies are kept in the cave to be used if needed. Each leader also carries a small first aid kit.

Leaders are expected to give participants instructions on how to deal with the Low Spot and traveling safely in the cave. To guard against the danger of drowning, leaders must ensure that all participants are wearing a personal flotation device and that boats stay close together in the Water Passage. Two people on a permit trip in the early 1970s died by drowning in the Water Passage. Other locations in the cave can pose a drowning danger as well. Leaders must learn where to cross at "The Wade" to avoid areas that are over one's head.

Leaders are instructed in ways to prevent injury including evaluating clothing and boots during the orientation. Hypothermia or injury are potential results if participants are allowed to enter the cave without appropriate clothing and footwear.

Also during the orientation, the leader should explain the nature of the cave and the dangers involved. The release form should be read aloud.

Testimony showing that participants were fully informed of the risks may prove to be important in a court of law.

We hope that discussing the risks will encourage those who are not up to it to decide not to go. Discussing the risks should also cultivate caution in those who decide to continue. There have been a few occasions at orientation meetings when people have decided not to go based upon information about the dangers involved.

The leader should check each form for any information on medical conditions and ask any pertinent questions.

In the cave, leaders many need to warn participants to evaluate their abilities and make the safe decision. This may be the case with an optional side passage which has a tight area.

Protecting the Cave

If someone did get stuck in a tight passage, the situation may require sacrificing cave resources to save the person. Thus, protecting the safety of participants may serve to protect the cave as well. Each of our goals are interrelated. One part of our mission as a state park is to preserve the natural resources of the park, so we are very concerned about minimizing the effect wild cave tours have on the cave resources.

We plan the destinations for wild cave tours in an effort to prevent one area from being over used. Leaders have the discretion to add to the trip as long as they do not add a major point of interest. Some sensitive areas are identified to be explored only with prior approval.

While traveling through the cave, leaders are encouraged to stay on well-worn paths and to ask participants to follow in single file. Leaders give specific instructions when necessary such as "Watch the floor formations" or "Keep a distance of about three feet from this formation." At the beginning of walking passage, leaders point out to participants how various parts of their bodies, helmet, pack, and so on. can easily harm or break off soda straws and other speleothems.

Leaders explain how participants can unwittingly harm cave animals and what to do to avoid harming them. For example, when observing a bat, participants are instructed to not touch, keep voices low, direct lights off to the side, and stay only briefly.

Because of the large impact just a few crumbs can have on the cave ecosystem, participants are careful to avoid leaving crumbs while eating lunch.

Interpretation is truly a valuable tool in controlling behavior and in preventing management

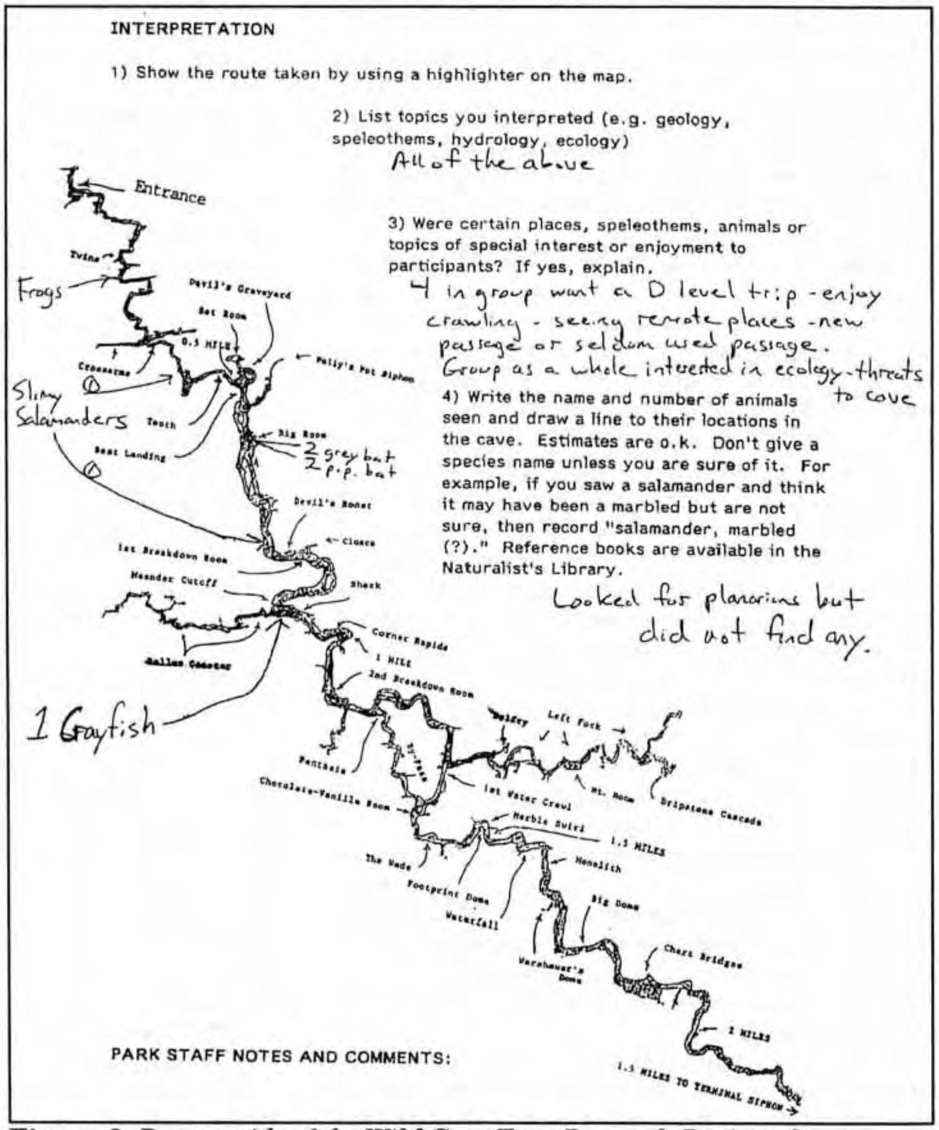

Figure 3. *Reverse side of the Wild Cave Tour Report & Register form.*

problems. However, if interpretation is not successful and a participant repeatedly and willingly acts to harm cave resources, the wild cave tour will be terminated.

The wild cave tours are also a tool for gaining data about the animals in the cave because leaders fill out Tour Report & Register forms on each trip.

Conclusion

Several ingredients are essential to producing successful wild cave tours. Nothing can replace the value of years of trial and error in coming up with what works best for the given situation. It's a matter of fitting your resources and abilities to the needs of your clientele. Once the basics are in place such as equipment, policies, literature, and procedures, then there remains the constant need to enforce policies and cultivate leaders. We have found that good leadership can be obtained from volunteers and co-sponsors as well as from staff members. Staff members should be generous in investing in training for leaders. Numerous comments from participants have confirmed that good leadership is very important in the success of a wild cave tour.

When all of the ingredients of the wild cave tour are mixed together properly, the results are satisfied participants and goals accomplished. The best way to know if you are being successful with any program is to ask participants for their comments. Below are a few of them:

"The cave was fantastic. The guides were knowledgeable, patient, and friendly. The cave was perfect, I loved the fact that it was not altered from its natural state. Please keep everything as is. Thanks very much, you have a great program here."

"The entire expedition was great. I enjoyed seeing the pink planarians, crayfish, and bats—they were great. [Our leader] explained the biology well. I liked sliding through the water crawlway a lot too. The geology was very interesting and spectacular in its variety."

"The trip was very adventurous. The combination of canoeing and climbing made the trip exciting. The trip was also very educational. It has allowed me to appreciate and respect the underground system."

"Thanks. Surpassed expectations."

While only a few hundred of the quarter of a million people who visit Rock Bridge Memorial State Park go on a wild cave tour, those who do receive an exceptionally high-quality experience that makes a profound difference in their lives and in how they feel and think about caves. And that makes a difference in securing the long-term protection of caves such as Devils Icebox. Again, comments received assure us that hands-on adventure programs such as wild cave tours are very effective.

Those who have the most power in whether the cave is protected are those who live in its watershed, so we recently invited them to special programs including wild cave tours. I'll close with excerpts from these letters:

". . . the cave tour definitely impressed upon us the necessity of keeping this wonderful natural resource clean and unpolluted. You can be assured that our family will be watchful and think twice about anything that goes into our septic system or onto our land. Thanks again to all who provided us with an incredible experience and a fun day."

"Jay and I would like to thank . . . for enabling us to 'discover' the Devils Icebox. This *huge* experience will be treasured, just as we hope the Icebox will be treasured by all who impact this natural beauty."

Ozark Cavefish Public Outreach and Habitat Management Project

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Abstract

The Ozark cavefish (*Amblyopsis rosae*) was officially listed as threatened by the United States Department of the Interior on December 3, 1984. It is an obligate troglobitic fish restricted to the Springfield Plateau of central North America. Habitat destruction, disturbance, excessive collection and declining water quality are typically cited as primary factors threatening this and many other cave species.

The Missouri Department of Conservation, in cooperation with the United States Environmental Protection Agency, the Missouri Department of Agriculture, the United States Fish and Wildlife Service and other natural resource agencies, has developed a public outreach and habitat management project to increase landowner awareness and enhance habitat management within the recharge areas of Ozark cavefish caves in southwest Missouri.

These efforts focus on informational and educational activities and direct landowner contact within the known range of the Ozark cavefish. Brochures, fact sheets, a poster and incentive items (e.g., coffee mug, refrigerator magnets, signs) have been developed and are currently being used in contact efforts. Landowners are offered advice and assistance to address existing and potential impacts on cave systems.

As a result of these efforts, several projects have been completed ranging from cave gating and capping abandoned wells to re-establishing riparian areas and buffer zones around cave entrances, springs and sinkholes. Efforts are currently underway to continue implementing habitat management projects within several delineated cave recharge areas.

The Ozark cavefish (*Amblyopsis rosae*) is a small, pale, almost colorless, blind fish that is found only in the caves of the Springfield Plateau of central North America. The Ozark cavefish is a sensitive indicator of cave and water quality. Similar to the miner's canary, the Ozark cavefish can provide an early warning of deteriorating water quality that may affect other species and humans.

The Ozark cavefish was officially listed as threatened by the United States Department of the Interior on December 3, 1984. The Ozark cavefish is listed as endangered in Missouri. Habitat disturbance, excessive collection, and declining water quality are typically cited as the primary factors threatening this species. Potential threats to groundwater that may also affect Ozark cavefish in karst topography include: runoff or leaching of pesticides used in a variety of farming practices; siltation of cave habitats resulting from excessive watershed erosion and the introduction of surface sediments via unbuffered sinkholes, losing streams, and cave openings; and the introduction of excessive nutrients from surface sources (that is, septic systems, abandoned and uncapped wells, trash dumps and related waste sites near cave openings or sinkholes, improperly functioning sewage lagoons, feedlots, poultry operations, and application sites related to sludge and other waste handling operations).

A revised recovery plan for the Ozark cavefish was written in 1989 by the U.S. Fish and Wildlife Service. The goal of the recovery effort is to remove the Ozark cavefish from threatened status by assuring that populations are restored and protected throughout a significant portion of the historic range. Recovery will be achieved when nine caves and important components of their recharge areas are protected and the cavefish populations in each of these caves remains stable or is increasing as evidenced by systematic observations over at least a ten-year period.

The Missouri Department of Conservation has worked successfully with private landowners who own the entrances of Ozark cavefish caves for many years. In addition, many of these cave entrances are registered as natural areas with The Nature Conservancy. Efforts to expand landowner contact and education into the recharge areas of these caves have been more recent. A pilot project was initiated by the Missouri Department of Conservation in 1991 within the known recharge area of a Jasper County, Missouri, cave. During the pilot project, landowners were informed that Ozark cavefish lived in the groundwater systems beneath their property. Few were aware of the presence of this species. Individual site assessments were made with landowners as they were educated about the importance of protecting groundwater quality. It was stressed that improved groundwater quality would benefit them (the landowner) as well as subterranean species like the Ozark cavefish.

The primary objectives of the pilot project were to conduct a landowner contact program in a small watershed, evaluate the response of landowners when they learned that a rare cavefish lived in their area, and determine what materials and information landowners needed concerning cavefish and groundwater protection. Site-by-site assessments were necessary to answer landowner questions, discuss solutions to potential problems, offer technical advice, and direct landowners to other resource professionals and related programs.

In 1993, U.S. Fish and Wildlife Service provided the Missouri Department of Conservation with funds to continue contact efforts on behalf of Ozark cavefish through a Service Challenge Grant. Using the recovery plan as a guide and the pilot study for perspective, challenge grant funding was used to increase public awareness concerning this species. Some of the accomplishments included:

- Dye-tracing to delineate the recharge areas of seven known and historic Ozark cavefish sites so that land use could be evaluated and current landowners could be contacted;
- Cave surveys, habitat studies and collection of genetic tissue samples to facilitate research in progress;
- Development of informational and educational brochures and incentive items (magnets, coffee mugs) about the Ozark cavefish and groundwater quality;
- Media contacts;
- Direct mailings to landowners;
- Presentation of informational and educational workshops for area landowners; and
- Presentations to school and special interest groups.

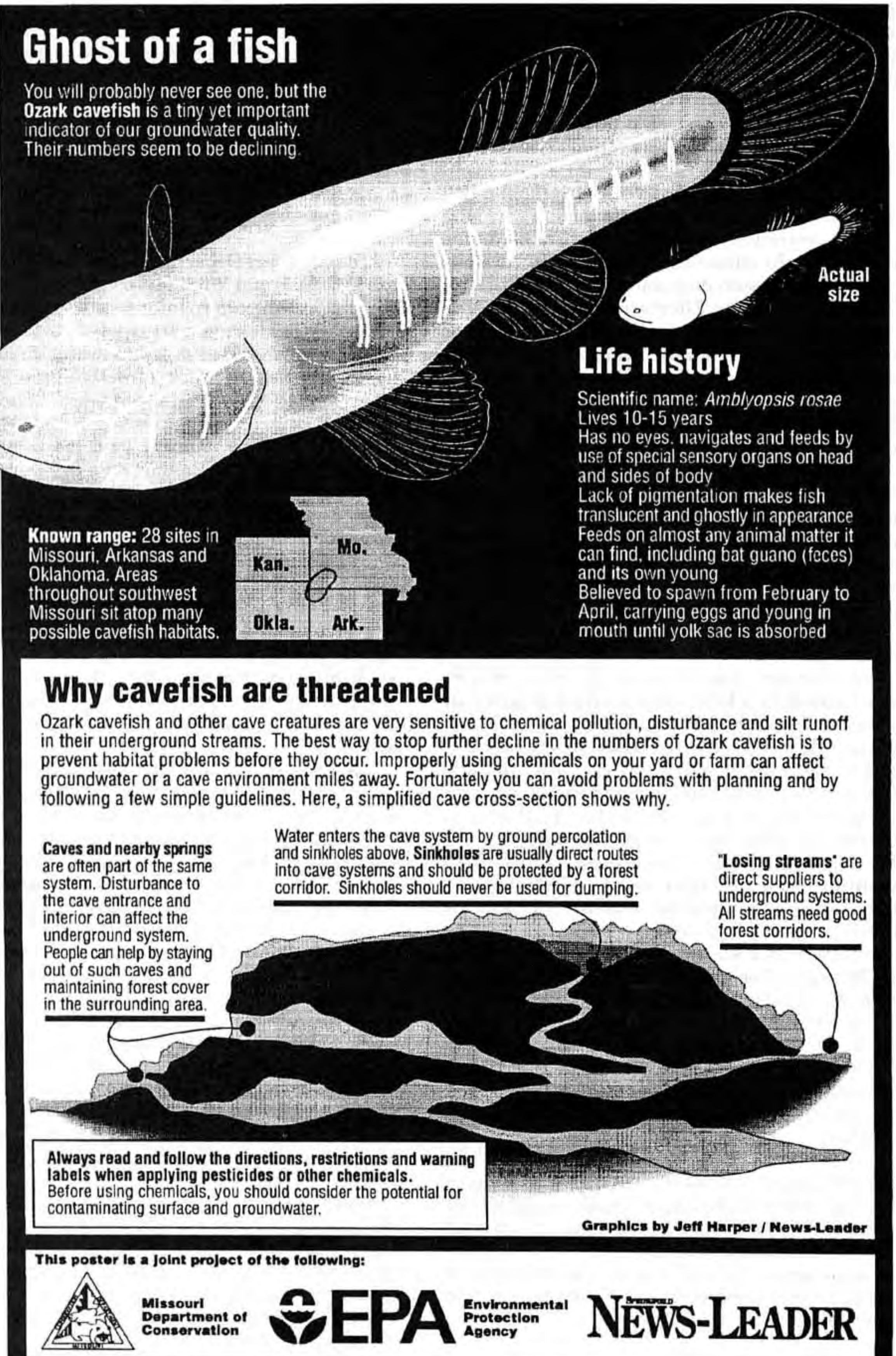
The Missouri Department of Conservation and the U.S. Fish and Wildlife Service then initiated a program of education, information exchange, and voluntary landowner participation to protect the Ozark cavefish and area groundwater quality. The next step was to work directly— more intensively—with private landowners to evaluate threats to water quality in cavefish recharge areas and take steps to improve land management to correct existing problems and avoid potential problems.

In September 1994 the U.S. Environmental Protection Agency provided funding to the Missouri Department of Conservation to continue efforts to recover the Ozark cavefish. This project includes efforts to enhance local public awareness of issues related to groundwater quality and the Ozark cavefish. Publications, media contacts, workshops, conferences and direct mailings are being used to reach the public with special emphasis on reaching landowners within cave recharge areas.

Again using the recovery plan as a guide, and earlier accomplishments for perspective, Environmental Protection Agency grant funding is being used to increase public awareness and implement habitat and pesticide management projects concerning this species and groundwater quality. The following are among the accomplishments to date.

Approximately 200 landowners have been contacted by mail, and site visits have been made to 37 private landowner properties, two Missouri Highway and Transportation Department right-of-ways (sinkhole sites), three City of Springfield sites, and five Missouri Department of Conservation sites. Some excellent contacts have been made at these sites, with the reconfirmation of historic 1951 and 1957 Ozark cavefish sites and the location of three new Bristly cave crayfish (*Cambarus setosus*, a state watch-listed species) sites in southwest Missouri.

Several recommended projects have been completed including reestablishing riparian areas and buffer zones around cave entrances, springs, and sinkholes; sealing and capping abandoned wells; cave gating and fence repair; and cave clean-ups. The following is a brief overview of some of the completed projects.


Ghost of a fish
You will probably never see one, but the **Ozark cavefish** is a tiny yet important indicator of our groundwater quality. Their numbers seem to be declining.
Actual size
Life history
Scientific name: *Amblyopsis rosae*
Lives 10-15 years
Has no eyes, navigates and feeds by use of special sensory organs on head and sides of body
Lack of pigmentation makes fish translucent and ghostly in appearance
Feeds on almost any animal matter it can find, including bat guano (feces) and its own young
Believed to spawn from February to April, carrying eggs and young in mouth until yolk sac is absorbed
Known range: 28 sites in Missouri, Arkansas and Oklahoma. Areas throughout southwest Missouri sit atop many possible cavefish habitats.
Kan.
Mo.
Okla.
Ark.
Why cavefish are threatened
Ozark cavefish and other cave creatures are very sensitive to chemical pollution, disturbance and silt runoff in their underground streams. The best way to stop further decline in the numbers of Ozark cavefish is to prevent habitat problems before they occur. Improperly using chemicals on your yard or farm can affect groundwater or a cave environment miles away. Fortunately you can avoid problems with planning and by following a few simple guidelines. Here, a simplified cave cross-section shows why.
Caves and nearby springs are often part of the same system. Disturbance to the cave entrance and interior can affect the underground system. People can help by staying out of such caves and maintaining forest cover in the surrounding area.
Water enters the cave system by ground percolation and sinkholes above. **Sinkholes** are usually direct routes into cave systems and should be protected by a forest corridor. Sinkholes should never be used for dumping.
"**Losing streams**" are direct suppliers to underground systems. All streams need good forest corridors.
Always read and follow the directions, restrictions and warning labels when applying pesticides or other chemicals.
Before using chemicals, you should consider the potential for contaminating surface and groundwater.
Graphics by Jeff Harper / News-Leader
This poster is a joint project of the following:
Missouri Department of Conservation
EPA Environmental Protection Agency
News-Leader

A citizen's phone call helped locate and contact the appropriate agencies to remove fresh asphalt from a sinkhole within the recharge area of a Greene County, Missouri, Ozark cavefish site. Cattle were excluded and trees were planted in a 75- to 100-foot buffer zone around another Greene County, Missouri, sinkhole site. At a third site, a recommendation for tree planting and herbicide elimination has been implemented around a developing sinkhole.

Landowners in several counties have implemented stream bank stabilization projects on losing streams that will improve area ground and surface water quality for all species. Improvements include reestablishing a vegetated buffer zone on both sides of the stream and at a cavespring known to contain cavefish at one site.

Abandoned wells, besides being a safety concern, are conduits to groundwater. A program administered by the Natural Resources Conservation Service and the Consolidated Farm Service Agency provides cost-share money to landowners to cap abandoned wells and cisterns providing they follow certain guidelines. To date, one abandoned well has been properly sealed and capped within the recharge area of an Ozark cavefish cave at very low cost to the landowner.

A Missouri Department of Conservation cave historically containing Ozark cavefish and gray bats (*Myotis grisescens*) is being gated following recommendations to protect these populations. Additionally, a local caving group has adopted this cave and is currently conducting cave clean-ups and gate monitoring under Missouri Department of Conservation supervision.

Additional accomplishments include the development of an Ozark cavefish informational poster (Figure 1), pesticides fact sheet, stickers for school programs, landowner cooperator signs, and the organization and hosting of Ozark Cavefish Conference II. The conference opened lines of communication between various individuals and entities involved in cavefish work and is helping to clarify the direction of recovery efforts for this species.

Continued emphasis will be focused on contacting landowners within the known recharge areas of Ozark cavefish sites. Landowners will be invited to workshops in an attempt to educate and continue voluntary on-site evaluations and subsequent habitat improvement and protection projects. As before, workshops, news releases, and direct mailings will be used to contact landowners and the general public. Detailed recommendations and project plans are being developed as appropriate. Other natural resource agencies will be contacted for their advice and technical expertise as needed. Education, general public and landowner outreach, and agency partnerships are the key to success for this cavefish recovery program.

Ozark cavefish and landowners . . . A Winning Combination!

Status of Arizona's Unique Bat Management Program

Shawn V. Castner
Tim K. Snow
Debra C. Noel

Abstract

In 1990, Arizona voters passed an initiative allocating 10 million dollars annually from the lottery to the Arizona Game and Fish Department for wildlife management. The Bat Management Program began in 1992 when three permanent biologists were hired to manage the 28 bat species in the state. Since then, surveys of over 2,000 mines and caves, and numerous buildings, dams, and bridges have documented several hundred bat roosts. This, along with many hours of mist netting, radio telemetry studies, and data compilation from external sources has dramatically expanded knowledge of species occurrence, distribution, and life history. Conservation measures have consisted of monitoring over 100 roosts, installing bat gates, scientific analysis, environmental assessment mitigation, public education, and training personnel from other agencies.

Introduction

The Arizona Game and Fish Department is responsible for the conservation of Arizona's 28 bat species. Their management can be divided into two periods: before and after 1992. Prior to 1992, one Department biologist was responsible for managing all non-game mammals, represented by bats and 77 other species. Therefore, bats received very little attention. Most of the data collected came from independent bat biologists in the southern part of the state. There was little coordination or prioritization regarding projects or survey areas, data sharing among these biologists or with the Department was sporadic, and many areas and species received little attention or were ignored. These conditions caused bat conservation measures in many land management policies and actions to be inadequate or non-existent.

In 1990, Arizona voters passed the Heritage Initiative, which allocated 10 million dollars annually to the Arizona Game and Fish Department for wildlife management. This enabled the implementation of numerous programs addressing many different species and issues that had long been neglected, hence, the creation of the Bat Management Program in 1992. Debra Noel was hired as coordinator, followed by Shawn Castner and Tim Snow to implement Bat Management Program activities. The Program's creation, and persistence, is an unprecedented commitment to bat conservation. Arizona is the only state with three full-time bat biologists, in contrast with most states which do not have even one.

Several reasons justify the effort directed towards bats. They are an important component of every ecosystem in Arizona, they occur statewide, little specific information is available for most species, and years of neglect and disruptive practices have compromised the survival of certain species. Natural habitats have changed or no longer exist in some areas and population declines of numerous colonies have occurred. Twenty-six species are natural predators of many insects, including numerous agricultural and human pests. The other two bat species are the primary and most effective pollinators and seed dispersers of saguaro (*Carnea gigantea*), organ pipe (*Lemaireocereus thurberi*), agave (*Agave* sp.), and other night-blooming plants.

Program Overview

The creation of the Bat Management Program was not accompanied by any specific directives, merely the responsibility of all Arizona's bats. To provide direction and set priorities, we formulated goals that we felt, if attained, would maximize bats' survival. The five goals are:

- Manage all 28 bat species by protecting roosts and sensitive habitats.
- Conduct statewide bat surveys to locate roosts: document species occurrence, range, and status; identify critical habitats; and determine basic life histories including reproductive, migrational patterns, and foraging strategies.
- Develop a cooperative network among bat biologists and cave specialists.
- Create and maintain working relationships with all land management agencies in Arizona.

- Educate the public and other professionals on bat conservation.

Many activities were directed toward accomplishing these goals. Surveys are one of our main endeavors. To date, we have completed projects on four Bureau of Land Management resource areas, four USDA Forest Service districts, one Department of Defense installation, and one National Wildlife Refuge. We have conducted specific surveys for four different species. In addition, many minor and impromptu surveys have been conducted in response to critical situations or specific requests from land management agencies such as Bureau of Land Management, USDA Forest Service, National Park Service, county parks, Indian Reservations, other government agencies not associated with land management, private business, and the public. These projects and surveys can be grouped into two categories: roost inventories at mines, caves, human-made structures, trees, and cliffs and mist netting. Nearly 1,000 roosts have been discovered, with 222 receiving monitoring efforts, and 180 nights have been spent netting locations statewide. These endeavors are responsible for many new discoveries regarding species biology and their requirements.

Since surveys alone will not accomplish all our goals, the Program participates in a variety of other activities. The development and implementation of management strategies to protect roosts is one. Another is educating groups and individuals in public and private sectors about bat biology and conservation. Some of the venues we participate in are professional conferences and workshops, presentations or lectures in scholastic environments, and providing educational talks or displays for events like wildlife fairs or for media productions. Along with education, we provide training for inter- and intra-agency personnel on survey techniques and assist the public in dealing with urban bat issues. Lastly, we created a computerized data management system for all roost and netting information. It includes historic and current data and is updated as new information is obtained. This system will enhance our ability to manage bats since our management recommendations will be based on the most current and comprehensive data source available.

Mine Surveys

Arizona has an estimated 120,000 abandoned or inactive mines. Since many caves are no longer habitable, or marginally so, bats that traditionally used them now occupy mines. In some areas, mines may provide roosting habitat where there previously was none, enabling some species to expand their range. For either reason, bats have taken advantage of these artificial structures. Abandoned mines are inherently dangerous to humans unaware of their existence or who are not equipped or trained to enter them. Many land management agencies have, or are beginning to, close them for hazard abatement. Dangerous mines receive less human disturbance, so they provide a refuge for bats. However, these mines are usually the first to be closed. Without mine surveys, many roosts could be lost.

Because of potential mine closures resulting in the loss of roosts or roosting habitat, statewide mine surveys have been a major focus of our field activities. Complete surveys have been conducted at 2,403 of the 2,737 mines visited. Bat signs (bat presence, guano accumulation, urine stains, or skeletal remains) was observed at 784 (32.6%) mines visited or completely surveyed. Significant roosts—based on species, roost type, colony size, or guano accumulations, have been located at 236 (9.8%) mines.

Based on our surveys, the most common occupant of abandoned mines in Arizona is the California leaf-nosed bat (*Macrotus californicus*). Other common residents are Townsend's big-eared bat (*Plecotus townsendii*), cave myotis (*Myotis velifer*), California myotis (*Myotis californicus*), fringed myotis (*Myotis thysanodes*), Yuma myotis (*Myotis yumanensis*), pallid bat (*Antrozous pallidus*), big brown bat (*Eptesicus fuscus*), and Mexican free-tailed bat (*Tadarida brasiliensis*). Less common species are Western pipistrelle (*Pipistrellus hesperus*), Allen's lappet-browed bat (*Idionycteris phyllotis*), occult little brown bat (*Myotis occultus*), long-legged myotis (*Myotis volans*), Southwestern myotis (*Myotis auriculus*), long-eared myotis (*Myotis evotis*), lesser long-nosed bat (*Leptonycteris curasoae*), and Mexican long-tongued bat (*Choeronycteris mexicana*).

We also document other wildlife use during these surveys. A wide array of animals use abandoned mines for many reasons—such as rearing young, relief from harsh environmental conditions, and protection from predation—which augments the importance of mines as wildlife habitat. Woodrats and white-footed mice are encountered most, but ringtails, skunks, javelina, owls, wrens, snakes, and lizards are regular inhabitants. Other species using mines to a lesser extent include deer, bighorn sheep, coyote, fox, mountain lion, bobcat, squirrel, raven, turkey vulture, loggerhead shrike, frogs, toads, and salamanders.

Human-made Structures

Human-made structures commonly used by bats for roosts include buildings, bridges, tunnels,

Table 1. Human-made structures surveyed for bats in Arizona by the AGFD's Bat Management Program

Structure	Total Surveyed	Total Roosts
Bridges	32	16
Tunnels	22	11
Buildings	16	14

and dams, and are surveyed whenever possible (Table 1). Often, these surveys are the result of contact from the public or public agencies. *T. brasiliensis* is a common occupant, and several roosts number in the thousands. Large colonies of *M. yumanensis* have also been discovered. Other residents of these structures include *A. pallidus*, *E. fuscus*, *M. velifer*, *M. volans*, and *P. townsendii*.

Roost Monitoring

Once a significant roost is identified, monitoring activities are undertaken to monitor colony size, confirm roost type, determine species use, identify seasons of use, and document changes to the site. Roost types are maternity, mixed gender and species, bachelor, transitional/migrational, and hibernacula—with some sites serving more than one function.

Mines represent the bulk of our monitoring effort, with 107 receiving at least two visits. *Macrotus californicus* roosts comprise most of them; the remainder are *P. townsendii*, *T. brasiliensis*, *M. yumanensis*, *M. velifer*, and *L. curasoae*. We are also monitoring populations of *T. brasiliensis* at five bridges and one cave. In addition, colonies of *M. thysanodes* at two other caves are also being monitored.

Mist Netting

Capturing bats at night with mist nets is another major field activity and has resulted in 27 of the 28 species in Arizona being captured. These surveys are conducted for two purposes: to capture bats foraging or drinking and to identify species at roosts where entry is not possible. Netting foraging and drinking bats accounts for nearly all netting activities, with 154 sites surveyed statewide. Several sites have been netted more than once. Types of sites are water tanks, ponds, rivers, creeks, lakes, and dry drainages. Roosts that have been netted include four mines and one bridge. We verified the presence of *P. townsendii*, *Macrotus californicus*, *A. pallidus*, *Myotis californicus*, *M. thysanodes*, *M.o. lucifugus*, *M. yumanensis*, and *E. fuscus* in the mines and *T. brasiliensis* in the bridge.

Training

Training professionals on proper bat survey techniques is an ongoing activity. With this training, they are able to conduct certain surveys and monitor roosts properly, thus collecting data we would be unable to obtain. Mist netting techniques are the most common form of training, but mine and cave survey techniques, exit count protocols, and radio telemetry procedures are also taught.

Formal training workshops we have been involved with are the BLM Mine Assessment Workshop (1993, 1995) and the Arizona Game and Fish Department's Kingman Region Bat Workshop. Informal netting training has been provided for the Imperial National Wildlife Refuge, Prescott National Forest (Bradshaw, Chino Valley, and Verde Ranger Districts), Kaibab National Forest (Tusayan and North Kaibab Ranger Districts), Bureau of Land Management Kingman District, and the Arizona Game and Fish Department's Pinetop Region. We have also trained a number of individuals on mine survey and monitoring techniques.

Radio Telemetry

We have participated in, or conducted, seven radio telemetry projects. This type of survey is most often used to locate roosts, but two projects also documented foraging patterns and areas. Often this is the best, or only, method to collect this data. This technique requires capture of the target species, attaching a small (<1 gram) transmitter to the back of the bat, and tracking it with a receiver on foot, by vehicle, or with an airplane.

Some of the information collected has been very important. Foraging areas and patterns and roosting locations were determined for a population of *Macrotus californicus* in an area proposed for renewed mining. With this information, the mining company will be able to decrease impacts on these bats. Another survey located several roost locations for the yellow bat (*Lasiurus ega*). Previously, there were no known roosts in Arizona.

There are two projects that have produced very important results. These projects are detailed below:

Forest Bat Project. The objectives of this three-year project were to locate maternity roosts for six bat species in the coniferous forests of northern Arizona. Results from the first two years of the project have identified snags as the most common maternity sites for *M. volans*, *M. auriculus*, *M. evotis*, *M. o. lucifugus*, and *I. phyllotis*. Other roosts were located in downed trees, stumps, rocky outcrops, and on the ground under rocks. The results of this project should have dramatic impacts on how forest stands are managed since these bats prey on many of the insects that damage timber.

Spotted Bat Project. The objective of this project was to locate roosts for this uncommon species. No roosts in Arizona were known prior to this survey. Eight bats were captured and transmitters were attached to seven. We located three day roosts in cliff crevices for two bats and one night roost in a ponderosa pine (*Pinus ponderosa*). Also during this project, we captured eight greater western mastiff bats (*Eumops perotis*), confirming a range extension for this species of over 120 kilometers.

Roost Protection

Locating roosts is important, but our ultimate goal is to ensure their future existence. To protect them, we must determine potential threats and develop solutions to eliminate, or at least reduce, them. Threats can vary in number and may require intensive study to fully understand. Developing strategies to remove the threat is easy; however, implementation usually is not. Even though nearly all threats originate with humans and can theoretically be removed easily, the reality is that many solutions are not feasible and acceptable alternatives may not exist.

There are several notable examples of the Bat Management Programs's roost-protection endeavors. We successfully gated one mine and one cave and plan to install gates at two mines, two caves, and two tunnels by March 1996. While we were unable to save a roost from renewed mining, the mining company is taking measures to conserve similar mines in the area, hopefully providing the colony with an acceptable alternative. Final approval is pending for a plan to protect a cave by severely limiting the human disturbances that, compounded over several decades, have reduced the colony to thousands of bats from an estimated hundreds of thousands. Also, prosecutors convicted a man who intentionally killed several hundred bats at a bridge roost.

While protecting individual sites is required and produces immediate results, employing methods to protect roosts on a large scale will be more effective. We are pursuing a cooperative effort between the Program and several state and federal agencies to integrate all critical concerns into survey objectives to reduce multiple inspections. We are also working with several agencies on a protocol requiring biological surveys by a qualified biologist of mines targeted for closure before the site is closed. In addition, recommendations made to management agencies, along with educating professionals and the public on bat conservation, have roost-protection attributes.

Educational Activities

Bat conservation education, in both public and professional sectors, is an important component of the Bat Management Program. We inform individuals and organizations on the importance of bats and ways to enhance the habitats they use, or at least not diminish them. We also use this time to dispel erroneous myths associated with them. These efforts hopefully curtail some of the negative influences people mistakenly, or knowingly, impart on bats and their habitats.

Formal settings are the most apparent medium by which we deliver our message. Many of these functions are attended by people already sympathetic to bats; however, there are usually a few who's beliefs are altered and even more leave with a heightened awareness of issues facing bats. These events can be divided into two groups: professional meetings attended by biologists or land managers from the same or similar disciplines and public meetings attended by professionals of distant or unrelated fields or by the general public. Some of the more important functions attended are symposia dealing specifically with bats or bat habitat, general wildlife conferences, workshops for professionals and teachers, and educational events for the public.

While meetings and conferences enable us to reach a large audience, the most effective contacts often are those with individuals in informal settings. This one-on-one format increases our effectiveness at promoting bat conservation because we can provide more detailed and pertinent information to the individual. They are usually random situations, and vary from individuals encountered during official duties to off-duty encounters during everyday activities.

Urban Bat Issues

Every year, the Bat Management Program receives calls from the public regarding bats roosting in or on their house or business. We obtain all information possible from the caller about the bat(s), where they are roosting, and duration of their stay. We provide them with potential solutions to their problem and give them a short talk on any misconceptions they have regarding bats, their importance, and bat conservation. The majority of these bat calls are received during spring and fall, when bats are migrating. The bats prompting these calls usually are only there for a day or two and the caller can usually be persuaded to leave them alone. If this is not possible, we provide them with ways to make the bats leave without harming them.

Occasionally, we receive calls regarding more permanent residents. This situation is more difficult to deal with, since the usual request is to remove the bats. We provide the caller with a variety of solutions they can perform themselves and the phone number of two permittees who deal with bats. Sometimes, for various reasons, we go on site to solve the problem. While there, we document species, colony size, and roost characteristics. The potential for physical harm or death to the bats is one reason for a visit. Examples are irate owners willing to kill or harm the bats and a seven-story parking garage with nearly 400 bats that was scheduled for sandblasting and painting. Large roosts at schools pose potential risks to students and we have worked with several to solve their problem. We also participated in excluding bats from the Governor's office.

Data Management

Conducting surveys is easy, but they are useless unless the data can be used in an effective and timely manner. Our goal is to obtain and manage all bat data that has been and will be collected in Arizona. By including all sources, our management decisions will be more effective and more comprehensive information will be available to parties with legitimate requests. Most of the Bat Management Program's data, along with some from external sources, have been entered. Many researchers have performed field work in Arizona so locating and receiving their data will be very time consuming.

To accommodate all data, we created two main databases, one for roost structures and one for netting sites. The overall structure of each is very similar; both consist of three relational databases for site, visit, species information, and many of the same data fields. The roost database is much larger however, consisting of 86 separate data fields compared to 38 in the netting database.

Conclusions

The Bat Management Program has accomplished a great deal since its inception in 1992. While these efforts have benefited many bats, some populations continue to decline and certain habitats are deteriorating. There is still much to learn about Arizona's bats. For most species, we lack a comprehensive understanding of their biology. More importantly, we do not know the exact role bats play in each ecosystem or all the factors

The Michigan Karst Conservancy: A Land-Trust Approach to Cave Management

Rane L. Curl
Michigan Karst Conservancy
Trustee and Past President

Abstract

The Michigan Karst Conservancy (MKC) was incorporated as a "land trust" in 1983, by members of the Michigan Interlakes Grotto of the NSS, with the purpose of acquiring and managing examples of the significant karst features of Michigan (and with related educational and scientific purposes). It is a non-profit, tax-exempt, all-volunteer corporation with about 100 members, governed by a member-elected board. The MKC bought 480 acres in Mackinac County, Michigan, in 1987, to form the Fiborn Karst Preserve, which protects much of a complete karst drainage system also containing Michigan's most significant limestone cave. It bought 29 acres in Alpena County in 1990 to form the Stevens Twin Sinks Preserve, on which occur two of the largest limestone sinkholes found in northeastern Michigan. These preserves are managed by committees of MKC members, always including persons from the local communities, under general policies adopted by the MKC Board of Trustees. The preserves are open to the public, except that permission and guides are required for visits to MKC caves.

The Land Trust Alliance defines *land-trusts* as "local, state, or regional non-profit organizations directly involved in protecting land for its natural, recreational, scenic, historical, or productive values." Many are called conservancies, foundations, or other terms, depending on their purpose, but most today are private efforts to preserve land containing significant features. Land-trusts carry out their goals by owning land, or owning rights (easements) on land, so that alterations in the land, incompatible with the land-trust's purposes, cannot occur. Land-trusts are a viable means of protecting caves if the human and monetary resources can be developed. This is the story of one such land-trust, told in the hope that it will encourage like-minded groups to pursue this approach to saving caves, karst, and related natural and historical features.

The Michigan Karst Conservancy Inc, a land-trust devoted to acquiring and protecting cave and karst features in Michigan, grew out of activities of the conservation committee of the Michigan Interlakes Grotto, a chapter of the National Speleological Society. The first proposal for such an organization appeared in the Michigan Interlakes Grotto's *Spelean Spotlight* in August 1983 and by November the Michigan Karst Conservancy was incorporated and its bylaws adopted. The main motivation was the rediscovery in 1975 by the Michigan Interlakes Grotto of a small group of caves in Michigan's Upper Peninsula, including the state's longest cave in limestone. The number of people visiting the cave, plus vandalism and surface impacts, increased rapidly thereafter. An attempt was made to interest The Nature Conservancy in buying the caves, but they did not meet Nature Conservancy acquisition standards. If anything was going to be done, those most interested, *cavers* in this instance, had to do it.

One must understand the situation with regard to karst and caves in Michigan to understand the function of Michigan Karst Conservancy. There are extensive bedrock exposures of carbonate rocks in Michigan, but most of them are overlain by glacial drift. Karst and cave features are rare, which forms the basis for their protection: it is *possible* for a small volunteer organization to acquire and manage most of those of significance. Other factors were that many of the features are mostly privately owned and were becoming inaccessible to the public as owners became leery of liability, or they were in remote areas with absentee owners and hence unprotected.

The Michigan Karst Conservancy was founded as a membership corporation, managed by a board consisting of twelve elected trustees and four appointed officers. The organizational structure was derived from that of the National Speleological Society, because the founders had been involved in Society programs and administration. It is almost essential for land-trusts intending to protect caves to begin as membership corporations because it is the enthusiasm of a small group that will make a volunteer land-trust accomplish its purposes—there is little reward, other than being a part of the effort, for the time and money that must be donated. Individuals are the base for cave protection.

Business Before Pleasure

Talking about protecting caves by purchase is one thing, but doing it also involves a lot of work. To make a longer story short—after incorporation, application was made for federal 501(c)3 tax exemption (granted in August 1984) and a Michigan Charitable Solicitation License and Sales and Use Tax Exemption, (granted in August and November 1987). These steps are necessary for an organization expecting to solicit money from the public, hold title to property, and make best use of the resources that are available. The Michigan Karst Conservancy was helped a great deal in its formative years by joining the Land Trust Alliance in 1985 (originally, the Land Trust Exchange), and obtaining, through them, information about good business practices, which culminated in 1989 with the Conservancy adopting the *Statement of Land Trust Standards and Practices* of the Land Trust Alliance as its own operating guidelines.

This is a good moment to make a strong "plug" for any group thinking of venturing into the area of private ownership and management of land (and caves) for conservation purposes to join the Land Trust Alliance. Their address is 1319 F Street NW, Suite 501, Washington, DC 20004-1106 (Phone 202 638-4725). They now represent some 1,100 land-trusts nationwide. They provide many information resources and an annual meeting (Rally) at which workshops in the numerous aspects of land ownership and management are offered for the participants from member organizations.

One benefit of Land Trust Alliance membership is access to liability insurance. Michigan Karst Conservancy first bought insurance coverage this way in 1985, well before owning any land. Carrying liability insurance is not just a matter of protecting the resources of an organization; it is a responsibility to the public with whom the organization deals to have the insurance resources to address accidents that may occur despite entirely good intentions. In addition, it encourages volunteers to participate, knowing that their activities on behalf of the organization are also covered by insurance. While it was moderately inexpensive back in 1985, premiums have since quadrupled, a financial burden now calling for careful long-range financial planning.

Forming a land-trust implies a broader view of cave management than owning an entrance and controlling access. It involves the full scope of land ownership issues—legal, ecological, and social. Examples of these that have been addressed by the Michigan Karst Conservancy form the rest of this article.

The Fiborn Karst Preserve

Hendrie River Water Cave is one of a group of caves located on a subdued exposure of the Niagaran Escarpment (Silurian carbonates) in Michigan's Upper Peninsula. The presence of one of the caves was first noted on a Northwest Ordinance surveyor's map of 1845. The first newspaper notice did not appear until 1901. Shortly thereafter a limestone quarry was opened at the site by a newspaper editor and land and timber speculator named Chase Salmon Osborn and a railroad officer named William Foresman Fitch. Their names were combined to form the Fiborn Limestone Company in 1905, which was sold to Algoma Steel (Canada) in 1909, and continued operating until 1937, resulting in a quarry of 80 acres that removed some cave features. Between 1937 and 1975, when Michigan Interlakes Grotto members learned of their existence from nearby residents, the caves were objects of interest in the area, but not heavily visited (few records of them exist from that period). Some small amount of quarrying occurred, unfortunately removing most of another cave as late as around 1952.

There is very little mention of the caves in any documents for most of their history before 1975. The person that claimed discovery in 1898, Chase Osborn (governor of Michigan in 1911 and 1912), wrote in correspondence in 1900 that he had found "a most interesting cave which will certainly not detract from the value of the property," but this did not translate into any specific efforts to either commercialize or protect the caves.

The Michigan Interlakes Grotto surveyed the caves and led field trips to them. The rediscovery of the caves set off a period of heavy visitation by the public. When the Grotto first went to Hendrie River Water Cave in 1975, the narrow two-track leading to it was knee high in spring grasses. It wasn't long before the track was so compacted, or torn up, that little grows on it even today, after nearly eight years of rest. In addition, visitors began camping near the cave entrance, littering and making campfires, while the first graffiti appeared spray-painted within the cave. It was time to act.

Although The Nature Conservancy had contacted the owners (then a West Virginia coal company owned by a Canadian steel company owned by a Canadian railroad), followed up by the Michigan Karst Conservancy after it was incorporated, no progress was made in attempting to negotiate for the purchase of the land until 1986, when approximately 600 acres were put on the market, with 440 acres of that offered to the Conservancy for $30,000. The Michigan Karst Conservancy negotiated that up to 480 acres at the same price, but could do nothing about another 80 acres with significant karst features, which had already been sold. The Conservancy closed on the purchase in May 1987, using donations of $6,000 and a $25,000 loan from a Conservancy member, to come due that October.

The story now became one of fund raising, the challenge faced by all land-trusts that depends on effort, dedication, and good luck. By October, $18,000 was still needed. At that month's Michigan Interlakes Grotto meeting, a member said "I will donate $1,000 if seventeen others will also donate $1,000." By the end of the evening, $12,000 had been pledged. The remaining debt was rolled over into another member loan, which was not paid off until January 1989, but the challenge had been faced and met that evening when those who cared put up the means to accomplish the project. Every fund-raising effort is a different story, but my hope is that recounting this one might encourage others to try these or their own innovative methods to accomplish their goals.

Property tax exemption was obtained for the Preserve in 1991, but it involved taking the township to court after they denied the exemption. This was an unhappy event in the management of the Preserve, and relations with some township residents still require mending.

The management of the Fiborn Karst Preserve is in the hands of a committee appointed by the Michigan Karst Conservancy president, with three officers (chairman, secretary, and treasurer) who have the official responsibility for carrying out the management policies adopted by the Conservancy. The preserve committee chairman appoints as many additional preserve managers as are willing to donate their time. Guides for most cave trips at the preserve come from the Michigan Interlakes Grotto. The committee must request an annual budget from the Michigan Karst Conservancy board. These procedures ensure accountability for programs and money, but permit local flexibility in preserve management. The participants of the preserve committee are still mostly Conservancy founders and early members, but more are coming from nearby communities. Someday we expect the Preserve to be managed primarily by nearby residents.

The management of the Fiborn Karst Preserve is directed toward protecting the *total land resource* while making it available for public appreciation, use, and scientific study. Monthly "work weekends" are held between May and October. Visits to the cave are led then, though an effort is always made to present the broader geological story of the karst drainage, and its historical setting. Groups also visit the cave with their own leaders with demonstrated knowledge of the use policies of the preserve and caving competence, but this is less effective in conveying information about all aspects of the Preserve to visitors. Trail maintenance is done on work weekends, as well as repairs required to signs, gates, parking areas, and other facilities. Hunting (in season) is permitted on the Preserve, but not trapping or visiting the caves without prior arrangements.

Scientific projects at the Preserve have been on small mammal ecology including bats, which hibernate in the caves; cave mycology; cave meteorology; and karst geochemistry. The most extensive project has been on the history of the town and business that was once Fiborn Quarry. Former residents have been contacted, oral histories obtained, and the industrial history examined. A number of former residents, including the last teacher in the school at Fiborn Quarry, have been members of the Michigan Karst Conservancy. His-

Figure 1. *Norma Peacock, Trustee, and Bill Fritz, Preserve Committee Chairman, perform road maintenance at the Fiborn Karst Preserve.*

torical information has been made available to the community by means of an open-sided "history pavilion" built at the Preserve, which displays six panels of text, maps, and photographs. A book is likely to come out of this project.

A trail system is being built. The "Sinkhole Trail" visits an area of sinkholes that developed when a swamp to the south of the preserve encroached upon exposed limestone outcrops. This trail has markers at points of interest, and a trail guide. The "Barb Patrie Memorial Trail" (named for the Preserve's first Trip Coordinator, who took visitors on tours that encompassed both the historical and natural features), follows the top of the south wall of the quarry, with many features of natural, industrial, and historical interest. The trail system does not go to Hendrie River Water Cave, to minimize it as the focus of the Preserve. The history pavilion and the trails provide alternatives to visiting the cave or waiting for a cave trip to start or end, or to make good use of the rest of the day. Having other activities available appear to lessen the pressure on the cave.

The site is remote and it would have taken many hours for experienced cave-rescue-trained persons to attend to an accident. As a result, Michigan Karst Conservancy made contact with the Ambulance (and Search and Rescue) Corp in a nearby (small) community, whom it would fall upon if a rescue were required. None had prior caving experience, so we took them on trips into the cave and arranged a weekend session of cave-rescue training from the National Cave Rescue Commission of the NSS. This not only provided skilled first-response personnel, but also created further links into the community of which the Preserve is part.

Each summer a "Neighbors' Get-Together" picnic is held, to which nearby residents, former residents, and Conservancy supporters are invited. These are enjoyable and reflect our obligation of community service as a non-profit, charitable corporation.

The Stevens Twin Sinks Preserve

A band of Devonian limestone outcrops, only a few miles wide, extends for some 30 miles east-northeast from Alpena, Michigan. The limestone is only lightly mantled with glacial drift and karst features abound. The most astonishing of these are a number of large sinkholes, some over 100 feet deep. There are disappearing streams flowing into some of the sinkholes, and there is even a disappearing lake, which goes dry some years. It is believed that the sinkholes result from collapse into large caverns in evaporites (mostly gypsum) in beds about 1,000 feet below the surface. Some of the water is known to resurge from equally large sinkholes below the surface of Lake Huron. These features fascinated Michigan Interlakes Grotto cavers for many years. It was natural, with the founding of the Michigan Karst Conservancy, to attempt to preserve examples.

We were contacted by the owner of the Twin Sinks property in 1985, after he saw a Michigan Karst Conservancy brochure, to ask if we were interested in purchasing his land. In 1986 we made a (low) offer for 20 acres, which was turned down. We then proposed a lease, in which the owner was not interested. Negotiations were reopened in 1988. We were paying off the loan for the Fiborn Karst Preserve, and had initiated contacts with the community of Alpena, where interest in the sinkholes of the region has always run high. These matters simmered until the summer of 1990, when into the picture came two cousins, retired Michigan businessmen, one of whom had summered in the area and was fascinated with the sinkholes. They offered to donate $10,000 toward the purchase of the Twin Sinks. This precipitated matters, and negotiations led to selecting an approximately 30-acre parcel with the Twin Sinks (and one-third of another sink), for a price of $17,000, based on a mortgage from the seller for the difference. Closing on the purchase took place in December 1990. The loan was repaid, through fund raising similar to that undertaken for the Fiborn Karst Preserve, in December 1991. In this instance, the Michigan Karst Conservancy was given property tax exemption upon request, with the sole condition that we did not permit hunting on the property.

The Stevens Twin Sinks Preserve is in a more settled farming community than the Fiborn Karst Preserve, and is near the medium-sized city of Alpena. In addition, the interest of cavers in the karst features—the sinkholes—was less than that of community members, the reverse of the situation at Fiborn Quarry. Therefore the preserve committee for the Stevens Twin Sinks Preserve has been composed mostly of individuals from Alpena and vicinity. The group was renamed the Thunder Bay Karst Preserve Committee, with a view toward the future acquisition of other karst features in the area.

The Stevens Twin Sinks Preserve offers two excellent examples of the sinkhole phenomenon in Alpena County. In addition to their geological interest, they provide habitats in their depths that are not found on the nearby surface. The sinkhole microclimate is akin to areas much further north. In fact, despite the easy access of plants and seeds to the sinkhole, the plant communities in the sinkholes are quite different from those on the surface.

The Jesse Besser Museum is a natural history and historical museum in Alpena. The community goes there for information and programs about natural features and programs on the sinkholes have always been part of their schedule. The Museum was a center for the early contacts of Michigan Interlakes Grotto with the community, and now the Museum is the contact point for public interest in the Stevens Twin Sinks Preserve. Conservancy members have given some of the sinkhole presentations at the Museum in recent years.

The Future

A challenge facing all land-trusts is preserving interest, and support, *in perpetuity*, for the lands preserved and managed by the trust. This requires a certain level of activity in the trust's purposes, not only because those purposes are why the organization exists, but to keep interest and support. This will mean an evolution over time from acquisition and management development to public educational activities.

Michigan Karst Conservancy has only two preserves and we have developed a "priority" list of sites to acquire in the future for preservation and management. We have formed a Landowners' Liaison committee to further the goal of preserving more examples of Michigan karst. This committee has the function of keeping in touch and providing information to landowners about karst in general, and the features they own in particular. Trails and interpretive materials are being developed for our current preserves to meet the goal of providing educational programs for the public.

The land-trust approach to cave preservation and management is not very old in the United States. Before Michigan Karst Conservancy, properties were acquired for private management by the NSS (1967), Butler Cave Conservation Society (1968), Northeast Cave Conservancy (1978), and the Perkins Cave Conservation and Management Society (1978). More have been founded since, and the pace is quickening as knowledge and interest in land-trusts as a management tool has spread. Michigan Karst Conservancy members have been pleased to have had a role in furthering this movement. We all believe it to be a worthwhile undertaking, and look forward to the challenges and successes that we are sure the future holds. Those are the motivations upon which future cave and karst conservation activities by private organizations must be built.

Inexpensive (and Easy) Temperature Monitoring in Caves

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Abstract

The technology to electronically monitor and record temperatures in caves has been available for several decades. However, until very recently, the typical instrumentation was complex, physically bulky, and expensive. With the recent advances in electronics, there are now miniature data loggers which provide comparable temperature collection functions at a fraction of the price, and have the added advantages of being very small and easy to use. This paper will provide a technology snapshot of one such device and describe its current use in monitoring temperatures in Indiana bat (*Myotis sodalis*) hibernacula. Undoubtedly, the equipment discussed here will be made obsolete very quickly with new and improved models adding more features and more data capacity, while being offered at a lower price.

Introduction

Monitoring temperatures in caves is nothing new. Scientists (particularly biologists) have been recording temperatures in caves for almost as long as scientists have been studying caves because it is one of the characteristics that make cave environments unique. Early temperature observations were generally made by reading lab-quality thermometers and manually recording these results into the scientist's field notebook. This methodology, of course, only captures very discrete points of data and becomes very labor intensive if there is a desire to examine fluctuation trends. In most instances, it is not practical to physically visit a cave to manually collect enough temperature data to provide statistically significant results.

To modernize cave temperature data collection, various automated devices have been used. First mechanical thermographs were utilized and more recently sophisticated multi-channel electronic data loggers have been employed. While these instruments provided the quality and quantity of data needed, they are not without their faults. Physical size, robustness in the field, complexity of operation, and initial costs limited their use to all but the most determined and well-funded researchers.

Recently (1992), an alternative solution has been introduced onto the market. While based upon similar solid-state technologies used in modern multi-channel data loggers, these "personal," single-channel data recorders are compact, robust, easy to use, and comparatively inexpensive (some would say almost disposable). With this new generation of data logger, it is now realistically possible for scientists, pseudo-scientists, or even just the curious to conduct their own cave-related experiments.

Aren't Caves a Constant Temperature?

One of the myths promoted by even the most knowledgeable of cavers is that caves generally remain the same temperature year around. While this is basically true in many instances, a number of caves can "breathe" due to changing external barometric pressures, while other caves with multiple entrances can form thermal "chimneys." Both instances can pull warm or cold air a great distance into caves causing significant temperature fluctuations. Furthermore, other caves will become cold air "traps" during the winter when the heavier outside air "flows" into downward-sloping entrances. It is often these varying micro-climate characteristics that provide situations which attract unique fauna species and ultimately the scientists who wish to study them. To fully understand these species, one must understand and characterize their environment, and temperature is often found to be a significant factor.

A perfect example, and the one I'm specifically interested in, is the observed selectivity of caves used by the Indiana bat (*Myotis sodalis*) for winter hibernation. While there are tens of thousands of caves in this species' known hibernation range, only about 135 caves have been documented as being used by these bats with only a dozen or so caves containing substantial populations[1]. Numerous researchers have concluded that this species favors "cold" caves (5 to 10°C), but little has been done to characterize these hibernacula's seasonal temperature profiles to understand what makes them special.

Data Loggers of the Past and Present

Mechanical thermographs and, more recently, multi-channel electronic data loggers have been utilized successfully in caves, but not without difficulty. Modern multi-channel data loggers come in a variety of shapes, sizes, and models including weatherized "portable" battery-powered ones, but even the smallest ones are typically the size of a shoe-box. This can lead to a few logistic problems including transporting these instruments into difficult caves, and concealing/burying them in unsecured caves so they will not be stolen or vandalized. Furthermore, having a centralized multi-channel data logger will require long strands of wire to be run to each of the thermocouple locations within the cave, making it nearly impossible to hide the experiment from intruders unless the cave is gated.

In the past, the operation of data loggers has been less than easy. This has been improved significantly in recent years now that these sophisticated instruments can download their data directly to personal computers, but there can still be a considerable intimidation factor for the less electronically inclined.

But perhaps the biggest obstacle to using modern-day multi-channel data loggers in caves is their cost, easily running into several thousand dollars for the most austere of models. While this may be pocket change to universities and consulting firms, few private researchers or para-biologists can justify this kind of expense, especially if only one or a few locations within a cave need monitoring.

The "Personal" Data Logger

In 1992, Onset Instruments[2] introduced their Hobo[tm] series of miniature, single channel temperature data loggers (see Figure 1). In addition to being small and easy to use, they were also relatively inexpensive at $117 each for a basic externally-cabled model (quantity discounts can reduce this price even more).

The physical size of the Hobo is approximately 2 by 2 by ½ inches with an external thermistor cable (available in 1-, 2- and 6-foot lengths) which plugs into the side. While the standard Hobos are not water-proof, they can easily be made cave-proof by bagging them in multiple zipper-type freezer food bags with only the cable left hanging out (I use three or four quart-size bags with rubber bands to bind each layer). It is recommended to include a small desiccant packet in the inner-most bag to absorb any moisture that might be trapped. Even in their protected form, the data loggers are very small and can be hidden in small cracks, on ceiling ledges, under rocks, or easily buried (however, avoid placing them were they might become completely submerged). If concealed correctly, they can be installed in unsecured caves with little fear that they will be discovered, vandalized, or stolen (losing both your equipment *and* your data). However, in regions where woodrats (*Neotoma*) or other rodents may be present, extra care must be taken to protect and secure the loggers because they can be (and have been) disturbed, gnawed on, or carried off.

Figure 1. *Actual size of the Hobo data temperature logger manufactured by Onset Instrument Corporation.*

Since each Hobo is independent and records only a single channel, you simply deploy as many devices as necessary at the desired locations without the need to run wires back to a central unit. This flexibility is a significant advantage over the multi-channel data loggers.

Operating the Hobo is relatively straightforward. All configuring and data downloading is performed via a personal computer running Microsoft Windows or Mac software. The Hobo is connected to the computer using a serial cable (the cable and software is purchased from Onset for $59). There are only a few parameters that need to be set before activating the data logger: the units of output (English or metric), a text legend to identify the data logger (this is optional since each Hobo can be tracked by its individual serial number), and the duration of data collection (there are 31 pre-defined selections ranging from 15 minutes to 360 days). As with all data loggers, the Hobo has a fixed memory size which determines the maximum number of data points it can retain (the standard model will record 1,800 points). The longer the data collection duration, the greater the time will be between samples. As examples, the 15-minute duration setting records and stores a temperature every 0.5 seconds, while the 360-day duration setting samples every 4.8 hours. Thus the duration should be set to the shortest period which still meets the need of the deployment period. Once the data logger is configured, it can be activated (or "launched"), disconnected from the serial cable, and placed in the cave.

When the Hobo is done collecting its information, it is retrieved from the cave, reconnected to the computer via the serial cable and the data is off-loaded into the program. A preliminary plot of the data is displayed immediately and the data can be saved in the program's native format. However, to statistically manipulate the data or make comparative plots, the data can be exported out to one of several industry-standard formats (ASCII, Excel, Lotus, and the like).

There is no maintenance to perform on the Hobo other than to change the lithium battery. Onset claims the battery will last a minimum of two years, although it may be prudent to change them more often considering the cost of the batteries is minor compared to lost research time and data. EEPROM memory is used in the Hobo, so if a battery does go dead, data recorded up to the time of the battery's demise can be recovered once a new battery is installed.

There are also no calibration adjustments (zero offset or gain) to make. This greatly simplifies the use of the instrument, but may also compromise the data recorded. Onset claims an accuracy of ±0.2°C within the temperature range of interest. My experience so far would concur with this stated accuracy, with little or no zero shifts observed after three years of using these data loggers. To check and document the accuracy of the data loggers with each deployment, I place all the thermistors in an ice bath to record "zeros" before installation and after removal in the caves. This allows verification of the instruments for zero drift during use, and allows the data to be zero-adjusted, if needed, during data post-processing.

As with all analog-to-digital recording devices, the Hobo is limited to recording temperatures at a fixed resolution determined by the bit-depth and range of the A/D chip. The Hobo uses an 8-bit converter meaning there are 256 possible steps. The Hobo is available in three standard ranges: -39°C to +123°C (0.63°C resolution), -37°C to +46°C (0.32°C resolution), and -5°C to +37°C (0.16°C resolution). For most in-cave situations, the -5°C to +37°C range is best. The -37°C to +46°C Hobo may be needed for capturing winter temperatures at or near cave entrances. If a finer resolution is required, Onset can custom build Hobos with custom ranges, but be prepared to pay a premium unless you are purchasing a large quantity of them.

The only significant disadvantage that Hobos have compared to a traditional multi-channel data logger is that there is no guarantee that the data at each location will be taken at exactly the same time. To "synchronize" the Hobos, you must launch each of them as quickly as possible, but this can take 20 to 30 seconds per data logger. Thus if you are using a dozen or so Hobos, the last Hobo launched may lag the first one by five minutes or more. This is not a major problem if your sampling intervals are large or the temperature transients are gradual.

In addition to non-synchronized launches, it is possible for the Hobos' sampling intervals to vary slightly since each Hobo is controlled by its own internal clock. With deployment durations of 9 to 12 months, even a small clock error could cause cumulative synchronization problems near the end of the sampling period. I have not observed any out-of-phase sampling which has exceeded one sampling interval, so Onset's clock circuit may be relatively accurate.

One final note. In addition to the standard Hobo, Onset offers enhanced versions including models with easier in-field launching, expanded memory for up to 32,000 data points, and sub-sampling between stored points to select average, minimum, or maximum samples observed. They also have data loggers to measure barometric pressure, humidity, light intensity, or voltage (allowing you to monitor other instrumentation with a DC voltage output).

A Case Study

By occupation, I am an engineer rather than a biologist. However, I have been interested in and involved with various aspects of bat research (specifically *Myotis sodalis*) for approximately 15 years, usually as an assistant to real biologists. As an out-growth of other bat research and protection projects, the interest in monitoring temperatures in bat hibernacula was born. The needs for such monitoring included:

- Collecting baseline temperature data that could be used later for comparison should an entrance be altered or a gate installed.
- Collecting baseline temperature data that could be used later for comparison should a bat population change significantly.

- Collecting hibernacula temperature profiles to compare with other hibernacula (that is, do the profiles look different for a hibernacula with a large and/or increasing population compared to one with a small and/or decreasing population).
- Collecting temperature data to compare locations within the same cave relative to the location where the bats cluster. Do the cluster locations within various caves correspond to the same temperature profiles?
- Collecting temperature data to understand fluctuations relative to the cave's outside temperature. Do the bats prefer a relatively stable temperature or are they tolerant to temperature fluctuations driven by outside temperature changes?
- Determining if a drastic bat population decline (that is, a catastrophic kill-off) can be caused by an extreme cold snap in a cave known to have temperature fluctuations driven by outside temperature? How tolerant to sub-freezing temperatures are bats?

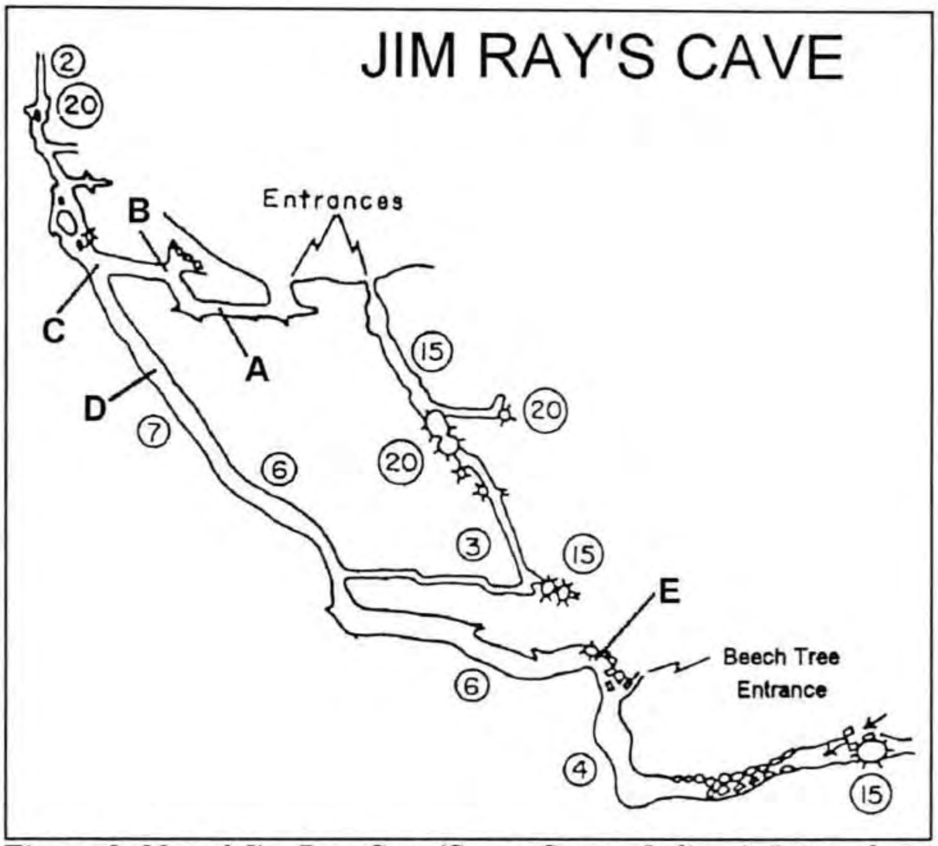


Figure 2. *Map of Jim Rays Cave (Greene County, Indiana). Letters depict locations of data loggers.*

The Caves

The specific temperature monitoring project I have undertaken involves three Indiana bat hibernacula in southern Indiana. The descriptions and reasons for investigating these caves are as follows:

- Jim Rays Cave is located in Greene County with a current population of approximately 40,000 Indiana bats making it the second largest hibernacula within Indiana. This population has been approximately the same for the last three censuses (41,854 in 1991, 38,386 in 1993, and 41,157 in 1995), which is significantly greater than numbers documented in the early 1980s (12,500 in 1981, 11,822 in 1982, and 13,475 in 1983). Furthermore, eight population counts performed between 1952 and 1975 never exceeded 3,200 bats.

Jim Rays Cave has over 8,000 feet of mapped passage, but the area of interest is the 800-foot horizontal trunk section between the main entrance and the "Beech Tree" entrance (see Figure 2) where all the bats are found. With the Beech Tree entrance being slightly higher, the cave creates a perfect winter chimney which draws cold air into the main entrance, making it suitable for *Myotis sodalis*. There has been much recent discussion as to whether the Beech Tree entrance has been enlarged (naturally or by cavers) over the past 20 years. Currently, the entrance is an easy crawl/climb-up, but several written descriptions in the 1970s called it "impassible." The unanswerable question: Has the Beech Tree entrance become larger, increasing the cave's airflow, thus providing a better habitat for the Indiana bat? While we can't move back in time, we can collect baseline data today for comparison should the Beech Tree entrance continue to enlarge or collapse in the future. There is also significant concern that this cave may now have too good of airflow, with a severe outside sub-zero cold snap causing a catastrophic bat kill-off in the cave.

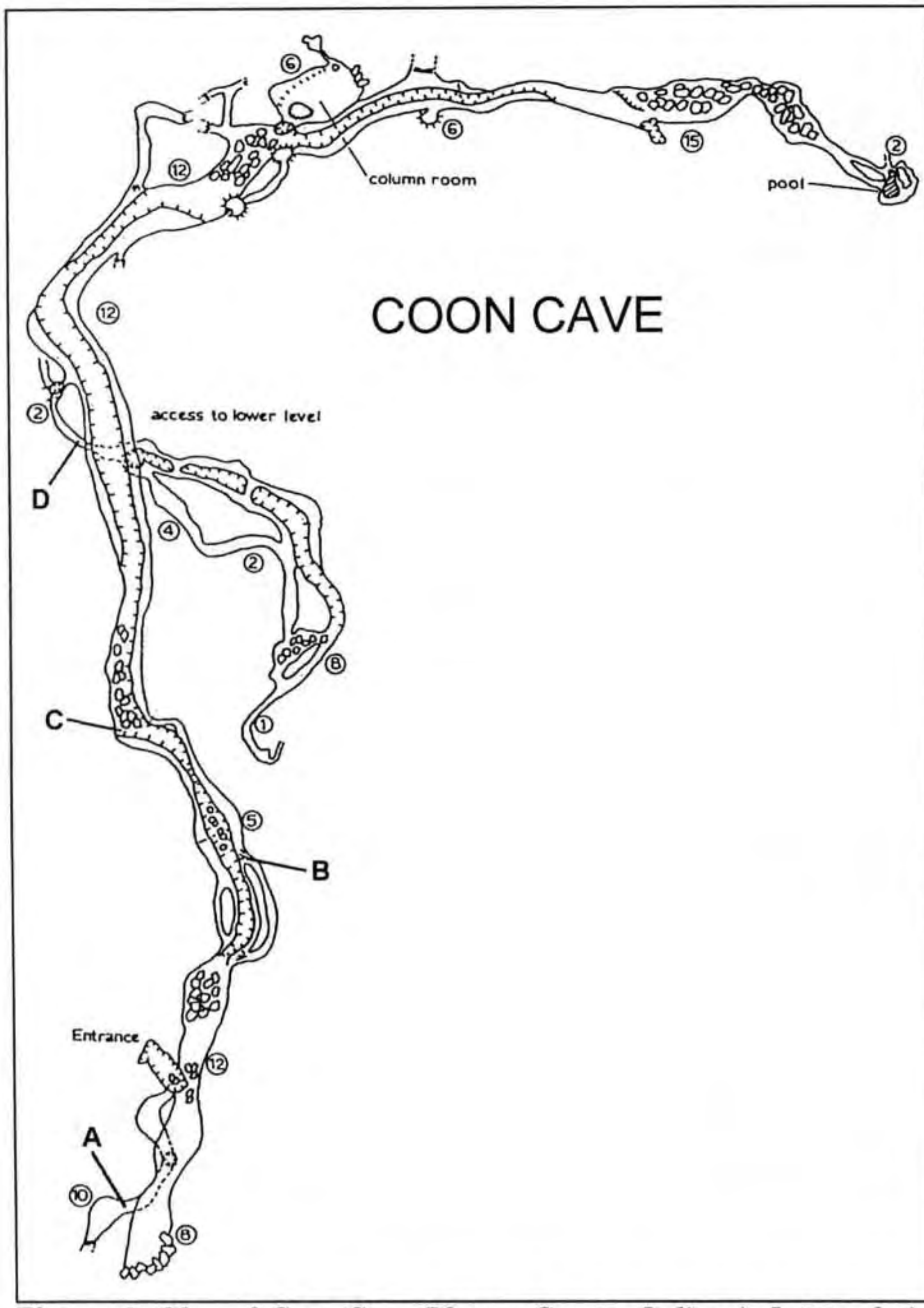


Figure 3. *Map of Coon Cave (Monroe County, Indiana). Letters depict locations of data loggers.*

- Coon Cave is located in Monroe County. Occasional population censuses in the 1950s through 1970s yielded only a few hundred bats. The first systematic census in 1981 counted 1,190 Indiana bats, but subsequent counts in 1982 and 1985 located only 550 and 777 Indiana bats respectively. However, since 1985, the population has steadily increased with the last two censuses (1993 and 1995) having counts of 4,451 and 4,455 bats. There is no clear explanation for this gradual increase.

- Grotto Cave is located approximately one-half mile from Coon Cave in Monroe County. Like Coon Cave, occasional surveys in the 1950s through 1970s documented only a few hundred bats, but systematic counts in the early 1980s found several thousand bats with a maximum of 4,198 Indiana bats counted in 1985. The next four biennial counts saw steady decrease with a low of 1,568 Indiana bats counted in 1993. The 1995 count saw an unexplained rebound to 2,018 bats. There is no clear explanation for this gradual decrease or the most recent increase.

Looking at the temperature profiles of the three caves, it will be of interest to see if there are similarities between Jim Rays Cave and Coon Cave with their generally increasing populations, compared to Grotto Cave with its generally decreasing population

In addition, all three of these caves are currently ungated, but it is likely that one or more will be gated at some point in the future. Having long-term baseline data will be very valuable for verifying that the gate(s) have not altered the air flow/cave temperatures.

Project Instrumentation

As a pilot project in September 1993, three Hobos were installed in Jim Rays Cave (locations A, C, and E in Figure 2) and a fourth Hobo used to record outside temperatures. On the whole, things worked as planned with two exceptions: 1) During an exceptionally cold spell, the -5°C to +37°C Hobo located nearest the main entrance (location A) missed data because the temperature dropped below its minimum range, and 2) A Hobo installed on a high ledge (at location E), but not completely concealed, was stolen sometime during the seasonal closure.

In September 1994, 14 Hobos were deployed as follows: five Hobos in Jim Rays Cave (A through E in Figure 2), one Hobo outside Jim Rays Cave, four Hobos in Coon Cave (A through D in Figure 3), one Hobo outside Coon Cave (also serving as Grotto Cave's outside data logger), and three Hobos in Grotto Cave (A through C in Figure 4). The two outside Hobos and location A and B in Jim Rays Cave used the -37°C to +46°C range instruments, the remaining data loggers used the -5°C to +37°C range. All the in-cave Hobos were placed at traditional cluster locations with their thermistors placed near or on the ceiling where the bats roost.

In September 1995, 15 Hobos were deployed, using the same 14 locations as the prior year, plus one additional Hobo installed at location C in Jim Rays Cave, placed near the floor to examine the ceiling-to-floor temperature gradient.

The Hobo deployment durations are approximately 220 days, from mid-September to mid-April. Using the 240-day setting, this provides a sampling rate of one sample every 3.2 hours (7.5 samples per day).

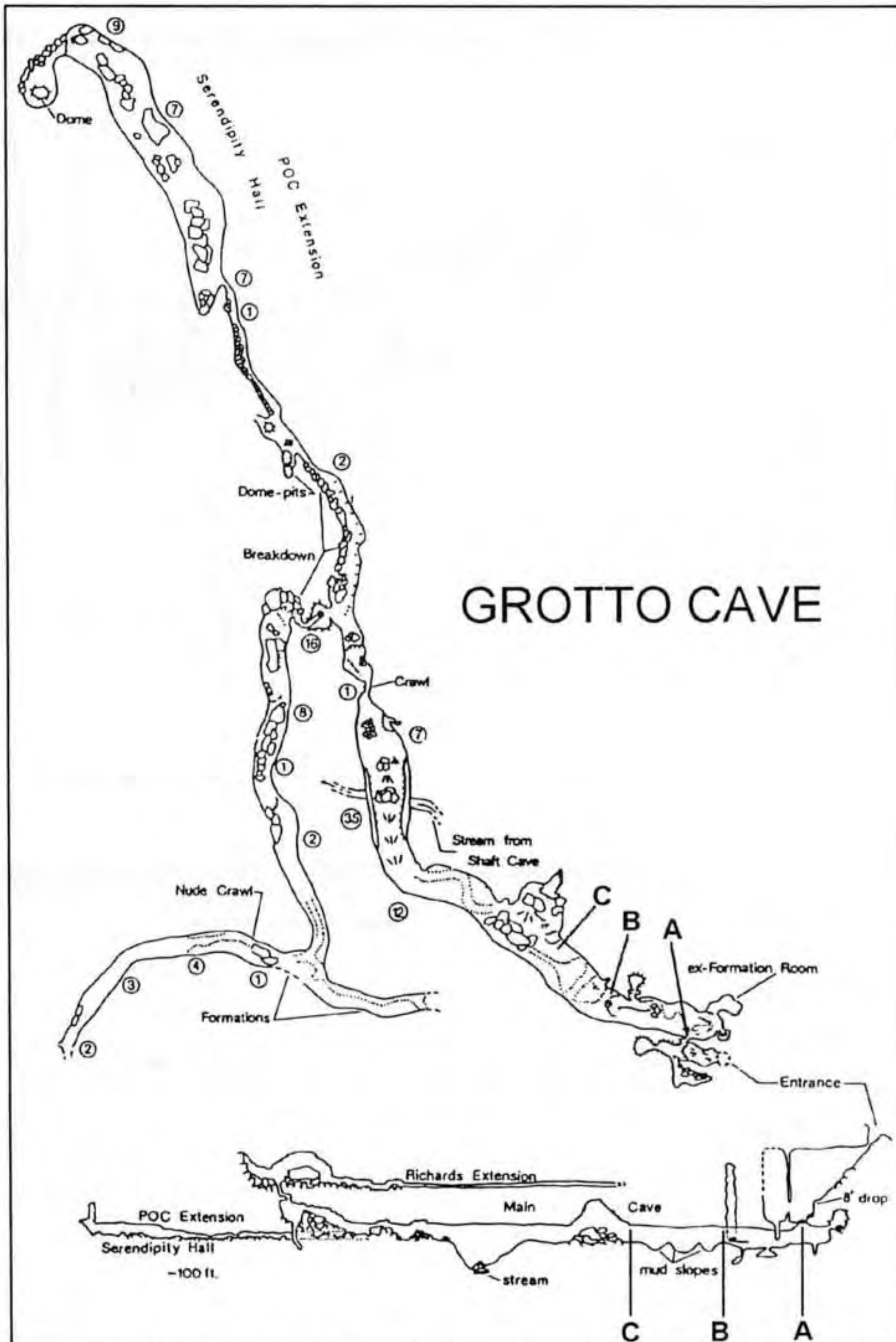
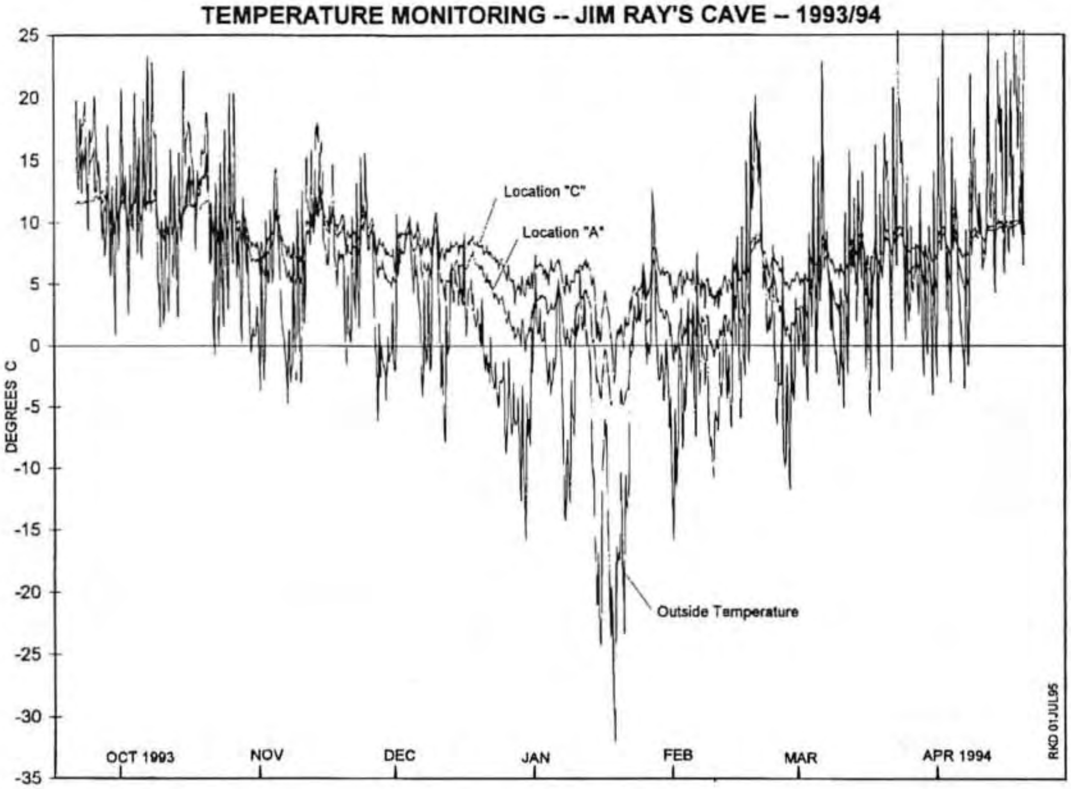


Figure 4. *Map of Grotto Cave (Monroe County, Indiana). Letters depict locations of data loggers.*

Preliminary Results

Since this project is only in its second full year of data collection, very few conclusions can be formed. However, I've included several plots of the raw data collected thus far to illustrate the temperature dynamics observed.

The data from the pilot experiment is plotted in Figure 5a (upper graph). This was recorded in Jim



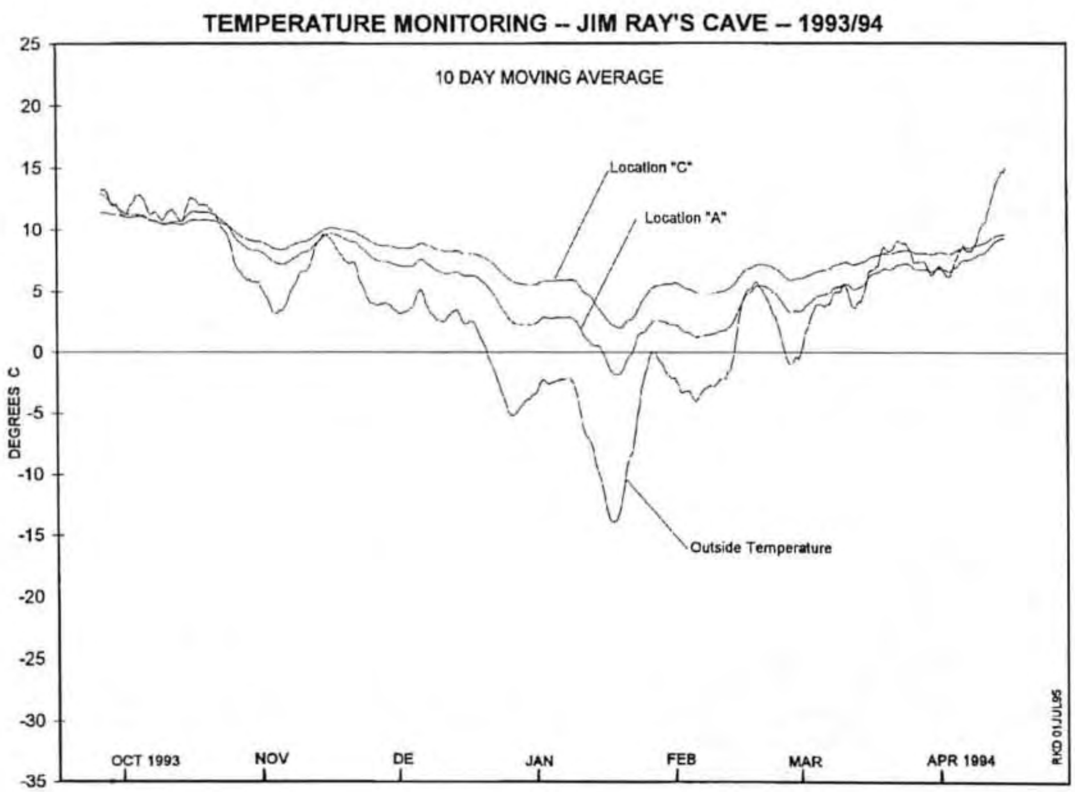


Figure 5. *Temperature data (raw and averaged) recorded in Jim Ray's Cave over the 1993/94 hibernation season.*

Rays Cave from late September 1993 to mid-April 1994. Referring to the map of the cave shown in Figure 2, location A is approximately 60 feet from the entrance and is the location where bats usually first start to cluster. Location C is approximately 190 feet from the entrance and is where the largest clusters are always found.

Of particular interest to note, the winter of 1993/1994 was one of the coldest on record, while the statewide temperatures on January 19, 1994, set many all-time, coldest-ever, records in Indiana. The data logger outside Ray's recorded a low of -32°C. At location A, the cave was below freezing for eight straight days, while the temperature at the main clusters (location C) was at or below freezing for over 24 hours with a minimum of -3°C recorded. In the past, there have been concerns that Jim Rays Cave, with its strong chimney-effect airflow, could cool too much and prove fatal to the bats. While there is no way to know if this extreme cold snap had any immediate impact on the bats, the 1995 census (one year later) did not reflect any population drop compared to the 1993 census that would support the theory that Indiana bats are tolerant to short periods of sub-freezing temperatures.

Figure 5b (lower graph) depicts the same temperature data, but using a 10-day (75 point) moving average algorithm. By smoothing the extremes, this graph provides a much easier way to compare cave-to-cave and year-to-year trends.

Figures 6a and 6b display the temperature data for Jim Rays Cave during the winter of 1994/1995. Additional locations were monitored as depicted on the map in Figure 2 and briefly described as follows: A—location of the first clusters, B—location of the first large clusters, C—location of the largest clusters, D—approximate end of the large clusters, and E—location of the bat's "active area" near the Beech Tree entrance.

What is most interesting is that location B (130 feet from the entrance) seem as responsive to outside temperature fluctuations as location A, but just a short distance further at C, the temperature is much more stable. This is even more remarkable considering the cave passage from the entrance to location B is on average only five feet high by five feet wide and contains several bends, compared to the straight passage from B to C which is 6 feet high by 15 feet wide.

Moving on to Coon Cave (Figure 3), data recorded during the winter of 1994/1995 is shown in figures 7a and 7b. Coon Cave's entrance is a ten-foot-diameter pit, 22 feet deep. At the bottom of the pit the main passage is intersected. Going right, one encounters another short pit with a small, elongated room at the bottom. Several hundred bats are generally found here and data logger A was placed in this room. From the entrance pit moving in the opposite direction, one walks up and over breakdown. The first bats are usually located under a knee-high ledge, approximately 70 feet from the entrance (location B). Approximately 110 feet beyond B is another large ledge where the largest clusters of bats are normally located (location C). The final clusters of bats are found in a rather obscure room (location D), approximately 150 feet from C.

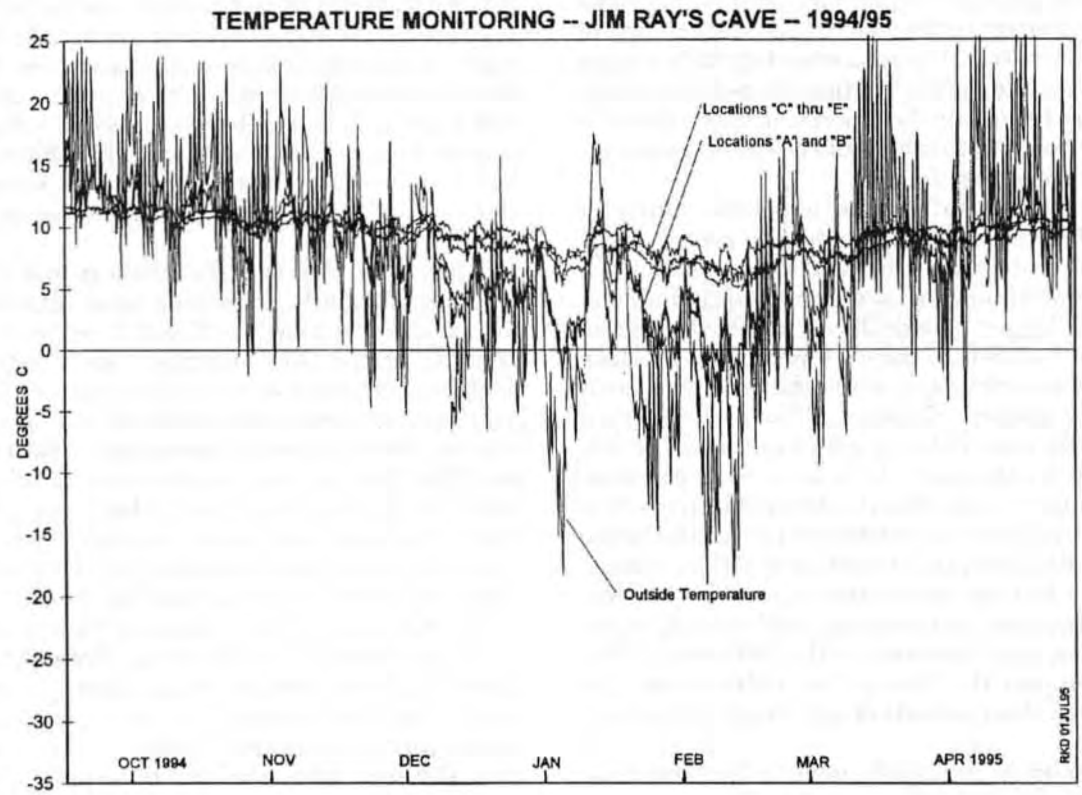
Looking at the data, locations A and B seem relatively dynamic, indicating good airflow with the outside. Yet locations C and D, where the vast majority of the bats hibernate, show very little fluctuation and are at the higher limit of the temperature range generally considered acceptable for *Myotis sodalis*. It is also interesting to observe that the 1994/1995 average temperature profile at location C in Jim Rays Cave, where the greatest number of bats were found, is nearly identical to the temperature profile at location A in Coon Cave, where only a few bats are typically found.

The final set of data shown in Figures 8a and 8b is from Grotto Cave (Figure 4). The entrance to Grotto Cave is a 50-foot, steep slope leading to a small climbdown into the main part of the cave. A data logger (location A—75 feet from the entrance) was placed in this climbdown to help quantify outside airflow into the cave. Unfortunately, the data logger malfunctioned several weeks after deployment (a bad EEPROM) so no usable data was collected.

At the bottom of the climbdown, a sizable (20-foot-wide by 10-foot-high) trunk passage is intersected. The majority of the Indiana bats are traditionally found on the opposite wall from the climbdown and extending towards the "mountain room." Location B on the map is central to the main cluster area, while location C is typical of where the last clusters are found.

The main observation of interest from Grotto Cave's 1994/1995 temperature profile was the unusually cool temperatures recorded at the start of the hibernation period, nearly 5°C colder than the constant rock temperature for central Indiana. Could this still be the cold air trapped from the previous record-cold winter, held in the cave all summer long?

Throughout the monitoring period, Grotto's temperature profile at the cluster areas seems several degrees colder on average compared to the main cluster areas in Jim Rays Cave and Coon Cave. This contradicts the discrete temperature data taken during 1987, 1989, and 1991 biennial censuses which had shown Grotto to be typically warmer than the other hibernacula. In fact, it was even suggested[3] that the decreasing population in Grotto Cave during this period compared to the increasing populations in Jim Rays Cave and Coon Cave might be directly



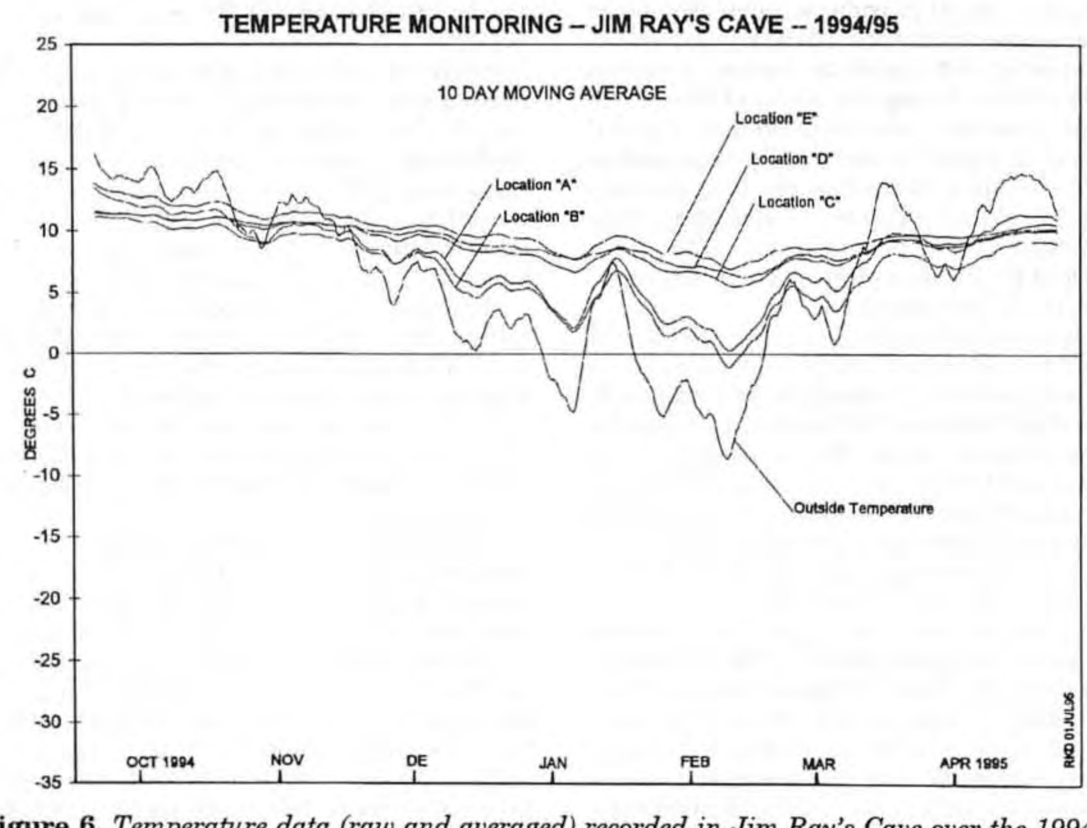
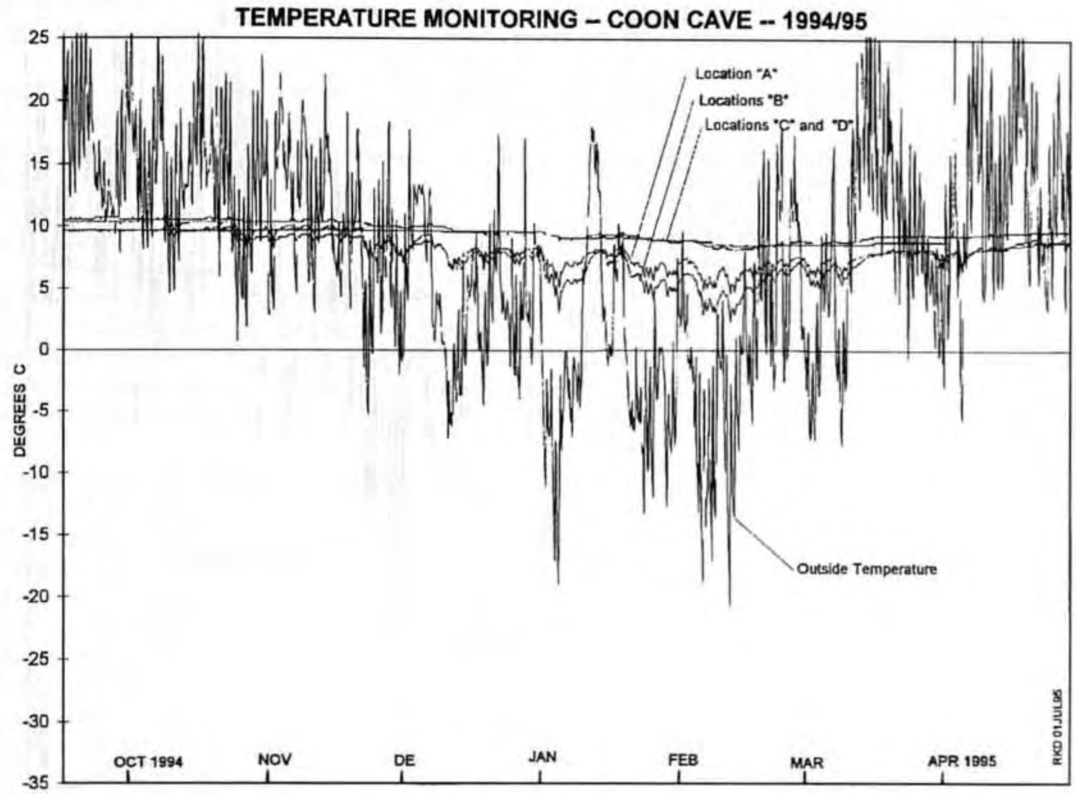


Figure 6. *Temperature data (raw and averaged) recorded in Jim Ray's Cave over the 1994/95 hibernation season.*



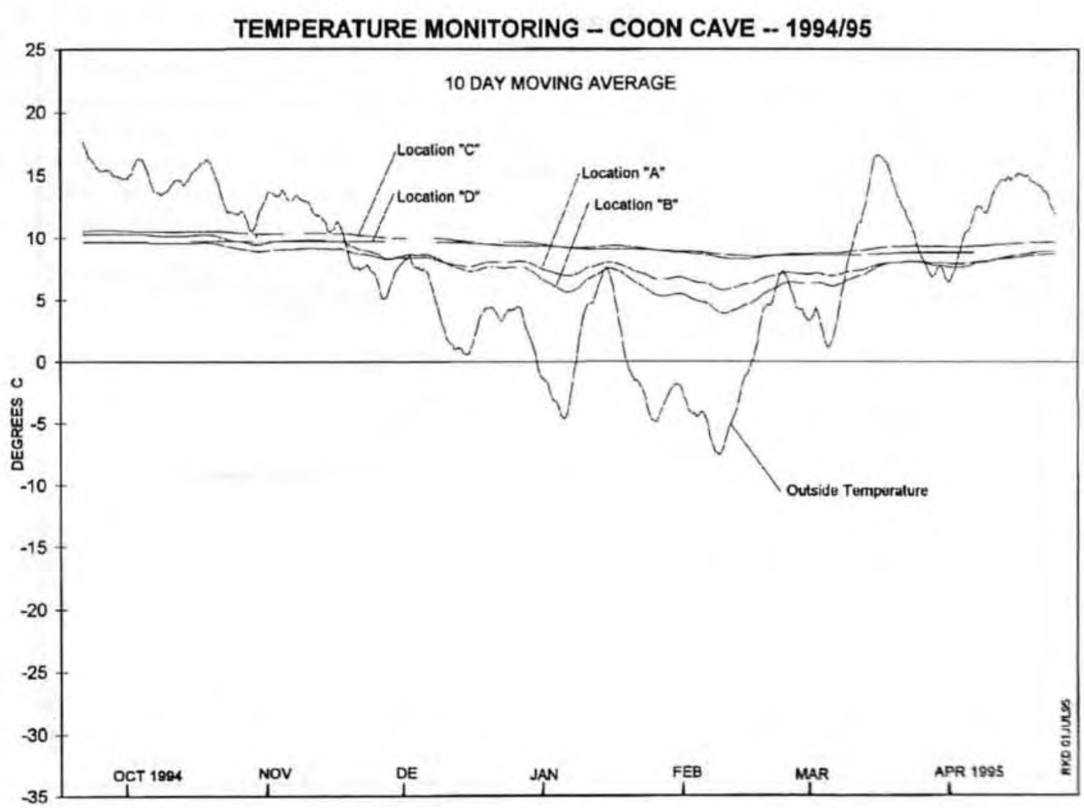
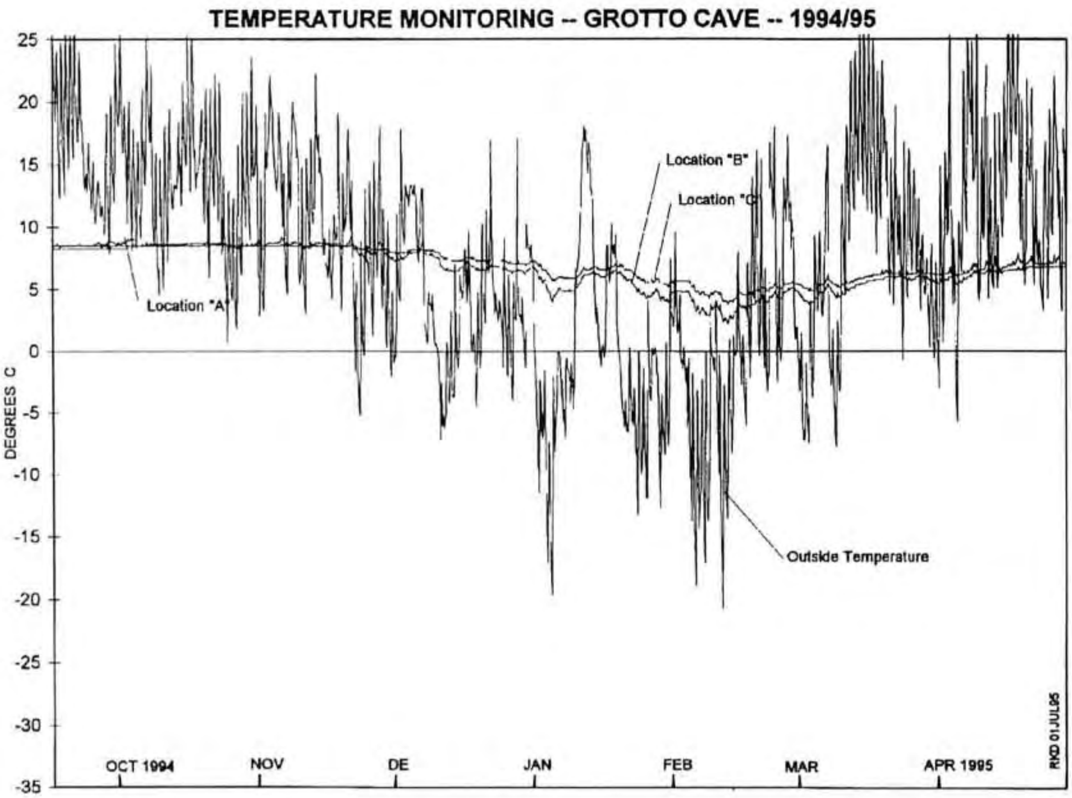


Figure 7. *Temperature data (raw and averaged) recorded in Coon Cave over the 1994/95 hibernation season.*



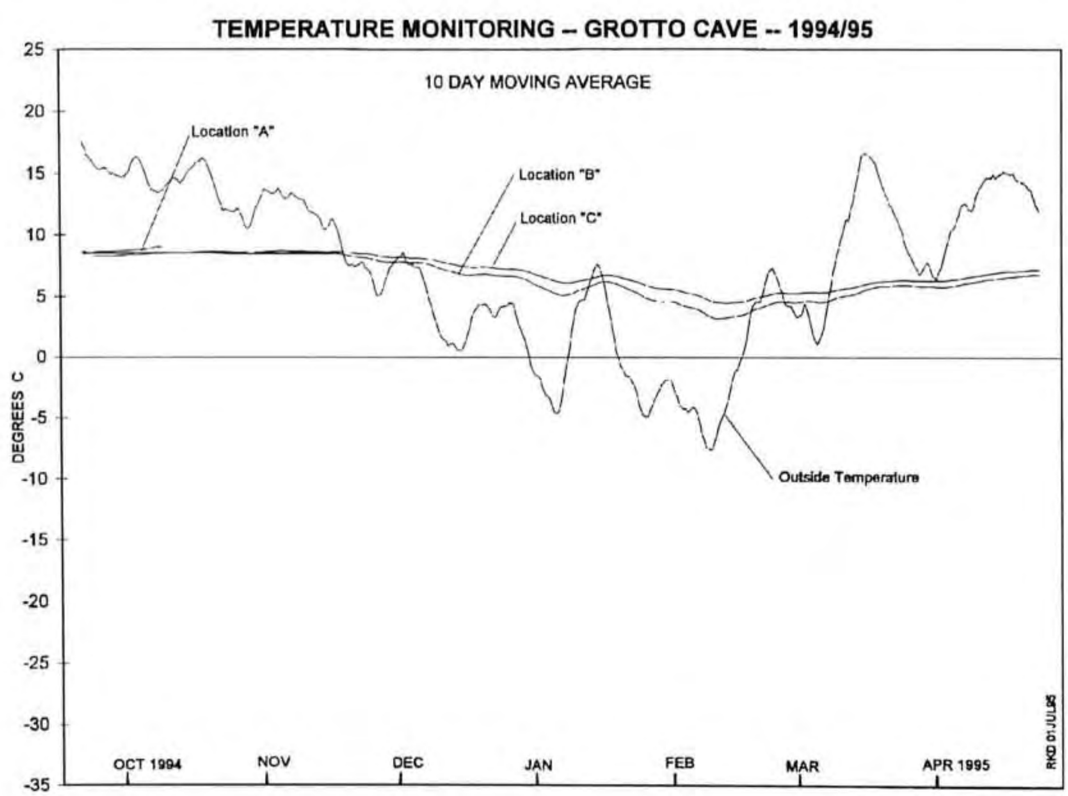


Figure 8. *Temperature data (raw and averaged) recorded in Grotto Cave over the 1994/95 hibernation season.*

related to Grotto Cave's warmer temperatures. Perhaps the comparative cooler temperature observed in 1995 helps to explain the first population increase in Grotto Cave in ten years. It may be found that Grotto Cave is a super-efficient air trap, with temperature cycles having cumulative effects spanning several years.

Conclusion

It is dangerous to draw conclusions from the limited data collected during the past two years, but it is becoming obvious that data spanning 10 or 20 years will be invaluable in answering lots of questions, some of which may not even be obvious to ask yet.

The technology to collect cave temperature data in the quantity and quality of the Hobo has been around for a number of years using multi-channel data loggers, but the simplicity and the relative inexpensiveness of the Hobo is what has made it available to the masses. While this paper focused on just one example for using the Hobo, there are literally hundreds of projects which could benefit from this type of data when it can be collected so easily and cheaply.

Future plans for the Indiana bat hibernacula temperature monitoring project will include one to two more years of data collection as currently outlined. The number of data loggers will then be reduced to just one or two per cave, with the remaining Hobos re-deployed to other hibernacula. It is also anticipated prices of the Hobo will decrease with time, allowing more devices to be purchased. With only twenty *Myotis sodalis* hibernacula known in Indiana, it is very realistic to expect that we will eventually collect data within all of them. This could allow us to develop a full spectrum of temperature profiles and possibly even characterize the conditions that make these unique hibernacula suitable for the bats.

Acknowledgement

I would like to personally thank Scott Johnson, nongame biologist for the Indiana Department of Natural Resources for his assistance in the field work. I would also like to thank Dr Virgil Brack, Jr for his input on this project and his long-term commitment to the study and census of the Indiana bats in Indiana. Finally, I would like to acknowledge the financial assistance provided by the Indiana Department of Natural Resources' Nongame and Endangered Wildlife Special Projects grant program.

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Protecting the Ancient History of Crumps Cave

Shelly Forbis
Valerie Haskins
David G. Foster

Abstract

Crumps Cave in south-central Kentucky is one of only a handful of caves in the eastern United States which contain prehistoric glyph drawings. The mud glyphs have been seriously vandalized and have been threatened with increasing vandalism since their discovery in the 1980s. In February 1994, the American Cave Conservation Association directed one of the largest cave-gating projects ever attempted to protect the ancient mud glyphs of Crumps Cave. The project involved over 100 volunteers from the National Speleological Society and the Cave Research Foundation and archaeologists from the University of Louisville, the University of Kentucky, and Eastern Kentucky University. Funding was provided by the Kentucky Heritage Council and the American Cave Conservation Association. This paper will describe the volunteer effort to protect Crumps Cave, and explores the historic and cultural significance of the cave.

It took six tons of steel, over a thousand work hours, and the combined efforts of nearly 100 volunteers to build the second largest bat cave gate in the world. People came from all over Kentucky and nearby states to help protect the fragile mysteries lying within Crumps Cave in the karst-rich region of south-central Kentucky.

Crumps Cave was "discovered" by European settlers sometime around the turn of the 19th century. The cave was known as an archaeological site as early as 1922 and was frequented by local explorers and "potholers." Yet, for most people, Crumps Cave was simply another large cavern in an area which seemed to have more than its share of large caverns. After all, nearby Mammoth Cave was an international tourist attraction when most of Kentucky was still considered part of the American frontier. So it is not surprising that, given the wealth of cave resources in the area, Crumps Cave had been overlooked for many years by the outside world. A fascinating discovery in 1989, however, changed all of that. This is the story of the discovery that led to a dramatic volunteer effort to protect Crumps Cave for future generations.

History

In 1802, Jacob and Mariam Wright built the first homestead near the cave's entrance. Their brick home was situated on a 300-acre tract of land in close proximity to the cave. The cave was of great importance to the Wrights, as it was to later owners, for its abundant water supply.

Over a hundred years ago, a white, wood-frame house, built by David Kirby, replaced the brick home; it is this house which today stands as a sentinel overlooking the cave entrance. William Crump purchased the house and the property from David Kirby in 1887; the Crumps owned the cave and adjacent property for 73 years. Since that time, the cave has been known as Crumps Cave.

Inside the cave's spacious entrance stand two large cedar tanks. They have endured as reminders of a time when the lives of the nearby occupants depended upon the cave for water. In 1890, William Crump erected the tanks to function as receptacles for water obtained from the cave. Pipes extended from the tanks into a dome where water precipitated from the ceiling and walls. A series of pumps—kerosene, gas, and electric—conveyed the water to a tower at the house. The water that accumulated at the tower was distributed to the farmhouse, barns, and a tenant house on the property. When Edward Spears acquired the property in the 1960s he ceased using the cave as a water supply.

The cave's size and location near a growing Kentucky community made it inevitable that large numbers of visitors would walk its somber halls. One of the earlier explorers to this dark, underground realm left his mark. Inscribed, in pencil, at the entrance to the cave's first crawl is this message left by a 19th century evangelist:

MY DELIGHT IS IN THE LORD
R.H. FITE EVANGELIST
OLATHE, KANSAS
SEPT. 1, 1897.

Legend has it that Andy Lee Collins, brother of the famous explorer Floyd Collins, discovered a

Figure 1. *The view looking down the trunk passage of Crumps Cave. Photo by Karl Niles.*

hidden crawlway which led to a passage filled with gypsum flowers. From there the passage continued to an enormous room decorated with stalactites and stalagmites. (To this date, that passage has not been rediscovered, although there has been extensive exploration in the cave.)

The early farmers apparently explored the cave to its maximum length. Graffiti, marked both with lead pencil in the 1800s and inscribed in the clay walls throughout the 1900s, provide a record of the historic exploration of the cave. The earliest recorded date is 1807, a date scribbled on the cave wall by a member of the Kirby family.

The cave was also "discovered" by pot hunters as an unparalleled archaeological site. Until W.C. Mills, a former owner of the cave, installed a wooden gate, looters unearthed and carted away bags of Native American artifacts.

For many years the landowners kept people out of the cave. But, as evidenced by the increase in graffiti, more people ventured into Crumps Cave in the 1960s through the 1980s. Unfortunately, the entrance room was used as a trash dump. The present landowners purchased the property in 1988 and have been actively involved in cleaning the cave and protecting it from further vandalism.

The archaeological significance of Crumps Cave was noted periodically throughout the twentieth century. In 1975, Ken Carstens visited Crumps Cave in July as part of the archaeological research for his dissertation. He noted some vandalism of the prehistoric cultural deposits in the entrance rooms at that time.

When Carstens returned to the site in September to assess the cultural deposits, he noted that approximately one third of the 300-square-meter entrance room had been affected by additional vandalism since July. Carstens and his crew made preliminary excavations and left the site due to time constraints.

By the time Carstens returned in November, 90 to 95 percent of the site had been destroyed. Thankfully, valuable data had been collected by the initial excavations, but this concluded the last formal archaeological investigation of Crumps Cave until the recent project.

The Discovery

The discovery of one of Kentucky's most important archaeological finds in 1989 suddenly vaulted the heavily-vandalized cave from obscurity. A group of local cave explorers from nearby Western Kentucky University had entered the cave in 1989 to survey its extensive passages. The group, known as the Green River Grotto of the NSS, noticed a mysterious series of markings on a mudbank half a mile back into the cave.

As they examined the markings more closely, they grew more excited. There, barely visible in the glow of their carbide lights, were numerous geometric designs, animals, and human figures drawn in the soft mud. Unfortunately, vandals had also left their marks in the mud and had obliterated some of the glyphs.

The Grotto members contacted Dr Charles Faulkner of the University of Tennessee and Phil DiBlasi of the University of Louisville because of their familiarity with prehistoric mud glyphs of the Southeast. Dr Faulkner visited the cave shortly thereafter and confirmed that the glyphs were indeed created by prehistoric Native Americans. In 1991, archaeologists Dan Davis and Valerie Haskins began working to photograph and document the Crumps Cave glyphs.

Prehistoric Glyphs

The first two years of the glyph study were spent surveying, photographing, and drawing the prehis-

Figure 2. *A series of glyphs referred to as the "Family Portrait." There are five human figures represented. Photo by Karl Niles.*

toric glyphs. The style of the forms led Haskins and Davis to believe that the glyphs were probably created during the Mississippian period about 900 years ago. The glyphs are similar to forms recorded by Faulkner and others in Mud Glyph Cave in Tennessee and a handful of other caves in the southeastern U.S.

Most of the inscriptions are "squiggles" and other geometric shapes such as chevrons. However, human and animal figures are also inscribed in the clay walls of the cave. These figures include forms which may represent a serpent, a deer, and a turtle. Many of the drawings have yet to be interpreted. At least two of the human drawings appear to be females. Representations of females have rarely been found in the prehistoric Native American art of the Southeast.

Because of the damp conditions and heavy traffic across the cave floor, little charcoal or carbonized material is present. However, organic material (probably bark) is imbedded in at least one glyph. Haskins and Davis originally planned to remove this material for radiocarbon dating; instead, they utilized pieces of a charred cane torch lying within the deep inscription forming the "leg" of one of the female figures. Surprisingly, the radiocarbon date obtained from this bit of charcoal indicates that at least some of the glyphs were drawn about 1,980 years before the present, probably sometime between 90 B.C. and A.D. 30. This is about 1,000 years earlier than was originally thought.

The earlier radiocarbon date has led to considerable debate as to whether the glyphs were created by Mississippian peoples, or by earlier prehistoric people. As in many archaeological inquiries, much more information is needed in order to understand the glyphs of Crumps Cave. What is undisputed, however, is that they are extremely rare and that great care must be taken to ensure their protection.

Protecting Crumps Cave

Obviously, with the discovery of the rare glyphs, archaeologists were concerned about protecting this fragile cultural resource. Unfortunately, the cave has a large entrance that is easily accessible and vandals, probably unknowingly, had already destroyed much of the prehistoric record in Crumps Cave. It was felt that gating the cave would be the only viable protection.

The task would be formidable. The entrance passage to Crumps Cave is approximately 65 feet wide and up to 10 feet high in places. In order to maintain the airflow and meteorological conditions present in the cave and to provide a circling area for bats, the gate needed to be built in this substantial passageway. The gate would also have to be constructed in a manner that would not impact endangered bats that seasonally occupy the cave. Furthermore, to ensure that the gate did not impact significant archaeological resources, every inch of a 65-foot-long trench below the gate's footer would have to be excavated and meticulously screened by archaeologists before the gate could be constructed.

The Kentucky Heritage Council provided grants to the American Cave Conservation Association and the Cave Research Foundation to design and build a gate. The Kentucky Heritage Council grants were sufficient to purchase the materials to construct the massive gate but were not nearly enough to provide a labor force to build it. In the fall of 1992, American Cave Conservation Association staff accepted a contract to direct the project and began garnering support for the project among volunteer caving groups. At the same time, Kentucky Heritage Council archaeologist, Valerie Haskins, began contacting archaeological groups throughout the state to obtain support to conduct the massive dig.

The project date was set for the first weekend of February 1993, a date that gave us great concern

Figure 3. *Dave Foster sifts through mud from the trench where the gate will be located. Photo by Karl Niles.*

After the steel was stacked near where the gate would be constructed, everybody joined the archaeological teams. The rest of the afternoon and the next day were spent sorting, sifting, and recording the archaeological materials that were found.

By the end of the weekend, numerous artifacts had been uncovered, but nothing was found that would preclude the construction of the gate. It was the opinion of archaeologist Valerie Haskins that most of what was being excavated was the backfill from previous looting of the cave.

because of the rough winter we had already experienced. We were working within a strict time frame to accommodate the schedules of our construction crews and to meet the deadline for the grant funds. A bad storm could cost us many of our volunteers and delay the project another year.

We arrived at the cave site early on Saturday morning to find that fate had conspired to reward our initiative with a beautiful weekend of sunny 60° weather. We watched in amazement as carload after carload of volunteers rolled into the driveway leading to the Crumps Cave farm. What a turnout! National Speleological Society members from around Kentucky and adjoining states had responded enthusiastically to the call for help. American Cave Conservation Association members showed up from several surrounding states. Archaeologists from Eastern Kentucky University, The University of Kentucky, the University of Louisville, and other local archaeological clubs also responded to the call. By mid-morning over 80 volunteers had assembled at the cave entrance.

The group was quickly organized into two teams. Those with archaeological experience began the process of excavating and screening the trench which would underlie the cave gate. The remaining volunteers began the arduous process of transporting 5½ tons of steel into the cave, a distance of approximately 500 feet.

The length and weight of some of the steel bars complicated this process. It took teams of eight people to lift and carry some of the heavier pieces.

The Gate

The arduous process of constructing the gate was completed in weekend increments over the next two months. A smaller gating crew was assembled to begin the more technical work of cutting steel and welding the pieces of the gate together under the supervision of Roy Powers, American Cave Conservation Association's Vice President of Conservation Programs. Roy's task was to construct a "bat-friendly" cave gate that would also be extremely difficult to breach.

Although we had plenty of eager help, only a few of the volunteers had previous cave gate construction experience. We desperately needed welders and steel cutters. Fortunately, Powers brought an experienced crew from Virginia to help.

Kelly Wilson, a professional welder and member of the nearby Green River Grotto, offered to provide the remaining welding services needed. During the course of the project, Kelly also managed to teach several Green River Grotto and Bluegrass Grotto members the basics of welding. We speculated that the project's motto should be "protect a cave . . . learn a new trade."

Over four weekends, approximately 10 to 15 volunteers faithfully kept the project moving forward. Although the basic construction of a cave gate is relatively simple, the reality of building a metal structure 65 feet long in a cold, dark, wet environment is fraught with complications. After many hours of sweat equity and problem solving, the door to the gate clanged shut as a

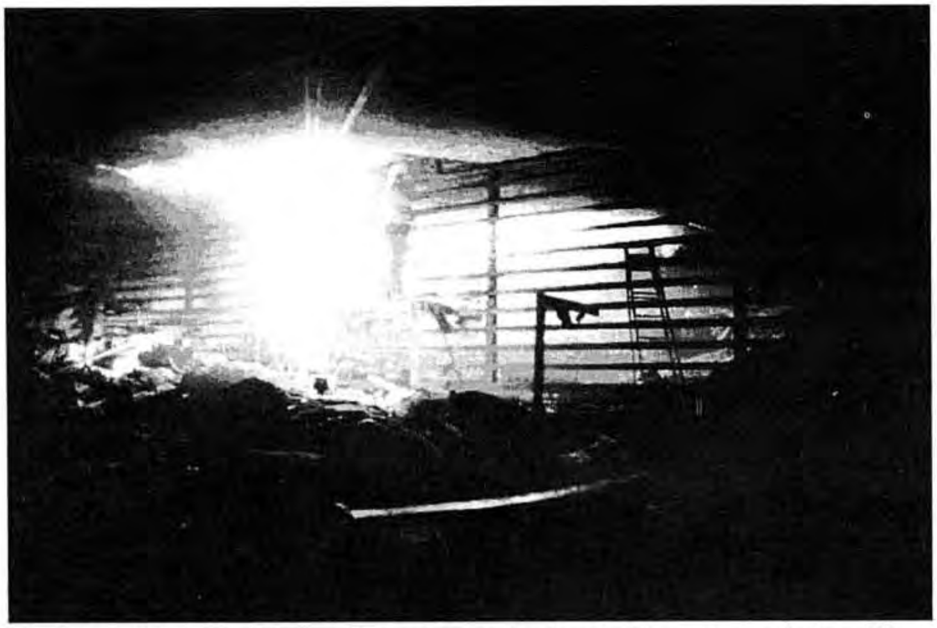

Figure 4. *The second largest bat cave gate in the world nears completion. Photo by Karl Niles.*

group of weary cave gaters looked on. We were too tired to celebrate, but Crumps Cave was finally safe.

Conclusion

Although the funds provided by the Kentucky Heritage totalled only $6,500, the return on the investment was great. Over 11,000 pounds of steel were used and over 1,300 volunteer hours were donated to excavate for the gate footer and to build the gate which, according to Roy Powers, is the second largest bat gate in existence. The credit goes to the successful partnership between the Kentucky Heritage Council; the American Cave Conservation Association; the Green River, Bluegrass, and Louisville Grottos of the National Speleological Society; the Cave ResearchFoundation; and archaeologists and cavers from nearbystates.

The gate was completed on April 8, but the story is not yet finished. If the gate is to deter future vandalism, we must maintain it and monitor its condition to ensure that it is not breached. A volunteer project to paint the gate will be held in the upcoming year. In addition, a management plan must be developed to set up rules for access to the cave. Analysis of the artifacts collected from the excavation is still in process and documentation of the glyphs is ongoing.

The lessons learned at Crumps Cave are valuable for all who venture into caves. There are still important archaeological discoveries to be made in the depths of America's caves. To ensure that future discoveries are not lost forever, cave explorers must learn to recognize and take care not to damage such resources when they are encountered. We must be prepared to respond quickly and effectively to protect them once they are discovered. Without the Green River Grotto's initial recognition of the glyphs' significance they most certainly would have eventually been destroyed by vandalism. Thanks to a great many volunteers, the ancient mudglyphs of Crumps Cave are still there, protected, and waiting for future archaeologists to unravel their meanings.

Learning To Live With Caves And Karst

The Educational Program of the American Cave and Karst Center

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Abstract

In 1993, the American Cave Conservation Association opened the American Cave and Karst Center in Horse Cave, Kentucky. This was the culmination of a decade-long dream to establish a national educational center and museum for caves and karst resources. One of the primary missions of the Center is to develop educational programs to increase understanding of natural resources in karstlands. The Center's educational programs are focused primarily on school children. Children are fascinated by caves; the Center's museum, cave, and programs provide a vehicle to help demystify science. This paper describes the educational programs that have been developed at the Center, including curriculum materials, school newspapers, slide programs, brochures, and teacher-training workshops.

Introduction

Cave and karst science in the United States is a relatively young field. Cave and karst education is even less established. While there are a few practitioners, such as Tom Aley at the Ozark Underground Lab, who have been doing it for more than two decades, public education about karst is in its infancy in most places.

Despite the lack of educational programs focused on protecting caves and groundwater environments, karst problems routinely destroy irreplaceable resources and affect millions of Americans. Pollution of karst groundwater systems and unwise land-use decisions in karst areas can lead to costly environmental mistakes in rural communities that can ill afford them.

Unfortunately, dramatic improvements in the protection and wise use of natural resources in cave and karst areas will not occur until the public has a vastly improved understanding of the nature and value of these resources. Additionally, the public must understand that, while these resources can be used, abuse of the resources has dire environmental, social, and economic consequences. The same applies to groundwater resources, whether in karst areas or elsewhere.

Bringing Earth Science Down to Earth

Although I had been involved with cave conservation for many years previously, the inadequacy of public school teaching about karst did not really hit home until I had the experience of working as a student teacher at a school in Bowling Green, Kentucky. The City of Bowling Green is built above a major cave system and is located near Mammoth Cave National Park in one of the world's most extensive karst regions.

Bowling Green has suffered from numerous high-profile environmental problems related to the underlying karst topography. Stories on karst have been regularly featured in local newspapers. One would think that teaching about the nature of karst regions would be an important part of local earth-science classes.

The reality was that the earth-science course that I observed in Bowling Green provided almost no information to students about local geologic conditions. At least half the year's curriculum focused solely on "space science." Consequently, students were more familiar with the atmosphere on Jupiter than with the world-class karst area beneath their feet.

It is no mystery why space science is emphasized in public school earth-science classrooms. Even today, science education is still feeling the effects of the Eisenhower and Kennedy administration's focus on improving science education in the late 1950s and 1960s, ostensibly with the goal of regaining scientific preeminence after the Soviet Union's launching of *Sputnik*. Consequently, NASA provides excellent teacher packets and lesson plans to teachers. These children grow up to become strong advocates for America's space program. However, back on planet Earth, we haven't done so well. Most teachers are inadequately trained and do not have appropriate instructional materials to enable them to conduct meaningful interpretation of local geologic features and land-use-related issues. And yet, karst problems are widespread. Approximately 20 percent of the United States and 40 percent of the heavily-populated lands east of the Mississippi River are underlain by karst. Substantial numbers of people are impacted annually by karst issues.

These impacts are poorly recognized because karst problems generally occur in rural areas and affect only a few people or businesses at a time. Taken as a whole, karst problems cause more damage in the U.S. than spectacular events, such as earthquakes; however, an earthquake affects many people all at once.

Thus, the reasoning behind designing structures in California that can withstand earthquakes is obvious to most people. Californians have learned that to live successfully in their environment they must make certain adaptations to geologic problems. Likewise, the people who live in karst areas need to recognize the importance of adapting to karst areas where subsidence damage and easily-contaminated groundwater are big problems.

Existing Educational Programs

Although public education about karst resources needs improvement, it is not for lack of adequate research or the availability of advanced educational training. Educational programs in groundwater hydrology and water resources management are becoming well established at colleges and universities in the United States. Degree programs and programs with emphasis in groundwater hydrology are available from several institutions of higher learning; many of the courses offered in groundwater hydrology are required for such degrees.

Educational programs on groundwater resources which are focused on school children and the general public are, however, extremely limited. A few federal and state agencies have prepared pamphlets and other materials for educational and public distribution. The greatest public exposure to groundwater-resource issues is through the press and its coverage of problems and disasters. While this attention has raised groundwater to a national issue, it has resulted in a public perception that is unbalanced. The public recognizes the problem of groundwater pollution without understanding what they can do to prevent it.

Education about cave resources is also available, but limited. Undergraduate courses in speleology, cave biology, and other cave-related subjects are taught at many colleges and universities in the United States. Such courses are taught at least occasionally in 50 to 100 schools. The courses are typically offered in biology, geology, physical education, or geography. Most of these courses are electives. Few are required for a particular degree program.

Few existing educational programs on cave and karst resources focus on school children and the general public. One such program, focused on elementary students, has been developed by Fantastic Caverns in Springfield, Missouri. Teachers are provided with a study plan and manual, an educational film is available, and educational tours of the cave are provided. It is an excellent program which reaches 10,000 students each year.

Show caves in the United States provide guided tours to approximately seven million people per year. The typical cave tour provides some public education. The trend in the private show cave industry is toward tours which provide more information to visitors. The trend at public show caves is mixed. The relevance and interpretive quality of tours at some of the largest public show caves has diminished in recent years while it has notably improved at some of the caves which have lesser annual visitation.

A few grottos of the National Speleological Society provide programs on cave conservation to civic organizations and schools. These programs are primarily provided by volunteers and vary widely in quality and scope. In general, the National Speleological Society's educational programs are targeted towards members of the caving community and not at the general public, with a few notable exceptions, such as the programs provided by the Richmond Area Speleological Society.

The Ozark Underground Laboratory has developed an intensive educational field-trip program for high school and college students. It is basically a day-long program which stresses interactions between the surface and subsurface resources (including caves). This program has been in operation for 20 years; about 70 sessions are run each year. Reservations are required, and the demand for the program exceeds the time available. The Ozark Underground Laboratory is now working at capacity, and has no plans to expand facilities or staff.

The Environmental Protection Agency's Non Point Source Program has supported the development of karst education programs in several states. Some of these are excellent programs; however, they are unlikely to be continued once their two- to three-year grant cycle is completed. Educational efforts, no matter how good, will be ineffective unless they span generations.

In summary, most of the public education programs available in the United States are isolated efforts which vary in quality and are primarily locally based. There is no national-level karst education program which attempts to reach areas which are receiving no karst education and enhance those programs already in existence.

Consequently, most children living in cave and karst areas receive little or no education in cave and karst resources or groundwater resources prior to entering college. Only a small percentage of college students take courses related to these topics. Filling the pre-college educational gap is the primary objective of the educational programs of the American Cave and Karst Center.

Creating the American Cave and Karst Center

Over the past decade, the American Cave Conservation Association has committed the bulk of its resources towards development of the American Cave and Karst Center. We have focused on creating this Center because of the need to make a dramatic effort to overcome the lack of public awareness and public interest in cave and karst issues. Caves and groundwater resources are largely hidden from public view.

Figure 1. *Hidden River Cave in Horse Cave, Kentucky.*

Only a small percentage of the public actively engages in the sport of caving. Consequently, one must first make the public aware that resource problems exist, and that they are significant problems, before any headway can be made to address these problems. Having a national facility, such as the American Cave and Karst Center, facilitates raising funds, less reinventing of the wheel, development of better educational programs, and greater public awareness of cave and karst issues.

The difficulty in finding funding sources for cave conservation required that a unique fundraising mechanism be utilized to create the American Cave and Karst Center. By tying into the economic revitalization plans of the City of Horse Cave, the American Cave Conservation Association was able to leverage over 1.2 million dollars from economic development agencies and organizations. These funds were used to create the American Cave Museum with exhibits focused on caves and groundwater.

This culminated in the opening of the Museum in 1993 and reopening of part of Hidden River Cave in 1994. A comprehensive museum exhibit plan, developed by Chase Studios and the Ozark Underground Laboratory, provided the framework for exhibits. The first phase of exhibits included a major interpretive section focused on people, caves, and groundwater. Additional exhibits focused on cave geology and biology are planned, but are as yet unfunded. With the museum project on track, the American Cave Conservation Association board and staff began working to develop the educational programs of the Center.

American Cave and Karst Center Educational Programs

The American Cave Museum and Hidden River Cave

The American Cave Museum and newly-restored Hidden River Cave provide a unique opportunity to educate thousands of people annually about cave conservation issues. Current museum exhibits explore groundwater issues in both karst and non-karst regions. A number of exhibits focus on man's cultural history and interaction with caves. Exhibits that are planned but have not been constructed yet include overviews of cave biology, geology, paleontology, and meteorology.

Hidden River Cave has dramatically recovered from the groundwater pollution that led to its closure in 1943. The American Cave Conservation Association reopened part of the cave in 1993 and will be working to restore additional parts of the historical section over the next two years.

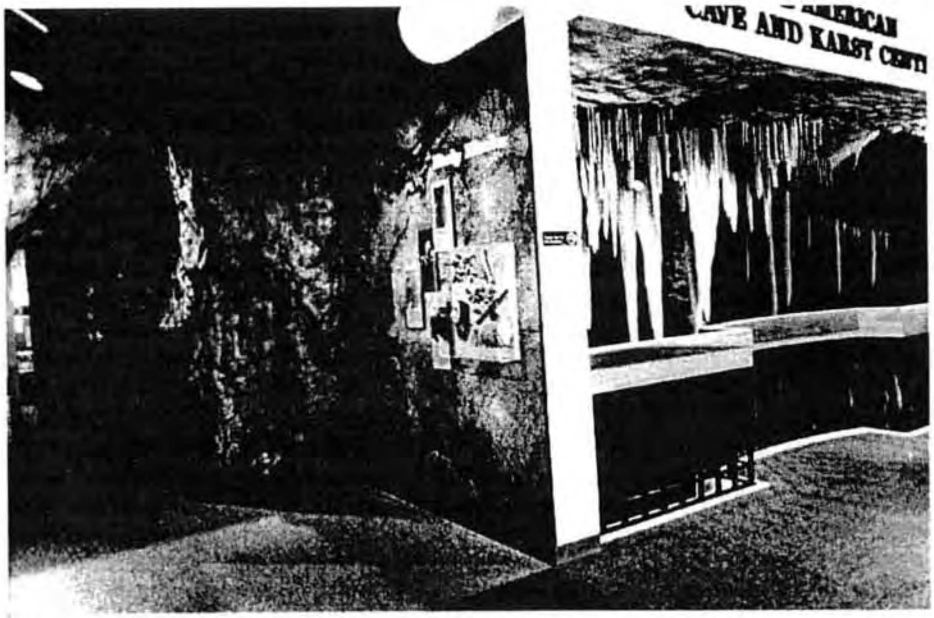

Figure 2. *American Cave and Karst Center exhibits.*

In keeping with this concept, we have developed a variety of educational packages for school and community groups which allow teachers to spend anywhere from an hour to a full day at the American Cave and Karst Center. Exhibit A is an example of one of our teacher mailouts which describes the various educational offerings at the Center.

The goal of restoring tours in Hidden River Cave is to provide an opportunity for people to directly experience an active karst groundwater system. Hidden River Cave's remarkable recovery provides a success story which can help visitors understand why cave resources are important to people.

The cave itself will serve as an educational laboratory for the teaching of groundwater science. We will avoid offering a "standard" cave tour, and instead develop learning activities in the museum, along the trail to the cave, and in the cave which enhance visitor understanding and appreciation for cave and karst resources. In essence, the cave will be an extension of the museum.

For instance, in 1996 we are installing a groundwater monitoring probe in the Hidden River which will be capable of identifying levels of dissolved oxygen, nitrates, pH, and other groundwater quality parameters. In addition to providing useful research information, the probe will be an important part of the cave tour interpretation. The equipment will allow the Center's guides to discuss and demonstrate groundwater science in action.

Learning to Live With Caves and Karst Curriculum

One of the primary reasons why information about caves and karst resources is infrequently presented in America's schools is the lack of appropriate educational materials. Most of the materials available were developed by the show cave industry to aid teachers who were bringing kids on field trips to caves. This material was primarily in the form of general information which the teacher could use to develop lesson plans.

In cooperation with the Kentucky Division of Water, the American Cave Conservation Association researched existing curriculum material and developed a curriculum for both student and teacher use. The Learning To Live With Caves and

Figure 3. *American Cave and Karst Center exhibits.*

Karst Curriculum consisted of nine topic areas which could be taught separately or in their entirety. Each topic section contained a short information section, an interesting article entitled "The Big Story," and an activity that went along with the topic.

The curriculum allows teachers to design an entire unit around caves. The curriculum is also flexible enough so that the biology teacher could teach a section, the art teacher could teach a section, the science teacher could teach a section, and so on. Furthermore, the curriculum followed the language of the Kentucky Educational Reform Act, an important consideration in getting teachers to use the materials.

The curriculum is available free of charge to Kentucky teachers, and for a small fee to cover costs to out-of-state teachers. The curriculum is not only in use throughout the United States, parts of it have been adapted for use in curricula under development by other organizations and individuals.

American Cave Adventures Newspaper

One of the goals of the American Cave and Karst Center is to strongly improve public education about karst in Kentucky schools, and particularly in the region surrounding Hidden River Cave and Mammoth Cave National Park. To accomplish this, we have developed an educational newspaper which is distributed to science, biology, and history teachers in Kentucky's karst areas.

The newspaper, called *American Cave Adventures* is modeled after the *Ozark Adventures* newspaper developed by Fantastic Caverns in Missouri. We publish 50,000 copies of *American Cave Adventures* twice a year and bundle them into packets of 30. These packets are sent to approximately 1,500 Kentucky teachers on our mailing list. The teachers then distribute them to their students. Each issue highlights an important karst topic, includes an article or articles about a project or program in which kids are involved, and provides a short puzzle or activity.

Teacher Workshops

The American Cave and Karst Center's teacher training program will begin in the spring of 1996. This aspect of our program is an effort to get as many teachers as possible involved in karst education. Since many educators are unable, or unwilling, to travel to Horse Cave to participate in the programs there, we are setting up a workshop series which will be held throughout Kentucky over a two-year period. Our hope is to directly involve approximately 500 teachers in these workshops.

We will be hosting a minimum of 20 workshops in 1996 and 1997. We expect to sponsor programs at the following locations: the American Cave and Karst Center, Carter Cave State Park, Mammoth Cave National Park, Land Between the Lakes, Otter Creek Park, Salato Wildlife Education Center, and Eastern Kentucky University. Additional sites are also being sought.

Conclusion

In developing the educational programs of the American Cave and Karst Center, we have tried to develop learning opportunities for students (through the American Cave Museum and Hidden River Cave); educational materials to facilitate learning (such as the curriculum and school newsletters); and a training program to reach teachers throughout Kentucky.

The programs we are providing in Kentucky are impacting several million people annually through museum visitation, educational materials that are printed and developed, and the publicity generated by our media campaign to increase television and newspaper coverage of cave conservation issues. It is our hope that the American Cave and Karst Center will substantially improve the level of teaching and public awareness about cave and karst resources throughout the United States. Ultimately, a better-informed public will result in improved protection of cave and karst resources everywhere.

EXHIBIT A.

Thinking about educational field trips?

. . . Please consider visiting the

American Cave Museum & Hidden River Cave!

The American Cave Museum features:

- An environmental education center operated by the American Cave Conservation Association (ACCA)
- Exhibits on geology, history, earth science, cave exploration, archaeology, and groundwater protection
- An interpretive walk into Hidden River Cave where students see an underground river and a recovering cave ecosystem
- A museum store with books, posters, minerals and rocks, puzzles, patches, dinosaurs, and more. Prices range from 25¢ and up.

Environmental Education Programs:

- Package A: $3.00 per student. 2-2 1/2 hours. Includes: 45-minute guided walk into Hidden River Cave & 2 group activities**
- Package B: $4.00 per student. 3-4 hours. Includes: 45-minute guided walk into Hidden River Cave & 3 group activities**
- Package C: $25.00 per student. 3 1/2-4 hours. Hidden River Cave Ecology Tour
- Package D: $27.00 per student. 3 1/2 - 5 hours. Hidden River Cave Ecology Tour & 2 group activities **

☞ New In 1996: ☜

Hidden River Cave Ecology Tour

Students explore upstream passages along unimproved trails in Hidden River Cave. Designed to explore the factors that contributed to the contamination of the cave and its remarkable recovery. Should be considered strenuous. No one under age 12 permitted. Stresses the importance of cave safety. Focuses on protection of cave resources and groundwater. Tour Features: an underground river; a turn-of-the century waterworks system; a variety of cave animals, including blind cavefish and crayfish; pristine flowstone and impressive dome rooms. Cave helmets provided.

** Suggested Group Activities:

Museum scavenger hunt; Cave Life; Bats & Their Habitats; Food Chain; Water Testing; Native American Culture; Early Kentucky History; The Story of Floyd Collins; Sinkhole Models; Community Planning. Other activities from ACCA's curriculum, "Learning To Live With Caves & Karst."

Please Note: ACCA staff will work with teachers to develop a program specifically designed to meet students' learning objectives. All times are suggested times; the length of the group activities depends on the teacher's schedule and the size of the group.

The American Cave Museum and Hidden River Cave are located in downtown Horse Cave, Kentucky, 2 miles east of Interstate 65 off Exit 58. Other area attractions include: Kentucky Down Under; Horse Cave Theatre; Mammoth Cave National Park; Crystal Onyx Cave; Mammoth Cave Wildlife Museum; and Diamond Caverns.

For Reservations or Additional Information: Write or call: The American Cave Museum, P.O. Box 409, Horse Cave, KY 42749. Telephone 502-786-1466.

Cave Permits and Permitting Systems

James R. Goodbar
Cave Specialist
Bureau of Land Management
Carlsbad, New Mexico

This paper discusses the reasons and some of the decision factors involved in initiating a cave permitting system. It covers some of the pros and cons of the different management philosophies of permit systems and the different types of permitting systems that are available for use. Also addressed is what should be contained in permit applications and the permit forms as well as a discussion of applicant screening.

One of the first things a cave manager should ask himself before deciding to initiate a cave permitting system is, "Why," or, what do I want to accomplish by requiring cave permits? There are two basic reasons to gate caves. One is to protect the cave and its resources from human impacts, and the second is to protect unsuspecting visitors from any hazards the cave may have to offer, such as pits, unstable ceilings, dangerous gases, or diseases like histoplasmosis. If the cave is on federal lands the Federal Cave Resources Protection Act requires that significant caves be protected. One way to provide a cave protection is to gate it and require permits for entry.

If a cave is gated and still made available for recreational use, some kind of permit system is needed. There are several philosophies when it comes to permitting depending upon the intensity and level of management involvement that is desired. Budget, manpower, and the availability of a specialist to administer the program may be some of the factors used in choosing which approach is best in your situation. At one end of the spectrum is a high amount of management interaction in which permits would be required for all caves whether they were gated or not. At the other end of the spectrum is a low level of management involvement which would not require permits for any caves. There is also a middle ground in which some caves are permitted and some are not. At some point in the decision making process a determination must be made as to whether permits will be required and if so which caves should be part of the permitting system. This determination can and should be guided by the inventory for each cave.

There is, of course, the philosophy that says that all caves should be closed and no one is allowed to enter for any reason. While at first this approach seems the easiest way out, in the long run it may prove to be very costly. Gate fabrication and installation in order to enforce the "NO ENTRY" policy will be expensive and the maintenance of those gates when people break them to get in anyway will also be costly both in materials and manpower. Additionally, the loss of exploration and research that could be conducted in the caves would deprive the land manager of vital information necessary to make informed and sound resource management decisions.

For instance, knowing that an interconnecting system of sinkholes and cave passages provide the ground water recharge area for a city's drinking water would be a major decision factor in choosing the location for a land fill for that area. Further, the impacts of a poorly-designed cave gate on that cave's ecosystem could be devastating to the biological community as well as some of the mineral formations.

Managing at the lowest level necessary (with the least management involvement) and still protecting the cave's resources and public safety is another philosophy. This approach requires an entry permit only for those caves containing high resource values or safety hazards. On these caves, management would need to maintain a higher level of control. Some of the situations which may prompt the use of permitting at this level might be: the presence of bat colonies that need seasonal or year-round protection, a cave that has known health or safety hazards such as air borne diseases or CO_2 gas, highly fragile formations or ecosystems, or cultural remains to name a few. The advantage to this approach is that it puts the least amount of restrictions on the user by not requiring permits to enter all caves. This leaves the spontaneity of going caving in the hands of the caver. Additionally, it is less work for the manager. It requires less time commitment, less man power, less gate installation and repair, and less money, but still leaves the manager in control of the more sensitive cave resources. This is the approach taken by the Bureau of Land Management Carlsbad Resource Area.

One of the disadvantages to this approach is that the manager does not have a accurate record of who is visiting the caves or the number of visitors using the caves. This can be compensated to some extent by the installation of registers in those caves where permits are not required. It is a good idea to put registers in permitted caves as well. This serves as verification of a party's visit and can also be used in visitor impact studies. It can give an indication of how many visitors actually make it to a specific area of the cave. For example, a register is placed near the entrance area of the cave and another is placed at a less accessible and more fragile portion of the cave. If 100 people are permitted to visit the cave and 75 of those visitors sign the entrance register and 25 visitors sign the back register, this information can be very useful in monitoring visitor use impacts and determining use limitations.

In permitted caves, comparing the number of signatures on the register with the actual use (the number of people who have signed the permit) can give an estimate of the percentage of the people who sign registers. For example, if 100 people have signed permits and 75 of them have signed the register in the cave then 75% of the people using the cave are signing the registers. This information can be used in caves that don't require permits but do have registers. Dividing the number of signatures on the registers by 0.75 will give the estimated "actual" use of those unpermitted but registered caves.

Another approach is to permit all caves. This requires a bit more management involvement. If there are to be physical controls to enforce the permit requirement that equates to a large commitment of time, money, and manpower to install and maintain the gates and locks needed to provide those physical controls. Bear in mind, not all caves lend themselves to be gated. Additionally, it requires more manpower to issue the permits and keep track of the system. The advantages to this approach is that management has very good visitor use records and much more control over cave use. This approach is used by the Guadalupe Ranger District of the Lincoln National Forest.

There can be any number of variations on these approaches. Carlsbad Caverns National Park has adopted an approach in which only ten caves are open for recreational use. All the rest are available only by special permit, that is for research or science trips. This has the effect of concentrating all of the recreational use on a specific number of caves and limiting the traffic and visitation in the rest. This is not considered to be identifying "sacrifice caves," but rather identifying those caves that have the highest recreational appeal and making them available to the public.

All three of the agencies mentioned above may be contacted to find out more information about their respective cave permitting systems.

Once an approach has been decided upon there are a number of different permitting methods to choose from. For each permitted cave a resource evaluation or inventory should be conducted to determine which method is best suited for that cave. This evaluation and determination can be done using the information in the cave inventory records, from first-hand knowledge of the cave, and from consulting with those people who are most familiar with the cave. Once a permitting method has been selected, that doesn't mean it cannot change. If at a later date the management situation changes due to newly-discovered information of increased visitation which has lead to unacceptable impacts to the cave, that may require the cave to be reevaluated and a new permitting method established.

The following are some of the different permitting methods that may be applied.

The General Permit

This is probably the most common type of recreational permit issued. It is primarily used to authorize access to caves or sections of caves which are not particularly subject to unintentional damage. Other than the standard types of stipulations and requirements of all permits there are few other restrictions.

Trip Leader Permit

This type of permitting requires that the trip leader (the person to whom the permit is issued) must have been to the cave a certain number of times in order to qualify for being issued a permit. The documentation of their visitation is easily acquired by looking at the signed and returned permits of their previous trips. This method can be used for caves that have moderately high resource values that may be subject to damage by the casual or unobservant user. The purpose of the trip leader is to thoroughly explain to the group all the areas in which to be careful.

Designated Trip Leader

The designated trip leader is the next level of protective permitting. In this method the agency designates specific people who are accepted as trip leaders for that particular cave. A list of these people is kept in the cave's case file. This method may be used for caves which have highly sensitive or fragile resources that are easily subject to damage. The individuals that are accepted as the designated leaders should be very accomplished cavers who know the cave intimately and can effectively serve as a trip leader. That means that if the trip leader feels that the group or a member of the group is not up for the trip then he may cancel the trip or ask the individual not to go with the rest of the group.

Guided Trips

With guided trips, a member of the agency leads the group. The purpose for guided trips is to provide the visitor with specific management guidance such as in caves having unique and highly sensitive resources or during restoration trips, mock rescues, collection trips, or on any trip where close supervision is necessary. The guided trip is by far the most costly to the agency in terms of manpower and money, however, it can also be some of the most rewarding to the visitor in terms of the personalized environmental education that can be given and the opportunity to develop good cave stewards.

It is often convenient to have a *cave entry application*. This allows the agency to get a limited amount of information about the visitor, such as: name, address, home and day-time telephone numbers, who to contact in case of an emergency, what caves they want to visit and their preferred and alternate dates, and signatures of the parent or guardian of those who are under 18 years old. Figure 1 is a sample of an application.

The permit itself should contain some basic information which includes: the name of the permittee, the cave(s) which they are authorized to visit, the authorized date of entry, the number of people permitted, and the signature of the authorizing officer. Signatures should also be provided by all those who enter the cave. Other items which might be useful to include on the permit are: The laws and regulations which protect caves, an indemnity clause, where and when to return the permit, and some general rules of conduct in the cave. Figure 2 is a sample of the permit used by the Roswell District of the Bureau of Land Management.

Permits may be restricted in other ways. They can limit the number of persons to enter the cave per trip and also limit the number of trips per week, month, or year. Establishing these restrictions should be closely tied to the use of the inventory and classification system in conjunction with information derived from visitor use data and cave register information.

Once a permit is issued, a Special Stipulations and Hazards Sheet may be enclosed with it (Figure 3). This sheet gives specific information about the hazards and restrictions particular to that cave. It also has the combination to the lock on it. This ensures that the permittee has a copy of the special stipulations and hazards prior to entering the cave. On the back of the Special Stipulations and Hazards Sheet is some general safety and conservation information. The object is to give the cave user the most information possible in order to make their trip safe and enjoyable, and provide the cave with the most protection.

Should *anyone* who wants a cave permit be able to get one? That is a sensitive question involving liability and the rights of the public to use public land resources. One of the goals of a conscientious cave manager is to match the group to an appropriate cave. In this way the group will be less likely to inflict damage on the cave and on themselves as a result of inexperience. It also helps to ensure that an enjoyable recreational experience.

A screening process is a good way to try to fit the caving group to a cave that is best suited to them. The screening involves asking the applicant some basic questions concerning the experience level of their group. Include questions such as: How long have the members of your group been caving? What types of caves have they been in? What level of climbing experience do they have? Do they have any vertical experience?

These types of questions will give the cave manager an idea of the competence level of the group and their leader. To some extent the group should be governed by the least-experienced member. However, a certain amount of flexibility can be exercised. After the initial screening process, it may be a good time to suggest a particular cave that is suitable to that group. Of course, that requires that the person conducting the screening and issuing the permit knows something about the caves to which they are issuing permits.

If people want to go caving or become interested in caves the best we can do, as cave managers and resource protectors and educators, is provide them with the best conservation and safety information we can. This lets them know that caves are important and need to be cared for and that there are people and organizations available from which to learn more about cave resources.

If you think educating the inquiring public about cave resources is too expensive a price for the caves to pay, just try ignorance.

UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT

CARLSBAD RESOURCE AREA, P.O. Box 1778, Carlsbad, NM 88220 (Ph: 505-887-6544)
ROSWELL RESOURCE AREA, P. O. Drawer 1857, Roswell, NM 88202-1857 (Ph: 505-624-1790)

APPLICATION FOR CAVE ENTRANCE PERMIT(S)

Including Trip Leader, Minimum Group Size Is THREE People.

Complete and return to the appropriate address - allow two weeks for processing.

A. **Cave Name(s) and Interior Destination(s)** — **Intended Use Date** — **Alternate Dates: 2nd Choice, 3rd Choice**

Cave Name(s) and Interior Destination(s)	Intended Use Date	Alternate Dates 2nd Choice	3rd Choice

B. **Person(s) to be Contacted in Case of an Emergency:**

____

____

Name, Address, Zip, Area Code, Day and Night Phone Numbers

C. **Trip Leader (Must be 18 years or older):**

1. ______________________________
   Name, Address, Zip, Area Code, Day and Night Phone Numbers

♦♦♦ Names, Addresses, Phone Numbers of other people who will enter the caves(s):

2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

♦♦♦ The consent of a parent or legal guardian is for all individuals under 18 years of age who will not be accompanied on the proposed cave trip by their parent or legal guardian. Please complete Consent Section on reverse of this application.

D. **Purpose of Visit:** Recreation ☐ Photography ☐ Education ☐ Research ☐ Inventory ☐ Mapping ☐ Administrative ☐ Other: Describe ____________________

NM060-8380-2

Figure 1. *Cave Entrance Permit.*

E. Parental or Legal Guardian Consent

As part of the application to enter the cave(s) administered by the Bureau of Land Management, I consent to allow my child to participate in the proposed cave trip. The trip leader named on this application form is delegated the responsibility for the care and instruction of my child while he or she is in the cave(s). By my signature on this form, I also agree on behalf of my child to be bound by the permit General Conditions and any Special Stipulations that will apply to authorization for the cave visit.

CHILD'S NAME AND AGE (Print)	SIGNATURE OF PARENT OR LEGAL GUARDIAN
1. ______________________	______________________
2. ______________________	______________________
3. ______________________	______________________
4. ______________________	______________________
5. ______________________	______________________
6. ______________________	______________________
7. ______________________	______________________
8. ______________________	______________________
9. ______________________	______________________
10. ______________________	______________________

Figure 1 (reverse).

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

SPECIAL RECREATION PERMIT - CAVES

ROSWELL RESOURCE AREA, P. O. Drawer 1857, Roswell, NM 88202-1857 (Ph: 505-624-1790)
CARLSBAD RESOURCE AREA, P.O. Box 1778, Carlsbad, NM 88220 (Ph: 505-887-6544)

__________ CAVE (PMT. NO. ______) DATE ______
__________ CAVE (PMT. NO. ______) DATE ______
__________ CAVE (PMT. NO. ______) DATE ______
__________ CAVE (PMT. NO. ______) DATE ______

Permission is hearby granted to __________ and a party of up to ____ other people as reflected by signatures below to enter the above named cave(s), located on public lands. Authorized by __________ Date ______

PLACE THIS FORM ON VEHICLE DASH, THIS SIDE UP

The following signatures indicate that permittees have received and understand information provided by the BLM on hazards which may be found in the cave(s), and agree to comply with the general conditions and the attached Special Stipulations ______ for this authorization:

1. __________ (Permittee) 6. __________
2. __________ 7. __________
3. __________ 8. __________
4. __________ 9. __________
5. __________ 10. __________

GENERAL CONDITIONS:

1. This permit neither authorizes nor implies permission for the intentional or unintentional damage or removal of cave resources, such as: archaeological and historical artifacts, natural materials or features, plant and animal life, or any item of public property. Violations of federal or state laws, general conditions or special stipulations are punishable, upon conviction, by fines up to $10,000.00, or imprisonment not to exceed one year, or both (Public Law 96-95, Public Law 100-691, Federal Cave Resources Protection Act of 1988, 43 CFR 8364.1, 43 CFR 8360.0-7, 30-15-6 NMSA 1978).

2. This authorization is validated only upon signature of the Permittees, and is valid only for those individuals whose signatures appear hereon.

3. Each person in the caving party will wear a safety helmet (hard hat) with chin strap at all times while in the cave(s) and have in their possession <u>at least two sources of light.</u>

4. At least one person in the caving party must be 18 years of age or older and will be responsible for the actions of younger members of the party.

5. This authorization is issued only for the time period specified on the face of this permit. It is revocable for any breach of conditions hereof, or at the discretion of the Authorized Officer of the Bureau of Land Management at any time upon notice. This authorization is subject to valid adverse claims heretofore or hereafter acquired. (General Conditions Continued on Reverse).

IN CASE OF EMERGENCY: (505) 624-1790, ROSWELL/(505) 887-6544, CARLSBAD, OR CONTACT STATE POLICE OR CALL 911.

Figure 2. *Special Recreation Permit—Caves.*

GENERAL CONDITIONS (continued):

6. Permittees shall exercise diligence in protection from damage of the land and property of the United States covered by this authorization, and shall pay the United States for any damage resulting from negligence or from the violation of the terms of this authorization or of any law or regulation applicable to public lands.

7. Permittees agree as a condition precedent to the issuance of this authorization, to indemnify, defend, and hold harmless the United States and/or its agencies and representatives against and from any and all demands, claims, or liabilities or every nature whatsoever including, but not limited to, damages to property, injuries to or death of persons arising directly or indirectly from or connected in any way with the use and occupancy of the lands and cave(s) described on this authorization.

8. All materials (flagging tape, litter, etc.) taken into the cave(s) by the Permittees must be removed and properly disposed of at the end of each cave visit.

9. All pets are prohibited from entering cave(s).

10. All fences and gates that are equipped with locks are to be secured while permittees are in the cave and before they depart from the cave area. Mechanical problems with locks will be promptly reported to the authorizing officer.

POST-TRIP COMMENTS: ____

YOU MUST RETURN THIS FORM WITHIN 5 DAYS

FOLLOWING COMPLETION OF THE CAVE TRIP.

Failure to return this form may jeopardize the issuance of future cave permits.

Return this form even if the trip is canceled.

Figure 2 (reverse).

HAZARD AND SPECIAL STIPULATION SHEET MKC

McKittrick Cave

(Upper & Lower Sinkhole Locks; ____Pit Entrance; ____)

GENERAL HAZARDS:

All wild caves, by their very nature, contain some hazards. Make your trip a safe and enjoyable one by being prepared and careful. General safety hints for exploring wild caves are listed on the reverse side of this page.

Just about all caves contain some hazards which are common to the underground environment, such as loose rocks, low ceilings, low tight passages, slippery surfaces, and unstable and uneven floors. Be prepared by wearing proper equipment, following safety hints, and using common sense.

Specific hazards described below are those which are known by BLM, but additional hazards due to natural causes could have occurred since the cave was last inspected.

SPECIFIC HAZARDS:

1. Rattlesnakes have been seen in or near all entrances.
2. One entrance is an 18 foot pit which can be chimneyed with difficulty. Unless you're good at friction climbing, either avoid this entrance or use a rope. The pit does not have to be entered to see the cave.
3. This is a maze cave. You cannot get lost, but you could become disoriented.
4. There are a number of low crawls throughout the cave.
5. Low ceilings.
6. Walking is difficult in many areas due to numerous small holes in the gypsum floor.
7. There is an interior pit approximately 15 feet deep located in the passage leading from the #1 entrance. Use caution as the hand and footholds are not readily apparent.

SPECIAL STIPULATIONS:

1. No renewable or nonrenewable resources-either plant, animal or mineral-shall be collected from this cave for personal use, sale, barter, or consumption unless specifically authorized in writing.
2. No one shall intentionally deface any natural surface in the cave.
3. Overnight camping, firearms and open fires (except carbide lamps) are prohibited in this cave.
4. Maximum group size in this cave is limited to 8 people; larger parties must separate into smaller groups of less than 9 members.
5. Avoid contact with bats; do not annoy or disturb bats at any time.
6. At times sections of this cave will be blocked off with flagging tape to protect bat roosts and cave studies. DO NOT ENTER THESE BLOCKED OFF AREAS.

Any exemption from the above special stipulations must be obtained prior to the date of permit use.

Figure 3. *Hazard and Special Stipulation Sheet.*

SAFETY HINTS FOR EXPLORING WILD CAVES

1. If possible, each cave exploration party should include at least one experienced caver.

2. Leave word with someone stating which cave you are visiting (and, in the case of a large cave, which part of the cave), and an approximate return time. Leave instructions that if you have not returned within six hours of the planned time someone be contacted for help.

3. No one should enter a cave alone. A minimum party size of three is recommended (see #4).

4. Each group should carry a first aid kit which contains a snake bite kit.

   In case of injury within the cave:
   (a) Send at least one person for help while someone remains with the injured party.
   (b) Keep injured person warm and treat for shock.
   (c) If there is any doubt concerning the extent of the injury, don't attempt to move the injured person until help arrives.

5. Two light sources are required and a minimum of three separate lighting systems are recommended for every person. Carry spare batteries and bulbs. Carbide lamps are recommended if available.

6. The use of "hard hats" is a must to avoid head injuries on low ceilings or in the event of a fall. The hats should have strong non-elastic chin straps fastened at all times while you are within the cave.

7. Carry a water supply adequate for at least 24 hours (a minimum of one quart per person plus additional quantity for carbide lamps). A spare emergency food ration is also suggested.

8. We strongly recommend ankle-supporting lug-soled boots with non-leather soles (leather is slippery on rocks). Climbing boots are suggested.

9. Wear coveralls or other long-sleeved protective clothing. For caves requiring extensive crawling, knee pads can be a great help. Remember, caves are cool (55-65 degrees) and humid. Leather gloves will keep your hands clean and warm.

10. In dusty caves, avoid stirring up too much dust. Not only does the dust impair breathing, but it sometimes contains disease germs. Wear dust masks when in these caves.

11. Don't enter a gypsum or other storm-drain type cave if there is the slightest possibility of a rainstorm anywhere near the area.

12. Never take alcohol or other drugs when you are caving. They may cause disorientation and impaired motor functions. If you do drink, do it after leaving the cave, not before.

13. Unless you have experts with you, stay away from vertical chimneys and other vertical climbing areas, and avoid attempting to penetrate piles of unstable or loose earth/rock breakdown. These can be very dangerous!

14. STAY WITHIN YOUR ABILITY AND EXPERIENCE. Never attempt to explore further into a cave than a point from which you can safely find your way out. Never exceed your climbing ability or experience. Continually look back as you travel through cave passages; they look much different from the opposite direction, and being able to recognize them might avoid trouble.

15. INQUIRE ABOUT THE CAVE BEFORE YOU GO IN! When taking a trip, you would make it a point to learn something about your route and the type of country you would be traveling through. Do the same with caves. Any BLM office or member of the National Speleological Society would be glad to help.

OUTDOOR MANNERS

1. Keep a clean camp; leave a clean camp. Earn the appreciation of those who follow you.

2. Be respectful of private property and obtain permission from the owner before crossing.

3. Leave all fences and gates as you find them. Park your vehicle where it will not block roads or gates.

4. Operate vehicles only where they will not cause ruts or start erosion — stay on established roads wherever possible.

5. Avoid disturbing wildlife and livestock by not camping near water sources.

6. Use only dead and downed wood for your campfires. Build campfires only in safe places and never leave them untended.

CAVE CONSERVATION PRACTICES

1. Remove all manmade litter you find in the cave, except for survey markers. Trash should be deposited in garbage cans (if provided) or taken home with you for proper disposal. Buried garbage may be exposed by the action of wind or animals. Small containers or plastic bags should be used for disposal and removal of spent carbide.

2. We request that you avoid contact with bats whenever possible, because they are easily disturbed. Disturbance of hibernating bats causes them to use up stored food reserves, which cannot be replenished due to a lack of insects for food. Hibernating bats may also die from shock if they are suddenly awakened. Some caves contain bat nurseries, and disturbance may result in the loss of young ones. All bats found in caves within Roswell BLM District depend on insects for food -- please help preserve these natural insecticides.

3. Caves are extremely fragile and have been subject to vandalism and unintentional damage. Many formations will break at the slightest touch and can't be repaired or replaced. Oil and mud from your hands will stain a formation and inhibit its growth. All natural features found within a cave should be left for others to enjoy.

4. Please don't smoke in the cave, if at all possible. Smoking generates trash and may bother other people. Because of natural airflow within a cave, smoke can travel for considerable distances and may disturb roosting bats.

5. Pets are not allowed in protected caves for the following reasons:

   (a) owners are reluctant to carry out animal waste ;

   (b) pets are difficult to control and may wade in water pools or break delicate formations;

   (c) pets may disturb animals, such as bats, which live in the cave;

   (d) pets may wander away from their owner and become lost or injured.

TAKE NOTHING BUT PICTURES AND INSPIRATION. LEAVE NOTHING BUT WELL-PLACED FOOTPRINTS AND THE CAVE JUST AS YOU FOUND IT.
CONSERVATION TODAY MAKES FOR BETTER CAVING TOMORROW.

Figure 3 (reverse).

How Cavers Learn Ethics

John Gookin
The National Outdoor Leadership School and
The Federal "Leave No Trace" Program

Abstract

This presentation will provide various ideas related to how cavers develop ethics. The presentation will focus on specific things land managers can do to nurture ethics in both new and experienced cave users, using both education and enforcement. A list of statistically ineffective traditional outdoor ethics teaching methods will be presented. The presentation will address the importance of rapport and social comfort in users' development of ethics, as described in recent research by Hungerford and Volk.

Many ethics education programs reflect an old bias that good information will develop ethics in people. Unfortunately information alone won't necessarily guide actions. Intellectualization helps, but the development of ethical habits is ultimately a social thing.

There's science to back up this sociable approach to the development of ethics. All cavers don't need to know this background material, but all caver educators should know the general strategy. First, let's define ethics *a la* Jasper Hunt.

Ethics is the study of competing moral values. For example: while it generally isn't okay to hurt a person, it is permissible to hurt someone by giving them a needle full of medicine because the medicine has more value than the pain (Hunt, 1990). Ethics is also the study of fundamental rights and wrongs; it is never okay to hurt a person just because you think hurting them with a needle is fun, this is indisputably wrong. We learn ethics by understanding different facets of a situation and by learning to value the pros and cons of situations.

Learning always includes knowledge and feelings; knowledge is important, but many humans guide their chosen actions more by their feelings. In *Emotional Intelligence,* Daniel Goleman describes how fast and powerful the emotions are. Emotional reflexes happen so quickly, they can predispose the rational brain to totally re-color situations. Imagine if this article's title offended you, like "How you dumb cavers can finally learn some ethics." Do you think you'd be exploring it for some tips on how to teach ethics on the next grotto trip? Most of us need to feel comfortable with people before we are willing to not only learn from them, but put their actions into daily use.

George N. Wallace describes how **people learn ethics best as an enjoyable discovery of how the world works.** For an instructor to help a student learn ethics, a comfortable relationship needs to be established first. This can usually be done with the appropriate voice and body language, key indicators of our mood. Finding something in common to talk about can be a good ice breaker. Students need to be convinced that we are there to help them, not to boss them around. Sometimes it takes students a few days to really believe that we are going to be much more helpful to them than most teachers they've had before. Then we have to help the students get excited about the material we are exploring; this usually comes from the contagiousness of our own enthusiasm for discovery.

Dr Wallace also talks about helping people develop ethics by using the "**authority of the resource**," meaning you should emphasize why adhering to a specific guideline protects their resources from being "loved to death." Focusing on the resource, rather than valuing blind obedience to some rule, can help students develop ethics they will endear and pass on. In summary, when we learn interesting things about how the world works, in a comfortable setting, we can then relate that material to other things we know, and we can use that information to guide future value judgments (ethics).

J.S. Leming addresses ethics development a little more specifically in terms of how a micro-society can not just allow ethics to develop, but encourage them: "Character develops within a social web or environment. The nature of that environment, the messages it sends to individuals, and the behaviors it encourages and discourages are important factors to consider in character education. Clear rules of conduct, student ownership of those rules, a supportive environment, and satisfaction resulting from complying with the norms of the environment (are what) shape behavior." Leming notes that students must not only get good social rewards for doing the right thing, but they must never get negative social feedback for a desired action. Leming's main points in character (ethical) development are:

- Clear rules of behavior
- Local ownership of the ethics
- A supportive social environment
- Consistent support for the behavior.

Matthews and Riley point out in their book *Outdoor Ethics Education Programs* that there are some key components to ethics education programs that work. They list these things:

- The importance of community and culture as a context for developing and nurturing ethical behavior.
- Teachers as guides, not as authoritarian figures.
- A positive climate of mutual respect.
- Group consensus building and ownership of group norms, including codes of moral behavior.
- The importance of peer teaching, counseling and support.
- The importance of responsible action strategies in the community.

Hungerford and Volk point out six critical educational components that research shows can maximize behavioral changes from environmental education:

- Teach significant ethical concepts and the learner's relationship with and obligation to them.
- Provide carefully designed and in-depth opportunities for learners to achieve a level of ethical sensitivity toward the environment, the outdoor activity and each other that will promote a desire to behave appropriately.
- Provide a curriculum that will teach the critical thinking skills needed for issue analysis and investigation of ethical problems and provide the time to apply the skills.
- Provide a curriculum that will teach the citizenship (stewardship) and interpersonal skills needed to address and resolve ethical issues and provide the time to apply the skills.
- Provide a learning setting that increases the learner's expectancy of reinforcement for acting responsibly, that is developing the learner's internal locus of control.

Teaching ethics alone teaches one person at a time. When people also develop leadership skills, they learn to foster those ethics in others. For cavers to do this successfully, more often, they not only need deeply-seated ethics, but they need a simple strategy for helping others to develop their own ethics.

Passing ethics on to others is an easy theme to slip into routine interactions. For instance, after your second caving trip with a new caver, just ask them, "okay, you've got cave movement pretty wired. So what'll you do if you go out with some other cavers next month and they slop carbide all over the cave?" They may recommend confrontation and ridicule: if so, say something like "Well, if you were a sloppy caver like that yesterday, what's an approach a friend could have used with you so you'd care about the situation instead of just butting heads?" They usually get the point that helping them learn in a more sociable manner is more effective than just "slamming" these perpetrators of underground crimes. Hopefully they'll end up seeing that offering to help clean up the mess in a polite manner would be much more effective, for most people.

Once an individual develops an ethic, they often **pass it on** to others; this is where the efficiency of "Education, not Regulation" helps both our federal land agencies and our natural resources. Competent cavers are usually held in high regard by novices. In fact, expertise is a universal credential for leadership. Another critical leadership credential is integrity: people don't follow people who only talk a good story; they follow people who consistently "walk the talk." Followers look really hard for this consistency in leaders (Hunt, 1990). Role modeling will have significant impact on the masses, especially in high use areas. Experienced cavers may also occasionally confront others regarding their high impact caving practices. This is perhaps the greatest reason for our cavers to be both competent cavers and confident leaders: so they'll pass on ethics more readily.

This system of learning ethics is as dependent on a comfortable atmosphere as it is on **rationalism**. Radical preservationism (like saying that nobody can ever go caving because "it changes the ecology of caves") will impede the development of an ethic that can be passed on to others. Indeed, when most of us realize that we are being told exaggerated points just so we'll behave a certain way, we feel deceived and alienated, often leading to an understandable skepticism about related topics as well. It is critical that our conservation methods are practical, and that we can explain why they are important. We should be sure new cavers are at the "one-why" level of knowledge: they should have at least one reason why they do any action a certain prescribed way.

Ethics help define a person's character. This is a very personal thing. Certain attitudes can easily turn this ethics education format into character pre-definition. If cavers are anything, they are a proudly eclectic group. Ethics education should respect individualism but focus on the common ground of cave conservation. We can't bog down if one individual doesn't seem to toe the party line. We must be content to nurture the leadership to pass the ethics and character development on to others.

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Use of Volunteer Groups in Cave Management

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Abstract

This brief presentation will discuss volunteer cave management projects done by National Outdoor Leadership School students and National Speleological Society grottos, ranging from picking up trash on the surface, to photomonitoring, to trapping bats. Potential projects and tips for management will be included.

Volunteerism is well established as an important part of cave management. As federal land management budget's dwindle, volunteerism may become even more important. Volunteerism has its pros and cons though. With careful management, volunteers can be a great asset to any land manager.

Management

The land manager can pass on lists of tasks to volunteers, but responsibility for those tasks being done correctly will always belong to the land manager. Volunteers may actually have greater specific expertise than some land managers, but the manager still needs to make sure expectations are crisp and that the standards of the completed job live up to the manager's expectations.

Clear expectations can be verbal for simple jobs given to small competent teams of volunteers, but they need to be written for complicated tasks, or for tasks that will be passed on to future volunteers. Bighorn Canyon National Recreation Area (Montana and Wyoming) uses a photo-monitoring form that offers thorough details and a sample picture for each routine picture. They also supply the camera and film. This makes it almost impossible to deviate from their expected routine. The system is near idiot-proof and is easy for first-time users.

Supervision should be at a higher level as you are "feeling out" a group. In the case of picking up in-cave trash, it is critical that a land manager make any important decisions based on historical or archeological significance. If you can't trust your volunteers to leave older trash *in situ*, then you need to supervise them more directly. As you become more comfortable with a group, you can count on the old hands to pass on information to new recruits, and you should be able to supervise less.

Groups vs Individuals

Established groups may offer stability in numbers and culture to the land manager. Greater **numbers** of people can provide a more constant volunteer source that offers greater reliability, eventually leading to more routine use of the volunteers. The established **culture** is a double-edged sword: get a group that has a strong social tradition of conservation, and you can generally expect them to pass that culture on to new members; get a group that is reckless, and you can expect them to pass on that culture as well. Assess whether these cavers routinely scrape their helmets on ceilings, short-cut established pathways, or leave any debris in your caves. If it isn't already in their culture to be careful, it will take a lot of education and social nurturing to create a more sensitive culture in the group.

Types of Projects

The author has participated in the following volunteer projects, either as a group leader, or as an individual.

- Bat mist netting
- Bat inventory
- Bat habitat studies
- Graffiti documentation
- Graffiti removal
- In-cave trash removal
- Surface trash removal
- Algae removal from tour path lights
- Gate bypass blockage with concrete
- Gate construction
- Gate key control (our local grotto maintains the lock and controls access, allowing the state park to avoid having to assess who should cave there and who shouldn't)
- Asphalt tour path removal
- Concrete tour path installation
- Rescue pre-plan development and documentation

- Rescue training for locals
- Rescue training for land managers
- Basic training and guiding for non-caving land managers
- Mapping
- General inventory
- Pre-NSS convention route inventory
- Photo-monitoring
- Guide off-trail "cave tours" for local citizens

Problems with groups

Any group is still a collection of individuals, each having individual background and prejudices. Many volunteer problems are based on unclear expectations and can be avoided by written standards and volunteer training. Wind Cave National Park (South Dakota) has developed written cave use policies and mandatory trip leader training that has almost completely eliminated the problems they were having with work camps there.

Listed are some past problems created by some volunteer groups.

- An overzealous conservationist "cleaned up" some historical figurines carved out of aragonite, the day after he had demolished nearby clay figurines he knew to be recent.
- Important paleontological resources were moved from their found site.
- Bats were disturbed from early torpor due to a lack of awareness by a person inventorying bats.
- Mapping had to be re-done to a greater accuracy level.
- Inventory had to be re-done to new standards.
- Hungover cavers needed to be screened from entering the cave.
- Volunteers have deviated from local human waste disposal standards.
- Volunteers were found smoking marijuana in the cave.
- Delicate passages have been damaged from thoughtless travel habits.
- Passages have been modified without land manager involvement in the decision.

Avoiding Problems With Groups

Here are some ways that some land managers minimize typical problems with volunteer groups.

- Have **written expectations** regarding low impact caving practices. Allowing the local cavers to help draft these standards will give them the direct involvement needed to turn these "rules" into local ethics.
- Offer **training** in low impact caving to volunteers. Consider making the training mandatory for trip leaders.
- Stay in **close contact** with the group leaders and make regular visits to the groups. Bring up concerns directly and quickly or it will be extremely hard for the group to police themselves.
- **Directly supervise** the more delicate jobs.
- **Provide ample work** to volunteers. Be flexible with completion schedules. Don't be flexible with completion standards.

Mutualistic Relationships

There are many things land managers can do for volunteers.

- Land managers can provide **logistical and moral support** for the volunteers. Just making a brief visit lets some of the volunteers get to see the land manager as a real person and as someone who cares about what the volunteers are doing. This occasional presence can also spur a higher level of responsibility in individuals who aren't as self-motivated as others.
- Land managers can help instill a **sense of stewardship** in individuals. Many citizens don't view public lands as "their" lands. Managers can help citizens understand the importance and methods of citizen involvement in land management decisions.
- **General government: citizen rapport** is increased by public employees working side by side with volunteers. Few things bond people as well as common causes and working hard together. As Erwin Rommel put it "Morale is increased by the accomplishment of difficult tasks." Pitch in on the really difficult or unpopular jobs.

Summary

Volunteerism has pros and cons, just like any other management tool. When utilized wisely, volunteerism benefits the land management agency, the volunteer, and especially the resource.

Search and Rescue Pre-Plans for Caves

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Abstract

This paper offers a format for simple cave search and rescue pre-plans. Also included are simple strategies for starting a cave search or rescue, dispatcher cheat sheets, staff cave search and rescue needs, and a bibliography.

Importance

Pre-plans are especially important in areas with infrequent search and rescue (SAR) incidents. It is important that any pre-plan is simple, or it won't be used in a time of crisis. It is also important that key people (managers and dispatchers) know how to quickly access the written pre-plan.

Pre-plans are documents that organize personnel and equipment for urgent incidents. They provide guidance through the initial response. For extended incidents, they are replaced by a plan drawn up during the first operational shift.

Searches and rescues are different types of urgent events. Both are emergencies since human life is at risk. The pre-plan is not supposed to provide step-by-step instructions for all personnel. The pre-plan is a document from the park superintendent to his/her staff that uses the incident command system[1] (ICS) to provide clear leadership and organizational guidelines in urgent situations. Your document should not restate what ICS is, or even what is in your Park or Regional Rescue Pre-plan; it is a simple document that helps organize cave rescues. Fremont County, Wyoming, uses a one page plan with four pages of appendices. The Worland, Wyoming Bureau of Land Management District[2] uses a 20-page plan that lists all local resources, item by item, and provides much more specific guidance. You should develop a plan that will help you move fluidly in a time of urgency. There are two very different types of pre-plans, general and specific.

Contents of Cave Rescue Pre-plans

Cave specific SAR pre-plans have information specific to one cave.

- **Cave description**: describes the cave, including temperature, humidity, flood potential, hazards.
- **Access:** describes how to get to the cave in simple terms so a deputy or ranger can go see if anyone's there.
- **Caver parking area**: this is a description of how to get to the most likely spot to find an overdue caver's vehicle. It also helps rescuers find the cave in the middle of the night.
- **Special Equipment**: this could include specialized gear needed for certain passages.

General cave SAR pre-plans describe your response to any cave incident. They don't contain specific cave information, but should have a simple referencing system so the general pre-plan steers the responders to documents or people with specific information. Here are some components to consider in a general pre-plan.

- **Search initial response plan**: this tells the Ranger who initially takes charge (Incident Commander)[3] how to respond and who to initially involve. This should only be about a page long. It should be the first part of the pre-plan you generate since it describes the strategy you want to employ.
- **Rescue initial response plan**: this is like the above, but specific to rescues.
- **Dispatcher's Cave SAR cheat sheet**: questions to ask the reporting party.
- **Cave Rescue Personnel lists** (with home phone numbers)
  Internal
  Local
  State and Regional (have a copy of the NSS Members Manual available)

- **Cave Rescue Logistics**
  Internal
  Local (County and State Emergency Management Coordinator can help here)
  Regional (find your Regional Cave Rescue Coordinator by calling the NSS[4])

- **Medical pre-plan**
  List of local medics who have trained in caves
- **Forms** (keep master copies of cave specific forms, just like in your ICS plans book)
  Search Team debriefing sheet (Maze caves need this more than others)
  Lost caver questionnaire
  Overdue caver questionnaire
  Injured caver questionnaire

- **References** (these could be kept in your Emergency Operations Center)
  Manual of US Cave Rescue Techniques, by Steve Hudson[4]
  Latest copy of the *NSS Members Manual*[4]
  Next latest copy of the *NSS Members Manual*[4] (format alternates annually)
  Any Search text (for example: *NASAR Field Commander's Notebook for SAR*)[5]
  ICS Plans Book (This has master ICS forms needed for photocopying)[5]
  Appropriate phone books for locales and agencies

Distribution of the Written Pre-Plan

This plan should be kept in your dispatcher's notebook. It should also be posted on the wall in your Emergency Operations Center; the Emergency Operations Center is often either a room in the Sheriff's Office with a phone and a radio, or else your Chief Ranger's Office.

Training as part of your pre-plan

Internal training begins with familiarization with the written pre-plan by dispatchers and Rangers. A next step is having your Rangers read appropriate parts of *Cave Rescue Techniques.* They don't need to memorize the book, but they need to be comfortable with the first four chapters and they need to be aware of the rest of the book as reference material. Finally, a simple cave mock rescue that your local SAR team participate in will be the most valuable preparation you can ever do.

External training can be done at your site or at national seminars. The National Cave Rescue Commission (NCRC) runs annual week-long cave rescue seminars and currently offers four levels of training (four weeks total.) NCRC also runs many weekend workshops. The best use of your staff's time would be to have an NCRC instructor offer a short workshop on your site. Inviting other local agencies to participate will help organizations coordinate and cross-train better.

Other external training includes ICS training and especially MSF (Managing the Search Function: a 40 hr NASAR course.) or MSO (Managing the Search Operation has a similar curriculum.)

References

1. The Incident Command System is a simple team organization structure, popularized by forest fire fighters, now widely adopted by emergency management teams across the U.S.

2. Source: Dave Baker, Worland District BLM Office, PO Box 119, Worland WY 82401 (307) 347-9871.

3. The person put in charge of directly managing the incident is the "**Incident Commander**." The incident commander reports to the "responsible agency" but need full authority to manage the incident.

4. Source: The National Speleological Society, 2813 Cave Avenue, Huntsville, AL 35810-4431, phone: (205) 842-1300, fax: (205) 851-9241, e-mail: nss@caves.org

5. Source: The National Assn for Search and Rescue (NASAR), PO Box 3709, Farfax, VA 22038 Phone: (703) 352-1349.

Generic Cave Search Preplan

Allen Padgett & John Gookin

Search is an emergency. If you can't call it an emergency, then call it a sudden intensification of activity around an unplanned event. Search management involves a sequence of steps that are begun in order and each step then continues until the situation is resolved.

The sequence is:

1. Preplan—be prepared: know your hazards and resources.

2. Interview—information must be gathered from first notice on. The more information the more focused the effort can be. The investigation scales up as the search progresses and more search areas are ruled out.

3. Call Out—trained help should be enlisted. At this time it is also time to evaluate just how urgent the situation is and this will determine the size and type of response. It is critical that in-cave tasks are dealt with by experienced cavers who can make the judgment calls needed underground.

4. Establish the search area—in a cave incident we can often assume simply the entire cave to begin with, but then we need to establish segments within the cave and prioritize these and assign rank. We must not ignore the fact that they may not be in the cave (rest of world) or in a portion of the cave not on the map.

5. Confinement and Attraction—once we have established the search area it is vital that we know if the subject leaves the search area. In a cave situation it is also vital that we know if the subject moves from one segment to another. Guard the entrance and maintain an accurate log of who entered and who left. Place lights with notes and other attraction devices at key cave intersections so wandering search-ees will stay there.

6. Hasty search—to begin active search the best action is to quickly check out the most likely places first. Speed is the primary objective here. Check the obvious, look for clues, report conditions.

7. Wide search—the objective here is efficiency not pure speed nor absolute thoroughness. In order of our priority segments we search the passages. This allows us to search the maximum amount of cave with the cavers we have on scene in the fastest time possible. If needed the process can be repeated for increased coverage if needed.

8. Grid search—now let's assume nothing has worked up to this point. As a last resort before suspending the mission a grid search can be conducted.Grid searching is slow and highly labor intensive and it is important that teams mark their teritory covered in some way. You may have to mount a clean-up trip later to remove all of the notes and flagging. In a complex cave system this process could take a huge number of people an incredible amount of time.

9.Rescue/Suspension—Whatever the method used, the goal is to find the person or determine that they are not within the search area. If we find them then the exercise becomes a rescue or recovery. Our options if we do not locate are to expand the search area (some other cave, or some part of the cave we do not know) or to simply scale down the operation. We don't just quit we scale back. The decision to scale back is a tough management decision and should be carefully documented.

10.Critique—How do we do it better next time?

Dispatcher's Sheet for **Cave Search & Rescue** p 1/2

Overdue parties: (cavers haven't returned home as expected)

Date:________________Time of call:__________

1) Who is calling?________________Their phone number:________________

2) Are they the contact person that the cavers were supposed to notify when they were out of the cave?__________

3) What time was the group supposed to return?____________________

4) Where, other than the cave, could the group be?

6) Has this happened before?__________

7) Please describe the vehicle they are in:______________________________

8) What cave were they going to?______________________________

9) What type of equipment did they take besides lights and helmets? (ropes, wet suits, scuba gear?)____________________

10) Have you contacted anyone else to go see if their car is still at the cave?________

11) Does anyone in the group have any known medical concerns?__________________

Lost caver: (one or more cavers is missing inside a cave)

Time of call:__________Reporting party: ______________Phone number:____________

1) Who's missing?
Name:__________________
Age:__________
Address:__________________
Physical condition:__________________
Medical concerns?(Asthma, Diabetic, Allergies, Medications)__________________
Experienced in caving?______________
Been in this cave before?__________

2) PLS
Where was the Point Last Seen?__________________
What time were they last seen?__________
What time did they enter the cave?________
When were they supposed to come out of the cave?______

3) Do you have any guesses where they are or what happened to them?

What equipment were they carrying?

How long do you think their lights will last?

4) Where are the other group members now?____________________________
Can they do a hasty search of the most probable areas?____________________
Do any of them know basic first aid?__________
Is someone watching the cave entrance to see if they come out?______
Have you contacted anyone else to help with the search?

Dispatchers sheet: **Cave SAR** p2/2

Injured Caver: (a caver reports that one of their partners is injured and still in a cave)

Date:__________________Time of call:____________
Reporting party:______________Phone number:_____________________

1)Who is injured?
Name:______________________Age_____________Ht:________Wt:________Sex:________
Home address:_________________________________
Physical Condition:____
Medical concerns: (Asthma, diabetes, allergies, medications)_________________________

2) What's wrong?
What's wrong with the patient?____
How did the accident happen?____
What time did it happen?____________
Did anyone do anything to keep them warm? What?______________________________
Who is with them?____
Will they be able to help drag themself out?___________________________________
Can other members of your party help? How many?_____________________________
We especially need a guide to take our Initial Response Team into the site. Who should do that?
____
Can you call some other cavers to come help? ___________Please call us to let us know who's coming to help.

3) Where are they?
Cave name:____
Where are they inside the cave?____
How hard is it to get to that part of the cave?__________________________________
Are they in a safe spot?____

Cave Search Team Debriefing Report

Filled out by the Search Team Leader and turned in to the Operations Director

Team Leader:____________________________ ____________________________

Team Members:__________________________ ____________________________

____________________________ ____________________________

Headed into cave: date/time ________________Returned:__________________________

Area of search assigned by Operations Director (general description)____________________

____

Type of search: ______Hasty ______Detailed ______POD[1]

Area actually searched (detailed description, please put a map on the back): ____________

____

____

____

____

____

Have all passages in this area been thoroughly checked?____________________

Is additional searching required for this area?__________________

Describe what you recommend we do next?______________________________________

____

____

Any comments, hunches or opinions?____

____

Tips for searchers

1) Look for clues more than the person.
2) Stop and listen for banging rocks once in a while. Banging rocks against the cave floor travels much farther than other cave noises. Call out the person's name and listen carefully for a response.
3) Tape off searched areas with labeled flagging (e.g. Team B, 95%POD, 7/28/93 10pm).
4) Work in pairs, but keep the team together.
5) Be sure to return to the surface with enough time and energy to brief the next shift of searchers. You will then be expected to get some rest before relieving that shift.

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[1]The **Probability of Detection**: if the person was actually in the part of the cave that you searched, what is the chance you would have found them using your search techniques? 100% means that there's no way they could possibly be in there. 5% means you could search that area forever and not be sure they're not there.

Cave Ecotourism Today

Jeanne Gurnee

Abstract

Many people are becoming involved in guided tour opportunities in undeveloped caves and karst regions. The current name, "conservation tours," has received discussion both here and overseas by those in the professional travel field, governments, people newly offering wild, guided tours, conservationists, cavers, and planners. What are the present effects of these wild cave tour endeavors? What will the cumulative effects be? How can eco-tours be made cave-friendly?

While we are listening to presentations during the next few days, we will probably realize again that we are talking, as they say in church, to the choir, because all of us here know how important it is to preserve and protect cave and karst environments. But because we can exchange ideas and focus our experience and knowledge, we as a group have the power to solve problems and to project this knowledge in places where it will do the most good—not only among us on the inside but also outside our organizations, outside our government agencies, and outside our private enterprises.

Cave Ecotourism, my subject today, is an area that will need concentration of effort both now and in future years, when this kind of tourism will have a still greater impact on wild cave environments. If you were to ask any of us about the ecotour business, we probably would prefer that there wouldn't be any. But, whether we like it or not, cave ecotourism exists, and the business is rapidly growing both in this hemisphere and throughout the world. To define cave ecotours: These are tours led by independent guides or tour operators who take groups of the public for a fee to explore wild caves that the tour operator does not own.

In order to be in business, the operator usually has a van and advertises that for a fee he will take explorers on an adventure underground. Sometimes this includes meals, overnight accommodations, and other activities centered around the wild cave experience. Some cost several hundred dollars a weekend, and some are offered at a flat fee for a cave excursion. Usually, but not always, the operator contacts a wild cave owner and asks permission to use a cave. He then advertises the tour and from time to time takes vans of people on caving experiences.

Each of us looks at cave ecotourism through different eyes. Some conservationists would like to stop group exploration of wild caves altogether. In Italy many "greens," as they are called, believe that no one should enter caves for recreational purposes.

Some people who lead cave ecotours emphasize adventure, and some emphasize the care and education involved in the recruitment of the students it takes into the caves owned by others. The caver worries about over-use by commercial groups and feels that he can cave softly and contribute to the study of the cavern environment. The cave owner in many cases may not yet realize the liability and responsibility he or she accepts when offering a cave for public visitation to those who are making an income from the experience.

In order to have the wide view, it is necessary to step back and take our personal interests and viewpoints out of the picture. To do this, it will be helpful to look at the ecotourism industry as a whole. It is just as impossible to separate the new trend in surface ecotourism from subterranean ecotourism, as it is for us to study a cave under the ground and not know or care about the conditions on the surface. In other words, what has been happening in above-ground ecotourism—particularly over the past 20 years—can be translated to what will happen when ecotourism becomes more common underground.

But first we'll have to define ecotourism in general. The Ecotourism Society says it is "responsible travel which conserves environments and sustains the well-being of the local people." The World Wildlife Fund defines ecotourism as "nature travel that contributes to conservation." In Britain it is called "green tourism." (Maybe in caves it would be called "brown tourism"). So the implication is that people, through tourism, can actually aid the environment. So much so that a congress I attended last year was called the "World Congress of Tourism for the Environment." Leaders of this congress, incidentally, said that we should not use the word ecotourism but should use "conservation travel" or "conservation tours."

We in cave management will probably be weighing the words carefully: Conservation tours. We feel soothed when we hear well-known words like ecology, education, conservation, and preservation. They have always sounded good to us, and we have a feeling of well-being when groups use these words to describe their efforts. In order for the words to be honored, much effort will be necessary on the part of everyone engaged in ecotours.

To give an idea of what kind of trend we are talking about, a recent survey reported that more than 8 million Americans said they had already taken an ecotour and another 35 million said they probably would take one in the next three years. The travel industry reports that the ecotourism business is exploding and that in 1992 nature tourism generated more than 2 billion dollars.

Developing countries see ecotourism as a way to help the economy of their citizens in the backcountry. The word *ecotourism* has tremendous appeal, and governments throughout the world welcome it as a means of income. Over the past year, I have received inquiries from two different African countries and one in the Pacific Rim asking about methods for showing wild caves as an ecotour adventure.

Sometimes countries embrace ecotourism without knowing all of the ramifications of what it entails. This has had some sad results—as an example when one safari unloaded eight vehicles of nature tourists, cameras clicking, to watch a tiger that was giving birth to a new cub. To the group's astonishment, the mother in a frenzy of confusion killed her newborn cub. As the vans were driven away, the tourists wondered what kind of animal ritual had caused such an act.

We all know about the death of coral reefs that have been over-populated by adventure tourists. Or the leveling of wilderness to construct buildings for ecology tourists who need motel-quality accommodations in the wilderness. Or the Russian icebreaker to the North Pole that allows high-paying ecologists the opportunity to have cocktails and a barbecue right at the North Pole itself.

At the World Congress I mentioned earlier, speeches by officials of the Puerto Rican government and the Governor spoke strongly for ecotourism. They mentioned that a tourism act of last year provides funds for adventure and nature tourism to the mountains, lakes, ocean, and caves. At the same Congress, a group of us were invited to a dinner when a representative of the Under Secretary of the U.S. Department of Commerce who had worked for the EPA said that he believed in "adventure travel." He said that the present administration has a strong commitment to environmental tourism and conservation.

These statements are probably made with good intentions. The governments of the world see ecotourism as a way to boost sagging economy, especially in areas where employment is low and living conditions are poor. It is a way of gaining money where it is much needed.

But often the steps necessary to prepare for ecotours have not been thoroughly thought out. Transportation, access roads, safety, medical and emergency resources, instruction, equipment, and food are all part of the picture.

What use will be made of the land near the cave? Does the group plan to eat outside at night around a campfire on someone else's cave land? Are they also planning to camp near the cave? If so, tour operators and property owners will want to consider what can be permitted and whether arrangements have been made for trash disposal, sanitary facilities, and much more.

Unfortunately, the world is realizing some of these things only after thousands of vans of ecologists have already been transported to the world's natural places. Conde Nast Traveler magazine reports that of the thousands of people who are leading educational nature tours as ecotourism professionals, the magazine could recommend only 18.

I participated in an cave ecotour recently, and would like to follow the steps of this tour: A van picked up a group of 15 of us nature tourists at a city hotel. We were told prior to the trip to wear comfortable shoes and that the leader would provide cave helmets and flashlights.

It was a congenial group, and two hours later we pulled over by the side of a one-lane road and unloaded. One participant wanted to make a telephone call, but there were no phones, no neighbors—and we were completely away from communication had we needed it.

We hiked about 15 minutes to the cave entrance and followed that special odor of wet earth as we skidded down a mud slide to the cave floor. Inside, the smooth, well-worn trail showed the way ahead (a good example of compaction). While the cave room was large, we did not take the clear route but climbed single file through a forest of stalagmites that were covered with mud from the hands of previous ecotourists until we reached the top of the formation area. There we sat among the formations to rest, as the leader gave a description of stalagmites and stalactites.

Because the route we took was considered more adventurous, the leader did not use an alternate trail that could have preserved formations and would have afforded a better view. Unusual? No. What makes a wild commercial tour experience successful is the effort necessary to get through the cave.

After the trip, there were no toilet facilities, and as various of us disappeared into the trees, the owner of the property arrived and offered us water from a thermos he had brought with him. Then the group spread out walking throughout the owner's farm looking for sinkholes and exploring until the horn of the van told us it was time to go. We know what is not appropriate in this tour, but it points up how important planning and conservation considerations are to commercial tour structure.

While we cave managers know about carrying capacity, compaction of cave trails, low-impact cave exploration, rescue techniques, and many other linked needs; do most ecotour business operators know of these considerations?

Ecotours are also offered in the undeveloped sections of this country's show caves. However, the difference between wild cave trips in show caves and other ecotours is that the show cave is owned by the tour operator and he or she has accepted the responsibility for the ecotourist under particular conditions, planning the wild cave tour using all the back-up facilities available at a show cave. The show cave owner has an added incentive: to preserve and maintain his own property as a business. As the show cave owner has already accepted responsibility for visitors in the developed portion of the cave, he is more easily able to adjust to the use of the cave for a natural cave experience.

As more and more ecotours lead below ground—especially in Europe where commercial wild cave tours are numerous—governments are putting constraints on ecotour companies because they have become so numerous, even when the caves are on private lands. We can learn from Europe, which is a number of years ahead of us in this business, and we can see how operators in Europe are handling incredible numbers of ecotourists, particularly in high season. Some governments now license ecotour cave businesses, and these licenses are reviewed yearly by commissions whose members represent of government, ecotour companies, and speleologists.

What kind of guidelines can we use to determine where and how commercial groups may operate on private and public lands? You probably know the Bureau of Land Management and others are currently setting such guidelines for commercial visits. But *all* cave owners, private or public, will want to have a process to follow. In searching for the process, I know you will want to come up with steps of your own, and that owners will benefit from the thoughts of experienced cave scientists and specialists. I would also like to add another viewpoint: John Sawhill, president of The Nature Conservancy, says he has always advocated science when making land conservation decisions, but that he realizes more and more that pristine landscapes and nature's majesty have—as he puts it—"the magical, mystical quality that may well be nature's greatest gift to us. And instead of spending our time trying to figure out the trick behind the magic, perhaps we should focus more on accepting the astonishing variety and beauty of the natural world on its own terms." Somebody might argue that we are in the science business and not in the pretty business. But Sawhill counters with, "to achieve our conservation goals, we must appeal to both heart and head—to beauty as well as reason." Where can this idea be more true than in the perfect, controlled environment of caves? Even though aesthetics seems to be an intangible measurement, it is really a known quality to us as connoisseurs of cave architecture. It is as strong an element in planning as the scientific study of cave life.

So how do we begin? Most of us start with the Cave Management Plan, but sometimes—once the plan is produced and on the shelf—it does not continue to be an active tool to be used, day by day. With changes in land ownership and management personnel, combined with public demand for the resource, the Management Plan needs revision and constant attention. To me this is the hardest part of cave management: the constant attention to the plan and to the resource. It involves sustainable design combined with vigilance and maintenance because the written word of a plan is only as good as the attention given to it as well as a resource that is constantly growing and changing.

A group of us through the National Speleological Foundation recently completed a study of environmental factors in Harrisons Cave, Barbados. Is the follow-up publication with its recommendations the end-all? The publication is nothing in itself. It is an empty thing until it takes life through the people who have accepted the responsibility of the cave. It is after the study and the publication that the hard part begins—making the environmental corrections that will nurture the cave and perpetuate its health.

Private, corporate, and not-for-profit owners, as they work with ecotour groups, need working plans that are referred to constantly. Commercial users of wild caves owned by others would be given copies of these plans yearly. In its simplest form, a plan would include:

- A cave map, so that, in the case of emergencies, all areas of a cave are known and can be reached easily. The cave map would also be used to determine the routing for ecotour groups. The trail options would be indicated on the map and distributed to ecotour leaders for their guidance. The importance of the cave map was emphasized recently when a member of the symposium said a rescue was necessary at a cave in Spring Mill State Park, but the rescuers were delayed because it was necessary for them to run out leads in the cave as there was no map to guide them.
- A map of surface topography, roads, and areas where vans would park. Also, walking-trails and any other surface facilities would be indicated, tied into the cave map below. Also noted on the surface map would be what areas above ground are *not* available to tour groups.

- A study of cave life. What influence would a succession of tour groups have on life identified in a cave? Under the permit system, how many permits would be issued for a particular cave, and how frequently would commercial groups be permitted to enter? Would permits be made for seasonal entry only?
- Identification of any features that would be fragile and sensitive to ecotour groups. Also marked would be any areas that could be dangerous to these groups, which usually consist of novices. You probably know that the NSS has made a number of rescues of tour groups. One that comes to mind is when an inexperienced adventure tour leader was not equal to the responsibility of a tour emergency. He left the cave in search of help, and the process resulted in the death of a participant.

There is another essential that most of us would think everyone would take for granted: If a commercial operator wants to use private or public lands and cave for ecotours, it is necessary to have permission from the owner. Some caves in the U.S. are being used commercially without the owner's knowledge. Has the individual, organization, corporation, or government agency given permission for commercial ecotours to take place? Does the owner know how many people would be transported by jeep or van to the cave and visit it in a given month or year?

When considering the use of a cave for ecotours, the owner, plus a speleologist, and the ecotour company should be certain that the surface karst and the cave environment would not be adversely affected. If it is determined that a cave is suitable, here are some other points that can be considered:

- Investigate insurance. Does the owner have liability insurance? Does the ecotour company have insurance? Who is covered by the owner's insurance and who is covered by the ecotour company's insurance? The reason I mention this is that in administering NSS cave preserves, we found that insurance coverage that an educational tour group claimed it had, provided coverage only for the leader of the tour.
- Give a pre-exploration talk about the fragile nature of the cave environment and provide all details that will help the tour participant understand his responsibilities underground.
- Provide proper equipment for each participant and show its use.
- Know the availability of emergency rescue help and have a system for obtaining the help if necessary.
- Set up a monitoring systeming so that the effect of all exploration is known by cave owner and manager.
- Determine what amount of traffic is acceptable (the acceptable limits of change).

And finally, I believe we *are* our brother's keeper. In our local regions, if we know of ecotour leaders, particularly those who may not have thought of the responsibilities of their business, we can reach out and help to acquaint them with exploration guidelines for four main reasons: The protection of the cave, the protection of the people they guide in caves, the protection of the owner, and the protection of their business.

For those of us who remember the true wilderness of wild caves or have discovered a cave where there were no footprints on the floor but our own, we will never forget this experience. Even if we were not the first but came later to a cave that had been treated well, we still felt that exhilaration of new discovery.

It is up to us now to make the hard decisions, because our personal caving aims and commercial caving aims exist for such a short space in time. We must build into our management plans sustained use not only for the near future but also for the year 3000 and beyond.

It should be possible for the groups of the future to have the experience and enjoyment of the underground as we know it now. During our lifetime, we who are here today have the opportunity to work to assure the continued health of these valuable resources, remembering that our lives and personal use of caves occupy only a brief flash in infinite time, while caves (if we let them) are eternal.

The Status of Cave Protection and Management Within The Nature Conservancy

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Abstract

The Nature Conservancy is a private, non-profit organization devoted to finding, protecting, and managing the best examples of rare and unusual plants, animals, and natural communities in the country. Since the Conservancy's beginnings in 1951, the organization has grown from protecting large popular animals, and familiar natural features such as old-growth forests; to less "popular" but just as ecologically-important creatures such as invertebrates, and complex, fragile communities such as caves. The staff of the Conservancy working in West Virginia spends a great amount of time in the area of cave protection and management. In order to aid in the dissemination of information and knowledge, a cave protection and management questionnaire was developed and sent to all state offices of The Nature Conservancy. The results of the questionnaire found nine states listing caves as a high protection and management priority. Caves are protected in a variety of manners including limiting access and using local grottos of the National Speleological Society to assist in the management of the caves. Several creative measures have been used to control access yet not completely limit visitation. Conservancy staff knowledge of cave biology and management is often limited, even in cave-rich states. Several gaps in knowledge exist with which the caving community could assist The Nature Conservancy.

Introduction

The Nature Conservancy is a private, non-profit organization begun in 1951. The Nature Conservancy emerged from a professional association of ecologists seeking to turn their knowledge of nature into positive action for conservation. The Conservancy began its tradition of conservation through private action with a modest 60-acre land purchase in New York state. Today, using the same market-oriented strategy, the Conservancy has protected over nine million acres of ecologically significant land.

The Nature Conservancy mission remains: preservation of plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. The Conservancy is now the operator of the largest private system of nature sanctuaries in the world, owning and managing more than 1,500 preserves throughout the United States.

From the simple beginnings in 1951 with a single preserve, the Conservancy has continually strived to improve its science base of knowledge. Over 20 years ago, the Conservancy initiated a conservation database in each state with the purpose of tracking each states' examples of rare plants, animals, and communities. Each state program now maintains an extensive computer database of rare and unique flora and fauna. Most of these programs have now been incorporated into state governments as "Natural Heritage Programs" and provide agencies with scientific knowledge.

Over time, the Conservancy has gone from protecting obvious rare features such as showy plants and large mammals to more obscure, but equally deserving, creatures and places. These less obvious creatures include invertebrates and bats and the less obvious places include caves and springs.

Survey of Cave Protection

Due to the abundance of karst features and numerous troglobitic and troglophilic endemics in West Virginia, caves have always been a priority for The Nature Conservancy of West Virginia. The surrounding states of Virginia and Maryland also have an emphasis on cave protection. Because cave protection involves unique species and an environment unfamiliar to many scientists, the problems and challenges of cave protection are often daunting to managers assigned this responsibility. The purpose of this study was to determine the status of cave protection across all state programs of The

Nature Conservancy and to determine the greatest needs and knowledge gaps in furthering the Conservancy's cave protection.

Access, biology, and inventory information was summarized for each state using a questionnaire format. A questionnaire was sent to all state Conservancy offices to determine the extent and priority of cave protection. In the United States the Conservancy has an office in each state. Some states including New York, Florida, and California are divided into regional chapters with an office for each area. The questionnaire was sent to each state office and to smaller chapter offices. The questionnaire was followed up with phone conversations and interviews.

Results of the Questionnaire

Ten state Conservancy programs considered cave protection a high priority: Alabama, Indiana, Kentucky, Maryland, Missouri, Oklahoma, Tennessee, Texas, Virginia, and West Virginia.

Six state Conservancy programs considered cave protection a lower priority: Florida, New Mexico, New York (Adirondacks), Pennsylvania, and Washington.

Twenty state Conservancy programs owned a cave as part of a preserve: Florida, Idaho, Indiana, Kansas, Kentucky, Maryland, Missouri, New Jersey, New Mexico, North Carolina, Oklahoma, Ohio, Pennsylvania, Tennessee, Texas, Vermont, Virginia, Washington, West Virginia, and Wyoming.

Overall, 113 preserves of The Nature Conservancy are centered around cave protection. While 20 cave openings are owned, 93 preserves protect other karst features such as springs and cave watersheds.

Protection Highlights

Assists to Other Agencies

The Nature Conservancy is known for its creative solutions to land protection. One protection technique aids state and federal agencies in protecting land. The Nature Conservancy can quickly purchase land and then hold it for later purchase by state or federal agencies once they have money appropriated. Several states have had important cave-protection "cooperatives" with state and federal agencies.

In Arizona, The Nature Conservancy purchased Kartchner Caverns from the Kartchner family in 1988. The cave is over 2.5 miles long and highly decorated. The cave was sold to the State to be included in the Arizona State Park system.

The Dakotas Chapter of The Nature Conservancy has an on-going program of assisting the National Park Service at Jewel Cave National Park in the threatened Black Hills area. The Conservancy has been instrumental in assisting the Park Service in the purchase of lands surrounding and above this beautiful and significant cave.

The Florida Chapter of the Conservancy has assisted several groups in cave protection. One cave was purchased and transferred to the State, a second cave has been kept as a Conservancy preserve. A third cave was donated to the National Speleological Society (NSS) in 1991 to become the NSS' Warren Cave Preserve.

The Alabama Chapter of the Conservancy has also been active in cave protection. The Alabama State Director, a former NSS Grotto Chair and caver has guided the chapter to assist the State, the U.S. Fish and Wildlife Service and the USDA Forest Service with cave protection.

Examples of Priority Cave Protection States

Cave preserves play a major role in the protection of a cave organisms in several state chapters of The Nature Conservancy. In Missouri, 95 percent of the state's population of the federally endangered Grey Bat (*Myotis grisescens*) hibernate in just three caves. The Nature Conservancy owns one of these caves, Bat Cave in Shannon County. Besides being a hibernaculum, the cave is also a Grey Bat maternity site. The chapter also has management leases on two other caves, Wilsons Cave in Jasper County and Ben Lassiter Cave in Newton County that provide habitat for the Ozark Cavefish, *Amblyopsis rosae*. The Missouri Chapter has also used its Natural Areas Registry Program, designed to educated and aid private landowners in protection of their own property, to protect Holton Cave, another significant Grey Bat hibernaculum. Holton Cave is located within a summer camp for diabetic children.

In Tennessee, the Conservancy owns one of the three most important bat hibernation sites in the entire country, Hubbard Cave. Hubbard Cave each winter protects eight species of bats from six states including over 250,000 gray bats. Hubbard has one of the largest bat cave gates ever constructed. The gate is 30 feet tall and 35 feet wide and required 30 tons of steel. The Conservancy purchased Hubbard Cave with 50 acres surrounding the entrance area in 1985.

The Texas Chapter also owns a significant cave—Eckert James River Bat Cave Preserve. The cave is home to an estimated four to six million Mexican free-tail bats (*Tadarida brasiliensis*), one of the ten largest free-tail populations in the world. The cave, which is used as a maternity site by the bats, was jointly purchased by the Conservancy and Bat Conservation International with a gift from Richard Eckert. From May to October the preserve offers public viewing of the dramatic nightly emergence of the female bats. A second cave owned by the Texas Chapter protects the Texas Blind Salamander (*Typhlomolge rathbuni*).

In West Virginia, the Conservancy owns five caves including the only known location for the West Virginia Spring Salamander (*Gyrinophilus subterraneus*) at the General Davis Cave Preserve in Greenbrier County. General Davis Cave is gated to protect the salamander, but access for scientific investigation is allowed. Other cave preserves in West Virginia protect rare amphipods, isopods, and beetles.

Examples from Other States

Many state chapters of The Nature Conservancy are located in states with few limestone or karst features, rendering cave protection a low priority. However, several states with limited limestone have accomplished considerable cave protection considering the overall extent of their resource. The Maryland Chapter of the Conservancy owns two caves in Garrett County which not only contain several rare amphipods and isopods, but are also among Maryland's few wintering sites for the federally endangered Indiana Bat (Myotis sodalis). While the caves are gated, Maryland has a unique and successful cave access program. Leader training trips each spring provide instruction in how to lead a conservation cave trip. Several caving trips are then offered to the public with the trained leaders explaining the critical role the caves play in conservation of Maryland's natural resources.

The Adirondack Chapter (New York) also has a small but successful cave conservation program. The Adirondack Chapter has teamed up with International Paper to jointly purchase land to protect caves and abandoned mines used as bat hibernacula. Timber practices have been altered or curtailed in some areas to aid in the protection of the bat caves. A cave protected near Hague, New York contains 125,000 hibernating bats including all six species found in the northeast. The cave was purchased in 1984.

Access

Eighty percent of the state Conservancy chapters that own cave entrances indicated that their caves were gated. Many are gated to protect either bat hibernacula or maternity colonies. However, all chapters that had gates also indicated that they had some type of seasonal access policy. In addition to Maryland's escort policy, some states have volunteers who will lead trips on request, other chapters allow certain caves to be visited only by researchers or students. When the Conservancy purchases a cave, this does not necessarily mean that access to the cave will be prohibited.

Areas of Expansion and New Opportunities

States Gaps

Much of the Conservancy's cave protection is based on well known species, especially federally endangered bats. Other bats, cave invertebrates, and plants living in the twilight zone are less studied and few inventories have been performed. Table 1, which displays this trend, totals the number of each type of organism afforded some type of protection by The Nature Conservancy.

Table 1

Results for Fauna Protection

Fish & Salamanders:	6
Bats:	45
Invertebrates:	14
Other:	2

On the cave protection questionnaire, many states cited a lack of faunal inventory and cave location knowledge as the main reason that they were not engaged in more cave protection. Of all states reviewed, the state chapter in Georgia may have the most to gain from additional inventory and cave location information. Currently the Georgia Chapter owns no caves and has not approached caves as a protection topic. Yet Georgia has many caves likely to contain rare invertebrates, in addition to the probability of rare plants growing on the sides of the many deep, straight-sided pits famous in the state. Colorado also lacks any cave preserves, primarily due to lack of inventory of their relatively inaccessible, high-elevation caves.

Involvement with the NSS

Most state Conservancy offices cited no involvement with local chapters (grottos) of the NSS. Notable exceptions to this are the states of Maryland, Oklahoma, Tennessee, and West Virginia which have all worked closely with local NSS chapters. Involving local grottos at the start of a cave protection program can ease tensions and controversy that the purchase of a cave may bring. The involvement may empower the local grotto to take on management responsibilities at the cave and be an active partner in developing access and use policies.

Significance Beyond Biological

The Nature Conservancy bases its protection upon biological significance, and protection priorities are based on a "Biodiversity Rank" determined by the frequency and quality of biological components in the cave. Geological formations and quality of karst features are not currently high priorities for protection. While some cave conservationists may question The Nature Conservancy's strict mission, this limit on what the Conservancy may target for protection opens the door for other organizations to compliment The Nature Conservancy's work. Several grass-roots cave conservation groups have formed with the goal to buy and protect karst features. These new organizations fill an important gap where The Nature Conservancy is unable to protect a cave due to the lack of biological features. Groups such as the Indiana Karst Conservancy have worked closely with The Nature Conservancy to protect caves that are less biologically significant. As more local cave conservation groups form, The Nature Conservancy will have additional opportunities to assist and help these local groups in acquisition and management of cave resources.

Conclusion

For many chapters of The Nature Conservancy, caves have only recently become a conservation issue. The greatest impediment to cave conservation is the difficulty of finding knowledgeable cavers and cave biologists to assist the Conservancy in locating and inventorying caves. Many state chapters have had no communication with the caving community or know of any cave scientists working in their state. If inventory information is known, it is usually for a well-studied animal such as a federally endangered bat. For many states, inventory information is entirely lacking for invertebrate species. For the Conservancy to expand its capacity for cave conservation it also must expand its communication network with both cavers and cave scientists.

Working at the local level is increasingly important to The Nature Conservancy. Outreach and contact with local groups makes for more effective conservation protection. Several states have begun to involve local grottos of the NSS in cave protection and management. A national Memorandum of Understanding between the NSS and The Nature Conservancy has aided in this partnership; however, more education is needed both to instruct Conservancy staff about the NSS and to familiarize local grottos with the Conservancy.

In the coming years, caves will become more of a protection priority for the Conservancy as impacts continue to threaten karst features. The Conservancy will continue to buy and otherwise protect cave environments and habitats. To be fully successful in this conservation, the Conservancy will also have to expand its communication and partnerships with the caving community.

Cave Management by a Non-Profit: A Case Study of The Nature Conservancy's Cave Management in West Virginia

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Abstract

The Nature Conservancy is a national, non-profit organization with the mission of finding, protecting, and maintaining the best examples of biodiversity that are found nationally and internationally. In West Virginia, much of the state's biodiversity lies underground. The Nature Conservancy owns five caves in the state, and has management responsibility over nine other caves. Each cave has its own management plan, including sections on working with local chapters of the National Speleological Society and the cave biology community. The Conservancy has initiated a cave registry program to engage private landowners in becoming involved in caring for cave resources. The West Virginia Conservancy works with private timber companies and the National Forest Service as a liaison between these groups and the caving community. Conservancy staff maintains a close working relationship with the State Endangered Species biologist involved in cave-related species. The Conservancy's greatest cave management challenge in West Virginia: to classify and prioritize the great number of diverse cave resources in the state.

Introduction

The Nature Conservancy is a private, non-profit organization begun in 1951. The Nature Conservancy emerged from a professional association of ecologists seeking to turn their knowledge of nature into positive action for conservation. The Conservancy started its tradition of conservation through private action with a modest 60-acre land purchase in New York state. Today, using the same market-oriented strategy, the Conservancy has protected over nine million acres of ecologically-significant land.

The Nature Conservancy mission remains: preservation of plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. The Conservancy is now the operator of the largest private system of nature sanctuaries in the world, owning and managing more than 1,500 preserves throughout the United States.

From the simple beginnings in 1951 with a single preserve, the Conservancy has continually strived to improve its science base of knowledge. Over 20 years ago, the Conservancy initiated a conservation database in each state with the purpose of compiling each state's examples of rare plants, animals, and communities. Each state program now maintains an extensive computer database of rare and unique flora and fauna. Most of these programs have now been incorporated in state government as "Natural Heritage Programs" and provide state agencies with scientific knowledge.

Over time, the Conservancy has gone from protecting obvious rare features such as showy plants and large mammals, to more obscure but equally-deserving creatures and places. These less-obvious creatures include invertebrates and bats, and the less-obvious places include caves and springs.

Caves have always been a priority for The Nature Conservancy of West Virginia, due to the abundance of karst features, caves, and many troglobitic and troglophilic endemics. This paper will look at the specific role the Conservancy has played in protecting caves in West Virginia. This paper is aimed at Conservancy employees or any other state, private, or federal managers responsible for cave management who may be unfamiliar with caves, or unfamiliar with the groups involved and interested in caves being managed. Case studies of several projects completed in West Virginia may be helpful to managers in other areas to create open and direct exchange with all parties interested in cave use and management.

A Look at the Different Groups

To be a successful cave manager, communication and open dialogue with many different interest groups is important. In West Virginia, The Nature Conservancy has worked with grottos, local chapters of the National Speleological Society (NSS), cave surveyors, cave researchers, the West Virginia Department of Natural Resources, the U.S. Fish and Wildlife Service, and the USDA Forest Service. Each of these organizations will be highlighted with a management example.

Local grottos

Caves with few management problems.

The Conservancy owns five caves in West Virginia. Two of these caves are managed by local grottos of the NSS. Contacts with the grottos were made after the caves were purchased. Ideally, grottos should be contacted prior to purchase. While land negotiations are ongoing, Conservancy staff can work with a grotto to develop a management plan and openly discuss how the cave will be used or not used. A little homework on which grottos in a state have interest in what caves can be very helpful in knowing whom to contact. Once the grotto most familiar with the cave purchased by the Conservancy was identified, Conservancy staff attended a grotto meeting to present information on the Conservancy. The cave of interest was discussed and a management agreement mutually agreed on.

This method was used to garner the support of the Monongahela Grotto from north-central West Virginia, that now manages a cave the Conservancy owns in Tucker County. The Grotto schedules regular trips to the cave to monitor for litter and to check the NSS use register they have installed in the cave. The register is helpful for the Conservancy to determine who and how many are using the cave. The Grotto then reports back to the Conservancy regularly to report any problems or concerns. This is an effective arrangement for both groups, made even easier by the fact that the cave receives little use and has few management problems.

What if the cave has management problems or is being harmed?

The Conservancy owns another cave located in Greenbrier County, West Virginia. The cave has a population of wintering Indiana bats (*Myotis sodalis*), a federally endangered species, and six rare invertebrate species. The cave also has a large entrance; large enough that all-terrain vehicles (ATVs) and cows frequent the cave. The cave receives moderate amounts of caver use, however; the ATVs and cows are the source of most of the impact to the cave, that is especially damaging when bats are present. The local grotto familiar with the cave was contacted and, again, a presentation was made at a monthly grotto meeting. The cavers were also concerned about the impact to the cave. A joint management plan was developed and activities at the cave were initiated to curb the abuse. The cave now has an entrance sign stating that the Conservancy owns the cave and that the cave is managed by Monroe County Cavers. The cavers regularly check the cave for ATV or cow trespass. A fence was installed in front of the cave to exclude ATVs and cows, but not cavers. The Monroe County Cavers assist in the repair and upkeep of the fence and monitor a use register in the cave. Because the cavers all live near the cave, they can visit the site much more often than Conservancy staff. While the fence is sporadically vandalized, ATV use has decreased and the cave area has a managed and "cared for" appearance, an important consideration in managing property in rural areas.

What if the cave is gated?

The neighboring state of Maryland provides an example of cave management when the cave is gated. The Conservancy owned Crabtree Cave in Allegheny County, Maryland provides habitat for rare invertebrates. Maryland has few caves, so this cave site was popular with locals and cavers. The cave was gated to protect the invertebrate resources and to halt the litter and graffiti that was increasing in the cave. Two grottos are now active in the management of the cave. Frederick Grotto, a participant in the original gating project, now stages a yearly "mock rescue" in the cave to train cave rescuers. The Western Maryland Grotto has held several "leader trips" to Crabtree Cave to train persons interested in leading trips to the cave. Each year, following the leader training, several caving trips are offered to the cave using the new trainees as leaders. This "trained escort" policy has allowed continued caver access, while ensuring the caves protection and monitoring.

Cave Surveyors and Researches

Another important group of cave users are the people who use caves for other than recreational purposes. There is a subset of cavers with a single goal of surveying and mapping caves. Others are primarily interested in inventorying the caves for their biological resources.

The Conservancy acquired a significant invertebrate cave in Pocahontas County, West Virginia. While the cave was biologically well known, the extent and size of the cave was not. A group of conservation-minded cave surveyors contacted the Conservancy and an agreement was established for the cavers to survey and map the cave. After a year of surveying, the Conservancy received a beautifully drafted cave map and were notified that another cave was found on the same property.

Important considerations to work out with a cave survey group include questions of digging and explosives to enlarge passages, and the policy on altering formations to extend a survey. The Conservancy in West Virginia prefers to leave the cave "as is" and survey only currently humanly-passable passage. Once communication and contact with cave surveyors is established, this group can be a valuable link to knowledge on caves locations and landowner contacts.

West Virginia karst features have been blessed with an abundance of biological inventory and study. Several prominent karst scientists have performed extensive surveys, and over 500 caves in the state have biological significance with many more having high potential. Due to this great number, a priority system was needed to rank and classify the caves to determine the true rarity of the creatures living in the cave, and the habitat the cave provided.

In 1991 the Conservancy contracted Dr David Culver to biologically rank the most significant caves in West Virginia and begin a cave community classification system. Dr Culver biologically ranked 21 caves in West Virginia and developed six cave community types including: Appalachian Terrestrial Riparian Cave, Appalachian Terrestrial Dung\Transitory Organic Matter Cave, Appalachian Cave Stream, Appalachian Edaphobitic/Epikarstic Terrestrial Cave, Appalachian Karst Phreatic Cave, and Appalachian Cave Drip Pool/Epikarstic Cave (Culver, 1991). His classification was based on how nutrients and water flow through a cave.

Maintaining close ties to the research community can be invaluable in determining which caves should be a priority for protection and management. In the early 1980s the Conservancy purchased a cave in Greenbrier County in which Dr John Holsinger had found a new species of salamander, *Gyrinophilus subterraneus*. The cave was gated to protect the salamander from a local habit of using the salamander as fish bait. However, while the cave was gated, researchers and students of cave biology are allowed regular access. An annual survey using cave biology students, inventories the rare salamanders found in the main cave passage.

The Nature Conservancy in West Virginia continues to expand cave biological inventory. With funds provided by the Cave Conservancy of the Virginias (a group dedicated to the education and protection of karst resources in West Virginia and Virginia) the Conservancy is currently studying how cave invertebrate endicism is tied to cave drainage basins and watersheds. This study will further shape and define the Conservancy's cave protection strategies within the state.

State and Federal Agencies

Within West Virginia, the state Department of Natural Resources—Endangered Species Program is active in inventorying and managing caves for the two species of federally endangered bat found in West Virginia Caves, the Indiana bat (*Myotis sodalis*) and the Virginia big-eared bat (*Plecotus townsendii virginianus*). To learn more about endangered cave species, Conservancy staff have assisted the endangered species biologist in the inventory of bats caves, night scoping of Virginia Big-Eared maternity colonies, radio tracking Virginia big-eared bats, and mist netting for summer occurrence of Indiana bats. All these activities have increased the knowledge of bat conservation for the West Virginia Conservancy staff and strengthened communication and partnership with state employees who have extensive knowledge of cave locations and owners.

The USDA Forest Service, Monongahela National Forest is a major cave owner within the state. Over 500 caves are on National Forest lands including 20 highly significant caves, two of which are gated for federally endangered bats. The Conservancy has acted as a liaison between the Forest Service and the caving community to discuss management, and to make each group aware of the others needs and requirements. The Conservancy has also worked with the Forest Service to jointly identify caves that should be included for acquisition within the National Forest boundary.

The U.S. Fish and Wildlife Service has provided federal money to the Conservancy for the cleanup of caves with known significant rare fauna. Several significant caves are associated with large trash dumps that are impacting the caves water system. The Conservancy is working with local grottos to coordinate individual cave cleanups. Again local grottos are the best source of cave location and landowner information.

The Conservancy's Land Protection Experience

Because the Conservancy is involved on a daily basis in all aspects of land protection, the Conservancy's staff can assist other groups in their own land protection. Several small non-profit land trusts have been initiated in West Virginia to protect cave and karst areas. Conservancy staff have been available to provide assistance in the start up of these cave trusts and have offered assistance on how to structure land deals as well as advice on how to oversee the complexities of preserve management, once the land is protected.

The Conservancy has a simple but effective tool that can be used by other cave protection groups. The Conservancy initiated and maintains a "Cave Registry" program. Conservancy staff contacts private landowners that have significant caves on their property. The landowner is educated about their special resources. If the landowner wants to register their cave, they promise to protect the cave to the best of their ability and to adopt conservation management practices that will insure that the cave is left in a clean and natural state. The registry program is not legally binding, but instead is meant to instill pride and commitment in the landowner and increase the landowners awareness about their special cave. The cave landowner is presented with a personalized plaque to commend them for being good stewards of their cave property. This inexpensive protection tool can easily be adopted by other cave protection groups and is a successful method to increase cave awareness among local landowners.

Conclusion

In West Virginia, caves are a hot-spot of biological richness and diversity. Because of their uniqueness, caves will continue to be a protection priority for the West Virginia Chapter of The Nature Conservancy. The West Virginia Chapter foresees using all types of protection tools, from registry to outright fee ownership to protect caves. The Conservancy will also continue to rely on NSS grottos for management assistance in terms of knowledge and expertise with caves and cave landowners. By working with all groups concerned with the protection of West Virginia caves, the Conservancy not only increases its own knowledge of caves, but also strengthens a valuable caving network that helps all groups involved.

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Management of Lava Tube Caves of Puna District, Hawaii

William R. Halliday
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Abstract

The portion of Puna District between Mauna Loa Volcano and the East Rift Zone of Kilauea Volcano is the world's leading area for the study of lava tube caves. In recent years, members of the Hawaii Speleological Survey have mapped more than 50 miles of caves here, and others have reported mapping more than 10 miles in other caves, by pace-and-compass. Best known is Kazumura Cave, 37.3 miles long and the world's longest lava tube cave. These caves vary in features, resources, and values. Most of them are beneath substandard subdivisions, long sparsely populated but now undergoing a building boom. Currently, Hawaii County is developing plans for an extensive infrastructure for this area which could severely harm cave resources and values if not prepared in cooperation with knowledgeable speleologists. The Hawaii Speleological Survey has made a preliminary report and some recommendations to the County of Hawaii. These will be presented in this paper.

Introduction

Until very recently, good progress had been made in cave management in residential subdivisions in Hawaii since my 1993 National Cave Management paper on that subject (Halliday, 1995a). During the summer of 1995, however, the Office of the Mayor of Hawaii County proposed to collapse part of Kazumura Cave and other world-class caves in the heart of the north Puna cave area—arguably the world's most important lava tube area.

Caves and Pseudokarst of Puna District, Hawaii

In the state of Hawaii, Hawaii County and Hawaii Island ("The Big Island") are synonymous. Puna District is the most southeasterly of the districts of Hawaii County. It extends about 30 miles from the eastern rim of Kilauea Caldera (and some of the adjacent southeastern slopes of Mauna Loa Volcano) to the Pacific Ocean just south of the city of Hilo, thence around the southeast point of the island and halfway along its south side. The district consists entirely of pseudokarst, with caves scattered throughout. In the section between the Southeast Rift Zone of Kilauea Volcano (which extends from the caldera to the southeast point of the island) and the east flank of Mauna Loa Volcano (approximated by Highway 11) is the world's greatest concentration of lava tube caves. Estimates of penetrable cave passages here are 100 miles or more. About 60 miles of passages are believed to have been explored, with about 50 miles mapped.

The caves of this part of the Puna District are in lava flows believed to be 300 to 800 years old. They arose from Ailaau Volcano, a small shield volcano on the rim of Kilauea Iki Crater. Largest and most important is Kazumura Cave. With 37.3 miles (60.1 kilometers) mapped, it is by far the world's longest lava tube cave. Some of the other world-class lava tube caves here are Keala Cave (5.3 miles mapped), Pahoa Cave or Caves (more than ten miles said to have been paced or mapped (McEldowney and Stone, 1991), the John Martin-Pukalani Cave System, Lower Uilani Cave, and parts of the D Road System or Systems. Even smaller caves here tend to have major scientific, utilitarian, and/or economic value, and not all the known caves have even been visited.

Subdivisions in the Main Puna Cave Area

Most of this cave area is covered by substandard subdivisions. Characteristically they lack such infrastructures as sewers and water lines. Electric and telephone lines are spotty. Few roads are paved; some are mere ungraded ruts over bare lava. Much sewage goes almost directly into the district's fresh water lens, sometimes through sections of caves. Mostly, caves are considered dangerous nuisances and are dealt with as such.

Figure 1. *View looking up hill on Ainaloa Boulevard, one of the few paved streets in the Puna subdivisions. The dip seen near the center of the photo resulted from sagging of the street into the partially filled entrance of Lower Uilani Cave during road construction. The skylight is just to the right of the light- and dark-colored surfaces. Underlying the light-colored surface and part of the road is a dump of household and automotive solid wastes, partially in plastic nonbiodegradable bags. (Photo by W.R. Halliday)*

Considerable solid waste is dumped in some of them. Some of it may be hazardous waste and much is undeniably toxic to interstitial small animal life commonly seen in Puna caves.

Until recently, these subdivisions were sparsely populated, and their impacts on caves and on ground water were mostly minor. However they represent the last low-cost residential area in Hawaii, and in recent years their population has skyrocketed, with increasing impacts and increasing needs for a standard infrastructure.

At the 1993 National Cave Management Symposium I presented a paper (Halliday, 1995a) outlining the problem of cave management in these subdivisions and relating the management plan we had proposed for Lower Uilani Cave, a major cave threatened by collapse of a main subdivision road. This paper discussed features, resources, and values of the major caves, human impacts since arrival of the earliest Hawaiians, the history of the subdivisions, the history of speleology in this area, and the destruction and contamination of some of the caves.

In addition it referred to Native Hawaiian issues, state and federal laws and noncompliance with them, potential mobilization of public support, and the proposed plan for Lower Uilani Cave. I asked for information on successful cave management in other urbanized areas. Little was forthcoming. Lower Uilani Cave remains intact, but no formal management plan is known to have been adopted, officiallyorunofficially.

Recent Hawaii County Planning

Meanwhile the Hawaii County Planning Department and Commission began to confront the need for subdivision infrastructures. The Department contracted for a Puna Community Development Plan. Its first draft was dated June 30, 1992, but was released in 1994 (Community Management Associates, Inc, 1992). Neither the Hawaii Speleological Survey nor the Hawaii Grotto of the National Speleological Society knew it was being prepared and this draft was completed without input from speleologists. Anyone reading it or its companion "Technical Reference Report" immediately recognizes that its preparers were almost totally uninformed about the lava tube caves of Puna and their significance.

Members of the Hawaii Speleological Survey and the Hawaii Grotto met with a staff person of Community Management Associates, Inc and found her receptive to new information. In follow-up of this discussion, the Hawaii Speleological Survey prepared a report of 16 pages plus appendices (Halliday, 1995b) with an unusual approach. Because of the utilitarian outlook of some of the planners in this system, it emphasized the uses—licit and illicit—of Puna caves as well as their scientific and cultural importance. Their resources and values were outlined as follows:

1) utilitarian
   a) show cave potential
   b) movie and video potential
   c) isothermic storage
   d) air conditioning
   e) physical medicine and rehabilitation
   f) housing
   g) water diversion
   h) solid waste disposal
   i) disposal of human and animal waste

Figure 2. *Lavafall and plunge pool with sunken crust in Olaa section of Kazumura Cave. (Photo by W.R. Halliday)*

j) concealment of illicit drug operations
k) concealment of crimes against persons
l) fallout shelters

2) earth science
   a) geological
   b) hydrological
   c) meteorological
   d) mineralogical
   e) paleontologica l—bedrock
3) biological sciences
   a) botanical
   b) paleontological —surface and sediment
   c) zoological
4) cultural
   a) Native Hawaiian uses and values
   b) historical values
   c) interpretive uses and values
   d) religious uses
   e) wilderness values
   f) scenic values
   g) recreational values

Each of these was discussed, then spelean hazards to life and to property were described, then existing damage and threats to spelean resources and values.

After a preliminary review of individual, agency, and organizational needs and responsibilities, the Hawaii Speleological Survey proposed that the County of Hawaii take the leadership in developing a Puna Cave Management Plan. This plan should reflect broadly accepted principles of cave management within the specific framework of laws, regulations, policies, and customs of Puna. Thirteen specific points were suggested:

- identification of data sources and restrictions on availability
- identification of resources, values, and hazards within that availability
- identification of agencies and others with "needs to know" and limitations on the "need to know" of each
- identification of agencies and others potentially impacting cave resources and values, and potential problem solvers
- identification and minimization of conflicts in protection and use of resources and values
- elicitation of interagency cooperation
- correlation of problem-solving agencies and others
- designation of contact persons in relevant agencies
- obtaining public awareness and support
- eliciting public and private sector compliance with statutes and regulations
- enforcement of existing statutes and regulations

Figure 3. *Hawaii cavers inspection lava karren and lava blades on an unusual thermal erosional remnant in Kazumura Cave. (Photo by W.R. Halliday)*

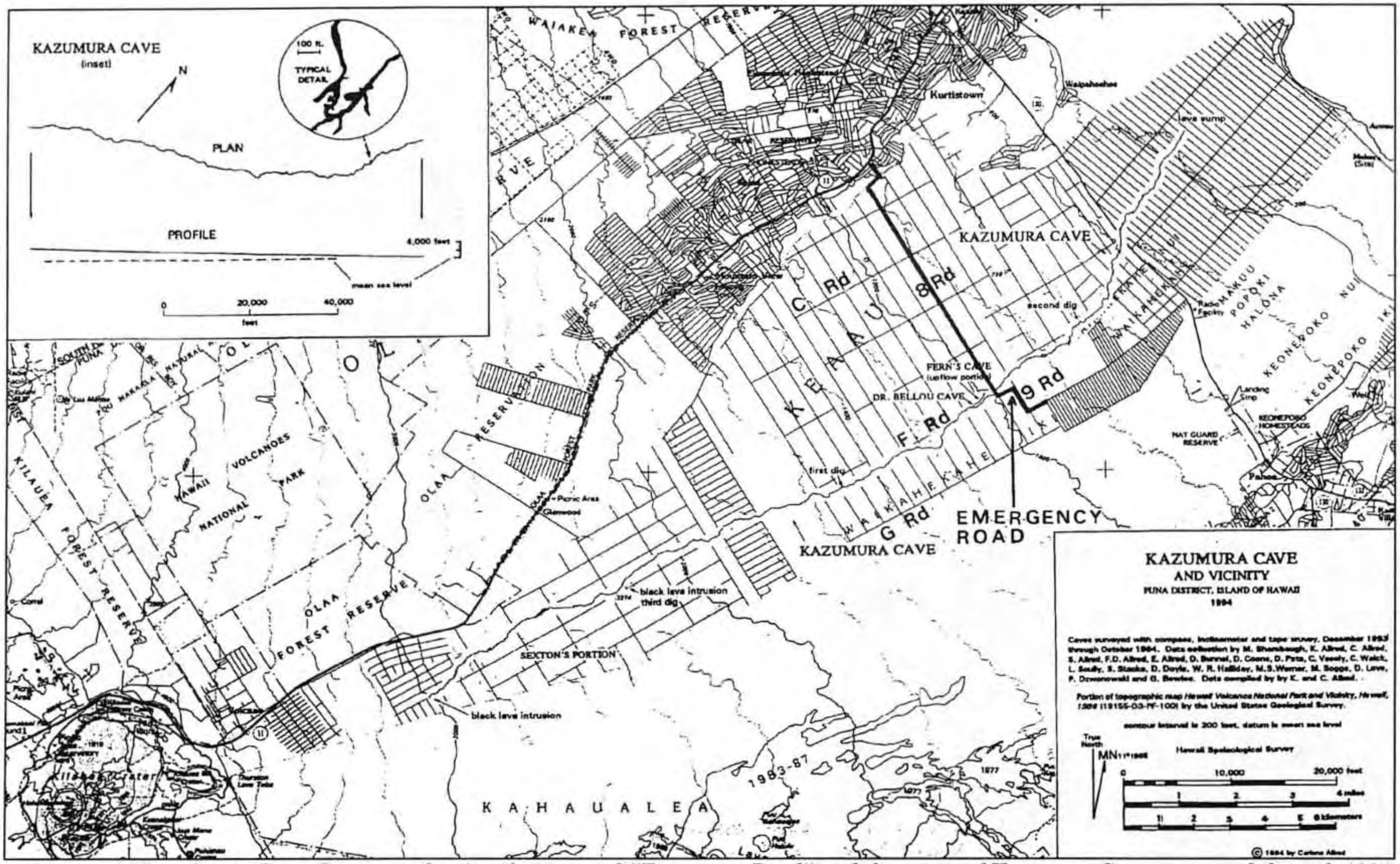

Figure 4. *Map of main Puna Cave area showing the proposed "Emergency Road" and the course of Kazumura Cave as mapped through 1994. The caves endangered by this proposed road reconstruction extend beneath 8 Road between C Road and F Road, and beneath F road between 8 Road and 9 Road. In October 1995, teams headed by Kevin Allred extended Kazumura Cave from the point marked "black lava intrusion" to a point near the town of Volcano. Map consists of 1995 additions to 1994 map by Carlene Allred based on U.S. Geological Survey map of Hawaii Volcanoes National Park and Vicinity, 1986.*

- consideration of new alternatives as problem solving, that is, use of knowledgeable volunteers as field consultants
- enactment or promulgation new statutes or regulations only as a last resort.

This report and proposal was well received by Community Management Associates, Inc. The second draft of the Puna Community Development Plan (Community Management Associates, 1995) contained a full page of well-reasoned considerations of Puna lava tube caves, their environments, and their significance.

The Hawaii Speleological Survey commended Community Management Associates, Inc and some of their members began joint planning to minimize the impact of the new infrastructure on caves and vice versa. This took the form of rerouting sewer and water lines and the like. We looked forward to presenting this as a model for teamwork in areas where planners had no previous knowledge or understanding of caves and karst or pseudokarst.

The "Emergency Road" Emergency

A few weeks later, however, the Office of the Mayor of Hawaii County announced plans for an "Emergency Road" through the heart of this cave area. Largely, it followed but upgraded miles of existing subdivision roads, crossing Kazumura Cave, Keala Cave, Pirates Cave, the D Road System, and probably others. Lower Uilani Cave might or might not be affected also. Because only $1 million was available for the entire project, simple cut-and-fill techniques were to be used, and the caves were to be "collapsed" unless declared "significant" by state archaeologists. Although several local speleologists and cavers introduced themselves to the Mayor's spokesman before his announcement, he specifically stated that he knew nothing about speleologists and obtained all his information about caves from archaeologists. He stated that he would "try to save the caves", but made it clear that there were no funds for roadbed reinforcement over the caves. He acknowledged that an Environmental Assessment was necessary for the project, and agreed that speleologists could accompany the assessment contractor's "walk-through" of the caves. Nevertheless he asserted that the Environmental Assessment was only a formality, insisting that Hawaii state law exempts counties from complying with Environmental Assessment conclusions.

As of the date of this symposium, land condemnation was underway, but no announcement of the Environmental Assessment had been received.

The Hawaii Speleological Survey and the Hawaii Grotto of the National Speleological Society expect to make a strong presentation as part of the Environmental Assessment, and will welcome input by other informed persons. There are many ways that the "Emergency Road" proposal can be modified to preserve the caves and their environments. The Hawaii Speleological Survey expects to take whatever actions are necessary to protect them. Hopefully, an successful outcome will be reported at the 1997 National Cave Management Symposium.

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Proposed Management of Caves of Kilauea Caldera, Hawaii

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Abstract

During the summer of 1994 the Hawaii Speleological Survey performed cave mapping and cave inventories in several parts of Hawaii Volcanoes National Park. Subsequently it made recommendations on management of caves of Kilauea Caldera and elsewhere in the park. Findings in the caldera included a major lava tube system of three caves 75 years old, with very unusual features, resources, and values. Early in its history, part of this system served as a show cave or interpretive cave. Also found were smaller lava tube caves and shallow sub-crustal caverns of several types. Considered as an entity, the caves of Kilauea Caldera present a notable opportunity for thoughtful cave management.

Introduction

Caves of Kilauea Caldera in Hawaii Volcanoes National Park have been attractions for visitors and scientists at least since the 1820s (Ellis, 1823). Numerous references exist. All the caves mentioned in print before 1900, however, have been destroyed by the volcanic activity intermittent in this area (Brigham, 1909; Halliday, 1994). With one small exception (Byron Ledge Trail Cave, in 1885 lava), all caves known on the floor of the crater are in 1919 to 1921 flows, north of Hale-maumau pit crater. Parts of the Postal Rift Cave System were commonly visited in the late 1920s and 1930s.

Following promulgation of a controversial cave management plan in 1990, all caves in the caldera were closed to entry administratively. In 1994, this policy of "management by exclusion" was partially reversed. The Hawaii Speleological Survey was invited to inventory resources and values of these and some other caves in the national park, and to make management recommendations. This was done in the summer of 1994 (Halliday, 1994), with some on-going follow-up studies.

Basic Geography

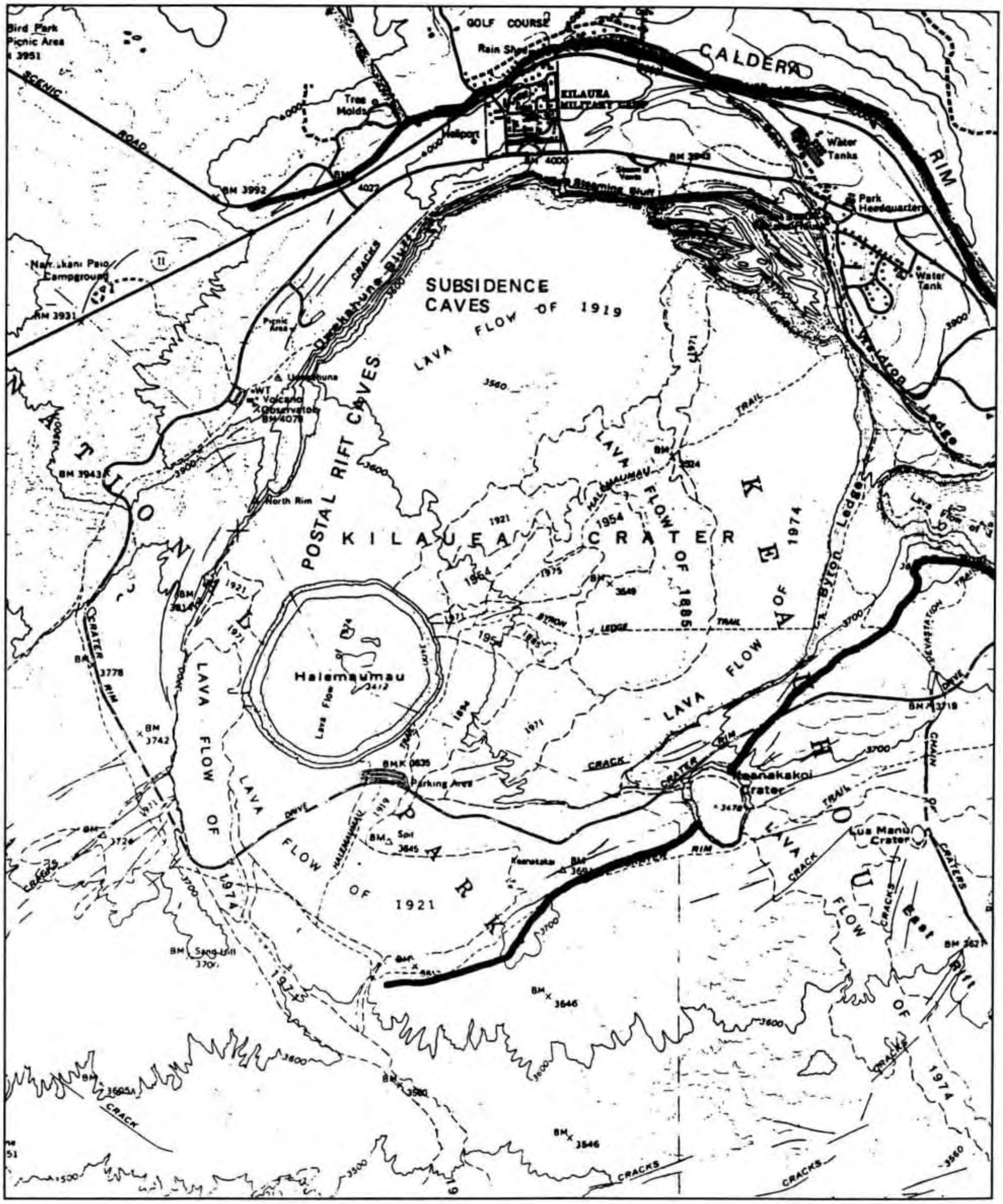
Kilauea volcano is a complex geologic structure located on the lower southeast slope of 13,679-foot Mauna Loa Volcano. The magma chambers of the two volcanos are interrelated in some obscure way, but their lavas are distinguishable. Kilauea caldera is a complex surface feature at an elevation of about 4,000 feet. At present it has a low, inconspicuous outer "ring" about three miles in diameter, in the form of a horseshoe open to the southwest. Within this low outer horseshoe, a closed inner crater has a much more conspicuous horseshoe of cliffs several hundred feet high on its west, north, and east sides. To the south, these cliffs slope down to a low ridge which forms the south rim of the inner crater. Two small pit craters (Kilauea Iki, Keanakakoi) interrupt its east rim.

This inner crater is about two miles wide from northwest to southeast, and about three miles from northeast to southwest. From its rim, most of its floor appears flat. Actually its floor consists of gently sloping, relatively smooth pahoehoe basalt lava flows with considerable local relief. Especially in the center of the crater, small areas are quite rugged.

Near the west wall of the inner crater is Halemaumau, a spectacular round, sheer-walled pit crater about 200 feet deep and half of a mile in diameter. Currently steaming but dormant, Halemaumau most recently filled and overflowed in 1974. Nearly all the caves on the crater floor are in lava which overflowed from Halemaumau in 1919 to 1921. One is in 1885 lava, the oldest exposed on the crater floor. Halemaumau's present width resulted from a spectacular phreatomagmatic eruption in 1924. This explosive event enlarged its diameter by several hundred feet, destroying the uppermost part of the Postal Rift Cave System in the course of this enlargement.

Distribution and Types of Caves

Existing caves of Kilauea Caldera are conveniently categorized as lava tube caves of the south part of the 1919 to 1921 flows near Halemaumau, and small subsidence caves of the remote north part of the 1919 flows, with a single additional example of the latter in an 1885 flow. In addition,



remnants of a single, small lava tube cave (Roadside Cave) exist in much older lava between the outer caldera rim and inner crater rim.

Numerous deep tectonic fissures or cracks (some of them roofed) also are present between the outer caldera rim and the crater rim. Some which are steamy are used by local people as natural saunas. At least one death has resulted from this practice, when a woman slipped off a ledge and fell deep into the hot depths of the crack. In this report, these cracks are considered as separate geological phenomena and are omitted except as they interface with lava tube or subsidence caves.

Lava Tube Caves

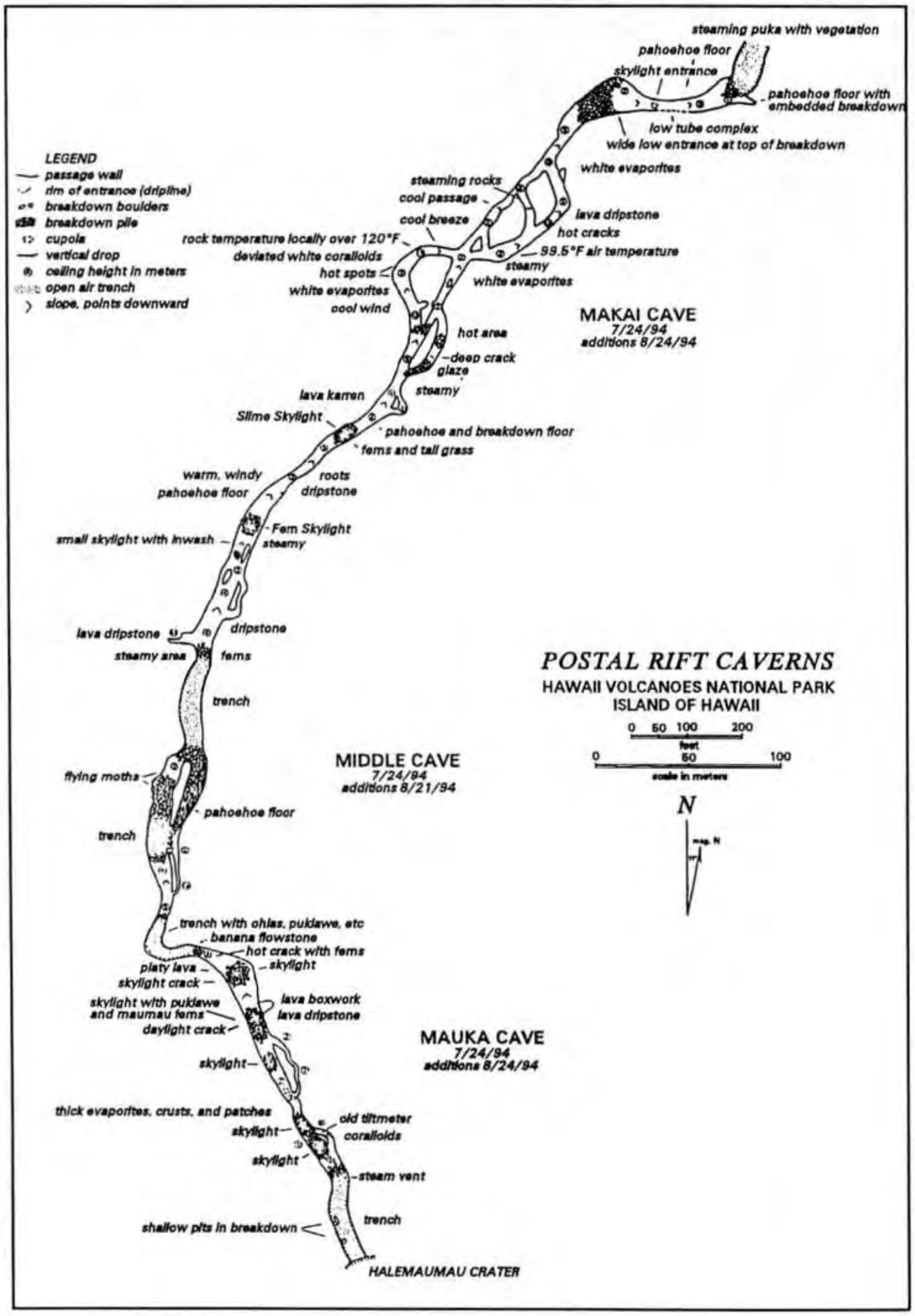
The largest caves of Kilauea Caldera are the lava tube caves of the Postal Rift System. Here, three sizeable lava tube caves have a combined length of 1,081 meters (3,550 feet). The system begins at the edge of Halemaumau with a lava trench about 150 feet long. Postal Rift Mauka (upper) Cave has 575 feet of mildly braided passage; three short cut arounds on the eastern side of the cave all are much smaller than the main corridor. Four skylights are present. Plants typical of the surface in this area grow beneath two of them.

Most of the main passage is easy walking and the rest is scrambling. Maximum width is about 50 feet and ceiling height about 20 feet. Rheogenic geological features and secondary mineral encrustations of undetermined type are well developed. Lava drip features are uncommon. Very small fumaroles are present in at least two locations. Rockfall hazards are localized and a trail could easily be routed away from them. Historic artifacts in the form of an obsolete tiltmeter are present in one cut around.

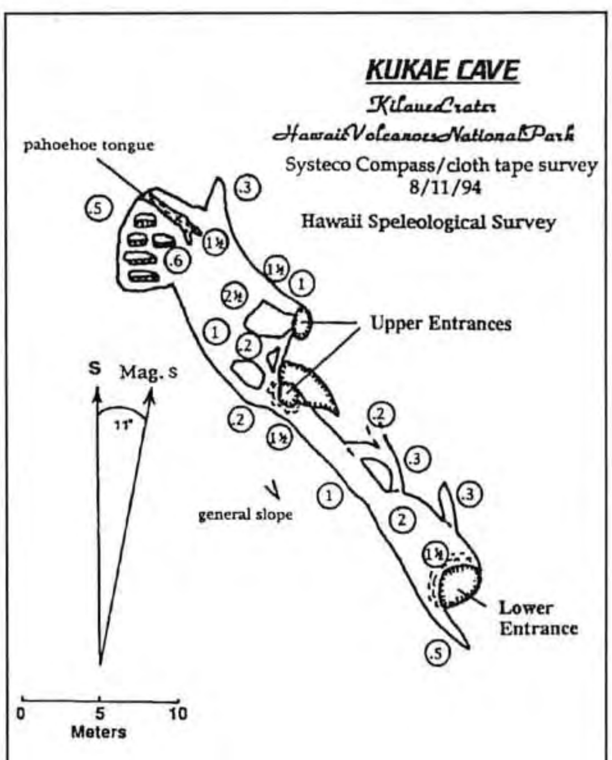
Postal Rift Middle Cave is the smallest and least attractive of the three Postal Rift Caves. It has a total of 561 feet of passages. After a steep entrance breakdown slope, its upslope section is much like the *mauka* cave, but with less prominent features. Near its lower entrance, however, its east cut around is as large as the main (west) passage, and the lower half of the cave is almost entirely floored with large breakdown blocks. Part of the roof of the main passage is entirely lacking for several dozen feet.

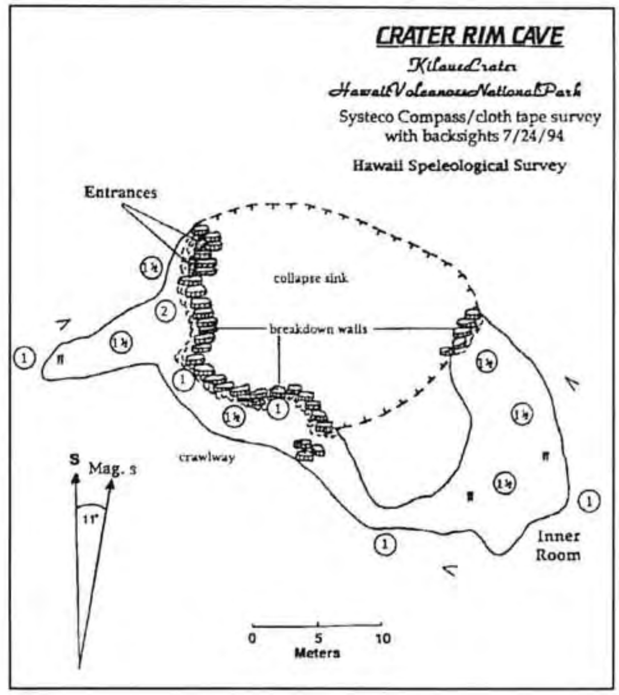
Postal Rift Makai (lower) Cave is the largest and most complex cave in the system. It has 2,412 feet of passages, many of them in a complex braided pattern. It ends alongside a steaming depression which supports a notable "island" of vegetation in a barren "sea of lava." This depression appears to have been a lava lake rather than part of a lava tube.

Several fumaroles are present in this cave. Rock temperatures locally over 120°F and air temperatures as high as 99.5°F have been recorded. Some



HVNP Superintendent, Jim Martin, at one of the entrances of the Steaming Sulphur System. Note the sulphur crystals at the corner of the entrance beneath his right knee. Photo by W.R. Halliday.





sections are as steamy as artificial saunas but steam concentrations and air flow are highly sensitive to external conditions.

Rheogenic geological features are notable locally. These include lava karren. Secondary mineral crusts are well developed in some passages. Some unusual biological features have been observed near fumaroles.

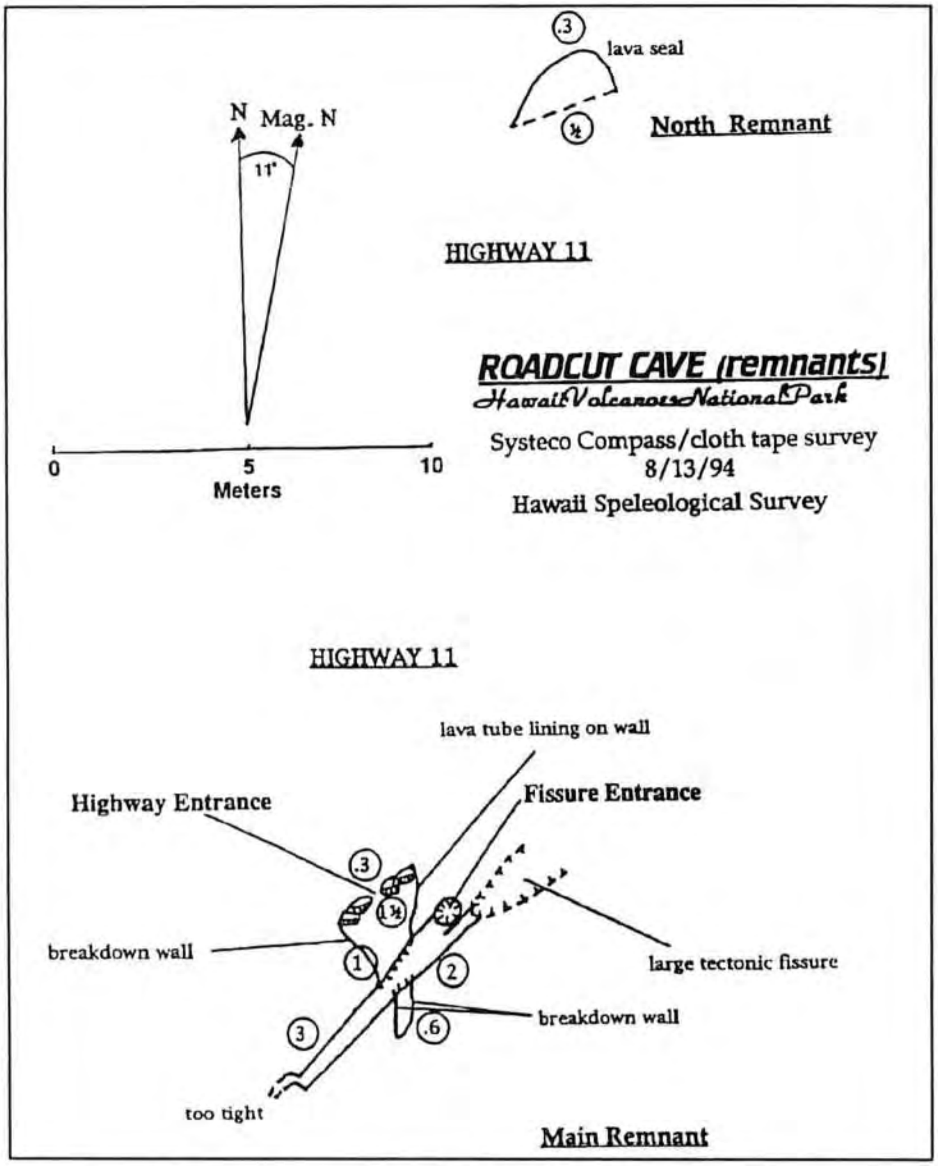
Most of the cave consists of easy walking passage, but some crawling and some clambering over annoying breakdown are required to visit the entire cave.

The Steaming Sulfur Cave System is a partially investigated sequence of small sinks and low, shallow caves. It is located a few hundred feet east of the Postal Rift Mauka Cave. No cave segment investigated to date is more than a short crawlway. A few of them contain thick beds and crusts of unidentified white and yellow minerals. Typical sulfur crystals can be seen in one entrance.

Kukae Cave is a small but complex lava tube cave located near the uppermost entrance of the Postal Rift System. Less than 125 feet of passage is present. Most of it is crawlway but interesting rheogenic geological features are present. Small mammal droppings are profuse.

Tiny remnants of Roadcut Cave are present on both sides of Highway 11 just inside the outer caldera rim; highway construction literally decimated this cave. It is of special interest, however, because its lower end is intersected by a large, roofed tectonic fissure which has not been investigated. The main roadside entrance is conspicuous despite partial obstruction with blocks of lava.

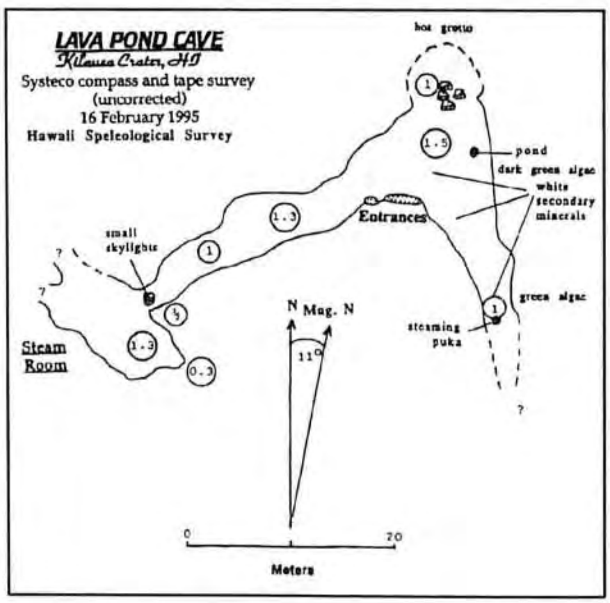
Crater Rim Cave traditionally has been considered a lava tube cave but its features are more

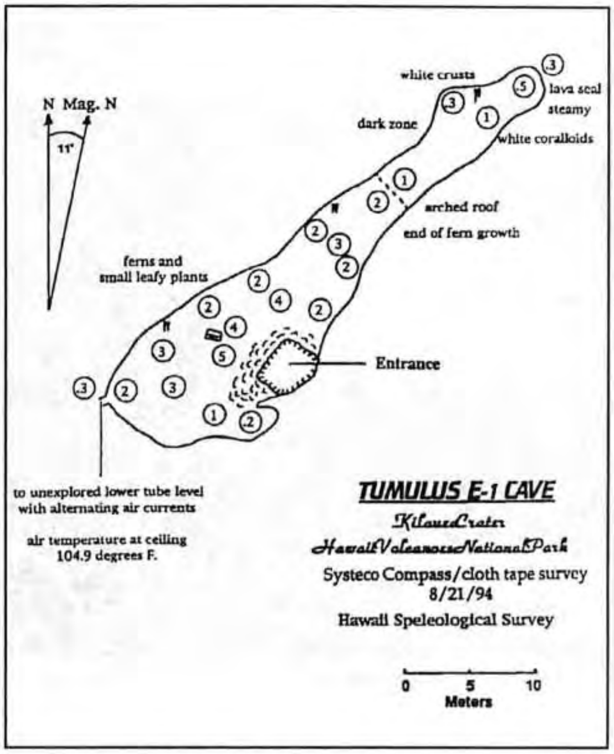


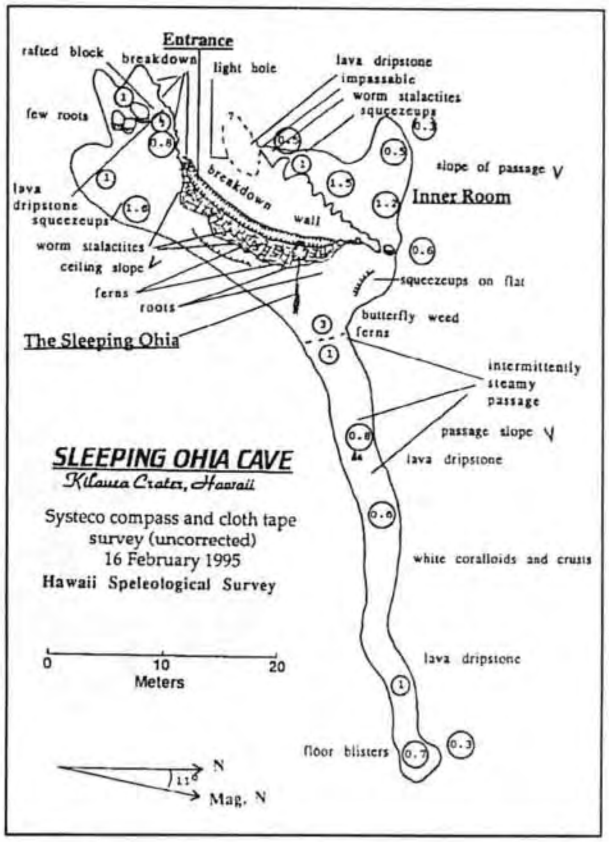
characteristic of a shallow subcrustal subsidence cave. Located about 150 feet from the northeast rim of Halemaumau in a 1921 flow, it is the closest cave to the Halemaumau visitor center and associated trails. Comparatively minor rheogenic and secondary mineral features are present, but lava dripstone is impressive locally. Breakdown forming the entrance sink filled most of what originally was a single ovoid room, demarcating two small, low residual chambers and a connecting crawlway about 150 feet long.

Subsidence Caves

Tumulus E-1 Cave is the prototype of a newly-recognized type of volcanic cave (Walker; 1991, 1992). Its conspicuous entrance on the side of a large tumulus below the Jaggar Museum is readily seen by hikers, but only a few hikers visit this remote, trailless section of the crater floor. This cave consists of a single wide, slightly-arcuate room 125 feet long which occupies most of a hollow tumulus about 30 feet high. Its south end is a spacious chamber illuminated by the entrance. Width is as much as 30 feet and the ceiling height as much as 15 feet. Beautiful ferns and other flora are present on the hanging wall opposite the entrance and on the floor. At its extreme southwest end, a sloping orifice about one meter in diameter extends downward to a subparallel tube-shaped low passage too hot to enter; an air temperature of 104.9°F was obtained here. From this orifice, steam emerges periodically into the south end of the main room and occasionally reaches the entrance. The north end of the cave is wide and low, warm and dark. Lava dripstone and secondary mineral crusts and coralloids are present.







Sleeping Ohia Cave is located in the same general area. It appears to have formed by cavitation of a wide, low tumulus, but if so, the tumulus was atypical. The cave was named because of the presence of an ohia tree with a long, nearly horizontal trunk, finally curving up to the entrance; it sprouted near the rear wall of the entrance room and followed a phototropic course as it grew. As in the case of Crater Rim Cave, this cave originally consisted of a single chamber, about 120 feet long, 60 to 75 feet wide, and up to 10 or 12 feet high. A low extension about 125 feet long and 10 feet wide continues north to a small chamber with lava blisters on the floor. The collapse forming the entrance walled off a small, dark inner room from what is now the entrance chamber. The latter is in twilight. Its botany is of obvious interest but has not been studied. Rheogenic features, lava dripstone, and secondary mineral encrustations are patchy. The low downslope extension intermittently contains dense steam.

Lava Pond Cave, Ring Cave, Half Moon Cave, and several others are farther northeast and are even more remote from current visitor areas and


Entrance sink of Sleeping Ohia Cave, Kilauea Crater. The ohia tree seen in the entrance sprouted near the far wall of the cave, and its trunk is nearly horizontal until near the entrance overhang. Photo by W.R. Halliday.

Steam emerging from one of the skylight entrances of Postal Rift Makai Cave. Photo by W.R. Halliday.

trails. Lava Pond Cave has about 200 feet of known passage; parts of it are too hot for reconnaissance and fumes also are a hindrance. At least three fumaroles are present. Much of the cave was steamy during the only known visit to it. It formed along the lower margin of a drained lava pond where the peripheral lava had cooled enough to support the roof when the center slumped. Most of it is too low to stand erect but it is of special interest because of extensive mineral beds and crusts. Geological features otherwise appear minor. Colonies of green algae are present.

Half Moon Cave is similar to Lava Pond Cave, but is much smaller. Ring Cave is shaped like a hollow doughnut 3 to 6 feet high, 6 to 10 feet wide, and about 35 feet in diameter. It is the prototype of caves formed by drainage of a lava pond, in this case originally round and about 50 feet in diameter. From the cave extend some low tubular passages which may be crawlable. Only one short visit is known and no significant internal geological or biological features were observed.

Byron Ledge Trail Cave has been entered even more briefly. It resembles Lava Pond Cave but has no active fumaroles. Formed in 1885 lava, it is the oldest cave known on the crater floor. Located about two minutes' walk from a well-used trail, it is the most accessible cave for interpretation. Botanical values were observed and must be protected.

Management Recommendations

Taken as a whole, the caves of Kilauea Caldera present a notable opportunity for thoughtful cave management. In addition to their wide variety of interesting features in an underground wilderness environment, the opportunity to observe manifestations of Kilauea's residual heat is unique in the United States. The diversity of their parameters, features, resources, and values, however, mandates individualized management prescriptions for each cave or small group of similar, adjacent caves.

Recommendations for the remote subsidence caves in the crater's north quadrant:

With the exception of Sleeping Ohia Cave these caves contain few vulnerable features. Although increased visitation to the area can be expected, only Sleeping Ohia Cave and Tumulus E-1 Cave are so conspicuous that they are likely to be increasingly visited in the foreseeable future. Pending botanical studies, the Hawaii Speleological Survey has recommended a very low profile for Sleeping Ohia Cave; its carrying capacity appears to be so limited that permits should be very restricted and monitoring should be frequent. A gate may be needed.

For Tumulus E-1 Cave, we recommended an interpretive sign inside the cave, with occasional guided interpretive tours. Otherwise we saw no reason to restrict entry nor require permits. On site and photographic monitoring were recommended to evaluate possible impacts by persons returning after interpretive hikes. Further geological, biological, and meteorological studies should be performed, and the hot lower level should be explored when possible.

For the other remote caves we recommended only occasional monitoring and further scientific studies as indicated individually.

Recommendations for the lava tube caves:

For Postal Rift Mauka Cave we recommended preparation of the cave for self-guided tours without permits, and occasional guided interpretive tours. We saw no reason to require permits, at least until after a considerable period of observation. We felt that development should be limited to underground trail marking, moving some loose rocks, and steps to permit egress at the lower end of this cave. On site and photomonitoring should be frequent to determine if visitors are keeping their hands off pristine white mineral crusts. Systematic mineralogical identification is needed.

For the Postal Rift Middle Cave, we recommended a permit system, mostly to insure that persons wishing to visit it are informed about its unpleasant features. Only occasional monitoring should be needed.

For Postal Rift Makai Cave, we recommended a different type of permit system. For this cave we recommended that well-informed sauna lovers and sport cavers receive permits on request, with episodic monitoring of impacts. We felt it appropriate to encourage use of this cave as a natural sauna in order to diminish use of the dangerous steaming cracks elsewhere in the caldera. Interpretive tours should be developed, perhaps in conjunction with some of the Steaming Sulfur Caves and/or Tumulus E-1 Cave. Information signs may be necessary at entrances and in the cave. Mineralogical and special meteorological studies were recommended, and also consideration of creation of a special interpretive area at the steaming depression at the lower end of the cave.

We concluded that Crater Rim Cave and Kukae Cave were suitable for sport caving despite their small size, primarily for cavers who want a quick, easy trip to a cave in the crater. They are too small to be the primary focus of a caving trip, but could be combined with Postal Rift Mauka Cave. Infrequent monitoring should suffice for Kukae Cave, but Crater Rim Cave is more fragile and more accessible and should he monitored frequently. This should include photomonitoring. Gating may be found necessary.

The Steaming Sulfur Cave System needs further study, but for part of it, we were able to recommend self-guided and interpretive tours *on the surface*, looking down into mineral-rich caves. Environmentally acceptable barriers, interpretive signs, and frequent monitoring were recommended. Mineral identifications are needed badly.

For Roadcut Cave, we recommended that the cave remain low profile until biological and possible paleontological resources are investigated by specialists qualified in vertical caving. We also recommended a roadside turnout and interpretive sign. Ultimately a gate will be needed to control access, whether or not the turnout is constructed.

Recommendations for Byron Ledge Trail Cave:

For this cave we recommended completion of exploration, mapping, reconnaissance inventory, and any specialized inventory indicated by it. Only then can a management prescription he prepared.

Acknowledgements

I am deeply appreciative of the field assistance of Olé Fulks, Louise Halliday, Douglas LaBarre, Ruth Levin, Jim Martin, and William McClellan in the course of these studies, and to Bobby Camara for his insightful discussion of this paper at this symposium.

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Cave Interpretation in Australia

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Abstract

This paper will review the history of cave interpretation in Australia, commencing with 19th-century themes of mystery, context, beauty, exploration, science and wonder, rugged reality, spirituality, and grand adventure. It will show how industrialization of caves has led to mass production and trivialization. Some suggestions will be presented for future directions; recapturing some themes from the past, diversifying the experiences to be offered, and enhancing the quality of all that is done. It will also comment on what might prove to be dead-end roads.

Introduction

Although heritage interpretation is often seen as a recent innovation, it has been with us at least since Herodotus (about 400 BC), who makes many comments upon the guides who informed and misinformed him on his travels (Casson, 1974, p 104-106). Some 300 years later, the art of interpretation was sufficiently advanced that Plutarch was able to report :

. . . *The guides went through their standard speech, paying no attention whatsoever to our entreaties to cut the talk short and leave out most of the explanations of the inscriptions and epitaphs.* (Casson, 1974: 265)

I have been recently engaged in writing a history of Australian caves, and this paper simply draws upon what we know of the Anglo-Celtic interpretation of caves over the last 150 years. I regret that time just will not allow me to do justice to the previous 50,000 years throughout the world, which would have included that of Australia's first people, but that would raise a whole lot of further questions. Even the limited time span I have chosen raises a whole series of issues and questions (perhaps even some answers) about the interpretation of natural and cultural heritage.

Mystery, Context, Beauty, and Exploration

We can commence with Augustus Earle in 1826. Throughout his Australian work, Earle showed a great fascination with rock forms, and at the Wellington Caves he not only portrayed the characteristic morphology of the cave tunnels, but more importantly, he highlighted the importance of mystery and the unknown, and even now, challenges us to confront the unsolved mysteries of our heritage (Hackforth-Jones 1980). It seems to me indeed unfortunate that so much of contemporary interpretation is full of answers, rather than pointing to the unsolved mysteries which demand continuing exploration.

Still at Wellington, Sir Thomas Mitchell and his colleagues showed the importance of relating heritage to its contemporary social and political context. On hearing of the discovery of bones in the Wellington Caves, the ever-ambitious Mitchell rushed to the site at the first opportunity, recognizing that these fossil remains might add something to the currently lively debate about the universal deluge. By further investigating this discovery, Mitchell virtually preempted the credit for the find, and achieved considerable fame.

His reports described the first excavation of the remains of the extinct Megafauna of Australia, and in addition to their original publication in Edinburgh were reprinted in the United States and also translated in at least German and Italian journals (Hamilton-Smith, in prep). A few pages of Australia's first children's book were devoted to the excitement of his discoveries (anon, 1841), and Bennett (1834: 189) was able to report that ". . . since the valuable discovery of fossil bones in those at Wellington Valley by Major Mitchell and others, limestone caverns have become one of the colonial lions."

Although Mitchell's talent for self-promotion no doubt contributed to the notice which his discoveries gained, there is no question that his sense of the opportunity offered by one of the great debates of the time played a central role. Today, some interpretation is similarly located within the context of wider and culturally-significant questions—but a great deal is not. On the other hand, Mitchell's approach demanded a simple view of the world which could be readily communicated, and

Figure 1. *Mitchell's* Large Cavern at the Wellington Valley. *(Copy of lithograph from his 1838* Three Expeditons into the Interior of Eastern Australia, *London: T & W Boone, 2 vols.)*

so he ignored or remained unaware of the caves themselves as interesting natural phenomena, and concentrated his interest upon their role as a container for megafaunal bones; accounts of his later exploration include occasional visits to caves—but after a brief hunt for bones, he lost all interest.

However, he did give attention to the aesthetic dimensions of both natural and cultural heritage. His sketches and paintings invite us to share the gaze and wonder of his friends, with whom we can identify; this simple artistic trick makes his communication more effective simply because we share the beauty and wonder with those who are right there. Conrad Martens also painted at Wellington, but particularly at Abercrombie Caves (Bonyhady 1985, Jones 1988). His many paintings were deservedly popular, and again demonstrate the importance of the aesthetic dimension. Yet, despite his superior technical skill as an artist, his cave painting lacks the impact of Mitchell's simply because he did not include the viewer in the picture; we look in from outside. So, these two artists both impress upon us the importance of simple beauty, but raise the question of how we might most effectively help other people become more sensitive to the potential beauty of what they view.

The greatest pioneer scientist of Australian caves was the astonishing priest, educator, mystic, musician, writer, and scientist, Father Julian Tenison-Woods. He explored the Naracoorte Caves, and in both his book, *Geological Observations in South Australia* (1862), and various newspaper articles, he endeavored to share his understandings of the caves. Unlike Mitchell, he did not simplify or trivialize his findings for easier communication; rather, he discussed his difficulty in interpreting what he saw. On one hand, he struggled to remain loyal to the writings of his mentor, Sir Charles Lyell, in his great *Principles of Geology,* but on the other, tried to remain true to his own observations. In hindsight, we can now see that through his own observations, he came within sight, indeed even closer, to theories about cave genesis in soft limestones which were not again recognized for 100 years, but these were somewhat concealed in his attempts to reconcile his own ideas with those of Lyell.

It seems to me that we can see a number of interesting themes being expressed here. Perhaps the most important is that, just as Woods did, we need to share the current struggle for greater understanding of any one phenomenon, rather than to pretend we have reached understanding. Again, the mystery and the unanswered questions can be more exciting than a neatly-packaged set of answers. Secondly, again as Woods did, we need to understand most phenomena are complex, arise out of a whole series of causative factors, can be explained on a number of levels, and anything like a comprehensive understanding demands that we draw upon a number of perspectives and disciplines. In other words, we need to not only place our interpretation in a social and political context, but also to help construct a truly holistic view of the total phenomenon which are trying to interpret. Thirdly, we should beware of textbooks, and try to help others develop a similar sense of suspicion. Lyell wrote from his experience of caves in very old, hard limestones of Western Europe (principally Yorkshire); wrote as if he had a full understanding of all caves; yet had never experienced caves like those which Woods was struggling to understand. Many of us, if we are honest, have experienced such textbooks; let us continue to use them, but to help others understand their limitations.

Rugged Reality and the Spiritual

Meanwhile, at Chudleigh in Northern Tasmania, visitors were receiving two very different experiences of what seems to have been Australia's first public access cave to be shown to tourists. The first was offered by "Old Pickett," who was showing that nature is not always user-friendly, but may be savage or at least extremely uncomfortable.

Pickett was the publican at Chudleigh, where he lived to be a centenarian. But he made a point of ensuring that every Governor (ten of them) who visited the famous Chudleigh Caves was given the pleasure of his own special kind of guiding services. One can only suspect that he rightly perceived the governors as representatives of the power which had sent him to this remote corner of the world and was determined to have at least some revenge for his own discomfort. Fortunately for us, Anthony Trollope accompanied one of those governors, and reported on the experience in his own inimitable style, so it is worth quoting him at some length:

The Chudleigh Caves are one of the wonders of Tasmania—and indeed, they are very wonderful. We went there in true gubernatorial style with four horses—for it must be understood that throughout the colonies, when it is known that the governor is coming, things are done as they should be . . . We had a very pleasant day, more than ordinarily so; but the Chudleigh Caves should not be visited by anyone lightly, and I think I may take upon myself to say that they should not be visited by ladies at all.

. . . an old man attached himself to us, who seemed to have the caves under his particular care, and assured us he had shown all the governors over them. He came out upon us from a public house, of which he was the proprietor, and promising us that we should have the benefit of his services, followed us on a wonderful rat-tailed mare, with which he jumped over every obstruction along the road, and made himself very busy, assuring the governor that no governor could see the caves aright without him, and taking command of the whole party with that air of authority that always carries success with it . . . Stalactite caves are not uncommon in the world. Those at Cheddar in Somersetshire are very well known and are very pretty . . . But are nothing to the Chudleigh caves in bigness, blackness, water, dirt, and the enforced necessity of crawling, creeping, wading, and knocking ones head about at every turn . . .

Mr Pickett lighted the candles . . . then he led the way gallantly, splashing down into the mud, and inviting his Excellency to take heart and fear nothing. His Excellency took heart and went on. Whether he feared anything, I cannot say. I did—when I had broken my head for the third time, and especially when I had crawled through a crevice in which I nearly stuck, and as to which I felt almost certain I should never be able to force my way back again . . . Pickett was insistent with us to go on to the end. We had not seen half the wonders of the place—which by-the-bye were invisible by reason of the utter darkness. But we were cold to the marrow of our bones, wet through, covered with mud, and assured that, if we did go on, the journey must be made partly on our hands and knees, and partly after the fashion of serpents. At last we rebelled and insisted on being allowed to return. I think that I will never visit another cave . . . Mr Pickett told us, as we took our leave of him, that he should not enter the caves again until another governor should come to see them. (Trollope 1873, in Dow 1966: 165-167)

At the same site, landowner Henry Reed often conducted his own visitors to the caves for a very different kind of experience. Reed was a successful pastoralist, businessman, and developer, but also a missioner of high repute, noted and admired for his sympathy, sensitivity, and kindness to both the Aboriginals and the convicts of Tasmania. Reed saw the caves as an opportunity for exciting people about the mystery and wonder of the natural world and giving them a chance to appreciate the spiritual dimension of our natural heritage. So, one of his visitors reported:

Three of us ventured within the high-roofed cave. What a change of atmosphere. It was fresh and cool as though we had reached the birthplace of the icebergs; a real refrigerator where sunbeams never wander, and solar light and heat are never known. Armed with candles and matches we penetrate the darkness. A considerable stream runs through the caverns, a winding stream, so that we are forced to cross it many times. We often appreciate our mercies most when we have lost them. Never before did I realise so intensely the advantage of wearing boots, for the rough stones were trying to my bare feet, and the icy chilliness of the stream, with the darkness so intense, made our bootless travelling anything but pleasant work. Still nothing can be done or seen without a certain amount of trouble, the enjoyment often being all the sweeter for the previous toils . . . How much depended on these lights we carried! They seemed the brighter for the unchanging gloom and lasting night in which we were immersed. We thought of Shakespeare's metaphor,

'How far yon little candle throws its beams,
So shines a good deed in a naughty world.'

and we prayed for grace to 'walk as children of the light.' But there are wonders above us as well as beneath and around. The rocky roof is bright with phosphorescent light. We stretch one hand towards it and find upon our finger a glow-worm, who made it has delight to do his little best to light the gloom; and there are myriads of them, like nature's tapers, shining in her palace underground (Reed 1906: 122-127).

Even though many of us today would not share the same spiritual sense or vocabulary of Reed and his visitors, there is no question that there is a widespread sense of spiritual quest in the community; our interpretive efforts cannot, in my opinion, be comprehensive unless we provide the opportunity for visitors to appreciate the spiritual dimension of any heritage experience.

Great Adventure and Industrialisation

So, we can learn some interesting things from the first part of the nineteenth century, but at least partly because of the success of cave interpretation during this period, Jenolan Caves became Australia's major single tourist destination by the 1880s, partly because of the excitement associated with travelling to what was, at that time, a truly remote location (Dunkley 1986, Stanbury 1988, Horne 1994), and partly because of the on-site excitement generated by curator Jeremiah Wilson and his successors. Wilson was a showman and entrepreneur of the first order, and his extravagant personality, fund of anecdotes, and sense of showmanship set a pattern for cave interpretation in Australia. He equipped visitors with candles,

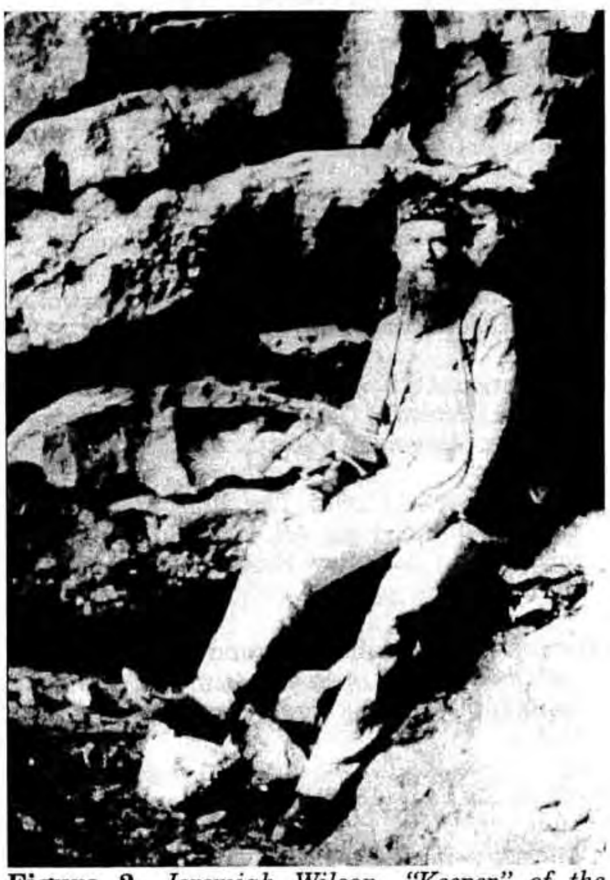

Figure 2. *Jeremiah Wilson, "Keeper" of the Jenolan Caves 1867-18967, and pioneer of cave display and interpretation. He is holding one of the clockwork-driven magnesium lamps which he introduced to cave guiding.*

and whenever they reached a site of special beauty, *"Jerry gave the word to 'douse candles' and then, when we were all standing in the dark on the tiptoe of expectation, turned the dazzling light of the magnesium wire on such a wonderful series of fairylike scenes as none can imagine who have not seen them."* Another visitor commented that *"Our guide 'Jerry' who, by the way, is as full of fun as he is deafness, was most indefatigable in his attentions to us all, and especially to the ladies."*

Jeremiah was the first of the "hero guides," who made much of their own exploits in the discovery of the caves, often embellishing the story appropriately. Wiburd at Jenolan, Moon at Buchan, Reddan at Naracoorte, and others all claimed a key place in interpretation. Only the shy and self-effacing Frederick Wilson endeavoured, at both Jenolan and Buchan, to develop a truly sensitive and environmentally-based view of the caves (Hamilton-Smith, in prep.).

Jeremiah Wilson, as the first of the entrepreneur-guides, set the pattern for industrialization of the cave experience. Visitors were herded into groups and conducted through the cave by a guide, who usually talked of his own, or his hero's, role in exploration, then displayed various scenes, usually described by some fanciful resemblance to other objects, real or imaginary: Lace Curtains, Cathedral Windows, the Bath of Venus, Madonna, the Christmas Tree, or whatever. The caves were trivialized into a series of fanciful pictures. This process was greatly assisted by the development of electric lighting (at Jenolan in 1880—one of the truly early uses of electric lighting, and certainly the first in a cave). Other signs of industrialization included coffee-table books, purpose-built accommodation, special transport arrangements, millions of postcards or other souvenirs, and the like. Massive advertising campaigns developed and were visible in newspapers, brochures, theater advertisements, posters, and a host of other media. In a way, all of this was, of course, interpretation, even if trivialized. It always amazes me that when a professional sets out to interpret a site, he or she generally acts as if the advertising and souvenir industries did not exist, when they often have the widest and most powerful public exposure; good interpretation should start long before a visitor reaches a site and advertising does just that.

One could spend a long time analyzing the 20th century experience of cave interpretation, but I will simply confine myself to a few illustrations. From a fanciful interpretation, it was only one step to enhancement of the natural cavescape. Sometimes this might be justified in terms of improving upon nature, such as Reddan's "Mirror" in the Alexandra Cave at Naracoorte or the Twelve Apostles (originally three) in the Royal Cave at Buchan. But it becomes hard to maintain enthusiasm for

Figure 3. *A selection of cigarette cards depicting Jenolan Caves.*

Lane's "Tantanoola Tiger" sign—supposedly illustrating a bit of local folklore at Tantanoola, or even the artificial calcite mosaic decorating Silver Stocking Cabaret Cave in Western Australia. There was some memorable humor, like the Jenolan guide who used to tell visitors that the Exhibition Chamber at Jenolan had three-quarters of an acre of roof—". . . *all of it held by that one broken column over there!*"

The good news is that over the last 20 years, cave managers have increasingly moved to an environmental interpretation. Sometimes this has simply replaced boring fantasy stories with equally boring science lessons, but overall, we know that it has had a major impact upon public understanding and values. Today, managers are experimenting with a range of less-industrialized approaches to cave tourism, and to the development of a new and wider range of interpretive models, some of which builds upon the almost-forgotten lessons of the 19th century. The potential role of visual arts and music, the creative use of silence, and the remarkable possibilities in infrared sensing and imagery and other technologically-based possibilities are all being explored.

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The IUCN Guidelines Project

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Abstract

The International Union for the Conservation of Nature is the major world body concerned with nature conservation and operates in a diverse range of ways, with a wide range of opportunities for involvement by governments, major non-governmental bodies and individuals. Its Commission for National Parks and Protected Areas has recently published a guidelines booklet on the protection of Alpine areas, and is now engaged in the production of a similar booklet on karst and caves.

A small group of Australians has prepared a first draft, and this is currently being circulated to all those who had earlier expressed interest and is also available through the Internet on a wide range of World Wide Web pages. We trust that cave managers, speleologists, and others interested will provide feed-back on the draft in order to ensure its relevance on a world basis. The draft also includes an appeal for photographs.

The contents of the draft include a description of karst and cave environments, their values and importance, threats to the integrity of karst and caves, strategies for better management and possibilities for international co-operation.

Management of Endangered Bat Caves in Arkansas

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Abstract

Three cave bat taxa endemic to Arkansas are listed as endangered: Indiana bat (*Myotis sodalis*), gray bat (*M. grisescens*), and Ozark big-eared bat (*Corynorhinus townsendii ingens*). All occur primarily in the Ozark Plateau region of the northwestern and north-central part of the state. Population monitoring and ecological studies of endangered bats inhabiting important hibernation, summer, and transient caves have been conducted annually since 1978. Through the efforts of several federal, state, and private agencies and organizations, as well as numerous private landowners, 14 important bat caves have been gated or fenced to protect bat colonies from human disturbance. Several additional caves have been afforded protection by intrusion alarm systems, control of access roads, and/or cooperative management agreements.

Introduction

Sixteen bat species are endemic to the state of Arkansas. Of these, three cave bat taxa are considered endangered (that is, in danger of extinction throughout all or a significant portion of their range) by both the U.S. Fish and Wildlife Service and the Arkansas Game and Fish Commission. They are *Myotis sodalis*, Indiana bat; *M. grisescens*, gray bat; and *Corynorhinus townsendii* ingens, Ozark big-eared bat. All three endangered bat taxa occur primarily in the Ozark Plateau region of northwestern and north-central Arkansas, the only area of the state where caves are numerous.

Three additional Arkansas bat species are also under review for possible listing as endangered or threatened by the U.S. Fish and Wildlife Service. They are the Southeastern bat, *Myotis austroriparius*; Eastern small-footed bat, *Myotis leibii*, and Rafinesque's big-eared bat, *Corynorhinus rafinesquii*. Although not listed as endangered or threatened, the remaining four Arkansas cave bat species also appear to be declining in numbers.

Several animals, including owls, hawks, raccoons, skunks, and snakes prey on bats; however, relatively few animals consume bats as a regular part of their diet. Man seems to be the only animal having significant impact on bat populations. Adverse human impacts include habitat destruction, direct killing, vandalism, disturbance to hibernating and maternity colonies, and use of pesticides (on their food, insects) and other chemical toxicants. Drastic reductions in bat populations have occurred during recent years in the United States and worldwide.

Human disturbance to hibernation and maternity colonies is a major factor in the decline of many bat species. Even well meaning individuals such as spelunkers and biologists cause these disturbances. Hibernating bats arouse from hibernation when disturbed by people entering their caves. When aroused, they use up precious winter fat needed to support them until insects are again available in spring. A single arousal probably costs a bat as much energy as it would normally expend in two to three weeks of hibernation. Thus, if aroused often, hibernating bats may starve to death before spring.

Disturbance to summer maternity colonies is also extremely detrimental. Maternity colonies will not tolerate disturbance, especially when flightless newborn young are present. Baby bats may be dropped to their deaths or abandoned by panicked parents if disturbance occurs during this period.

The following accounts contain information on the biology and status of endangered Arkansas cave bat species.

Gray Bat—*Myotis grisescens*

The range of the endangered gray bat is concentrated in the cave regions of Arkansas, Missouri, Kentucky, Tennessee, and Alabama, with occasional colonies and individuals found in adjacent states (Barbour and Davis, 1969). The species' present total population is estimated to number over 1,500,000; however, about 95% hibernate in only eight caves—two in Tennessee, three in Missouri, and one each in Kentucky, Alabama, and

Arkansas. Although gray bat numbers are still relatively high, their total population has decreased significantly during recent years (Harvey, 1986).

gray bats are cave residents year-round, although different caves are usually occupied in summer and winter. Few have been found roosting outside caves (Barbour and Davis, 1969). They hibernate primarily in deep vertical caves with large rooms acting as cold air traps. gray bats hibernate in clusters of up to several thousand individuals, about 170 bats per square foot. They choose hibernation sites where temperatures average 42° to 52°F (Barbour and Davis, 1969).

During summer, female gray bats form maternity colonies of a few hundred to many thousands of individuals, often in large caves containing streams. Maternity colonies prefer caves that, because of their configuration, trap warm air (usually 58° to 77°F) or provide restricted rooms or domed ceilings capable of trapping the combined body heat from clustered individuals (Tuttle, 1975). Because of their highly specific habitat requirements, fewer than 5% of available caves are suitable for gray bat occupation (Tuttle, 1976a). Male gray bats, along with non-reproductive females, form summer bachelor colonies.

gray bats occupy a wider variety of caves during spring and autumn transient periods. During all seasons, males and yearling females are less restricted to specific cave and roost types (Tuttle, 1976a). Summer caves, especially those occupied by maternity colonies, are rarely more than two miles, and usually less than one mile, from rivers or lakes (Tuttle, 1976b). Each summer colony occupies a home range that often contains several roosting caves scattered along as much as 50 miles of river or lake shore (Tuttle, 1976a).

Mating occurs in September and October when gray bats arrive at hibernation caves. Females enter hibernation immediately after mating. Males remain active several weeks, replenishing fat supplies depleted during breeding activities. Juveniles and adult males enter hibernation several weeks later than adult females. Adult females emerge from hibernation in late March or early April, followed by juveniles and adult males (Tuttle, 1976a).

Females store sperm through the winter and become pregnant soon after emerging from hibernation (Guthrie and Jeffers, 1938). A single young is born in late May or early June. Growth rates of young vary with temperatures at maternity roosts; young in warmer roost situations grow more rapidly. Most young begin flying within 20 to 25 days after birth.

gray bats forage primarily over water along rivers or lake shores. Most foraging occurs within 15 feet of the surface. Mayflies are apparently a major item in the diet, but like most species, they often feed on other insects as well. Longevity data indicate life spans of at least 14 to 15 years.

Estimating gray bat population declines is possible because of the presence of guano deposits and ceiling stain left in caves by roosting bats. Estimates based on guano and ceiling stain have indicated an 89% decline in Kentucky (Rabinowitz and Tuttle, 1980), a 72 to 81% decline in Missouri (LaVal and LaVal, 1980), a 76% decline in Tennessee and Alabama (Tuttle, 1979), and a 61% decline in Arkansas (Harvey, 1986).

An estimated 180,000 gray bats are known to inhabit about 20 Arkansas maternity and bachelor caves during summer, while an estimated 300,000 hibernate in five Arkansas caves during winter (over 55% in Bonanza Cave). Several additional caves serve as transient caves for gray bats. Of the three endangered bat species inhabiting the state, the gray bat is doing by far the best. The population appears to be relatively stable, or possibly increasing.

Previous banding studies have demonstrated that the difference between estimated Arkansas summer and winter populations (about 120,000) results from the fact that many gray bats that hibernate in Arkansas are known to migrate to summer caves in nearby states (Missouri, Oklahoma, and Kansas). Also, some gray bats that hibernate in Missouri caves are known to summer in Arkansas caves.

It is difficult to accurately assess the total gray bat population in Arkansas for various reasons. The hibernating population in Bonanza Cave is very large, and the configuration of the cave makes it very difficult to obtain an estimate that is reliable. The usual estimate in the past has been 250,000. However, when last checked during February 1994, the hibernating population was estimated at 165,000. Although that number is considerably less than previous estimates of 250,000, other caves in the vicinity have shown significant increases, possibly due to movement from Bonanza Cave. A small cave located near Bonanza Cave contained an estimated 25,000 hibernating gray bats in February 1995. Prior to the winter of 1991 and 1992, gray bats were not known to utilize this cave.

Prior to development by the U.S. Forest Service, Blanchard Springs Caverns in Stone County housed a gray bat hibernating colony of 5,000-7,000 individuals. Construction in the caverns was begun in 1963, and the cave was opened to the public in 1973. By the winter of 1978 and 1979, the hibernating colony decreased to about 150 gray bats and reached a low of only 33 bats during the winter of 1985 and 1986. Since that winter, the U.S. Forest Service has limited disturbance at the roost site, located near the natural entrance, and the bat population has increased dramatically. During the last ten winters, the population was estimated as follows: 33; 55; 188; 520; 6,200; 8,000; 10,000; 18,000; 20,000; and 58,650. The summer bachelor colony also increased to an all-time high of about 42,000 during the summer of 1993.

Cave Mountain Cave, located on Buffalo National River lands in Newton County, houses hibernating colonies of both gray bats and Indiana bats. The greatest number of gray bats reported to hibernate in this cave prior to the winter of 1990 and 1991 was about 700 during the winter of 1980 and 1981. During the following winter (1981 and 1982), only about 50 gray bats were present. To protect endangered bat colonies from disturbance, the cave was fenced during the summer of 1982 and closed to visitation during the bat hibernation period. Since the cave was fenced, the hibernating gray bat population has gradually increased to an all time high of 44,480 during the winter of 1994 and 1995.

Thus, although the hibernating colony at Bonanza Cave may have decreased, significant increases at three other caves have kept the total Arkansas gray bat hibernating population relatively stable over the past several years.

Because of intercave movement in summer, it is also difficult to obtain a reliable estimate of the Arkansas summer population. Since only one or two maternity caves are monitored each night, movement of bats between caves may result in overestimating or underestimating populations by counting individuals more than once, or by missing them altogether. In addition, estimates of numbers of bats exiting large maternity or bachelor colonies are difficult to make and are probably much less than accurate. The most recent total gray bat count at 10 maternity sites was 109,230 up 30,220 (38%) from the previous summer count.

Indiana Bat—*Myotis sodalis*

The range of the endangered Indiana bat is in the eastern U.S. from Oklahoma, Iowa, and Wisconsin east to Vermont and south to northwestern Florida. Distribution is associated with major cave regions and areas north of cave regions (Barbour and Davis, 1969). The present total population is estimated at less than 335,000, with more than 85% hibernating at only nine locations—two caves and a mine in Missouri, three caves in Indiana, and three caves in Kentucky.

Indiana bats usually hibernate in large, dense clusters of up to several thousand individuals in sections of the hibernation cave where temperatures average 38° to 43°F and with relative humidities of 66 to 95% (Barbour and Davis, 1969). They hibernate from October to April, depending on climatic conditions. Density in tightly packed clusters is usually estimated at 300 bats per square foot, although as many as 480 per square foot have been reported (Harvey, 1986).

Female Indiana bats depart hibernation caves before males and arrive at summer maternity roosts in mid-May (Humphrey *et al*, 1977). A single offspring, born during June, is raised under loose tree bark, primarily in wooded streamside habitat. During September, they depart for hibernation caves (Cope and Humphrey, 1977). The summer roost of adult males is often near maternity roosts, but where most spend the day is unknown (Hall, 1962). Others remain near the hibernaculum. A few males are found in caves during summer.

Until relatively recently, little was known about this bat's summer habitat and ecology. The first maternity colony was discovered in 1974 under loose bark on a dead bitternut hickory tree in east-central Indiana (Humphrey *et al*, 1977). The colony, numbering about 50 individuals, also used an alternate roost under the bark of a living shagbark hickory tree. The colony's total foraging range consisted of a linear strip along approximately one half of a mile of creek. Foraging habitat was confined to air space from 6 feet to about 95 feet high near foliage of streamside and floodplain trees (Humphrey *et al*, 1977).

Two additional colonies were discovered during subsequent summers, also in east-central Indiana. These had estimated populations of 100 and 91 respectively, including females and young. Habitat and foraging area were similar to the first colony discovered. Additional evidence gathered during recent years indicates that during summer, Indiana bats are widely dispersed in suitable habitat throughout a large portion of their range.

Through the use of radio telemetry techniques, several maternity colonies have recently been discovered and studied in Illinois (Gardner *et al*, 1991). These studies reinforced the belief that floodplain forest is important habitat for Indiana bat summer populations. However, maternity populations were also located in upland habitats. It was also discovered that Indiana bats exhibited fidelity to specific roosting and foraging areas they returned to annually (Gardner *et al*, 1991).

Between early August and mid-September, Indiana bats arrive near their hibernation caves and engage in swarming and mating activity. Swarming at cave entrances continues into mid or late October. During this time, fat reserves are built up for hibernation.

It is thought Indiana bats feed primarily on moths. A longevity record of 13 years, 10 months for this species has been recorded.

Hibernating bats leave little evidence of their past numbers, thus it is difficult to calculate a realistic estimate of the species' overall population decline. However, estimates at major hibernacula indicated a 34% decline from 1983 to 1989.

Only six Arkansas caves are known to house hibernating colonies (of ten or more) of Indiana bats. The Arkansas hibernating population declined by about 60% during the past 11 years from about 6,000 to about 2,540.

During the winter of 1980 and 1981, the population of the largest colony, in Edgeman Cave, numbered about 5,000. It now numbers less than 1,200. Thus, the Edgeman Cave population decreased by over 75% in 15 years. Edgeman Cave was gated by the Arkansas Game and Fish Commission during the latter part of the summer of 1990.

A few male Indiana bats occupy Arkansas caves during summer. It is likely that females migrate northward to maternity roost sites located to the north of the Ozark Mountains.

Ozark big-eared Bat—*Corynorhinus townsendii ingens*

The range of the endangered Ozark big-eared bat includes only a few caves in northwestern and north-central Arkansas, southwestern Missouri, and eastern Oklahoma (Harvey, 1986). The total surviving population of this race is probably less than 1,700. Approximately 1,400 inhabit a few caves in eastern Oklahoma. In Arkansas, only two caves are presently known to be regularly inhabited by colonies of Ozark big-eared bats—a hibernation cave and a nearby maternity cave. The Arkansas population numbers about 200 individuals. They are no longer known to exist in Missouri caves.

Because Ozark big-eared bats are so rare, little is known about their biology. However, much is known about the species in other parts of its range, most of which may also apply to Ozark big-eared bats. In parts of its range, this species occupies buildings in summer. In the eastern U.S., with rare exception, it has been reported only from caves during summer and winter.

This species hibernates in caves (sometimes mines) where the temperature is 54°F or less, but generally above freezing. Cave hibernation sites are often near entrances in well-ventilated areas. If temperatures near entrances become too extreme, they move to more thermally stable parts of the cave (Humphrey and Kunz, 1976). They hibernate in tight clusters of a few to a hundred or more individuals. During hibernation, the long ears may be erect or coiled. Solitary bats sometimes hang by only one foot.

Ozark big-eared bat maternity colonies are usually located in relatively warm parts of caves. During the maternity period, males are apparently solitary. Where most males spend the summer in unknown (Harvey, 1986).

Mating begins in autumn and continues into winter. Young females apparently mate during their first autumn. Sperm are stored during winter, and fertilization occurs shortly after arousal from hibernation. A single young is born during June (Pearson *et al*, 1952).

Ozark big-eared bat pups are large at birth, weighing nearly one-fourth as much as their mother. They can fly in 2½ to 3 weeks and are weaned by 6 weeks. Record longevity for the species, based on recoveries of banded bats, is 16 years (Paradiso and Greenhall, 1967).

These big-eared bats emerge from caves to forage later than most bats. It is usually relatively dark before they leave. Observations indicate most return to roosts before midnight, although bats may leave or return throughout the night. They forage primarily near tree and shrub foliage. Food habits are poorly known, though moths apparently make up part of their diet.

No long distance migrations have been reported for this species. Banded individuals have rarely been recovered more than 20 miles from the banding site. Like many other bats, they return year after year to the same roost sites (Harvey, 1986).

Protective Measures

The U.S. Fish and Wildlife Service has had recovery plans prepared for the Indiana bat and the gray bat by recovery teams composed of bat experts. A recovery plan for the Ozark big-eared bat has also been written. Certain protective management measures have already been taken, as recommended in recovery plans. These include gating or fencing important bat caves and placing of warning or interpretive signs at other caves to minimize human disturbance to bat colonies. Signs placed at selected cave entrances tell what endangered bat species inhabits the cave, the season when they are present, information concerning their beneficial nature, and adverse effects of disturbing bat colonies. Signs also point out that entering these caves during restricted times is a violation of the Federal Endangered Species Act, punishable by fines up to $50,000 for each violation.

Fourteen important Arkansas endangered bat caves have been gated or fenced to protect bat colonies from human disturbance. Several additional caves have been afforded protection by intrusion alarm systems, control of access roads, and/or cooperative management agreements.

Several federal, state, and private agencies and organizations have been actively involved in the Arkansas bat protection effort. These include Arkansas Game and Fish Commission, U. S. Fish and Wildlife Service, USDA Forest Service, National Park Service, U.S. Army Corps of Engineers, Ar-

kansas Department of Parks and Tourism, Arkansas Natural Heritage Commission, The Nature Conservancy, Arkansas Geological Commission, Arkansas Soil and Water Commission, National Speleological Society, Cave Research Foundation, Association for Arkansas Cave Studies, American Cave Conservation Association, and Ozark Underground Laboratory.

Personnel from several universities as well as numerous other volunteers have been involved in the bat protection effort. Private landowners in Arkansas, with rare exception, have been exceptionally helpful throughout many years of bat research and management efforts.

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Protection and Management of the Cave Cricket (Hadenoecus subterraneus) At Mammoth Cave National Park

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Abstract

On the one hand the cave cricket has a relatively wide geographic distribution, is frequent and nearly ubiquitous both among caves and among habitats within caves, and it consumes a wide variety of food items. But accumulating evidence indicates that the cave cricket could be at risk because it cannot recover quickly after disasters that preclude or greatly diminish foraging opportunities outside. Such disasters could be widespread, like drought, or local, such as retrofitting of entrance doors in the National Park. Evidence from abundances of small and large crickets in nine entrance roosting habitats is that overall cave quality varies dramatically among local populations. Based on four criteria for habitat quality and abundances of small and large crickets, most cave entrances are "sink" habitats (negative cricket population growth) and few are "source" habitats (positive cricket population growth). Even sink populations should be protected because their emigrants can "rescue" source populations that experience local decimation.

Introduction

The impetus for some aspects of this research came from a program by Mammoth Cave National Park to modify cave doors through the installation of airlocks. The retrofitting of these doors was deemed necessary by park officials to mitigate possible effects of cold, dry winter air on the growth and formation of speleothems and on biological communities associated with these entrances. With the old doors, daily tours of these caves made it necessary to open the doors many times each day. To observe any possible impacts of the modifications of the biological communities associated with retrofitted entrances, we were contracted by the National Park Service to do a study that includes population censuses both before and after entrance retrofitting. We also included two caves and one cave entrance not slated for retrofitting to serve as controls in our study.

In this paper we will discuss aspects of *Hadenoecus'* population ecology in the context of abiotic/biotic factors that affect *Hadenoecus*. *Hadenoecus* is a key species overall and so any negative impacts on its entrance roosting area could have far-reaching effects. In the process of describing our research, we will demonstrate the value of cooperation between cave management and scientists as well as the importance of using the hypothetico-deductive method in conservation research.

The Players

Concern for cave entrance communities is not unwarranted. The keystone species, the cave cricket (*Hadenoecus subterraneus*), is sensitive to entry of cold, dry winter air that we suspected was occurring before entrance retrofitting. If such an important species as *Hadenoecus* is not enhanced by the retrofits, the resultant trophic cascade could have a negative effect on the rest of the entrance community. In fact, the communities associated with *Hadenoecus* guano in our two small control

Totals	Size 1 & 2	Ratios: 4/1 & 4+3/1+2
5114 New Discovery	2116 New Discovery	Carmichael 0.5/0.7
3116 Frozen Niagara	1108 Violet City	New Discovery 1.1/0.5
2184 Violet City	916 Carmichael	Violet City 1.0/1.0
2134 White	913 Frozen Niagara	Great Onyx 3.2/2.3
2074 Great Onyx	630 Great Onyx	Austin 4/3 & 3/2
1830 Austin	413 White	White 7/4 & 4/2
1352 Carmichael	329 Austin	Frozen Niagara 16/3 & 4/3
1129 Little Beauty	247 Little Beauty	Little Beauty 9/4 & 12/6

Table 1. *Population size and structure for each cave broken down by size class taken from censuses in May 1995. Note that rank order for each cave differs in each column. These ratios led us to conclude that caves might either be source or sink habitats.*

caves are just now recovering from droughts in the 1980s that caused reductions in *Hadenoecus* densities (Poulson *et al.* 1995).

In our study area, *Hadenoecus* has a high importance value to the entrance community by any measure. First, *Hadenoecus* shows a high frequency among cave entrances. Second, where ever we find *Hadenoecus* at entrances it is usually present in very high densities. Third, *Hadenoecus* shows a significant impact per individual in terms of allochthonous food input. Indeed, an entrance community depends on its feces and another community depends indirectly on its eggs (Poulson 1992). Fourth, *Hadenoecus* is the largest organism that regularly inhabits the cave environment.

As an obligate trogloxene, *Hadenoecus* is constrained to roost inside cave entrances during the day, exiting only at night to feed when the epigean temperature and humidity approximate those inside the cave. One of the reasons for this behavior is that *Hadenoecus* has a greatly-reduced, waxy epicuticle that retards water loss in epigean arthropods. After feeding at night, *Hadenoecus* returns to the cave where it roosts on the ceiling. At these roosts *Hadenoecus* gathers to rest, digest food, and finally defecate. Below these roosts a thin veneer of *Hadenoecus*' guano builds up, which is the basis of one the entrance communities found in Mammoth Cave. A wide array of troglobitic organisms are found here: *Scoterpes copei* (a troglobitic millipede) and *Ptomaphagus hirtus* (a troglobitic beetle) are just two of the organisms associated with cricket guano. Farther back in the cave are sandy areas that make ideal egg-laying sites for *Hadenoecus*. A troglobitic beetle, *Neaphaenops tellkampfi*, feeds on *Hadenoecus*' eggs (Griffith and Poulson 1993). It is *Neaphaenops*' feces that forms the basis for the other community for which *Hadenoecus* is the key contributor.

It was during the process of censusing various caves' entrance communities that we noticed what seemed like a pattern in *Hadenoecus*' population sizes among caves. Some caves definitely had larger *Hadenoecus* populations than others. In addition, there was a high variance in numbers and proportions of four size classes among caves. The four size classes, based on hind femur length, are those that can be reliably distinguished by observation in the field, one being the smallest size class and four being the largest. Three caves (Violet City, New Discovery and Carmichael) showed a low ratio of large-size classes to small-size classes. In the remaining study caves the ratio of large-size classes to small is even or high (Table 1). Ratios less than one tell us that in these three caves juvenile crickets outnumber adult crickets. Our observations suggested two alternative hypotheses. First, *Hadenoecus* exhibits a metapopulation structure with many local populations which spread the risk of local extinction; thus migrants from unimpacted populations may act as a reserve that can "rescue" extinct populations. Second, that populations may not go extinct but there are "sink" habitats, with negative population growth, that are maintained by emigrants from "source" populations, with positive population growth.

Metapopulation Structure

A metapopulation is an assemblage of local populations weakly linked by immigration and emigration. For our purposes, the *Hadenoecus* metapopulation is the collection of populations within the artificial geographic boundary delineated by Mammoth Cave National Park. Realistically, the metapopulation structure of *Hadenoecus* that we studied probably extends over the entire central Kentucky karst.

The concept of metapopulations is important to conservation biology and management. Within the region inhabited by a metapopulation, theoreticians posit that local populations can, and likely will in time, go extinct. It is regional extinction that most worries conservationists and park managers.

Indeed, environmental factors that uniformly affect large areas, such as weather, can increase the possibility of regional extinction (Kindvall 1995). Implicit in the metapopulation concept is the existence of local populations weakly linked by emigration/immigration that make regional extinction less likely (Gotelli 1995).

Local populations that are weakly linked by migration can spread the risk of extinction among themselves. Local populations not linked by migration have a risk of extinction which only increases with number and kinds of disasters. For example, a density-independent disaster, such as fire, could wipe out a local cave cricket population by destroying surface foraging habitat. A density-dependent disaster, such as disease, could wipe out some of the remaining local populations which further increases the likelihood of regional extinction. However, if the same two disasters wipe out local populations that are part of a metapopulation structure, then migration ensures the eventual recolonization of the now-empty habitat patches.

Source and Sink Dynamics

Unlike the metapopulation hypothesis, the source-sink hypothesis involves habitat heterogeneity where some habitats or patches are always more suitable than others to the existence of local populations of a species. The habitat or patch that allows the species birth rate to exceed its death rate is known as a **source** habitat. The habitat where the species death rate exceeds its birth rate is known as a **sink** habitat. In addition, it follows logically that due to density dependence, with high competition in the source, that the emigration rate will exceed the immigration rate in a source habitat and vice versa within a sink habitat; thus sink habitats are maintained by source habitats (Pulliam 1988).

One may question why an individual would risk emigration from a source habitat? The answer lies in a concept taken from population ecology: the ideal-free distribution. One of the assumptions implicit to the concept of the ideal-free distribution is that an organism's behavior will increase its Darwinian fitness. Thus organisms respond sensibly to their environment. If a crowded source habitat affects the individual's fitness so that it declines, for instance due to intraspecific competition, then the individual loses any advantage conveyed by the source habitat and may respond through emigration (Rosenzweig 1991). The émigré may find itself in a less-suitable habitat than the one it previously inhabited in terms of lower carrying capacity for the population. However, the individual's fitness in the less-crowded environment now equals that of an individual living in the crowded environment because there is, for example, less intraspecific competition within the population in the less suitable habitat. Thus, while carrying capacity may increase or decrease depending upon habitat, the fitness of the individual remains the same. So individual *Hadenoecus* may distribute themselves among habitats in proportion to the amount of resources available in each habitat. The concept of ideal-free distribution may be summed up by a quote from Milton's *Paradise Lost*, "It is better to reign in Hell than to serve in Heaven."

Source and Sink Habitats

We have not seen evidence of local extinctions and so tentatively we reject the metapopulation hypothesis. We are currently exploring the hypothesis of source and sink structure and how this relates to local populations at entrances slated for retrofitting. Presently we are testing alternative hypotheses about what aspects of our study caves differentiate them in terms of habitat suitability. We are using the criteria of size structures that suggest possible population growth (source) or decline (sink).

Entrance	Temperature (°C)	Relative Humidity (RH)	Overall Rank
Carmichael	3 (8.3-10.4)	1 (90-99.5%)	1
White	2	2	2
Violet City	1 (7.2-11.7)	3 (91-97.5%)	3
New Discovery	4	5	4
Great Onyx	5 (10.5-11.3)	4 (89-98.2%)	5
Little Beauty	7	6	6
Frozen Niagra	6 (8.0-12.1)	7 (74-94%)	7
Austin	8	8	8

Table 2. *Rank of increasing temperature and humidity depression during the first 120 days of 1995. Rank varies between temperature and relative humidity categories. The final column is overall rank when considering T and RH together, where relative humidity was given greater weight due to a presumed greater effect on evaporative water loss.*

Entrance	Ranked number size class 1 & 2	Rank T/RH Depression	(Difference in Ranks)^2
Violet City	65 1	3	4
Great Onyx	57 2	5	9
Carmichael	38 3	1	4
Frozen Niagara	15 4	7	9
White	12 5	2	9
Austin	9 6	8	4
Little Beauty	1 7	6	1
New Discovery	0 8	4	16
			$\Sigma=56/r_s=.333$

Table 3. *Results of Spearman's Rank Correlation test comparing the number of juvenile crickets found within ten meters of the entrance in winter with temperature/humidity depression; the last column is the squared difference between ranks for these two cave attributes. Test results indicate no significant correlation.*

The first hypothesis we consider here is that the abiotic factors of temperature and relative humidity affect habitat suitability. These abiotic factors may play a role in *Hadenoecus*' ability to forage outside (Studier and Lavoie 1990). When we examined and ranked study caves by winter temperature and humidity regimes most of the caves we hypothesized as being source habitats on the basis of size distribution (Table 1) had the least severe winter microclimate (Table 2). However White Cave, which we have identified as being a sink habitat, ranks second overall among study caves in microclimate stability. Clearly temperature and humidity regimes are only small pieces of a much larger puzzle.

As an alternative hypothesis, we consider the number of juveniles in the first ten meters during the winter months as a possible indicator of habitat suitability. Our logic is that the greater surface area/volume ratio of juveniles may make them more vulnerable to evaporative water loss than adults. Those caves with large numbers of juveniles roosting within ten meters of the entrance may make more suitable habitats due to more equable temperature/humidity regimes (Table 3). However a Spearman's rank correlation test comparing the number of juveniles within the first ten meters of cave entrances and temperature/relative humidity depression showed no significant relationship ($r_s=.333$; $p<.25$).

Next we considered the area, height, and complexity of ceiling refugia in our study caves. Our rationale for examining these attributes was that complex ceiling structures allow juvenile *Hadenoecus* to take advantage of the microclimates found in the cracks and crevices. Crevice complexity offers them protection from the influx of cold, dry air when the old doors are opened during

Area/Height/ Complexity ceiling hypothesized refuge best-worst	d^2 T/RH depression vs. hypothesized refuge	d^2 # 1 & 2 in first 10m winter vs. hypothesized refuge
Violet City 1	4	0
Great Onyx 2	9	0
Frozen Niagara 3	16	1
White 4	4	1
Carmichael 5	16	4
Austin 6	4	0
Little Beauty 7	1	0
New Discovery 8	16	0
	$\Sigma=70/r_s=.167$	$\Sigma=6/r_s=.93$

Table 4. *Results of Spearman's Rank Correlation tests. The first test indicates no relationship between the two attributes but the second test (column 3) indicates a significant relationship exists between the attributes in column 1 and column 3; where d^2 is the squared difference between ranks for the cave attributes. These results suggest area/height/complexity of ceiling near entrance affect the number of juveniles that can exist near entrance.*

winter months. Those ceilings with a greater area simply allow more refugia for juveniles to exploit. Ceiling height is also a factor because even when the old doors were closed cold, dry air managed to seep in beneath the door (as evidenced by ice formations on some cave floors) and so higher ceilings allow juvenile *Hadenoecus* to be further away from winter air. Thus we next correlated area/height/complexity of ceilings near the entrance with number of juvenile *Hadenoecus* found within ten meters of the cave entrance in winter. This time our rank correlation test results indicated a highly significant relationship (r_s=.93; p<.002) (Table 4). Good refugia mean that juvenile *Hadenoecus* can roost closer to cave entrances and so use less energy when leaving the cave to forage and returning to the cave to roost. Caves with less-favorable refugia may cause juvenile *Hadenoecus* to roost farther back inside the cave where temperature/humidity regimes are more equable and so must use more energy to travel the distance to the entrance. Juveniles may use more energy to travel the same distance as adults because their smaller legs force them to take more steps to travel the same distance. Juveniles must navigate over every irregularity in the cave ceiling whereas adults, with their stilt-like legs, can bypass many of these irregularities.

While these results are informative with respect to optimal conditions during the winter months they do not reconcile the contradictions of the data on overall number of juveniles compared to adults provided in Table 1. Thus while Violet City does have the low juvenile/adult ratio indicative of a source habitat, none of the other top-three-ranked caves, with respect to winter refugia for juveniles, is considered a source habitat according to our criteria. Other factors are probably involved that make some caves source habitats and others sink habitats. Currently we are searching for attributes of the epigean environment that might make some caves more favorable habitats than others. These include risk of predation from various predators, local topography, and maturity of surrounding forest.

Our last indicator of whether a cave is a source or sink habitat that we consider here is of increases in censused population over time, particularly increases in juvenile size classes (Table 5). Recall that both Violet City and Carmichael entrances were judged to be source habitats because of their size distributions. Both caves had high numbers of juveniles compared to relatively low numbers of adult *Hadenoecus*. In a one-year period the number of juvenile crickets in Carmichael had doubled and the number of juveniles in Violet City had increased 14 fold. While we do not have comparable data for hypothesized sink habitats these data do tell us that we should expect less or no recruitment at all in sink habitats.

Cooperation Between Park Staff and Researchers

Our interactions with personnel in the Division of Science and Resource Management might well be used as a model for the optimal working relationship between researchers and park staff everywhere. Some of the temperature/humidity data we used for our hypothesized source/sink habitats came from baseline data taken by park staff. Park staff have also been invaluable to our research efforts by assisting us with data collection. In addition, many of the suggestions we made during the new doors' design process were implemented when installation finally occurred. We recommended that natural openings at the sides and tops of entrances remain unplugged or that pipes be added where retrofitting precluded leaving natural openings because our observations and National Park Service Atmospheric Monitoring data indicated these openings were not significant sites of air invasion. The length and diameter of the pipe that crickets would use came from our experimental data. On the basis of our observations of Hadenoecus' tendency to exit caves at the top, large- and small-diameter PVC pipes were set in concrete in the door lintel area to allow egress/ingress for Hadenoecus, wood rats and other cave-dwelling organisms. Based on these past interactions, we have every reason to believe that future interactions with park officials and staff will be just as productive. It is better to solve problems with continual dialogue than to react after management decisions that are difficult and expensive to reverse.

Month Censused	Cave	Increase Size Class 1	Increase Size Class 2	Increase Size Calss 3	Increase Size Class 4
May-May	Violet City	14.1 X	4.6 X	4.0 X	1.7 X
May-May	Carmichael	2.0 X	1.5 X	1.5 X	1.0 X

Table 5. *Recruitment/population increases for hypothesized source habitats. Data taken from one year period 1994-1995.*

Acknowledgements

Our research is supported by a grant from the National Park Service at Mammoth Cave National Park. The grant (No. CA5530-4-9005) is administered by the Cave Research Foundation and logistic support is provided by the Division of Science and Resource Management at Mammoth Cave National Park. We particularly thank John Fry, Rick Olson, Joe Meiman, and Bobby Carson of the National Park Service—Science and Resource Management Division and Joel Brown of Biological Sciences at the University of Illinois in Chicago. Lastly, we would like to thank our many field assistants for enduring the necessary tedium to make repetitive and reliable observations.

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Volunteers and Cave Management on the Daniel Boone National Forest

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Abstract

The Daniel Boone National Forest has an estimated 2,000 caves on National Forest lands to manage and an estimated total of 8,000 to 10,000 caves within the Proclamation Boundaries that would have to be managed if the National Forest acquired the land they were found on.

The Forest found itself in a difficult situation: how to manage a large, complex, resource outside the experience of most National Forest managers. In response to the large number of cavers willing to do volunteer work, an umbrella organization known as the Boone Karst Conservation Task Force was created in the late 1980s to coordinate volunteer efforts on the Forest cave management program.

The development of the Boone Karst Conservation Task Force was not easy or simple. Issues such as trust between cavers and a federal agency, lines of communication, project planning processes, and the implementation of the revised Cave Management Regulations in 1994 were involved. The efforts of the Conservation Task Force has greatly improved the Daniel Boone National Forest's ability to manage its cave resources. Conservation Task Force volunteers have assisted in locating caves, surveying caves, and five cave-gate projects.

Volunteers have played a critical role in the management of caves on the Daniel Boone National Forest. In order to give you an idea of how important their contributions were, I need to give you some background on the Forest and forest cave management. The Daniel Boone National Forest is managed by the USDA Forest Service under the philosophy of conservation, wise *use* of the resources for present and future generations. The Daniel Boone National Forest is located in eastern Kentucky, and the Forest Service manages 682,000 acres of federal land spread over 21 counties. The terrain is typically rolling hills and mountains with over 3,400 miles of cliffs. Many of these cliffs are sandstone caps on extensive limestone layers. Five out of the seven districts on the Forest have extensive limestone resources of the Newman and Saint Genevieve Formations. Where there is limestone there are usually caves. There are an estimated 2,000 caves on federal lands in the Daniel Boone National Forest, and an estimated 8,000 to 10,000 caves within the boundaries of the Forest. On one 7.5-minute series topographic quadrangle alone we have located 400 caves. Caves vary from large openings to small openings. There are caves with extensive sinkholes and vertical cave opportunities. There are plain solution tubes, caves with fantastic formations, caves with active hydrology, and some caves with unusual formations, such as ice tubes. There are threatened, endangered, and sensitive species such as the Indiana bat and the Rafinesque and Virginia big-eared bats found in the Forest. We also monitor common species, such as the salamander, to indicate the health of caves. We have found that historical artifacts are common in caves, such as saltpeter mines and historical grafitti, which indicates historical use of the area (not only dates of use but family names in the area). Clothing, such as moccasins, and petroglyphs have also been found on the Forest.

The Daniel Boone National Forest found itself in a difficult situation: how to manage a large, complex, resource, outside the experience of most National Forest managers. The Forest was managing activities such as construction projects, wildlife pond construction, off-highway vehicle use, timber sales, rock quarries, oil and gas development, and coal mines, all of which could impact cave resources if they were present. To be honest, we didn't have a handle on cave resources on the Forest in the early 1980s. Luckily, there were a large number of cavers willing to help out.

Volunteer cavers have done cave surveys and cave inventories, put up signs for seasonal and permanent cave closures, and built cave gates, both large and small. They have assisted in research projects and review of proposed projects to let us know if they may impact caves or cave watersheds. Possibly the most overlooked help has been in cave exploration expertise. We went from permitting Forest Service personnel to go into caves without proper caving gear to advising personnel on the equipment they need when they go into caves, based on the advice of cavers.

With eight or more grottos using the Forest and the potential for a large number of projects to be going on at the same time, we realized that coordination and communication would be tough. An umbrella organization of cavers was needed to help coordinate the volunteer efforts. In the late 1980s an organization first known as the Boone Karst Foundation and later changed to the Boone Karst Conservation Task Force was developed under a Memorandum of Understanding with the Daniel Boone National Forest. This organization is made up of a chairman who does the overall coordination with all the grottos that are participating and a Board of Directors made up of representatives from each participating grotto, usually a member of the individual grotto's conservation committee.

The development of the Boone Karst Conservation Task Force was not easy or simple. The cavers were willing to work with the federal government only grudgingly at first, but have become more cooperative as time passed. The major issues that had to be resolved were:

Grotto Territory

There are seven districts on the Forest and each district was assigned a grotto by the Boone Karst Conservation Task Force to do the volunteer work needed by the district. This brought up the issue of "grotto territory." Grottos do not like to give out information about "their" caves. Therefore the grotto that was assigned to a district had to rely on their cave information and contacts with other grottos. So where possible, the grotto with the most experience and information on the area was assigned to the district.

Proprietary Information

Some cavers wanted the right to control the dissemination of the information they supplied, thereby preventing the Forest Service from handing out the information in an uncontrolled manner. In essence, we are proposing that any information provided by the grottos, which they developed while not working as a volunteer for the Forest Service, has proprietary control or approval rights over the Forest Service's release of that information. Information developed while working as a volunteer on a project is the property of the U.S. Government, is confidential, and subject to the restrictions in the Freedom of Information Act and the Federal Cave Resources Protection Act. This was a change from the attitude by the Forest Service that the government can do what ever it feels is appropriate with the information since it deals with resources on public lands. This attitude went over really big with the cavers and that is why we, on the Forest, have changed our attitude.

Trust

The biggest issue was the feeling of distrust that cavers had with giving information to the government. The cavers feared that information they provided would be posted on a bulletin board open to the public or handed out as opportunities for recreation on the Forest. The development of trust has been one of the hardest issues to come to grips with. Points we have stressed with cavers are:

- We as mangers have repeatedly assured the cavers that the information is considered confidential information and that we are sensitive to this delicate resource.
- How can we, as managers, manage a resource that we don't know is there? That favorite cave that we do not know about may have a timber sale or construction site developed over it with possible damage to the caves ecosystem. We have tried to impress on the cavers that thorough management can only be done with thorough knowledge of the resources.
- Trust has to be earned and is still an ongoing issue.

Conclusion

Developing the Boone Karst Conservation Task Force was not easy and is an organization to which we have had to devote a lot of time for coordination, however the volunteer work from this organization has been phenomenal. Since the creation of the Conservation Task Force, cavers have constructed six cave gates, one of which is the second longest in the world, done hundreds of acres of ridge walking looking for caves in proposed project areas, assisted in the signing of numerous caves on the forest, assisted in cave inventories, developed a cave information data base, submitted numerous nominations for significant caves on the Daniel Boone National Forest, and improved the health and safety aspect of Forest Service employees who go into caves.

Impacts of Surface Perturbations in Karst Areas in the Southeastern United States: A Biologist's Perception

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Abstract

Evidence continues to accumulate globally that indicates that surface perturbations have far-reaching effects in subsurface ecosystems in karst terrains. Studies in temperate, subtropical, and tropical caves show that surface activities of humans result in altered subterranean habitats and reduced biodiversity. In the United States the Federal Cave Resource Protection Act and the Endangered Species Act have resulted in many caves on government lands being protected and in numerous cave-adapted species being listed, respectfully. Too many karst areas are not situated in the confines of Federal land and examples of extirpated populations, such as the blind cave shrimp, *Palaemonias alabamae* (Smalley) and the gray bat, *Myotis grisescens* (Howell), in Shelta Cave, Madison County, Alabama demonstrate that simply being listed may not afford adequate protection. These and numerous other examples confirm that immense management problems exist in karst areas and often mismanagement is realized long after damage has occurred.

Obviously, surface perturbations and their effects in karst areas need to be documented. In addition, detailed and long-term taxonomic, life history, and ecological studies of surface and subsurface karst ecosystems are required. Sadly, too few students are being trained as karst geologists and cave biologists. Without adequate baseline data for hydrological, physicochemical, and biological parameters, decision for appropriate short- and long-term protection and management of karst ecosystems will be grossly inadequate.

Sloans Valley Cave System: Managing an "Open System"

Hilary Lambert Hopper
Wayne Hansen

Abstract

After three years of challenging, activist-oriented efforts, the situation at Sloans Valley Cave System can now be described as moving beyond crisis management and toward cave management. This is a brief description of the activities of the Sloans Valley Conservation Task Force, NSS, during those years.

History, Discovery, Use, Exploration

The Sloans Valley Cave System is located at the rural southern end of Pulaski County in southern Kentucky, just south of the growing city of Somerset, which benefits from the tourism traffic that flocks to Lake Cumberland, a sinuous reservoir impounded in 1951.

Parts of Sloans Valley Cave System have been used by local residents since the 19th century. During the 1960s and 1970s a 26-plus-mile-long cave system with over 16 entrances was surveyed and mapped in an effort led by Dave Beiter, Louis Simpson, Bill Walden, and other, mainly Ohioan, cavers from the Dayton and Cincinnati areas. The exploration of Sloans' lower depths and the potential for connection to the many adjacent cave systems has been limited by regular back-flooding of the cave system by Lake Cumberland following reservoir impoundment.

During these years the Miami Valley Grotto was established and a fieldhouse for caver use was built on land leased from local landowners. (That land is presently for sale.) Sloans many entrances are on several different private properties; there are also entrances on USDA Forest Service land, and one, chronically flooded by Lake Cumberland, is on land regulated by the U.S. Army Corps of Engineers.

The Pulaski County Landfill Opens for Business

Sloans is situated in and along valley edges in the Neuman Limestone on the western edge of the Cumberland Plateau. The surrounding hills contain economically-useful coal seams. From the 1940s to the 1960s a ridge-top across US 27 from Sloans Valley Cave System was first deep-mined and then surface-mined. The surface mining's legacy was a large, flat area, a valuable resource in this region. Thus a local businessman, Junior Weddle, was seen as a hero to Somerset residents in the late 1970s when he proposed opening a landfill on the site.

Louis Simpson, Nick Crawford, biologist Tom Barr, and many other local residents and cavers actively opposed this proposal, as it was feared that off-site surface runoff would flow toward or into the Sloans Valley Railroad Entrance on one side of the landfill, and into the semi-explored, largely unmapped warren of karst features on the southeastern flank of the proposed landfill. These protests, via the public hearing process, were regarded as trivial by the Kentucky Division of Waste Management which, in agreement with the landfill company's environmental consultants, determined that the Pennington Shale layer below the proposed landfill site would act as an excellent natural liner.

In 1979 and 1980 the Pulaski County Landfill opened for business. It was intended to be a five-year temporary operation but you know how these things go. It received extensions, renewals, and expansions and obtained an asbestos permit in the mid-1980s. Also, producers of "special wastes"—industrial wastes legally defined as non-hazardous—were given temporary or long-term permission to dump in the Pulaski County Landfill. Over the years, the local residents along Dixie Bend Road also reported midnight dumping, the burial of an entire semi, eye-burning chemicals, nauseating chemical odors, and other problems. Inspectors dutifully came, wrote these complaints up, found everything "okay," and went away.

Meanwhile, back down across U.S. 27, the main Sloans Valley Cave System owners, Tom and Cathy Crockett, noted that overflow runoff from the landfill's sediment pond was settling on their property in a swallet, creating an impoundment of grey and brown sludgy sediment a few inches to several feet deep, and 10 by 20 feet on a side. The Crocketts and cavers speculated about what this sediment might contain, and noted that it ran

Sloans Valley Cave System

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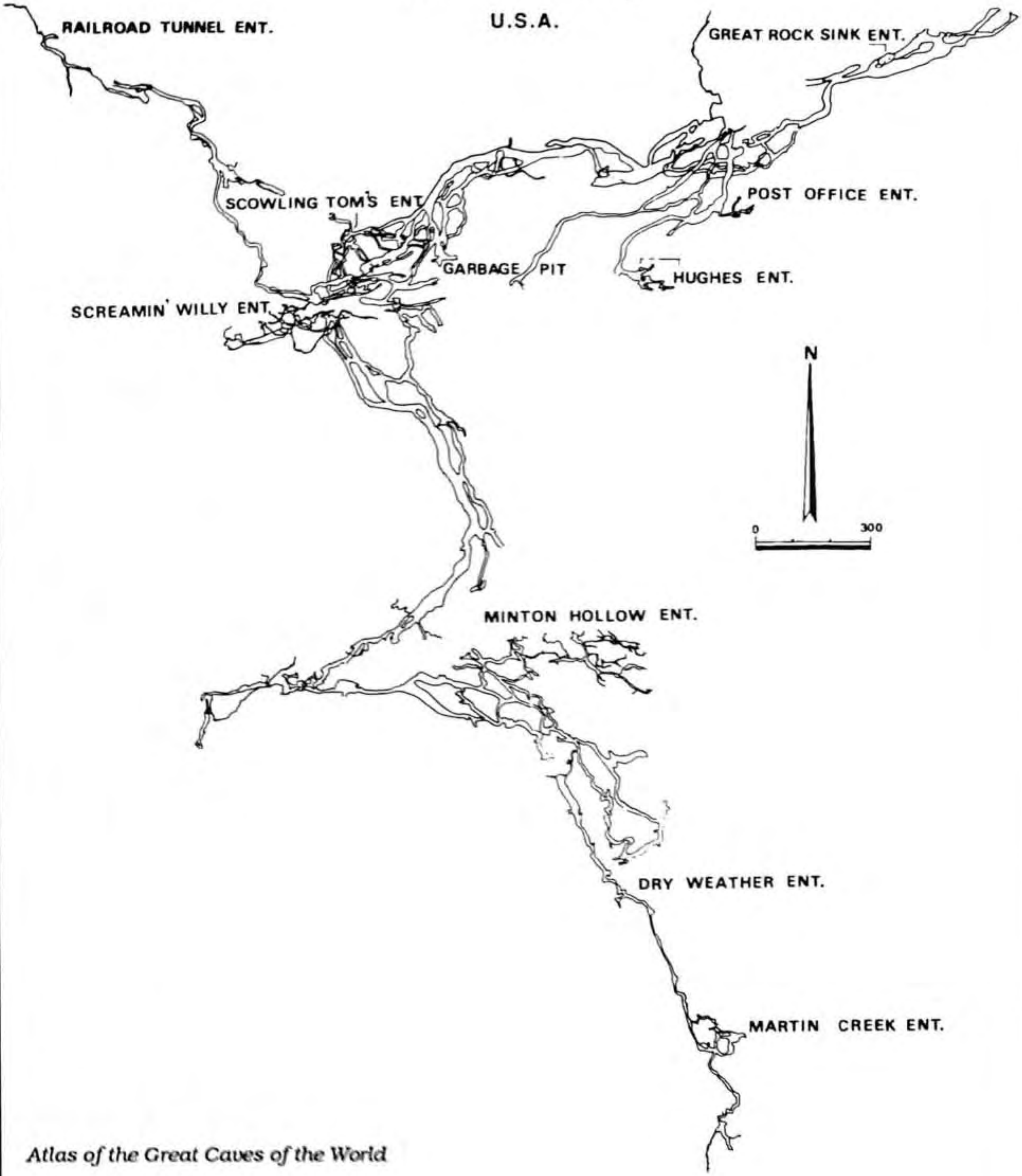

Atlas of the Great Caves of the World

overland into the Railroad Entrance of the Sloans Valley Cave System and was probably also entering the cave system via an opening in the swallet. Kentucky groundwater experts came and looked at the situation, promised to return, and then never came back.

Activism, Combining Scientific Data, and a Knowledge of the Law

This was the situation in 1992 when scientific- and regulatory-minded cavers joined forces with a local citizens' activist group that had been complaining—to no avail—about the Pulaski County Landfill for years. The Landfill had recently changed ownership to a West Virginia company, and it was in need of a permit renewal to keep it open to July 1, 1995. This date, set by the Kentucky Division of Waste Management, was the final compliance date for all of Kentucky's landfills that planned to operate beyond that date.

The Pulaski County Landfill also announced that it was commencing the application process for a major expansion. Under the expansion plan, the original Pulaski County Landfill would close June 30, 1995, and the expansion would open for business on July 1, 1995. This expansion and upgrade would include a state-of-the-art plastic liner and other wonders. In the state-level landfill-siting process, the Pulaski County Landfill would become a major regional landfill for southeastern Kentucky, taking garbage from 18 Kentucky counties and all surrounding states.

With these announcements also came the windows of opportunity for citizens to have input through the public comment and hearing process. Although this had been to no avail during the fight against the original Pulaski County Landfill, we resolved that we would make a difference this time. In May 1992, the Somerset/Pulaski County Concerned Citizens Coalition (hereafter the "Citizens") and the soon-to-be-NSS-designated Sloans Valley Conservation Task Force met on the Crocketts' front patio. Our first product was a blistering, fact-based, regulation-smart press release and accompanying vile green brochure authored by geographer Hilary Hopper, geologist Duke Hopper, and world-famous industrial advertising genius Roger Brucker.

Both local newspapers carried excerpts; at about that same time, the International Geographical Union's 1992 karst problems field trip came to Somerset, led by Drs Doc Dougherty and George Huppert. This also made the local papers—that some 20 international karst experts were being shown the local environmental mess.

Sediment and Water Sampling Indicate Hazardous Leaks

This publicity got the Secretary of the Environment Cabinet, Philip Shepherd, involved to the point that in October 1992 he sent a one-day army of state-level water and waste division people into the field to be shown the situation and to take a broad array of water and sediment samples, as dictated by the Sloans Valley Conservation Task Force. Hilary Hopper led the all-day field trip through rugged terrain. Support was provided by Duke Hopper, who prepared the itinerary and listed the sampling to be done, and by the Citizens who were witnesses, hikers, and made lunch.

A telling moment on the trip was when one of the state people first spotted the Crocketts' pond of goo and called back to the waste management manager in an excited voice, "George, wait till you get a look at this!"—and George remarked that he had never seen this on any of the maps. Well of course not, it was off the permitted landfill property.

Another indicative incident: the Sloans Valley Task Force had documented and mapped a series of leaks from the old underground mine works, all around the base of the landfill. These leaks were characterized by the red water of acid mine drainage. We were asking that these leaks be tested to determine if they contained landfill leachate and, if so, what was in the leachate. One of these leaks was on the southeastern flank of the landfill, up a snake-infested, logged-over slope, above a series of sediment ponds built by the coal company and landfill company (all of which drained into a swallet). The Sloans Valley Conservation Task Force's goal was to show this red leak to the experts and have them take samples.

As Hilary jogged up through the trees, setting a fast pace, she could hear a bulldozer rumbling and roaring up ahead. She finally burst out of the woods to where she could get a good look at the leak we were coming to sample. And what did she see but a bulldozer, poised one minute from obliterating the red leak and its trail downslope toward ponds, swallet, caves, and Lake Cumberland. She called back into the woods, "You'd better hurry up!" Give the 'dozer driver credit—he stopped as soon as he saw us. So as the state experts and Citizens tore out of the woods, they saw a bulldozer, blade up, parked next to the water we had come to sample. These two incidents exemplify the attitude and actions of the Kentucky state officials and the landfill owner/operators.

By December 1992, lab results of the sediment and water samples, and a re-test, indicated that several of the red leaks contained organic chemicals, some worse than others, in addition to what you might call the "natural" acid mine drainage ingredients. A leak (called a "spring" and used by locals for water) next to the landfill's entrance, right next to several homes, repeatedly contained vinyl chloride, which according to some laws is a shut-'em-down carcinogen. The Crocketts' goo pond was officially—but only verbally—characterized as "hazardous waste" that would have to be removed and taken to a permitted disposal site.

Also by the end of 1992 Duke Hopper, with Joe Morgan's and Hilary Hopper's field assistance and Jim Currens' lab work, had conducted a short, sharp dye-trace that physically tied the landfill's runoff to the Crocketts' goo pond, and to the underground stream within the Railroad Entrance of the Sloans Valley Cave System (also, in early 1992, caver Mark Turner was attempting to dye-trace the swallet on the southeast side of the landfill).

In 1993, Conservation and Continued Landfill-Busting

During 1993, in an effort manned most steadily by Wayne Hansen, the Sloans Valley Conservation Task Force in cooperation with the Miami Valley Grotto, installed John Wilson's fabulous cave registers in six of Sloans' most popular entrances to begin to get a handle on the caver-, spelunker-, church-, and scout-trip visitors. Sloans is a major cave system, a natural regional treasure, and deserves respect and research. It can be a showpiece of realism-based conservation. To assist us, Gina Turner, E.T. Davis and other cavers came up from Atlanta's Dogwood City Grotto on several occasions.

Meanwhile the struggle continued, intending to shut down the present Pulaski County Landfill and prevent the expansion from opening in July 1995, and to get the landfill and state to acknowledge their responsibility regarding the Crocketts' property and probable underground contamination by landfill runoff. We—Sloans Valley Conservation Task Force, Crocketts, and Citizens—found that we were shut out of most of the give-and-take between the state, landfill, legal advisors, and environmental consultants. This was, we were told, because we were not "contractually involved." For those readers who are environmental consultants and public employees, this is commonplace. For American citizens it is a disgrace, that we be forced to play childish games to obtain documents that pertain to the future of our resources, and in the case of the Crocketts, of the future of their own property.

In the summer of 1993, probably the Pulaski County Landfill's most amazing stunt was to attempt to sneak into its expansion permit request a doubling of the cubic feet it would be allowed to excavate downward toward the limestone beneath the expansion site's shale. The Citizens caught this stratagem, and used the regulations to require that the Pulaski County Landfill go back through the public hearing process. These chess moves culminated in a public hearing in April 1994—our chance to get the data in to the state that might counterbalance what they were being fed by the consultants.

Here is what we took into that hearing: A performance by Roger Brucker in which he demonstrated with a plate, peg-board, sponge, tube, and bucket, what happened to the leachate as it left the landfill property and headed for Lake Cumberland. He very deliberately poured brown "leachate" from a bottle labelled "vinyl chloride" with a skull and crossbones. When some splashed on front-row audience members he exclaimed, "Oh, I'm sorry, I hope you don't *die*;" this great performance made it clear at a very simple level that the landfill leaked no matter what the county-level waste management board had been told by the landfill owners. One man in the audience growled, "I wonder how much they paid *him*."

Secondly, Duke Hopper had prepared a map—three feet by six feet—in which he mapped the original landfill, the proposed expansion, the cave system, all of the known surrounding caves and karst features, and the surface and groundwater flow. This was big enough to communicate to an audience, with a copy for the Division of Waste Management. Hilary Hopper presented this map along with letters from the country's karst experts—and this is where the wonderful nature of the karst research and conservation community comes in.

The Sloans Valley Conservation Task Force asked for help via fax, and we got it: letters to the Kentucky Division of Waste Management from—Jeanne Gurnee, then-NSS President; from Al Krause, NSS Conservation Chair; Carl Anderson, Secretary of the Georgia Speleological Society; E.T. Davis, Chair of the Dogwood City Grotto; Roger Brucker; John Mylroie with the backing of the Karst Waters Institute Board; George Huppert; and messages also from Doc Dougherty and Ralph Ewers.

Their message was simple: this is not the right place to put a landfill, even less to put a major new landfill, and here is the literature and research to back us up. At the hearing each of these letters was slowly and carefully read into the record. An audience member said later, "I could have listened to those letters all night." This is the power of the scientifically-oriented caving community.

The evening was rounded out by a several-hour presentation by the Citizens on the regulations and laws that had been broken, ignored, and side-stepped. The meeting went on until 1:30 A.M.

The Landfill Expansion is "Back-Burnered"

That was in April 1994. In May, these things happened:

- The Division of Waste Management sent the landfill company a list of 26 major deficiencies in their expansion application. These included such things as "please put the contours on your map" and "you are required to do an extensive and comprehensive dye-trace study of the site." The deficiencies and their remedies were serious, big-ticket items. At this point it is useless to ask why they were never brought up before.
- The original Pulaski County Landfill entered the Superfund investigation process. This was the result of work initiated by Roger Brucker with the help of Dogwood City Grotto and other Atlanta-area cavers and Environmental Protection Agency people; via a request for an investigation submitted by the Citizens to the Atlanta Environmental Protection Agency office.
- The Sloans Valley Conservation Task Force found an attorney who was willing to help the Crocketts for little or no money. He could not resist; and he was committed to it, after the landfill company's president called him an "ambulance chaser."

(Also, in May 1994, the landfill company let the payments lapse on its performance bond, the insurance policy that keeps things rolling if a company decides to walk. However this was not discovered by the Pulaski County Solid Waste Board until June 1995.)

As Roger Brucker said at this point, "I think this game is in its third quarter." By late 1994 the Kentucky Division of Waste Management told the landfill company that its expansion application was "back burnered" indefinitely beyond the July 1, 1995, deadline because of the company's continuing inability to deal with the application's deficiencies. On December 31, 1994, the Crocketts issued a notice of intent to file suit regarding the contamination on their property, because of the company's and state's inability to do anything about it.

A Temporary Celebration and Continued Vigilance

During 1995 the landfill company has been struggling to move forward, while their once-excellent position in the Kentucky landfill game slips away from them. Temporarily they have become a transfer station, shipping local garbage to a landfill in an adjoining county. They are supposed to cap the original Pulaski County Landfill. They have agreed to have Ralph Ewers conduct a groundwater monitoring program of the original Landfill. The Landfill has now moved up another rung in the Superfund process. The Crocketts have heard nothin' from nobody and the pond of goo continues to slop into the Railroad Entrance. The landfill company continues to assure the county waste board that they will soon have what they call a "draft permit," but we hear that their consultants keep losing dye in the expansion area's sinkholes. The sinkholes that the state found out about from our map.

On July 1, 1995, the Sloans Valley Conservation Task Force and Miami Valley Grotto conducted what we called a "solemn, celebratory hike" from the Railroad Entrance of Sloans, uphill along the drainage ditch that eventually took us to the leak next to the landfill's entrance. As Miami Valley Grotto Chairman, John Cole, was quoted in the resulting newspaper article, we "followed the path to the poison." This was a day to celebrate the decades of work that cavers and others have put into this struggle, and to celebrate that the expansion that was supposed to be open for business on this date, was not.

The Sloans Valley Conservation Task Force, in cooperation with many individuals and groups, has at least temporarily achieved its short-term goals and is now hoping to be able to turn to long-term realism-based conservation of the Sloans Valley Cave System. However the Pulaski County Landfill continues to maneuver its way toward obtaining a permit for its expansion, and the state cannot seem to deny that permit, although the landfill's engineering consultants keep obtaining negative results in attempting to make the site "monitorable." Apparently, data that does not reflect favorably on the landfill's application process does not have to be reported to the Kentucky Division of Waste Management, and hence there are no concrete grounds for denying the permit. The process and struggle continue.

Managing a Situation that Cannot be Controlled

Even as we continue to monitor the landfill company's closeted efforts to obtain an expansion permit, we are turning more fully to come to grips with managing an "open system" like Sloans. First, we need to know what it is we are dealing with, in terms of both human use and natural characteristics. Sloans is, according to Doc Dougherty, one of the USA's "major under-researched cave systems."

We now have two years of data from our cave registers. Although we placed six registers to begin with, the one in the Screamin' Willie's Entrance has not yielded any data either because cavers have not been able to find it or because it disappeared in the mud from a new sinkhole opening up less than 20 feet away on the surface. However the data collected from the other five registers, from mid-1993 to mid-1995, includes 800 respondents.

Among the tasks still to perform is a full statistical analysis of the register data, but the Sloans Valley Conservation Task Force has been able to draw some conclusions already. First, there are many more male cavers than female cavers using Sloans. Second, a large number of people who have been caving for awhile are not NSS members. This is evidenced by the 128-trip average and 9.6 years caving average. Fortunately, people do seem to be following a safety standard with regard to light sources and helmets. Third, 83% of the cavers are coming from Kentucky and Ohio to cave in Sloans, but the other 17% seems to represent regular visitation by cavers from other states, although less frequently. Fourth, the most frequently-listed main purpose for a trip is recreation and exploration, although the exploration seems to be of the type that involves personal knowledge, not seeking virgin cave. And fifth, there is no apparent seasonal pattern for the visits of cavers. Some months see heavy visitation, but May is surprisingly low.

The results of this data analysis have raised several questions for us that we hope to address as we continue to attempt the conservation of the Sloans Valley Cave System. Among these questions is: what adjustments can we make to the NSS register form so that we can more accurately track cave users from entrance to entrance, so that data from the same group is not entered twice for a single trip? Hopefully when the statistical analysis is complete, this is a question we will be able to answer. The cave register data will provide us with an understanding of the human traffic in and through Sloans. We can learn which passages are over-used, and which could benefit from restoration and conservation.

The Sloans Valley Conservation Task Force and Miami Valley Grotto are discussing, with Jorge Hersel of the USDA Forest Service, the possibilities of developing a marked trail section within Sloans that would begin the work of restoration and education, and might steer the more destructive visitors away from sensitive areas. The Forest Service, under the direction of John MacGregor and with the help of the Boone Karst Conservation Task Force, installed a bat gate within the Minton Entrance area in 1993.

The Sloans Valley Conservation Task Force is completing the installation of a weather station at the Crocketts' residence, for detailed and accurate monitoring of hydrologic conditions affecting the Sloans Valley Cave System. The funding for this project came from grants awarded to the Sloans Valley Conservation Task Force by the NSS and the Dogwood City Grotto. The Forest Service is showing interest and involvement in the data from this weather station.

Richard Hand, of Wittenberg University in Ohio, has begun the long-term task of compiling a biological inventory of cave life within the Sloans Valley Cave System. This will update such studies as those done by Tom Barr in earlier decades, and will indicate which life-forms have suffered and which flourish under the heavy traffic areas within much of the system.

In 1994 Frank Reid, with his radio-location technique, helped us take the first steps toward accurate above-ground siting of Sloans cave passages. We are augmenting our 1994 map with the latest USDA Forest Service boundaries, and other surface data as they come available.

Descriptive, historical, and geological studies have been collected over the past three years. This is ongoing. Many of these documents were used to compile the Significant Cave Nomination submitted in 1994 on behalf of the Sloans Valley Cave System's several entrances on Forest Service land (the Minton Hollow and Martins Creek entrances).

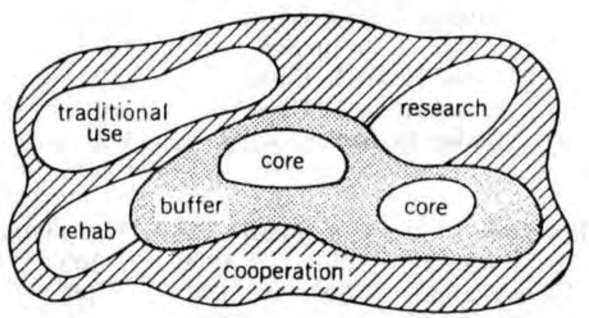

Figure 2. *Idealized diagram of a biosphere reserve. (Cutter* et al *(1991) by permission.*

The ideas behind the Biosphere Reserve system, a United Nations concept used worldwide for conservation of major ecosystems, can be brought to bear on Sloans Valley Cave System. A biosphere reserve-based management plan for this largely-unprotected system would include a core area for preservation, with human traffic discouraged; buffer areas, where greater traffic would take place; and heavy-use areas for conservation, education, and restoration. On the surface is the traditional human-use area, for active conservation and discouragement of incompatible land-uses such as landfills; and for the education of people locally and within Pulaski County toward a better understanding of the cave system they have been using, often unknowingly, for over a century.

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Report on Sloans Valley Register Data

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Conditions: registers #1-5 — Number Respondents: 800

Garbage Pit, Post Office, Minton Hollow, Railroad, Scowling Toms

Age:	<10	10-14	15-19	20-24	25-29	30-34	35-39	40-44	>44	AVG
	19	41	58	121	105	76	144	67	49	29

Males:	710	88%	Females:	90	11%	NSS Members:	260	32%

	Mean	Mode
Years Caving Experience:	9.6	0
Number Caving Trips:	128	5-10
Group Size:	6.0	
Planned Hours In Cave:	5.7	6
Actual Hours In Cave:	4.6	
Number Light Sources:	3.2	3

States cavers came from:		
Kentucky:	300	39%
Ohio:	340	44%
Wisconsin:	9	1%
Michigan:	40	5%
Tennessee:	20	2%
Georgia:	10	1%
Other:	44	6%

Purpose	Main		Other	
Education:	156	19%	109	13%
Conservation:	50	6%	55	6%
Mapping:	3	0%	10	1%
Exploring:	206	25%	81	10%
Photography:	43	5%	21	2%
Recreation:	307	38%	116	14%
Science:	42	5%	22	2%
Management:	26	3%	24	3%
Dig/Modify:	3	0%	1	0%
Rappelling:	3	0%	1	0%
Other:	5	0%	19	2%

How found cave		
Friends:	392	49%
Locals:	45	5%
Caving Pub:	7	0%
Other Pub:	6	0%
Maps:	19	2%
Cave Club:	182	22%
Other Club:	51	6%
Other:	20	2%

Lights/Equip	Main		Other	
Carbide:	64	8%	28	3%
Electric:	543	67%	18	2%
Flashlight:	99	12%	467	58%
Candle:	2	0%	237	29%
Other:	4	0%	35	4%

Hardhat: 637 79%

Monthly Cave Visitation:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
1993:	—	—	—	—	—	27	60	115	90	80	97	153	99
1994:	78	79	54	32	26	39	100	88	86	67	102	121	73
1995:	18	133	73	147	46	77	12	—	—	—	—	—	82
Ave	48	106	64	90	36	58	80	102	88	74	100	137	82

If you have any comments or suggestions, please feel free to write us at one of the listed addresses.

Cave Inventories and Data Management Through Cooperative Projects in Kentucky and Missouri

R. Scott House

Abstract

In 1994 a new cooperative program, funded by the National Park Service and Cave Research Foundation, was initiated to begin a comprehensive resource inventory of less-extensive caves within certain drainage basins in Mammoth Cave National Park. Caves are relocated, brass caps are installed, and locations are determined by Global Positioning Satellite equipment. The caves are mapped and data about the contents, suitable for use with a geographic information system, are recorded in reference to the survey net. An additional product of this study is a separate database that will contain general information about the cave. This effort is compared and contrasted to similar cooperative efforts that Cave Research Foundation is currently engaged in on state, federal, and private lands in Missouri.

Introduction

Quite often government land managers wonder how they can get cave inventories and surveys done on their land without busting their budget. The Cave Research Foundation has managed to take on several such projects through a variety of approaches. Cave Research Foundation is a facilitator organization; the framework of the Foundation allows cave projects and research to occur that would otherwise go undone. The purpose of this paper is to describe the nature of the projects that Cave Research Foundation has undertaken in the Midwest (or Mid-South), how these projects are funded, and how they are designed to meet the needs of the land managing agency.

Kentucky: Mammoth Cave National Park

The world's longest cave is located in and around Mammoth Cave National Park. However, within the park itself are entrances to over 300 other, less-extensive caves. Most of these caves lie south of the Green River; however, a large (and largely undetermined) number are on the north side of the river. Despite, or because of, the fact that Mammoth Cave has been extensively studied, mapped, and written about, little is known about the vast majority of these less-extensive caves. Management of these resources is a critical need and cannot be accomplished without first obtaining a great deal more information about the resource. A cooperative project between the Cave Research Foundation and Mammoth Cave National Park is establishing an inventory system that will produce usable data on these caves on an on-going basis.

An initial study area, selected by the National Park Service, consists of several drainage basins on the north side of the Green River. Included within this area are at least five caves longer than 1,000 feet and approximately 35 other, mostly unverified, locations of smaller caves. Previous work in the study area includes surveys done in the 1970s by a group of Louisville cavers called the North Shore Task Force, a few cartographic surveys and locations from Cave Research Foundation files, and locations of caves and hydrologic studies by National Park Service personnel. This study area was scheduled for a three-year project, the first year of which has been completed.

The project has two objectives: to develop the materials and methodology, and to test the system by inventorying the caves within the study area. Field materials and equipment to be developed include simple field guides, instructions, inventory sheets, Global Positioning Satellite (GPS) hardware, monumenting tools, biological inventory gear, and the like. A database suitable for recording the data was to be investigated and tested. The methodology was planned in advance but was to be refined over the course of the first year.

Field work has taken place on a regular basis every month for the past 12 months. Virtually all of this field work has taken place during regularly-scheduled Cave Research Foundation expeditions at Mammoth Cave National Park. The field work has had three important objectives which are occurring simultaneously: the field work is being accomplished, the methodology is being refined, and training of personnel is on going.

Field work over the last year has been extremely successful and above expectations. One large cave (one mile long) and 19 smaller caves have been inventoried. Nineteen GPS locations have been obtained and a brass cap, with identification number, has been placed at the entrance of 21 caves. In cooperation with the Cave Research Foundation cartography program, 13 caves were mapped during the past year; in addition, survey data from 14 caves that were previously mapped were utilized. There was also survey and inventory work done in four larger caves which are still in progress. Inventory data was collected on the entrances and at approximately 200 data points (survey stations) within the caves. Entrance photographs were taken at 22 inventoried caves. Additionally, another 25 cave locations were visited and found to be in error; there were no caves at these locations. Sometimes these locations were springs, sinks, blowing holes, or other karst features; many times, however, the locations were apparently just errors or mistakes in transcriptions from other sources.

The process for surveying, inventorying, and monumenting a single cave usually involves two separate visits. An inventory/mapping crew visits the location first. This is a priority since so many of the locations are in error. The entrance is photographed, described, and located on a topographic map. The cave is then surveyed using standard Cave Research Foundation techniques, that is, a compass, clinometer, and tape survey with sketching done to scale.

As the cave is surveyed, it is also inventoried by several of the team members. The inventory process is somewhat free-form, a different approach from most earlier inventory processes. In these earlier approaches, which are currently used in several inventory projects, the cave is inventoried using checklists which are done either for the entire cave as a single entity or are done at each survey station. These approaches were not used here for a variety of reasons: 1) quality control is very difficult with the checklist format since anyone can make a check mark whether it is appropriate or not, 2) the whole cave approach is not appropriate because the data is to be incorporated in the MACA Geographic Information system (GIS) utilizing the cartographic data as the link, and 3) we want inventoriers to concentrate on the features of the cave, relating those features to a survey station rather than focusing on the survey station and then looking for a feature to be checked off. This final reason is a philosophically-different approach: we want people to go into the cave with their eyes wide open for features, not survey stations.

As the cave is inventoried a note taker records the inventory information and notes what station the features are found near. The goal of the inventory is to obtain as much information as possible within the restrictions of time and money. The data are qualitative but only relatively quantitative; that is, standard transect sampling techniques useful for surface work are not being used. Further, the biological sampling is restricted to field identification; no specimens are collected.

After the inventory, another crew will visit the locale to obtain the GPS location and monument the entrance. The GPS equipment used is a Trimble Pathfinder Professional Plus with an MC-V datalogger. This equipment can, under ideal conditions, give locations to within five-meter accuracy for the horizontal elements. The vertical (elevation) element is not very accurate, however, giving up to 40-foot elevation errors at control points. An altimeter was also tried but failed to give useful readings either due to instrument errors or operator inexperience. At present the elevation data is extrapolated from field observations and comparisons of the different topographical maps available of the park.

Using the cross-platform program FileMaker Pro, the inventory data are entered into two separate database files which can be relationally linked. The first consists of one record per cave with 42 fields primarily describing the entrance and its location but also including a very brief narrative description of the cave. The second database consists of one record per inventoried station (not all survey stations have noteworthy features) and has 11 fields with inventoried contents grouped by category. This database can be linked to the cartographic survey output (the two databases share the survey station numbers) for utilization in the park's GIS. The park's GIS data will probably be handled through ARC/INFO but the conversion of the survey data has not yet been tested.

Entering the inventory data into the database requires familiarity with the process and the subject matter because the person entering the data must be able to put the data into the correct fields in the correct format. This may be seen as a drawback since it requires technical knowledge and restricts the use of part-time clerical help. On the other hand, this process serves as a final filter for data integrity and, rather than a drawback, insures a higher degree of accuracy. The process can be speeded up through a selection of pop-up menus and spell checkers but still must be done by experienced personnel. Since the integral data is the final, desired result, this step is seen as very important.

Currently, work is continuing on the project. The databases have already shown themselves to be useful tools even without full GIS integration. All other aspects of this project are on or ahead of schedule and we anticipate that additional caves and drainage areas will be added to the study area for full testing of the methodology and system. Training of inventory personnel, including National Park Service employees, is continuing at a rapid rate thus assuring us of a body of trained personnel. The great objective of this project is to spread the inventory to all the caves of the park and, based on our experiences thus far, there seems to be no reason that this cannot be done.

Missouri: Ozark National Scenic Riverways

The Ozark National Scenic Riverways consists of about 70,000 acres along the Current and Jacks Fork Rivers in southeast Missouri. Approximately 290 caves and many springs, including some of the nation's largest, lie within the park boundaries. They are particularly important biologically, geologically, and hydrologically. Over the years, however, cave management in the park has been somewhat inconsistent as priority was given to river management problems (which are extensive). A cave management plan was written in 1988 but not fully implemented, partly due to budgetary restrictions. To partially implement the cave management plan, the Riverways has taken several steps. First, a functioning cave management committee was formed consisting of three National Park Service and three non-National Park Service members. Second, an archaeological survey of caves was initiated. Third, a cooperative project to get information on Riverways caves was begun, partially as an outgrowth of the first two steps. It was particularly noted that the Park Service's information on Riverways caves was incomplete and somewhat inaccessible. In 1994 the Ozark National Scenic Riverways and Cave Research Foundation wrote a cooperative project proposal for synthesizing the available information into usable formats. This proposal was partially funded for 1995.

The project consisted of two components. The first was to redesign and expand an existing database on Riverways caves. The second component was to assemble copies of all known printed material on Riverways caves, and put this material into an organized filing system suitable for use by land managers. The project got under way in early 1995 and the completed products were delivered to the park in September, 1995. For the database aspect we took an old database and expanded into a "soft" version of the Cave Research Foundation/Missouri Speleological Survey cave report form. For example, locations are given in three different systems and the cave description is contained within a single expanding field. Furthermore, a cave classification (open, restricted, or closed) was given and a short cave prescription was written (as yet another field). This prescription system will be modified by the cave management team in an annual review. Report forms were designed to give rangers, land managers, and researchers the types of information they need in an easily accessible format. For example, the management report form gives a short bit of information about the requested caves as well as their classification and prescriptions.

The file assemblage took a considerable bit of time. A great deal has been written about the caves and springs of the Riverways and there were many sources. These sources included: Cave Research Foundation files, Missouri Speleological Survey files, National Park Service files, contracted works by the Missouri Department of Conservation and Ozark Underground Laboratory, photographs, endangered species studies, canoeing guides, reports of the Missouri Geologic Survey, historical publications, and a wide variety of other books. Hard copies were obtained, somewhat laboriously, using a photocopy machine purchased for the project by the National Park Service. These copies were filed into archival legal-sized folders with labels created by the database and inserted into hanging file folders, one for each of the 288 known caves. The assembled files filled four large boxes and quickly exceeded the capacity of the file cabinets purchased for them. Furthermore, the files will be even larger when copies of all of the maps are folded and put into them as well.

Missouri: Missouri Department of Conservation

Missouri Department of Conservation lands in Missouri consist of state forests, conservation areas, river accesses, wildlife refuges, and natural areas. Many of these have caves and other karst features within them. Cave Research Foundation activities on these lands began with surveying projects that were funded through volunteer agreements. These agreements paid for certain travel and drafting expenses. With the purchase of additional lands near the Current and Jacks Fork Rivers, the Department found a need for information on caves and other karst features within these areas. This need has led to direct grants that enable Cave Research Foundation not only to survey the caves but also to inventory them for biological, cultural, and other types of features. This project is continuing at this time. The data here is also being put into a database compatible with the Ozark Riverways project.

Missouri: Mark Twain National Forest

Originally, work on the Forest was funded through volunteer agreements. This allowed surveying to be done on a number of Forest caves. Most of Cave Research Foundation's activities on the Mark Twain Forest in the last few years have been on the Eleven Point District where we have been engaged in bio-inventory and surveying projects. This large district lies along the Eleven Point National Scenic River and includes the Irish Wilderness, an area of 17,000 acres. We have completed the fourth year of this extensive program, which began as a project to map and inventory caves surrounding a mineral lease area. Following completion of a first study (Sutton, 1992), the project expanded to cover other caves within the district. Further background on the project is given in the Cave Research Foundation Annual Reports for 1990-1993. This project is funded through a challenge costshare grant. The funds allow for a salary for the principal investigator to identify cave invertebrates, manage the project, and write reports. All other time (including survey, cartography, and database work) is volunteered by Cave Research Foundation personnel.

Missouri: Pioneer Forest

Pioneer Forest is a privately-owned forest which consists of about 180,000 acres, virtually all of which is in the "scenic rivers" region of southeast Missouri. Pioneer Forest only has a few full-time employees and the Cave Research Foundation is helping out with the survey and inventory of caves on Pioneer lands. Here we perform cave surveys and do biological inventory and database work as well. The Pioneer Forest provides a modest amount of funds in the form of direct purchases on an as-needed basis.

Conclusion

Different agencies with different agendas and different goals in different geographic area probably have, and ought to have, different needs for different types of cave data. The idea that has come across as we have worked with these different agencies is that it is not possible to apply a uniform set of procedures for obtaining this cave information. Several axioms ought to apply:

- Cave research groups must work with an agency to determine what that agency's goals and needs are.
- Agencies must realize that inexpensive, good help comes with a price; the people who do this valuable work must be listened to.
- Agencies should realize that inventory and survey procedures developed for one agency or geographical area are not necessarily useful in another setting.
- Standardization and sharing of data is easy in today's electronic world.
- Cave researchers must understand the necessity of getting work into final product form
- Agencies must actually use this cave data and not just let it collect dust on the shelf.

In the climate of reducing federal budgets there should be many possibilities for getting good work done through not-for-profit cave groups. How much can be done is a result of finding the right people to do this work and then giving them the latitude and responsibility they need.

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Caves and the Law: Liability

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Abstract

This is the second in a series of articles on laws and caves by the author. The first article concerning federal and state cave protection laws appeared in *Environmental Geology* (Huppert 1995). Future articles are planned on state archaeological protection laws and state endangered species and biological protection laws that may be applied to caves.

Recreational liability laws in the individual states generally protect landowners from liability as the result of the recreational use of their land. However the distinction between the recreational user, a caver, and a trip leader is often not as clear as might be expected. Landowners may thus find themselves liable because of activities that could be considered non-recreational in nature. The understanding of these distinctions in the various states is especially critical in these days of explosively expanding recreational opportunities in an increasingly litigious society.

For many years the author read and heard numerous anecdotes of situations in which landowners with recreational opportunities on their land, especially those who own caves, have found themselves involved. Therefore the author systematically reviewed the recreational liability laws of the 50 states in the nation.

Most states have quite similar laws in regard to the recreational use of private land, a use that would certainly would include caving. Most states have specific laws that separate recreational liability from other forms of liability in order to encourage landowners to open their lands to recreational users. These laws are referenced under a number of headings in the state statutes. Some of these headings are: recreation, liability, recreational liability, landowner liability, and sportsman's law. The major headings one may also look under in the legal indexes are: torts, property, and private property. In the most general sense all of the laws state that if a landowner lets individuals use his land (presumably caves also) for recreational purposes without charging a fee then the landowner is free of liability. There are exceptions to the previous statement and a few of those will be noted later in this article.

According to Huppert (1995), 22 states, Puerto Rico, and the Cherokee Nation have specific cave protection laws, and for nine of these states the cave protection laws have clauses concerning landowner liability. Those states are:

Alabama
Arkansas
Illinois
Kentucky
Maryland
Montana
North Carolina
Ohio
Virginia

Among the 48 states for which the author could locate more general landowner liability laws for recreational use, seven specifically make note of caves, caving, or spelunking as recreational sites or activities. Those states are:

Alabama
Arkansas
California
Colorado
Indiana
Montana
Pennsylvania

It will be noted that Alabama, Arkansas, and Montana have liability clauses in their cave protection laws and also mention caves or caving in their recreational liability laws. Presumably this should give additional protection to cave owners in those states. Also three of the other four states have cave protection laws without mention of liability. Colorado does not have a cave protection law. Some of the state liability laws hold trip leaders responsible for accidents and some specifically absolve them from liability if "due care" is practiced. Of course there can be a wide range of opinion of what constitutes due care.

Vermont's recreational liability law only covers snowmobile use. A call to the state attorney general informed the author that the office felt that landowner liability would be minimal in a caving accident under common law statutes.

Recreational liability laws could not be found for Hawaii and New York. Calls to the appropriate authorities (the Supreme Court Library and the Attorney General's Office) did not bring any satisfaction. It is difficult to imagine two such tourist-oriented states not having recreation liability laws.

In most of the states, the laws are worded to cover many activities but generally not caving. They usually state that hiking, skiing, photography, nature study, and educational activities are covered. Almost all of the state liability laws have a clause at the end of the list of covered activities which is usually as follows: "and all other recreational activities." This should cover caving.

Almost all of the liability laws do not hold the landowner to any duty to warn recreational users of any "normal" hazards; however what normal is, especially in reference to caves, may well be a subject of courtroom debate. What this means is that the landowner is not required to assure the recreational user of any level of safety. Most of the laws do hold landowners liable for gross negligence or willful misconduct. Thus the owner cannot set up any dangerous conditions for the users, such as any kind of trap against trespassers. However the interpretation of this wording is also open to debate and that is one reason cases come before the courts. The case law in each state is different and the precedent-setting decisions in each state would have to be examined in order to decipher the meaning of the language for each state. One example is illustrative. In Wisconsin a landowner is not liable for an injury to a recreational user but if that user dies as the result of the accident then the landowner can be held liable. (A bill is now being considered in the Wisconsin Assembly to change that clause.)

Another aspect to consider is who exactly is a recreational user of the cave. The answer is not truly clear and thus also leads to court cases. A distinction must be made between "invitees" and "licensees" as related to private recreational property. *Black's Law Dictionary* (1990) defines these terms as follows:

Invitee. A person is an "invitee" on land of another if (1) he enters by invitation, express or implied, (2) his entry is connected with the owner's business or with an activity the owner conducts or permits to be conducted on his land and (3) there is a mutuality of benefit or benefit to the owner (p 827).

Licensee. A person who has a privilege to enter upon land arising from the permission or consent, express or implied, of the possessor of land but who goes on the land for his own purpose rather than for any purpose or interest of the possessor (p 921).

It seems clear that the recreational user of the land (which includes most cavers) is a licensee. The issue gets confused by the varied roles many cavers take when "recreating" in caves. They make maps, do research, restore formations, clean up caves, and lead others on trips, sometimes for a fee. Often the caver's efforts lead to benefits to the landowner, both financial and otherwise. Then the role of licensee caver arguably changes to that of invitee. These circumstances may therefore change the legal relationship between landowner and caver. One needs to look at Black's extended definitions in both cases. For the invitee, Black (1990, p 827) goes on to state:

The leading English case of Indermaur *v.* Dames laid down the rule saying concerning those who enter premises upon business which concerns the occupier, and upon his invitation express or implied, the latter is under an affirmative duty to protect them, not only against dangers of which he knows, but also against those which with reasonable care he might discover. The case has been accepted in all common law jurisdictions, and the invitee or, as he is sometimes called, the business visitor, is placed upon a higher footing than a licensee.

For the licensee Black (1990, p 921) states, "Formerly, the duty owed to a licensee was that of refraining from willful, wanton, and reckless conduct. This rule has been changed and now, in most jurisdictions, the occupier of land owes the licensee the duty of reasonable or due care. Mounsey *v.* Ellard, 363 Mass. 693, 297 N.E.2d 43."

Obviously these definitions show that cavers and landowners must take great care in the relationships that they create. It would seem easy to step over the fuzzy line from licensee to invitee thus shifting the debt of liability largely to the landowner. This is an undesirable situation for recreational cavers as it is sure to lead to the closure of many caves. Just the perception of it has already done so.

The author knows of a number of ongoing practices that most likely would remove the protection from recreational liability from the landowner. Some of these situations include a private cave owner charging a low admission fee to recreational cavers, a commercial cave operator encouraging cavers to explore and map new passages in his cave (thus gaining a benefit), a private cave owner getting a "cut" from a cave-for-pay business, and many other marginal examples.

The opinions presented in this article should not be construed as legal advice. The recreational liability laws of each state do differ and some of those differences can be significant. The roles of invitee, licensee, and landowner can also vary from state to state. More importantly, how the various laws are applied in each state (how they are interpreted by the courts) can vary. One needs to study the court decisions on recreational liability (and perhaps torts in general) for the state in question in order to get a clear idea of the actual use of the recreational liability law in that state. It is beyond the scope of this short article to attempt that prodigious task.

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Huppert, George N. (1995) "Legal Protection for Caves in the United States," *Environmental Geology*, Vol 26, No. 2, pp 121-123.

Zinc Leaching from Galvanized Steel in Mystery Cave, Minnesota

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Abstract

Zinc is being leached from galvanized steel structures installed in Mystery Cave in the early 1990s. Zinc averaged 25.2±17.0 ppb (n = 13) in Frozen Falls Pool between 1991 and 1994, but only 3.1±3.2 ppb (n = 14) in its primary tributary Frozen Falls Drips, which occasionally splashes onto a galvanized steel bridge. Zinc in the pool was about eight times higher than in waters not known to come into contact with galvanized steel (mean = 3.2±3.3 ppb; n = 29). Although significantly lower in zinc, such waters need not represent background natural zinc concentrations if $ZnSO_4$ is locally used as a corn starter or other anthropogenic sources of zinc are present.

If zinc concentrations rise toward action limits, remediation may be necessary to protect aquatic wildlife, which includes springtails in shallow pools along the tour route. Galvanized structures should be inspected regularly for excessive corrosion. Zinc concentrations should be monitored periodically in cave waters throughout the lifetime of the structures. Speleothems near galvanized steel should be monitored for changes in growth, because zinc may interfere with deposition of calcite.

Location and Operation of Mystery Cave

Mystery Cave—the largest cave in Minnesota—is in Fillmore County in the heart of southeast Minnesota's karst land. It is a joint-controlled network maze (Milske and others, 1983). A network maze consists of a net of intersecting passages with closed loops that formed more or less contemporaneously (Palmer; 1975, 1991). Over 13 miles of passage have been surveyed in sections known as Mystery I, Mystery II, and Mystery III. Mystery Cave has two entrances (Mystery I and Mystery II) and is owned and operated by the Minnesota Department of Natural Resources (DNR) as part of Forestville State Park. The State Park staff conducts tours through the commercial parts of the cave from May to September. Commercial sections are located in Mystery I and Mystery II.

Cave Restoration and the Installation of Galvanized Structures

The installation at Mystery I was renovated in the early 1990s. Extensive modifications included a new entrance building and flood gate, a modern lighting system, concrete walkways, and new galvanized bridges, floor grates, and railings. Floor grates and bridges are used to span fissures and low points in the passage floor. This allows pathways to have a low gradient and eliminates the use of stairways at many locations. Hand rails are used for safety on bridges, floor grates, and a few stairways. Hand rails are also used as containment to separate visitors from delicate cave features, for example at shallow pools containing calcite rafts at the Rock Gardens.

Purpose and Scope

In the humid environment of Mystery I, the galvanized steel is moistened by condensation water, particularly near the entrance in the summer. At numerous locations, notably at Frozen Falls, but also at the Ceiling Joint Drips, galvanized steel is wetted by dripping and splashing water. On rare occasions, when the Root River undergoes major floods, water rises from the lower level fissures and flows through parts of the tourist route. It can then wet the galvanized steel and deposit surface coatings of clays and other sediments. Although some drying occurs during winters, when the land surface is frozen and water flux through the cave is at a minimum, much of the cave never completely dries. Some galvanized steel bridges and railings are therefore in a perennially moist environment conducive to the corrosion of zinc.

Corrosion processes result in zinc compounds that can be removed by flowing or dripping water. The zinc coatings can be transferred from the railings and bridges directly onto visitors' hands, clothing, and feet. From feet, zinc can be transported throughout the cave on the concrete pathways. The walkways are occasionally washed to remove sediment deposited by turbid waters or to remove sediment carried in on visitors' feet. Zinc on walkways can be transmitted wherever washings are drained.

Within the first year of installation, brown spots on some galvanized steel were noted by Mystery Cave staff. The brown spots were interpreted by Zalk (written communication to DNR staff, 1992) as clay particles apparently deposited during construction activities. Katsoulis (written communication to DNR, 1992) interpreted rusty spots at one location (long beam of the Devils Kitchen bridge) as being due to poor quality galvanization.

During the course of our work on the groundwater portion of the 1991-1993 Mystery Cave Resources Evaluation, Mystery Cave staff and other DNR staff expressed some concern about the leaching of zinc and its possible accumulation in cave waters or sediments. As with other heavy metals, zinc in high concentrations can be toxic to aquatic plants, invertebrates, and fish (Moore and Ramamoorthy, 1984). Pools in Mystery I are known to harbor springtails. Other aquatic organisms are present in lower-level cave streams. Accordingly, this paper discusses our analyses of zinc concentrations in several waters of Mystery Cave; the accumulation of zinc in sediments is beyond the scope of the study.

This work was initially funded by the Minnesota Legislature, as recommended by the Legislative Commission on Minnesota Resources (LCMR) for the period 1991 to 1993. Additional funds were provided by DNR for 1993 and 1994. Additional information on the groundwater portion of the Mystery Cave Resources Evaluation is in Jameson and Alexander (1994a, 1995a, 1995b) and in Alexander and Jameson (1993, 1994b).

Galvanization and Zinc Surface Coatings

The process of galvanization uses zinc as a surface coating to protect underlying metals from corrosion. The zinc acts first as a physical barrier. More importantly, once the coating is breached by abrasion or deep scratches, zinc also serves as a sacrificial anode. As long as zinc is present, it is removed by electrochemical reactions in preference to the less reactive iron or steel.

According to the American Galvanizers Association (AGA, 1989), the initial surface coating produced by hot-dip galvanization consists of a series of layers of zinc and zinc-iron alloys. Pure zinc is at the surface and the percentage of iron increases from 6 to 10 to 25% with depth in coatings described by the AGA (1989).

Exposed to the environment, zinc oxidizes in air, forming a film of zinc oxide (AGA, 1989). In the presence of moisture, the zinc oxide reacts with water to form zinc hydroxide. The zinc hydroxide reacts with carbon dioxide to form a zinc carbonate layer, characterized by the AGA (1989, p 2) as a "thin, compact, and tightly adherent layer." The layer is whitish gray and conceals the zinc crystals below. The layer is considered to be relatively insoluble and weather resistant.

Nonetheless, zinc is sufficiently soluble to be leached from galvanized steel and enter cave waters. In contact with liquids, zinc is amphoteric. That is, zinc is relatively insoluble at low (<6) and high (>12.5) pH. For the pH ranges normally encountered in karst waters (roughly 7.2 to 8.2), zinc tends to hydrolyze, forming $Zn(OH)_2$ at pH >8.0 (Moore and Ramamoorthy, 1984).

Initial Sampling of Zinc

Several bridges are located near Frozen Falls, where drips splash onto the bridge from two drip sites (Frozen Falls Drips and Drips Across Bridge) before collecting in Frozen Falls Pool. To investigate the possibility that zinc from the bridges would affect water quality, water samples from drips at Frozen Falls and Frozen Falls Pool were collected and analyzed in the summer and early fall of 1991. To check background levels of zinc, 11 additional samples were collected in August 1991 at locations throughout Mystery Cave, away from known locations of galvanized steel. Sampling began before installation of the bridges, in June 1991, to provide a pre-installation control group. Samples were collected using standard 60-milliliter polyethylene cation bottles and 6N HCl for sample preservation. At most sites, water was initially obtained from drips or waterfalls in one-gallon buckets (lined with plastic) and was then poured into sample bottles. Where possible at pools and streams, water was obtained directly by immersion of the entire sample container.

Early analyses (for example, August 1991) suggested higher levels of zinc in Frozen Falls Pool (87 ppb) than in Frozen Falls Drips (37 ppb). This result supported the interpretation of leaching of zinc from the bridges. However, we were concerned that these zinc values might be erroneously high. Numerous workers have documented the need for strict protocols and specially-prepared sampling containers when sampling for trace metals. It was possible, we feared, that trace amounts of zinc might be leached from the bottles or might be derived from the preservation acid.

To test these hypotheses, a comparison sampling test was run in November 1991 using polyethylene bottles, high-purity deionized water for blanks, and water collected at Frozen Falls Drips. Two bottles normally used as anion bottles were filled with high-purity deionized water in the lab and taken along with an empty anion bottle for filling with water at Frozen Falls Drips. Two bottles normally used as cation bottles (these differ in shape and size, and possibly in composition, from the 30 mL anion bottles) were filled with high-purity deionized water in the lab and taken along with an empty cation bottle for filling with water at Frozen Falls Drips. The anion bottles were not acidified. All three cation bottles were acidified in the cave with two drops of 6N HCl.

The results (derived from plasma emission spectroscopy; see Appendix 1 in Jameson and Alexander, 1995a, for additional details) are shown in Figure 1 as a series of histograms of zinc concentration. Each analysis was run twice. Note that the deionized water blanks contained as much or more zinc as did the natural water samples from Frozen Falls Drips. The acidified samples contained higher levels of zinc than did the unacidified samples. The lowest zinc contents were measured in the unacidified cave water sample (collected in the anion bottle). We therefore concluded that (1) zinc present in the normal anion and cation polyethylene bottles was leached from the bottles by deionized water. Also (2) it appeared probable that some zinc was present in the HCl. Therefore, we began collecting cation samples in special Teflon bottles and switched to high-purity reagent grade nitric acid for sample preservation. The data obtained from the initial round of zinc sampling (summer and fall, 1991) is considered unreliable. Later analyses of zinc in acidified high-purity deionized water in Teflon bottles failed to detect significant concentrations of zinc.

Results

Forty-two samples were obtained during the initial LCMR project at 16 sites in Mystery I and Mystery II between December 1991 and April 1993. Most samples were collected from sites in the Frozen Falls area of Mystery I—the primary study area—but eight samples were also obtained from Mystery II. Ten additional samples were collected from ten sites in Mystery I, Mystery II, and the South Branch of the Root River at the end of May 1994 at

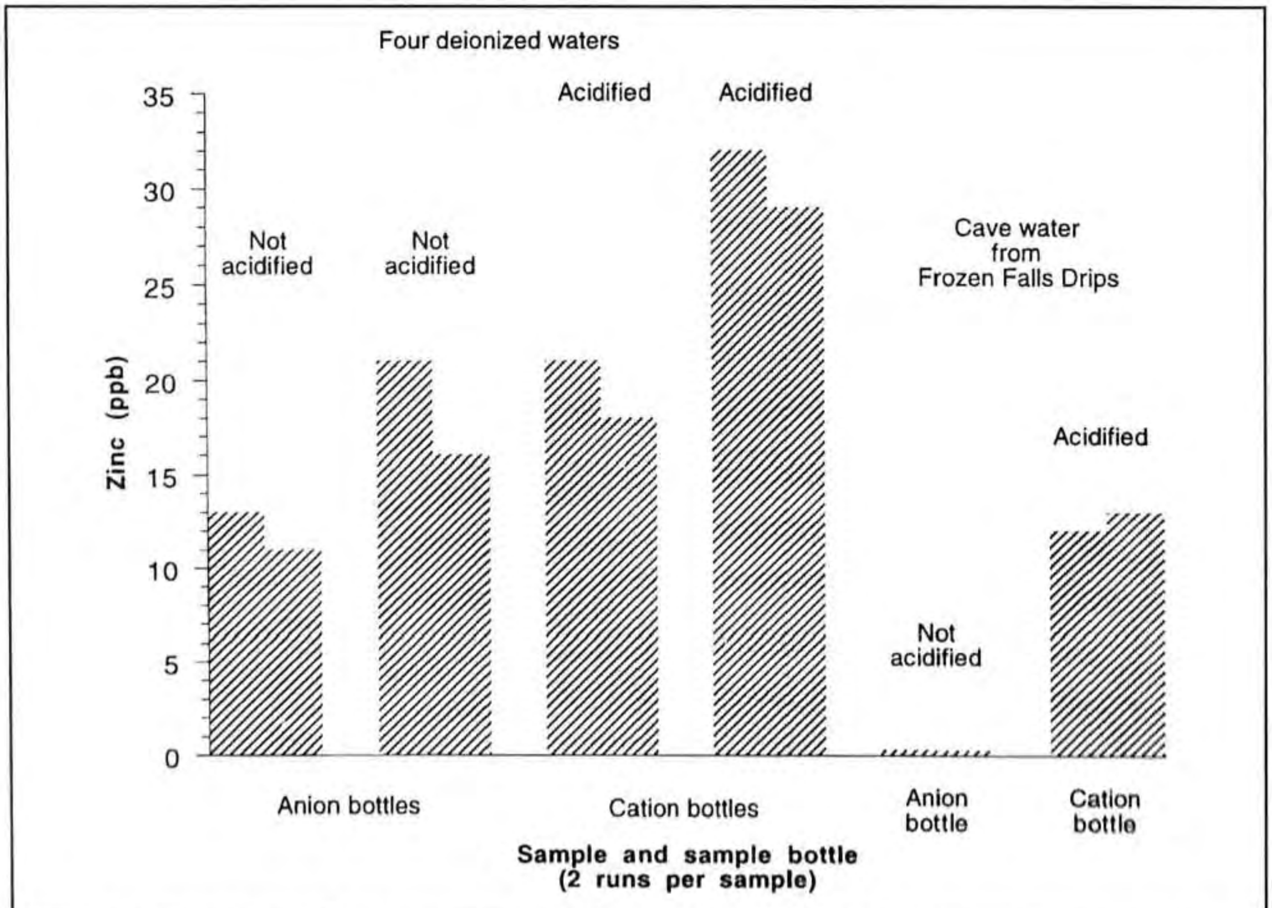

Figure 1. *Comparisons of zinc concentrations in test of polyethylene bottles.*

the conclusion of the 1993-1994 DNR project. This produced a sample size of 52 analyses from 18 sites. Results are enumerated in Table 1 and presented as time-series plots in Figures 2 and 3.

Groups of Analyses

For the purpose of discussion, the analyses are most usefully divided into three groups (Table 2). Group 1 consists of sites whose water chemistry was known or suspected to be influenced by contact with galvanized steel. These sites include Frozen Falls Pool, Drips Across Bridge, and possibly Turquoise Lake and Blue Lake. Frozen Falls Pool receives water that splashes onto a galvanized steel bridge from Frozen Falls Drips and Drips Across Bridge. Both sites splash variably onto the bridge, the amount of contact depending on discharge. Drips Across Bridge is included in this group because of the manner of sampling: a plastic-lined bucket was placed near but below the bridge to catch drips falling from the Drips Across Bridge stalactites, but some of the drips probably splashed onto the railing and bridge grate before entering the container. Turquoise Lake is in this group because inundated light fixtures or associated construction materials may contain galvanized steel. Blue Lake is in this group because its bridge has angle-iron and other bracing that may be galvanized and some of this material is periodically inundated.

Group 2 consists of sites whose water chemistry was not known or was suspected to be directly influenced by galvanized steel. We suspected that analyses of these sites might elicit a natural background zinc concentration against which we could evaluate the influence of the recent installations.

Table 1. Zinc concentrations at Mystery Cave*

Date	Turquoise Lake (TL)	±	Frozen Falls Drips (FFD)	±	Frozen Falls Pool (FFP)	±	Drips Across Bridge (DAB)	±	Pipe Organ (PO)	±	Pipe Organ Pool (POP)	±	Across from Pipe Organ (APO)	±	Flim Flam Creek (FFC)	±	Coon Lake Drips (CLD)	±
12/21/91	-		11.2	0.2	11.3	0.2	-		-		-		-		-		1.1	0.1
2/23/92	-		4.0	0.2	25.2	0.4	-		-		-		-		-		-	
4/4/92	-		1.4	0.1	53	1	-		-		-		-		-		-	
5/13/92	-		2.5	0.2	34.1	0.8	-		-		-		-		-		-	
6/22/92	-		2.3	0.2	-		5.53	0.09	7.1	0.1	-		-		-		-	
7/29/92	-		0.00	0.09	48.7	0.9	-		-		-		-		-		-	
9/14/92	-		1.2	0.1	48.6	0.5	-		-		-		-		-		-	
10/22/92	0.1	0.2	0.0	0.1	0.0	0.1	-		-		-		-		-		-	
11/20/92	-		8.7	0.3	27.7	0.4	3.4	0.1	2.2	0.1	-		12.6	0.1	-		-	
12/21/92	-		2.1	0.1	21.2	0.5	36	1			6.4	0.2	-		-		-	
1/22/93	-		1.44	0.03	9.3	0.1	-		-		-		-		-		-	
3/1/93	-		1.59	0.04	5.9	0.1	-		-		-		-		-		-	
4/3/93	-		1.83	0.09	22.7	0.3	-		-		-		-		-		-	
5/29/94	20.2	0.1	4.6	0.1	20.0	0.4	35.6	0.4	8.0	0.2	-		2.0	0.2	4.7	0.1	3.9	0.1

Date	Blue Lake (BL)	±	South Branch Root River (RR)	±	Enigma Pit (EP)	±	Rimstone Creek (RC)	±	Wishing Wells Drips (WWD)	±	Garden of the Gods1 (GG1)	±	Garden of the Gods 2 (GG2)	±	Blue Lake Drips (BLD)	±	Needle's Eye Drips (NE)	±
12/21/91	8.2	0.1	-		0.84	0.07	0.11	0.04	1.29	0.1	0.80	0.1	1.2	0.1	0.76	0.1	2.68	0.1
2/23/92	-		-		-		-		-		-		-		-		-	
4/4/92	-		-		-		-		-		-		-		-		-	
5/13/92	-		-		-		-		-		-		-		-		-	
6/22/92	-		-		-		-		-		-		-		-		-	
7/29/92	-		-		-		-		-		-		-		-		-	
9/14/92	-		-		-		-		-		-		-		-		-	
10/22/92	-		-		-		-		-		-		-		-		-	
11/20/92	-		-		-		-		-		-		-		-		-	
12/21/92	-		-		-		-		-		-		-		-		-	
1/22/93	-		-		-		-		-		-		-		-		-	
3/1/93	-		-		-		-		-		-		-		-		-	
4/3/93	-		-		-		-		-		-		-		-		-	
5/29/94	3.8	0.1	3.6	0.2	-		-		-		-		-		-		-	

* all concentrations in ppb (parts per billion), as sampled in teflon bottles acidified with 6N HNO3

\- designates no sample taken

± one sigma error based on standard deviation of five replicate analyses

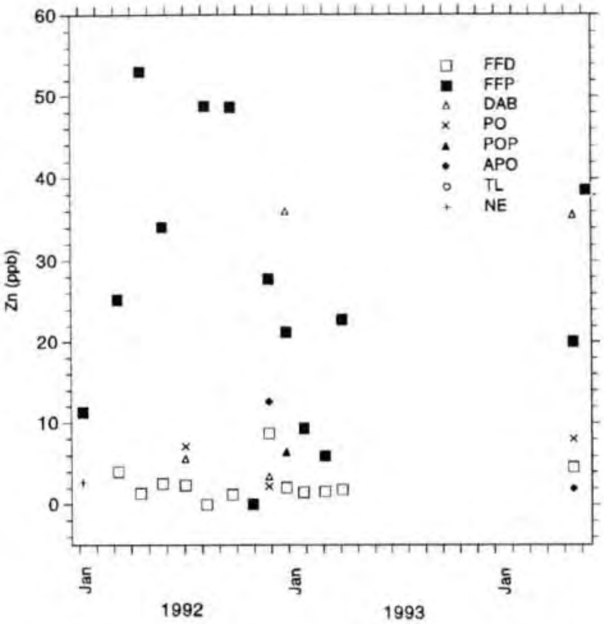

Figure 2. *Time series of zinc concentrations in Mystery I waters. For abbreviations see Table 1.*

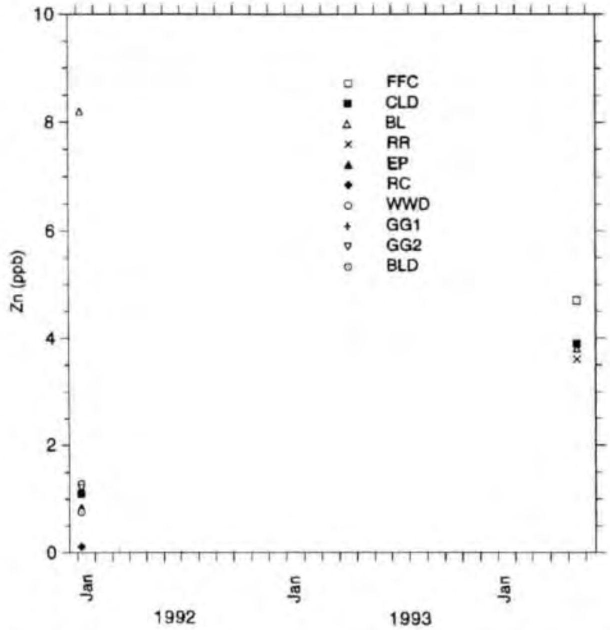

Figure 3. *Time series of zinc concentrations in Mystery II waters and in water from the South Branch of the Root River. For abbreviations see Table 1.*

The sites include Frozen Falls Drips, the Pipe Organ, Pipe Organ Pool, Across from Pipe Organ, and Needles Eye Drips in Mystery I. The sites also include Rimstone Creek, Enigma Pit, Wishing Wells Drips, Blue Lake Drips, Coon Lake Drips, Garden of the Gods 1, and Garden of the Gods 2 in Mystery II.

Group 3 consists of two sites whose water chemistry is affected significantly by direct surface runoff. These sites consist of water sampled on the surface in the South Branch of the Root River and the water of Flim Flam Creek in the subsurface of Mystery II. During a wide range of flows, Flim Flam Creek receives the bulk of its recharge from the Root River. Neither site was expected to have a water chemistry measurably affected by the installation of galvanized steel in Mystery I. Although some Group 1 sites may contribute to the flow at Flim Flam Creek, that contribution is probably negligible. None of the Group 1 waters contributes to the flow of the South Branch of the Root River at its sampling site upstream of the Mystery I entrance.

Comparison of Groups 1 and 2

Summary statistics comparing the groups and the entire data set are in Table 3. The mean zinc concentration for all 52 samples was 10.4 ppb and the median was 3.95 ppb. These numbers are not particularly meaningful, however, because the observed distribution is apparently a composite, being influenced by both natural and anthropogenic sources of zinc. As shown in Figure 4, there is an obvious and significant difference (at the 0.05 α level using the nonparametric sign test) in zinc concentrations between Groups 1 and 2. Group 1 concentrations (mean, 20.9 ppb; median, 20.2 ppb) from sites with waters exposed to galvanized steel are much higher than those of Group 2 (mean, 3.2 ppb; median, 2.0 ppb), which lack known exposure to galvanized steel. Group 3 concentrations from the surface stream and Flim Flam Creek may be intermediate, but with only two samples, data are too sparse to generalize or perform statistical tests.

Concentrations of natural zinc in regolith (soil and loess) and bedrock (shales, limestones, and dolomites) at Mystery Cave are unknown. Possibly, the bulk of the zinc in Group 2 samples derives from natural sources. However, $ZnSO_4$ is used as a starter for corn in many areas of the Midwest. $ZnSO_4$ may provide a second, non-point anthropogenic source of zinc to the ground water and thus increase zinc concentrations above natural background levels in water from all three groups.

Results at Frozen Falls Pool and its Tributaries

The water in Frozen Falls Pool comes primarily from Frozen Falls Drips. Even at low flow in the winter, the flux from Frozen Falls Drips is greater than a few liters per hour. During storms, discharge at Frozen Falls Drips can increase to 20 liters or more per hour. The water may become turbid, reflecting a local source of rapid direct runoff from the forested hillslopes above Mystery I.

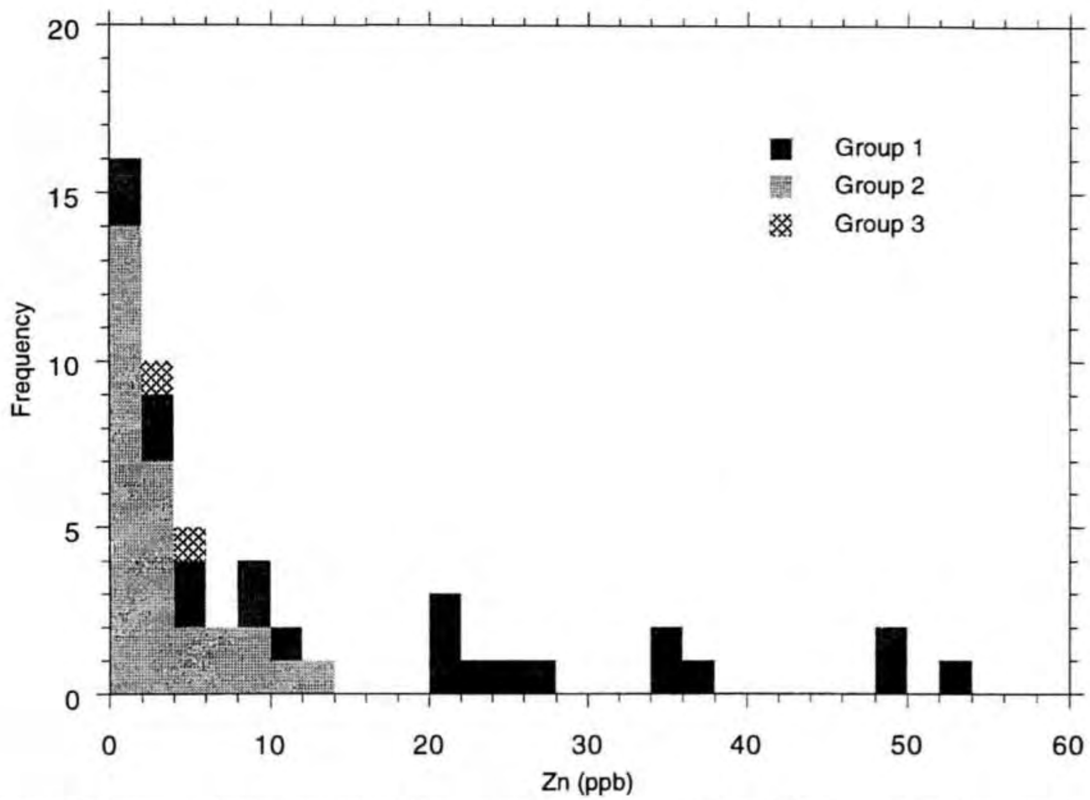

Figure 4. *Histogram of zinc concentrations in water groups 1, 2, and 3. Group 1 waters are known or suspected to have been in contact with galvanized steel. Group 2 waters are not known to have been in contact with galvanized steel. Group 3 waters are a surface stream, the South Branch of the Root River, and a cave stream, Flim Flam Creek, that derives the bulk of its discharge from the Root River.*

Table 2. Water groups*

Group	Site	Description
1	FFP	Speleothem-lined pool (ca. 6-7000 L), uncovered in restoration project
	DAB	Stalactite drips on wall
	TL	Speleothem-lined pool, artificial wall in present configuration
	BL	Very large pool with raft cones and speleothem lining at former water level
2	FFD	Waterfall and drips from flowstone and stalactites at a ceiling joint
	PO	Flowstone flow from wall
	POP	Very small pool (ca. 1 L) below PO
	APO	Flowstone flow on wall; issues from wall joint
	NE	Stalactite drips
	CLD	Flowstone flow on wall from ceiling joint
	GG1	Stalactite drips
	GG2	Flowstone flow from ceiling joint
	EP	Waterfall from wall/ceiling joints
	WWD	Waterfall from ceiling joint
	RC	Cave stream
	BLD	Flowstone flow beneath flowstone mound to west of Blue Lake
3	RR	Surface stream: the South Branch of the Root River
	FFC	Cave stream derived mostly from the Root River

* For abbreviations of sampling sites, see Table 1.

Table 3. Summary Statistics for Water Groups*

Group	Mean	σ	Median	Min	Max	No samples
1	20.9	16.7	20.2	0	53	21
2	3.2	3.3	2	0	12.6	29
3	4.15	-	-	3.6	4.7	2
All data	10.4	13.9	3.95	0	53	52

* Concentrations are in ppb

Zinc concentration in Frozen Falls Pool was almost always greater than that in Frozen Falls Drips (Figure 2); it averaged 25.2±17.0 ppb (n = 13; median = 22.7 ppb). Zinc in Frozen Falls Drips averaged 3.1±3.2 ppb (n = 14; median = 2.1 ppb). The mean concentration of zinc in the pool is thus about eight times higher than it is in the drips feeding it. Zinc in the pool is about four times higher than zinc in all other sampled waters (mean = 6.65±2.5 ppb; median = 2.5 ppb; n = 27) in Mystery I. Zinc thus is measurably being leached from the bridge above Frozen Falls Pool.

Frozen Falls Pool is also fed by drips and flows originating from Drips Across Bridge, the Pipe Organ, the Pipe Organ Pool, and the flow out the wall joint that feeds Across from Pipe Organ (Figure 5). These sources all exhibit low concentrations of zinc except for two samplings at Drips Across Bridge, when zinc was measured at 36 and 35.6 ppb (Table 1). None of the waters except Drips Across Bridge appears to contact galvanized steel railings adjacent to the tourist trail. Nearly all of the zinc above cave background levels in Frozen Falls Pool could originate in splash from Frozen Falls Drips and Drips Across Bridge. However, there may be sufficient condensation directly onto the bridge materials to wet surfaces and then drip into the pool or onto flowstone sloping toward the pool.

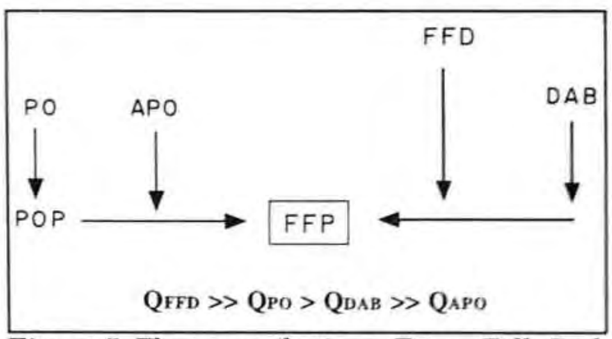

Figure 5. *Flows contributing to Frozen Falls Pool. FFD=Frozen Falls Drips. DAB=Drips Across Bridge (stalactite drips). PO=Pipe Organ (a flowstone flow). POP=Pipe Organ Pool. APO=Across from Pipe Organ (a flowstone flow from a wall joint).*

Effect of Flooding on Zinc Concentrations at Frozen Falls Pool

The flood on the Root River in late March 1993 resulted in flooding in the main passage of Mystery I. Water infiltrated occluded fissures in the streambed and flowed into the lower levels of Mystery I. Infiltration rates were so large that backflooding resulted in a rise in water from the lower levels up into the main passages. Floodwaters flowed past the Frozen Falls Area and water levels and apparently remained high for more than a day (Jameson and Alexander; 1994, 1995a).

Frozen Falls Pool first filled with turbid water on March 31. Three days later, the April 3 sampling of zinc showed near-average values for Frozen Falls Pool (22.7 ppb) and Frozen Falls Drips (1.83 ppb). It is unlikely that flooding did not alter the zinc chemistry of Frozen Falls Pool. The zinc concentrations of floodwaters derived from rain on snow should be very low (this is a reasonable, but undocumented assumption). A simple, but speculative hypothesis that accounts for these observations is that after flooding ceased and water levels lowered, the flux of water into Frozen Falls Pool from Frozen Falls Drips and Drips Across Bridge was sufficiently high, and leaching rates sufficiently rapid, to restore zinc to "normal" bridge-influenced concentrations in the pool within three days.

Implications for Management

The measured concentrations of zinc are not particularly high. They are unlikely to reach dangerous concentrations in pools or streams along or near the tourist trails—at least in the near future. Although zinc appears on the list of contaminants subject to regulation under the Safe Drinking Water Act Amendments of 1986, apparently no maximum contaminant level or secondary maximum contaminant level standards for drinking water have yet appeared. The World Health Organization has set an aesthetic water quality limit of 5 mg/L. Canada uses a maximum acceptable zinc concentration in drinking water of 5 mg/L (as reported in van der Leeden and others, 1990). The standards for protection of aquatic life in freshwater for total recoverable zinc set a limit of 180 micrograms/L at any time, assuming a water hardness of 50 mg/L as $CaCO_3$ (U.S. EPA, Water Quality Criteria, Federal Register, November 28, 1980).

Little is known about long-term leaching of zinc from galvanized steel in moist cave environments. Speculatively, we might expect leaching rates to be relatively rapid after installation, as initial chemical alterations produce protective zinc hydroxide and zinc carbonate coatings. Leaching rates might then decrease slightly, but later increase with time as scratches and abrasion increase. We might expect a marked increase in leaching rates of zinc, along with rises in iron concentrations in affected waters, toward the end of the useful lifetime of the galvanization, assuming the structures remain in the cave that long. We do not know the expected useful lifetime of the galvanized structures, but it apparently is greater than 50 years.

We recommend that the galvanized steel structures be systematically inspected in the near future to locate and describe potential sites of concern for long-term monitoring. This includes sites subject to accidental scraping by equipment used in maintenance; that undergo wetting and drying cycles from condensation or dripping waters, or that are perennially wet; and any parts of structures identified by engineers as high risk for corrosion, such as attachment points. Nearby water sites of special concern should be identified and monitored periodically for zinc concentrations throughout the lifetime of the structures. In particular, pools near bridges or railings (such as Frozen Falls Pool, Turquoise Lake, and the pools at the Rock Garden) should be monitored periodically for zinc. If zinc concentrations rise toward action limits, remediation measures should be taken to protect aquatic wildlife such as springtails that inhabit pools.

An additional concern is the possible deposition and accumulation of zinc in clastic sediments or on speleothems. The latter is of particular concern in show caves, because there is a growing body of evidence to indicate that zinc and other cations (for example, magnesium or lead) can inhibit precipitation of calcite (Hamdona and Khader, 1994). In at least one Australian cave, zinc from galvanized steel is suspected of strongly inhibiting or stopping calcite deposition (Gillieson, personal communication to Alexander, 1995). Thus there is a potential problem of inhibition of speleothem growth at Mystery Cave. Our analyses (Jameson and Alexander, 1995a) show that waters throughout the cave are generally supersaturated (often highly so) with respect to calcite and aragonite. Deposition of calcite can be extremely rapid. For example, calcite coatings appeared on the concrete walkway near the Rock Garden of Mystery I within months of its construction; they continue to grow rapidly today. It would be unfortunate if zinc leaching from galvanized steel affected speleothem growth along the tourist trails. We therefore recommend that speleothems near galvanized steel be monitored for changes in growth or accumulation of zinc. To date, we have no solid evidence that zinc is inhibiting speleothem growth in Mystery Cave. However, it is worth noting that calcite does not appear to be growing at sites where supersaturated water drips or splashes directly onto galvanized steel. In the winter of 1995, with the assistance of DNR personnel, we installed a monitoring system at Frozen Falls Drips to measure water temperature, conductivity, and discharge. Within a few months, the plastic collection sheet, a plastic funnel and storage container, and an anodized aluminum rain gage were all coated with calcite to thicknesses of as much as two millimeters. However, galvanized steel on the bridge failed to acquire distinguishable calcite deposits from the same water after the water dripped from the equipment onto the bridge.

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Consideration of Caves and Karst in Selection of Corridors for Power Transmission Lines and Highways

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Abstract

Most regions of karst in the United States, like most other types of landscape, are crossed by transmission lines for electric current, pipelines for oil and natural gas, and transportation routes such as railroads and highways. Each of these conveyances consists of highly elongate, but narrow, corridors that may transect entire geographic and geologic regions, partitioning the land in the process. The width of any corridor is determined by requirements for construction and maintenance, as well as by the size of the structure, be it a highway, pipeline, or powerline. As an area of karst becomes progressively laced with criss-crossing transmission or transportation routes, it is likely that these corridors will encounter and impact caves and their contents, including groundwater.

The process of planning and siting corridors is complex and addresses several issues. Considerations include directness of routes and efficiency of transport, economics of construction, economic benefits or liabilities to communities along routes, safety, and potential environmental impacts. Unfortunately, site selection is too often influenced and determined by the political and socio-economic factors, at the expense of sound scientific and technical studies regarding feasibility and environmental impact. In areas of karst, subsurficial conditions, including caves and groundwater flow systems, typically remain under-investigated and often totally ignored.

Most existing corridors and rights of way were established years ago when the vulnerability of karst to environmental hazards and degradation was little known, studied, or understood. As a result, caves and related karst features have been damaged or outrightly destroyed and, in some cases, the quality of water has been reduced through contamination of surface streams and groundwater. The situation has improved through the years; the Federal government and most states now require site evaluations and statements or assessments of environmental impact during the planning stages. Outcrops of carbonate and other soluble rocks are now mapped and, for some projects, karst features such as caves and dolines are routinely inventoried. Disappointingly, however, some mapping and inventories along corridors are performed hastily, sporadically, or superficially, and miss important features.

The New River Valley, a major drainage area with karst in southwestern Virginia and southeastern West Virginia, is currently under simultaneous consideration for routing of a 765-kilovolt power transmission line and several highways, including a major new interstate. Several proposed alternative corridors for each project cross exposed karst terranes in Montgomery, Craig, Giles, and Bland counties in Virginia and Monroe County in West Virginia. Karst has been mapped in the case of planning studies for the powerlines, albeit the level of detail is wanting. Karst has not been seriously considered during site evaluation for the proposed highways. In all cases, caves in the paths of corridors have not been adequately considered. Some of the caves are recognized as significant by the speleological community and by governmental ecologists. Along several proposed routes, corridors for powerlines and highways overlap. Maps compiled by citizens action groups and this author indicate potentially threatening envi-

ronmental problems to several notable caves and karst systems in the New River Valley. This information is being provided to state and federal agencies that will influence or ultimately decide whether the corridors are constructed and, if so, where they will be routed.

Introduction

An inevitable outcome of population growth and the concomitant expansion of residential, commercial, industrial, and agricultural land use is a progressive reduction of natural environments. With urbanization and suburbanization comes an increase in the number of buildings, parking lots, and various corridors for transmission of energy or for the transport of people and commodities. Corridors differ from other types of construction in one major way: corridors are narrow and highly elongate. They transect the landscape, whereas buildings and similar constructs are site-specific, occupying sites that are areally compact and do not extend disproportionately far in a linear or curvilinear fashion. It is expected, therefore, that corridors constructed for the purposes of conveyance of commodities and energy will pass through karst regions as swaths or cuts.

There are many sizable karst areas in the United States (Davies, 1970; Herak and Stringfield, 1972; Kastning, 1986). In fact, approximately 20 percent of the land area is immediately underlain by soluble rock. Existing corridors cross all of these areas. Most were constructed years ago when the vulnerability of karst to environmental hazards and degradation was little known or poorly understood. Many corridors were built without impact assessments or implementation of environmental regulations. As a result, there are numerous documented cases where karst features have been damaged or outrightly destroyed or where water quality in karst has been affected by contamination of surface streams and groundwater.

However, the situation has improved through the years. The federal government and most states now require, during the planning stages, thorough evaluations of proposed sites and statements or assessments of environmental impact. Today, outcrops of carbonate and other soluble rocks are well mapped and in some site assessments, the karstic groundwater recharge zone and karst features such as caves and dolines are routinely mapped and inventoried. Disappointingly, however, some mapping and inventories along corridors are performed hastily, sporadically, or superficially, and in many cases important karst features are missed. This is particularly true of caves and routes of subsurficial water flow that are not easily detected because they are hidden from view.

Types of Corridors

Corridors of transport of energy include oil and gas pipelines and high-voltage transmission lines. These are generally narrow. The former vary in width from 5 to 40 or 50 meters and the latter from 50 to 80 meters. Pipeline corridors may become revegetated after emplacement of the pipes; however, power-transmission-line corridors are kept in a clearcut condition with vegetation limited to a height of less than one or two meters.

Corridors for vehicular transportation include highways and railroads. Widths of these corridors vary, from several meters for small roads and single-track railroad lines to hundreds of meters for superhighways (interstates) and multiple-track rail systems.

In the case of highways and railroads, corridors are constructed with relatively gentle grades, generally less than a few percent or a few degrees in slope angle. This is necessary for efficient and safe movement of vehicles. Pipeline corridors are also constructed at gentle grades where possible, but in places high-gradient lines are unavoidable, especially where steep terrains dominate. Highways, railroads, and pipelines for fluids transport materials. The movement of materials along steep gradients is energy consumptive. In contrast, electric power transmission lines transport energy rather than materials. In this case, energy used in transmission is virtually independent of gradient. The only factor involved in gradients for powerlines is ease of construction of transmission towers and access to the lines for maintenance and clearing of vegetation. There is an inherent loss of energy in the transmission of electric power that is primarily proportional to the length of the line. To minimize this loss and conserve transmitted electric energy, routes for powerlines are governed more by minimizing the length of the line, than by the topographic gradients along the way. The shortest distances are typically over high terrain, such as hills and mountains, rather than around them, following lowlands and river valleys.

Steeply sloping topography is usually undeveloped for residential, commercial, industrial, or agricultural use. For this primary reason, natural surroundings are often best preserved where slopes are steep. Under these conditions, large areas of land may remain contiguous and thus natural landscapes and ecosystems within these tracts are preserved intact and safe from development. However, corridors for power transmission and some pipelines often cut through such steep areas. The net result may be a partitioning of these natural areas.

Caves and other karst features are found in areas of steep slopes as well as in areas of lesser slopes. For this reason, karst landscapes are affected by corridors of all types. One of the principal environmental factors involving the paths of corridors centers around the karst "fabric." The direction of groundwater flow in karstic aquifers is strongly governed by the structure of the bedrock. In most cases, flow is along the strike of the bedrock. This is particularly true in folded rocks such as those in the Appalachian Mountain region. Fractures, caves, and sinkholes, as well as the axes of mountain ranges and intervening valleys, are commonly oriented parallel to the structural axes (along strike). This gives both the topography and the karst a hydrologic "grain," so to speak. Hence, surface water and groundwater generally flows with the grain and less commonly across it. "Transverse corridors," cutting across the grain may lead to partitioning of flow systems (see later discussion). Corridors that align along the grain ("longitudinal corridors") may be positioned over karst for long distances, increasing the potential for harm of the underlying aquifers.

Criteria for Siting Corridors

Selection of potential corridors is a convoluted process. State and federal agencies are heavily involved in the decision making. There are always multiple issues that require study and input. The siting process is typically one of compromise and reconciliation between advocates and adversaries and between those favoring economic growth and those concerned with protection of the environment or with preservation of lifestyles. Dialogue and study involved in review of proposals for new corridors require consideration of many factors, including determination of the need for the new routes, assessment of numerous economic factors, and investigation of potential threats to the environment and to the welfare of those living in or near the paths of the corridors. Typically, several alternate routes are chosen for further analysis. Presumably the route that maximizes benefits to the population, yet minimizes potential environmental and health risks, will prevail and eventually be used. However, public reaction often complicates the selection process. Today, for nearly every proposed corridor there is opposition by the citizens living within or near to its boundaries. Within local and regional communities, activists form groups that may organize campaigns, stage protests, attend hearings and governmental meetings, and in some cases, generate considerable support for their opposition through the media. In response, new alternate sites may be proposed or the permitting process may be delayed through lengthy legal posturing and maneuvering.

Pragmatically, corridors are usually chosen with the shortest route in mind, given the terrain considerations discussed above. It is obvious that costs of construction and future maintenance rise proportionately with length of the route. In the case of transportation, short routes are also beneficial to the consumer in the form of reduced costs of transport. In the case of highways, fuel and inherent vehicular costs are considered on a per-mile basis. For powerlines, energy is lost as electromagnetic radiation all along the line; the longer the lines, the more energy is lost from point of origination to point of use.

Unless the landscape is low in relief and the terrane is uniform, corridors do not go long distances in a straight line. Rather, the path becomes curved, and in severe cases, may be very convoluted (for example, switchbacks in a highway that crosses a mountain range). In many situations the eventual path of the corridor is governed by geologic constraints. One of the overriding geologic considerations is the extent to which excavation will be necessary for construction, and if so, how difficult will the earth materials be to remove or to use as fill? For example, in highway construction, the need for roadcuts and cut-and-fill adjustments for gradients are primary factors.

In the past, karst has been a lesser factor in the corridor selection process than have many other parameters. In recent years there has been an emerging awareness of environmental and engineering problems associated with land underlain by soluble rock. Yet, on the part of planners, developers, agency officials, political office holders, and engineers, there is still an insufficient appreciation or understanding of karst processes and potential negative impacts associated with construction on this terrane. The main problem is rooted in the fact that the most sensitive zones of karst are in the subsurface where they are hidden from view. Unfortunately an "out of sight, out of mind" approach to karst is very much the case in some sitings of corridors, not necessarily intentionally, but because the sensitive nature of karst is not yet universally understood (Kastning and Kastning, 1991).

Impacts of Corridors on Karst Areas

There are five general types of environmental problems associated with karst terranes: (1) land instability and collapse, (2) flooding and siltation, (3) groundwater contamination, (4) destruction of caves or their contents, and (5) alteration of hydrologic flowpaths. Each of these is an important consideration where corridors for energy transmission or for transportation cross karst. The following descriptions are modified from Kastning (1995a):

Instability and collapse. In some localities, karst terranes may be inherently unstable and prone to unexpected collapse. Catastrophic failure of the roof of a cavity can suddenly modify the land surface, causing damage to buildings and other man-made edifaces, including roadbeds, pipelines, and powerline transmission towers. The extent to which sinkholes can disrupt the surface and the frequency of occurrence of collapse are evident from a plethora of papers published in the proceedings of multi-disciplinary conferences on environmental and engineering problems regarding karst (for example, Beck, 1984, 1989, 1993, 1995; Beck and Wilson, 1987). The mechanisms of the collapse processes are well described in papers of those meetings.

Natural sinkholes (dolines) formed by sudden collapse of a roof of a cavity in bedrock are relatively uncommon. However, this type of collapse can be triggered as a result of construction. For example, if the load on a thin roof of a cavity is augmented by construction of an ediface above the opening, or if some bedrock overlying a cavity is removed during excavation on the surface, resulting in a thinner roof span, then failure may easily occur.

Sinkholes often form in unconsolidated surficial materials (soil and regolith) that blanket soluble rocks. In this process, known as "suffosion" or "piping," surficial materials are gradually sapped into fractures and solutionally-enlarged openings in the bedrock. The cavity grows laterally and upwardly within the unconsolidated material until the thinning roof span fails. This is the most common type of collapse in areas that have corridors. In fact, many of the collapses occur within fill material emplaced during construction. This material is typically less compacted than naturally occurring, unconsolidated materials.

Flooding and siltation. Closed depressions, such as sinkholes, have no natural surficial outlets for excess meteoric water. Under normal conditions, sinkholes drain to the subsurface at rates sufficient to allow the recharge water to percolate into the underlying aquifer. However, at times the bottoms of sinkholes become silted and wholly or partially plugged. This may cause sinkholes to periodically flood under storm conditions. Siltation is often caused by erosion brought on by improper land use adjacent to sinkholes (Kastning and Kastning, 1994b). Disruption of the surficial topography, clear-cutting, and removal of vegetation along corridors often lead to flooding and siltation in sinkholes unless proper mitigating measures are implemented.

Powerline corridors are kept relatively clear of vegetation and unpaved access roads usually parallel these lines for maintenance purposes. Both of these practices augment erosion and, in karst, it is likely that the sediment will be washed into sinkholes, causing siltation and flooding (Kastning, 1992, 1993, 1995c). The same problem can occur adjacent to highways if embankments and cutbanks result in over-steepened slopes or if naturally steep slopes along corridors are clear-cut of vegetation.

Contamination of groundwater. Increasing development of urban and rural karstlands invariably results in the introduction of contaminants into the groundwater. A casual perusal of published papers in the proceedings of symposia and conferences on karst strongly suggests that contamination is the prevailing environmental problem in this type of terrane. Groundwater in karst flows through solutionally-enlarged openings, much the same as water flows through pipes. Contaminants are conveyed rapidly from where they enter the ground to where groundwater is discharged at springs or wells. Moreover, flow through these natural conduits remains largely unfiltered and the concentration of contaminants remains high from source to destination (Kastning, 1990; Kastning and Kastning, 1991).

Accidental spills of toxic substances from tanker trucks on highways or from derailed railroad cars are all too common. Most highway and railway accidents with toxic spills are covered by the news media. Statistically, spills such as these should be regarded as inevitable on any stretch of highway, including of course, those through karstlands.

Contaminants are also introduced along highways in other ways. Rain washes oil and other hydrocarbons from the road surface onto the adjacent land and into the ground. De-icing salts, such as sodium chloride, are often applied to the road surface during winter storms. This salt is very soluble and is easily carried into the groundwater by rain or by meltwater from snow and ice.

Herbicides are often applied to corridors for powerlines in order to control vegetation near the lines. In karst, runoff carrying quantities of these toxic chemicals may enter nearby sinkholes and other openings and be quickly conveyed through the aquifer (Kastning, 1992, 1993, 1995c).

Destruction of caves or their contents. Highway and railroad cuts often intersect caves. Occasionally, small caves are totally obliterated. In other situations, new artificial entrances may be added to caves during excavation. Aside from the degradation or elimination of the aesthetic character of a cave (for example, broken speleothems), there may also be subtle, yet significant, damage to delicate cave ecosystems. In some cases the effects are catastrophic. Globally rare or endangered fauna may be threatened or killed. In some cases, archaeological sites in caves are disturbed. The impact of highway construction on archaeologically-significant Native American material in caves has been a recent concern in some localities (for example, in southwestern Virginia).

Alteration of hydrologic flowpaths. Corridors have the potential to significantly alter the direction of water flow and to disrupt zones of recharge and discharge, particularly in karstic aquifers. Transverse corridors, cutting across the hydrologic and structural grain, may not only partition the surface environment, such as segmenting contiguous forests, but may do likewise to flow networks for surface water and groundwater. Partitioning of aquifers occurs where flow paths are interrupted by excavation or where infilling occurs during construction of corridors or after subsequent siltation.

Derangement of drainage networks brought on by corridors can result in severe imbalances in the water budget, resulting in a critical reduction down gradient in water levels in wells or discharge through a flow system, such as a cave, and/or an increase up gradient in discharge at rates above the capacity of the natural system. Thus, blockage of natural flowpaths could result in backflooding upstream of the blockage. Alteration and derangement of flowpaths can readily impact existing water supplies and can change the hydrologic character of caves, severely affecting the growth of speleothems or disrupting delicate biological ecosystems. Unfortunately, once corridors are in place, these effects may not be easily detected from the surface and it may be too late to correct any harm that may have been done.

It is clear from the foregoing comments that the five types of environmental impact with respect to construction of corridors in karst are intimately associated with sinkholes and other subsidence phenomena. Considerable information on the environmental significance of sinkholes is available in the literature on karst (for example, see LeGrand, 1973; White, 1988, pp 355-405; and bibliography by Kastning, 1994). Problems associated with sinkholes and suggestions for management of terranes having sinkholes are summarized in Hubbard (1989) and Kastning and Kastning (1990, 1992, 1993, 1994b).

Problems with Siting Corridors in the Karst of Southwestern Virginia

During the last few years, two major proposals for corridors have been brought before governmental agencies and the general public for consideration and permitting. American Electric Power (formerly Appalachian Power Company) has submitted a request for a major new power transmission line from Wyoming, West Virginia, to Cloverdale, Virginia (Figure 1). Additionally, the United States Department of Transportation has encouraged consideration of a major new north-south interstate from Charleston, South Carolina, to Detroit, Michigan, that would cross southwestern Virginia (Figure 1). Both proposals have generated considerable debate and concern throughout that region. Each has resulted in grass-roots opposition to the projects.

Alternate corridors for each project have been proposed. Nearly all cross regions of karst in southwestern Virginia. In fact, it would be nearly impossible for these corridors not to cross karst owing to the northeast-southwest trending exposures of carbonate units that extend parallel to the Appalachian structural fabric. There are two fundamental questions to be resolved: (1) Are the powerline or interstate highway truly needed? (2) If so, which of the alternate routes in each case is the best, based at least in part on environmental factors?

American Electric Power 765-kilovolt transmission line. American Electric Power initially proposed a preferred route for the transmission line that would cross karst in Monroe County, West Virginia, and Craig County, Virginia (Figure 1). Testimony was presented before the Virginia State Corporation Commission (the agency that has decided to permit the line in Virginia) by both proponents and opponents to the line. Both sides of the issue had addressed the vulnerability of karst in Craig County to the proposed line. At the time of this writing, American Electric Power has changed its preferred route to one that does not cross Craig County, but crosses Giles County instead. In the meantime, the National Forest Service of the U.S. Department of Agriculture, in conjunction with the National Park Service, and Army Corps of Engineers, has commissioned a study of alternate routes through the Jefferson National Forest for the purposes of selecting a corridor with a minimal environmental impact on the forest. Some of the USDA Forest Service proposed alternate corridors pass through Montgomery, Giles, and Craig counties in Virginia as well as through Monroe County in West Virginia (Figure 1). Up to the present time, agencies in West Virginia have not yet ruled on permitting

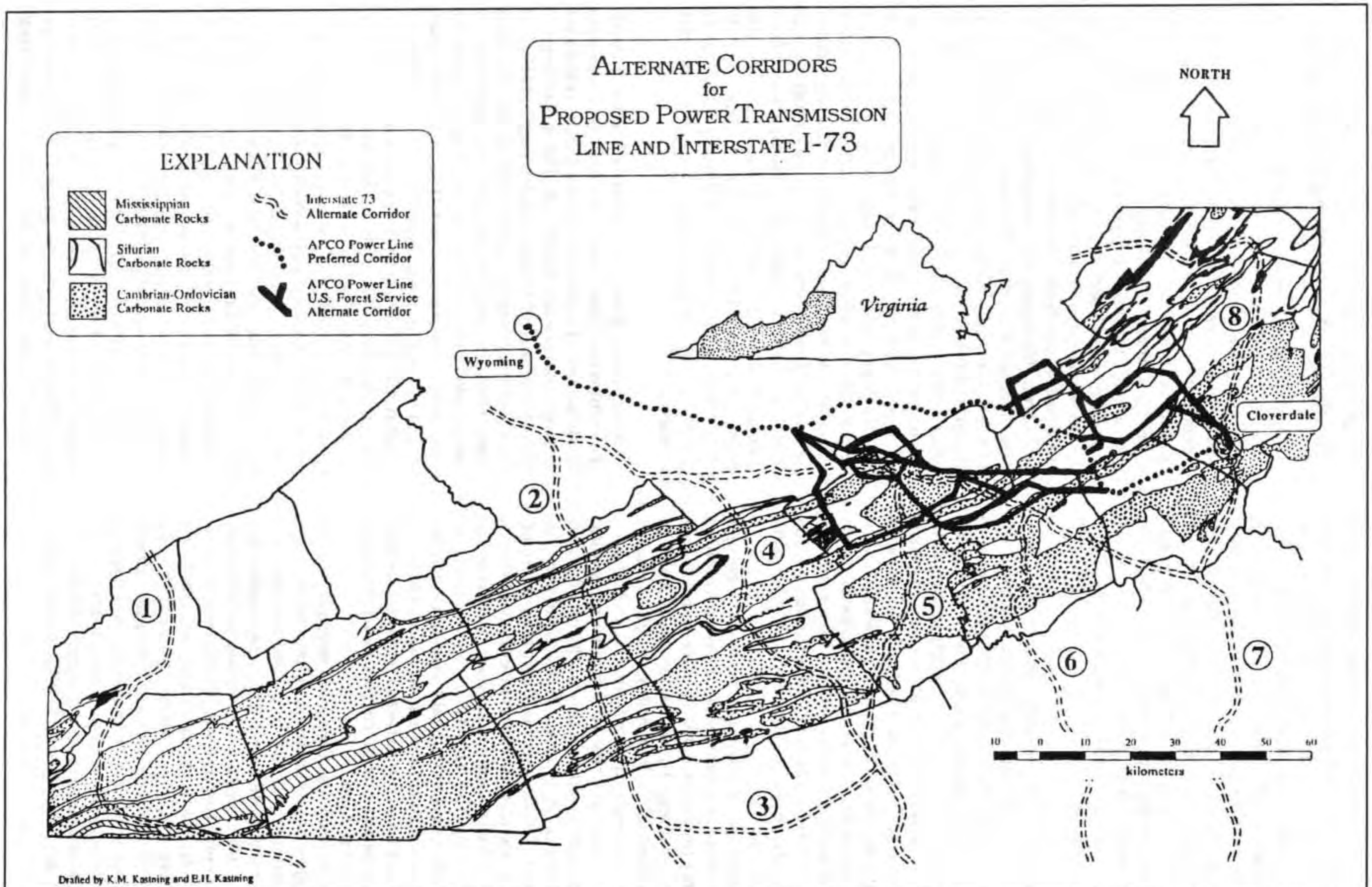


Figure 1. *Geologic map of southwestern Virginia showing major exposures of carbonate rocks and alternative corridors for the proposed American Electric Power 765-kilovolt power transmission line and for the proposed new Interstate I-73. Geology compiled by Karen M. Kastning from maps of Butts (1933) and Hubbard (1988).*

the line in that state. The outcomes are currently pending.

Alternate Corridors for Proposed Interstate 73. A similar situation has arisen for the proposed Interstate 73. Eight alternative corridors have been selected for consideration (Figure 1). Each connects the Winston-Salem, North Carolina, area to a point in southern West Virginia from which the main corridor of I-73 continues north to Michigan. Several alternative corridors pass through significant karst regions, including Giles County with a high density of sinkholes and caves (Kastning, 1988, 1989). Selection of the final corridor currently rests with the U.S. Department of Transportation and the U.S. Congress.

It is interesting to note the wide geographic spread of the eight original prospective routes for I-73 (Figure 1). Each of these converge at the same point in North Carolina off the southeast part of the map and in West Virginia in the northwest part of the map. The route that is the most direct between the two points is route number 4 on the map of Figure 1. This route is also coincident with a segment of existing Interstate Highway 77. Both the shortness of route 4 and the fact that it would use an already-existing corridor should make it the favorable choice, if for no other reason than it would be the least expensive to construct and it would be the least costly on a per-mile basis for travel through the area. Additionally, preliminary studies of all eight alternate corridors, conducted by governmental agencies and consultants, determined this route to be the best one environmentally, with the least impact on the landscape. Note that route 4 crosses less carbonate terrane than do nearly all of the other routes (Figure 1); thus, in all likelihood it should have less impact on sensitive karst terranes. Yet, reason has not prevailed.

The Virginia Department of Transportation, with the support of several influential people (including the senior U.S. Senator from the state), has chosen route 7, much further to the east. This "dog-leg" route is over 100 miles longer than route 4, between the two destination points; in addition, the existing corridor along route 4 would not be utilized. Not only will the highway that follows route 7 be much more costly than route 4, owing to the additional length of pavement, but route 7 will also have several more interchanges along it in comparison to route 4, thereby increasing the cost considerably.

Why, then, was route 7 chosen? The explanation, however seemingly illogical, is simple. The most emphatic argument for route 7 has been that I-73 would pass through Roanoke and improve the economic growth of that city. It should be noted that Roanoke currently lies along I-81, one of the major interstates in the country. I-81 already provides sufficient connectivity for commerce. One could argue that making Roanoke an interstate hub may provide growth, but it is also demonstrable that this growth would severely impact the natural and living environments in that vicinity. Route 7 would also bring an interstate highway to the cities of Danville and Martinsville in the southeastern part of the map. However, this could have been accomplished by upgrading existing U.S. Route 220 from that area north to Roanoke (near where route 8 branches from route 7).

Of all of the proposed alternative corridors for I-73, the chosen route, number 7, will have the greatest impact on karst. It will pass through areally extensive carbonate terrane in Montgomery and Giles Counties. Large-scale excavation and fill will be required to build the road. This will likely disrupt local groundwater flow. The highway will impact caves, particularly in Giles County. Once the highway is operational, there will undoubtedly be mishaps and spills of contaminants. Along Interstate 81 in the region shown in Figure 1, there have been several serious vehicular accidents with toxic chemical spills over the last decade (Kastning, 1989, 1990). Potentially, subsidence and collapse will occur along the roadbed of I-73. In 1995 a large sinkhole collapse occurred in the northbound lanes of I-81 near Salem, causing a major traffic snarl (Chittum, 1995; DeVaughn, 1995; Hoke, 1995a, 1995b; Knachel, 1995; Martin, 1995a, 1995b; Moody, 1995a, 1995b).

As of this writing, it is conceivable that if approved and constructed, the American Electric Power powerline and the new interstate highway may occupy virtually the same corridors in parts of Montgomery and Giles counties. Whereas combining corridors may reduce the total area affected, the combined routes may have an unusually high impact on some local caves and karst.

Two Case Studies Regarding the Proposed American Electric Power Powerline

The following discussion summarizes a study by this author of potential environmental impacts of siting the proposed American Electric Power 765-kilovolt powerline through karst terrane in Montgomery and Giles counties, Virginia (Kastning, 1995c). This study addresses the 1995 Updated Alternative Corridor Segments as presented by the USDA Forest Service, National Park Service, and Army Corps of Engineers and as detailed by the consulting firm of Woodward-Clyde as contracted by the governmental agencies.

The study was initiated at the request of residents of two valleys that lie within or immediately

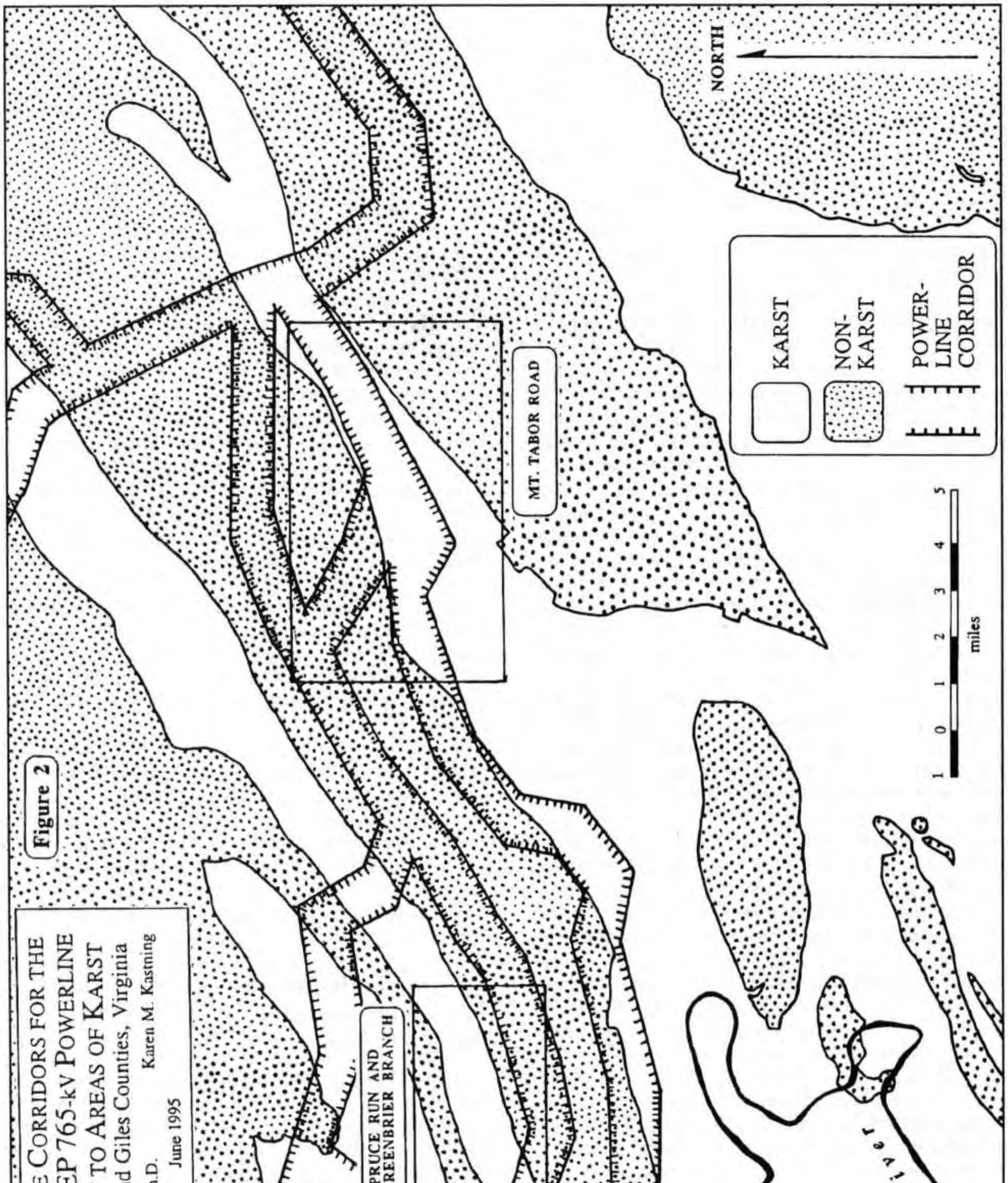


Figure 2
ALTERNATIVE CORRIDORS FOR THE PROPOSED AEP 765-kV POWERLINE IN RELATION TO AREAS OF KARST
Montgomery and Giles Counties, Virginia
Ernst H. Kastning, Ph.D.
Karen M. Kastning
June 1995
SPRUCE RUN AND GREENBRIER BRANCH
MT. TABOR ROAD
NORTH
KARST
NON-KARST
POWER-LINE CORRIDOR
1 0 1 2 3 4 5
miles
New River

adjacent to the announced alternative routes (see Figure 2). In each case, there is considerable potential for environmental degradation from installation of powerlines, powerline towers, and access roads for servicing the lines. The results of the study were submitted as a geotechnical deposition for inclusion into the USDA Forest Service Draft Environmental Impact Statement, due to be released in June 1996. Even though this study describes potential problems at two specific sites where the landscape is sensitive to environmental deterioration, it must be emphasized that many of the segments of the updated alternate corridors cross karsted carbonate terrane (Figure 2). Thus the findings for the two sites are relevant to the entire area of karst in these sections of Virginia and West Virginia.

In the Valley and Ridge of western Virginia, carbonate bedrock and karst cover more than half of the surface area of most counties (Hubbard, 1988; Miller and Hubbard, 1986; Kastning, 1995b; Kastning and Kastning, 1995). Geomorphically, much of the lowland in this region is floored with carbonate rock. It is an established fact that most people of these counties live in the intermontane lowlands (broad valleys). Therefore, in many of these counties, 70 to 90 percent of the population lives on karst. Because so much of this land is rural, most of these people derive their drinking water from private wells driven into karstic aquifers. Protection of those karstic aquifers is of paramount concern.

Karst along Mount Tabor Road, Montgomery County. A series of parallel valleys crosses Mount Tabor Road (Route 624) in Montgomery County (Figures 2 and 3). This site extends from Mount Tabor (southeastern Newport 7.5-minute quadrangle) to the Roanoke County line (eastern McDonalds Mill quadrangle). The southeastern parallel valleys drain Brush Mountain on the northwest and flow into the North Fork of the Roanoke River to the southeast. The valleys include Mill Creek, Turkeypen Hollow, Dry Run and its tributaries (Sites and Mullins Branches), Jack Hollow, Pepper Run, Smith Run, and Gallion Branch.

The land along Mount Tabor Road (Route 624) is underlain by the Elbrook Formation, a dolostone of Cambrian age (Butts, 1933, 1940). Along its northwestern boundary, just to the northwest of the road, this unit forms the leading edge of the Pulaski thrust sheet. The trace of the thrust fault on the surface marks the northwestern boundary of a zone of karst that lies between it and the North Fork of the Roanoke River to the southeast. The Elbrook Formation is exposed as a one- to two-mile-wide band (Figure 2). The rocks dip to the southeast.

The nine parallel valleys that the road crosses contain small streams that flow southeast along the direction of dip to the North Fork. Between these streams, in the interfluves, the land is quite hilly with local relief averaging about 300 to 500 feet. The land is partially drained on the surface by the nine streams and their numerous small tributaries. However, the outcrop of the Elbrook Formation is also drained internally to a significant extent. A large amount of water infiltrates along joints and is carried into the cavernous beds.

The Mount Tabor Road corridor exhibits moderate to mature karstification. Evidence for this includes numerous sinkholes and caves (Figure 3). Groundwater generally flows southeast toward the North Fork. Owing to the incisions of the nine streams and high local relief, underground hydraulic gradients are quite steep (on the order of 100 to 200 feet per mile or steeper). Cavernous porosity, high permeability, and steep gradients result in high rates of velocity of groundwater flow. Discharge through conduits (natural cavernous openings) is likely to be high in this area.

The corridor of Mount Tabor Road as shown on Figure 3 has at least 20 documented caves. Several of these have been well explored and mapped and data for most of them are in the files of the Virginia Speleological Survey (Douglas, 1964; Holsinger, 1975). Several of these caves are small; however, one cave is highly important. Slussers Chapel Cave at the far western part of the corridor (Figure 3) is one of Virginia's significant caves, as listed by the Virginia Cave Board and the Division of Natural Heritage of the Virginia Department of Conservation (Holsinger, 1985). This is the longest cave in Montgomery County, with over a mile of surveyed passages. The cave harbors some globally rare, troglobitic invertebrates including an isopod (*Caecidotea vandeli*), an amphipod (*Stygobromus fergusoni*), a beetle (*Pseudanophthalmus pusio*), and a millipede (*Pseudotremia cavernarum*) (John Holsinger, personal communication, 1994). As a result, the cave is owned and managed by the Cave Conservancy of the Virginias, an advocacy organization committed to cave conservation. Access is carefully controlled. The stream in Slussers Chapel Cave is thought to originate in Fred Bull Caves Nos. 1 and 2 approximately 0.7 mile to the west, flow underground through Slussers Chapel Cave, and ultimately issue from the spring at Mill Creek Cave. This is a subsurficial flow route no shorter than two miles. The center of one of the proposed alternative corridors of the American Electric Power powerline passes directly over this highly significant cave system.

High rates of discharge through the carbonate aquifers beneath the Mount Tabor Road area implies that contaminants entering at the surface in this vicinity would be quickly conveyed to springs and wells downstream. There are numerous documented springs in the vicinity of Mount Tabor

Road (Figure 3). Most, if not all, of these issue from the Elbrook Formation. Therefore, it is highly likely that contaminants entering the recharge zone along Mount Tabor Road will be rapidly carried into caves and to nearby springs and wells.

Much of the runoff from the relatively insoluble and low-porosity rocks of Brush Mountain, to the northwest, will sink into the karst aquifer upon flowing onto the carbonate surface. Thus contaminants introduced on the flanks of Brush Mountain, a likely route of the powerline, would also contribute to degradation of groundwater in the karstic aquifer.

Based on the above geologic and hydrologic conditions, it is logical to conclude that any contaminants introduced during the construction and maintenance of the powerline will enter the groundwater of the Mount Tabor Road corridor. Because every home in this area has a private well and is not on a municipal water pipeline, harmful contaminants would impact everyone's drinking water. Contaminants may include herbicides, such as those used to control vegetation in powerline corridors.

As with many other sites along the proposed powerline corridors, this segment is adjacent to steep flanks of mountains. Many unpaved access and maintenance roads leading to existing powerlines are severely eroded (Kastning, 1992, 1993). Eroded sediments on karst will contribute to siltation in sinkholes and other natural openings that serve as recharge points to the aquifer. This can negatively impact karstic groundwater by blocking flowpaths and may cause localized backflooding and reduced flow from springs. Thus, domestic and agricultural water supplies may also be adversely affected by erosion and siltation.

Contaminants introduced into the groundwater will severely impact the biological ecosystems of caves. Indigenous cave invertebrates are particularly sensitive to any environmental changes within the caves. Moreover, if the caves contain globally rare organisms or endangered species, contamination may cause a loss of habitat and possible extinction of species. Because several of the caves of the Mount Tabor corridor have fragile ecosystems and harbor some globally rare organisms, they are at risk from development on the surface, including powerlines. Like canaries in mines, the existence of sensitive cave organisms tell us that the water is relatively clean; conversely, their extinction would confirm that the water is no longer potable—for man or for beast.

Karst of the Valley of Spruce Run, Giles County. Colinear valleys of Spruce Run and Greenbrier Branch in southeastern Giles County (Figures 2 and 4), are located in the southern part of the Eggleston U.S. Geological Survey 7.5-minute quadrangle. This combined valley, approximately six miles in length, is centered on Route 605 and is bounded by Spruce Run Mountain on the north and Gap Mountain on the south. The valley extends from the village of Newport on U.S. Route 460 to Goodwins Ferry on the New River.

The valleys of Spruce Run and Greenbrier Branch are floored by dolomitic rocks of Cambrian age, including the Mascot Dolomite, Kingsport Dolomite, Chepultepec Formation, and Copper Ridge Formation (Schultz and others, 1986). Midway up the southern valley wall (that is the northern flank of Gap Mountain) is a narrow outcrop of undivided (unnamed) limestones of middle Ordovician age. This is followed in order by beds of the Reedsville, Eggleston, Moccasin, Juniata, and Tuscarora formations. These form the resistant ridge of Gap Mountain. To the north, the dolomitic formations are bounded by the Saltville Thrust Fault, a major fault of the Appalachian tectonic system. The trace of another thrust fault, parallel to the Saltville Fault, occurs approximately one-third of the way up the flank of Spruce Run Mountain to the north. Thin exposures of the Honaker and Nolichucky Formations run parallel to and just south of this fault. Nearly all of the beds in the valleys dip to the south-southeast at 35 to 60 degrees. Large colluvial deposits, consisting of boulders, gravel, sand, and silt occur along the slopes of the valleys. Some of these deposits include rockfalls, talus, trains of debris, and block-field material. Colluvial deposits are more prevalent higher on the valley sides where slopes are steeper.

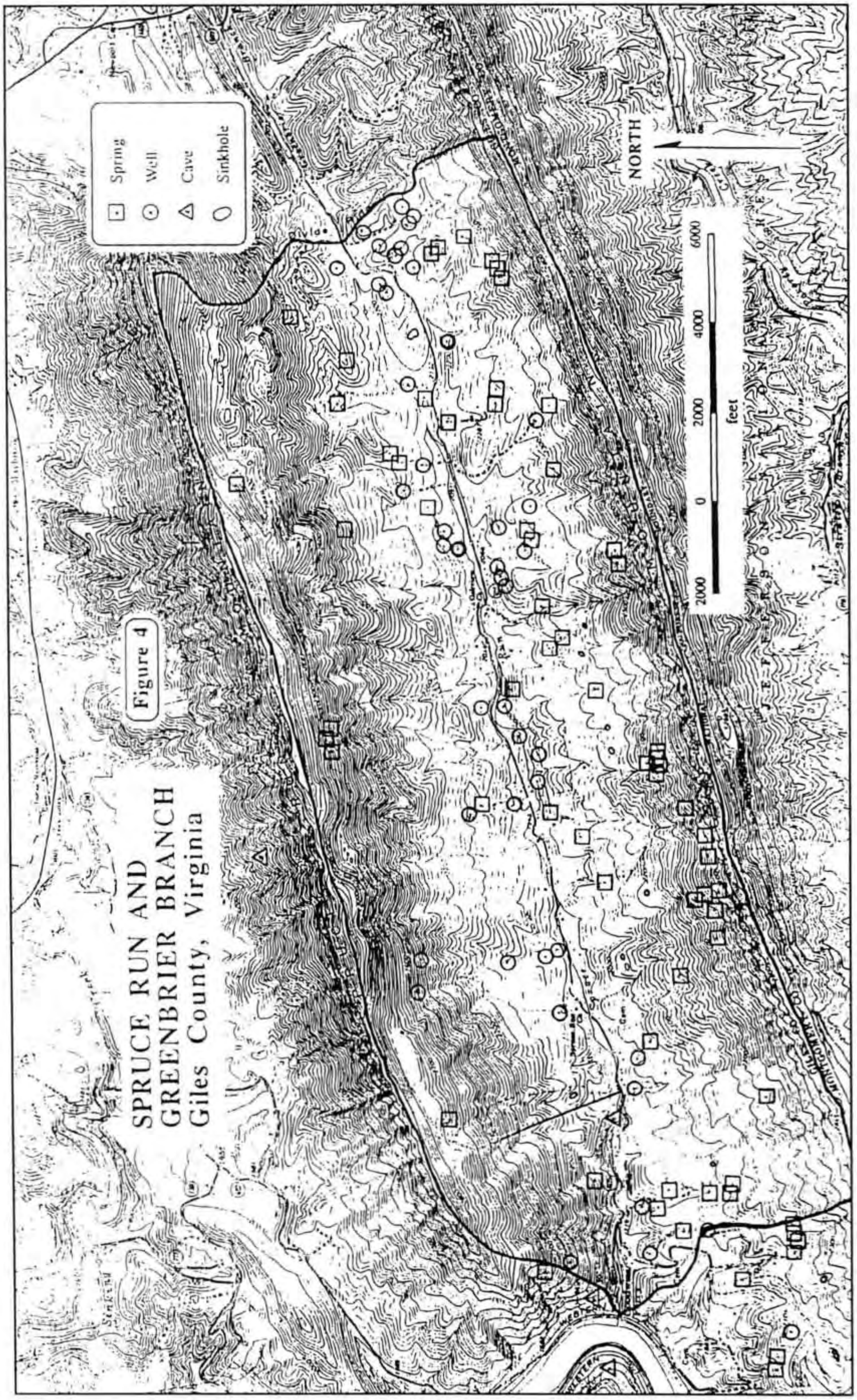
All of these beds are moderately dissected. Surficial runoff, flowing down the slopes of Spruce Run and Gap mountains, sinks into the limestone and dolostone beds along the courses of numerous small creeks along the valley sides. Once in the carbonate rock, flow is readily transmitted to springs. Many of the springs (certainly not all of them) have been inventoried for this study and are shown on the map of Figure 4. There are numerous water wells in the valley, averaging one per household.

The karst within the valleys of Spruce Run and Greenbrier Branch is not as well developed as it is in some other areas of these counties. However, there are a number of sinkholes in the valley, as indicated on the map of Figure 4. These happen to be most concentrated in the band of "undifferentiated middle ordovician limestones" that runs along the southern slope of the valley, parallel to the axis of the valley and about half way up to the crest of Gap Mountain.

It must be emphasized that in less-karsted carbonate rocks, such as the dolomitic units of Spruce Run and Greenbrier Branch, there are still solutionally enlarged fractures and other openings in the subsurface that form integrated flow systems which in turn convey water efficiently from points of recharge to points of discharge (springs and wells). The subsurficial karst, however, is often disguised by surficial colluvial deposits and soil cover. It is these areas that are more typically prone to suffosion, resulting in collapse of the ground cover.

Even though the valleys of Spruce Run and Greenbrier Branch have only a few small caves, some caves in the vicinity are large. New River Cave, just outside the Spruce Run drainage basin, and adjacent to the New River on its east bank, is one of the longest caves in the state, with several miles of mapped passages (Krinitzsky, 1947; Kastning and Kastning, 1994a; Kilby, 1995). It contains a stream fed by recharge from sinkholes located along the upper parts of Spruce Run Mountain. Even small caves, however, are integral components of groundwater systems and can transmit considerable discharge. The presence of caves, small or large, confirms the presence of karstic groundwater flow.

The valleys of Spruce Run and Greenbrier Branch are highly susceptible to degradation of groundwater. Surficial runoff form the flanks of


SPRUCE RUN AND
GREENBRIER BRANCH
Giles County, Virginia
Figure 4
Spring
Well
Cave
Sinkhole
NORTH
2000 0 2000 4000 6000
feet

adjacent mountains is both rapid and of high discharge and much of this water infiltrates the ground before reaching the creeks. The aquifer beneath the valley floors is prolific; yet, as in all karstic aquifers, flow travels along natural conduits or pipes and undergoes little or no filtration.

The greatest threat of powerlines in the vicinity of the valleys of Spruce Run and Greenbrier Branch, as elsewhere in the karst, is that of contamination of groundwater by herbicides. Even if the powerline is sited on the dense sandstone units at ridge tops above the adjacent valleys, runoff during storms may carry contaminants downslope to the carbonate units where rates of infiltration are high.

Many people of these valleys derive their water from springs. At present, the quality of water is very high, owing to the rural character of the land. Should a powerline be constructed within the drainage of these valleys, the water will likely be chemically degraded. Depending on local geologic conditions, such as fracture density, presence of caves, and composition of the carbonate rock, the extent of deterioration of potable water may be high.

As in the case of karst along Mount Tabor Road, a second environmental problem is erosion of sediment from the swath of devegetated land along a powerline and from access roads used for maintenance by American Electric Power. Erosion may lead to sedimentation problems downstream, in this case in the residential and farming areas of the valley bottoms. Additionally, sediments may clog natural openings for infiltration such as sinkholes and fractures. It is a known and documented fact that American Electric Power has not taken adequate measures in erosion and sedimentation control on many of its existing powerlines (Kastning, 1992, 1993). It follows that control of erosion and sedimentation on future lines remains questionable.

Conclusions and Recommendations for Management

Awareness of the importance of karst in siting corridors is gaining momentum in southwestern Virginia (Kastning and Kastning, 1991). Karst is often a topic introduced at public hearings regarding corridors. Currently, karst is a "red-flag" parameter being considered by the USDA Forest Service in their deliberations on alternative corridors for the American Electric Power powerline. Karst has also been scrutinized by the Virginia State Corporation Commission in its assessments. To date, karst has not been adequately considered in the determination of a route for Interstate 73 through southwestern Virginia. Locally, however, citizens have become concerned with the impact of potential new highways on karst in the region.

There is a need for upgrading procedures used in site assessments and management regarding corridors through karstlands. Numerous environmental problems are manifest in existing corridors for transportation and energy. Adequate studies of karst are not being carried out in many current projects, at least to the level necessary for siting corridors and establishing proper management practices to ensure environmental integrity once the corridors are in place. Individuals in agencies and decision-making bodies often do not have sufficient knowledge about karst to render proper decisions on siting. The public at large (as voters and activists) is often under-informed about the nature of karst and does not necessarily appreciate the unique aspects of this type of terrane that make it particularly sensitive to environmental degradation. For these reasons, it is highly recommended that those who do have experience of karst processes become more involved in the education of those who assess potential sites and who design and engineer corridors. The general public and those in political office must likewise become better informed through education.

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INDOT Implementation of a Memorandum of Understanding to Reduce the Impacts of Highway Construction In Indiana Karst

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Abstract

In 1993, A Memorandum of Understanding was signed between the Indiana Department of Transportation, The Indiana Department of Natural Resources, the Indiana Department of Environmental Management, and the U.S. Fish and Wildlife Service. The Memorandum of Understanding establishes guidelines and procedures for mitigating or eliminating the impacts of road transportation projects in Indiana karst areas. The Indiana Department of Transportation is responsible for implementing the requirements of the Memorandum of Understanding prior to undertaking any highway construction or upgrade projects in karst areas. The Indiana Department of Natural Resources is required to implement Memorandum of Understanding requirements for road construction projects in karst areas under its management. The Indiana Department of Transportation is presently conducting Memorandum of Understanding-related activities and field studies on approximately 16 miles of state highways in the karst terrain of south central Indiana. The information and techniques developed from these studies are applicable to future highway and road development projects in Indiana and other states, and will increase the understanding of the karst drainage systems of south central Indiana.

Introduction

On October 10, 1993, the Indiana Department of Transportation (INDOT), the Indiana Department of Natural Resources (IDNR), the Indiana Department of Environmental Management (IDEM) and the U.S. Fish & Wildlife Service (FWS) entered into a Memorandum of Understanding (MOU) that establishes and delineates guidelines for the construction of transportation projects in karst regions of Indiana. The goal of the MOU is to develop highway-related design and construction practices that insure the transportation needs of Indiana are met in an environmentally sensitive manner that protects ground water quality, public health and safety, and the habitat of endangered cave adapted species such as the Northern cavefish (Amblyopsis spelaea). This paper discusses the provisions of the MOU and presents the results of case studies of its implementation as part of three INDOT highway construction projects.

Provisions of the MOU

It was agreed that INDOT, in cooperation with the other agencies, would "determine the location of sinkholes, caves, underground streams, and other related karst features and their relationship prior to proposed alterations or construction in karst regions of the state." In most cases, INDOT will be the agency responsible for MOU implementation. IDNR will also be responsible for MOU implementation for construction activities on its properties located in karst regions. MOU information is developed and utilized by the responsible agencies through each construction project as follows:

Early Planning

1. INDOT, utilizing a qualified outside consultant, conducts record searches and field studies to identify and describe potentially affected karst features.

2. A report of Task 1 findings is prepared for INDOT by the consultant and circulated to the other agencies for review and comment.

3. INDOT intends to avoid karst areas and features whenever possible. Report information will be used by INDOT to initially evaluate proposed highway alignments. Utilizing input from the other agencies, INDOT will also begin formulating appropriate measures to offset any unavoidable impacts to karst features on each alignment to be considered.

Design Phase

1. During the design Phase, INDOT will invite IDNR, IDEM, and FWS to field checks and meetings dealing with efforts to negate or minimize adverse impacts. When necessary, project designs and measures formulated to offset environmental impacts will be revised by INDOT and presented to the other agencies for review and comment.

2. Prior to acceptance of the final design plans, a project agreement will be developed and signed by the four agencies that sets forth the appropriate and practicable measures to offset unavoidable impacts to karst features. The agreement will become a part of the contract documents for the project; it will be discussed at the pre-construction conference, and will be on file at the office of the project administrator.

3. Depending upon the type and scope of planned highway construction, runoff water quality may be monitored by INDOT before, during and/or after the project. The other agencies will be invited to review and comment on any monitoring plan developed by INDOT and informational copies of monitoring reports will be submitted to the agencies on a regular basis.

Construction Phase

1. INDOT will assure that the terms of the project agreement are adhered to with all safeguards given to the karst area. The project administrator will insure that erosion control standards set forth in Indiana Amended Code 327 IAC 15-5 (Rule 5) are being adhered to by the highway contractor.

2. IDEM, IDNR, and FWS personnel will monitor construction as deemed necessary to ensure that the terms and conditions of the project agreement are fulfilled.

3. If during construction it is found that the project agreement must be altered for a given area, all agencies will be contacted and agreement reached before construction proceeds in that area. In order not to unduly delay construction, a two-day response time is agreed to by all agencies.

4. Erosion control measures and land treatments will be maintained during construction and will be visually inspected weekly or after heavy rains.

5. If an endangered or threatened species is encountered during construction, work in that area of the project will stop. IDNR and FWS will investigate the situation, advise the project administrator, and assume responsibility for directing the appropriate actions to be taken to protect the species.

Post Construction

1. The locations of sinkholes, swallow holes, drainage structures, and other identified features in the project area that direct surface runoff to the subsurface will be provided to IDEM who will provide the information to local emergency management authorities and HAZMAT teams to assist them in formulating emergency response measures in the event of a highway spill.

2. A low salt/no spray strategy will be developed for highway corridors in sensitive karst areas, and a signing strategy will be developed on a project-specific basis.

3. Where runoff treatment structures have been installed in or adjacent to sinkholes, regular post-construction visual monitoring will be conducted to ensure that structures are operating, physical integrity is being maintained and that structures are not being bypassed by runoff.

Implementing the MOU

As of September 1995, the MOU has been implemented for three highway construction projects located in south-central Indiana (see Figure 1 for locations):

SR37N. Construction and post construction phases—Indiana State Road 37 from the intersection with U.S. Highway 50 south a distance of 4.364 miles (widen to 4-lane, no curb, with median strip);

SR37S. Design phase—Indiana State Road 37 from the southern terminus of the previous project south a distance of 2.883 miles through the town of Mitchell (widen to 4-lane, curbed, no median strip);

SR60. Early Planning Phase—Indiana State Road 60 from its intersection with State Road 37 at Mitchell, Indiana, west a distance of 8.8 miles to its intersection with U.S. Highway 50 (resurface, widen pavement and shoulders, replace selected drainage structures).

Projects SR37N and S are broader in scope than Project SR60, involving widening the existing roadway to a 4-lane highway and acquiring additional right-of-way. Project SR60 involves signifi-

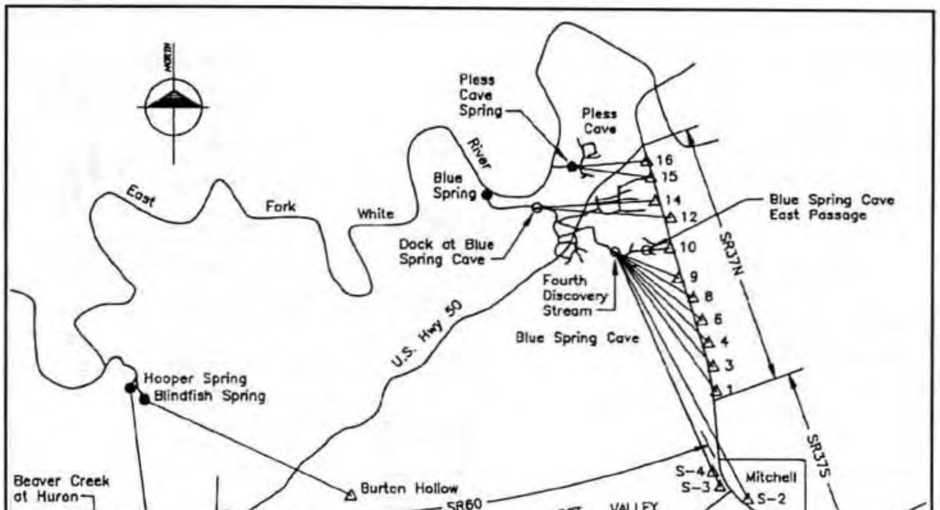

Figure 1. *Location of INDOT project corridors and results of dye tracing.*

cant ground disturbance only at locations where stream crossings and/or drain pipes are to be replaced. Major MOU-related tasks and findings are discussed below.

SR37N and SR37S

Physiography and Hydrology

Both projects are located in the Mitchell Plain physiographic unit (Beede, 1911). The Mitchell Plain is developed on limestones of Middle Mississippian Age, assigned to the Blue River and Sanders Groups (Figure 2). The surface of the Mitchell Plain is characterized by karst features produced by dissolution of the underlying limestones. The most common karst features are sinkholes, sinking streams, and caves. In the area of SR37N and S, virtually no surface streams exist. Runoff drainage is entirely through sinkholes and sinking streams into subterranean drainage conduits that convey water to resurgence points at springs along entrenched rivers and streams. The most practical method of handling highway runoff is to direct it into sinkholes through drainage structures that provide a measure of runoff detention, dilution, and filtration. Eleven sinkholes in the 37N segment and four sinkholes in the 37S segment were to receive this treatment. Five small sinkholes located beneath the pavement in the SR37N segment were to be excavated, stabilized with backfilled rip-rap, and capped.

MOU-Related Tasks

Construction began on SR37N in Spring 1992 and was completed in 1994. Additional right-of-way had already been purchased by INDOT for the corridor. SR37S was in the early design phase and right-of-way had not yet been acquired. Two state-protected Northern cavefish (*Amblyopsis spelaea*) were discovered in a partly-excavated sinkhole during the early phase of construction of SR37N. As a result of that discovery and the ongoing MOU negotiations between the four agencies, both State Road 37 projects became subject to the then-provisional requirements of the MOU.

After compiling a list of caves, sinkholes, sinking streams, and other karst features which could be directly or indirectly affected by the projects, the following tasks were conducted by INDOT and its consultant Earth Tech:

Task 1. Dye trace sinkholes within or adjacent to the project right-of-way that would receive highway runoff along both project corridors. Determine which sinkholes drain water to caves harboring *A. spelaea*.

Task 2. Plan and implement modifications for in-sinkhole drainage structures to enhance runoff treatment, dilution, and detention, and still remain within the acquired right-of-way along the SR37N corridor.

Task 3. Design, install, and evaluate alternative runoff treatment and spill recovery systems (for example, peat filters, in-line ditch basins, oil and grease traps) along both project corridors.

Task 4. Determine drainage areas, drainage basin characteristics, and expected runoff to features receiving drainage structures for 2-year, 5-year, and 10-year 24-hour-design storms along the both project corridors.

Task 5. Conduct semi-annual monitoring of construction and post-construction storm water runoff quality in the SR37N corridor to evaluate sinkhole drainage structure performance and post-construction changes in runoff quality. Monitor preconstruction storm water quality semi-annually in the SR37S corridor.

Task 6. Consult with design engineers regarding sinkhole drainage structures to be installed along the SR37S corridor and determine additional land acquisition needs.

Task 1 Findings

Detailed results of dye tracing along State Road 37 is presented in (Keith and others, 1995). Eleven sinkholes in the SR37N corridor and four sinkholes in the SR37S corridor were successfully traced to resurgence points (Figure 1). The two northernmost sinkholes in the SR37N corridor were traced west to nearby Pless Cave; the southernmost sinkhole in the SR37S corridor was traced northeasterly to Hamer Cave in Spring Mill State Park. The remaining 12 sinkholes were traced to various portions of the Blue Spring Cave System. With the exception of the two traces to Pless Cave, all highway runoff entering the subsurface has the potential to affect the habitat of *A. spelaea*. The extension of the Blue Spring Cave subsurface watershed to the town of Mitchell was not expected; nor was the trace in an updip direction to Hamer Cave. Underground flow route information is being provided to IDEM for emergency planning in the event of a major highway spill.

Task 2 Findings

Specifications for drainage structures to be installed in sinkholes receiving highway runoff in the SR37N corridor were revised to include detention basins and graded-stone filters. Figures 3A and 3B depict the most common graded stone filter configurations employed. The drainage structures reduce sediment/contaminant loadings to runoff

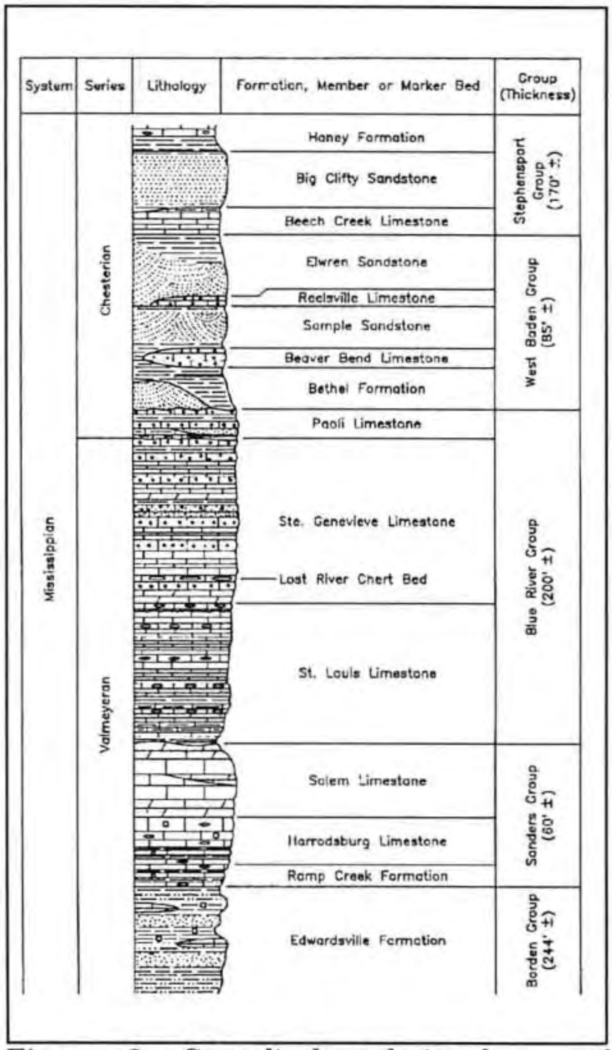

Figure 2. *Generalized geologic cloumn of Mississippian strata for Lawrence County, Indiana.*

through filtration, dilution by flow from off site, and settling of particulates. Because of space limitations within the existing right-of-way, some SR37N structures required extensive excavation and backfilling with large quantities of aggregate. Visual monitoring and reporting was conducted quarterly once the structures were in place to ensure that they remained stable, were not subject to slumping or soil piping, and that runoff was not bypassing them in any way. Most problems noted were minor and were corrected by INDOT construction or maintenance personnel. Soil piping near sinkhole 10 in the SR37N corridor (see Figure 1) led to the collapse of a roadside ditch carrying runoff to the drainage structure and the formation of a void 15 feet deep adjacent to the roadway. An examination by Earth Tech geologists indicated that the collapse was not caused by the drainage structure, but by soil piping induced by the discharge of concentrated drainage from multiple pipe outfalls at a single point in a ditch line.

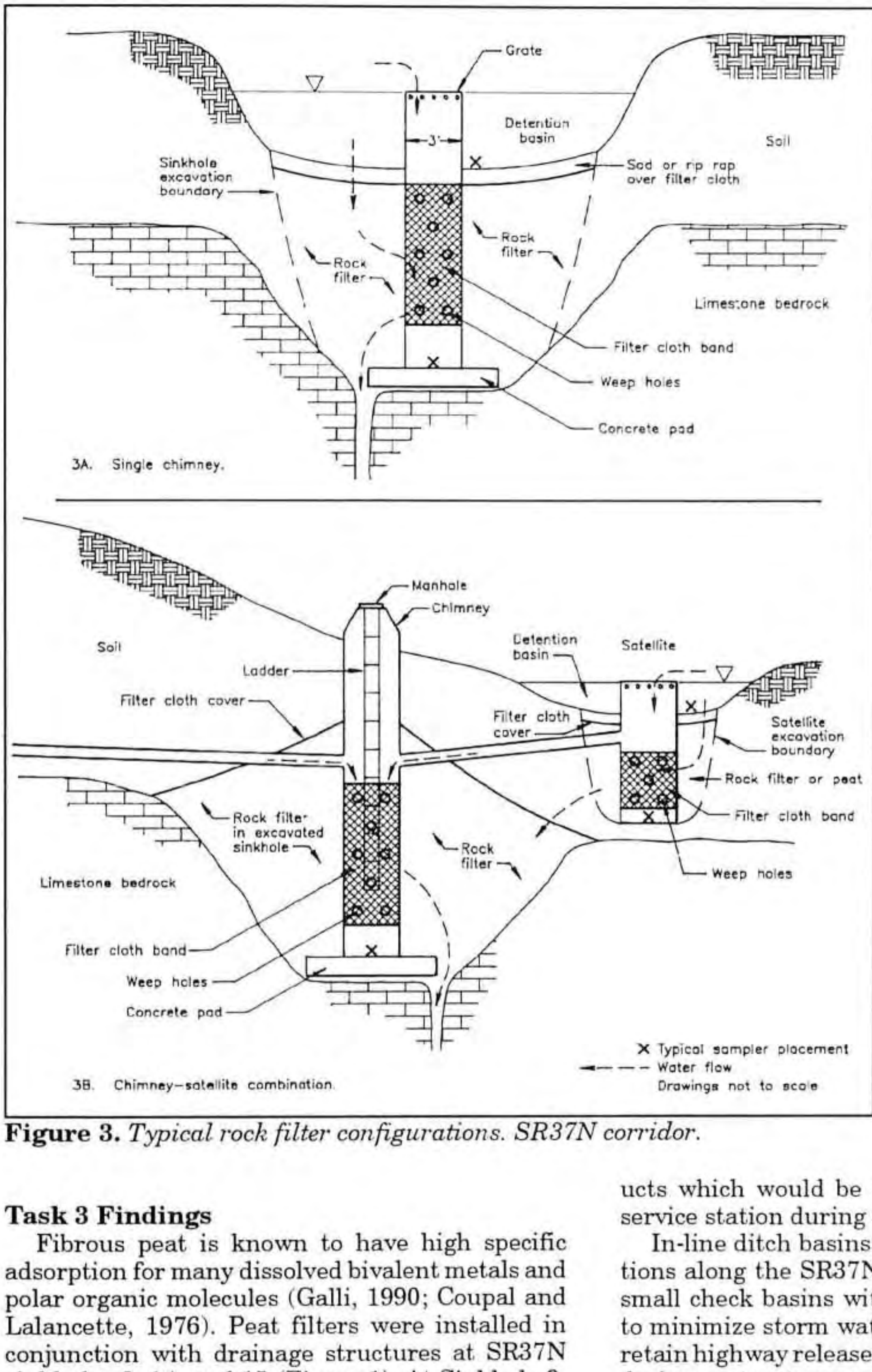

Figure 3. *Typical rock filter configurations. SR37N corridor.*

structures through which runoff must flow before it enters the subsurface.

An oil and grease trap consisting of a 10,000-gallon siphon discharge basin was installed upgradient from Sinkhole 16 (Figure 1). The presence of a busy highway intersection and an auto service station in the sinkhole watershed led to the decision to install this structure. The trap was designed to intercept and retain a catastrophic release of gasoline or diesel fuel from a transport vehicle until it can be cleaned up by emergency response crews. The siphon outfall will retain all or most floating petroleum constituents in the event of a spill during a storm event. To date, there have been no catastrophic spills or releases of sufficient size to enter the trap. Concentrations of Total Petroleum Hydrocarbons (TPH) in trap sediments suggest that the trap is retaining the small quantities of petroleum products which would be carried in runoff from the service station during any storm event.

In-line ditch basins are installed at many locations along the SR37N corridor. These consist of small check basins with rip rap armored outfalls to minimize storm water erosion. The basins also retain highway releases and spills upgradient from drainage structures so that they can be removed by an emergency response crew.

Task 3 Findings

Fibrous peat is known to have high specific adsorption for many dissolved bivalent metals and polar organic molecules (Galli, 1990; Coupal and Lalancette, 1976). Peat filters were installed in conjunction with drainage structures at SR37N sinkholes 9, 14, and 15 (Figure 1). At Sinkhole 9, where *A. spelaea* was discovered during excavation, a peat filter bed approximately 220 feet long and 8 feet wide was installed. The filter bed consists of 2.0 to 2.5 feet of fibrous sphagnum peat overlain by filter cloth and 6 inches of gravel, and underlain by filter cloth and 4-inch perforated PVC underdrain pipes imbedded in pea gravel (Figures 4A and 4B). Peat filters at the other locations consist of peat rings surrounding drop

Task 4 Findings

A document titled *Report on Watershed Characteristics, Structure Size, and Structure Storm Water Capacity for Sinkholes in the Northern Construction Segment of State Road 37, Lawrence County, Indiana* was prepared by the consultant for INDOT. The intent of the report is to provide for each drainage structure location a summary of runoff characteristics, structure capacity, as-built plans and measurements, location-specific problems and solutions, and any future plans or monitoring required. This report will be used for future highway planning, and provides a record of activities in the SR37N project.

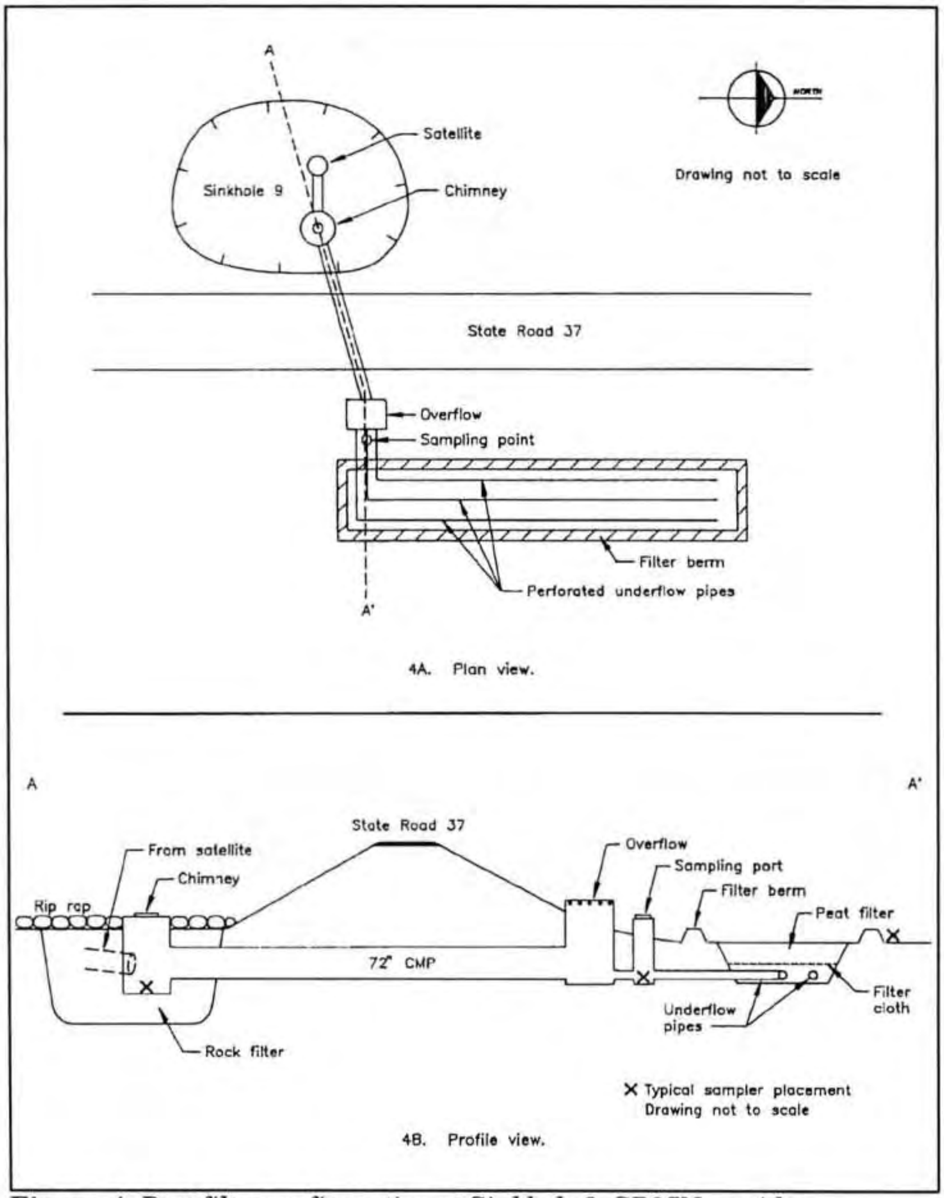

Figure 4. *Peat filter configuration at Sinkhole 9. SR37N corridor.*

Task 5 Findings

Storm water runoff in both corridors has been sampled twice yearly from early winter 1993 through summer 1995. Each year, one sampling event occurred in winter when soils tend to be saturated, road salt is in use, and vegetative ground cover is minimal. The second event occurred in summer, when storm events tend to be episodic and intense, and vehicle-derived metals and oil and grease tend to accumulate on pavement (Wiland and Malina, 1976, as discussed in Barrett and others (1993). Storm water at each sampling location was collected in single-stage samplers (U.S. Interagency Report, 1965) that sample "first flush" runoff on the rising limb. Typical sampler placements are indicated on Figures 3 and 4. Analytes included: Total Suspended Solids (TSS), Hardness, Oil and Grease, Chloride, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, and Zinc. Commonly-used pesticides were analyzed in runoff from basins containing row crops and orchards. Total recoverable metals (both dissolved metals and metals on particulates) were analyzed at all locations. Dissolved metals were analyzed at selected locations along SR37N.

Storm sampling results permit comparisons of runoff loadings between the two SR37 segments, and allow pollutant loadings in the runoff to be tracked over time. Average loadings for combined total recoverable (or dissolved) chromium, copper lead, nickel, and zinc were calculated for each sampling event. Figure 5 shows average loadings by sampling episode in storm water for TSS, average total recoverable metals (both segments), and average dissolved metals (SR37N only). Since no construction was occurring in the SR37S segment during this period, it is taken to be indicative of baseline runoff conditions in this area. In the SR37N segment TSS and total recoverable metals peaked during the construction period and post-construction loadings have declined to levels comparable with baseline values.

Total recoverable metals in runoff correlated well with particulate loadings (TSS) in the SR37N segment. Dissolved metals did not vary signifi-

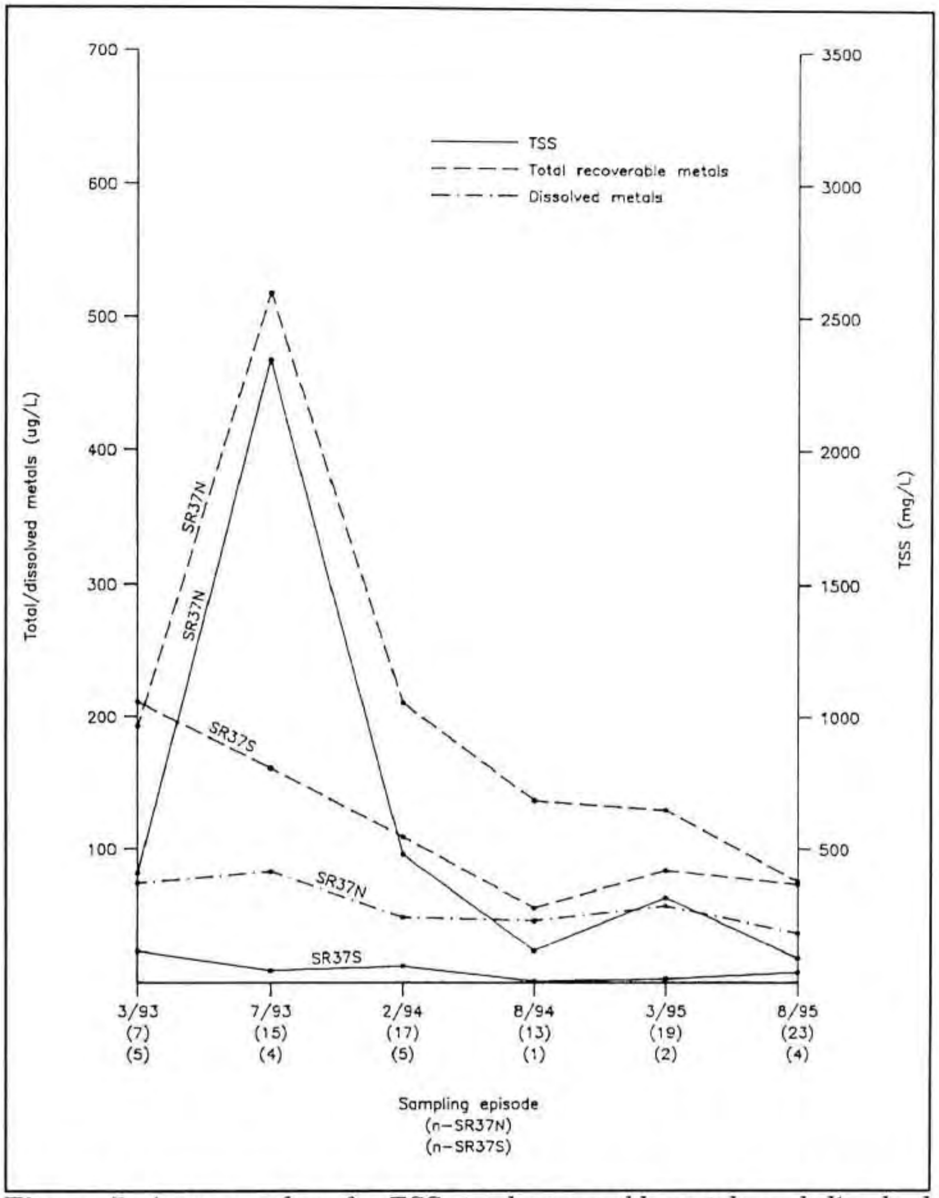

Figure 5. *Average values for TSS, total recoverable metals and dissolved metals loadings—SR37N and SR37S construction segments.*

cantly throughout the study. They are only a fraction of the total metals loadings and appear to be little affected by particulate loadings resulting from highway construction. An interim evaluation of SR37N drainage structure effectiveness based on storm event sampling is presented by Keith and others (1995). Drainage structures which rely upon basins and graded stone filters alone to treat runoff were found to have average removal efficiencies as high as 55.3 percent for TSS and Total Recoverable chromium, copper, lead, nickel, and zinc. Graded stone filters were found to be ineffective in removing dissolved metals. The peat filter at Sinkhole 9 had average removal efficiencies as high as 83.5 percent for TSS and Total Recoverable Metals and 48.7 percent for dissolved metals.

Runoff sampling will prove valuable in planning highway construction projects by identifying "hot spots" of total recoverable/dissolved metals or other pollutants at an early stage in the planning process so that treatment structures and right-of-way needs can be properly addressed.

Task 6 Findings

All SR37S drainage structures will employ peat filters. These will be constructed incorporating runoff detention basins and siphon traps. Experience with SR37N indicated that peat drainage structures required additional right-of-way land. Additional land was acquired in the SR37S corridor once space requirements for these structures were determined. Performance of these structures will be monitored as well.

Post-Construction Considerations

Road signs have been installed throughout the SR37N segment warning motorists that they are in an environmentally-sensitive area. The segment is visibly posted as a no-spray and low-salt zone for the benefit of highway maintenance crews. Future monitoring of runoff in the segment will allow INDOT to assess the effects of this signing strategy. Similar steps will be taken on the other road segments as required.

SR60

Physiography and Hydrology

This project is situated in the Mitchell Plain (Beede, 1911) and the Crawford Upland (Malott, 1922) physiographic units. The eastern project terminus is the junction of State Road 60 with

State Road 37 at Mitchell. About 1.4 miles west of Mitchell, the highway enters a dry re-entrant valley at the east edge of the Crawford Upland and follows the floor of this valley westerly. The Crawford Upland is characterized by hills and ridges underlain predominantly by clastic rocks assigned to the West Baden and Stephensport Group (Figure 2), These overlie limestones of the Blue River and Sanders Groups which form the floor of the re-entrant valley.

The re-entrant valley contains no flowing streams of any appreciable length and is referred to as the Beaver Creek Karst Valley (Figure 1). Karst development beneath the valley floor has diverted surface runoff from surrounding hill slopes into subsurface solution conduits via swallow holes and sinkholes. The Beaver Creek Karst Valley is joined by the main Beaver Creek about 7.4 miles west of Mitchell. Below this point for a distance of several miles, Beaver Creek is a normal surface drainage system that receives inflow from tributary valleys in the Crawford Upland. The highway runs parallel with Beaver Creek an additional 1.4 miles to the western project terminus at the junction with U.S. Highway 50. Near the town of Huron, about 1.5 miles west of the project terminus, Beaver Creek disappears in a series of swallowholes in the stream bed.

Beaver Creek and the dry re-entrant valley have received little study by geologists in the past. Subterranean drainage routes of the karst drainage system have remained largely unknown. There are few enterable caves in or near the valley floor and the few previous dye-tracing studies have been performed have been unsuccessful.

MOU-Related Tasks

Planned construction and upgrade for this segment of State Road 60 are limited in scope. With the exception of replacing a number of pipe arches and culverts, no extensive excavations are planned that would result in high sediment loads to runoff. In addition, surface drainage patterns along State Road 60 differ from those of State Road 37, in that there are a number of surface drainage ways that convey flow beneath the highway via pipe arches or culverts. Many of these drainage ways ultimately end at swallow holes, sometimes hundreds of feet down gradient from the highway.

The following tasks were conducted by INDOT and its consultant:

Task 1. Conduct literature reviews, interviews with knowledgeable sources, and field reconnaissance to locate and identify karst features that might be affected by planned construction and upgrade activities.

Task 2. Perform dye-tracing investigations to identify subterranean drainage routes of runoff entering karst features. Determine which features drained water to caves harboring *A. spelaea*.

Task 3. Provide recommendations for construction and erosion-control measures that will protect karst features, construction areas, and highway and slope stability.

Task 4. Determine surface drainage basin areas, drainage basin characteristics, pollutant loadings, and expected runoff to karst features that will receive runoff from construction areas in the project corridor.

Task 1 Findings

Based on a search of available literature, interviews with knowledgeable sources, field reconnaissance, and consulting construction plans provided by INDOT, 18 karst features were identified that could potentially be affected by construction and upgrade activities. Seven of these features were swallow holes receiving water from sinking streams, or were sinkholes with openings in the bottom or sides. Nineteen springs, caves, and points along surface streams were identified as potential dye monitoring points for Task 2.

Task 2 Findings

During the winter and spring of 1995 seven karst features identified in Task 1 were successfully traced to resurgence points located at the Orangeville Rise and Sulphur Spring in the Lost River drainage basin (Figure 1). As a consequence of heavy rainfalls that accompanied some of the dye injections, additional information was gathered about subsurface flow during periods of flooding. Dye injected at Feature 4 immediately following a 2.3-inch rainfall was traced to Sulphur Spring, Hooper Spring, and Beaver Creek downstream from Huron. This demonstrated the existence of multiple storm water overflow routes and resurgences associated with this portion of the drainage system. Similar storm-water overflow routes were discovered in the Lost River "dry bed" and Dry Branch north of Orangeville during the dye trace of Feature 20. Tracing results indicated that all highway runoff entering the subsurface may potentially affect the habitat of *A. spelaea*. Underground flow route information is being provided to IDEM for emergency planning in the event of a major highway spill.

Task 3 Findings

The State Road 60 roadway was constructed in the late 1930s, and has since received few modifications or upgrades. Following field location and description of karst features, potential problems were identified and pointed out to INDOT personnel during a field trip. One was a capped sinkhole with a standpipe that had been undermined as a result of soil piping and would require additional repair work (Feature 5 on Figure 1). A second consisted of a large swallow hole receiving drainage from about 500 acres (Feature 7 on Figure 1). The swallow hole had a standpipe installed which had subsequently become plugged with trash and debris. Ponded water had undercut the road embankment, and there was back flooding and inundation in the area of a large pipe arch that was to be replaced. Several recommendations for reducing back flooding, protecting the karst feature, and protecting the highway embankment were made. Proposed erosion-control methods at each feature were reviewed and modifications were recommended as appropriate to minimize impacts to karst features.

Task 4 Findings

A summary report was prepared by the Consultant for INDOT that locates and describes each feature identified in Task 1. Watershed size and land uses are discussed and expected runoff for 2-year, 5-year and 10-year 24-hour storm events are calculated for each feature. Pollutant loadings are estimated based upon the storm-water monitoring results from the State Road 37 corridor; and temporary erosion control measures and modifications to permanent structures are recommended. The document provides a permanent record of the karst features along the highway corridor and will be used as an aid in subsequent design work and contractor bidding.

Summary

The Indiana Memorandum of Understanding provides a formal interagency framework for identifying and addressing potential impacts to Indiana karst features that may result from highway construction projects. To date, construction work on about 16 miles of Indiana state highways has come under the provisions of the MOU. Information generated by MOU-mandated studies is now incorporated into project-specific INDOT planning, bidding, construction, and post-construction procedures in karst areas.

MOU information should be of value to agencies that must plan and implement impact studies and mitigation measures in other karst areas of the United States. Information will be made available to a wider audience through dissemination to interested local, state, and federal agencies, and publications in scientific journals, symposia proceedings, and trade journals. Although MOU studies are intended primarily for use in highway construction projects, many of the findings should prove useful to a variety of construction and development projects. The results of MOU dye-tracing studies should be of interest to geologists and hydrogeologists, and will increase overall understanding of the dynamics of subsurface water flow in karst systems. Agencies that must plan and implement emergency responses to catastrophic highway spills will find the dye tracing results to be beneficial in cleanup operations and protecting public health and safety.

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The Discovery of Aboriginal Mud Glyphs in Bath County, Virginia

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Abstract

Aboriginal Cave Art in the eastern United States is very rare with only one previously known occurrence in Virginia. On September 3, 1994, a second site was discovered in a little known cave located in the George Washington National Forest, Bath County, Virginia. The events leading to the discovery and the significance of the discovery will be discussed.

Introduction

On September 3, 1994, Roy Powers, Professor of Mountain Empire Community College, and I set out to investigate possible resources in a little-known cave, Little Mountain Cave, located in Bath County, Virginia. Mr Powers and I had been contracted by Ferrum College, in Ferrum, Virginia, to investigate cave resources in the caves owned by the George Washington National Forest.

Approximately 500 feet beyond the entrance of Little Mountain Cave, I noticed numerous unusual markings on a smooth, vertical mud wall. I called this to the attention of Mr Powers, who agreed we may have made an extremely significant discovery. At this time we exited the cave and proceeded to report our discovery to the proper authorities. The George Washington National Forest was quick to respond with funding to authenticate our discovery. George Tolley, an archaeologist for George Washington and Jefferson National Forest and David Hubbard, a Geologist for the Virginia Division of Natural Resources collected radiocarbon samples from four sites in Little Mountain Cave.

Aboriginal cave art in the eastern United States is very rare with only one previously-known occurrence in Virginia. The results of the radiocarbon samples collected validated Little Mountain Cave to be the second site discovered in Virginia.

Telephone Interview with George Tolley

On October 20, 1995, I spoke with George Tolley regarding radiocarbon dating of charcoal samples collected at Little Mountain Cave. He revealed the radiocarbon dates to be 975 AD, 1030 AD, 1235 AD, and 1425 AD. He also explained that close to the back of the cave, after going through an extremely tight crawl space, charcoal was scraped from flowstone, which turned out to be the oldest of the dates, 975 AD. Directly above that, on a little ledge, there was more charcoal taken which dated back to 1030 AD. Midway between the back and the front of the cave, underneath another set of mud glyphs, a third charcoal sample was taken. This dated 1235 AD. Closest to the entrance, in the 1860s Room, a fourth charcoal sample was collected. Tolley said, "This room had the most fascinating glyphs, with chevrons. In fact there was one, it had an ellipse within an ellipse, and from there, there were chevrons that came off of it and went up and over the top of the ceiling and down so that you actually had to lie on your back to see that." These came out to be 1425 AD. The charcoal samples were taken from beneath the ellipse within the ellipse.

Tolley pointed out that this is his speculation and his only; He said, "Much of what we saw was what they call spaghetti or macaroni which are just squiggles. There are places in the mud wall where there are obvious bear claw marks, real bear claw marks in either threes or fours, depending on how many claws were extended at the time. This is not speculation but what we can call fact, when you look at those glyphs, you cannot look in terms of individual lines. Individuals do not mean anything, they're in groups of three or four and if you can train your mind not to think of individual lines but to look at threes or fours, I think that we will be able to get more meaning out of them."

Tolley also revealed that there were places in the cave where people actually seemed to have gouged big chunks of clay out with their fingers. The goal of the National Forest is to have the cave mapped and get good photographic and video camera documentation so the mud glyphs can be studied further. (Tolley, 1995.)

Telephone Interview with Dr Charles Faulkner

Little Mountain Cave was also investigated by Dr Charles Faulkner, an expert on mud glyphs, pictographs, and petroglyphs. Dr Faulkner is an anthropologist with the University of Tennessee, in Knoxville, Tennessee. I spoke with Dr Charles Faulkner October 26, 1995 . He suggests the glyphs discovered in Little Mountain Cave and Williams Cave, the only other known site in the eastern United States, are very similar. These mud glyphs were of the Late Woodland or Mississippian period. (Faulkner, 1995.)

A research team from the University of Tennessee studied the glyphs in Williams Cave. The radiocarbon dating of three collected samples produced a "tight cluster of dates between 995 AD and 1060 AD" (Faulkner, 1988).

The glyphs in Williams Cave are similar to those found in the 1860s Room of Little Mountain Cave. The glyphs in Williams Cave are also located on smooth vertical walls thinly coated with silty mud. The glyphs found on two walls of Williams Cave are arranged in "wavy serpentine lines in groups of threes and a palimpsest of vertical and horizontal lines." The majority of these glyphs have been drawn with fingers. However, there were a few lines that had been drawn with the end of a stick. The clay walls also had gouge marks which seem to have been made with fingertips (Faulkner, 1988). These glyphs differed greatly from other sites found in Kentucky. Crumps Cave, located in Kentucky, was approximately dated as 2000 to 3000 BC. Rogers Cave, also in Kentucky, dated approximately 1200 to 1700 BC. These sites do not have the sort of classic Mississippian Southern Cult motifs discovered in Little Mountain Cave and Williams Cave. The 1235 AD and 1425 AD dates are similar to the majority of dates taken from Mud Glyph Cave. The correlation between the prehistoric Indians entering Little Mountain Cave and the dates of the radiocarbon samples insinuate these mud glyphs are the creation of these prehistoric Indians. The big question being asked is why these prehistoric Indians were drawing these glyphs in the caves? (Faulkner, 1995.)

Research was funded in Mud Glyph Cave in 1982 by the National Geographic Society. This research suggests the thousands of trailed and incised designs were created during the Mississippian period near 1300 AD (Faulkner, 1986).

"These 'mud glyphs' included a number of Southern Cult motifs in addition to many designs not previously attributed to Mississippian artists, indicating this art was probably a ritual expression in some kind of subterranean ceremony. While increased knowledge of Mississippian religious symbolism was an important contribution of the Mud Glyph Cave research, more significant was the revelation that some eastern North American caves were used for ceremonial purposes, especially during the late prehistoric period." (Faulkner, 1988)

Summary

The significance of this discovery is extremely important to future knowledge of the prehistoric Indians. As there is only one other known site in the eastern United States containing aboriginal cave art, experts now have this site (Little Mountain Cave) to compare with the only other known occurrence, Williams Cave. As more sites are discovered, more information is collected and more patterns are formed. Maybe more discoveries will allow us to answer questions such as why these prehistoric people entered the caves leaving evidence of their presence behind. What did these mud glyphs represent for the prehistoric Indians?

Little Mountain Cave has been gated since this discovery. During the summer of 1995, Roy Powers who engineers "bat gates" at the entrances of caves, and I were again contracted by the George Washington National Forest to build a "bat gate" at the entrance of the cave. The purpose of the gate at this site is to protect the many wonders which lie inside Little Mountain Cave and to allow this cave to be studied without further disturbances from the outside world.

Acknowledgments

A note of appreciation is due to both George Tolley and Dr Charles Faulkner for supplying information pertinent to the descriptive process involved in discussing the mud glyphs discovered in Little Mountain Cave. My gratitude also goes to Dr John Leffler of Ferrum College and Roy Powers of Mountain Empire Community College for their support regarding the discovery of the mud glyphs in Little Mountain Cave.

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The Devastation and Recovery of Caves and Karst Affected by Industrialization

Julian J. Lewis, PhD

Abstract

The effects of industrialization on two karst areas are presented herein:

The Hidden River Cave system in central Kentucky was commercialized in 1916, co-existing with water pumping and hydroelectric generating systems. However, increasing groundwater contamination from indiscriminate sewage disposal led to closing of the cave's tourist operation in 1943. In 1970 industrialization of the area included the addition of waste water from a chrome-plating factory to the sewage plant effluent entering the cave. The troglobitic community was extirpated as a result of degradation of the cave. In 1989, new sewage-treatment facilities were opened and the flow of effluent to the cave stopped. Now, about five years later, the original animal community has substantially recolonized the once-heavily-polluted section of the cave.

The Indiana Army Ammunition Plant covered an area of 10,649 acres along the Ohio River near Charlestown, Clark County, Indiana. The plant was constructed during World War II for the production, shipping, and storage of nitrocellulose propellant. This industry was built on a karst area of Devonian and Silurian limestones replete with caves, sinks, and springs. As documented by Wickwire (1947), the caves of the Jenny Lind Run drainage received an estimated 22,500 gallons per minute of nitric acid as a waste product of the nitrocellulose production process. The caves were presumably sterilized by the presence of the nitric acid. Now, 50 years later, six species of troglobites have recolonized the nitric acid caves of Jenny Lind Run. The aquatic troglobite *Caecidotea stygia* has recolonized all of the caves and springs on Jenny Lind Run. Terrestrial troglobites inhabiting the caves include *Pseudotremia nefanda*, *Litocampa* sp., *Pseudosinella* sp., *Spelobia tenebrarum*, and *Phanetta subterranea*.

Introduction

The tale told herein is that of the destruction and recovery of two cave systems that were used as convenient receptacles for the waste products of industries. In the first example, the Hidden River Cave System of central Kentucky received a combination of toxic metals from a chrome-plating plant and creamery waste. This waste was mixed with domestic sewage and then injected via wells directly into the groundwaters of Hidden River. The account herein is an updated version of my previous reports on the cave (Lewis; 1990, 1993a, 1993b).

The second case is that of the caves and karst of the Jenny Lind Run at the Indiana Army Ammunition Plant, near Charlestown, Indiana. At the Ammunition Plant, the waste products of smokeless powder production were a complex mixture of inorganic acids containing an assemblage of organic chemicals. This chemical waste was discharged into Jenny Lind Run, where it profoundly modified the karst. The effects were first chronicled by Wickwire (1947).

The Hidden River Cave System

The Thomas Era

Initially known as Horse Cave, the town of the same name grew up around the yawning entrance to the cave. Ironically, Horse Cave gained notoriety in the late 19th century when the cave itself was the home of an industry. In 1887 the owner, Dr G.A. Thomas (a dentist), built the first of a succession of waterworks in the cave. The first system installed consisted of a 10-inch intake and hydraulic ram that pumped water to a surface standpipe via a 2.5-inch pipeline. In 1890 a dam was constructed just downstream of the entrance and a vertical-shaft turbine was installed. Although this stone dam reached to within a few feet of the cave's ceiling, a notch through the center allowed a boardwalk trail to traverse it. A piston pump was placed near the bottom of the entrance slope, with a booster pump installed just inside the iron fence under the dripline of the cave.

In 1892 Dr Thomas purchased an electrical generator and installed it in the cave. Thus, Horse Cave was one of the first towns in Kentucky to have electricity. Incandescent lights were first installed in Dr Thomas' home (located directly over the cave entrance), the dental office, a store and one other building in the town.

Dr G.A. Thomas died in 1905 and his son, Dr Harry B. Thomas (also a dentist) inherited the property and continued to operate the waterworks. He placed a large three-cylinder pump on a ledge over the cave river to increase the capacity of the system. The cave was first opened for business as a tourist attraction in 1916 under the name of Hidden River Cave.

The Demise of Hidden River

Dependence on Hidden River as a municipal water source declined as wells were more frequently used. However, starting with the drought of 1930, there was increased demand on the cave's water for several years. In 1931, oil refinery waste dumped into a sinkhole south of the cave appeared in Hidden River. Several cases of typhoid were attributed to the contaminated water of Hidden River during this period of time and a chlorinator was installed in 1932. The town of Horse Cave was finally forced to develop Rio Springs, on the north side of the Green River, as a water source.

Although its days as the municipal water source were over, Hidden River Cave continued to be operated as a tourist attraction until 1943. At that time, according to Bill Austin, the commercial operation succumbed to a combination of groundwater pollution from creamery waste and declining tourism due to the gas and rubber rationing of World War II.

The fauna of Hidden River Cave prior to its degradation by pollution was only partially recorded. However, enough can be reconstructed from the bits and pieces of records to get an idea of what animals were present in the cave. The Horse Cave blind fish (*Typhlichthys osborni*) was described by Eigenmann (1909) from specimens taken from Hidden River Cave (this species is now a synonym of the Southern cavefish, *T. subterraneus*). During the French expedition to U.S. caves in 1928, the blindfish were also seen and 17 specimens of the cave crayfish *Orconectes pellucidus* were collected (Bolivar and Jeannel, 1931). Other species reported from this expedition were the harpacticoid copepod *Echinocamptus morrisoni* (Chappuis, 1931), cave crickets *Hadenoecus subterraneus*, *Ceuthophilus brevipes*, and beetles *Pseudanophthalmus menetriesi*, *Neaphaenops tellkampfi*, and *Ptomophagus hirtus* (Jeannel, 1931).

Bailey (1933) reported that during a 1929 visit the blindfish were seen in the stream below the dam. At that time the guides reported the fish to be so common that they were given to tourists as souvenirs. The last known occurrence of a troglobite in Hidden River Cave prior to its polluted era was the collection of the amphipod *Crangonyx packardi* (sensu latu) by Leslie Hubricht in 1939 (John Holsinger, personal communication).

Until 1964, residential sewage in the Horse Cave area was disposed of through septic fields or outhouses; creamery waste was dumped into sinkholes. In 1964 the Horse Cave Sewage Treatment Plant was completed and started receiving all of the town's sewage. At first a sinkhole behind the plant was used for the effluent discharge, but when it became clogged, two disposal wells were drilled. Both the sinkhole and the wells drained into the South Branch of Hidden River Cave. During this same period a similar sewage treatment plant was constructed at Cave City. It discharged its effluent to a sinkhole draining to the East Branch of Hidden River.

The effluent being discharged to Hidden River was particularly rich due to its high content of creamery waste. Bill Austin tells that at one time he attempted to walk up the South Branch to see where the waste entered the cave. He was prevented from reaching that point by accumulations of rotting creamery waste which were chest deep.

In 1970 the first of several other industries sprang up in Horse Cave along State Road 31W, just south of the Hart County Creamery. The Ken-Dec chrome-plating plant started operation and contributed about two-thirds of the influent waste water at the Horse Cave treatment plant. This sewage was heavily laden with metals (Table 1) at concentrations toxic to aquatic life (EPA, 1981, Quinlan and Rowe, 1977). Like other sewage-treatment plants, the Horse Cave facility's secondary treatment relied heavily on biological treatment. The rock filter bed of the trickling filter unit, usually covered with a microbial film that would break down the sewage, was poisoned by the heavy metals. Thus, little secondary treatment was afforded prior to discharge of the effluent to Hidden River. The presence of the metallic ions in Hidden River allowed the discovery of the river's resurgence on the Green River by the anomalous conductivity of these springs when compared to adjacent unpolluted springs. Later confirmed by dye tracing, the Hidden River groundwater basin

	Horse Cave STP influent	Horse Cave STP effluent	Hidden River Cave South Branch
heavy metals, mg/l			
Chromium (total) 5.0 (0.05)	0.156-21.7	0.810-4.75	0.202-8.90
Nickel 5.0	0.198-27.2	6.21-12.2	1.15-19.4
Copper 0.02 (1.0)	0.090-5.36	2.95-4.72	0.30-1.17
Zinc 0.3 (5.0)	0.220-11.9	0.396-0.952	0.074-2.12
other ions, mg/l			
chloride	35-216	35-110	11-48
sodium	61-213	70-480	28-197
potassium	10.6-59.0	4.45-114	2.95-54.0
specific conductance umhos/cm	715-8000+	960-1350	299-690
sample size	13	10	8

Table 1. *Results of water samples at the Horse Cave Sewage Treatment Plant (STP), indicating minimum-maximum values and EPA criteria for toxicity to aquatic life (in parenthesis)(Quinlan and Rowe, 1977)*

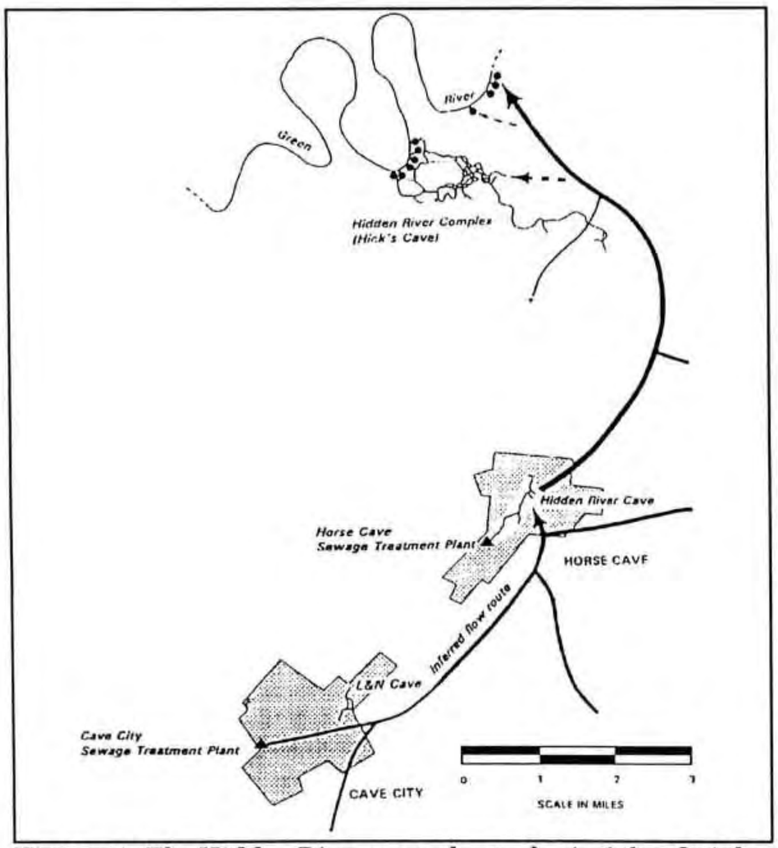

Figure 1. *The Hidden River groundwater basin (after Quinlan and Rowe, 1977).*

was delineated by Quinlan and Rowe (1977) (Figure 1).

On July 30, 1982, I entered Hidden River Cave for the first time. The stench coming out of the cave was nearly overwhelming. The predominant life seen in the South Branch stream consisted of bright red tubificid "bloodworms" (*Tubifex*) along the silt edges of the stream and gray strings of the sewage bacterium *Sphaerotilis natans* clinging to rocks and boards. Similar to that found in the Enviromental Protection Agency (EPA) report (1981), the dissolved oxygen was about 1.5 milligrams per liter (mg/l) and the stream temperature was nearly 19° Celsius. Two stream pools totaling 85 feet in length were observed in the South Branch for fauna. These pools would become the measuring stick of the destruction and recovery of Hidden River's community.

Along with the heavy metals (Quinlan and Rowe, 1977), the EPA (1981) also reported the Biological Oxygen Demand (BOD5) of the South Branch water at 133 mg/l, almost as high as untreated sewage (typically about 200 mg/l). The water from the East Branch, contaminated by the South Branch under low flow conditions, had a reported coliform MPN of 17,500/100 ml (200/100 ml was considered the maximum safe level for even secondary contact per EPA standards) (EPA, 1981). In the pool downstream from the dam, where the sewage was diluted by the water of the East Branch, the tubificids and sewage bacteria were still present. Also present were 26 large troglophilic crayfish (*Cambarus tenebrosus*). Not surprisingly, troglobites were not found.

The Recovery

Periodic visits were made to Hidden River with the invariable result: unbearable stench emanating from the cave's polluted stream and ever-present sewage community. In 1981 the EPA draft proposal for regional sewage treatment alternatives was presented. Of the four primary contributors (Horse Cave, Cave City, Park City, Mammoth Cave National Park), the alternative in which the Horse Cave and Cave City sewage treatment plants would be upgraded was chosen. The plan included the discontinuation of subterranean effluent discharge, instead entailing a pipeline routing the more-adequately-treated effluent directly to the Green River for discharge. On December 16, 1989, the new Horse Cave Sewage Treatment Plant started operation. The discharge of effluent to Hidden River was discontinued and the discharge wells were destroyed. The recovery of the animal community in the South Branch of Hidden River Cave is summarized in Figure 2.

My first trip to the cave after the sewage was diverted was March 3, 1990. The two stream pools in the South Branch still contained only *Tubifex* and *Sphaerotilus*. A single *Cambarus tenebrosus* occurred in the interface between the South Branch and East Branch streams. The water coming from the South Branch was creamy in color (it had the appearance of diluted milk); the East Branch water was clear.

On October 10, 1990, the *Tubifex* were not seen, but strings of *Sphaerotilus* still clung to the rocks. A single *Cambarus* was found crawling around the mudbank adjacent to the 85-foot stream pool census area. No organisms other than the sewage community were found upstream in the South Branch at this time. However, on this visit the troglobitic isopod *Caecidotea bicrenata* was found

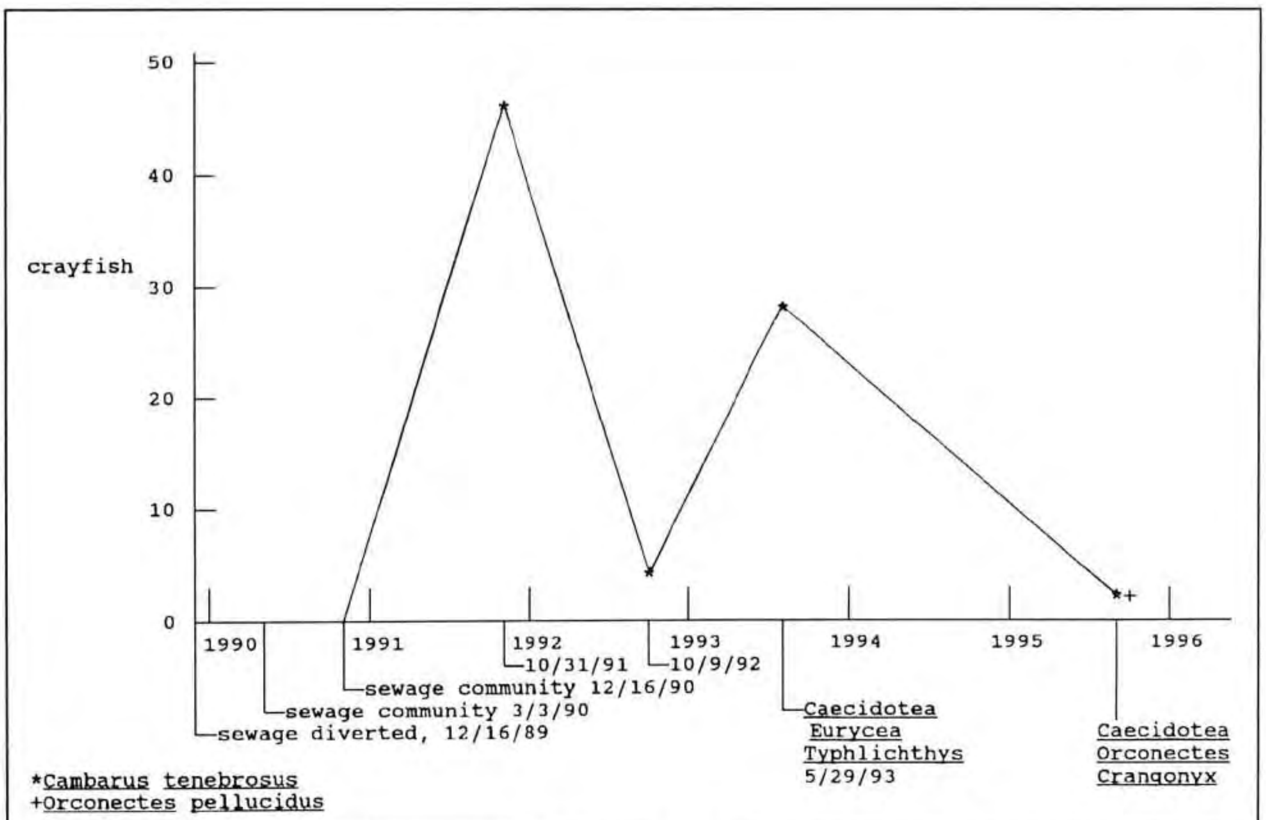

Figure 2. *The chronology of the recovery of the stream community in the South Branch of Hidden River Cave. Crayfish population is for an 85-foot (26-meter) section of stream divided into two mud-bottomed pools, littered with breakdown.*

for the first time in the downstream end of the large pool below the dam.

On December 16, 1990, one year after the sewage had been turned off, the stream flow was grayish in color and the *Tubifex* were back in force, along with the sewage bacterial strings. My next trip, on October 31, 1991, found an amazing change in the cave. The odor was significantly decreased, the water in the South Branch was clear and 45 *Cambarus tenebrosus* were present in our two stream pools. One year later, October 9, 1992, most of the crayfish population had disappeared. The water was milky-looking again. At that time we found three *Cambarus* in the pools, one of which was sitting out of the water on a small island of breakdown.

On May 29, 1993, the water was again clear and 29 *Cambarus* were present. For the first time, other animals were present in the stream pools of the South Branch. We also found three small larvae of the cave salamander, *Eurycea lucifuga*, in the edges of the stream. On the undersides of the rocks were *Caecidotea bicrenata*, the first troglobites seen in the South Branch in 54 years. However, the big surprise of that day was the presence of a cavefish, *Typhlicthys subterraneus*, swimming in a South Branch stream pool just downstream of the first dome room.

My most recent visit to the cave was on September 17, 1995. This inspection of the South Branch stream revealed further progression of the recovery of the ecosystem. For the first time, one troglobitic crayfish, *Orconectes pelludicus* (an 80-millimeter female), was present in the stream pools that we had been monitoring for 13 years. Only one *Cambarus* (125-millimeter female) was present. A rock census revealed eight *Caecidotea bicrenata* distributed on 20 rocks pulled from the upstream pool. And finally, the last troglobite to be seen in the cave before its destruction, the amphipod *Crangonyx packardi* (in the broad sense; this is actually an undescribed species of *Crangonyx*, John Holsinger, personal communication) made its debut in the "new" Hidden River.

Now, five years after the sewage was diverted from Hidden River Cave, the ecosystem has made significant steps toward the re-establishment of its original community. Of the four macroscopic species previously recorded from Hidden River (*Caecidotea bicrenata*, *Crangonyx packardi* s. latu, *Orconectes pellucidus*, *Typhlichthys subterraneus*), all have now been observed in the South Branch. The recovery of the stream community in the South Branch of Hidden River has been expedited by recolonization via the nearby East Branch stream passage.

A few other species are potential inhabitants of Hidden River, but unfortunately their presence or absence prior to pollution of the cave was not documented. Of particular interest are the cave shrimp *Palaemonias ganteri* and the cave snail *Antroselates spiralis*. Both are found in base-level cave rivers in the Mammoth Cave area. Only time will tell if these or other troglobitic species will eventually be found in the former devastated zone of Hidden River Cave.

The Nitric Acid Caves of the Indiana Army Ammunition Plant

The facility now known as the Indiana Army Ammunition Plant (INAAP) was opened in 1941 for the production of smokeless powder propellant charges to supply the U.S. military during World War II. The facilities were originally called the Indiana Ordnance Works Plant 1 (propellant and explosives area, "P&E"), Hoosier Ordnance Works (load, assemble, and pack, "LAP"), and the Indiana Ordnance Works Plant 2 (Double-Base Rocket Propellant Plant). During World War II the Ammunition Plant employed 19,000 people. In 1945 the facilities were consolidated into the Indiana Arsenal, then redesignated the Indiana Ordnance Plant in 1951. Finally, in 1963 the name was changed to the Indiana Army Ammunition Plant (Environmental Assessment, 1992).

The INAAP occupies an area of 10,649 acres along the Ohio River in Clark County, Indiana. The plant was built on karst in which features such as sinkholes, solution enlarged joints, caves, and springs are common. Most of the caves were formed in the Devonian Jeffersonville Limestone or the Silurian Louisville Limestone. The area of primary interest herein is the Jenny Lind Run drainage. This approximately four-mile-long stream empties into the Ohio River about 13 miles upstream from Louisville, Kentucky. Several caves that drain northward into Fourteen Mile Creek are also known to underlie the propellant facility.

The chronology cited here of modifications to the karst features of Jenny Lind Run caused by the discharge of industrial waste were documented by Wickwire (1947). Information on INAAP structures and additional documentation of effluent components were taken from the INAAP Environmental Assessment (1992). Stratigraphy of the area was drawn from Powell (1967) and Hendricks, *et al.* (1993). Approximate elevations were taken from the 1963 (revised 1991) U.S. Geological Survey Charlestown, Indiana quadrangle map.

Phase 1 (1940 to April 1941)

In 1940 construction started on what would become 1,400 buildings. Jenny Lind Run was slated to be used as a conveyance for liquid industrial waste to be discharged to the Ohio River. Sinkholes in the upstream part of Jenny Lind Run were channelized and connected to form a continuous drainage ditch to receive the effluent of the sewage outfall. The stream was lengthened artificially to reach a point near the nitric acid production facility. A site called the "Aniline Pond" also drained into Jenny Lind Run and joined the sewage from the plant outfall. Adjacent to the Aniline Pond was the South Ash Settling Basin (known as ASB 611-2). Solid waste produced by the coal-burning electric generating plant at Powerhouse 401-2 were ground, slurried in water, then pumped to this basin for disposal.

Phase 2 (April 1941 to October 1942)

Starting in April 1941 nitrocellulose explosives were made at INAAP. The manufacturing process consisted of oxidizing ammonia to nitric acid, concentrating the acid, then combining it with cotton, which resulted in nitrocellulose. The primary waste product of this process consisted of a reported average of 22,500 gallons per minute of nitric acid, discharged at a temperature of 80° Fahrenheit and a pH of 2.3. Peak flows (late summer) increased to 32,000 gallons per minute. Among the substances included in this effluent were sulfuric acid, particulate nitrocellulose, nitrobenzene, aniline, and domestic sewage. Pulverized limestone was added to the effluent to bring the pH up to 3.2.

This effluent was discharged to Jenny Lind Run and flowed via this "open ditch" to the Process Waste Settling Pond about two miles downstream. This settling pond was created for the purpose of water purification. After sedimentation of the particulates in the effluent, the purified water flowed through a spillway with numerous baffles designed to oxygenate the water (Powder Horn, 1941).

Phase 3 (October 1942 to March 1943)

In the fall of 1942, probably sometime in October, the first major change in the Jenny Lind Run karst occurred. At this time the effluent disap-

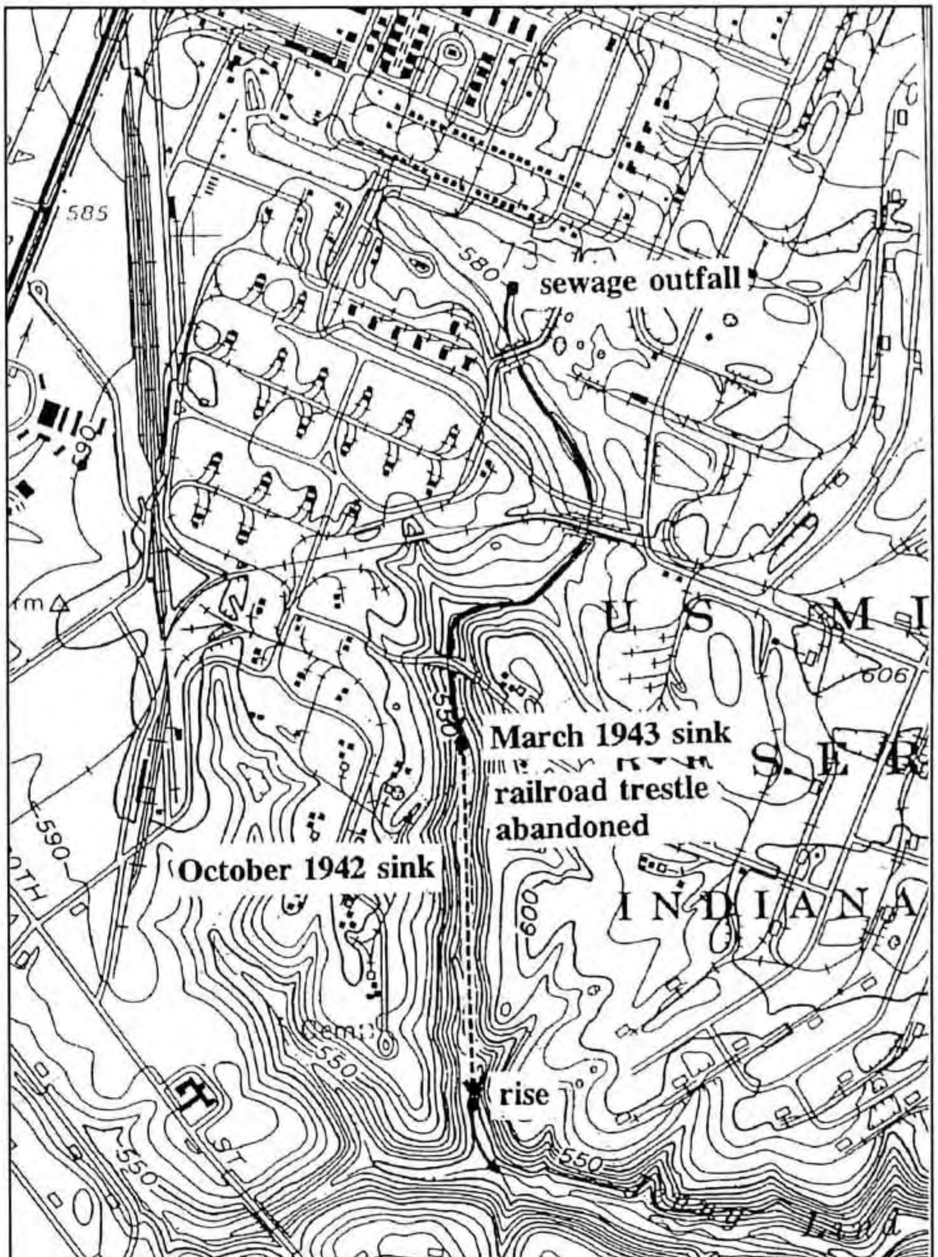

Figure 3. *The Jenny Lind Run drainage as it appeared in March, 1943. Surface drainage is indicated by a continuous line, subterranean drainage is shown by a dashed line.*

peared into a swallowhole and reappeared 1,750 feet downstream at a spring (Figure 3). The portion of the stream abandoned was not again used for surface flow. Wickwire measured the amount of stream entrenchment into the limestone bedrock in three places. At the first site, 50 feet downstream of the swallowhole, the entrenchment averaged 5 feet, 6 inches in depth and 7 feet, 5 inches in width. At the second site, midway in the abandoned stream channel, entrenchment was 8 feet 1 inch deep and 7 feet 2 inches wide. At the third site, from 15 to 50 feet abovethespring,theentrenchmentaveraged7 feet,6inchesdeepby8feet,6incheswide.

Phase 4 (March 1943 to May 1943)

In March of 1942 a new swallowhole opened about 1,000 feet upstream of the first hole. The effluent continued to reappear at the same spring. Stream trenching in the newly-abandoned section of Jenny Lind Run varied from 2.5 to 3.5 feet in depth and was about 10.5 feet in width. A railroad trestle crossing Jenny Lind Run between the two swallowholes was abandoned due to fears that it would collapse because of the undermining of the bedrock (Louisville Limestone) by the acid.

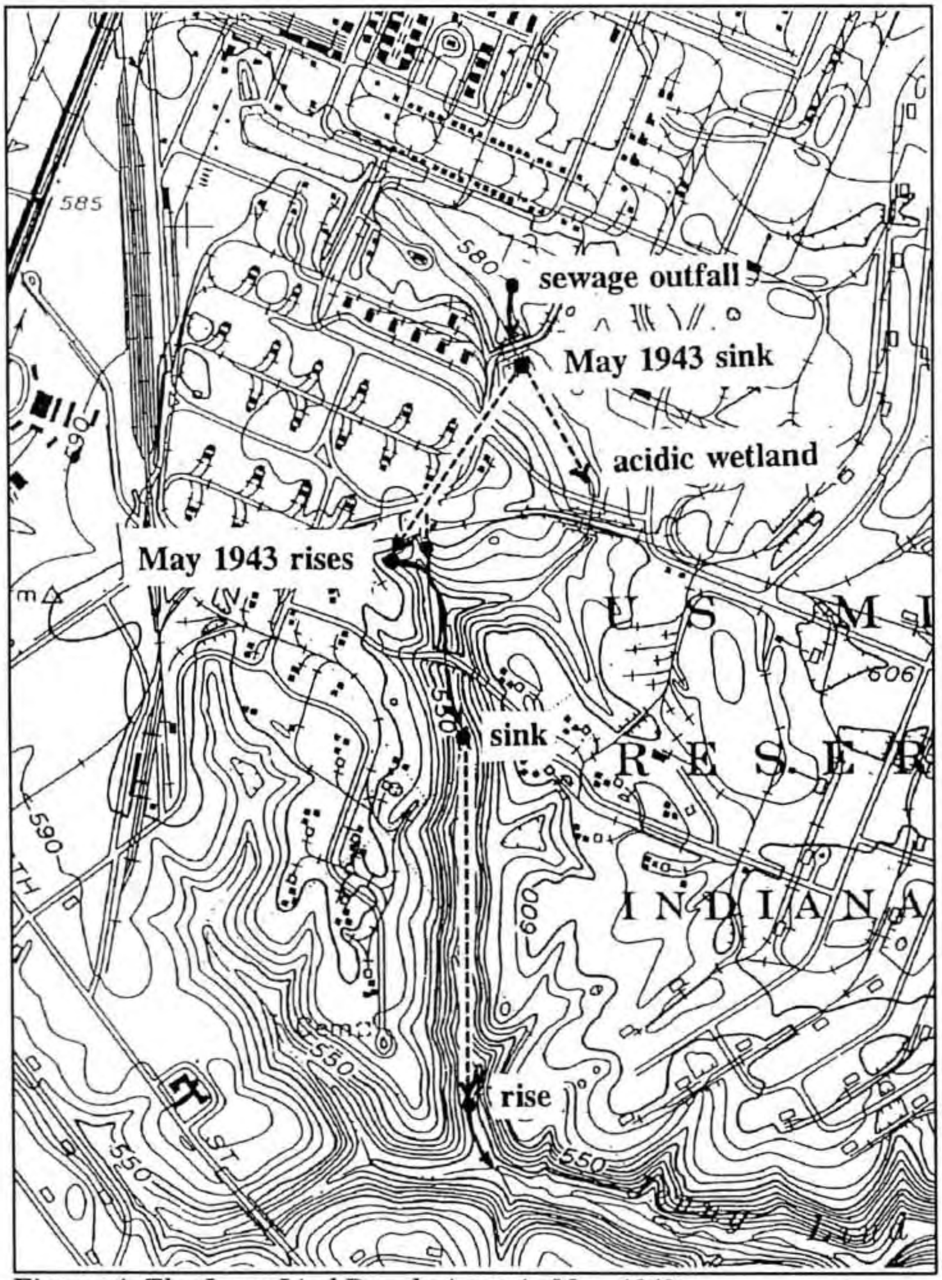

Figure 4. *The Jenny Lind Run drainage in May, 1943.*

Phase 5 (May 1943 to July 1944)

Two months later a new swallowhole appeared (Figure 4) considerably further up the valley, only 800 feet below the outfall and directly downstream of a vitrified culvert carrying the stream under a railroad. The upstream part of the effluent flow now sank at this swallowhole, then re-emerged at two different springs, at least one of which was formerly a small cave. Some of the effluent created an acidic wetland, killing most of the vegetation. The section of stream above this new swallowhole was trenched as much as 8 feet, 4 inches deep and a similar width.

After flowing through the first subterranean conduit, the waste water surfaced and flowed down Jenny Lind Run tothesecondswallowhole,whereitagainsankand reappearedattheoriginalspring.

Phase 6 (July 1944 to October 1945)

In midsummer 1944, a large cave-in occurred 225 feet below the outfall, creating a new swallowhole. Besides the two springs and wetland described in phase 5, acid waters also started flowing from a cave in an adjacent tributary valley of Jenny Lind Run (Figure 5). The entrance to this cave contained a concrete dam. Rather than breaching the dam, the acid dissolved a hole 56 inches deep and 48 inches wide underneath the dam. The stream of this side valley is trenched downstream to the confluence with Jenny Lind Run.

The manufacture of nitrocellulose (and the discharge of waste to Jenny Lind Run) was discontinued in October 1945 with the cessation of hostilities in World War II.

Phase 7 (Korean War Era)

Powder production resumed in 1950. Documentation of acidic waste in the fashion of Wickwire (1947) was not done, but presumably nitric acid was again discharged to Jenny Lind Run. In 1953 the Jenny Lind flume was built. This structure was a heavy wooden trough five feet wide by four feet deep that extended several thousand feet from the sewage outfall to just below the downstream spring resurgence, bypassing all of the swallowholes and caves.

Phase 8 (October 1995)

At the time of this writing many of the karst features created during World War II are still present. I have inspected (on foot) the section of Jenny Lind Run between the upstream headwaters and the furthest downstream spring. Documentation of the karst features of Jenny Lind Run has been done (Figure 6) in some detail to allow future comparisons.

At the upstream artificial extension of Jenny Lind Run is a sign "INAAP-5, Aniline Pond." This pond and the ash basin were shown on the 1991

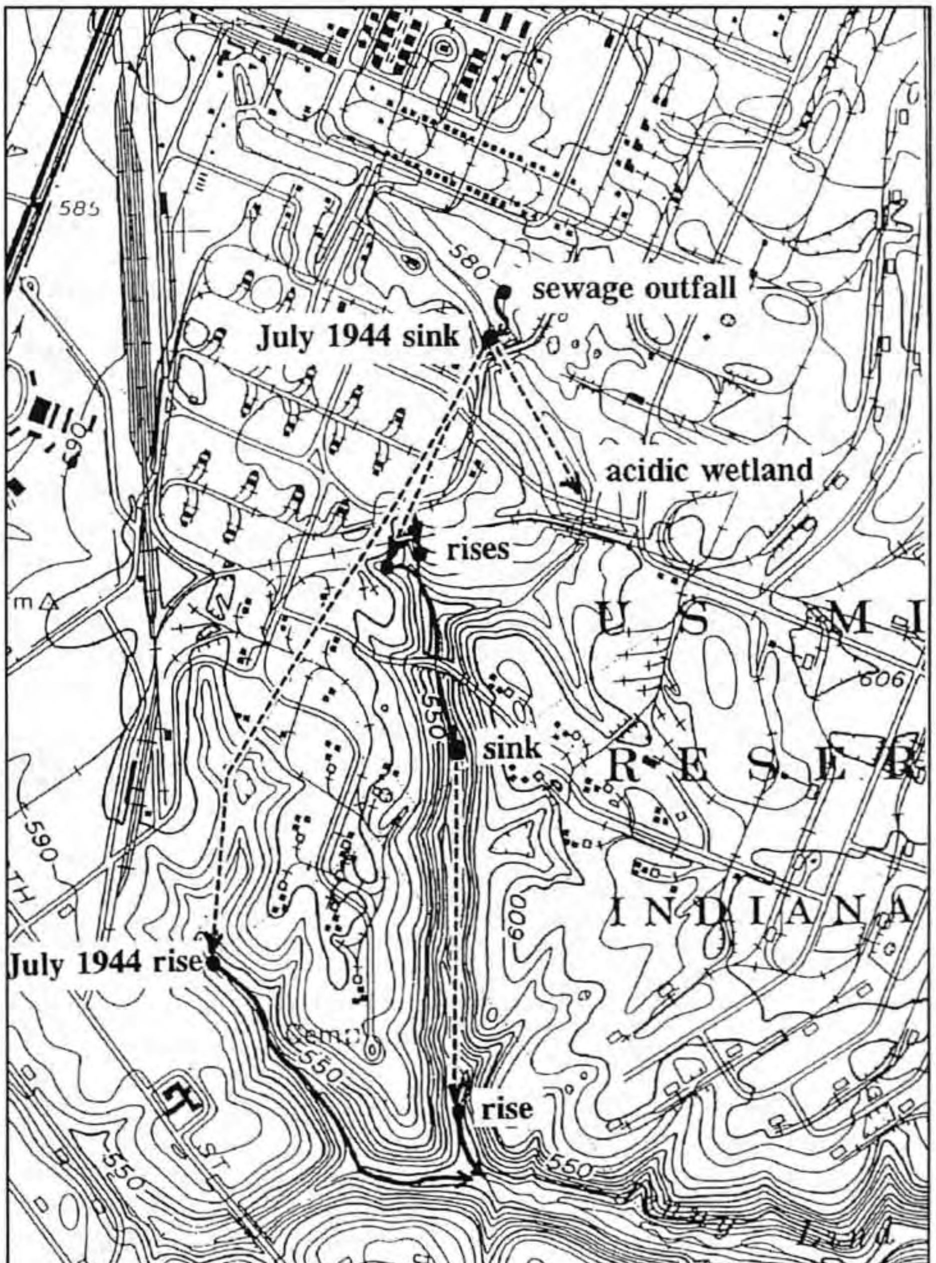

Figure 5. *The Jenny Lind Run drainage in July, 1944.*

revision Charlestown quadrangle map. The ponds have been drained and the area is a grassland. Downstream from the ponds the five, three-foot-diameter sewage pipes described by Wickwire (1947) as the plant outfall remain, but are dry. A red brick dam has been constructed across the outfall. This dam diverted flow to the far side of the original yellow brick basin to another set of pipes that routed the effluent downstream to a second masonry basin. This second basin was built on top of the original stream bed that led to the tile passage through a railroad grade. On the south side of the railroad grade a third yellow brick basin junctions with the upstream end of the Jenny Lind Flume.

From the outfall, continuing down the dry stream bed entrenched limestone is first encountered, then a small spring. The water emerges from a nine-foot-long, horizontal cavity in the Jeffersonville Limestone. Under stones in the orifice of the spring were found the obligate subterranean isopod *Caecidotea stygia* and the spring flatworm *Phagocata gracilis*. The spring stream flows 81 feet to the presumed swallowhole of July 1944. Here the stream flow sinks below a 45-foot-long, 8-foot-high limestone cliff. The elevation is about 580 feet. An orifice approximately eight feet wide was choked with debris, but an enterable stream crawlway 15 inches high was present. On the north side of the swallet a natural bridge about nine feet wide separates a sink from the entrenched stream. This natural bridge and sink lead toward an adjacent 75-foot-long, U-shaped collapse sinkhole about 15 feet deep. Three more similar natural bridges are part of this sinkhole.

Directly above the swallowhole to the west a railroad has been destroyed by the formation of a sinkhole, with 38 feet of the rails hanging over the overgrown sink. A similar sink, recent in origin with fresh dirt walls, has undermined a 12-foot section under one rail of a track to the southeast of the swallowhole. This has left the crossties and track hanging over an 11-foot-deep hole on one end of a 40-foot-long sinkhole. The Speed Member of the North Vernon Limestone is exposed in the lower walls of the sink.

The May 1943 swallowhole could not be located. A third down-

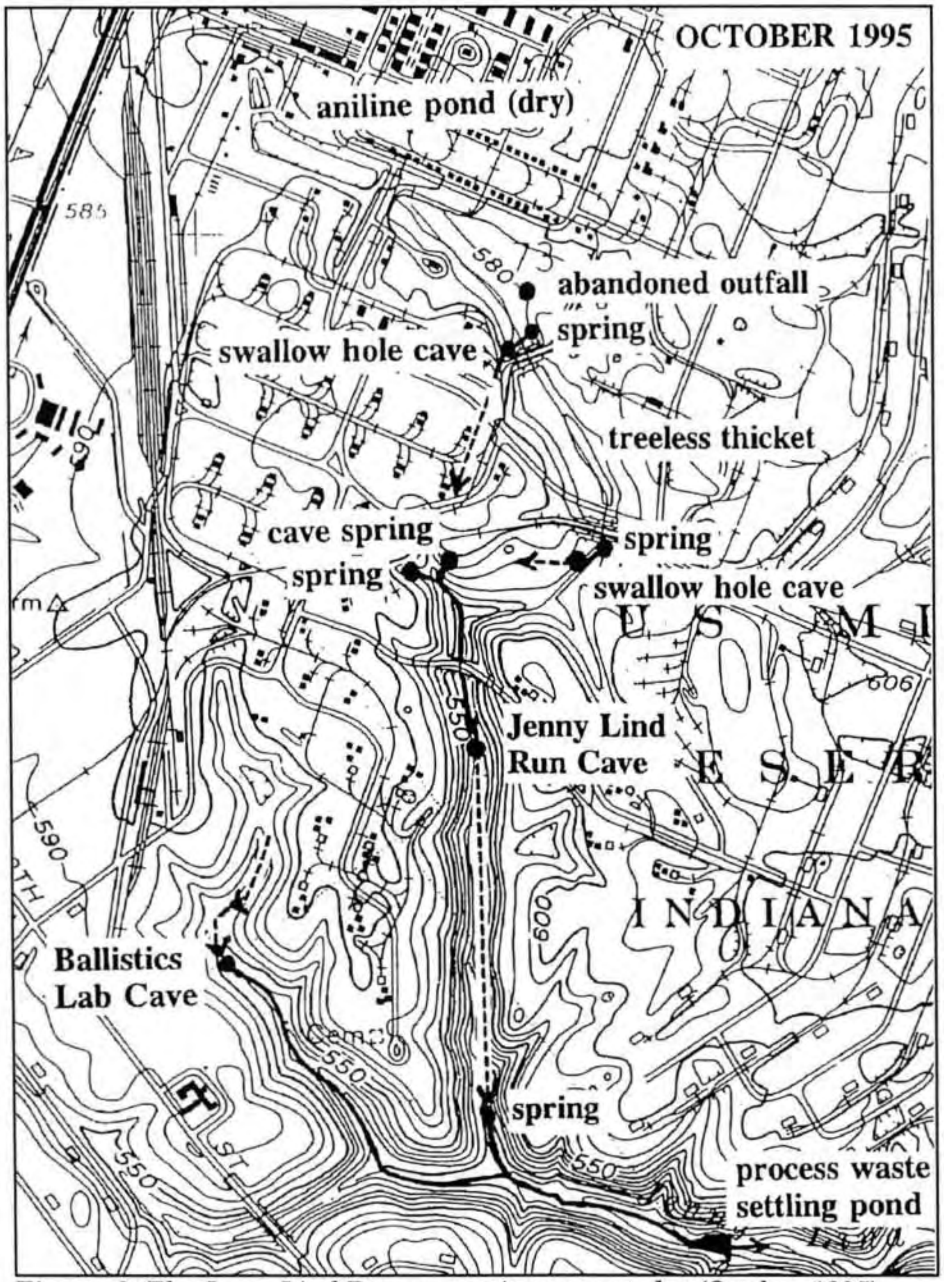

Figure 6. *The Jenny Lind Run area as it appears today (October, 1995).*

stream collecting basin receiving the effluent from the second basin described above may have been constructed over the site. The wooden Jenny Lind flume also originates at this third basin/outfall. Although I have hiked through the area, the former acid wetland is now overgrown with nearly impenetrable briars and it is difficult to ascertain all of the features present. Trees are absent in the valley floor. All but wet-weather stream flow is underground at this point.

Jenny Lind Run next passes under an asphalt road and an earthen railroad grade. The stream originally was routed under the railroad via a 12-foot-diameter culvert, the lower six feet lined with lead, and reinforced with heavy timbers. The Jenny Lind flume penetrates the grade nearby. Today water flows from a five-foot-wide cavity nearly under the flume just downstream of the lead-lined culvert. Inspecting the west side of a concrete retaining wall abutting the lead-lined culvert revealed an underlying dry horizontal fissure. A dry-bed entrenched about 10 feet into the terrain leads about 50 feet to an unenterable (presently unused?) swallet.

The spring below the lead-lined culvert flows about 90 feet to sink into an enterable stream crawlway on the north side of the valley at an elevation of about 565 feet. This swallowhole is in the lower part of the Jeffersonville Limestone. The entrance, about 14 feet wide but only 19 inches high, lies in a jumble of breakdown boulders.

The two springs first carrying acid flow in May 1943 are still present. Flow from these springs may come from the water that sinks in the swallet cave on the other side of the ridge and/or the upstream 1944 swallowhole. These springs have formed near the contact of the Jeffersonville and Louisville Limestones. Fauna found at both of these springs included *Caecidotea stygia*, *Phagocata gracilis*, and an amphipod, *Gammarus* sp. The eastern spring issues from a dangerous-looking cave passage formed in the Coralline Zone of the Jeffersonville Limestone. The cave blows cold air out of an orifice about 3 feet wide by 15 inches high. There is evidence of active collapse occurring at this site with much unstable rock hanging over the crawlway. The more-westerly spring emerges from a low passage, apparently unenterable, at the base of a 53-foot-long, shallow, shelter-like outcrop in the top of the Louisville Limestone. The spring stream is about six feet wide and is littered with corals and cobbles, along with scattered pellets of propellant.

In the hillside directly across from the spring are two cave entrances formed in the Coralline Zone of the Jeffersonville Limestone, the larger five feet high by eight feet wide, the other four feet high by five feet wide. The larger passage was explored for a short distance and consisted of a dry, breakdown-strewn passage that increased in size and continued. There is some question as to the cave's stability (that is, safety to enter) due to the effect of the nitric acid on the highly fossiliferous Coralline Zone of the Jeffersonville Limestone.

The water from these two springs joins and flows on the surface below another asphalt road to swallowhole called herein Jenny Lind Run Cave. The entrance, 10½ feet high by 28 feet wide, is in the Louisville Limestone at an elevation of about 530 feet. This is presumably the swallowhole created in March, 1943. A concrete dam 2½ feet high on the upstream side was built to divert stream flow from the swallowhole. The dam has been undermined with all of the stream falling about eight feet into the cave entrance under normal conditions. The water continues to cascade below breakdown in the shelter-like entrance. After a heavy rain, about 50% of the water was bypassing the cave on October 7, 1995. This water was flowing to another unenterable swallet 63 feet downstream from the end of the dam. Other swallowholes draining to Jenny Lind Run Cave occur at 109 and 157 feet below the downstream end of the dam. Inside the cave the water cascades down an eight-foot waterfall to a canyon passage. Having fallen about 30 feet from the level of the dam above, the floor of this passage is probably not far above the contact with the underlying Waldron Shale.

Sharp limestone blades extend from the passage walls and many fossil corals protrude. The ceiling of the passage shows a honeycombed pattern in evidence of total flooding of the cave by acidic waters. The rock is unnaturally brittle and footholds have to be chosen carefully, as seemingly sufficient ledges crack off when a person's weight is placed on them. At one point a shallow flowstone deposit has formed, cementing sticks and other flood debris to the passage wall. The stream continues as pools and riffles, flowing through gravel with riparian mudbanks in some areas. No unusual odor was present in the cave. The results of collections made in Jenny Lind Run Cave are discussed below.

Two hundred feet downstream of the swallowholes are the ruins of the old railroad trestle. Only the large concrete foundations remain. According to Wickwire (1947) this trestle, probably 60 to 70 feet high, was abandoned due to the undermining of the bedrock supporting the foundations. Continuing down the valley are numerous small swallowholes. The presumptive October 1942 swallowhole (the first to form) is encountered and consists of a 75-foot-long by 10- to 15-foot-wide sinkhole about 6 to 10 feet deep with a cave entrance at the downstream end. The entrance was choked with driftwood logs, but was blowing out cold air. Another sinkhole blowing cold air from an apparent cave entrance lies downstream before reaching the spring.

The spring consists of a deep, flooded cave entrance about 6 feet wide by 40 feet long at an elevation of about 490 feet. The orifice is composed of the lower Louisville Limestone, probably at least initially formed above the Waldron Shale. The spring is at least six feet deep and may actually contact (penetrate?) the shale. No water was flowing from the spring orifice during either of my visits during the summer of 1995. Seepage emerged downstream from the spring just above the confluence with the stream coming in from the east (carrying almost the entire flow of Jenny Lind Run). During times of high flow artesian conditions reportedly exist and large quantities of water emerge from the spring. A large gravel bar directly beneath the spring orifice is presumably the result of scouring from the conduit.

Most of the flow in this adjacent branch emerges from the site known as the Ballistics Lab Cave that started discharging acidic flow in July, 1944. The dam in this cave reported by Wickwire still exists and is 11½ feet wide by 2½ feet high. Entrance to the cave is allowed by passing through the entrenched limestone that supports the dam. Probably originally (pre-acid flow) a 46-inch-high passage, a walking height passage eight feet high is now present. Following the stream from the main entrance a series of rapids are formed as the floor rises to turn the cave from a stream-entrenched, tubular, walking-height passage to a wide stream crawl. Much sharply etched rock and fossilized coral protrudes from the passage walls. The cave extends approximately 200 feet to a second entrance allowing egress from the stream crawl. Over a small intervening rise lies a karst window where the cave stream emerges for 45 feet. Upstream there is another entrance 3 feet high by 14 feet wide with two other small entrances within a few feet. Continuing up the valley 124 feet to the northeast is a 14-foot-deep pit, 1 foot wide by 3 feet long, with the cave stream flowing visibly across the bottom. The result of collections in this cave are discussed below.

Recovery of the Subterranean Community

No documentation exists of the fauna of the caves or springs of Jenny Lind Run prior to industrialization. Eleven species of troglobites are known from caves in the Pleasant Run and Fourteen Mile Creek drainages directly adjacent to Jenny Lind Run (Lewis, 1983): the flatworm *Sphalloplana weingartneri*; two amphipods, *Stygobromus mackini*, *Crangonyx* sp.; one isopod, *Caecidotea stygia*; (a spider, *Phanetta subterranea*; a millipede, *Pseudotremia nefanda*; a dipluran, *Litocampa* sp.; three beetles, *Batrisodes krekeleri*, *Pseudanophthalmus barri*, *P.* sp.; and a fly, *Spelobia tenebrarum*.

The Jenny Lind Run and Ballistics Lab Caves were sampled to ascertain the present status of the fauna. Two other INAAP caves, CC Dryer Cave (a 1,500-foot+ stream cave) and RDX Cave (a 110-foot-long, streamless cave), received no nitric acid effluent and were sampled for comparative purposes. Sampling was performed in all four caves by hand collecting and the placement of two pit-fall traps in each cave baited with Limburger cheese spread. Detritus from Jenny Lind Cave was placed in a Berlese funnel for extraction of insects. Stream census was conducted in Jenny Lind Run and CC Dryer Caves. The combination of high stream gradient and deep water prevented conducting a stream census in the Ballistics Lab Cave.

A total of six species of troglobites were found in the nitric acid caves of Jenny Lind Run. In Jenny Lind Run Cave four troglobites were present: *Caecidotea stygia*, *Phanetta subterranea*, *Pseudotremia nefanda*, and *Spelobia tenebrarum*. In the Ballistics Lab Cave five troglobites were found: *Caecidotea stygia*, *Pseudotremia nefanda*, *Litocampa* sp., *Pseudosinella* sp., and *Spelobia tenebrarum*. Seven species of troglobites were found in CC Dryer Cave: *Sphalloplana weingartneri*, *Caecidotea stygia*, *Crangonyx* sp., *Sinella alata*, *Phanetta subterranea*, *Pseudotremia nefanda*, and *Spelobia tenebrarum*.

The results of collections taken from pit-fall traps are shown in Table 2. The dominant species in the traps in the nitric acid caves were troglophiles: the fly *Megaselia cavernicola* and the beetle *Platynus tenuicollis*. The troglobitic fly *Spelobia* was abundant in CC Dryer Cave, but scarce in the nitric acid caves and RDX Cave. The paucity of *Spelobia* in the Ballistics Lab Cave was problematic as raccoon scats were abundant. These dung flies are usually quite abundant in any Indiana cave where raccoon droppings are present (Banta, 1907). Explanations for the dominance of *Megaselia* over *Spelobia* in the Ballistics Lab Cave include biotic and abiotic possibilities. Certainly in any cave that has been totally sterilized some period of equilibration between the reinvading species is going to happen. The presence and quantities of flies of either of these species available to recolonize the caves is also unknown. The troglophilic *Megaselia* may have become re-established in the cave prior to *Spelobia* and are outcompeting them. The flies may also be differentially susceptible to the toxic chemicals likely to still be in the substrate. The Process Waste Settling Basin downstream of the Jenny Lind Run caves contains a deposit of nitrocellulose fines, calcium sulfate, and the possibility of any of the other chemicals discharged to the stream (Environmental Assessment, 1992). Mercury was also found in fish in Jenny Lind Pond downstream of the caves (Associated Press, 1995). It is presumed that some of these substances are also present in the caves reached by the effluent prior to the Process

Taxon	CC Dryer		RDX		Ballistics		Jenny Lind	
Oniscoidea								
Trachelipus rathkei	0	0	0	0	0	0	1	0
Cleidogonidae								
*Pseudotremia nefanda**	0	0	1	0	0	0	1	2
Pseudoscorpionida								
Apochthonius sp.*?	0	0	1	0	0	0	0	0
Acarina spp.	0	0	1	1	0	0	0	0
Linyphiidae								
*Phanetta subterranea**	0	0	0	0	0	0	0	1
Collembola spp.	0	0	7	0	0	0	0	0
Arrhopalites sp.*?	0	0	3	0	0	0	0	0
*Sinella cavernarum**	1	0	0	0	0	0	0	0
Pseudosinella sp.*	0	0	0	0	1	0	0	0
Hypogastrura sp.	0	0	109	61	0	0	0	0
Gryllacrididae								
Ceuthophilus sp.	0	0	0	0	0	2	0	0
Sphaeroceridae								
*Spelobia tenebrarum**	298	287	7	5	3	0	6	7
Phoridae								
Megaselia cavernicola	4	4	6	7	113	134	40	33
Sciaridae								
Sciara sp.	8	12	2	0	2	2	0	0
Heleomyzidae								
Aecothea specus	2	2	0	0	1	1	0	0
Psychodidae								
Psychoda sp.	0	0	1	1	0	0	3	3
Staphylinidae spp.	1	2	7	3	0	2	2	1
Coleoptera sp.	0	0	1	0	0	0	0	0
Carabidae spp.	1	0	0	0	0	0	0	0
Platynus tenuicollis	0	0	0	0	0	0	6	20
Bembidion sp.	0	0	0	0	0	0	1	0
Siphonaptera sp.	0	4	0	0	0	0	0	0
Formicidae sp.	0	0	1	0	0	0	0	0

Table 2. *Results of collections from pit fall traps placed in four caves at the INAAP (7 day periods, 4 ounce traps, baited with limburger, ethanol preservative. The Ballistics Lab and Jenny Lind Run caves were exposed to nitric acid effluents. CC Dryer Cave is under the propellant area but was not exposed to nitric acid. RDX Cave is in the Gate 26 area (Charlestown State Park).*

Waste Settling Pond or Jenny Lind Pond. The effects of chemicals such as nitrocellulose, aniline, nitrobenzene, or any of the organic solvents used at the plant on *Megaselia* or *Spelobia* are unknown.

The results of stream censuses are shown in Table 3. In the nitric acid cave sampled, Jenny Lind Run Cave, 29% of the individuals found were the troglobite *Caecidotea stygia*, with the rest of the community composed of troglophiles (*Lirceus*, *Gammarus*, *Phagocata*) or trogloxenes (insect larva). Juveniles of unidentified surface crayfish were also found in stream pools near the entrance. In the CC Dryer Cave stream 100% of the organisms found were troglobitic. The majority were *Caecidotea stygia* (typical for Indiana caves), with *Crangonyx* sp and *Sphalloplana weingartneri* also present. As with the terrestrial community, the reasons for the aquatic community in the nitric acid caves being composed primarily by troglo-

Site:	Jenny Lind Run Cave, Indiana Army Ammunition Plant, riffle area, 3 meter transect, 50 centimeters wide, depth 2-8 centimeters, substrate stream gravel on silt/sand; numbers indicate sight estimations of length; census 8/30/95 per J. Lewis, S. Knowles				
	Caecidotea stygia	Lirceus fontinalis	Gammarus	Phagocata gracilis	insect larva
	4, 4, 5, 5, 5, 6, 6, 6, 6, 6, 7, 8, 8, 8, 9, 9,	3, 5, 6	2, 3, 5, 5, 5, 6, 6, 7, 8, 8, 10, 10, 10, 10, 10, 10, 10, 10, 10, 12	3, 3, 3, 4, 4, 4, 5, 5, 5, 5, 5, 6, 6, 7, 7, 12, 12	4
Site:	CC Dryer Cave, Indiana Army Ammunition Plant, 1 meter transect, 50 centimeters wide, depth 1-3 centimeters, substrate stream gravel on silt/sand; numbers indicate sight estimations of length; census 9/20/95 per J. Lewis, S. Knowles				
	Caecidotea stygia	*Crangonyx* sp.	*Sphalloplana weingartneri*		
	2, 2, 2, 2, 2, 3, 3, 3, 3, 4, 4, 4, 4, 4, 4, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 7, 8, 9, 10	4, 6	7		

Table 3. *Results of aquatic censuses at the INAAP caves.*

philes are unknown. Regardless of the reasons, the presence of these predominantly troglophilic communities is the signature of disturbed cave ecosystems.

Acknowledgments

Initial funding for the work in Hidden River Cave was provided by the Ralph Stone Graduate Research Award for 1981 of the National Speleological Society, and a grant-in-aid of research by the University of Louisville. Funding at the Indiana Army Ammunition Plant was provided by the Non-game and Endangered Wildlife Fund, Division of Fish and Wildlife, Indiana Department of Natural Resources, administered by Dr Catherine Gremillion-Smith.

I would like to thank Bill Austin and David Foster, Executive Director of the American Cave Conservation Association, for allowing access to Hidden River Cave over the years. Mr Kerry Dupaquier kindly provided access to INAAP, facilitated security clearance for entry and provided several cave locations on the grounds of the plant. Mr Larry Gray, property manager of Charlestown State Park, facilitated access to the Gate 26 area of INAAP (Charlestown State Park).

Many individuals provided field assistance during the two projects discussed herein, but I would like to especially acknowledge James Lewis, Victor Lewis, James Eckstein, Hank Huffman (Indiana Department of Natural Resources, Nature Preserves), and Steve Knowles (Indiana Department of Natural Resources, State Parks).

Finally, I would like to thank my wife, Ann Marie Lewis, for accompanying me on countless trips on which she provided field assistance, moral support, and pulled me out of the sewage on more than one occasion.

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Cave Bioinventory as a Management Tool

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Abstract

The path of habitat destruction caused by urbanization is affecting an ever-increasing number of caves, springs, and other habitats of karst regions. Recent evaluation of troglobitic species in Kentucky and Indiana has revealed that the habitats of many have been obliterated by subdivisions, roads, malls, and the like. In some cases, the animals can be found in other suitable habitats nearby. In other cases, some species have been destroyed by the time they have been "discovered" in museum collections. A proactive approach is suggested wherein caves and springs are inventoried for rare organisms *prior* to their destruction. A case history of a successful instance in which the possible degradation of a biologically significant cave was prevented is presented herein. A preliminary natural areas map detailing biologically significant sites for the management of the Indiana karst is also introduced.

Introduction

Over the past 25 years a statement that I have become weary of hearing is "That's where the cave used to be." All one has to do to see this in its literal form is drive through a karst area on an interstate highway and see the evidence in the roadcuts. For example, on I-65 about a mile north of Cave City, Kentucky, a roadcut on the east side of the road contains the remnants of what must have once been a beautiful display of flowstone and draperies. Passing through a similar cut in western Virginia with John Holsinger, he related that the hill we had just driven through once contained a cave that had been the type-locality (and only known locality) for a subterranean amphipod, now presumed extinct.

The type-locality of the troglobitic beetle Pseudanophthalmus troglodytes was Oxmoor (Highbaugh) Cave, Jefferson County, Kentucky. Described by Krekeler (1973), this entrance to this cave was originally on farmland east of Louisville. As the city continued to grow the area became the Oxmoor Woods subdivision. The entrance to Oxmoor Cave has now been destroyed, the only evidence of its presence being two grass-lined sinkholes in the front yards of homes in Oxmoor Woods. The area over Oxmoor Cave is now covered by asphalt streets, houses, swimming pools, and manicured lawns, devoid of sinks other than the entrance area. Much of the recharge of the subterranean stream in the cave has been diverted into storm sewers, along with the nutrient input of the cave.

The case at the type-locality of the subterranean isopod *Caecidotea jordani* has been even more severe. The only site at which this unique isopod has been found was a spring in the subbasement of Jordan Hall (housing the biology department), at Indiana University, Bloomington (Eberly, 1965). The isopod was formerly common in the spring stream arising at this site. However, during the early 1980s work on the building stopped the flow of the spring. Subsequently problems with termites necessitated poisoning of the habitat. *Caecidotea jordani* has not been seen for over 20 years. In the course of my dissertation research on subterranean isopods of the genus *Caecidotea*, I was given a vial of crustaceans collected from the spring stream by a limnology class. In addition to *Caecidotea jordani*, there were specimens of some subterranean amphipods present in the collection that were forwarded to Dr John Holsinger for identification. The amphipods were determined to be two undescribed species, a *Crangonyx*, fortunately known from other localities, and a *Bactrurus*. No other species of the genus *Bactrurus* has been found in the Indiana karst.

In the example of Oxmoor Cave, the only thing known of its community was the presence of *Pseudanophthalmus troglodytes*. Although the cave still exists under the asphalt and concrete of Oxmoor Woods, the continued presence of the community is dubious. At the Jordan Hall spring, the community was destroyed before it was discovered, existing now only as a museum collection.

A Bioinventory Case History

Over the past 25 years I have been conducting bioinventory projects in various parts of the midwestern U.S. (Lewis, 1974; Peck and Lewis, 1977; Lewis, 1983; 1993; 1994; 1995). In 1993, in a project for the Non-game and Endangered Wildlife Program of the Indiana Division of Fish & Wildlife, I recommended that protection of seven sites would serve to protect the habitats of a significant percentage of the subterranean species known in Indiana (unfortunately, one of these was the Jordan Hall spring).

The only cave recommended for special protection in the southeastern Indiana karst was Indian Cave, Clark County. This cave was the type-locality of the millipede *Pseudotremia nefanda*, the beetle *Pseudanophthalmus barri*, and the only known locality in Indiana of the amphipod *Stygobromus mackini*. Other troglobites known from the cave include another amphipod, *Crangonyx* (undescribed species), isopod *Caecidotea stygia*, spider *Phanetta subterranea*, dipluran *Litocampa* sp. (probably undescribed), collembolan *Sinella alata*, beetle *Pseudanophthalmus chthonius*, and fly *Spelobia tenebrarum* (Lewis, 1983).

During the time that Indian Cave was initially inventoried during the mid-1970s, the area to the south consisted primarily of farms. Over the next 20 years the Louisville metropolitan area continued to expand and significant urbanization of the land along the Pleasant Run occurred. In 1994 the owner of Indian Cave, Mrs Dorothy Couch, was informed that a sewer line was to be run across her property to serve the subdivisions sprouting up to the south of Charlestown. The limestone bedrock in the area lies close to the surface and it was anticipated that dynamiting would be required to run the line. Mrs Couch, fearing for the well-being of the cave, contacted the Indiana Department of Natural Resources. Through a chain of events the problem was brought to the attention of Hank Huffman, Indiana Department of Natural Resources, Division of Nature Preserves. Mr Huffman was familiar with the 1993 inventory and the sites recommended for protection, including Indian Cave. A site visit was made by Department of Natural Resources employees to investigate the situation. Subsequently the engineering firm responsible for the placement of the sewer line volunteered a new route that avoided the cave.

Thus, a possible calamity involving Indian Cave and its unique community was avoided. The point of this example is that with inventory data on this cave it was possible to avert the problem. Without this bioinventory there would have been little foundation for saving this cave other than on its own intrinsic merit. It is entirely possible that other caves with equal biologic, archaeologic, historic, or geologic significance may be destroyed by the sewerlineorotherforcesofurbanizationbecause theyremainunknown.

Cave Bioinventory in Indiana

There are over 2,000 caves presently known in Indiana, and the animal communities present in the majority of them are unknown. No comprehensive cave bioinventory has been conducted in Indiana, although a number of faunal lists for various areas of the state have been published or appeared in reports. Blatchley (1896) made a journey via horse and wagon to several of the more prominent caves in the southcentral karst and compiled a list of the fauna collected. Banta (1907) conducted a detailed study of the fauna of Mayfields Cave in Monroe County, Indiana. Banta also compiled what was known of the fauna of other Indiana caves. The troglobites of the southeastern Indiana karst area were inventoried by Lewis (1983), with additional faunal lists prepared subsequently of parts of the area (Jennings County, Lewis, 1995; Clark County, Lewis, in preparation). Lewis (1994) also conducted a faunal inventory of the Lost River karst in Orange County, Indiana. Many other smaller contributions, typically taxonomic works, have appeared for example, beetles (Barr, 1960), pseudoscorpions (Muchmore, 1963), isopods (Lewis and Bowman, 1981, Bowman and Lewis, 1984, Lewis, 1982).

A proactive approach is suggested wherein caves and springs are inventoried for rare organisms prior to their destruction. The list of troglobites and phreatobites in Figure 1 represents a compilation of all of the published references cited above and elsewhere, along with collection records from a number of unpublished reports and the additional unpublished records from my own collections over the period from 1971 to 1995. A knowledge of the zoogeography of these organisms allows their placement among one or more regional faunal basins (modified from Barr, 1967) (Figures 2, 3). In some cases endemism of the fauna is prominent and sub-basin faunas can also be specified to a greater or lesser extent. Although it is impractical to inventory all caves in Indiana (or elsewhere), with a reasonable knowledge of the fauna of the area it is possible to predict with some degree of accuracy the fauna that will occur in caves of any given region of the state. In conjunction with the box diagram presented in Figure 4, the vulnerability of the species in question can be determined. Certainly any animal known from only one site (the species included in the first column) is extremely vulnerable to extinction, regardless of how common it is at that site. Other species definately vulnerable are those that are felt to be of low biotic potential.

Figure 1.,
A faunal list of the troglobites and phreatobites of Indiana with approximate distribution patterns.

Sphalloplana chandleri	spring, Floyd County
Sphalloplana weingartneri	Clark, Crawford, Harrison, Jefferson, Lawrence, Orange counties
Phagocata sp.	well, Floyd County
Fontigens cryptica	spring, Clark County
Fontigens sp.	Harrison Cave Spring, Harrison County
Antroselates spiralis	Crawford, Harrison County
Hamohalacarus subterraneus	Donaldson Cave, Lawrence County
Pseudocandona marengoensis	Marengo Cave, Crawford County
Pseudocandona jeanneli	Marengo Cave, Crawford County
Sagittocythere barri	Crawford, Green, Harrison, Lawrence, Monroe, Orange, Washington counties
Megacyclops donnaldsoni donnaldsoni	Donaldson Cave, Lawrence County
D*iacyclops jeanneli*	Crawford, Floyd counties
Bryocamptus morrisoni morrison	Donaldson Cave, Lawrence County
Cauloxenus stygius	Crawford, Harrison, Lawrence counties
Bactrurus mucronatus	Grant, Henry, Noble counties
Bactrurus sp.	IU-Bloomington, Monroe County
Crangonyx packardi	Clark, Jefferson, Jennings, Lawrence, Orange counties
Crangonyx sp. 1	Crawford, Harrison counties
Crangonyx sp. 2	Clark, Crawford, Decatus, Harrison, Jennings, Lawrence, Martin, Monroe, Owen, Washington counties
Stygobromus mackini	Indian Cave, Clark County
Stygobromus sp.	IU-New Albany, Floyd County
Stygobromus sp.	Devils Graveyard Cave, Harrison County
Caecidotea jordani	IU-Bloomington, Monroe County
Caecidotea kendeighi	Henry, Lake, Porter counties
Caecidotea rotunda	Decatur, Jennings counties
Caecidotea stygia	Clark, Crawford, Green, Harrison, Jefferson, Jennings, Lawrence, Martin, Monroe, Orange, Owen, Washington counties
Caecidotea teresae	IU-New Albany, Floyd County
Orconectes inermis inermis	Crawford, Harrison, Lawrence, Martin, Monroe, Orange, Washington counties
Orconectes inermis testii	Green, Monroe, Owen counties
Phanetta subterranea	all counties
Porhomma cavernicola	Lawrence, Jennings, Orange counties
Kleptochthonius packardi	Wyandotte Cave, Crawford County
Apochthonius indianensis	Lawrence, Orange counties
Hesperochernes holsingeri	Wilson Cave, Jefferson County
Pseudotremia indianae	Crawford, Harrison, Washington counties
Pseudotremia nefanda	Clark County
Trichopetalum uncum	Jennings, Monroe counties
Litocampa sp.	Clark, Crawford, Orange counties

Sinella cavernarum	Clark, Crawford, Greene, Harrison, Jennings, Washington counties
Sinella alata	Clark, Jennings, Monroe, Lawrence, Orange counties
Sinella barri	Mays Cave, Lawrence County
Sinella sp. 1	Saltpeter Cave, Crawford County
Sinella sp. 2	Jennings County
Arrhopalites bimus	Lawrence, Orange counties
Onychiurus sp.	Jennings, Monroe, Orange counties
Pseudosinella sp.	Clark, Harrison, Jennings counties
Pseudosinella fonsa	Clark County
Hypogastrura lucifuga	Crawford, Harrison counties
Batrisodes krekeleri	Cave Spring Cave, Clark County
Batrisodes sp.	Big Mouth Cave, Harrison County
Pseudanophthalmus barri	Clark County
Pseudanophthalmus blatchleyi	Monroe County
Pseudanophthalmus chthonius	Jefferson, Jennings counties
Pseudanophthalmus eremita	Crawford, Harrison counties
Pseudanophthalmus emersoni	Donnehues Cave, Lawrence County
Pseudanophthalmus jeanneli	Elrod Cave, Orange County
Pseudanophthalmus leonae	Hert Hollow Cave, Lawrence County
Pseudanophthalmus morrisoni	Donaldsons Cave, Lawrence County
Pseudanophthalmus shilohensis boonensis	Boones Cave, Owen County
Pseudanophthalmus shilohensis mayfieldensis	Monroe County
Pseudanophthalmus shilohensis shilohensis	Shiloh Cave, Lawrence County
Pseudanophthalmus stricticollis	Crawford, Orange, Washington counties
Pseudanophthalmus tenuis	Crawford, Harrison counties
Pseudanophthalmus youngi donaldsoni	Donaldsons Cave, Lawrence County
Pseudanophthalmus youngi youngi	Cave River Valley, Washington, County
Pseudanophthalmus sp. 1	Clark County
Pseudanophthalmus sp. 2	Hudelson Cavern, Orange County
Pseudanophthalmus sp. 3	Mayfields Cave, Monroe County
Pseudanophthalmus sp. 4	Buddha Cave, Lawrence County
Spelobia tenebrarum	all counties
Amblyopsis spelaea	Crawford, Harrison, Lawrence, Orange, Washington counties

Figure 2.
The faunal basins of Indiana and the species known to inhabit them, with examples of sub-basin faunas for some of the regions.

Blue River Faunal Basin	**Wyandotte Sub-basin**	**Harrison Spring Sub-basin**	**Marengo Sub-basin**
Sphalloplana weingartneri	X		
Fontigens sp.		X	
Antroselates spiralis	X	X	
Pseudocandona marengoensis			X
Pseudocandona jeanneli			X
Diacyclops jeanneli			X

Crangonyx sp. 1	X	X	X
Caecidotea stygia	X	X	X
Orconectes inermis inermis	X	X	X
Phanetta subterranea	X	X	X
Kleptochthonius packardi	X		
Pseudotremia indianae	X	X	X
Litocampa sp.	X		
Sinella cavernarum	X		
Sinella sp. 1	X		
Pseudosinella sp.			
Hypogastrura lucifuga	X		
Batrisodes sp.			
Pseudanophthalmus eremita	X	X	
Pseudanophthalmus stricticollis			X
Pseudanophthalmus tenuis	X	X	
Spelobia tenebrarum	X	X	X
Amblyopsis spelaea	X	X	X

Bedford Faunal Basin	**Spring Mill Sub-basin**	**Lost River Sub-basin**
Sphalloplana weingartneri	X	X
Hamohalacarus subterraneus	X	
Megacyclops donnaldsoni	X	
Bryocamptus morrisoni	X	
Crangonyx packardi	X	X
Crangonyx sp. 2	X	X
Caecidotea stygia	X	X
Orconectes inermis inermis	X	X
Phanetta subterranea	X	X
Porhomma cavernicola	X	X
Apochthonius indianensis	X	X
Litocampa sp.		X
Sinella alata		X
Sinella barri		
Arrhopalites *bimus*		X
Onychiurus sp.		X
Pseudanophthalmus emersoni		
Pseudanophthalmus jeanneli		X
Pseudanophthalmus leonae		
Pseudanopthalmus morrisoni	X	
Pseudanopthalmus shilohensis shilohensis		
Pseudanopthalmus youngi donaldsoni	X	
Pseudanopthalmus youngi youngi		
Pseudanopthalmus sp. 2	X	
Pseudanopthalmus sp. 4		
Spelobia tenebrarum	X	X
Amblyopsis spelaea	X	X

Monroe Faunal Basin

Bactrurus sp.
Crangonyx sp. 2
Caecidotea jordani
Caecidotea stygia
Orconectes inermis testii
Phanetta subterranea
Trichopetalum uncum
Sinella alata
Onychiurus sp.
Pseudanophthalmus blatchleyi
Pseudanophthalmus shilohensis boonensis
Pseudanophthalmus shilohensis mayfieldensis
Pseudanopthalmus sp. 3
Spelobia tenebrarum

Clark Faunal Basin

Sphalloplana weingartneri
Fontigens cryptica
Crangonyx packardi
Crangonyx sp. 2
Stygobromus mackini
Caecidotea stygia
Phanetta subterranea
Pseudotremia nefanda
Litocampa sp.
Sinella cavernarum
Sinella alata
Pseudosinella sp.
Pseudosinella fonsa
Batrisodes krekeleri
Pseudanophthalmus barri
Pseudanophthalmus chthonius
Pseudanophthalmus sp. 1
Spelobia tenebrarum

Muscatatuck Faunal Basin

Sphalloplana weingartneri
Crangonyx packardiCrangonyx sp. 2
Caecidotea rotunda
Caecidotea stygia
Phanetta subterranea
Porhomma cavernicola
Hesperochernes holsingeri
Trichopetalum uncum
Sinella cavernarum
Sinella alata
Sinella sp. 2

Onychiurus sp.
Pseudosinella sp.
Spelobia tenebrarum
Phagocata sp.
Diacyclops *jeanneli*
Stygobromus sp.
Caecidotea teresae

Central Lowlands Faunal Basin
Bactrurus mucronatus
Caecidotea kendeighi

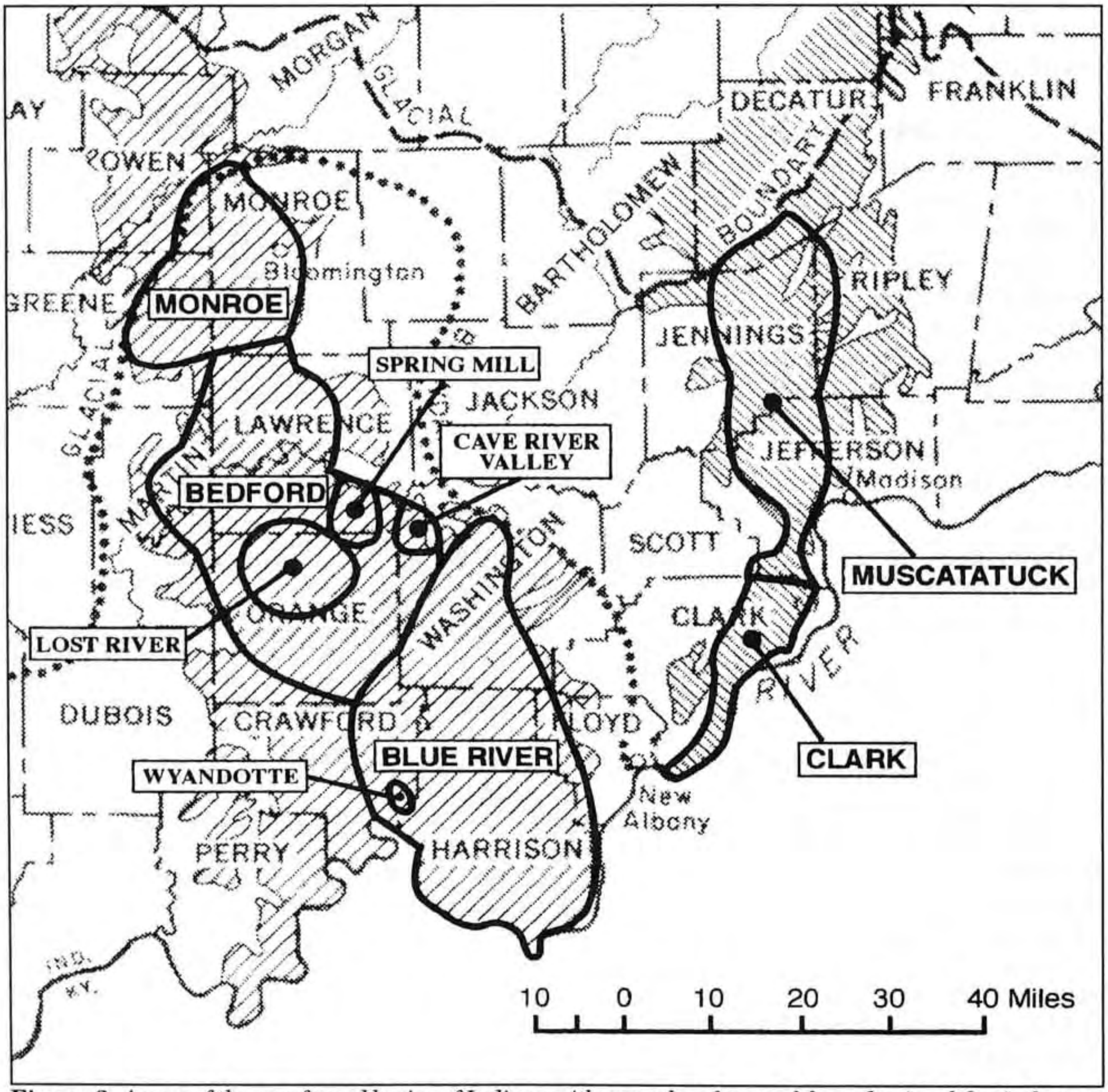

Figure 3. *A map of the cave faunal basins of Indiana with examples of some of the endemic sub-basin faunas.*

Figure 4.
A box diagram describing the vulnerability of the troglobites and phreatobites known from Indiana.

BIOTIC POTENTIAL	RANGE: One Locality	RANGE: One Basin	RANGE: >One Basin
Low	Hamohalacarus subterraneus *Fontigens* sp. *Stygobromus* sp. 1 *Stygobromus* sp. 2 *Bactrurus* sp. *Kleptochthonius packardi* *Hesperochernes holsingeri* *Pseudanophthalmus emersoni* *Sinella barri* *Sinella* sp. 1 *Sinella* sp. 2 *Batrisodes* sp. *Pseudanophthalmus jeanneli* *P. leonae* *P. morrisoni* *P.* sp. 3 *P.* sp. 4	*Apochthonius indianae* *Pseudanophthalmus barri* *P. eremita* *P. chthonius* *P.* sp. 2 *Hypogastrura lucifuga* *Sinella barri* *Pseudanophthalmus blatchleyi*	*Sphalloplana chandleri* *S. weingartner* *Orconectes inermis* *Stygobromus mackini* *Porhomma cavernicola* *Pseudosinella* sp. *P. fonsa* *Litocampa* sp. *Amblyopsis spelaea* *Pseudosinella* sp. *P. fonsa* *Pseudanophthalmus shilohensis* *P. stricticollis*
Moderate	*Fontigens cryptica* *Pseudocandona marengoensis* *Pseudocandona jeanneli* *Megacyclops donnaldsoni* *Bryocamptus morrisoni* *Batrisodes krekeleri*	*Pseudotremia indianae* *P. nefanda* *Pseudanophthalmus* sp. 1 *Pseudanophthalmus tenuis* *P. youngi*	*Antroselates spiralis* *Diacyclops jeanneli* *Crangonyx packardi* *Crangonyx* sp. 1 *Crangonyx* sp. 2 *Caecidotea rotunda* *Trichopetalum uncum* *Sinella alata* *Onychiurus* sp.
High	*Caecidotea jordani* *Caecidotea teresae*	*Arrhopalites bimus*	*Bactrurus mucronatus* *Caecidotea kendeighi* *C. stygia* *Phanetta subterranea* *Sinella cavernarum* *Spelobia tenebrarum*

Acknowledgements

Funding for the faunal inventory of Indiana caves has been graciously provided by a number of agencies, listed here in alphabetical order: Indiana Department of Natural Resources, Endangered Wildlife Fund; National Speleological Society, Research Advisory Committee; University of Louisville, College of Arts & Sciences Grant-in-aid of Research; U.S. Army Corps of Engineers, Environmental Analysis Branch, Louisville; U.S. Fish & Wildlife Service; U.S. National Museum, Smithsonian Institution.

I also gratefully acknowledge the map of Indiana Cave Bioregions, computer-generated for me by graphic artist Rick Daugherty.

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Use of a Laser System to Survey Caves

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Abstract

This paper discusses the use of a laser system to survey Cottonwood Cave, one of over 110 known caves on the Guadalupe Ranger District of the Lincoln National Forest. Illustrated are laser system capabilities and the potential for automated manipulation of resulting data into resource cataloging, monitoring tools, and improvement design to aid in cave management. Discussion includes recommendations for performing cave surveys, difficulties of cave surveying, and the triangulating traverse survey routine. Discussion of caves is made against the backdrop of the Guadalupe Ranger District, as it has been instrumental in developing USDA Forest Service cave management programs.

Introduction

The purpose of this report is to document results of a laser system survey of Cottonwood Cave, one of over 110 known caves on the Guadalupe Ranger District of the Lincoln National Forest. Illustrated are laser system capabilities and the potential for automated manipulation of resulting data into resource cataloging, monitoring tools, and improvement design to aid in cave management. Cave resources exist the world over; the location for this trial of the laser system was chosen based on accessibility and the willingness of district personnel to try new technologies. Discussion of caves is made against the backdrop of the Guadalupe Ranger District, as it has been instrumental in developing Forest Service cave management programs.

No permanent benchmarks were established during the survey; it was intended for test purposes only and not to officially map the cave or provide the basis for design of improvements. The effort was made mainly to test the underground performance of the laser instrument, to aid in developing cave-surveying methodologies, and to experiment with the automated reduction and manipulation of resulting data.

The test and subsequent manipulation of data met expectations. The laser system is useful for mapping, and data can provide the basis for design of improvements as well as assist in monitoring cave resources and developing trending information. Futuristic applications include computer-aided virtual-reality trips into caves.

This report provides background information on caves in the Guadalupe Mountains, cave surveys, specifics on the Cottonwood Cave survey, and recommendations for planning and performing cave surveys. An appendix contains a discussion of difficulties to be expected when surveying caves, details of a survey routine developed for caves in which the instrument compass fails to function properly, and information concerning manipulation of cave survey data.

Background

Caves exist under federal, state, and private lands across the country and on every continent. The Lincoln National Forest has remarkable and important cave resources; indeed, visitors and scientists come from the world over to explore, study, and enjoy these caverns in the exposed Permian-age reef. The nonrenewable resources are extremely fragile; rising spelunking popularity and scientific interest has increased the potential for damage. The federal Cave Resources Protection Act mandates federal agencies to secure, protect, and preserve significant caves on federal lands for the perpetual use, enjoyment, and benefit of all people. This involves management designed to preserve the delicate balance between natural undisturbed ecosystems, recreation, research, and use of surface areas above caves.

Description of Caves on the Guadalupe Ranger District

Caves on the District contain undisturbed, significant, world-class formations, depositions, and speleothems of rare form, size, and beauty. Most caves are relatively dry; however, the humidity in deeper caves is normally 99 percent, allowing many actively-growing speleothems. Known caves contain pools, but none have running streams.

Rooms vary in size; some exceed 100 meters in diameter. Some have ceiling heights of 60 meters, and some contain vertical pits over 100 meters deep. Surveys reveal some caves contain several kilometers of passages.

The development of many caves is joint-controlled. Joints or fractures dictate water migration, solutional activities, and the unique geologic process in which hydrogen sulfide gases mix with ground water to dissolve huge chambers in limestone.

Cave Resources of the Guadalupe Ranger District

Caves exhibit prehistoric and historic use; fossils; bat hibernacula and nurseries; solutional formations; sediments; and other examples of hydrologic, geologic, and biologic processes. Unique, non-renewable geological formations and paleontological and biological resources, including a variety of rare and endangered plants and animals, exist in the caves.

Wildlife and vegetation are found near entrances while interiors also support bats, snakes, insects, and microorganisms. Isolated pools within unexplored passages likely contain invertebrate and micro-organism populations undisturbed for thousands of years. Pristine cave ecosystems provide unique opportunities for scientific research. It is necessary to prevent disturbance or destruction from contaminants brought in by explorers or resulting from surface activities.

Faunal remains thousands of years old are found in several caves, some being quite rare. One cave contains two complete skeletons of an extinct Pleistocene jaguar, (only a few specimens are known) another perhaps the most complete Pleistocene short-faced bear skeleton ever found. Many caves contain clay deposits rich with pollen and charcoal. Stratified deposits, dating back 30,000 years, present an unparalleled record of past ecosystems. These deposits offer a unique opportunity for paleoecology study and enable reconstruction of plant and animal communities that lived in and around the caves long ago.

Recreational Opportunities in Caves

Recreation constitutes the majority of cave use. Many spelunkers hike ridges on the district in the attempt to find new caves. Some caves offer physical challenges not available anywhere else. The scenery around many caves is unsurpassed in the state, and caves on the forest are among the most beautiful in the world.

Cave Management

In 1972 the district began the first Forest Service cave management program. It became clear that cave management prescriptions were necessary if delicate cave resources are to be preserved and protected from vandalism and unintentional damage caused by caving. Priorities included cave inventory and establishment of classifications for contents and hazards.

Cave Surveys

Surveys are a necessary part of a cave management program. Mapping and inventory are required for documenting physical attributes while realizing the extent of caves, their size and shape, and the composition and location of their various resources forms the basis for management. Surveys provide information useful to visitors, including length and grade of trails and the locations of points of interest along the way.

Viewing cave survey plots can provide the flavor of spelunking to cave enthusiasts unable to physically enter caves. To active cavers, they are a useful aid in determining which cave best deserves devotion of limited time and energy.

Methods used in the past for cave surveying include the standard traverse and cross section routine using cloth tapes, hand clinometers, and hand or staff compasses. This is probably the simplest routine used to document features along a strip or corridor.

Higher precision instruments, such as engineering levèls, transits, theodolites, and electronic distance measuring (EDM) devices, are used for higher-order work. Distances to breaks and points of interest on walls and ceilings must be estimated when using conventional instruments, as these locations are inaccessible to head chainmen or prism rodmen. For example, the maximum ceiling-to-floor dimension in the main chamber of Cottonwood Cave was previously estimated at 27 meters (90 feet). The laser instrument measured the much greater distance of 53 meters (173 feet).

Past survey systems required head chainmen or prism rodmen to hike across the cave floor to walls, formations, or points of interest. The laser system functions with much less foot traffic, greatly reducing disturbances and irreversible impacts.

Cost information for past surveys is unavailable. Extrapolation of information from road projects indicates possible savings of 59 to 75 percent when using the laser system for cave surveys.[1,2] Laser system functionality and economics make possible the completion of more individual cave surveys—with more extensive information gathered—within the same time and budget allowed for standard methods.

The Cottonwood Cave Survey

The instrument: the Laser Technology, Inc., (LTI) Criterion 400 Survey Laser functioned well underground, making and downloading three-dimensional measurements to the Lasersoft survey management platform. The accuracy and precision of the laser exceeds that of hand instruments[1], providing data suitable for most applications. (See Figure 1 for the field hardware setup.) Prior to the effort, uncertainty existed as to the performance of the instrument compass in supplying azimuth measurements below ground.

Lasersoft converts survey data into stacks of 3-D coordinates importable to CAD software, allowing plan, profile, cross section, and perspective views to be constructed and contoured as shown in Figure 2. At the time of survey, no metric version of Lasersoft existed; therefore, Figure 2 plots are in feet rather than meters. Lasersoft was created by Laser Technology software engineers to manage laser surveys, and runs on certain hand-held MS-DOS compatible data recorders and the personal computer. The Corvallis Microtechnology, Inc., (CMT) PC5-L recorder was used for this survey.

The survey was performed by Tony Beke, facilities engineer on the Lincoln; Pete Brady, maintenance worker; Warren Sutton; and Jeff Moll. The survey was supervised by Mike Harrison, a cave technician on the District, and sponsored by the recreation program at the San Dimas Technology and Development Center, San Dimas,California.

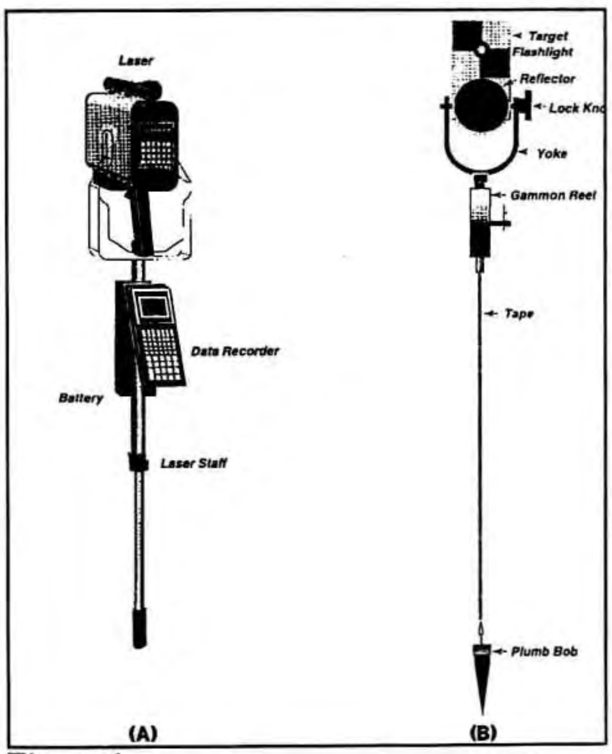

Figure 1.
(A) instrument, battery, and data recorder mounted on telescoping rod.
(B) yolk-mounted reflector assembly with gammon reel, tape, and plumb-bob.

The Cottonwood Cave survey began with foresight/backsight traverse links in an effort to determine compass performance underground. This is recommended practice for detection of local attraction problems, such as those caused by magnetic materials in the bedrock. The azimuth readings were within manufacturer tolerances, allowing a standard traverse and cross section routine. If the compass functions adequately in the cave, a "repeating radial" routine may also be used for side shots made from Points of Intersection and turning points. This results in the increased survey efficiency and effectiveness, as side shots may be quickly made to any point in any direction. Compass malfunction due to magnetic anomalies would dictate execution of a "triangulating traverse" routine, with cross sectioning, as described in the appendix.

The survey consists of a 342 meter (1120 foot) traverse having 19 Points of Intersection (PIs), and shows a 70-meter (230-foot) drop in elevation. Each traverse "link" is composed of a foresight from one PI to the next, and a backsight from that PI back to the previous Point of Intersection.

This traversing routine allows averaging of FS/BS data, increasing accuracy and highlighting discrepancies, as backsight data should be the same—within instrument sensor tolerances, operator error, and accounting for directional differences—as the FS data. Table 1 provides the data for traverse link 3-4.

The occurrence of discrepancies between distance and inclination readings on a link, barring instrument operator error (such as not properly plumbing the instrument or reflector rod, and sensor tolerances) are unlikely. Azimuth readings, however, are subject to localized attraction and should be carefully monitored as to differences between FS and BS on a link. Note the opposing sign on the vertical inclination, as the FS is looking downhill (and thus has a negative sign) and the BS is looking uphill. The difference in azimuth is approximately 180 degrees.

The plan, or plot of horizontal change on the traverse, shows change in direction versus horizontal distance between PIs. The profile, or plot of vertical change on the traverse, shows slope versus horizontal distance between PIs. Each PI is cross sectioned along the bisect angle in the traverse. The cross section is simply a slice illustrating cave dimensions on the angle bisector, and is made up of "side shots" from the PI (or a turning point) to points of interest on the cave floor, walls, ceiling, or formations. (See Figure 2 for plots of the survey.)

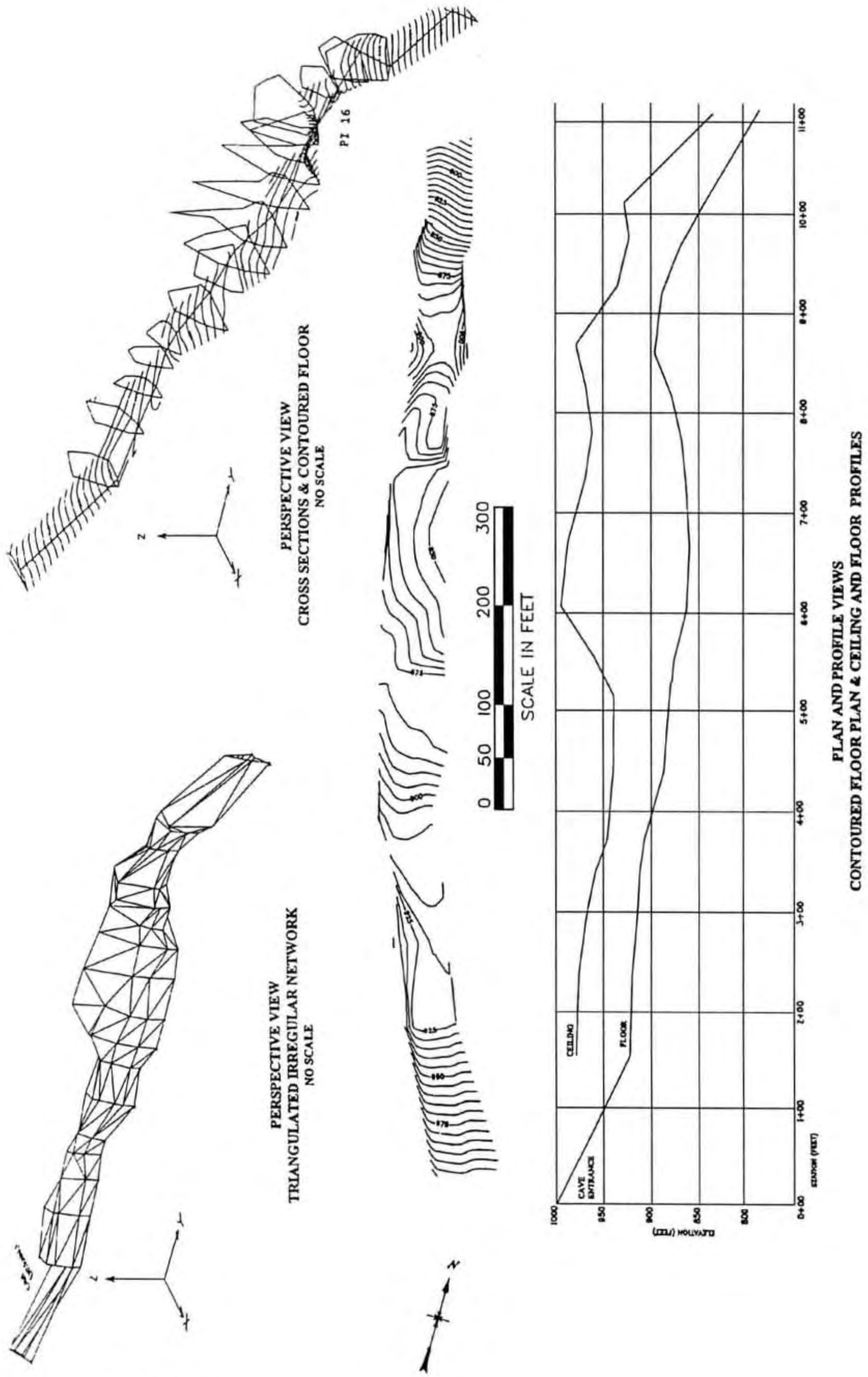

Figure 2. *Cave survey plots.*

Table 1.—Traverse 3-4 data

	FS - PL 3 to PL 4	BS - PL 4 to PL 3
azimuth (degrees)	333.7	153.5
vertical inclination (degrees	-5.7	5.8
slope distance (meters, feet)	17.34, 56.9	17.47,57.3

The bisect direction can be determined by Lasersoft or approximated using the road surveyor's method know as "throwing a wammie."

To throw a wammie, you stand over the PI facing your best guess as to direction, extend one arm towards the back PI and the other towards the front PI. Close your eyes and bring palms together in a clap; your hands will be pointing in the approximate direction. With practice, the direction may be determined within ±3 degrees of actual.

Some difficulties to be expected during cave surveying are found in the appendix.

Conclusions

The laser-survey system is available to aid in cave management. The laser instrument functions properly in limestone formations devoid of bedrock containing magnetic anomalies, while a "triangulating traverse" has been developed for sites that do contain local attraction problems. The system provides accurate and effective measurements of "hard to reach" cave walls and floors, with potentially less disturbance to fragile underground resources.

Based on information from laser system use on road projects, cost savings of 59 to 75 percent are possible.

Recommendations for Performing Cave Surveys

A. Ensure the cave management plan includes establishment of survey parameters including what the survey is expected to accomplish. Survey standards, precision, location of points to be surveyed, and survey methodology will be dictated by this information. Some examples are as follows:
   1. Measure, map, and plot physical features, such as size, length, slopes, depths, heights, sections, formations, and resources.
   2. Provide the basis for design of improvements, such as gates, trails, handrails, and other facilities.
   3. Provide the basis for monitoring and trending of cave resources.

   An example of this in Cottonwood Cave involves the slope between PI 16 and PI 19, as shown in Figure 2. Cave specialists estimate each visitor moves 0.03 cubic meters (1 cubic foot) of soil down the slope. Contour maps generated from subsequent surveys may be overlaid and earthwork quantities calculated to monitor this situation and plan its alleviation.
B. Prior to conducting the survey, the points to be surveyed must be located and the formations and features to be documented or cataloged should be reviewed by the crew.
C. The survey crew must be fully trained on laser system use, capabilities, and limitations.
D. The survey crew must be familiar with the cave and the information in A and B above.
E. Perform a test of the compass, such as FS/BS traverse links, to determine available or required survey methodology. Remember, the compass is extremely sensitive not only to naturally-occurring magnetic attraction, but ferric metal and equipment including flashlights, watches, and the data recorder.
F. When performing simple mapping surveys, using the standard traverse and cross section routine, consider making cross sections perpendicular to the length of the cave rather than on the bisect angle in the traverse line. This will typically minimize cross-sectional measurements and area, and give a better representation of cave dimensions.
G. A safety plan specific to survey crew activities must be prepared. The crew must receive training on special safety gear for caves. Safety meetings designed to increase awareness of safe practices in caves are highly recommended.

Additional information on the Lasersoft survey platform and the laser survey instrument may be found in the January-April 1994 issue of *Engineering Field Notes*[3].

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Appendix

Difficulties of Cave Surveying

Several difficulties were encountered during the Cottonwood cave survey, some of which are specific to surveying in low-light or no-light environments. Use of "reflector assemblies," with flashlight targets, reflectors, and bull's-eye plumb bubbles, is helpful as the flashlight is necessary for sighting the laser instrument.

- In the course of rod plumbing, the rodman's headlamp sometimes was confused for the target light by the laser operator. (See figure 1.) This results in null laser readings, as the instrument must be aimed at the reflector for measurements to be made (with the filter installed on the instrument). The rod person can alleviate the problem by shielding the headlamp and any lights other than the target from the view of the laser operator.
- The laser instrument successfully makes azimuth measurements only when instrument inclination is in the vertical window of ±15 degrees. Several traverse links were steeper than 15 degrees; the instrument makes slope distance and inclination measurements, but not the azimuth.

The azimuth measurement is made by scrolling to the azimuth screen on the instrument, holding the instrument within the 15-degree window, sighting the target with the EDM sight, re-triggering the instrument, and scrolling back to the horizontal vector screen. The problem arises when attempting to use the EDM sight in the dark.

The operator on this survey shined a pen light into the sight, illuminating it, but this introduced sufficient local attraction to cause compass errors of up to 12 degrees. A scope light may be the solution to this problem. The sighting triangle is visible in the low-light environment; with practice, properly using the EDM sight in the dark may become easier.

Vertical inclination readings are made only in the vertical window of ±60 degrees. When cross sectioning walls and the ceiling of the cave—which involves removing the filter from the instrument and not using the reflector assembly—inclinations are often outside this window. One solution is attaching a vertical inclination scale, in degrees, to the side of the instrument. Vertical inclination readings may be manually estimated from the scale and keyed into the VI slot of the Lasersoft data entry screen. A sheet of plastic, with scale gradations in indelible ink, would make a suitable scale.

For cross sections made along the angle bisect, the direction may be estimated by throwing a wammie and illuminated with a flashlight. This azimuth is manually keyed into the appropriate slot of each data entry screen as are the inclination readings.

The Triangulating Traverse Survey Routine

Should local attraction adversely affect laser instrument azimuth readings, a triangulating traverse routine may be used to complete the survey without relying on horizontal angle measurements, except possibly a reference azimuth. Basically, PIs for more than one traverse—the number depending on the width of the project corridor and site conditions—are located, with sufficient side shots made to form triangles linking all PIs. If traverse #1 has "n" PIs, traverse #2 has "n-1," then traverse #3 again has "n" PI's, and so forth. Each traverse is surveyed in the standard fashion, with foresights and/or backsights between PIs, depending on the required accuracy. An example of how traverse #1 might appear in plan view is as follows:

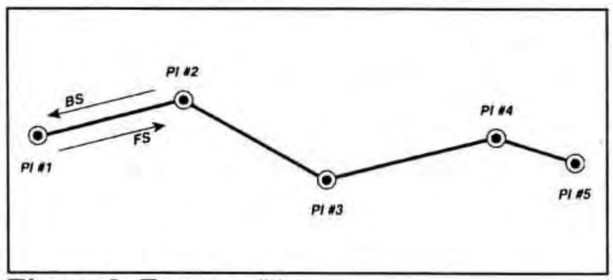

Figure 3. *Traverse #1.*

Traverse #2 PIs are laid out as follows, with enough distance between traverses to give depth to the resulting triangles (approximately one half of the distance between PIs):

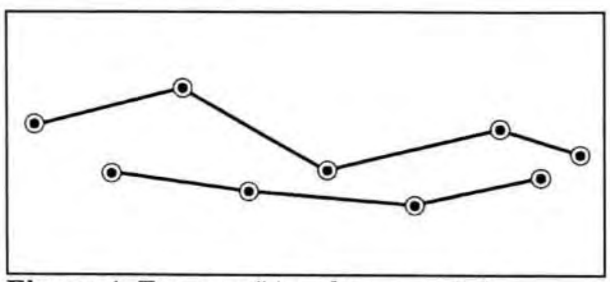

Figure 4. *Traverse #1 and traverse # 2.*

Subsequent traverses are laid out in similar fashion. Side shots between PIs are surveyed-in as

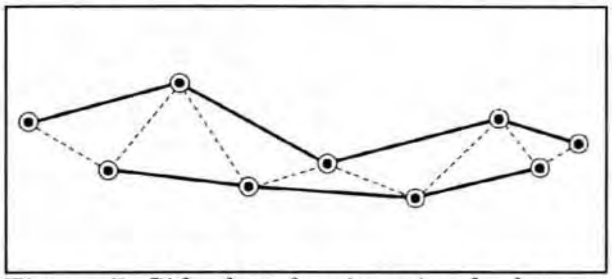

Figure 5. *Side shots forming triangles between traverse #1 and traverse #2.*

follows:

The law of cosines is used to reduce horizontal distances on triangle sides to a solution of all interior angles, which, with a reference azimuth made—perhaps outside the cave—are used to calculate azimuths for all traverse links and, subsequently, 3-D coordinates for all PIs. Bisect directions are estimated for cross-section side shots from select PIs by throwing a wammie.

Data Conversion and Import Into AutoCAD®

The ASCII conversion routine in the Lasersoft software converts raw traverse and side shot data into an ASCII file containing 3-D coordinates for each point surveyed. The points are then imported into Tontocad as follows:

1. The ASCII file built from Lasersoft is renamed from having an .ACD extension to a .DAT extension.
2. From Tontocad, a horizontal scale factor is selected from the File/Utilities menu so that text brought in will have adequate size. For this project, 50 was used. Under the Programs menu and the Survey/COGO sub menu, Import Point/Traverse File option is selected.
3. From the dialog box that appears, the appropriate file to be imported is selected. "Plot points only" option is selected. The format of the ASCII file Lasersoft creates is comma delimited as follows: point number, northing, easting, elevation, comments.

This option may be selected from the dialog box. The options "plot point numbers as text," "write comments as text," and "plot AutoCAD points" are also selected.

The 3-D points of the cave can be viewed from any direction by changing view point (point command).

Sorting Points

Now comes the task of determining from the scattering of points which points are associated with the floor, walls, and ceiling of the cave. Since an organized approach of gathering the survey data was used, it was not difficult to construct the cross sections at each of the traverse points. All of the points were assigned a number by the conversion routine. The point numbers are organized such that traverse point number is first, then the side shot numbers are consecutive in the order they were made. This rule applies to each cross section. The side shots were made along the bisect angle, starting at the left side from the floor working toward the ceiling, with the same procedure on the right side. The corresponding point numbers were in the same sequence. Using the following procedure, the traverse and cross sections are drawn in AutoCAD:

1. The traverse is drawn by connecting all of the traverse points with a 3-D poly line. The traverse points are easily identified, as they have the smallest point number along a cross section.
2. The point numbers along the cross section of each traverse point are connected by a 3-D poly line, starting at the traverse point, and follow the sequence of point numbers for left and right sides of the cross section.

Contouring the Floor

The surface-modeling module from Eagle Point Software was used to assist in contouring the floor of this particular cave. Eagle Point uses the TIN (triangulated irregular network) method for modeling surfaces. The TIN is an array of lines connecting 3-D points in the form of triangles. Once the TIN is formed from a set of data points, a grid—or contours—may be constructed.

Before the floor is contoured, its separation from the ceiling is required. The overhanging data points along the walls and the ceiling of the cave would obviously confuse the software. Building a TIN from all of the data points was attempted in this case, but resulted in a fatal error in the software. It is likely contouring caves is an application not foreseen or provided for by software designers. Separating the floor from the ceiling is accomplished by selecting the floor points and placing them in a separate AutoCAD layer. By viewing the cave from a 3-D view point, the floor can easily be visualized and selected for a layer change. A TIN is then constructed only on the points in the floor layer. These steps are summarized below:

1. Initiate Eagle Point and open the cave drawing. Freeze all layers except the floor layer.
2. A boundary is drawn around the perimeter of the floor points with a closed 3-D poly line. The Surface Modeling menu under EDSC is selected. Under TIN, select Boundary. A dialog box pops up and asks for the surface model library. At this point, surface model for the floor is created. The boundary is then selected.
3. Under the TIN menu, Make TIN is selected. From the dialog box that appears, Make TIN and Make Contours are selected. When prompted by the software to select points, "all" is entered. When prompted concerning a boundary, "yes" and "p" for predefined are entered.
4. The program proceeds to generate contours.

The initial completion of the above procedure, including transferring survey data into AutoCAD, constructing cross sections, and contouring the cave floor required three hours of CAD operator time. It is estimated that the experience gained would allow the operator to cut this time in half for subsequent executions of the effort. The time required will obviously depend on the individual CAD operator's experience and abilities.

Practical Applications of Show Cave Development

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Abstract

The 1991-1992 cave development project at Forestville State Park, Minnesota, involved examining other cave operations in 13 states to help determine what was appropriate for the Historic tour route in Mystery Cave. The project objectives were: making the cave accessible to all visitors, installing the least-intrusive accouterments in terms of visual obstructions, and doing so with the least impact on the cave environment. Walks are designed for periodic cleaning with water which is filtered before being released into the cave. Galvanized steel grating is used on bridges and walks. The cave entrance tunnel restricts airflow and has access for bats and people. The lighting system has low voltage switching and an emergency back-up and is programmable. A variety of lamps and techniques were used during light placement. Various strategies are used to camouflage features. Although some errors were made in this project, the development is functioning well after three seasons of operation.

Though little is written about various aspects of cave development work, there are individuals who have years of practical experience and considerable knowledge of the subject. The following are notes of the approach taken in redevelopment of the Historic tour route at Mystery Cave in Forestville State Park, Minnesota, from spring 1991 to spring 1992. It is a description of what worked favorably for this particular cave. It is not a suggestion of how to approach development at other caves.

Some of these ideas will work at other sites, others are probably inappropriate. Nevertheless, there is a lot of common ground that may have application for other cave development. For instance, the perpetual search for affordable, noncorrosive material is of interest to many, and the fact that virtually all of this type of work is done by hand is another example.

Tour Route Description

The tour route development included one main passage 700 feet long and three side passages that branch off within 125 feet of each other. The total passage distance is 1,400 feet. Most ceilings are flat and the passage shapes are typically square or rectangular. Passage widths vary from four to ten feet wide, and ceiling heights vary from 5½ to 20 feet high. Several crevices or holes are encountered on the route. The two deepest are sheer drops of 20 feet. When the cave was purchased in 1988, a multitude of problems plagued the tour routes, including serious safety issues. These were the impetus that led to the redevelopment efforts at Mystery Cave.

An effort was made to examine what is used at other show caves to see what is working, what is not, and what the owners, operators, managers, and maintenance personnel would like to have done differently. We visited over 30 caves in 13 states and talked with personnel at most of them. In addition we listened to the opinions of many dozens, if not hundreds, of individuals associated with caves, ranging from cave developers to cavers.

One of the requirements of the bidding for the lighting design contract was for each firm to retain the services of an individual experienced in cave development work. Of all the caves visited in preparation for this project, we found Blanchard Springs Caverns, Arkansas, managed by the USDA Forest Service, a particularly fine example of outstanding cave development. The lighting design contract required the successful bidder visit Blanchard Springs as an example of the type and quality of work desired at Mystery.

Consideration was given on all material, equipment, methods, and designs used in the cave to minimize environmental impacts. We were just as cognizant of the visual impacts. Both issues were dealt with constantly. A considerable effort was made to search for innocuous, durable materials that could withstand the corrosive effects of the cave environment. On high-cost items, such as bridges and handrails, material costs were a major factor in decision making.

The direction of the project was the result of a core group of six Department of Natural Resources people and one contracted lighting-design engineer. There were dozens of meetings held among these team players to clarify details and communicate what our goals were. In retrospect, this professional teamwork, which kept the players informed, was probably one of the major positive influences that led to the successful completion of the work. It was not idyllic. We faced lots of aggravations and difficulties. However, for the most part, these were dealt with constructively. Each individual contributed some very good ideas that were used in the project. Design by committee may sound disagreeable to some, however, here it appears we respected and captured the expertise of each player.

In the spring of 1991 a $750,000 contract was let to a general construction company for the bulk of the cave work: electrical, water lines, telephone system, walks, handrails, entrance building, and outside bridges. This company did most of the concrete work and subcontracted the other jobs. A couple contracts with other companies covered the cave bridges and specialty concrete work. Approximately one million dollars in development costs were incurred on this project and the preparatory excavation work which had commenced in 1989.

Walks and Curbs

Concrete was selected as the walking surface that could withstand the foot pounding of thousands. Considering the cost, durability, appearance, and chemical make-up of concrete, it was the practical solution to our needs. For years crushed limestone and pea gravel had been in use, but it required at least annual maintenance and got kicked off the trail and onto speleothems. Concrete also offered the opportunity to contour with the natural lines found in the cave (passage shape, bedding planes, joints, and the like) .

Pumping concrete to the pour site in the cave was rejected for fear of a spill from the line, complications of cleaning the line, clogging the work areas in narrow passages, and other miscellaneous factors. Concrete for the walk was mixed at a plant in town and delivered by truck to near the cave entrance. It was transported from the truck to the pour site in the cave by wheelbarrows. In a couple of locations, buckets were filled in the cave from the wheelbarrows and carried by hand up or down stairs. In areas with a grade, aluminum oxide chips were imbedded in the wear surface for traction.

Depending on the situation, the concrete was poured either to abut against the cave walls, or, more often, concrete forms. Nowhere does the concrete gently taper off on the edges and disappear in the cave floor, a practice we find counterproductive. All edges are distinct and fulfill several functions.

Small curbs (two by four inches) are used on walk edges (Figure 1). These did not require special forming. They were constructed by the concrete finisher building up the edges against the

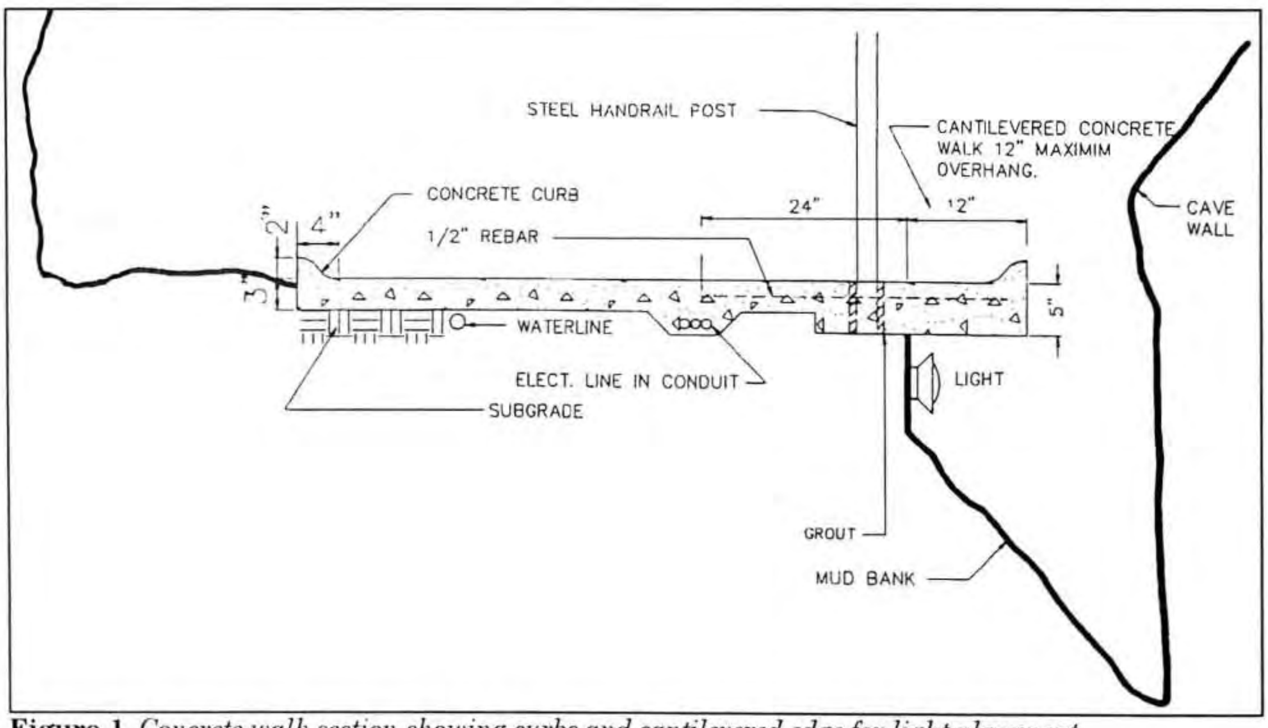

Figure 1. *Concrete walk section showing curbs and cantilevered edge for light placement.*

forms as the pour was in progress. The curbs are well proportioned from the aesthetic viewpoint and serve five purposes.

- Clearly delineates the edge of the walking surface.
- Confines much material carried in by visitors to the walks (lint and debris on shoes for example).
- Confines water used to clean the trail and routes it to drain structures.
- Acts as a physical barrier to keep wheelchairs on the walk.
- In some spots where the walk is adjacent to mud banks, the backside of the curb acts as a mini-retaining wall, catching mud or gravel that sloughs off.

Although the cave passages are quite linear, where the cave does change direction the walk has flowing curves as opposed to sharp angles. This was simple to do while forming. It gives a visual effect that is similar to many of the smooth and rounded cave wall contours. Care was taken to pitch the entire walk to prevent water from forming puddles and assure drainage to catch basins and trench drains.

In some sections, floor lights are flush with the ground and the walk curves around these, again prolonging the natural curves of the cave walls. In a number of locations, lights are in cavities below cantilevered walk edges (Figure 1). Where this was done additional forming was necessary along with reinforcing rods in the concrete.

One mistake made in the walk design is where the grade changes from steep to gentle the change is not at right angles to the direction of the walk. The result is that when this portion is traveled by wheelchair, one wheel comes off the walk, and the visitor is stuck. This construction error was not realized until the route was traveled in wheelchairs months later.

Water Lines, Trench Drains, and Catch Basins

A water line is buried under the walks and runs the length of the tour route. It is used for cleaning purposes. Spigots are located in plastic handholes in the concrete trail or hidden behind structural members of bridges. The line carries untreated well water from an aquifer below the cave water. Any section of the walks is reached by using 100-foot lengths of hose from the spigots.

Rather than run the water line across a crevice bridge on the tour route and have to deal with camouflaging it, a temporary hose is used to bridge the gap. The water line buried underneath the walk ends at one side of the bridge in a hose connection. It begins again on the far side of the bridge with another hose connection. To get water to the line on the far side of the bridge, a short length of hose is used to connect the two permanent lines. Since the water is only used a few times each year, this arrangement is only a minor maintenance inconvenience and is a way to keep the crevice visually unimpaired.

Walks are sprayed to wash away debris tracked in by visitors. The combination of walk grades and curbs routes the water to trench drains or catch basins. In the walks, these appear as grates approximately six inches across that extend the width of the path. Beneath the grate, water is contained in a watertight box.

Solids settle to the bottom of the drain box (4 inches wide, 19 inches long, and 22 inches deep) and may be removed with a trash bucket that nests inside. At the top of the trench drain box a four-inch PVC outlet pipe allows water to flow out. Water in the PVC outlet pipe is released into the cave. The final adjustment, yet to be installed to the trench drains, is a simple filter system such as filter fabric over the intake end of the outlet pipe.

The catch basins are identical to the trench drains except there is no outlet pipe. Water must be pumped out. Unfortunately the catch basin boxes are too narrow to put in a conventional sump pump. This has been a maintenance headache and requires the use of a special pump which is clumsy to use.

In one situation where water is directed over the edge of a concrete platform, it is caught in a plastic house gutter and routed into a five-gallon bucket via a downspout. The bucket acts as a settling basin. Even without the filter setup in place, these systems work. The amount of mud, hair, and smelly material collected in the settling basins is remarkable.

Although we only spray down the paths a few times a year, other water on the trail from sources such as condensation or stalactite drips takes a slow but decided route to one of these basins. Any time the trail is wet the debris cleaning system is in operation.

Grating

Despite cautions from other cave operators about using grating, we felt it would be an important aesthetic addition to areas where the trail passes over speleothems, a pool, or crevices to provide the visitors views which would otherwise be largely obstructed if the walking surface were solid. Indeed, in some narrow passages of the tour route the walking surface makes up the floor from wall to wall. The concern about using grates expressed by others involved additional maintenance time needed to pick up items dropped by visitors. In the last three years this has not been a problem. Of as much or more concern to us were reservations we shared with Russell Gurnee regarding the noise from squeaking and shifting metal grates as witnessed at other caves.

Numerous products were considered for see-through walk designs, including various conventional steels, cor-ten steel, stainless steel, coated steel, expanded metal, fiberglass, glass, plastic, and aluminum grating. Although initial inclinations leaned toward fiberglass, it has a relatively large amount of flex to it which we felt too many visitors would find objectionable. Although the sag can be addressed by more support beams and thicker grating members, the visibility through the grates was significantly diminished, defeating the whole purpose of using them. Similar issues cropped up with other materials. Except for the brilliant shine, stainless steel was appealing, but prohibitively expensive for our budget. For our application, galvanized steel simply had the best strength-to-visibility ratio coupled with corrosion resistance, and cost. After consulting with the state aquatic invertebrate specialist and discussing the issue with a cave biologist, it appeared the impact of galvanized steel to the cave environment would be minimal for our application. Although a variety of steel grating designs are available, an open-bar grate (15 W4 1 inch x 3/16 inch) providing clear openings of 3/4 inch was selected. The grating is oriented in an unconventional manner. The length of opening is aligned with the direction of the passages, or, in other words, the bearing bars are parallel with the direction of the passage (Figure 2). This gives the visitor the best view of features below, both ahead and behind tens of feet. Had the grates been oriented in the typical fashion, with opening at right angles to the direction of travel, visitors looking into the crevices below are only able to see what is more or less directly underneath. Although the orientation selected is not as structurally strong for a given span and required a few more cross beams, the overall viewing area is markedly increased.

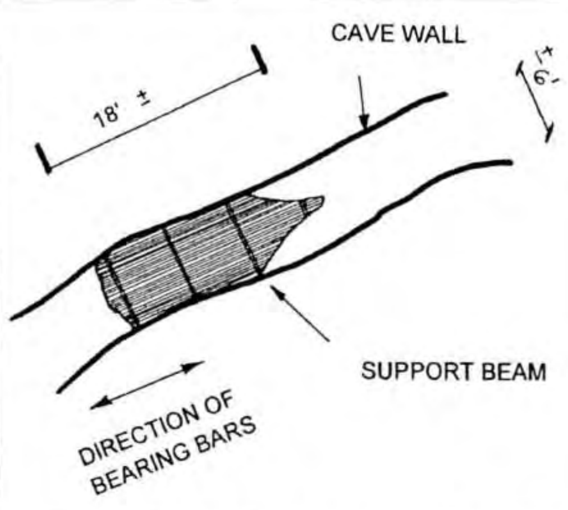

Figure 2. *Bearing bars oriented parallel to the cave passge for maximum visibility. Grating is contoured to the cave walls.*

In areas where grating is used and the tour route is adjacent to the cave wall, the grating is cut to match the wall. This approach gives the impression to viewers of a custom fit—a design especially for the cave trail. In our application it also eliminated the need for a handrail.

Most of the grating used is on a slope. Although the walking surface of the grates has a serrated edge, it is somewhat rounded. In one spot with a 12% grade, visitors occasionally slipped on the grating. To rectify the situation, the section was removed from the cave, and a metal cutting blade on a circular saw was used to cut grooves in the serrations. Although this violated the galvanizing, the slipping was eliminated and rusting has been minimal.

Initially, our grates were "quiet" when clipped down tightly, but the clips were difficult to tighten, sometimes loosened, and occasionally broke. Eventually an alternative way of securing the grates was found that successfully eliminates the sharp, squeaky noises and is methodically being installed as time permits. The grates certainly take more maintenance time than a solid treadway, but it is worth it for what we are trying to accomplish. There is a certain amount of reverberation from the grates if a group is walking across them rapidly. However the benefits of the grates in this application far outweigh the noise issue.

It is true that material cannot be washed off the grates and routed to the trench drains. Thus, the 250 to 300 feet of grated walks compromises the filtering system. However, the natural advantage this cave has is that periodic flooding and normal dripping along the tour routes flushes material to the stream level 20 feet below from there it is an eight-hour river trip to the surface. No, this is not a perfect system, but compared to what is flowing in the cave stream as it enters the cave, the deleterious effects of unfiltered water washed off the tour routes and entering this stream is absurdly minute.

Handrails and Strip Lights

Handrails are galvanized steel pipe. Whenever possible, attempts were made to eliminate sharp angles or corners in the pipe. The pipe is bent in curves to match the flow of the cave passage and walks.

In most cases the hand rail is a single 32-inch-high pipe parallel to the walk and supported every six feet by posts of the same material. Cores were cut in the walk every six feet for the handrail posts. Unfortunately, today the grout which was specified for the posts is slowly turning to mush from the surface down. This is happening in areas that are wet most of the year. Fine for outside use, the grout does not hold up under perpetually-wet conditions. Today, the old grout is being chipped out and replaced with waterproof grout as time permits.

At the time of construction, a search to locate round fiberglass handrails proved fruitless. Although we had seen steel and aluminum clad in plastic coatings, we had difficulty finding someone who handled these products. The project time line eventually closed in, plus it appeared the handrails would have to be "flame" coated in the cave which precluded this solution.

Bridges

Again, after a considerable search for affordable, innocuous materials that would hold up under cave conditions and provide a view below, galvanized steel bridges with grating were selected. The load-bearing beams of the bridges either bolt into concrete abutments or into the cave wall. Most beams are tubular steel, and designed with the idea of running conduits through them. This was done to a limited extent on the Mystery Cave project. There wasn't enough time available to research this thoroughly when the contract specifications for bridges were written. What was constructed was not necessarily what the electrician could use. This was a missed opportunity for hiding the conduits.

Entrance Tunnel

The Mystery Cave entrance is located adjacent to a river in an interbedded limestone and shale formation that is particularly susceptible to frost wedging. Because of the flood potential, problems from rock falls around the entrance, and various other engineering considerations, loose debris was cleaned from the entrance with a crane and bucket and a 40-foot-long concrete entrance tunnel constructed. Afterwards the slope was back filled, sealing off the entrance except for the outside door of the tunnel.

The tunnel provides access for both people and bats. Separate openings for the bats allow cave access anytime. Both ends of the tunnel have locking fiberglass doors (Fib-R-Dor) designed for use in wet areas. Previous perpetual door problems caused by moisture seem to have been averted with this product. The tunnel restricts airflow in a way that is probably similar to what existed at the time of discovery. An airlock at this entrance would be inappropriate. On the outside of the outer set of fiberglass doors is a flood door which is kept open during tour hours.

The flood door was selected to prevent recurrences of what occurred in 1942 when a flash flood broke down the entrance doors to the cave. Water gushed in and left thick layers of stinking muck, resulting in the cave being closed for five years. The massive 1,500-pound steel door provides security in addition to restricting floodwater. The cave can still readily flood, but it is from the relatively gentle upwelling of water from the lower level of the cave, not a silt-laden torrent rushing in the entrance. The flood door normally catches the visitor's eye and like the other cave accouterments, gives an unspoken message—"Minnesota's treasures are inside."

Cave Lighting

Cave lighting is a very a subjective art. It is rare to find an individual without an opinion about it. Indeed, perhaps no other subject relating to caves harbors more strong opinions from naive individuals than how the lighting should be done. Relatively few cave enthusiasts have practical field experience with cave lighting. Nevertheless, the results are appreciated and judged by virtually everyone who enters. The following is a succinct discussion of our approach.

Lighting Objectives. For a final product we wanted a lighting system in which lights could be turned on and off as a group progressed through the cave. Indirect lighting was desired, that is, wires and fixtures were to be hidden. If there was not a way to hide the fixtures, they were to be fully exposed. We were not interested in "sort of" hiding lights. They were to be completely hidden or obvious—all or nothing. Also, only incandescent lamps were considered.

Equipment. The cave entrance is provided with 240-volt power to an electrical room adjacent to the cave end of the entrance tunnel. The entire tour route is fed from there with 110-volt runs. The electrical room contains an emergency lighting system (Holophane) which is capable of providing 110-volt power to the cave lights for four hours from a bank of batteries. A Honeywell two-wire low-voltage lighting control system is in place and interconnects all light switch and relay components. The switches may be addressed to operate any circuit in the cave by a very simple and quick hand-held programming unit. Light emitting diode (LED) lights at the switches identify whether the circuit is on or off. This is an important feature considering the complexity of three passage junctions meeting in the same vicinity: multiple switches control some of the same light circuits and frequently multiple cave tours are in progress at once. Two master panels (one is in the electrical room and another in the ticket building) identify the status of all circuits in the cave. The system offers a lot of flexibility and is simple to adjust. Although automatic dimming is not available, the time-delay "off" feature is often used in our application.

Due to the narrow passage configuration at Mystery, the potential for dramatic effect from variations in light selection or sequencing is severely limited; there just aren't that many options. However, in a more voluminous cave, it would appear from our experience that considerable variety could be achieved with such a system. Apparently Mystery Cave is the only cave using this Honeywell system.

Conduits. The electrical cables are in conduits extending from the electrical room and running underneath the concrete walks. The conduit ends in either the light fixtures, such as a rigid fixture mount, or plastic junction boxes. Extending from the junction boxes are flexible three-wire cables that feed fixtures which can be moved readily. The flexible wires are hidden in cracks, under rocks, in shadows, or in the ground.

Switch Stations. Switch stations are mounted on posts with switches mounted on the face of an angled box (Figure 3). Twenty-four-volt heating devices inside are operated with a thermocouple to drive off moisture. A plastic drip plate extends from the top of the box, protecting the switches from the top but leaving the face and sides open to the operator. This design has proven effective in keeping the switches clean and dry. It has also served as a cozy home for mice until all access holes in the post and conduit were plugged. The top of the drip plate is typically wet from drips and catches a film of particles (clay and dust).

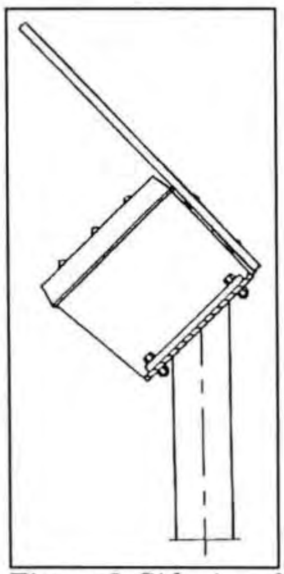

Figure 3. *Side view of a switch station with plastic drip plate.*

Fixtures. Most of the exposed light fixtures are of two types designed for outdoor use (Bronzelite) with Par 38 lamps. One design is for a recessed floor mount. The other is built to attach to a spike to stab into the ground or may be mounted to a surface with bolts. The bolt mount is used on the main beams of the bridges.

Bare Bulbs. In areas where lamps are hidden from view, bare-bulb sockets are used. In some situations bulbs are laid on the ground and small rocks or clods of soil are used to adjust the lamp to direct the light beam as desired. More often, if enough room exists, the socket is affixed to a plastic stake cut out of PVC conduit and attached by means of a plastic tie strap. The stake is pushed into the soil (Figure 4).

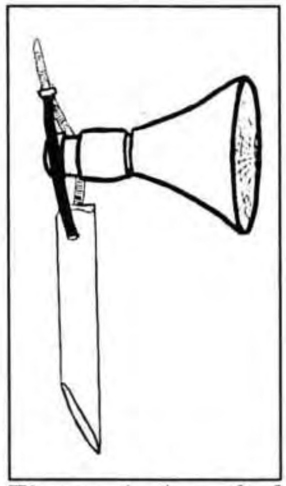

Figure 4. *A method used to affix a bulb socket to a conduit spike.*

Strip Lights (Tube Lights). At several sites 24-volt strip lights (Litelab) are used. These lights consist of a string of evenly spaced tiny bulbs in a clear, plastic tube. A small transformer nearby provides the power. These strips give an even, soft glow to features. We have used these under the edge of concrete overhangs and in handrails to illuminate cave floors or delicate features (such as tiny rimstone dams) or to provide trail light for walking.

Strip lights work particularly well in handrails (Figure 5). A portion of the pipe is cut away lengthwise, and the strips are wedged in place with rubber discs. The wires for the tube are run up the handrail post. At this location the handrail functions as a definitive barrier between the trail and delicate cave features, a rail for visitors to hold on to, a step for children to stand on, a location to hold and hide feature lights, and a location to hold and hide trail lights

Flooding destroyed several transformers for the strip lights. One type of transformer that can and has held up after flooding is encased in epoxy, as opposed to another type with windings exposed to air.

Junction Boxes. All junction boxes have 1/4-inch holes drilled in the low points. We learned the merit of this after listening to the advice of other show cave operators and then experiencing our first flood on the tour routes. Each box was full of water that could not drain out. Had holes been

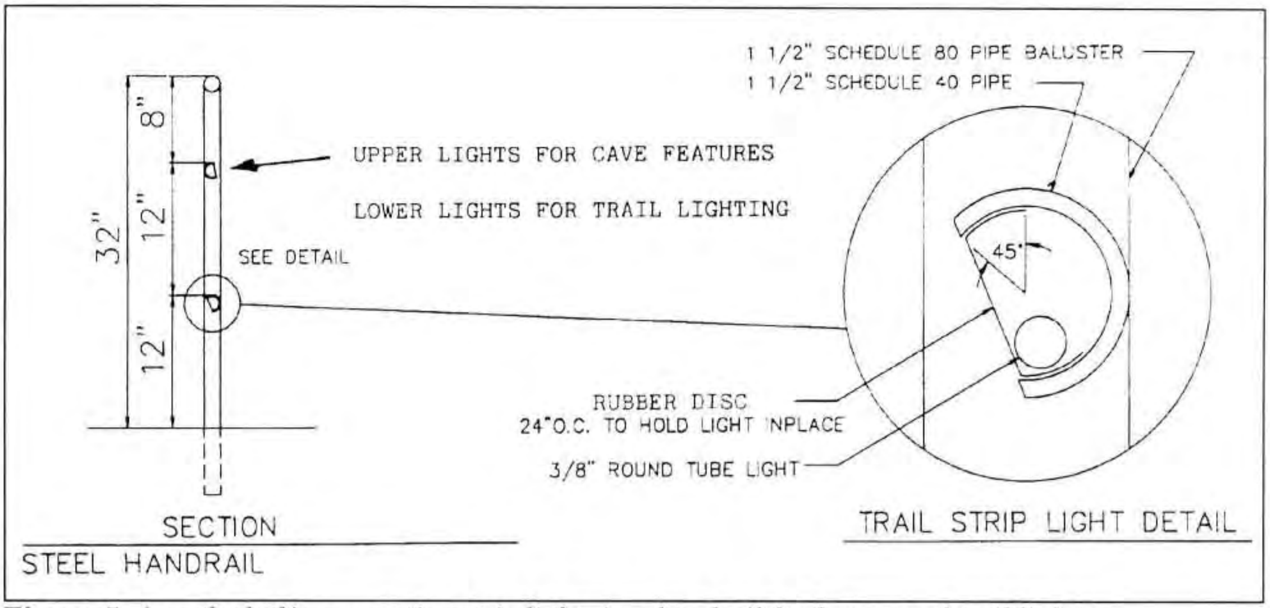

Figure 5. *A method of incorporating strip lights in a handrail for feature and trail lighting.*

drilled when installed, a lot of time could have been saved. A similar situation existed with the light fixtures which came with a rubber seal that seats between the socket threads and the base of the lamp. These seals allow water in and keep it there.

Lamps. There are a dazzling variety of incandescent bulbs manufactured. Most of our lamps are 45-watt PAR 38 VWFL (very wide flood). Other lamps used include standard bulb 37- and 64-watt sizes plus a few PAR 20 and PAR 30 types. None of these are available locally, a concern initially. However, there are plenty of suppliers that carry these and are able to ship them promptly. Although we certainly were not interested in any exotic lamps, the PAR 38 VWFL lamps used in Mystery give a significantly wider beam than the typical floodlights available off the shelf. The point is, there are lamps available to do the job and they are not hard to obtain.

In-Cave Light Testing. A major flaw in the Mystery Cave development process involved lack of in-cave experimenting and testing of lights. Although circuitry, wattages, and plans specifying how the cave was to be wired were detailed on paper, there was neither time nor money allocated for this hugely important task. Many lighting placement decisions were made only hours, or even minutes, before construction activities commenced. This was absurd considering a widespread opinion of many show cave people that the lighting can make or break the whole development project.

Virtually no other activity can be in progress during the testing. The passage has to be cleared of equipment and people in order to move lights around to various areas and work with shadow and light on the cave features. There were no provisions in the contract to stop or redirect the contractor's work to other areas of the cave to allow time for this testing. In spite of this, experimental testing was done with successful results. We cobbled together every extension cord available, along with trouble lights, Christmas tree lights, and a few light fixtures the designer had borrowed from a supplier. Such a key part of the lighting efforts should never have resulted in such last-minute haphazard arrangements. It was clearly an error in the light design planning. Had it not been for the personal dedication and perseverance of the on-site field managers, the cave lighting was doomed to failure.

Light Positioning Strategies. The ways lights are positioned are:

- Under concrete walk overhangs (Figure 1).
- Behind bridge beams.
- Atop ledges, behind natural cave contours, in crevices, behind corners, in grottos, and the like.
- In handrail members.
- In wall recesses we dug.
- Within or behind rock piles that we arranged.
- As a fixture in an exposed position.

In the linear, narrow passages of Mystery, it quickly became apparent how few opportunities there are for hiding lights within or behind the natural cave features.

The interbedded layers of shale and limestone lend themselves to digging wall recesses, an option used a couple of times. A hole was cut in the relatively soft shale layers near the ceiling to tuck in a lamp with a bulb socket. Although we only used this method a couple of times, given the right geology in a cave, it could probably be used effectively much more often.

After seeing many examples of rock piles contrived to hide lights in other caves, we took care in arranging ours to appear as natural breakdown. This involved considerable experimentation and using large rocks. We felt all too often this approach fails partly because so many small, easy-to-carry rocks are used. We worked with a variety of sizes but favored large, hard-to-move ones. We achieved satisfactory results in some places, and other spots didn't work out as well.

Two of us did the in-cave selection and placement of the lights. There was hardly a light that we didn't argue over the placement of or about what lamp should be used. If we did agree on a light initially, one would play the Devil's advocate. This process worked well for us. A third participant would probably have been a hindrance. Most of the lamps are precisely oriented. Shadows are as important as illumination. Collectively, the effect is considered striking by many. Unfortunately, as bulbs have burnt out and been replaced, workers were unable to maintain the optimum orientation. This gradual divergence from the original arrangement is discouraging to see. Others just don't recognize how the facets of light work with wall contours and shadows. They have not had the experience of working with the various lamps and positions and simply don't recognize the finer points of the whole lighting arrangement. Hopefully, this situation will be helped by developing a maintenance schedule of lamp types, fixture locations, and placement description.

Temporary Protective Measures

In addition to wooden guard structures erected around sensitive or delicate areas, a couple of other techniques were used to protect the cave during concrete work.

An effective barrier to catch concrete splatters is a very thin (about one- or two-mil) plastic sheet. We had a 5½-foot roll of the material. In wall sections needing protection, the proper length was pulled off and easily affixed to the wall.

The sheet is so thin and light that molecular attraction of water on the wall keeps the sheet in place. The walls in our work areas were normally wet, however water sprayed on a dry wall would give the same effect. In some spots with extreme overhang, the sheets were simply affixed in place on a ledge with clods of mud and hung down to the floor. Long sections of wall can easily be protected from splatters in a few minutes using this method.

At a number of areas on the tour route, flowstone was discovered during our excavation work that had been buried by previous cave operators 50 years earlier. Some of these sites were in areas where considerable construction activity was scheduled to take place. To protect these areas, plastic sheeting was laid down on top of the exposed flowstone and loose, excavated material dumped back on top, creating a soil layer that would absorb and disperse the impact of activity above. When the time came to uncover the flowstone, fill was shoveled off and one end of the plastic pulled up to expose the previously-cleaned flowstone.

At one point this technique was used, but burlap bags were laid down rather than plastic. It was a material we had on hand. It had worked out well for some of the previous excavation work. At the time it was thought the bags would be removed in a few weeks. Instead, months passed, and the bags began to deteriorate, necessitating more clean-up time than if plastic had been used.

Superior materials to plastic are synthetic carpeting and foam carpet pads. Care should be taken to ensure the carpet or foam is not so deteriorated it crumbles or falls to pieces underground. If carpet is laid on the flowstone, make certain the rug surface is put against the flowstone and not the abrasive backing. We got our used carpet and pads free from a carpet layer before they were hauled to the landfill.

Techniques of Camouflage

Except for the accouterments that must be visible (walks, handrails, bridges), we made an attempt to hide or camouflage everything else. Many of the camouflage techniques are obvious, but a few are worth mentioning.

Fake Rock. Several areas on the tour route were selected for an imitation surface coating of concrete textured to look like the natural rock or mud of the cave. This treatment was chosen to eliminate attention to man-made scars or structures and subtly direct visitors' attention elsewhere—to the natural cave features. For example, a concrete block dam, dry-laid rock wall, and broken edges of flowstone were handled this way. Additionally, there are spots that required retaining-wall structures to prevent mud or gravel from sloughing onto the trail. We hired a contractor that specialized in this type of work. Some results were exceptional, others not as good. The less-than-favorable results arose from the contractor's limited experience observing natural cave surfaces, not from lack of artistic skill. Indeed, in some areas, aside from the lack of crinoid stems in the rock, the surface looks identical to the real thing. The concrete veneer is an inch or two thick, supported by chicken wire, hardware cloth, and reinforcing rods.

Conduits. Conduits are exposed on bridges. Although they are run inside the tubular beams or are affixed underneath, in a couple areas the conduits run parallel to the wall and extend across a crevice. Fortunately, the sections are mostly in the shadows. Black filter fabric is draped over the conduits and coated with mud. This is not ideal, but in conjunction with the shadows, the conduits are effectively hidden.

Wiring. The absence of visible wires in the cave appears to make quite an impact on visitors. Many comment about it. They aren't seen. Also, unless water has washed off a section of mud or raccoons have been up to mischief, there is no evidence of the wires. Producing this effect is time consuming, but not difficult to do.

The flexible wire extending from junction boxes to fixtures are hidden in floor sediments, around rocks, and frequently in wall cracks. With the pronounced bedding planes and well-jointed rock in Mystery Cave, we could often tuck a wire into cracks without any alteration to the rock. All that is needed is a crack the width of the wire. A plastic putty knife or screwdriver blade works well to push in the cord, though care must be taken. In one case a worker got too aggressive hiding a 40-foot cord in a crack and cut a hole in the cord. An hour-and-a-half of meticulous work had to be torn out and replaced because of the cut. Occasionally, one- to four-inch-long plastic wedges cut out of PVC conduit works well to hold the cord in position. By cutting many wedges of varying sizes and shapes, it seems there is always one custom cut to fit the particular situation at hand. Most of the time the cord fits snugly into position in many of the wall cracks in Mystery and no wedges are needed. Although we never did it, the positive and negative wires do not have to follow the same path to the light. Separate single wires could be used in cracks too small to accommodate a cord with both leads. The flat "Brewer's Cord" cable we used had three wires, positive, negative, and ground. In situations where the cable fed a rubber bare-bulb socket, the ground wire is useless—there is nothing to ground. A two-wire cable could have been used instead and the cable hiding would have been easier. Sadly, however, as many cave developers know, it can be easier to chip out a wider crack for the cable than to get approval for a different one from the regulatory authority.

In some sections with hidden wires in cracks, a thin coat of cave mud or clay was smeared over the top of the wire, disguising it completely. There were a few spots where a wire needed to be carried across a bed that had no cracks. In those cases a hammer and cold chisel were used to chip and score a groove for the cable. Clay was then packed on top to hold it in place.

Jack Burch (Caverns of Sonora), who explained to us how to use these wire-in-the-crack techniques, suggested using thin coatings of a colored cement and fine sand mix rather than the mud and clay we have used. Our mud washes off periodically and the cement would seem to be superior. However, he cautioned to carefully experiment with the mix of coloring to get the correct match.

The wire-hiding methods described above are very effective for our geology. In numerous places the wires are hidden "right under your nose." Those of us who installed them tend to forget the route the cable takes up the wall, even as we later stare at it.

Junction Boxes. In many instances, four- by four-inch junction boxes are adjacent to the trail. The cut-off bottom of plastic milk jugs will fit nicely over these and protects them from the mud, rock, and soil piled on top for camouflaging purposes.

Water Handholes. These plastic boxes containing water spigots are set into the walk, the box lid being part of the walk treadway. One box is located adjacent to the walk and surrounded by natural cave floor. To disguise the green lid, a rigid piece of oversized Plexiglas rests atop the lid. On top of the Plexiglas rest rocks and mud that appear as part of the surrounding floor. There is about an inch between the cave floor and the bottom of the Plexiglas so one is able to reach underneath to lift it off. The box is kept free of mud and may be uncovered or hidden instantly.

Mud Floors. In areas where the mud floors had been disturbed, spraying with a hose helped to restore a somewhat natural appearance. However, natural floods on the tour routes did more in an hour or two to restore the ubiquitous thin veneer of silt than any of our efforts. The floods gave an even, dark hue to all the surfaces, eliminating the brighter sediment colors that had been exposed during construction digging. In the absence of such floods, which had not occurred for at least five years, we had discussed using a hand sprayer slurry of silt in an attempt to imitate this natural effect. Our technique remains untried.

Ceiling Textures. Mystery Cave is remarkable for it's flat ceilings. They look as though they have been plastered. In most places there is a thin coating of mud on the rock ceiling. The ceiling had marks from people dragging fingers across that surface. After trying water sprays, rags, and other materials to try to dab the mud to re-create the natural ceiling textures, we discovered that a natural sponge works quite well. Other materials we tried simply didn't work.

Summary

Not all our visitors like the development work; however, an overwhelming number give us unsolicited, favorable comments about it. After three seasons of use since the project's completion, there have been a number of adjustments made to the facilities or equipment. Nevertheless, it is largely proving quite satisfactory in day-to-day operations. Aside from simply providing a way to get visitors through the cave, the development work sends a continual, unspoken message to the visitors. The custom-designed grating, attention to detail on the lighting, and the flow of the cave walks all indicate "this place is special." These silent messages appear to instill respect and appreciation in our visitors for the cave as a natural wonder.

Conclusions

The finished product at Mystery Cave reflects our effort to "harden" the cave to withstand the impact of thousands of visitors annually, provide accessibility to all, and present the cave with the least intrusive accouterments needed for visitor safety. We consider the results as state-of-the-art cave development for the approach we took within the available budget. Some of the techniques and approaches used may have value at other caves in similar situations.

The Rescue of McConnell Springs Historic Site: A Partnership Between Local Government and the Citizens of Lexington, Kentucky

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Abstract

McConnell Springs comprises the initial area of discharge for a significant karst system situated in the heart of the urban-industrial district of Lexington, Kentucky. This feature, consisting of a series of sinks and rises, is fed by underground drainage from a large portion of south and southwest Lexington. It ultimately discharges from a small cave three-quarters of a mile west of the springs. The major feature of this grouping of karst landforms is a large blue hole.

The location is historically significant for several reasons. Circumstantial evidence suggests that the springs may be the site of a 1775 explorers' camp where the name for the future community of Lexington was proposed. During the War of 1812 the flow from the springs powered the largest gunpowder mill in Kentucky and later supplied water to a bourbon whiskey distillery. In addition, during the late 19th century, the springs were a major focus in the controversy to provide the city with a public waterworks.

Almost precisely a century later, the site again became embroiled in public controversy. The site of the springs was farmland during much of the 20th century. After World War II, Lexington's accelerated urban growth spread to surround it, creating a hidden oasis of water and greenery. One consequence of the adjacent industrial development was increased dumping of trash and fill dirt at the edges of the depression that contained the springs. This situation reached crisis magnitude following the 1985 purchase of the property by a developer who intended to turn the entire parcel into an industrial park. In violation of local ordinances, the developer attempted to eliminate the springs by dumping and grading. Enforcement of the Lexington ordinances resulted in the bankruptcy of the developer and preserved the springs site from further degradation. Attendant publicity stimulated citizen interest in the springs. Through private donations, a 20-acre tract surrounding the springs was purchased and donated to the city as a park. Today, many Lexington citizens are actively involved in restoring the springs tract.

Introduction

Historically, urban development has often resulted in the contamination or disruption of ground water systems and the physical obliteration of significant karst features as well as caves and cave ecosystems. Prior to the general increase in public awareness of environmental issues that evolved from the late 1960s, this situation was of little concern to anyone other than a handful of cave explorers and karst scientists. Not until the late 1980s did urban planners in karst regions begin to acknowledge the significance of the relationship between karst systems and development. In addition, citizen concern over such issues as ground water contamination, the decline of city centers, resource conservation, endangered species and ecological integrity, historic preservation, and environmental education, have led in recent years to the preservation of several karst systems or features located in urban regions. Such was the case in Lexington, Kentucky, where a karst system, whose most visible manifestation was known as McConnell Springs, was spared from a developer's bulldozers to become a cherished city historic site and natural preserve.

This achievement, accomplished at literally the eleventh hour, was not brought about easily or quickly. Nearly two decades passed between the first proposal, in 1975, for the city to acquire the springs tract, and the realization of that goal in 1994. During that period the springs were increasingly threatened by encroaching industrial development. Given the location of the site, scarcely a mile from the city center, the wonder is that the land was not developed long before. As it is, the 21.5 acres of the McConnell Springs site comprise a startling oasis of water and greenery in the midst of urban Lexington, surrounded on all sides by concrete, steel, brick, and asphalt.

What motivated the citizens of Lexington to stir themselves to preserve these particular springs, when, in the past, so many similar features had been destroyed in Lexington and communities similarly situated on karst terranes, to create landscapes conformable to the designs of urban and suburban developers? What was so noteworthy about these springs that they were rescued where others were condemned? The purposes of this paper are to discover the characteristics of McConnell Springs that aided in their preservation, to describe the process by which these features were brought under protective management, and to examine the management issues that arose subsequent to acquisition. We hope that the lessons in this situation might be applied to preservation of significant karst features elsewhere.

Description of the Springs

Less than a mile from the commercial center of Lexington, Kentucky, is a little oasis of water and vegetation that, until recently, was virtually unknown to most of the residents of the city. In this depression, enclosing about 21.5 acres, water boils up from the ground to form a deep pool 20 feet across, cold as the earth's bones, blue-green in color. Having escaped from subterranean confinement, the flowing water seems uncertain, even shy, for it sinks quietly back into the ground within a hundred feet of its emergence; only to bubble vigorously up again through the rocks at the base of a small bluff an equal distance away.

Liberated once more, it flows along placidly for about three hundred feet in a shallow stream edged with watercress, overhung by trees, until, suddenly agitated, it gathers itself to swiftly plunge again into safety and darkness. Here the valley ends abruptly. For yet 1,800 feet more this stream shelters in the bedrock security of its underground conduit, finally issuing into the sunlight from the low mouth of Prestons Spring Cave, remaining at last on the surface of the earth to mingle with other waters on the way to the sea.

The springs themselves are but the most visible point of a major ground water system that drains much of south Lexington. The precise boundaries of this basin are not known with certainty, but an approximation has been made by hydrogeologists, derived from available data. Using the concept of normalized base flow (Quinlan and Ray, 1995), the recharge area for McConnell Springs has been calculated at 2.6 square miles, derived from a winter base flow measurement of 1.46 cubic feet per second (Ray, 1995). By comparison, the recharge area estimated from local topography and dye trace data (Spangler, 1983) is 3.8 square miles. The area enclosed within the hypothetical boundaries encompasses much of urban Lexington as well as portions of the industrial area and some of the city suburbs (Figure 1). The old city landfill is situated just north of the springs but does not contribute drainage to the McConnell Springs basin.

Although there is no heavy industry within the projected basin boundaries, the quality of the waters of McConnell Springs are at risk from urban non-point runoff, leaking underground storage tanks, lawn and garden chemicals, and the waste

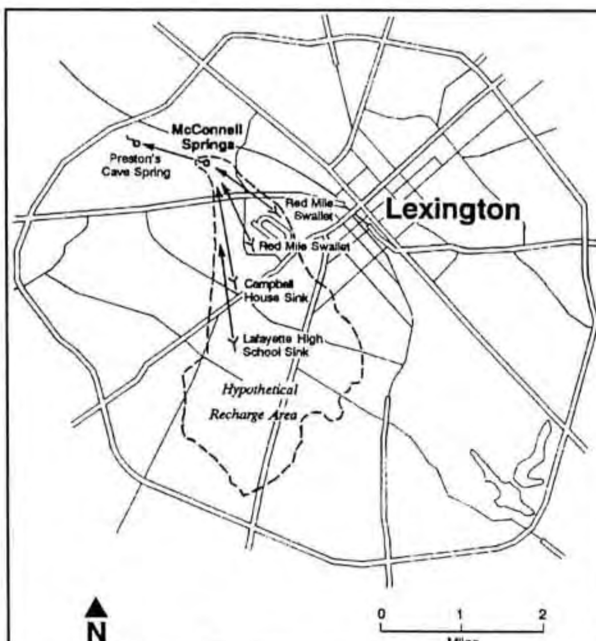

Figure 1. *The hypothesized recharge area of McConnell Springs, esitmated at 9.8 km2 by Spangler (1983). The recharge ares encompasses a substantial portion of the urban and suburban landscape of western and southwestern Lexington.*

products of existing light industries. Despite this risk, no significant contamination has been detected to date. The water quality of the springs is currently being monitored on a quarterly basis as a sampling station in the Kentucky Division of Water's ground water monitoring network.

Historical Significance

The Naming of Lexington: McConnell Springs achieves historical significance due to its close association with the events of three important periods in the development of the city and the region: the early exploration and settlement of Kentucky (late 18th century), the establishment of interstate commerce and industry in the Bluegrass (early 19th century), and the beginnings of modern infrastructure development in Lexington (late 19th century).

When the first explorers crossed into the lands now known as Kentucky, they were impressed by the numerous springs that were present throughout the karstlands of the region. Many of the more prominent springs became landmarks in the wilderness, and served as campsites and rendezvous. Close on the heels of the explorers came men with compass and chain who were determined to claim parcels of this rich new land and to establish stations and towns. The presence of a good water supply in the form of a flowing spring always enhanced the appeal of a tract and such were the first to be claimed and settled. A whole new language was evolved to describe karst features in deeds and depositions that referred to "blue holes," "sinking springs," and "cave springs." Stockades were built beside the best of the springs, and often grew into towns (O'Dell, 1993a).

In late spring 1775 a group of men were camped at a sinking spring, on lands claimed by William McConnell, near the middle fork of Elkhorn Creek (later Town Branch). The camp was used as a base from which to explore the surrounding countryside and choose the land they intended to claim. News of the April battle of Lexington, Massachusetts, came to the camp from Fort Boonesborough. Some thought had been given to the desirability of settling a town in the vicinity of the spring, so that when this news arrived, "Lexington" was chosen to name the future community in commemoration of the event. It would, however, be four more years before the establishment of Lexington was actually undertaken.

From our vantage point two centuries later, there is some confusion as to exactly which spring among the many along Town Branch was the site of the camp in 1775 where this christening occurred. Many accounts were written of the occasion, not all of which were in agreement as to details. Recent research, particularly that by local historian Carolyn M. Wooley (Wooley, 1975), indicates the location now known as McConnell Springs. Not all scholars of Kentucky history agree, but it is this site that has been officially so designated.

Gunpowder: William McConnell, for whom the springs are named, built a crude cabin near the springs in 1776 as part of his improvements to secure legal title to the land. Apparently he did not reside there for very long, if at all. McConnell died in 1805, a respected member of the Lexington community, and his property was divided among his heirs. In February and March 1810 the McConnell heirs sold a total of about 184 acres, including the springs, for $4,125 to Samuel and George Trotter (O'Malley, 1996). The Trotter brothers, among the wealthiest residents of Lexington, were merchants and entrepreneurs willing to risk substantial capital on new ventures. With a second war with Great Britain appearing inevitable, the Trotters had decided to build a gunpowder factory and purchased the springs property specifically for this purpose (O'Dell, 1990).

The manufacture of gunpowder was not a new industry in the Bluegrass. The first gunpowder factory in the state had been established by Richard Foley in 1793 near Lexington, and many other powder mills were built in subsequent years. The proliferation of gunpowder mills in Kentucky was made possible by the abundance of saltpeter (calcium or potassium nitrate) found in the many rock shelters and caves of the state. Lexington, as commercial center, became a focus for trade in saltpeter, the main ingredient used to make gunpowder, which was exported in quantity to the east as well as used in local manufacture. By 1810 there were at least 63 gunpowder factories in Kentucky. As war approached, many more people sought to take advantage of the steadily-increasing prices for gunpowder and saltpeter by building powder mills and mining saltpeter (O'Dell, 1989, 1996).

Samuel and George Trotter were the largest wholesale and retail merchants in Kentucky during that era and it seemed that nearly everything they ventured prospered greatly. The "Trotter Powder Works" became the largest powder mill in Kentucky and supplied gunpowder for many important engagements of the War of 1812. The Trotter mills, through Samuel's political connections (and on the superior merit of the powder) landed two large military contracts for gunpowder totaling 140,000 pounds. Trotter powder was used in the battles of the Northwest Territory, including the famous battle of Thames River (Canada) against the British and the Indian forces under Tecumseh,[1] and was also sent south to Andrew

1. Samuel Trotter's younger brother, George, was one of the commanding generals in the battle of Thames River.

Jackson and used in the celebrated Battle of New Orleans. At a time when the United States was desperate for military supplies, gunpowder manufactured at McConnell Springs filled a vital need (O'Dell, 1990).

A powder mill was not simply a large building in which gunpowder was manufactured. Because of the ever-present explosion hazard, each step involved in making gunpowder was usually carried out in a separate building spaced away from the others so that a conflagration in one would not result in the loss of all. At the Trotter Powder Works in 1820, in addition to buildings used in other process steps, there were five separate structures containing stamp mills. These stamp mills each contained a series of mortars and pestles, connected by a camshaft that ran the length of the building, used to pulverize and incorporate the raw ingredients. Trotter reported that these were:

- Two powder mills by water power carrying 40 heavy pestles or pounders
- Two by horse power carrying each 40 pestles
- One by oxen power carrying 16 light pestles used for beating up powder dust (1820 Census).

The two mills operated "by water power" evidently were turned by the flow from McConnell Springs. There is what appears to be the remnants of an old earth and stone dam on the stream, but archaeological investigations conducted in 1995 were not able to determine the precise layout of the buildings (O'Malley, personal communication, 1996). Although much of the stone fencing remains that dates from early in the 19th century, subsequent land uses and the encroachment of fill dirt on the property hindered the investigation.

After the end of the War of 1812, demand for domestic gunpowder declined dramatically and most western powder mills ceased operation. The Trotter Powder Works, however, remained a viable operation for many years. Not until 1833, when Samuel Trotter died during the severe cholera epidemic that then gripped Kentucky, did the mills cease operation. Trotter's will left the powder mill operation to his sons, but they declined to continue the business (O'Dell, 1990; Fayette Will Book L:115). The springs flowed placidly along, as they had for untold millennia, for nearly half a century before they again achieved a significance in the history of the community.

Water Supply: During the latter 19th century, the issue of water supply became of paramount importance to the citizens of Lexington. Throughout the early settlement period, the community was provided with water carried by hand from a series of minor springs along the banks of Town Branch creek. As the frontier town grew into a city, springs were no longer sufficient and many wells were dug. In time, these also proved inadequate and many individual and public cisterns were constructed. With continued community growth, cisterns, too, proved insufficient as well as unreliable. The situation reached crisis proportions in the 1880s when fire insurance rates took a drastic upward hike due to the inability of public or private cisterns to control fires in the city.

Up to this point, water supply had been largely an individual matter; there had been no such thing in Lexington as a public water system piped to homes and business. Certain citizens with the foresight to envision a future Lexington with a greatly-expanded population and industry urged the construction of a municipal water system. The issue became controversial, dividing the news media and the civic authorities into opposed camps. It took several years to resolve the conflict in favor of those who supported a public system, during which various sources were proposed as a basis for a city water supply. One of the sources that was frequently urged was McConnell Springs, which at the time was known as Wilson Springs for the current property owner.

From our modern viewpoint it seems rather ludicrous that a spring of the size of McConnell Springs, with a winter base flow less than two cubic feet per second, could even be considered as the primary water source for an entire city. One must take into account, however, that at the time there was little general comprehension of the origins and flow of groundwater. Many persons believed that the numerous springs of Lexington all tapped a huge subterranean lake, of which McConnell Springs was simply a convenient and inexhaustible outlet. Nevertheless, the opposing groups surveyed the blue hole spring for its potential, and came to contrary conclusions. One newspaper reported that the spring was bottomless, cold and clear, and would be "delightful" to the citizens of Lexington in their homes; the rival newspaper sent its own team out who concluded that the spring was a little rill "scarcely sufficient to wash the filth from the gutters of Broadway." The spring was never put to the test, for wiser heads ultimately decided to construct a large reservoir and, later, to pump directly from the Kentucky River (Dugan, 1953; O'Dell, 1993b).

The springs again faded into obscurity, forgotten save by those few that used the water for various purposes. A nearby distillery and a slaughterhouse ran lines to the spring and withdrew sufficient water for their respective purposes (O'Dell, 1987). During most of the twentieth century, the property around the springs was a dairy farm and well-maintained. Then, in the 1960s, the farm operation ceased and the farmland began to revert back into a wilderness of brush and trees.

There the tale of the springs remained, until Lexington suddenly remembered its heritage in the face of threatened destruction of the springs.

Saving the Springs

In 1974 James R. Rebmann, an experienced cave explorer, had recently been employed as a planner by the merged government of Lexington and Fayette County. He first learned of McConnell Springs in that year when documentation came to his desk proposing the inclusion of the springs site in the National Register of Historic Places. He made a visit to the site and immediately recognized the springs tract as having great significance not only for its historic associations but also for its aesthetic appeal and potential as an outdoor educational laboratory. At this time the site, owned by Lexington Concrete Products, Inc., was about 80 acres. Although Jim vigorously promoted the acquisition of the springs for a city park, and this concept was endorsed by the local Historic Commission, it was not then acted upon. The idea lay dormant for another decade.

Lexington, surrounded by thoroughbred horse farms, has long possessed a national reputation as a desirable place to live. In consequence, the city has remained dynamic, sustaining growth and a strong economy in a era when many similar communities have been plagued with a dwindling tax base. Ironically, those very aspects that have symbolized the attractiveness of Lexington, the picturesque Bluegrass countryside with tree-lined lanes and high-spirited horses capering in manicured paddocks, have been increasingly threatened by suburban development. Although city planning in Lexington began in the 1930s, following the merger of city and county administration in 1974, the new Lexington-Fayette Urban County Government was better able to manage development. While admittedly political and economic pressures have often thwarted sensible development, county-wide planning has in many instances been able to control and channel land use.

One important tool available to the Urban County Government for this control is the so-called Lexington Sinkhole Ordinance, adopted October 23, 1985. Lexington is one of a handful of communities in the nation that possesses the legal means to protect karst landscapes from uncontrolled development. Previously, land developers in Lexington generally ignored the presence of karst landforms and rearranged the landscape to conform to artificial designs. Sinkholes were eradicated *en masse*; long-established drainage patterns interrupted, often later causing flooding problems; and the foundations of structures erected over buried sinkholes often cracked and twisted due to uneven settlement. There was no legal recourse to the consequences of ill-planned development on unsuitable karst terranes (Watkins and O'Dell, 1994; Crawford, 1988; O'Dell, 1988; Quinlan, 1986).

As a result of a long-standing interest in cave conservation, coupled with professional training in urban planning, Jim Rebmann had a strong awareness of the hazards of uncontrolled development on karst terranes. Jim was one of the prime architects in creating and bringing about the enactment of the Sinkhole Ordinance. This ordinance requires developers to take cognizance of the karst aspects of a proposed development before approval will be given by the urban county government. Sinkholes and adjacent land may be classified to exclude any surface development such as filling of low places or erecting structures upon sinkholes (Watkins and O'Dell, 1994; O'Dell, 1988; Rebmann and Dinger, 1985; Lexington-Fayette Urban County Government, 1985). The passage of the Sinkhole Ordinance later proved to be one of the most important factors in the preservation of McConnell Springs.

At about the same time as the passage of the Sinkhole Ordinance, the Lexington Concrete Products company went out of business and the facility was left vacant. Subsequently, illegal dumping in the area around the springs increased. The property was purchased for $3.1 million in November 1985 by a company that intended to develop the 66 acres surrounding the springs as the Cahill Industrial Park. The five acres containing the springs were offered to the city as a donation contingent upon the city's purchase of an additional 15 acres at a price between $50,000 to $75,000 per acre.[2]

The asking price for the adjoining 15 acres was far too high in the opinion of many persons. Furthermore, Rebmann felt that there was a strong possibility that, pending hydrogeological studies to the contrary, this additional tract was an integral part of the sinkhole system. If that was true, then by the provisions of the Sinkhole Ordinance those 15 acres could not be developed as part of the industrial park and would therefore be worth considerably less. As it stood, though, a year later, the city government under Lexington Mayor Scotty Baesler was "not very interested" in purchasing the land.[3]

By 1987 numerous citizen groups and governmental agencies had expressed their support for the proposal, including local chapters of both the Sierra Club and the Audubon Society, the Bluegrass Land and Nature Trust, Kentucky Historic Commission, and the Kentucky Nature Preserves

2. A later appraisal indicated about $12,000 per acre.

3. Lexington *Herald-Leader* October 1, 1987

Commission. The Lexington *Herald-Leader* gave its editorial benediction to the concept. Even with the support of these groups, the city administration balked at the proposed acquisition. For three more years the matter rested in an impasse, until finally, early in 1991, the pot came to a boil.

Just after Christmas 1990 city officials issued a stop-work order against a local contractor who had been dumping large quantities of dirt and rock so close to the springs that they would soon have been obliterated. The contractor stated that he had been requested by the property owner to dump the fill at that location. Eight to ten acres of trees had also been graded away from the locale. The Sinkhole Ordinance and another environmental tool, the Erosion Control Ordinance, were used to halt the actions of the developer. Despite prior assurances from the development company that the springs would not be harmed, apparently their destruction had been intended. By midsummer 1991, the contractor had been required to grade the fill back away from the springs and install erosion control fences.[4]

By year's end, the plans to convert the site and surrounding land to an industrial park had evaporated. Blocked from being able to develop the 20 acres around McConnell Springs by enforcement of the Sinkhole Ordinance, the selling price of the remaining parcels had to be increased. Unfortunately, the high cost exceeded the demand, and only one parcel was sold. The company had borrowed money to develop the land and defaulted on the $1.2 million mortgage. In January 1992, First Security National Bank foreclosed on the loan. At a forced sale held February 10, 1992, 68 acres including McConnell's Springs were purchased by top bidder First Security for $802,000.[5]

The debate on city acquisition of the land resumed, at a far greater intensity. The *Herald-Leader* was now an active promoter of acquisition, and kept its readers informed of developments. Stimulated by the heavy publicity, Lexington citizens became increasingly interested in the controversy. Rebmann's name was constantly linked with the preservation efforts reported in the media, and one Versailles woman called him and offered to donate $50,000 toward purchase of the springs. Other, lesser, but equally appreciated, offers of financial aid were made by other local citizens and companies.

Lexington Mayor Baesler continued to have reservations about the feasibility of the concept, although several council members had expressed their support. In March 1992, the mayor and some of the council met with officials of First Security. Afterward interviewed by the press, Baesler stated that an inspection by the city showed some "potential problems." No one knew what might be buried on the site after years of illegal dumping. There might be "environmental horrors," hazardous materials that would make the cleanup prohibitively expensive. Baesler believed that the potential cost to the city might rule out any idea of purchase.[6] After this, events occurred in rapid succession. Increasingly, citizens and organizations voiced their support of the acquisition of McConnell Springs. The local chapter of Trout Unlimited, a group that promotes trout habitat and trout fishing, became interested in taking on the cold, spring-fed stream as a project for an urban fishery. Lexington Directions, a civic group fostering charitable and educational activities, approved a unanimous resolution to give their support to the acquisition efforts. The Lexington Environmental Commission sponsored a cleanup of trash from around the springs, in which more than 50 University of Kentucky fraternity and sorority members took part.[7]

In July 1992, First Security Bank and Trust offered the springs tract to the city for $100,000.[8] Still the Urban County Government dithered, and failed to act. By spring 1993, Lexington had a new mayor, Pam Miller, who was strongly in favor of the acquisition. The council authorized funding for an environmental assessment prior to beginning negotiations.[9] By September the assessment was complete: McConnell Springs was free of environmental problems.

At this time First Security Bank notified Jim Rebmann that an offer had been received from a developer to purchase some of the industrial land adjacent to the McConnell Springs site. Through prior talks with Rebmann, the bank was aware that the land the developer wanted to purchase was included in the planning for McConnell Springs for use as a parking lot and nature center. The bank (under new ownership as Bank One) gave notice that some definite action must be taken to acquire the site within the next 30 days. The bank agreed to reserve the 3.5-acre additional tract for the parking lot and nature center if the government would agree to make a down payment of ten percent of the purchase price for this smaller parcel.

Jim contacted the anonymous donor who had been willing to give $50,000 toward purchase of the Springs. Unfortunately, due to the long delay, her donation had been allocated to other worthy causes. Even so, she was still willing to contribute $10,000 to the cause. Then, at a meeting of the Board of Directors for Lexington Directions, Jim

4. Lexington *Herald-Leader* January 2; June 11, 1991
5. Lexington *Herald-Leader* February 12, 1992
6. Lexington *Herald-Leader* March 14, 1992
7. Lexington *Herald-Leader* March 23 & 29, 1992
8. Lexington *Herald-Leader* July 7, 1992
9. Lexington *Herald-Leader* March 26, 1993

asked for and received a $5,000 donation from the organization. A few days later, Isabel Yates, a member of Lexington Directions and of the Urban County Council, volunteered to head a fund-raising effort to buy the property.

Two months later, the citizens of Lexington received a gift from Bank One. In a ceremony at the site on November 22, the Urban County Government was handed a ceremonial deed to 21.5 acres of land surrounding the springs, with the stipulation that the additional 3.5 acres must be purchased by the end of the year for $130,000. In order to acquire this land from the bank for parking and a visitor center, an organization called the Friends of McConnell Springs was created from Lexington Directions. The Friends soon came to include a diverse group of citizens and Urban County Government officials.

At the end of the year, the goal had at last become reality. McConnell Springs now belonged to the city of Lexington. In the months ahead, the Friends of McConnell Springs and individuals within the organization would be presented with several conservation awards for making possible the rescue of the site. Yet this parcel of land was unlike any other greenspace or parkland property in the city, and provided challenges in development and management that could not be accomplished by traditional means of parkland administration and maintenance.

Developing the Mission of McConnell Springs

McConnell Springs occupies a unique niche in the hierarchy of Lexington's public lands. Although the property is owned by the city, and the Department of Parks and Recreation is responsible for its maintenance, it is the Friends of McConnell Springs, through its Board of Directors and advisory committees, who make the decisions as to how the property will or will not be developed. In addition, the Friends, having raised the initial funds necessary to acquire the acreage adjacent to the springs, continues to raise funds for the development of the property.

The establishment of this organization, the Friends, provided an immediate structure and hierarchy for future development and management of the land. The Friends of McConnell Springs is able to tap a vast pool of skilled and unskilled volunteer labor, including not only citizens of Lexington but also many residents of other communities who share a common interest in the state's heritage. On the Board of Directors and the various advisory committees are representatives of local and state government, planners, architects, geologists, botanists and biologists, and members of various environmental, civic, and preservation special-interest groups. Certainly, drawing as it does from such a diversity of viewpoints, the management of the Springs is not always in perfect agreement, but all hold in common the concept of management for the long-term preservation of McConnell Springs.

From the beginning, the Friends have sought to encourage maximum public participation in evolving this vision of the future of the Springs. To increase public awareness of the needs and goals of the Springs, and to produce a comprehensive master plan representing a consensus of public opinion for present and future guidance, a design *charette* was held in Lexington from July 22 through 24, 1994. A *charette* is an intense design process which assembles a team of professionals to examine a narrowly-focused design issue. The McConnell Springs charette brought together 31 design professionals and 120 interested members of the public to build a common vision of the Springs' future. During the intensive two-day process, recommendations and concerns offered by the public in facilitated focus groups were integrated by the design professionals with other design issues to produce a conceptual master plan for the site (Friends, 1994).

In addition to addressing administrative concerns such as parking, maintenance, and security, charette participants developed a set of long-term primary objectives for the property. These objectives were: preservation of the land from further physical and environmental degradation, restoration of the vegetation and of certain historic structures, development of the property to enhance accessibility and utility, and development of educational programs based upon the most significant conceptual aspects of the property. To a great extent, all these objectives are interrelated.

Of these objectives, the first, preservation, was in large part achieved through the acquisition of the property by the city of Lexington. Although this now assures that the property will no longer be threatened by urban expansion, the elements of the property must be protected from future degradation in detail. For example, there are two large bur oaks on the land of McConnell Springs that date from the pre-settlement era and survived the many vicissitudes of the property's subsequent history. In another example, the tract contains numerous dry-stack rock fences, constructed by Irish stone masons during the early 19th century. Over the years, these fences have been gradually disintegrating, pushed down by frost heaving, vegetative growth, and vandalism.

Features such as these need to be protected from further harm, and in some cases, such as the rock fences, it is possible to restore them to their original condition. One of the major goals of the management is, over time, to restore the rock fences. It has also been proposed that some of the 1812-era powder mill structures be reconstructed. The existing traces of these, however, are faint, and it is uncertain whether such an ambitious project will be undertaken any time soon.

At present, the existing vegetative cover in most of the property is in sad shape. Only a small part of the land has mature woodlands, mostly along the stream course, and even these are relatively young. Much of the rest consists of scrub or nearly barren land scraped clean just prior to acquisition. Much of the vegetation present is not native to the region but represents volunteer growth of foreign species, such as *Euonymous coloratus* groundcover. According to pioneer accounts, the Bluegrass region during the settlement area was part woodland, part grassland, a savannah-like biome. The consensus of charette participants was that the property should be restored to a condition representing, as near as possible, the pre-settlement vegetation.

This in itself presents numerous management challenges. Much of the existing vegetation is seen as undesirable, but there has been substantial debate as to replacement species that should be used. In addition, removal of the vegetation is not only an enormous task in a physical sense, but exposes the land surface to soil erosion hazards. Recently, a new sinkhole developed in the area at the end of the property where the stream sinks for the last time, and the growth of this sink has been exaggerated by the denuded condition of the slope here—the result of overenthusiastic volunteers who stripped all "undesirable" vegetation away from the margin of the old sink. Renovating the vegetation will have to be a slow and carefully-considered process to avoid problems of this sort.

Unfortunately, the most prominent feature of the property, the springs themselves, is one over which the management has very little control. Increasingly, managers of karst systems such as Mammoth Cave and Carlsbad Cavern National Parks have come to understand that the ground water systems in their charge are strongly influenced by land use practices outside the legal boundaries of the property. Such is the case with McConnell Springs. The springs are, in effect, only a way station along the course of a drainage system that occupies much of the central and south Lexington urban area. Although land use activities elsewhere cannot be controlled by the managers of McConnell Springs, risks can be reduced by educating the general public in the recharge area about the vulnerability of the springs and by maintaining close liaison with state and local environmental agencies.

The educational role of McConnell Springs is perhaps one of the most exciting challenges that faces the management. During the charette, several important themes were developed that participants felt should be represented at McConnell Springs. These themes fall into overlapping categories of environmental and cultural. The Springs are, foremost, a splendid and rather unusual example of a karst hydrologic system, displaying in one place several different manifestations of karst landforms. This presents a fine opportunity to expose the public to interesting lessons in local hydrogeology and to develop an awareness of the sensitivity of ground water to human activity. Next, the Springs provide an outdoor laboratory for the study of Bluegrass flora and fauna, particularly in regard to the transformation of wilderness to an urban environment. The various uses made of the land over two centuries provides a study of sequent occupance, and the role of the springs in certain aspects of local and regional history helps focus upon the rich historical heritage of the Bluegrass.

The charette envisioned a number of structures designed to enhance the educational aspects of the property, including an environmental education center and an amphitheater. Construction of these structures, located on the 3.5-acre addition, is currently in progress, and should be completed by the end of 1996. More than $180,000 in donations was raised by the Friends for this construction. Other improvements in progress include a series of trails that wind and loop through the area of the springs, providing non-intrusive access to each of the major features: pond, blue hole, artesian head (second resurgence), and final sinking of the stream. A portion of these trails are to be constructed to allow access by disabled persons; others would be primitive hiking paths (Figure 2).

The Friends of McConnell Springs has been active in promoting educational activities focused on the Springs, even though facilities on-site are not yet ready. Among these have been guided tours, annual roundtable lectures on regional history, training classes for teachers and Scout leaders, and public service television presentations on the history of the Springs. One of the most interesting events was a series of two hands-on seminars in autumn 1995 on the art of dry-stack rock fence construction, taught by a master stone mason from Scotland. Several sections of the rock fences at McConnell Springs were repaired.

The most important issue identified concerning the development and maintenance of McConnell Springs is how to protect the integrity of the land and ecosystem while at the same time furnishing access to potentially large numbers of visitors. Much of the appeal of the site lies in its apparently secluded nature, providing a tranquil oasis of greenery and flowing water in the heart of the city. In recent decades, parklands and preserves across

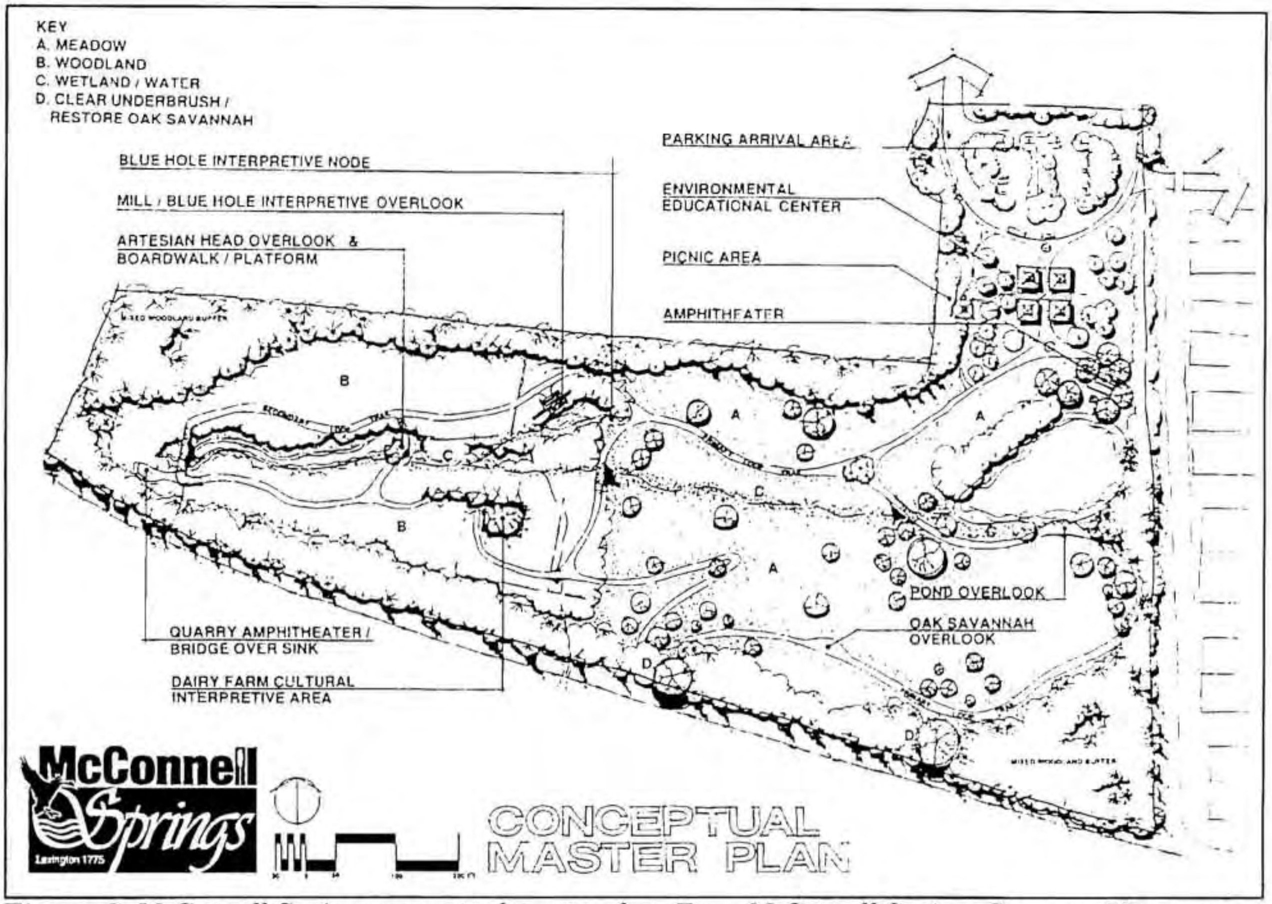

Figure 2. *McConnell Springs conceptual master plan. From McConnell Springs Resource Management Plan (1994).*

the nation have become increasing congested as more and more people seek to temporarily escape the urban environment. One board member noted that the mission of McConnell Springs is somewhat analogous to that of a library or archive; each is charged with preserving a valuable resource, but at the same time must make that resource available to the public.

There is often considerable difficulty in adapting ideals to practice. Having achieved the initial goal of saving the McConnell Springs site from impending destruction, it has since become apparent that there is considerable diversity of thought in regard to how the site should be managed. From various planning discussions in committee and subcommittee have emerged two opposing management philosophies. One school holds that the site should be managed much as other city parks, concerned primarily with accessibility and maintenance. The opposing school supports the practice of minimum-impact modifications and management that do not overwhelm the natural features.

It is here that opposing value systems and perceptions of the purposes of the site come into conflict, which might perhaps be summed as "utilization" and "preservation," although each philosophy, in the case of the Springs tract, incorporates elements of the other. The utilization supporters wish to preserve the tract from urban development, and the preservation supporters wish to encourage public use; the conflict arises from differing interpretations of "preservation" and "use."

It is because of these differing viewpoints that the development of a master plan such as that arising from the McConnell Springs design charette is important, in that it provides guidance based on a consensus of an involved public. Certainly, over time, planning can evolve in new directions, to take cognizance of evolving circumstances. Planning and development should always, however, reflect the mission of the organization in all its parts.

Conclusion

What was it about this place, this McConnell Springs, that stirred so many people to work for its preservation? Countless other features of Lexington, of equal aesthetic or historic significance, have in the past been destroyed without attracting the interest generated by this little wetlands tucked in a corner of the industrial section of the city. In the 1970s, entire blocks of historic homes in downtown Lexington were razed to make room for a hotel and box-like convention center complex. The few feeble protests at the time were wholly ineffective. Historic connotations alone are apparently not enough to stimulate vigorous citizen protest.

Yet, when in 1992 Calumet Farm, on the outskirts of the city, went into bankruptcy and was placed on the auctioneer's block, a wave of dread passed through the citizens. Calumet, home of Derby winners, with its trim white fences and lush green paddocks, had long been the quintessential Bluegrass horse farm. A vast collective sigh of relief was uttered by the population when the new owner gave public pledges to do nothing to harm the visible image of the farm.

Paris Pike, connecting Lexington and Paris, has long been considered one of the most dangerous roads in the Inner Bluegrass. At the same time, outlined with historic rock fences and shaded by a canopy of trees, it was also one of the most scenic drives in the region. For more than a decade, plans were constantly aired to widen the highway to four lanes and reduce the threat to life and limb. For more than a decade, these plans were met with vigorous opposition by those who wished to preserve the fences and trees. In 1995, a compromise was announced. The highway would be widened, and the rock fences would be rebuilt, at great expense, along the margins of the new road.

What do McConnell Springs, Calumet Farm, and Paris Pike have in common? What attributes of sufficient power do such features possess to protect them from harm, that the historic homes of South Hills could not grasp to forestall demolition? The answer may perhaps be found by discovering what each symbolizes to both local government and to the people of the city.

In 1932, Carl Becker noted that "history" has two manifestations, the actual and the ideal. The actual series of events is an absolute; the ideal is relative, a construct that is constantly evolving with an increase or refinement of knowledge. The actual series of events, according to Becker, "exists for us only in terms of the ideal series which we affirm and hold in memory" (Becker, 1932, p 222).

This dichotomy between the actual and ideal was echoed six decades later by Perry (1996). While Becker had made a distinction between the actual and the ideal based on the extent of available knowledge, Perry goes further in contending that, while the history of a site is fixed, "its meaning and significance mutate according to the concerns of the age or the visitor" (Perry, 1996, p 423). For any age, it is the interpretation of past events through the looking-glass of contemporary perspectives that produces an accepted "reality."

In a 1990 paper on the landscape of the Kentucky Bluegrass, Raitz and Vandommelen address the concept of the creation of symbols for popular consumption that represent "selected slices of reality." According to the authors, "Many place images are based on very narrow, carefully selected segments of real landscapes. These landscape segments contain artifacts and bits of physical environment that can be abstracted to yield a few visual elements that are then used to symbolize the broader reality." (p 110)

Regional image is created through the use of symbols of selected landscape features. Hence, the image projected of Kentucky to the greater world is one of manicured paddocks, tree-shaded lanes, and sleek horses, even though such represents conditions for only a tiny segment of the state. This is the regional image for contemporary Kentucky, reinforced through local and national media, theme parks, and most notably, in widespread architecture constructions that carry a stylized horse-farm motif.

Just as present-day Kentucky is represented by symbols and themes that represent only ideals, so is regional and local history idealized for popular consumption. The popular tradition of the early history of the state consists of the image of hardy white pioneers striving against a wilderness to create settled places. The major theme of McConnell Springs, as the site of the naming of a yet-to-be-created Lexington, fits perfectly into this tradition, and so enhances the regional image that image-makers wish to maintain.

Raitz and VanDommelen note that the process of creating a regional image can involve an entire community of individuals or a much smaller elite who direct the symbol-creation process. The authors divide the symbol-making elite into two functional groups, patrons and interpreters. Patrons create or contribute artifacts to a prototype landscape. They may finance and direct design and construction, they may be innovators who create a new form or function, or they may be borrowers who bring in ideas from elsewhere. Interpreters are architects, planners, or promoters who "select and filter elements of a prototype landscape for reproduction and adaption in new formats, contexts, and locations." (p 111) Patrons and interpreters have interacted in the past and continue in the present to "create and articulate" the landscape image for the Kentucky Bluegrass.

This process can be clearly seen in the creation of McConnell Springs as a symbolic artifact. The "elite" associated with the Friends of McConnell Springs comprises representatives of business, industry, and local government as "patrons," and historians, planners, architects, and scientists as "interpreters." These individuals are working together to produce at McConnell Springs a landscape symbolic of cherished local traditions. The themes involved are idealized: taming the wilderness, winning independence from Britain, building a great city.

Whether or not McConnell Springs was in fact the actual site of the naming of Lexington has largely become a dead issue. Lacking evidence to the contrary, the belief that "this is the place" has been officially embraced by the Friends of McConnell Springs and the Urban County Government and so will no doubt be accepted as true history by future generations. As an ethical issue, this is somewhat troubling; yet it is an issue that cannot be resolved with our present state of knowledge. As interpreters are unable to determine the "correct" locale with absolute certainty, McConnell Springs becomes the symbol of the event and this symbolism in turn becomes the perceived reality.

McConnell Springs, Calumet Farm, and Paris Pike all represented powerful symbolic artifacts of the Bluegrass landscape that conformed with the visions of the elite who maintain the regional image. The historic homes of South Hills were endowed to a far lesser extent with this cloak of symbolic sanctity, and had not the same aesthetic appeal. Even so, they might have been preserved had not their continued existence come into conflict with the enhancement of another cherished Kentucky tradition—basketball. In the eyes of the nation and of many residents, basketball, as played by the University of Kentucky Wildcats, is as potent a symbol of Lexington and the Bluegrass as all of the other regional images. The concept of preserving the historic homes of South Hills could not begin to compete effectively against the desire to construct a major sports arena and hotel/retail complex. When symbol competes against symbol, the less powerful image loses.

The story of the rescue of McConnell Springs and its transformation into a symbol of Lexington's heritage is a drama that may perhaps be enacted again and again in other contexts to preserve other threatened karst features. It has usually been the case that the initial group formed to preserve a particular karst feature or system consists of "cavers" or karst researchers, who are the first to recognize both the value of the feature and the threat. Representatives of such a group are often ineffective when acting alone in the role of interpreters to a community, simply because their perspectives and estimations of "significance" frequently differ from that of the general public. Preservationists should act to enlist the support of the community elite, both of potential patrons and other interpreters of relevant professions, as well as working at the grassroots level.

It is the interpreters who inform and educate potential patrons and the general public as to the significance of a site. This significance may be historical, aesthetic, scientific or environmental in nature, or a combination of many elements. It is not enough that a site simply be "significant," but it must have some particular significance that is, or can come to be, valued by the general population and by those having authority to act. By endowing a site with a meaning symbolic to the local population, the perception of the worth of the site is greatly enhanced. In addition, the preservation of a site must project the concept of a continuing future value to the population. Finally, the site must be perceived as of such worth that it is capable of overriding proposed or potential alternative land uses.

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Research Aimed at Management Problems Should Be Hypothesis-Driven: Case studies in the Mammoth Cave Region

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Abstract

Inventory and monitoring that is conceptually and hypothetically-driven forces us to critically determine the relevant measures needed to develop and distinguish among alternative hypotheses. As we proceed in a scientific study we attempt to falsify original and develop new hypotheses. In addition to solving management problems efficiently, this approach has the added bonus that natural differences among caves and anthropogenic impacts comprise natural and inadvertant experiments that give greater insights into processes and mechanisms. If we understand processes and mechanisms we are in a better position to do effective proactive management and reactive mitigation. It is critical to appreciate the range of natural differences over time among and within caves if we are to assess whether anthropogenic impacts have occurred and are occurring. In this context it is important to pick the appropriate scales of sampling, control habitats, and species. No one species is an index species for all potential impacts but any key species must be monitored.

To illustrate, I discuss two examples from the Mammoth Cave Region. In cave streams habitat heterogeneity and food supply tend to decrease going downstream while upstream pollution may be diluted by clean water from new downstream inputs. In this context I discuss the effects on species and communities of pollution loads that are greatest with flood pulses, how different kinds of pollutants (toxins, organic enrichment, and silt) affect different kinds of species, stream habitat heterogeneity, and nearness to surface input of natural particulate organic matter. In terrestrial entrance areas any anthropogenic impacts are localized so it is relatively easy to separate local from regional effects using several control entrances. At entrances the cave cricket is the key species. In this context I discuss leaky cave doors, air exchange while doors are open for tours, size and complexity of entrances and adjacent passages, and suitability of habitat for reproduction and roosting of crickets inside and foraging outside.

Good Management Depends on Good Science

When managers see or anticipate ecological problems or wish to establish baselines, they too often proceed in the wrong sequence. For example, it is inefficient to proceed from inventory, to monitoring, to determination that a species is declining, to elaboration of causal hypotheses to explain the decline. Even without inventory of the species present it is possible to identify species at risk, monitor their abundances, and start proactive management. The way to start is by using concepts and principles together with observed patterns in different ecological and geological settings. This will allow you to develop alternative hypotheses about the nature and likely locations of potential threats and which species are likely to be impacted. These were the arguments we used to develop a long-term monitoring plan for Mammoth Cave National Park (Poulson *et al*, 1993).

There is an important caveat about developing a codified, long-term monitoring plan. Long-term is relative. The five-year plan for Mammoth is nothing compared to intervals between rare natural events, like drought or flood, and among year variation in temperature and precipitation. Such events are not predictable and so changes in a species or community might be due to natural variation rather than to anthropogenic effects. Thus, codified monitoring protocols will never replace expert judgement by scientists who can differentiate natural variation from anthropogenic signals. The experts can deal with the problem that there are no real controls because of natural differences among sites and gradients of abiotic conditions within sites.

A Regional Scale of Threats to Groundwater Ecosystems

Background

The threats to the aquatic ecosystems of Mammoth Cave exemplify the worldwide problems of groundwater pollution in karst regions. Rapid transfer of water and contaminants occurs from the surface to the subsurface and we now know that most contaminant transfer occurs in association with rainfall events (Poulson *et al*, 1993, Hall and Meiman 1995). Mammoth Cave is at particular risk because of the extensive groundwater recharge areas which include a wide variety of land uses and threats. Agricultural activities in the recharge basin have been demonstrated to be the major chronic threat to the cave's aquatic ecosystems. Some of the most productive farm lands in Kentucky are located among sinkholes and sinking creeks and contribute non-point source sediments, pesticides, herbicides, animal wastes, and bacterial loads to cave streams. Point source spills have occurred along Interstate 65, the Cumberland Parkway, and the CSX Railroad which traverse the watershed. These spills have included cyanide, anhydrous ammonia, ink, diesel fuel, gasoline, heating oil, and paint. Oil and gas production have threats from spills and leaks of drilling fluids, hydrocarbons, and brines. Brines encountered during drilling are high in sodium, chloride, sulfates, sulphides, and some heavy metals. Illegal release of brines has occurred and is occurring as oil production is expanding. Urban development is also expanding throughout the watershed. Common problems are sewage and solid waste disposal and leakage from buried storage tanks and pipelines. Such population-growth-related problems will increasingly burden aquatic ecosystems downstream. Threats from downstream in the aquifer come from dams on the Green and Nolin Rivers. These dams have altered water levels, flow velocity, and flow direction in the large base-level cave streams. Unnatural sediment deposition, entry of exotic species, and changes in deposition of particulate organic matter from upstream threaten base-level ecosystems.

Understanding threats has allowed proactive management. In the long run, education in environmental ethics and sustainability is important; the American Cave Conservation Association is already doing a fine job with the importance of clean groundwater to citizens and businesses. Unlike other places where there are threats beyond park borders with conflicting interests—as in the Everglades and greater Yellowstone—in the Mammoth Cave Region it is of mutual advantage to the farmers and conservationists to keep fertilizers, manure, herbicides, and pesticides on the fields. This has fostered partnerships of non-government organizations and local, state, and federal agencies that foster a whole suite of watershed protection mechanisms such as Best Management Practices and conservation easements. By knowing the landscape and karst processes in detail it has been possible to develop hazard risk maps with plans for emergency spills along transportation corridors (Fry and Meiman 1995) and, in Indiana, to mitigate potential spills by a series of interception structures at locations of greatest risk of contamination during spills (Keith *et al*, these proceedings).

Reactive management also requires good science to be most effective. First, restoration of degraded communities requires us to understand the processes of degradation. That will allow us to focus on the most important mechanisms of mitigation.

Second, one must know the main factors that limit the rate of recovery. Can we expect natural dispersal of organisms back to the area where impacts have been removed? Must species that invaded as a result of the degradation be removed before the original species can reinvade? What is the importance of random natural events, such as 50- or 100-year floods, in promoting or prohibiting reinvasion?

Biological Monitoring of Water Quality

It is now recognized that biological monitoring, compared to chemical monitoring, is more reliable, cheaper, and less dangerous to the investigator (Poulson, 1992a, 1992b). To sample water for laboratory chemical or toxicity tests one must sample as a pollution pulse passes after a flood event. This either involves risk to the investigator or high costs of wells and automated sampling. A biologist need not face risks of floods in caves to determine pollution impacts because the community has both a short- and long-term memory for all types of pollutants. Laboratory chemical and toxicity tests are done on only a few of suspected pollutants and do not assess non-toxic but negative impacts of silt and biological oxygen demand.

Even biocriteria for pollution are often flawed and/or inadequate. Biocriteria ranked from worst to best are standard toxicity tests, indicator species, diversity indices, indices of community similarity, indices of biological integrity, and community pollution signatures. Environmental Protection Agency laboratory toxicity tests, for example *Ceriodaphnia*, have the advantage of being rigorously standardized, but responses of the few species used in such tests are often not relevant to communities in the field. Cave species are impossible or hard to raise in the laboratory and the conservation problems do not justify the large number of individuals needed for statistically reliable toxicity tests even with the most common species such as isopods. In addition, lab toxicity testing and use of bioindicator species in the field are subject to the myth that they are the most sensitive species. Thus there is no single "canary" or "white mouse." In groundwater and caves where there are few species, each potentially tells us something different. Thus diversity indices such as H and H/H_{max} (evenness) are also faulted because they treat pollution-tolerant and pollution-intolerant species equally and partially confound number of species and evenness. Indices of community similarity are better for example:

$$2\,\frac{\text{(\# of species in A \& B)}}{\text{(\# of species in A + \# of species in B)}}$$

However, such indices neglect the relative abundance of species and neglect their well-being as judged by indices of health and reproductive output. Still better are indices of biological integrity because they include not only the number of species but also include metrics for species' well-being and the presence and relative abundances of tolerant and intolerant species. Indices of biological integrity work well for fish and/or benthic macroinvertebrates that have many species in surface streams with many continuous miles available for sampling but do not differentiate well among cave streams (Jones *et al*, 1995). For caves or wells, there are few miles available, and sampling points above and below suspected pollution inputs are often not accessible. There are only a few species and some closely-related species cannot be differentiated in the field. As one result the index is highly dependent on distance from the headwater (stream order) and habitat heterogeneity (for example Figure 1 in Poulson, 1992). In addition, presence or absence of one or a few individuals of a tolerant or intolerant species greatly changes the index. For all of these reasons, I have been developing community signatures for different kinds of pollutants.

My hypothesized pollution signatures are based on natural experiments, physiological principles, and ecological principles. The pollutant types are acutely-acting toxins, chronically acting toxins, organic enrichment, and siltation. These differ in the temporal and spatial scale at which they operate, their effects on species with different lifespans and metabolic rates, their effects on large versus small individuals of a species, and their relative effects on troglobites (obligate cave species), troglophiles (facultative cave species), and accidentals.

Acutely-acting toxins, such as cyanide or sulphides, are usually from point sources, like spills on transportation corridors or oil wells. They are fast acting and may be transitory if due to spills. If any species survive it may be large individuals of the long-lived troglobites with the lowest growth and metabolic rates, especially crayfish that will crawl out of the water. Just as fast-growing weeds are selectively killed by herbicides, the fast-growing, short-lived troglophiles are at most risk and troglobites with the longest lifespans and lowest metabolic rates are at least risk.

In contrast **chronically-acting toxins** are usually present at sublethal concentrations and often are non-point in source, such as pesticides. They have the opposite selectivity of acutely acting toxins. The oldest predatory troglobites are at most risk and will be affected first because there will be the most biomagnification of toxins to the end of food chains and the most bioaccumulation of toxins with the longest lifespan. Sublethal effects are expected to first compromise reproduction, just as DDT first affected eggs of predatory birds like ospreys and eagles. In troglobites this would result in progressive loss of the smallest size classes with continued failure of reproduction. Any morphological anomalies, such as tumors or deformed vertebral columns are sure signs of chronically-acting toxins.

Organic enrichment is usually point source such as from overflow from a feedlot, sewage treatment plant, septic tank, or a highly-eutrophied sinkhole pond. At low levels one can detect, by rubbing with a finger, a slippery biofilm of bacteria and/or fungi on cave stream rocks and the reproduction of short-lived troglobites such as flatworms and isopods is stimulated. With higher levels troglophiles, with their higher food needs, may be able to survive and eventually replace troglobites. With extremely high levels of organic enrichment, such as the creamery wastes in the past in Hidden River Cave in Horse Cave, Kentucky (Lewis, these proceedings), the smell and visible accidental species, especially colonial bacteria and sewage worms, leave no doubt as to the kind of pollutant. By this time the troglobites are long gone ("up that well-known estuary with no visible means of locomotion").

Siltation can be nonpoint and slow, such as from slow erosion of soil from rowcrop agriculture.

or point source and fast, such as from construction sites. In either case there is a more or less non-selective loss of species diversity as preferred rock, pebble, and sand microhabitats and particulate organic foods of amphipods, isopods, flatworms, harpactacoid copepods, and shrimp are covered by silt. Numbers of these species, especially isopods, continue to decline since they are now more vulnerable to predation by crayfish and shrimp. The smaller individuals of troglobitic crayfish and fish leave as their food supply declines because they have higher food needs than adults. Thus large, efficiently-foraging crayfish and fish are the last to disappear.

I recommend a hierarchial and complementary approach to monitoring groundwater quality in karst. Biological and chemical monitoring are complementary as early-warning systems and provide more reliable pollution signatures than either alone. At Mammoth Cave, synoptic and flood-pulse-conditional sampling for inorganic ions and fecal bacteria at major cave stream and watershed confluences and at Green River springs detect possible upstream problems (Poulson *et al*, 1993). For example, high sulphates and chlorides suggest oil field brines whereas high chlorides alone could be road salt and high chlorides plus bacteria could be septic tank leakage. The use of biological pollution signatures can detect some problems not assayed by water chemistry and narrow down the possibilities by sampling nearer to suspected sources. Together, chemical and biological pollution signatures suggest what new chemicals to sample to further narrow possibilities. Once there are only one or two alternative hypotheses left, water tracing is used to identify actual point sources. Once the source(s) is(are) identified, negotiation and existing laws will hopefully result in mitigation by the landowners responsible. If all else fails we may have to sue the bastards.

Case Study: Loss of Diversity in Base-level Communities

I exemplify the appropriate scientific methodology by considering the causes of apparent decline in number and abundance of troglobitic species over the last century in the Styx-Echo River areas of Mammoth Cave (further background and details can be found in Poulson, 1992c and Poulson *et al,* 1993). In general the observations are as follows. Though the methodology and investigators changed it appeared that frequency and abundances of shrimp, two species of cavefish, and cave crayfish declined greatly from the late 1800s to the second and third decade of the 1900s. In 1908, Lock and Dam #6 was installed on Green River below Mammoth Cave. After the dam was installed new maps no longer showed a number of base-level passages (for example, Stevenson's River and the later connection route between Flint Ridge and Cascade Hall in Mammoth Cave). From the late 1950s to the 1970s only large cavefish and cave crayfish were observed, and in low numbers. Late in the same time period a major tributary to Green River just below Mammoth Cave, the Nolin River, was dammed and the far-upstream Green River Dam went on line. Since this time the maximum height of floods have decreased and time to return to base-level flow after floods have increased. The supposed extinction of the shrimp was not supported by detailed surveys using SCUBA and snorkel; shrimp were found in high numbers further upstream, especially in Mystic River and in springs further upstream from Echo and Styx Springs (Poulson, 1992c). On the basis of these observations and my hypothesized community signatures for different pollutant types, I have developed and helped to test the predictions of three plausible alternative hypotheses.

I reject the hypothesis that chronically-acting toxins have resulted in the historical decline of species in Styx-Echo Rivers. In favor of the hypothesis is that potential pollution loads from pesticides, herbicides, and oil field development have clearly increased in the upper Green River watershed and in the headwaters of the karst aquifer. Against the hypothesis is the observation that base-level springs and streams further upstream from Styx-Echo still have common-abundant shrimp and other large troglobites, but this evidence is equivocal since these groundwater basins are all or mostly within the Park and it is not clear how much Green River water enters during floods. However, the biological evidence allows rejection of the chronic-toxicity hypothesis since large individuals of the longest-lived top predatory troglobites are the last instead of the first to disappear.

I also reject the alternative that organic enrichment by decomposable organic matter is the culprit. On the one hand there have been increases in human and domestic animal wastes in the karst watershed due to septic tank leakage and feedlot operations, but on the other hand fecal coliform counts in Styx-Echo have never been high enough to suggest much undecomposed fecal matter. The predicted community signature for this hypothesis is missing since there is no hint of a biofilm on rocks, increased reproduction of isopods, or increase in troglophiles. In fact all the evidence is for a diminished energy input.

I cannot reject the hypothesis that increased siltation is responsible for faunal decline in Styx-Echo. Once erosion and runoff from row crops and construction have occurred, silt loads will not be diminished downstream. Also Lock and Dam #6 has certainly ponded water in Green River and slowed release of flood waters from the Nolin and

Green River Reservoirs have exacerbated this effect by keeping river level at about ten feet for many weeks after a flood crest. Together this increases silt deposition in the cave because the natural scouring at the end of an uninterrupted flood hydrograph does not occur. The silt comes both from Green River water that enters Styx Spring during reversed flow and from upstream in the karst aquifer. This scenario is supported by the decrease in silt cover on breakdown from Styx to Echo to Cascade Hall. In those areas the only places now with isopods and snails are on the undersurfaces of breakdown which are protected from silt deposition. Previous suitable habitat of sand, gravel, or small rocks is now buried by silt. A complementary hypothesis for the faunal decline is that the prolonged hydraulic damming due to control of Green River level has prevented fine particulate organic matter food from getting to the Styx-Echo area from the vertical shaft headwaters of the local karst aquifers. Instead this material is deposited further upstream. In support of this possibility is recent data (Pearson and Jones, personal communication) that shrimp, fish, and crayfish decreased further in Styx-Echo and increased dramatically in Mystic River after the last major Green River flood.

Localized Threats at Cave Entrances

Background

The main management issue is whether cave gates or doors compromise cave resources by modification of microclimate, restriction of animal movement, or restriction of the inwash of organic matter. Clearly sizes of entrances, diameter of passage, volume of cave beyond the entrance area, and location of passages and other entrances above or below entrance elevation all influence the distance into the cave that microclimate will be influenced by outside weather (Tuttle and Stevenson 1975) and the kinds of organisms that are likely to be near to or use the entrance (Poulson, 1992c; Poulson *et al*, 1993). For example, cold sinks are good as bat hibernacula but often too dry and windy for troglobites, whereas short, horizontal, dead-end pieces of passage are excellent for troglobites because they remain moist, still, and cool year around. Of particular importance are entrances that have the right conditions for cave crickets because they are a key species (Helf *et al*, these proceedings).

Case Studies at Mammoth Cave

One current issue is whether the cross-sectional area of the Historic Entrance gate should be reduced in winter to historic dimensions of the "Narrows" to mitigate progressive drying and prevent further ceiling breakdown attendant with extreme temperature fluctuation and/or subfreezing temperatures around the Rotunda. Subfreezing air even penetrates to Little Bat Avenue which we hypothesize, based on the passage name and presumed difference in microclimate historically, to have been a less-cold passage and so a suitable hibernaculum in the past. Based on suspected historic winter temperatures and the present quite variable winter temperature and humidity in adjacent areas (Fry and Meiman, 1995) I have hypothesized that the bats would have been Indiana bats because they tend to hibernate "at the edge" with such cold conditions that the bats arouse and move when the temperature remains below for a day or two; the dense clusters are presumed to buffer the bats so they do not respond to shorter term temperature fluctuation. Toomey (these proceedings) is testing whether the bats are Indiana bats using the detailed statistical analyses of skull dimensions needed to differentiate little brown bats from Indiana bats.

It took some persuading by us to convince the Park Service to provide for animal movement at artificial entrances originally slated for complete airlocks. They argued that such areas should be treated as if there never had been natural openings. We argued that entrances come and go in time and that some entrances (especially Frozen Niagara, Violet City, and Great Onyx) have too extensive guano deposits to have developed since people-size entrances were created 50 to 100 years ago. Thus we hypothesized that these areas were so close to the surface that they probably had cricket-sized openings before entrance enlargement by humans. In the future we may be able to assess the age of entrances and whether they have been alternately accessible and inaccessible to crickets by taking minicores of stalagmites to look for continuous or discontinuous guano and dating the guano with depth into the speleothem. We also argued for leaving mini-openings above retrofitted doors even at entrances clearly blasted for significant distances, like Carmichael and Austin, since these now have well-developed entrance communities with crickets and sometimes salamanders and pack rats also. In the Park, with even fewer entrances per kilometer of cave than in sinkhole plain caves, we suggested that it would be prudent to allow animal movement around all doors, especially since cave salamanders and pack rats are now found at only few entrances whether natural, enlarged, or artificial. Even the ubiquitous cave cricket apparently has few source habitats, with net positive cricket population growth, compared to sink habitats, which depend on immigration from sources to maintain populations (Helf *et al*, these proceedings) and the best source habitats we know are at supposedly-artificial entrances. We also argued that even sink entrances should be maintained because some of them, especially White and Little Beauty, have some of the best cricket-guano communities.

Despite all of these arguments we only convinced the Park Service to provide mini-openings around retrofitted cave doors when we showed that this would not allow significant ingress of cold, dry winter air. The critical data were on continuous records of temperature and relative humidity at a permanent station 60 meters away from the entrance (Fry and Meiman 1995) and temperature, humidity, and cricket numbers from floor to ceiling at the entrance of Frozen Niagara. The continuous data clearly showed that the major changes in temperature and humidity were associated with 10 to 20 minute periods when the door remained open as tours entered and left. With the door closed the cold, dry winter air was detectable to only about 25 meters. There was periodic ice at floor level just inside the entrance next to a rat-sized opening to the outside. There were no crickets at floor level. The first were seen at ceiling height 2.5 to 3 meters above the entrance door where there was little temperature or humidity depression. Most of the crickets were in ceiling pockets and crevasses 3 to 4 meters up where temperature and humidity were virtually the same as the deep cave. Based on these data we reasoned that leaving natural mini-openings for crickets above the new door would not compromise the positive effect of a people-sized airlock since our night observations showed that crickets only left the cave through cricket-sized convoluted openings at ceiling level when openings at all levels were available. We will be able to test this prediction next winter after the people-sized airlock is in place.

It remains to be seen if crickets will use the PVC pipe openings that are being installed around entrances where natural mini-openings cannot be left when doors are retrofitted. The failure to install these PVC pipes at the ceiling above the first door retrofitted underscores the importance of continual communication between scientists and resource managers even when one thinks that agreement has been reached. At Violet City the new door has not yet been sealed with weather stripping so we do not know if the crickets that are still leaving the cave to forage outside are using the PVC pipes installed alongside the door well below the ceiling. We experimentally determined that crickets will use pipes ≥ 1.5 inch and as long as a foot if they are confined in a small volume and have no other exit route. We do not yet know whether they will use much longer pipes such as may need to be used for the proposed Austin entrance retrofit.

Finally, I want to emphasize that we would not have a sufficient understanding of entrance microclimate-faunal interrelationships if we were not studying many entrances both with doors and without doors. One problem is that there are no real controls because many things affect habitat suitability for crickets in addition to microclimate inside entrances (Helf *et al*, these proceedings). For example, White and Little Beauty Caves have no closed doors but their size, configuration, and lack of connection to large cave make them completely unlike the entrances connected to the vastness of Mammoth Cave and the absence of good reproductive areas nearby make them sink habitats rather than sources. New Discovery is connected to all of Mammoth Cave but it is a blasted entrance and unlike all other entrances in having a quality reproductive area very close to the entrance roosting area. Though there are no real controls, the diversity of entrances constitute natural experiments that are allowing us to tease apart the relative importance to cricket well-being of a wide variety of biotic and abiotic factors. Another advantage of studying multiple cave entrances is to separate regional trends from local trends. At a decades scale, extremely favorable weather in the mid 1970s and a drought in the late 1980s greatly affected cricket guano communities by affecting foraging success and survival of crickets (Poulson *et al*, 1995). At a year-to-year scale there was a great decrease in numbers of crickets from December 1994 to December 1995 at Violet City but this may not be due to the new door since there were major declines in several other cave entrances that had no entrance modifications.

Acknowledgements

The opportunity to be a Consulting Ecologist (GS 14) at Mammoth Cave in the Division of Science and Resources Management for three summers (1992 through 1994) gave me invaluable perspectives. I now appreciate how hard it is to get things done with the constraints on resource managers by government bureaucracy, including constant demands for more reports and continued requests to put out "brushfires" while understaffed and under-budgeted. On the positive side, I understand how important it is to evaluate alternative hypotheses carefully if one is to maintain credibility in the face of the Park Service conflicting mission of protection of resources for future generations and provision for the enjoyment of the current generation of visitors. Many of the general ideas in the first part of this paper were developed

in the grant proposal to NPS for Long-term Ecological Monitoring at Mammoth Cave National Park for which I was the point person (Poulson *et al*, 1993).

Many individuals have contributed to my ideas and have shared data on which my ideas are based. For the relations between indices of biological integrity and pollution signatures, I am especially indebted to Bill Pearson and Tom Jones, who have continued, expanded, and improved the aquatic biosurveys that I started in the 1960s. For the Entrance Biomonitoring Grant from Mammoth Cave National Park I thank my co-investigators Kathy Lavoie and Kurt Helf. Mammoth Cave National Park personnel in the Division of Science and Resources Management have helped with both the aquatic studies and the terrestrial studies. While I worked for him, Jeff Bradybaugh protected me from most of the picky details and tempered my predilection to push too hard sometimes. Joe Meiman, Rick Olson, John Fry, and Bobby Carson continue to provide ideas, design of equipment, logistic support, and help in the field.

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A Study of Acoustical Confusion

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Abstract

Bats are critical to maintaining a stable and healthy environment in their role as predators of insects and pollinators of plants. Several species have become endangered due to the disruption of the bat habitats in caves caused by human intrusion ranging from field studies of cave environments and archaeological digs, to recreational excursions, and vandalism. Gating of caves has been used for many years as a last-resort effort to protect the bats providing for movement of the bats while restricting entry of humans. Many of the gates, however, have adversely affected the bats, including leading to the abandonment of some caves. It is not known why some gates work with some species and in some caves while others do not.

A study was initiated by the author in the spring of 1991, with support from various governmental agencies, to research this problem. Caves populated with the endangered gray bat (*Myotis grisescens*) were studied in Alabama, Kentucky, and Virginia. Bat movements were monitored at cave sites with gates and without gates. An analysis is also being made of the various cave environments and the location of the gates within the caves. The hypothesis being tested by this researcher is that gates create acoustical confusion and slow the passage of the bats through the gates. This confusion becomes acute when large populations inhibit the cave and maintain high traffic.

The anticipated outcome of this study was to determine cave gate specifications and provide recommendations for future cave gate designs. Specifically, the findings could: 1) provide specifications for the size of cave gates (full and half sizes) needed for a given populations of bats, and 2) provide determinations of the location of cave gates (light or dark zones) for a given population of bats.

Introduction

This study was initiated in the spring of 1991 and field work was conducted through the fall of 1993. The study was funded primarily by the Natural Heritage Division of the Tennessee Valley Authority and was supported by various other state and governmental agencies. Gating of caves has been used for many years as a last resort effort to protect bat colonies by providing for the movement of bats while restricting entry of humans. Many of the gates, however, have adversely affected the bats, including abandonment of some sites. It is not understood why some gates work with some species at some sites while others do not. The hypothesis being tested by the researcher is that gates create acoustical confusion and slow the passage of the bats through the gates and that this confusion becomes acute when large populations inhabit the cave and maintain high traffic in and out of the site. Caves populated with the endangered gray bat (*Myotis grisescens*) were studied in Alabama, Tennessee, Kentucky and Virginia.

Methodology

Audio recordings were made at selected gray bat cave sites on a stereo recorder. The heterodyned output of a bat detector was recorded on one channel and the divided output of the full frequency range was recorded on the second channel. The frequency selection of the heterodyned signal was sometimes varied from the natural frequency of 42.5 kiloHertz (kiloHertz). The tapes were then analyzed by studying the wave forms. The frequency range and relative sound intensities were measured.

Sites Studied

Hubbard Cave Tennessee	(Hibernaculum CCI angle-iron gate)
Pearsons Cave Tennessee	(Hibernaculum no gate)
Blowing Wind Cave Alabama	(Maternal round-bar gate)
Collier cave Alabama	(Abandoned maternal CCI angle-iron gate)

RMCcave Kentucky	(Maternal no gate)
Scott1 Cave Virginia	(Bachelor no gate)
Scott2 Cave Virginia	(Bachelor no gate)

Three of the study caves with large gray bat populations have been successfully gated (Hubbard, Pearson, and Blowing Wind).

The Hubbard Cave site has a large cross-sectional area. The gray bats roost in an un-gated portion of the cave until they gradually move behind the gate in the fall. The geometry of the cave allows the gated portion to be avoided during the period of high activity prior to hibernation, and allows the bats to move to the protected hibernation site over a period of time and in smaller numbers. This indicates that the bats cannot or do not like to use the gate in large numbers.

The Pearson Cave site has one horizonal and two vertical entrances. Only the small horizontal entrance is gated. No bats were observed using the gated entrance during the study. However guano in front, behind, and on the gate suggests that there is a limited amount of occasional use. As at Hubbard Cave the geometry of the cave gives the bats an option of not using the gate during periods of high activity.

There are two entrances to Blowing Wind Cave. The upper entrance has a full-height, round-bar gate and the lower has a half gate also of the round-bar type. The vast majority of bats use the lower entrance, flying above the gate. Observation at both entrances suggest that the bats use these gates with great difficulty. Bats at both entrances were observed to collide frequently with signs located behind the gate.

The Collier Cave site has a full-height Cave Conservation International (CCI) angle-iron gate. Collier Cave was gated after traffic had driven the maternity colony to abandon the cave in favor of another nearby cave. The gate was installed as an experiment to see if the colony could be reestablished. The bats returned for a short period of time after the traffic was reduced but they roosted in front of the gate. Only a few gray batss were observed using the gate.

Scott2 Cave has two entrances and is ungated. A large transient colony of about 15,000 to 20,000+ uses the cave in the spring and fall for a few days most years. The population of this colony is assumed to consists of both males and females. The cave also has a summer population of several hundred males.

Scott1 Cave has only one entrance and is ungated. The summer population varies between 1,000 and 6,000 gray bats. Some years all gray bats leave the cave by the end of June. It is suspected that when the numbers are low during the summer that the site is strictly a bachelor colony site and when the numbers are high that a maternity colony may be present.

RM Cave is a maternal site and is ungated. It was visited during the investigation to determine if the gray bats using the cave behaved differently than those at other sites.

The Bandwidth Phenomenon

The investigator had noticed on several occasions when using a bat detector to monitor gray bat emergences that the frequency range used by the bats appeared to increase from the natural frequency of 40 to 43 kiloHertz to 20 to 200+ kiloHertz. This increase will be referred to as the bandwidth phenomenon. Part of this phenomenon could be explained as a result of signal clipping within the detector. When the detector amplifier circuits become overloaded, the peaks of the signal are clipped. Clipping results in the signal approximating square waves and the generation of odd harmonics. The investigation of this phenomenon was a primary focus of this study. Two questions were to be answered. The first was why the phenomenon occurred and the second was if it were possible to use the phenomenon as a tool to determine what sites could be successfully gated.

Results

The bandwith phenomenon was observed at all sites. Observations made with care given to the avoidance of clipping, revealed that there was a real increase in bandwidth. Observation also showed that this increase was accompanied by an increase in milling and was related to the cross-sectional area of the entry and the number of bats attempting to use the entry.

A gray bat emergence usually begins with a single bat and is detected with the bat detector at a frequency about 42.5 kiloHertz. As more bats emerge the frequency range increases at a rate that is related to the number of bats. At the peak of the emergence the frequency range and the intensity of the sound is at the highest level. When the number of bats is small, individual bats can be distinguished at frequencies other that 42.5 kiloHertz. No harmonics are detected during this condition. As the number of bats increase and the intensity increases, harmonics (other than those created in the equipment) are probably present. When the signals are observed on an oscilloscope, individual bats can be distinguished when the number of bats is small, but when the signals of large numbers are observed the display resembles noise and individual signals can be observed only with a storage display. When the signals are subjected to a spectrum display, with detector overload eliminated, some higher frequencies have a higher amplitude than lower frequencies.

Conclusions

This study indicates that when a large number of bats attempt to use an entrance (or a gate) an individual bat cannot easily distinguish its own echo from that of another bat. The bat therefore changes the amplitude and/or frequency of its call. The bat is receiving its own signal, the sounds, and the echo of the sounds of other bats. The result is confusion and inability to determine a safe exit route. The bat is then forced to mill about until it has a clear audio picture of the entrance or obstruction. An analogy of this situation would be an individual trying to understand what another individual is saying from across a room of people all talking at once. This condition will be called acoustical confusion. The inability of the colony to rapidly exit a site creates stress. The maternal gray bat must eat enough in order to support herself and her young. She must have easy and rapid access to the foraging area and for this reason the maternal colony will naturally be very sensitive to gates.

Although limited, the results of this study indicate that there is a direct relationship between the size of the population and the usable cross-sectional area of the passageway and that sites that meet all other environmental requirements suitable for bat habitation are limited to specific populations by the size of entry or passageway. When that size is reduced by obstruction, such as a bat gate, the population may find the site unsuitable for habitation.

Cave Radio as a Management Tool

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Abstract

Magnetic-induction "cave radio" is a well-established method for accurately determining the surface location above an underground transmitter, and measuring depth. It is useful in cave mapping, rescue, and hydrological research. Management applications include locating caves relative to property boundaries, searching for cave connections, and finding sites for digging new entrances or drilling cave-penetrating wells.

Cave radio's capabilities imply ethical considerations: artificial entrances can harm the cave environment or create landowner-relations problems.

Cave radio is a surveying tool which can determine the surface location above an underground transmitter accurately enough to dig or drill into the cave. Upon acquiring the signal on the surface, the location and depth-measuring processes can usually be completed in less than 20 minutes. The alternative to cave radio is labor-intensive optical survey. Conventional survey of the required accuracy may not be practicable due to the difficulty of the cave passage to be traversed.

Cave radio is useful for assessing the accuracy of cave maps because it can provide a loop closure at any desired point. As a cave-management tool, cave radio can verify passage location relative to property boundaries, hydrologic features, or sources of pollution. It has been used to locate drilling sites for hydrological monitoring wells and for agricultural water supply, the latter being economically significant to landowners. It has located sites for artificial entrances and utility conduits for commercial caves.

Cave radio can determine relative positions of different caves when there is a search for connection between them. The usual procedure is to radiolocate both caves on the surface, but cave-to-cave methods have been developed for cases where the caves are very deep or the surface terrain is especially difficult.

Very-low-frequency magnetic fields will penetrate the overburden of most caves with little attenuation by soil and rock. A transmitter connected to a coil of wire with its axis oriented vertically is placed inside the cave at the point to be located. A receiver on the surface with a similar antenna can detect the signal and, using the directional properties of the antennas, locate the point directly above the transmitter. Horizontal accuracy is typically less than one percent of the depth. Depth measurement is usually 95% accurate.

The references describe the procedure for making radio locations. U.S. cavers have used cave radio in its present form since the late 1950s; its accuracy has been verified by numerous artificial entrances and cave-penetrating drill holes.

The transmitting coil's magnetic field is exactly vertical at its center, a point which is unique and easily found. The vertical angle of the field decreases with horizontal distance from the center. Depth is calculated by measuring the vertical angle at measured horizontal distances from the center; the measurement is independent of signal strength.

The depth-measuring process intrinsically detects error; several sets of depth data are taken and averaged. Their standard deviation assesses accuracy. Random dispersion of the data around the mean value indicate that the data are valid but an increasing or decreasing trend indicates that the transmitter may not be level or that the center has been determined incorrectly. For additional horizontal accuracy, as may be required for cave-penetrating drill holes, several transmitter placements may be made in the area of interest. Each is located on the surface, and their relative positions are compared.

Since it operates by the principle of near-field induction (that is, like a loosely-coupled electrical transformer) and does not create true electromagnetic waves, cave-radio range is intrinsically limited by the physics of magnetic dipoles; signal strength varies inversely as the cube of the distance between transmitter and receiver. Maximum detectable range of 500 to 800 meters is considered good. In practice, working range is perhaps one third of maximum detectable range because strong signals are needed for accurate direction-finding. Atmospheric noise ("static") and interference from nearby power lines can limit range. Atmospheric noise is absent during winter.

Newly-designed equipment using synchronous detectors has improved performance and can measure the electrical conductivity of the earth. In traverses over known caves it has detected anomalies believed associated with cave passage.

At this writing, cave-radio equipment is not commercially available in the U.S. Equipment is hand built, and some designs are incompatible with each other. The NSS Electronics Section and the British Cave-Research Association's Cave Radio and Electronics Group have published numerous plans for cave radio equipment, and other plans are available in caving literature.

Users of cave radio must consider its environmental, economic, and social impact. Given the capability to make an "instant entrance" anywhere that digging is practicable, certain ethical considerations must be addressed. Additional entrances could be detrimental to the cave environment by modifying the cave airflow or introducing additional caver traffic. New entrances on adjacent property could cause significant problems for commercial-cave operators. Cavers often rationalize construction of new entrances for safety reasons. British cavers have established networks of pre-radiolocated sites where excavation could be performed in case of a rescue emergency.

The author's own cave-radio equipment operates at 3,500 Hertz and has been optimized for surveying applications. Others have designed two-way voice communication equipment which can make radiolocations and also support cave rescues and expeditions. Voice cave-radios have been interfaced with conventional amateur-radio equipment for very-long-range communication over the surface.

References

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Speleo Digest 1964 (NSS). Several articles on cave radio appear in Section 3, "Equipment and Techniques."

Resources

NSS Electronics Section, P.O. Box 5283, Bloomington, IN 47407

British Cave-Research Association Cave Radio and Electronics Group (BCRA CREG), David Gibson, secretary; 12 Well House Drive, Leeds LS8 4BX, Great Britain.

Techniques and Volunteer Issues in the Restoration of Cathedral Cave

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Abstract

Cathedral Cave is a secondary cave attraction in Onondaga Cave State Park, under the control of the Missouri Department of Natural Resources, Division of State Parks. This former commercial cave, now open for lantern tours to the public, has been undergoing restoration to remove commercial improvements, chiefly concrete, and to do repair of speleothem damage incurred during commercialization prior to becoming a state park. Cave restoration has intensified since 1992. This paper will address both techniques used in cave restoration and the procedures required in using volunteer labor, mostly from Saint Louis area NSS grottos, on a state park project.

Cathedral Cave is a 4,767-meter-long former commercial cave now within the boundaries of Onondaga Cave State Park located in Leasburg, Missouri. The cave was discovered in 1919; first commercialized in 1930 (this required the digging of a walk-in entrance); and closed as a commercial operation in 1941, due to lack of visitors and gas rationing during the second World War. After being purchased in 1952 by Lester Dill and Lyman Riley, owners of nearby Onondaga Cave, it was used sporadically by spelunkers from the Rolla School of Mines, but remained largely undeveloped until 1973.

A dam proposed along the upper Meramec River by the Army Corps of Engineers in the late 1960s put both Onondaga and Cathedral Caves under the threat of condemnation and of backflooding of the proposed lake into their systems. According to a man who worked for Dill at the time[1], even though Dill was fighting the dam project, he figured the Corps would win and he had decided that if the government took his land, they were going to have to pay for two commercial caves, not just one. Concrete walkways, handrails, and a fluorescent lighting system were installed. Largely constructed during the off seasons of 1973 through 1975, no unusual care was taken to preserve speleothems or even clean up the construction debris from the improvements. Cathedral Cave has showcave-quality speleothems. The most impressive of these is the Cathedral column, briefly renamed the "Liberty Bell" by Dill in a fit of bicentennial fervor. During this time, Dill also renamed the cave Missouri Caverns, formerly the name of a portion of Onondaga, starting a confusion which remains to this day.

It is the effects of this second commercialization which we are currently removing from the cave. The proposed dam was defeated in a referendum in 1978 and commercial operation of the cave ceased. Sometime between when it closed and the property was acquired as a state park in 1981 after the death of Mr. Dill, the cave was broken into and vandalized, apparently for the scrap value of the light fixtures and wire. The walkways and railings were left untouched, as were the "wire runs"—places where the electrical cable had been encased in concrete to hide and protect it. Glass shards and even entire fluorescent tubes remained in the cave as well. The cave stayed closed to the general public until 1984, although caving groups were allowed access. This access ended in 1989, when a group of inconsiderate cavers woke a superintendent in the middle of the night, demanding to be let into the cave. Part of the official management policy for the cave now forbids trips into it unsupervised by staff.

But not all cavers are inconsiderate, and there is work to be done. The Missouri Division of State Parks has a Volunteers in Parks program, to enable citizens to aid park staff in their duties, and there is a long history of cooperation between the Department of Natural Resources, (the parent agency of the parks) and the Missouri Speleological Survey—whose member grottos contain many of the organized cavers in the state. Other groups, such as geology students from Northeast Missouri State and people from the Washington University School of Medicine, have worked in the past on this project to clean up and restore Cathedral Cave—and still have an opportunity to do so. But my project, using cavers from Meramec Valley and Middle Mississippi Valley Grottos in Saint Louis, is one of the longer sustained efforts. We're going on three years now, and we're about 100 meters into the cave. This is about one-fifth of the length of the commercial trail.

The aim of our restoration is to restore the cave to the most natural condition consistent with its current use as a lantern tour and off-trail group-use cave. This consists of removing the concrete, wire, and glass remains of the lighting system, repairing speleothems, and general housekeeping along the paved walkway. Since 20 years have passed since the improvements were made, in a wet cave, some judgement must be used—when removing concrete would mean breaking new flowstone as well. Areas visible from the trail have a higher priority than those away from it, and sometimes cosmetic repair is all we can do. For instance, there were concrete pedestals for light fixtures along flowstone until this year. They were successfully removed, but cement from them had leached into the flowstone over the years, and nearly an inch of flowstone had grown over the wall. A little judicious "pruning" was done, but we are just waiting for flowstone to cover the scar along this fast-growing area.

Tools

Concrete seems to be everywhere—spattered on and covering cave coral nodules, in the wire runs, and coating chert where cave fill was dipped in a thin mortar for use as chinking. The most effective tools for its removal are standard weight hammers and tack hammers, cold chisels from 1/4-inch to 1/2-inch, dental picks, small parts grabbers, and tweezers. Bolt cutters and side cutters are needed to cut cable. Goggles and leather gloves, five-gallon buckets, brushes, spray bottles, and regular horizontal cave pack complete the restoration worker's kit, though some people bring boat cushions to keep from sitting on the cold, wet floor. I personally use a geologist's pick, 3/8-inch chisel and scrub bucket, since I usually am doing detail work.

Technique

The best ways we have found to take up wire runs depends on the concrete. In wetter parts of the cave, it has retained its rocklike structure, and can sometimes be popped off the flowstone by striking it parallel to the ground along the contact. In drier places, the concrete is crumbly, and a persistent light tapping is the best method. A sharp blow, like that used to trim mineral specimens, usually makes for more progress than pounding and we take no sledge hammers into the cave. Also, we almost always chisel at an angle, not perpendicular to the floor or speleothem. Sometimes the angle is easier to control than the force of the blow. But the hardest thing to convince a new recruit is that force is not the answer. One of my best workers partied too much the night before a trip. He didn't *want* to hear that hammer go, "bam! bam! bam!"

We take the broken and de-wired (or at least, trimmed) concrete out of the cave in five-gallon buckets. This debris is being used to fill gullies and check erosion on the hillside over the cave.

The next-most-popular activity is tweezing glass shards and bits of concrete. This is very tedious and often takes place in contorted positions. On the last trip, one woman brought a parts retriever, designed to clean between the keys of her computer, and it worked quite well for picking up little bits where fingers cannot go.

Our usual means of operation is that Eugene Vale, park naturalist and supervisor of our work, shows me what needs to be done. I then point out the various things we will be working on that day, and people choose themselves what they wish to do. We switch around if people get tired of a specific task in the three- to five-hour work period underground.

Other housekeeping we do includes removing wire which is concealed under loose rock, moving broken speleothems beyond the view of the trail, rearranging or removing obviously foreign pieces of stone, and general litter removal. Neither broken speleothems or blast rock from trail construction were adequately cleaned up originally. Park staff have had comments from returning visitors asking what has been changed and saying how much nicer the entrance section looks; we feel good that someone is noticing.

Cave Glue

Everyone seems to have a favorite adhesive for gluing broken speleothems, but we think we have found a real winner. I talked to a friend who used to work in cut stone fabrication, and he mentioned the glue they would use whenever a marble slab was broken. Since marble is also calcium carbonate, is wet sawed, and installed in bathrooms where it will get wet again, we decided to try it. Its name is Akemi®—it is classed as a polyester adhesive, and contains styrene monomers (see appendix).

Last February we repaired a group of stalagmites with Akemi, they are still solidly joined. We found that the clear glue is the least obtrusive. Even though the adhesive holds when wet after it has cured, the surfaces to be joined must be bone dry. In the factory, they used a blowtorch. In February we took a standard propane torch to heat the rock, but that is still fairly awkward to haul, so in April I tried a butane pocket torch, about eight inches long, and it worked fine.

Stalagmites are easy to repair because their own weight provides bonding pressure. Although there are many broken stalactites in this cave as well, we didn't have a matching stump and 'tite right at hand. Merely as an experiment, we took a three-inch piece of broken stalactite and stuck it to the ceiling, in a bare spot so we could keep track of it, with a gob of almost-hardened Akemi. One of the nicest things about this stuff as cave glue is that once the hardener is added, it sets up in about ten minutes, so tight you can't budge the rock. We did not torch the ceiling, but just stuck it on there, and held it about five minutes. When I came back in April, the stalactite was still there, and it was dripping water. It has been eight months now—it looks like Cathedral Cave has a new stalactite.

Missouri Cavers as VIP Volunteers

I mentioned earlier that we are doing this restoration under the Missouri Department of Natural Resources Volunteers in Parks program, and the on-site direction of the park naturalist. The advantage of working within this established system is that after filling out minimal paperwork (name, address, phone and social security numbers, and signature) all volunteers are unpaid staff for the purposes of liability under Missouri state law. This frees us up to actually be useful.

Several things become available to us with this unpaid staff designation. First of all, the cave. As I mentioned, this cave is closed to recreational caving without staff present. Cave restoration is hardly recreational caving, but as is the case with many such projects, after the tasks for the day are done, the workers get a little time to see the cave on their own as a reward for their labor. And, though we get checked on occasionally, we are free to work without tying up Eugene or another paid staff member to babysit us all day. Our work, however, does get inspected.

Second, we are able to use park equipment. Most people bring their own tools if they have them, but if not, we can scrounge at the maintenance shop for spare chisels, goggles, and such. We usually walk the one fourth of a mile to the cave entrance with our gear, but there is no problem using the park truck or jeep, if the need arises, to take bulkier tools over the old cave road.

Third, part of administering the VIP program means that naturalists keep track of volunteer hours worked. At year's end, a report is submitted to Central Office in Jefferson City, which sends out a thank-you letter, appreciation certificate, and volunteer patch. The parks get free labor, the cavers get some access to an otherwise commercial-access-only cave, and the cave gets fixed. Everybody wins.

We often have people who volunteer once, work like the dickens, and decide not come back. There are also others who just seem to like to break concrete in the dark. In screening caver-volunteers, I always let them know it is work, and that they need to be at least a novice caver so they are comfortable being underground and have the proper lights and clothes. People usually work two or three to a location. I limit the trips to 12 people maximum, as that is the largest group I feel comfortable overseeing. I know any big disasters are going to come down on my head—and I like volunteering at the park. There is one group of guys, most of whom work in construction, who like "their trip." They call me and we arrange a date with the naturalist staff.

Where does this project go from here? It continues. The magnitude of what needs to be done to restore the cave is such that thinking about the whole thing is daunting. Years and years will be required to completely remove concrete and it is impossible to ever put all the speleothems back. Luckily, these "wet, muddy Missouri caves" at least have a chance to heal themselves over time. I have averaged four trips a year because I don't want to wear out our welcome, or the pool of volunteers. I don't have an exclusive contract on this—any people who want to can go to the naturalist staff and arrange their own restoration trips. But I hope by making this a continuing, instead of one-shot, affair that cavers and park people will see that where preserving cave resources are concerned, we really are on the same side of the effort.

Footnotes

1. Personal communication, Don Rimbach, *circa* 1987.

Other historical information taken from:
Weaver, H. Dwight and Paul Johnson, *Missouri—The Cave State*, Discovery Enterprises, Jefferson City, MO, 1980.

Naturalist's Files, Onondaga Cave State Park, Leasburg, Missouri.

Appendix
Akemi Marble Glue

Directions for Using Akemi Marble Glue

Tools needed:
approximately 10 or 15 parts adhesive to 1 part hardener
Bernz-O-Matic or other propane/butane torch
wire brush—preferably brass or new
rags—towel sized and absorbency
rubber bands and trash bags
chipboard & multiple mixing sticks (can only be used once)
sparklighter or matches
razor and X-Acto scrapers

1. Find pieces to be matched. Brush well to remove debris (mud or loose pieces.)
2. Heat both surfaces lightly, just until a white coating about 1/32 of an inch thick appears. This is best done by heating the air just above the rock, not the rock directly. If the rock sizzles and/or spits, it is too hot.
3. When you have prepared several sets of pieces (about as many as it will take to attach and seat in a five- to seven-minute period), mix *just enough* glue to do so. The more hardener you mix in, the faster the glue will set. It sets in about 15 minutes, so you need to have your work lined up before you mix the glue. *Use a new piece of chipboard and mixing stick each time.* (The hardener really is noxious stuff. Only add about a dime-size amount to about a three- to four-inch-diameter glob of epoxy.)
4. Apply glue in all crevices to *one* side of the stone. Work fast. Seat the stone together, and press hard, making sure a good bond is achieved. When finished, place the mixing stick back on the chipboard. The chipboard will get hot, but the stick can be used as a measure of how fast the glue is curing.
5. If you want to fix stalactites, use the stick as a time measure. Apply glue to piece when runny, but attach to ceiling when the glue is still just barely plastic. It should set almost immediately.
6. If you wipe excess glue off immediately after setting the stone, it should come off fairly well. A little dry mud over the break should conceal the crack, if the formation is already discolored, but concrete colors work better as coloring agents. Clear Akemi seems to do the best job on colored formations, though white should obviously be used on white.
7. If you end up with a "glue bead" around a joint after seating, and the glue has obviously started to set up, *wait*. When glue has cured, the bead can be razored off easily. Cold, it has the consistency of hot-melt glue.

Akemi Plastics Inc
Eaton Rapids, MI 48827
Phone (517) 663-8191
(Polyester adhesive containing styrene monomers)

Distributed by:
Wood & Stone, Inc
10115 Residency Rd
Manassas VA 22110

Agua Caliente Cave: Protecting the Future

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Abstract

In 1994, the Arizona Game and Fish Department, under a Right of Entry Permit from the Arizona State Land Department, placed bat gates on three entrances to Agua Caliente Cave. A popular recreation site for at least 25 years, this cave also contained a maternity roost of approximately 100 Townsend's big-eared bats (*Plecotus townsendii*) and a winter roost of about 50 California leaf-nosed bats (*Macrotus californicus*). Research results showed that the maternity colony had experienced a 50% decline culminating in complete reproductive failure in 1994. This presentation reviews our conservation efforts and the hope for the future at Agua Caliente Cave.

Introduction

Natural caves have attracted humans since prehistoric man. They have provided shelters from the elements, places to cache food and valuables, and sources for water and important mineral deposits. Today, caves are used primarily for exploration and recreation.

Besides the recreation values of caves, these sites offer habitat to an array of wildlife. Most notably, caves are the home to many different species of bats. Unfortunately, roost disturbance can have serious implications on the bat populations. During the maternity season, disturbances can lead to abandonment of dependent young or total roost abandonment by the entire colony. For species that do not hibernate or migrate, disturbance at winter roost may result in the abandonment of a critical micro-habitat that cannot be found elsewhere.

Agua Caliente Cave, in southeastern Arizona, is a prime example of a bat roost impacted by human visitation. This paper reviews our conservation measures for protecting Agua Caliente Cave by examining the cave's recreational and biological values, our gating efforts, and our future management objectives.

History

Agua Caliente Cave is a natural solution limestone cave with three entrances and nearly 1,500 feet of underground passages. It is divided into two levels with a total depth of approximately 150 feet below the upper-most entrance. It is a complicated cave with several technically challenging passages. The interior is warm and dry with a few water pools.

Agua Caliente, managed by the Arizona State Land Department, is located on State Trust Land in the Santa Rita Mountains of southeastern Arizona. The Santa Rita Mountains receive heavy recreational use throughout the year due to the proximity of Tucson and Nogales, Arizona, which have a combined population of approximately 750,000.

Although the Arizona State Land Department requires permits for access into the cave, legal and illegal entries have occurred for many years. Increased visitation has been shown by increased vandalism to the speleothems within the cave, the number of entries to the cave register, and the increased visibility of the trails leading to the cave entrances. In addition, Santa Cruz County Sheriff Department Search and Rescue reports an increase in the number of rescues from Agua Caliente Cave over the last few years. Most of these rescues have assisted inexperienced and unauthorized cavers.

Biological Values

The biological values of Agua Caliente Cave are primarily the bats; however, other sensitive wildlife have been observed in the cave including lyre (*Trimorphodon biscutatus* lambda), green rat (*Senticolis triaspis*), and brown vine (*Oxybelis aeneus*) snakes.

Townsend's Big-Eared Bat: Between April and September, Agua Caliente Cave is inhabited by a maternity colony of Townsend's big-eared bats (*Plecotus townsendii* pallescens). Like most other bat species, females give birth to a single pup or baby per year, usually in June. Between 1988 and 1992, the adult population was estimated at approximately 100 individuals (Dalton and Dalton, 1994). In 1992, 29 dead juvenile bats were found near the entrances of the cave. In 1993 and 1994, the adult population declined to between 50 and 70. In addition, no pups were observed during 1994, indicating a complete reproductive failure for this colony.

California Leaf-Nosed Bat: Agua Caliente Cave is also used by California leaf-nosed bats (*Macrotus californicus*) as a winter roost site. This species does not hibernate or migrate from Arizona and must select winter roosts with internal temperatures greater than 75°F. The California Leafed-Nosed colony does not arrive until November, after the Townsend's big-eared bats have migrated, and remains in Agua Caliente Cave until March.

Agua Caliente's Significance as a Bat Roost

Townsend's big-eared and California leaf-nosed bats typically roost from the open ceiling in caves and mines. They do not use cracks and crevices as do some of the other bat species. Thus, they are more susceptible to disturbances. The decline in the population and the 1994 reproductive failure show the effects of Agua Caliente's high visitation.

Currently, we know of only 14 verified maternity roosts of Townsend's big-eared bats in Arizona. The Agua Caliente colony represents approximately 10% of the known adult female population of Townsend's big-eared bats in the state.

Very few bat roost sites in Arizona support both maternity and winter populations. Female bats require warm summer roosts in which to raise their young, and California leaf-nosed bats need warm internal roost temperatures to sustain active over-wintering populations. Agua Caliente Cave provides these warm temperatures and is one of three known natural caves in Arizona that support year round bat populations.

Gating

Because of the bats' sensitivity to human disturbance, liability issues stemming from unauthorized entries, and the damage to the speleothems within Agua Caliente Cave, the State Land Department requested our assistance in preserving the cave.

Cave protection laws are effective; however, they are difficult to enforce. The Federal Cave Resources Protection Act—which secures, protects, and preserves caves—only applies to federal lands. Our state adds further protection with Arizona Criminal Code, Title 13. This law makes it a Class 2 misdemeanor to harm anything in a cave, including plants and animals. However, individuals must be seen in the act of vandalism in order to prosecute. Therefore, we felt our best protection plan must include gating Agua Caliente Cave.

In 1994, the Arizona Game and Fish Department was issued a right-of-entry permit to construct and install gates at Agua Caliente Cave. Because bats were found roosting near all three entrances and all human visitation routes inevitably pass under or around roosting bats, we decided that gating a single portion of the cave would not adequately protect the colonies. Therefore, all entrances to the cave were gated.

We approached our local grottos for assistance, not only with installation, but also for vandal-proof gate designs. By presenting our gating plans at grotto meetings, our goal to protect Agua Caliente Cave was well received even though it included restricting future entries.

With the help of many dedicated volunteers, bat-friendly angle-iron gates were installed during November 1994. They were constructed inside the cave entrances and not flush with the outside for three reasons: 1) to appear less noticeable; 2) to make them more vandal-proof and harder to remove; and 3) to make them more acceptable to the bats.

Costs for Gating

Many factors determine gating costs including size of the structure, remoteness of the site, and the amount of reinforcement required. Therefore, gating costs are site specific. The cost for gating Agua Caliente Cave was estimated to be in excess of $16,000 with approximately half of the cost absorbed by 829 volunteer hours (Table 1).

Table 1. Estimated Cost of Agua Caliente Cave Gates.

Right-of-entry permit	$1,200
Department Personnel*	$3,775
Equipment Rental	$1,250
Materials	$1,060
Labor (Volunteer)	$8,290

*Does not include off-site planning or coordination time.

Future Management Objectives

The 40-acre parcel of land containing Agua Caliente Cave is currently being considered for the Arizona Game and Fish Department's Heritage Land Acquisition Program. In 1990, Arizona voters overwhelmingly passed an initiative to direct $10 million from surplus lottery money toward the protection of the state's wildlife. We are attempting to purchase the cave with a portion of these funds.

The acquisition of Agua Caliente Cave will mark the Arizona Game and Fish Department's first opportunity for direct cave management. In the past, cave management decisions have been developed by the land management agency, with the Department making recommendations relating to wildlife.

In preparation for this purchase, the Arizona Game and Fish Department, with input from the grottos, developed a management plan for Agua Caliente Cave. However, this plan will not take effect until the acquisition of the cave has occurred. Our plan emphasizes controlling human visitation to allow the bat colonies to stabilize and possibly increase in an undisturbed state. We will continue to monitor the bat populations to determine if any recreational windows exist. Entry requests will be evaluated on a case-by-case basis. Also, we will evaluate the need for signing and fencing the property surrounding the cave. Cave gates will be monitored monthly and any necessary maintenance will be conducted.

Conclusion

Our 1995 data showed that the Townsend's big-eared bats have accepted the gates; approximately 50 individuals returned during the summer. We have not received information regarding the number of volant young at this time, as our monitoring efforts did not include entry into the cave. Additionally, there has been no evidence of attempted gate removal or trespassing.

The anticipated return of the California leaf-nosed bats in November will mark the successful beginning for Agua Caliente Cave's future. Only by managing the important roosting habitats of bats can we insure the continued existence of these unique creatures.

Literature Cited

Dalton, V.M. and D.C. Dalton (1994) "Roosting use of Agua Caliente Cave by the big-eared bat (*Plecotus townsendii*) and the California leaf-nosed bat (*Macrotus californicus*)," Arizona Game and Fish Department, Phoenix, Arizona.

Endangered Cave Invertebrate Conservation in Texas

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Abstract

The shallow limestone caves in central Texas provide habitat for a variety of unique and endemic species, including a particularly diverse array of terrestrial cave-adapted invertebrates. Seven such invertebrates in the vicinity of Austin, Texas, are currently listed as endangered species by the U.S. Fish and Wildlife Service. Most of the caves inhabited by these species are located on private land in areas highly desirable for suburban development. Threats to the species include pollution and other secondary impacts related to development as well as predation by imported fire ants. A recovery plan completed in 1994 presents a strategy for protecting these endangered species as well as the karst ecosystem on which they depend.

The Internet and the World Wide Web as Tools for Cave Conservation and Management

by Rob Stitt, President
NSS Cave Conservation and Management Section

Abstract

The Internet (sometimes known as the "Information Super Highway") connects together millions of computers throughout the world into essentially instantaneous communications. It can be used for electronic mail, data exchange, and bulletin board type message posting. The World Wide Web is a graphical, hypertext interface that enables Internet users to post information, exchange e-mail, and collect information from users. To take advantage of this as a communication and educational tool, the NSS Cave Conservation and Management Section has established a web home page at: **http://www.halcyon.com/samara/nssccms/**. Additional web home pages have been established for the NSS Human Sciences Section at: **http://www.halcyon.com/samara/nsshss/**, for the 1995 National Cave Management Symposium at: **http://www.halcyon.com/samara/ncms95/**, and for the 1997 National Cave Management Symposium at **http://www.halcyon.com/samara/ncms97/**. This paper discusses the current content of these pages, and how they can be used as management and conservation tools.

This paper explains how you can use the Internet World Wide Web to help accomplish your conservation and management goals and projects. As President of the NSS Section on Cave Conservation and Management, I have established several home pages on the World Wide Web to provide information and alert readers to conservation issues and crises. These pages are continuously updated and changed to bring new information and progress reports to the cave conservation community. The current access addresses are listed in the abstract above. It is possible that these might change in the future, so if you are unable to access one at the above addresses, you should search for "Cave Conservation" using one of the comprehensive web search engines such as Lycos or Alta Vista.

The Internet (sometimes known as the "Information Super Highway") connects millions of computers throughout the world together into essentially instantaneous communications. You can access it easily if you own a personal computer with a fast (14,400 BPS or faster) modem by connecting to one of the commercial on-line services such as Prodigy, CompuServe, or America On-line; though a local Internet Service Provider (ISP); or at your work via a direct connection. It should cost you around $20 a month for access via ISP, less for minimal hours access through an On-line Service. If you need information on how to access it, pick up one of the computer magazines or the ubiquitous books about the Internet that you can find at your local computer store or book store. In this paper I assume that you are connected and can access the World Wide Web via a graphical interface and browser such as Netscape, Internet Explorer, or Mosaic.

When you are connected to the Internet, you have numerous tools to help you obtain and disseminate information. You can use **e-mail** to send messages and transfer documents to other cavers or managers. You can receive responses from them or from managed mailing lists such as the **Cavers Digest** or **Batline**. You can use **FTP** to transfer files from other computers anywhere in the world. **Telnet** allows you to log onto other computers anywhere in the world and read bulletins, gather information, or otherwise participate as if you had dialed in locally. You can access the **Usenet**, which is a collection of thousands of computer bulletin boards where messages are posted for anyone to read. The caving community has tended to stay away from the Usenet to avoid undue publicity about caving, but there is one Usenet board, **alt.caving**, that is patronized mostly by non-cavers and new cavers. Most cavers and cave conservationists use the **Cavers Digest**, which is sent only to those who have subscribed, and thus is more private.

The World Wide Web is a graphical user interface to the Internet that incorporates most of the above features within one program. In addition to viewing graphical information and being able to jump around via hypertext links, you can send e-mail, transfer files, log onto other computers, and read Usenet groups on the World Wide Web.

The latest versions of some browsers have more sophisticated e-mail features that eventually could mean that you don't need any other program for access to the Internet. The web has millions of pages of information (over 8 million when this paper was given in October 1995 and 18 million when it was written in January 1996). There are also millions of users (more than 9.5 million in the U.S. as of January 1996) and the number is growing rapidly. As computers grow more universal (at least in the developed world) the number of users will continue to grow. I won't predict whether the Net and the web will replace other media, but it certainly will be an increasingly-important communications tool in the future.

So who is on the web? The following are a few of the available pages. As of this writing, there are:

- NSS http://www.cavers.org/~nss/
- NSS CCMS: http://www.halcyon.com/samara/nssccms/
- NSS HSS: http://www.halcyon.com/samara/nsshss/
- Most Federal Agencies
- Lots of Caving Organizations
- Many cavers throughout the world
- International Subterranean Heritage Association
- Australasian Cave and Karst Management Association

There are several programs that search the web for references and allow a user to conduct a search in a few seconds by typing in key words. The one that is my current favorite, Alta Vista, turned up 40,000 references to the word "cave," 3,282 to "speleology," 100 to the phrase "Cave Conservation," 65 to "Cave Management," and 300 to "National Speleological Society." Lycos, which currently indexes over 18 million pages, got 5,785 on "cave," 399 on "speleology," 75 on "cave conservation," and 16,191 on "nss," which is clearly looking at non-caving nss's like the National Space Society also. Curiously, Lycos turned up only two pages with "National Speleological Society." These numbers will change rapidly as more and more people become web users and put up their own information.

Some members of the cave conservation community are concerned about the proliferation of these cave pages. web page presenters on the whole have been responsible, conservation-oriented cavers who have refrained from publishing cave locations and steer new cavers to NSS Chapters (in the U.S.) or to recognized caving groups in the rest of the world. To date, the number of cave-related pages is well below the relative percentage of the population in the U.S. that the NSS represents. But we do need more cave-conservation-related pages and information to help reach new cavers who do find caves on the web.

The web page represents a powerful tool for presenting information to others. The caving community can be mobilized by the posting of information, and can use e-mail as a tool for communicating their opinions to cave managers. The Cavers Digest has been a vital tool in the past for transmitting this information, and will continue to be (lots of the material posted on the web comes from the Cavers Digest).

It is typical for web page publishers to attempt to obtain the widest possible circulation for their web site address, to encourage as many people as possible to see it. The caving community has been much less interested in obtaining wide circulation, and instead has relied on the ingrown link lists of the various cave-related web pages to obtain circulation. The Lycos and other search engines will find you anyway, but at least there is no "posted" reference to the cave conservation home page on one of the public web indexes. The result of this is that there have been under 1,000 visits to the page in the seven months or so that I have been keeping track. And I would guess that 100 or so of them are me checking out links from other places. So the page is not as popular as something like the "Alice-in-Chains" rock group home page that has had 25,000 hits since October 1995. Although I would like to see cave conservationists checking the page frequently for updated information, I certainly hope that we never get 25,000 hits in only a few months, because that will be a sign that caves are in much worse shape than we feared.

The best way to find out what is on the NSS Cave Conservation and Management home page and web is to log on and check it out. It will probably have changed a lot from what was when this paper was written. But I will describe some of the content to give you an idea of what was there.

The main page, the page you will access if you enter the code listed above, includes references to many other pages. In addition it contains a section on hot issues, that includes current problems and some that were current not too long ago. It's the nature of information posting that things will get put up and not taken down (at least until we run out of space). Each of the hot links has its own page or pages with information about that issue. Current issues right now are the Puna caves in Hawaii, Hong Kong speleothem sales, New Mexico Bureau of Land Management issues, and several others.

The next section of the home page includes links to Section resources on the web—including our information brochure, membership information, and more things about the section. There is a link to the *Cave Conservationist*, our publication, and several recent issues are posted on the web in their entirety. More will be added in the future. There is a link to a calendar of events that provides information about all the cave-conservation-related events that I find out about.

The last section includes links to other group's pages with related purposes. There is also a link to a more complete list of cave-conservation-related links, and my personal home page which has a link to my personal list of cave-related web sites. There is a link to a "What's new?" page that will bring you up to date on things I have added. And finally, there are links to the home pages for the 1995 and 1997 National Cave Management Symposiums.

Lots of information. Lots of work keeping it up. You can help by sending me information, via e-mail to rstitt@wingedseed.com. If it's an urgent issue I will attempt to get it up within a few days. If not so urgent, when I get around to it. I do have a life, after all.

The following is the text of the NSS Cave Conservation and Management Section home page. The underlined words are the hypertext links that will lead you to another page. Depending on the browser, they will show up with a contrasting color. If you have a Netscape browser, for example, and probably with several others, the background will be black and the text will be white. Links will be either red or yellow, depending upon whether you have jumped to them.

National Speleological Society

Cave Conservation and Management Section

Welcome to the Home Page for the Cave Conservation and Management Section of the National Speleological Society.

The Section provides this Home Page as a focal point for information about Cave Conservation and Management. Of course it is always under construction, and may be different the next time you visit. This version was updated January 6, 1996.

New Hot Issues

Kazumura Cave (world's longest lava tube) threatened by a road building project. Letters needed. 12/12/95 Update. Letters Still Needed! See article in November 1995 NSS News for more information about the cave! 12/19/95 Update. Partial success but letters still needed!!!

Read the Blackwell Report on Karst in a Forested Environment - Vancouver Island, Canada.

Find out how to participate in the 1996 Black Hills Lint Camp.

IUCN Guidelines for Cave and Karst Protection Draft - needs your comments by December 31 , 1995!!! Or until January 31 if you have to.

Cave Formations for sale in Hong Kong

USFS Issues Proposal for Fees for Caving in the Guadalupes

Dave Jagnow named NSS Conservation Chairman (coming soon, as soon as we get him on the Internet).

He issues a hot request for letters to Congress about the Tongass National Forest Logging Bill. (September 95). Read about the issues in an article from the October 1 Juneau Empire.

Old Hot Issues

- BLM Cave for Pay Issue: Petition that was submitted to the BLM Note: A new BLM issue has arisen (Commercial Cave Guides) and information updated to May 25 has been posted.
  Results of the June 15 meeting between cavers and the BLM.
  BLM Issues its [predictable] Findings (August 23)

- New Mexico BLM Does it to us AGAIN! But it should be fixed by now (Nov 28)

- Portuguese Coa Dam Issue and web page for it (in Portuguese and English).

- Development threatened at Mexico's Cacahuamilpa Cave. If you know anything new, please e-mail us with details.

Section Resources on the Web

- The Section's Information Brochure
- NSS Policy for Cave Conservation
- The Cave Conservationist, our publication Now includes several recent issues live on the web
- A copy of the Federal Cave Resource Protection Act of 1988
- Section Membership Information
- Calendar of upcoming Cave Conservation and Management Events
- What's new - Last update January 9, 1996.

Other Related Resources on the Web

- Home page for the 1995 National Cave Management Symposium that was held in October 1995 in Indiana
- Cave Conservation Servers on the web is a list of cave conservation related hot links.
- Federal Government Cave Management Entity Home Pages, including the National Park Service, the U.S. Fish and Wildlife Service, the U.S. Forest Service
- The NSS Human Sciences Section Home Page
- Other Conservation Organizations
- Australasian Cave and Karst Management Association
- ISHA Home Page (International Spelean Heritage Association)
- Southeastern Cave Conservancy Home Page
- Amazing Environmental Organization Web Directory!
- Never too early to start thinking about the 1997 National Cave Management Symposium to be held in Bellingham, WA and Canada's Vancouver Island.

This page has been accessed **Error! Not a valid filename**. times since May 23, 1995.

To provide some feedback on this assemblage of information, mail to: rstitt@halcyon.com.

Or check out Rob's Home Page: Rob Stitt

Please feel free to browse the Home Page for current information. Download newsletters as you wish. Send in information on your project for posting. Solicit support for your project. Pass on current information. This page is intended as a living document. It will change frequently. Permanent reference materials will be published in the *Cave Conservationist*, which will be posted on the Web shortly after it is published and will be available for your perusal or download.

The Web and the Internet are ideal communications tools for the exchange of information about cave conservation and management issues. By using it, we will obtain support for our projects and management initiatives, extend information about them to others, and generally further our cause.

Cooperative Cave Paleontological Resource Management, Mammoth Cave National Park, Kentucky, USA

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Abstract

Paleontological resources are frequently overlooked in the management of cave resources, especially in caves where the paleontological resources are dispersed or are not dramatic. Often cave managers are not aware of the presence of paleontological resources until after they have been negatively impacted by some activity. In order to minimize the number of these types of surprises, the Division of Science and Resource Management, Mammoth Cave National Park, the Illinois State Museum, and the Cave Research Foundation have begun to systematically document paleontological resources of caves of Mammoth Cave National Park.

As a part of the on-going paleontological work, Toomey, Colburn, and Ward worked with five volunteers provided by Earthwatch in making a detailed survey of a small area of Mammoth Cave near the Historic Entrance. This survey carefully examined a large area of terminal breakdown for bones, guano, and other traces of vertebrates. The paleontological resources were identified, catalogued, and mapped by the team.

Identifying and inventorying paleontological remains is important for cave management. The data acquired during the Earthwatch project and other cooperative paleontological activities provides at least two important types of information for cave management. First, information on paleontological remains is needed in order to correctly manage the resources. Second, the paleontological data from the Earthwatch project is providing important baseline data on bat use of Mammoth Cave before significant European impact. This information provides some of the only data for reconstructing the pre-impact cave ecology in the area near the Historic Entrance.

Introduction

Previous work in Mammoth Cave National Park has established that paleontological remains are present in various caves in the park (Wilson, 1985). Unfortunately, other than Wilson's work, there has been almost no paleontological investigation in the caves of the park. Recently, growing concern about how various activities might impact non-renewable cave resources has led to increased inventorying and monitoring of cave resources. As a part of this trend, recent cooperative research involving personnel from the National Park Service, Illinois State Museum, and Cave Research Foundation has been instigated to inventory paleontological remains in the park.

Paleontological remains are not uncommon in caves. Types of vertebrate paleontological resources found in caves include bones and teeth, mummified remains, guano and feces, footprints, scratchings, and other traces of animal activity (ceiling stains, woodrat middens, bear beds, and the like). Vertebrate remains are an important non-renewable natural resource. Like surface paleontological remains, paleontological remains from caves provide important information on the faunas of the past, on the evolution of animals, and on the development of past ecosystems. In addition, remains from caves can provide important information on changes in individual caves and cave ecosystems.

Unfortunately, paleontological remains in caves are sometimes overlooked in the management of resources. This occurs for several reasons. Paleontological remains are often not recognized. Small bones, subtle traces, degraded guano, and remains in sediment deposits are difficult to spot. Some people assume that bones on the floor of a cave are very recent and do not need to be protected, but surface bones may be old or young. In addition, relatively recent bones may provide as much vital information as older ones.

Inventorying of paleontological remains in caves has many benefits. First, unless a cave manager knows what resources are in a cave system, it can be difficult to adequately protect them. Second, inventorying paleontological deposits may identify scientifically-important deposits that can provide valuable data. Third, some paleontological deposits can provide information that will assist in other aspects of cave management.

As a part of this continuing inventory project, Mammoth Cave National Park, the Illinois State Museum, and Earthwatch cooperated in mapping and inventorying remains in a small area near the Historic Entrance of Mammoth Cave during the summer of 1995. The initial goals of the project were threefold. The first goal was to assess the abundance, distribution, and condition of faunal remains in the area of the historic bat roost. The second goal was to gather paleontological data that can be used to reconstruct climatic conditions in the Historic Entrance area prior to impacts associated with entrance modification. The third goal was to determine the effectiveness of Earthwatch volunteers in identifying and mapping the distribution of paleontological remains in a cave setting.

Rafinesque Hall Project

Rafinesque Hall, a large room off Audubon Avenue near the Historic Entrance of Mammoth Cave, is an historically recorded winter bat roost. Early in the history of the cave, biologists recorded thousands of bats wintering in this area (see for example Hovey and Call, 1897 and Bailey, 1933). Unfortunately, these bats were recorded before the difference between little brown bats and Indiana bats was scientifically recognized. Descriptions of the roosts suggest Indiana bats were the primary bat present in the hibernaculum. However, human impact in this area apparently caused bats to abandon this roost sometime in the nineteenth century. One of the most important impacts on the area may have been the enlarging of Houchins Narrows starting with the saltpeter mining in the cave. Today entrance size changes are known to cause cave climate changes that affect suitability of hibernacula for Indiana bats (Richter *et al*, 1993).

Enlarging the entrance passage (Houchins Narrows) appears to have caused profound changes in air movement through the entrance. These changes have led to important changes in the cave climate over an important section of the cave. Climate changes in this area are now thought to be contributing to several important management concerns in the cave, including increased rock fall and speeding deterioration of some archaeological remains.

For this reason, the Division of Science and Resource Management at Mammoth Cave National Park is interested in determining what the climate of the area influenced by the Historic Entrance was before the changes in the entrance configuration. An analysis of the paleontological remains from Rafinesque Hall provided an important opportunity to do this.

Initial reconnaissance of Lookout Mountain by Rickard Toomey and Rick Olson indicated that bat bones and potentially-interesting guano remains are present in at least one area that may have been an old roost site. Lookout Mountain is a large valley wall terminal breakdown in Rafinesque Hall. Bone and guano deposits were identified on the talus concentrated along both walls of the room. Preliminary examination suggested that bat bones and guano were present in moderate quantities and that large guano deposits were present along the east wall of the Rafinesque Hall.

The results of the initial reconnaissance suggested that a more detailed study of the faunal remains of the area might provide important data that could be used both for the management of the paleontological remains and also for the other cave management concerns. Because of its potential, the Lookout Mountain area was chosen to test the use of Earthwatch volunteers in performing paleontological inventory in Mammoth Cave.

Between July 28 and August 4, 1995, a team of five project staff, five Earthwatch volunteers, and three National Park Service employees surveyed and inventoried the paleontological remains on Lookout Mountain. The procedure for this survey was as follows:

- Volunteers located and identified paleontological remains,
- The location of the remains were accurately mapped,
- Some of the remains were photographed, and
- Some materials were collected for further identification and/or dating.

Locating and identifying vertebrate remains involved teams of volunteers crawling over the entire breakdown and along ledges on the side walls searching for bones, areas of guano accumulation, raccoon scratchings, and other signs of vertebrate use of the area. Concentrations of vertebrate remains—including isolated bones, groups of bones, guano, raccoon scratchings, and combinations—were identified. When identified, these concentrations were marked with flags and the person who found them filled out a card inventorying the remains. Identification of individual bat bones was accomplished using a combination of a set of laminated cards showing different types of bat remains and a comparative set of modern bat skulls, jaws, and humeri from the skeletal collection of the Illinois State Museum. Final confirmation of the identifications made by volunteers was made by Toomey or Colburn.

After the paleontological concentrations were marked and identified, the team mapped them. The mapping was accomplished using a total-station theodolite. The use of this instrument allowed rapid and accurate mapping of the specimens. The theodolite stations are tied to the Walker benchmark (TT 2 W 1936) in the Rotunda. Tying the data from this inventory to the benchmark allows the paleontological concentrations to be related to other mapping efforts.

Following mapping, Chuck Swedlund photographed representative specimens. The photographs will allow us to monitor changes in the condition of the remains. They also document the *in situ* condition of remains collected for further study or dating and allow additional study of some remains without removing them from the cave.

The last step in the procedure was to collect representative material both for more detailed analysis and for radiocarbon dating. Three different classes of material were collected: material that required further identification, voucher material that serves to verify what was found, and material to be dated. Approximately 30 specimens were collected in total.

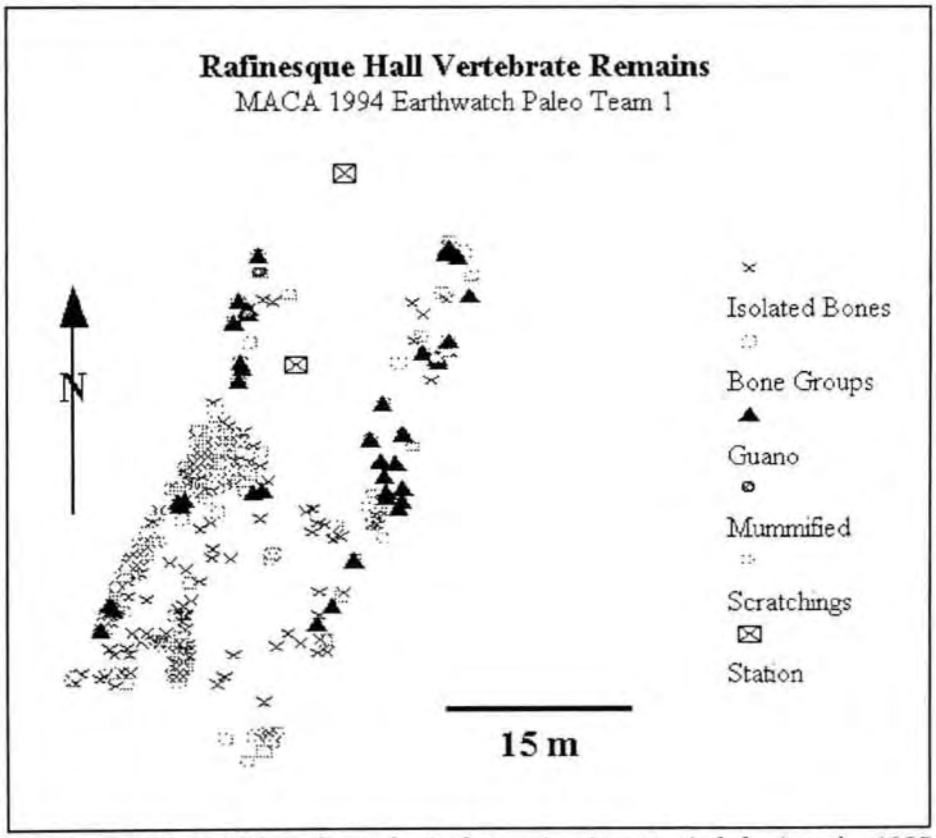

Figure 1. *Map of the paleontological remains inventoried during the 1995 Earthwatch Paleontology Project in Rafinesque Hall, Mammoth Cave National Park, KY. Paleontological Inventory conducted under the direction of R. S. Toomey, III (Illinois State Museum). Mapping of remains was accomplished by Earthwatch crew using a total-station theodolite. Points indicated as "Station" are theodolite stations from which the remains were mapped.*

Results

During the project the Earthwatch volunteers identified almost 300 concentrations of paleontological interest in Rafinesque Hall (Figure 1). Most of these were on Lookout Mountain; however, a significant number were on ledges on the walls of Rafinesque Hall or on several large spall blocks along the east wall of the Hall.

The most common category of remains mapped consisted of concentrations of bone which belonged to a single animal (45% of all points). The vast majority (90%) of this type of concentration consisted of a single isolated bone. The second-most common type of concentration identified were those that had multiple bones but for which it was not possible to determine whether one or more animals were represented. This type of concentration represented about 34 percent of all concentrations. Concentrations of bones representing multiple animals represented just over two percent of the concentrations mapped. Guano deposits were also well represented in Rafinesque Hall with six percent of concentrations consisting of just guano and eight percent consisting of guano and bone. Scratchings and claw marks represent three percent of the concentrations.

Bat remains were the most commonly encountered remains as would be expected in an area that was an historic bat roost. At least three species were represented in the area. A few bones from eastern pipistrelles (*Pipistrellus subflavus*) and big brown bats (*Eptesicus fuscus*) were identified; however, the vast majority of identifiable bat remains were from either little brown bats (*Myotis lucifugus*) or Indiana bats (*Myotis sodalis*).

Unfortunately, the bones of little brown bats (*Myotis lucifugus*) and Indiana bats (*Myotis sodalis*) cannot be separated in the field. For this reason all *Myotis* skulls, and some mandibles and humeri that were encountered during the inventorying were collected for further study. Unfortunately, only one well-preserved *Myotis* skull was collected from Rafinesque Hall (Field number ISM EWP-189). The presence of a moderately-developed sagittal crest suggests that this skull can be best assigned to *M. sodalis* (Thomson, 1982). This identification is supported by the relatively narrow braincase (7.1 mm) of the specimen (Thomson, 1982). The identification of the skull indicates that at least the Indiana bat used the historic roost. The analysis of mandibles is continuing and may help determine whether both species are present in the sample.

The bones of two non-bat species were also identified in Rafinesque Hall. One complete Allegheny woodrat (*Neotoma magister*) skeleton and parts of a second were found near the top of the breakdown. In addition, a metatarsal of a raccoon (*Procyon lotor*) was found near the top of Lookout Mountain.

The guano deposits in Rafinesque Hall are intriguing. Three very different types of guano were identified during the study. Two were relatively easy to identify; the third was more difficult.

The first type of guano encountered was bat guano. Deposits of bat guano are concentrated along the edges of Rafinesque Hall. The pattern may relate to bat usage patterns of Rafinesque Hall or may relate to reworking of the central part of Lookout Mountain by water flow. The concentrations of bat guano varied from small areas of granular bat guano to a relatively thick (at least 20 cm) mass of somewhat compressed guano on the east side of Lookout Mountain.

The second type of identifiable guano consisted of concentrations of isolated feces referred to raccoon (*Procyon lotor*). The individual feces were cylindrical with a diameter of about one centimeter. Pieces varied in length from about one centimeter to about ten centimeters. The feces conform well to the description of raccoon feces in Murie (1954). Raccoon feces were concentrated on the top of several large spall blocks that abut the east wall of Rafinesque Hall and extend to within about 60 centimeters of the ceiling. The raccoon guano was especially intriguing because the individual feces contain large numbers of bones of little brown bat or Indiana bat.

The third type of guano is more problematic. This guano is concentrated on the top of the large spall blocks and on numerous ledges on the

Sample Field Number	Material Dated	INSTAAR lab number	LLNL Number	Age (years Before Present)
ISM EWP-129	*Myotis sodalis* or *M. lucifugus* humerus	NSRL-2840	CAMS-24971	170±50
ISM EWP-269	*Procyon lotor* coprolite	NSRL-2841	CAMS-24123	410±50
ISM EWP-256	*Myotis* guano 17 cm down	NSRL-2842	CAMS-24124	200±60

Table 1 — Radiocarbon dates on paleontological remains from Rafinesque Hall. These dates suggest that the paleontological remains found in Rafinesque Hall reflect the bat roost that was recorded in the area during the early 1800s. Further dates will provide more information to test this conclusion.

side of these blocks. These guano deposits consist of dense masses of fibrous material. The upper surfaces of these deposits have a felt-like consistency. The deposits of this guano has relatively large numbers of *Myotis* bones associated with them. This guano appears to be the remains of degraded raccoon feces similar to the feces described above. The fibrous texture is a result of large amounts of bat hair from the degraded raccoon feces.

Also relatively common in the areas in which the two types of raccoon guano are encountered are scratching and claw marks on the walls. These markings appear to be made by raccoons trying to scramble up areas of the wall.

The presence of large amounts of raccoon feces containing *Myotis* bones suggests the following scenario. Raccoons entered the cave during the winter while the bats (probably Indiana bats, possibly also little brown bats) were hibernating in Rafinesque Hall. The raccoons apparently climbed up on large spall blocks that extend to within about 60 centimeters of the ceiling. From that vantage, they took hibernating bats off the ceiling and ate them. It is possible, based on the amount of raccoon scat, that they consumed many or most of the bats that were within reach. Similar concentrations of raccoon scat have been recorded in several Indiana bat hibernacula, including Long Cave in Mammoth Cave National Park, Kentucky, (Toomey, 1995, unpublished observations) and Wyandotte Cave, Indiana, (Munson and Keith, 1984). The observations from Mammoth Cave National Park caves support the possibility that raccoons represent an important source of mortality for hibernating Indiana bats (Munson and Keith, 1984).

In order to determine whether the results of the paleontological investigations provide information about the climate of the cave before significant modification of Houchins Narrows, it is necessary to determine the age of the paleontological remains in Rafinesque Hall. For this reason samples of bone and guano were collected for radiocarbon dating; seven sample from Rafinesque Hall have been submitted to the radiocarbon laboratory of the Institute of Alpine and Arctic Research, University of Colorado, Boulder. These samples are processed by T.W. Stafford Jr. and are dated at the accelerator facility of Lawrence Livermore National Laboratory. As of this writing three determinations are available (Table 1).

Conclusions

Several important conclusions can be drawn from this project. First we discuss some of the specific conclusions of the project. Following that we will discuss some of the more general implications of this type of project.

The study of the paleontological remains of Rafinesque Hall suggest that the historic bat hibernaculum recorded from that area could have been an Indiana bat hibernaculum. This conclusion is tentative because only one specimen that has been identified to species were recovered. However, the one good skull that was collected belongs to that species. Further study of the mandibles may provide more information.

The paleontological remains inventoried represent the results of several dynamic processes that appear to have been associated with the bat roost. Although older bone may be present on Lookout Mountain, our study of the surface material found no evidence for older material.

The abundant feces and guano attributed to raccoons suggests that raccoon predation may be an important source of mortality for hibernating Indiana bats. The possibility that it is a significant source of winter mortality should be investigated further. Predation by raccoons may be an important factor to consider in managing hibernating populations of the Indiana bat.

Identification of Indiana bats in the historic roost area of Rafinesque Hall constrains probable winter temperatures for that area before the modification of Houchins Narrows. These constraints are now being used in a study of the temperature effects of modifying airflow through the Historic Entrance of Mammoth Cave. The data from Rafinesque Hall provide information on the pre-modification climate conditions that provide a guide for on-going attempts to restore the climate of the Historic Entrance area to one similar to what was present before large-scale modification in the early 1800s.

This project provides an example of how a paleontological inventory can provide data that is important for cave management in several ways. The data on the paleontological remains, their age, distribution, and condition will assist in reducing impact on the remains from human activities. In addition, the remains provide information that can be used in managing the climate and ecology of the cave.

This project has also demonstrated that volunteers are effective in assisting in the inventory of surface paleontological remains. They can be efficient and effective even when the resources are small (such as isolated bat bones) or in areas where the topography is rugged or complex (such as a large talus or breakdown cone). Volunteers were, in fact, necessary to the completion of a project requiring such labor-intensive fieldwork.

Acknowledgments

We would like to thank many people for their help in this study. First we must thank the National Park Service, the personnel of Mammoth Cave National Park, the Illinois State Museum, and the Illinois State Museum Society. We thank Earthwatch, Canon USA, and the National Park Foundation for their financial support. At Earthwatch we would especially like to thank Gretchen Bowder for her help. Many people from the Cave Research Foundation provided information and logistical support in the initial study and preparation for the Earthwatch project, in addition they have been instrumental in the continuing study. George Crothers shared much advice based on his experience with similar archeological projects.

Most of all we would like to thank the personnel who worked on the Earthwatch project. They are (staff) C.A. Swedlund, Andrew Mickelson, and Kappy Mickelson; (Earthwatch volunteers) Katy Hall, Barbara Ross, Seumas Soltysik, Glen Stanley, and Pat Yale; and (NPS volunteer) Colleen O'Conner. Without them this project would not have been possible.

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When Do You Think They'll Get Here?

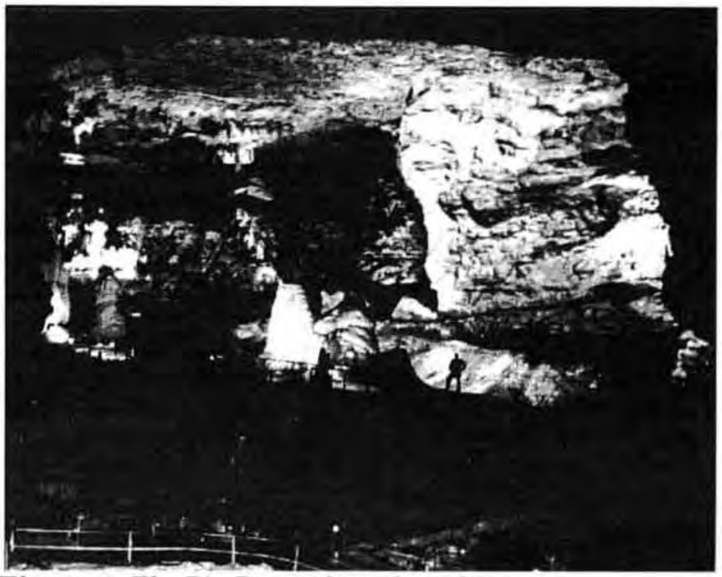

Figure 1. *The Big Room, Onondaga Cave.*

Patterns of Visitation at Onondaga Cave and Their Management Implications

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Abstract

Much show cave management has been "by the seat of the pants." This study looks at the last 13 years' attendance at Onondaga cave and determines seasonal, weekly, and even daily patterns of visitor use. This is used to more efficiently determine staffing needs (number of guides) and hours of operation. Data prior to 1994 is by day only. Computerized record keeping since then has allowed for hourly records and exploration of daily patterns to even more effectively serve our visitors and control their impact on the delicate cave environment.

Onondaga Cave State Park is located near Leasburg in Crawford County, Missouri, 90 miles out Interstate 44 from the Saint Louis Gateway Arch. It is in a ridge bordering the flood plain of the Meramec River and is contained within the Eminence and Gasconade Formations.

The cave was discovered off the mill pond of the Davis Mill in 1886 and has been toured since 1897. The cave remained a privately operated show cave until the death of its last owner, Lester B. Dill, in 1980. It was his wish that Onondaga be preserved as a state park. It has been managed by the Missouri Department of Natural Resources, Division of State Parks since 1981, and is a memorial to Mr Dill.

Onondaga remains a beautiful cave, despite nearly a hundred years of tours and commercial development. This includes a rich and diverse ecosystem in which 60 different species have been catalogued, including two for which Onondaga is the type locality. Onondaga Cave has been designated a National Natural Landmark.

Onondaga Cave entered the Missouri State Park System during one of our most financially difficult periods, and so it was decided at that time to let the tours out to a private operator under a concession contract. Nevertheless, the stewardship of the resource and the quality of the visitors' experiences were of the utmost importance. Of particular concern was tour size.

There has been much discussion in cave management about a cave's carrying capacity, or how many visitors can a cave take over a period of time before it suffers unacceptable levels of damage. Significant papers on this subject were presented at the 1975 National Cave Management Symposium (Aley, Brucker, and Van Cleve) and at the 1976 Symposium (Forssell, Middaugh, Knutson, and Larson). To minimize the impact of large numbers of people, the management plan adopted the standard rules of a show cave: No smoking in the cave, no littering, and no touching or breaking of the cave deposits.

The cave management plan also identified a maximum tour size of 30 people to insure that all visitors could hear the guides and see what was being interpreted, and so that the guides could see and control their tours at all times.

Unfortunately, this and some other requirements of the cave management plan did not show up as requirements in the concession contract. The concessionaire was supplied with a copy of the plan, and verbally agreed to abide by it. However, evaluations by park staff showed that tours numbering in the mid-forties were commonplace at peak times, and this was accompanied by a small litter problem. During slack times, concession guides often lounged around the visitor center, even playing cards while other maintenance requirements went unmet.

The last concession contract expired December 31, 1992, and with these problems in mind, the new contract went out for bid with tour size restrictions, and quality control measures specified. No responsive bids were received. The last concessionaire was given a one-year extension to liquidate his stock and recover some of his investment, while the Division of State Parks embarked on an ambitious undertaking.

Rather than try for a second round of bids on the concession contract, it was decided to try to manage the cave and gift shop as a part of park operations. This was no light decision. In order to get the legislature to appropriate the necessary funds several promises had to be made:

- The quality of interpretation and resource stewardship would improve.
- The tour size could be reduced without reducing overall visitation.
- Enough money would be taken in to pay for the entire operation, and indeed return a net profit equal to or greater than the income from the concession contract.

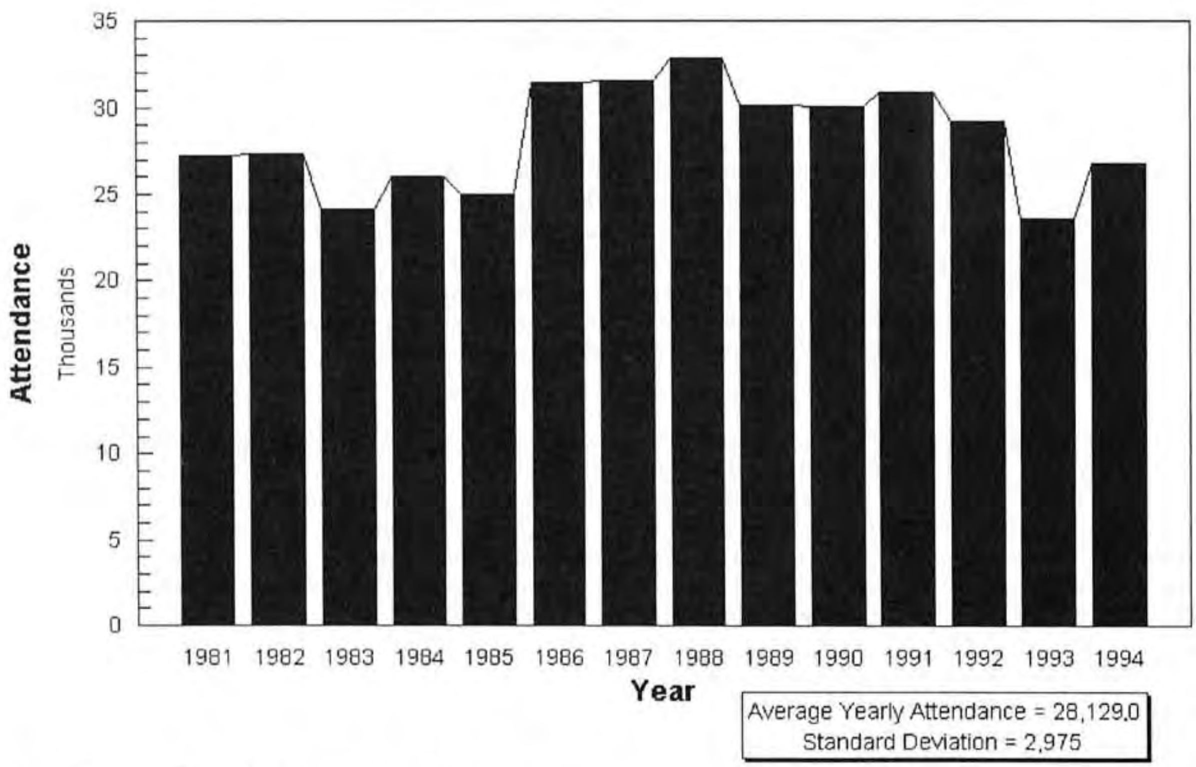

Figure 2. *Onondaga Cave attendance by year.*

Thus, not only was good interpretation and resource stewardship promised, but also a profitable business.

It was felt that this could be done based upon the belief that human behavior on this scale is somewhat predictable. Also, an analysis of the attendance records since Onondaga became a state park showed a number of possibilities. An on-going analysis of our attendance is proving to be a valuable tool in meeting these goals. Here are some of the results:

First, look at the yearly totals, Figure 2. These are often looked at to detect trends, and they are surprisingly consistent. It is apparently very hard to do extremely well, but also hard to do very poorly. Onondaga Cave seems to have a very stable and reliable customer base, unless something really serious goes wrong. Furthermore, our attendance is low compared with many other publicly operated show caves. Therefore, provided visitation is limited to well supervised and guided tours which remain on the developed trail, the cave is probably not yet near a carrying capacity. With vigilance, any such problem may be cut off if and when it starts.

Limiting the annual visitation to the cave is not the goal at this time, but instead the goal is to limit the number of people per tour. As both Aley (1976) and Van Cleve (1976) point out, human impact on a cave is more related to the behavior of humans than to numbers of humans. An individual vandal can do more damage than hundreds of cavers caving softly. Experience demonstrates that in a show cave situation, bad behavior is often a function of tour size. This is probably because of a number of factors:

- The guide can more easily monitor the group and detect and correct any misbehavior in a smaller group;
- This fear of detection is itself deterrent to unacceptable behavior; and
- Smaller groups lead to a friendlier atmosphere and better communication. This produces a higher quality tour and increases the visitors' enjoyment and appreciation of the cave.

Both Forssell (1977) and Middaugh (1977) talk about the quality of the experience, visitor attitudes, and satisfaction as important factors in determining the carrying capacity of a cave.

Thus, although yearly totals provide some valuable information, there is not enough detail to provide for a day-to-day, tour-to-tour plan to control visitor numbers. Payroll, monthly reports, and hiring and laying off staff are done on a monthly basis. How many visitors are expected, how many guides are needed, and when they should be hired

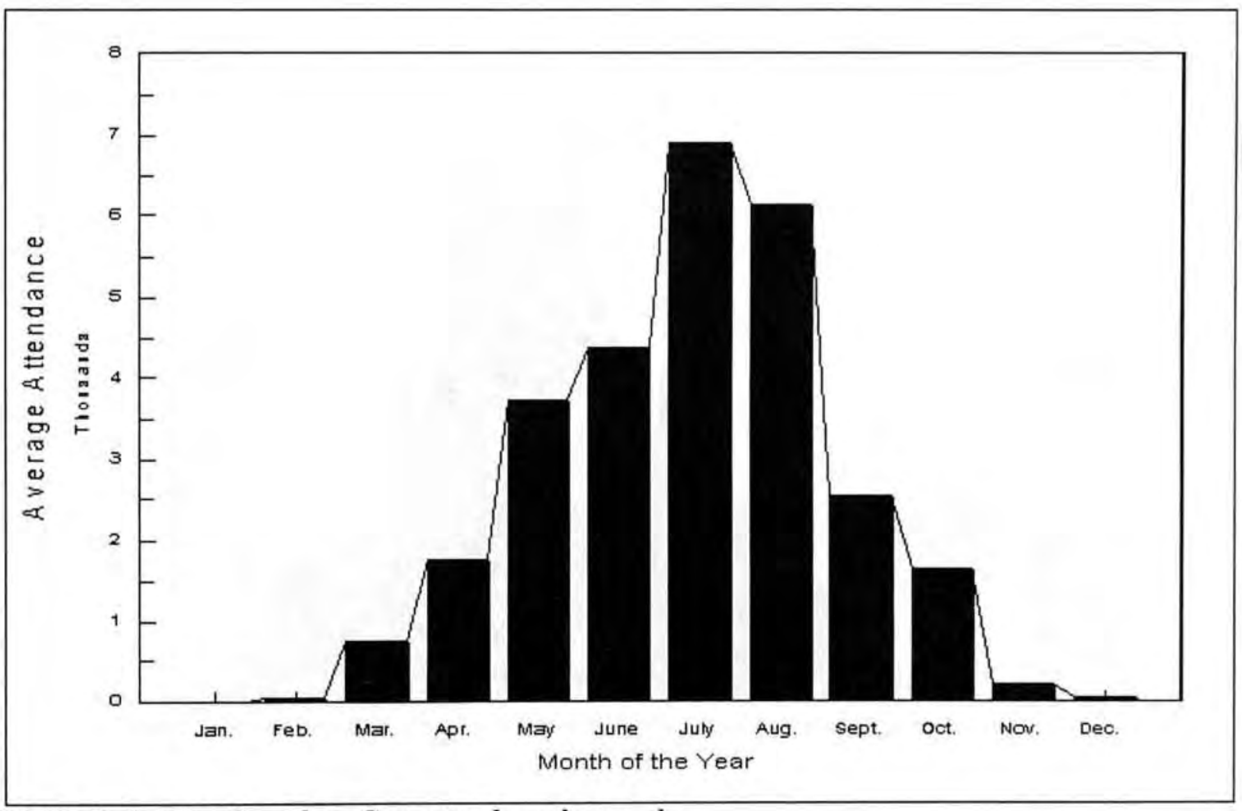

Figure 3. *Average Onondaga Cave attendance by month.*

and trained, are the kinds of information which are needed.

Average monthly attendance for the last 13 years is shown in Figure 3. Although of very broad and general use, this graph does disprove the assumption that the "ON" season begins with Memorial Day and ends Labor Day. The month of May has virtually the same number of visitors as June. This has important management considerations. Students make up the bulk of temporary seasonal (summer) employees; they are often not available during the week until some time after the season actually starts. One way of coping with this has been to use the temporary help on weekends in May and reserve classified employees for the weekdays. By providing a number of surface activities, especially for the groups which come in May, visitors can be kept occupied until guides are available to take them into the cave.

However, some questions about the abruptness of these changes arise. Is July 1 really all that different from June 30? Furthermore, federal labor laws are based upon the work week. Thus, it is useful to go to a greater level of detail and look at weekly attendance, Figure 4.

At this resolution there is a more gentle transition, but some changes are, indeed, abrupt. In addition, the effects of the three big holidays during the "ON" season—Memorial Day, Independence Day, and Labor Day—can be seen. An anomaly in September is due to a special event held in 1986 to celebrate the 100th anniversary of the cave's discovery.

Since everyone cannot work every day and there is some variation in visitation across the week, the visitor use by day of the year was also investigated, Figure 5. This also shows quite clearly the peaks at Memorial Day, Independence Day, Labor Day, and our special event. It also demonstrates the similarity between May and June.

Visitation by day of the year is not as useful as it might at first seem. Jagged as it is, this curve is too smooth. It may adequately represent the yearly cycle but it ignores another simultaneous cycle which is going on.

Besides a repeating yearly cycle of visitation there is also a weekly cycle of visitation and these two effects occur simultaneously in combination. Taken by itself the weekly cycle is shown in Figure 6.

If this weekly cycle is superimposed on the attendance by week of the year a jagged, but very useful, representation of visitation over a typical year results. There is, however, one thing to beware of in using this as a model of visitation: Unlike Memorial Day and Labor Day, Independence Day is not tied to a specific day of the week. Thus, the Independence Day peak has disappeared from Figure 7.

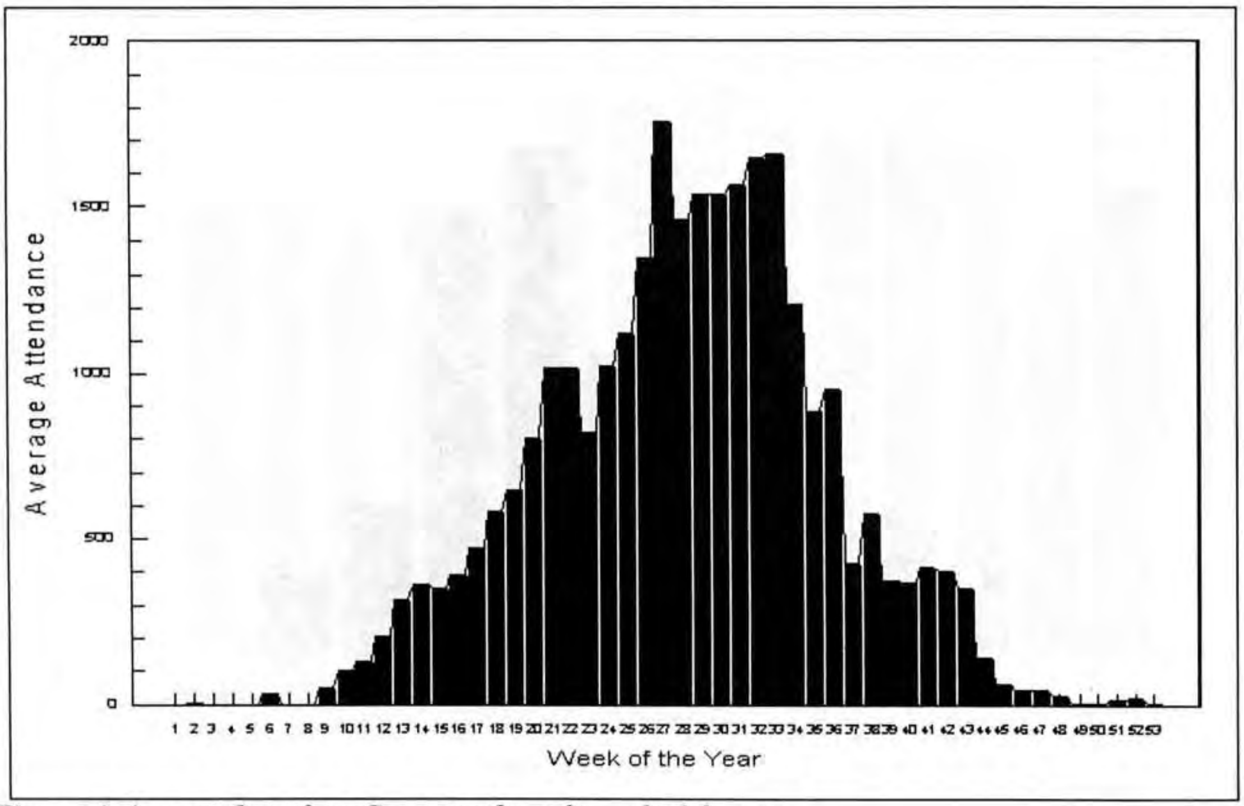

Figure 4. *Average Onondaga Cave attendance by week of the year.*

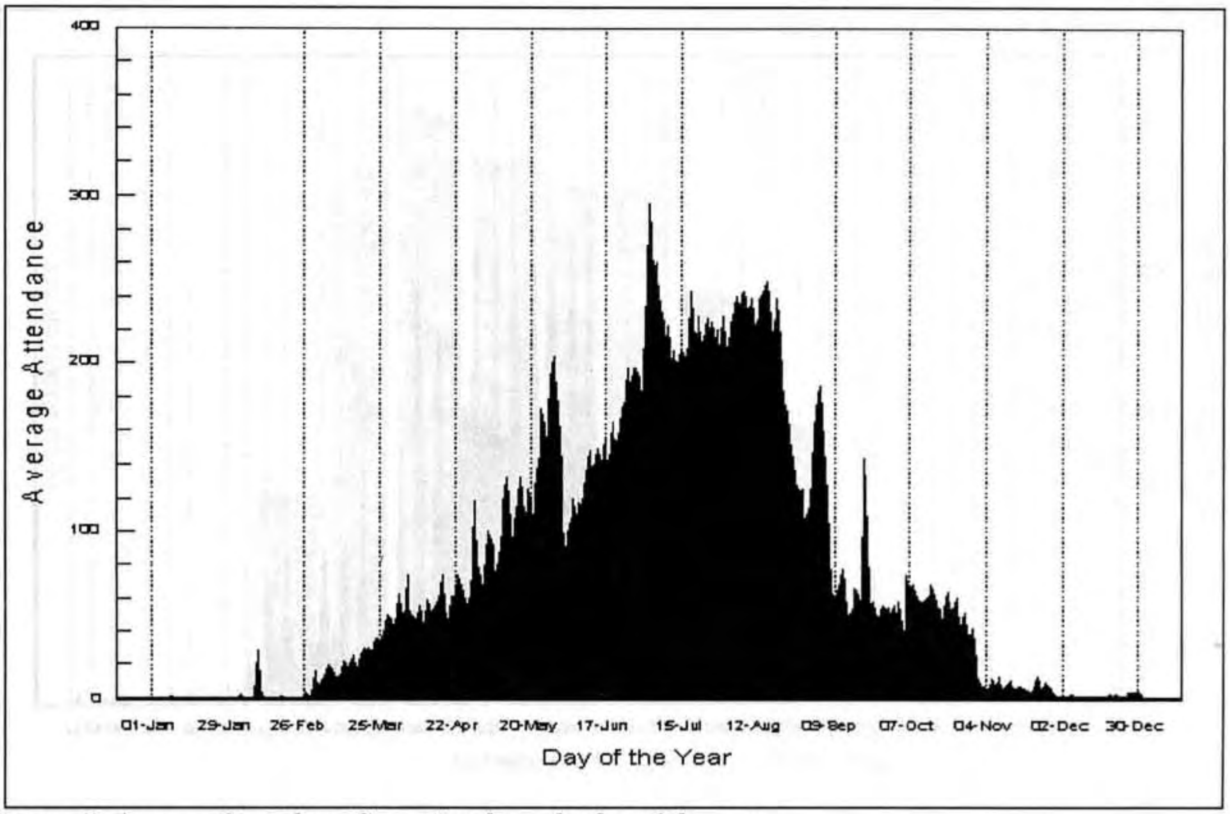

Figure 5. *Average Onondaga Cave attendance by day of the year.*

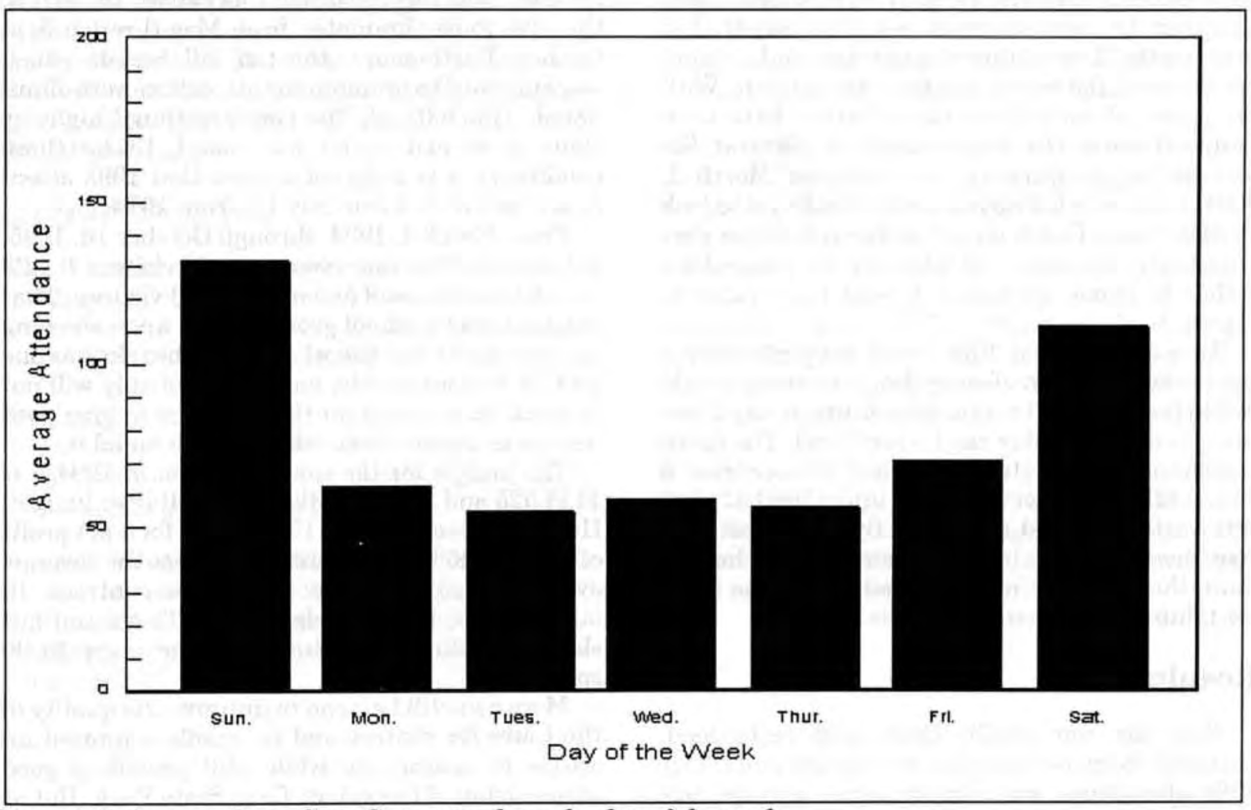

Figure 6. *Average Onondaga Cave attendance by day of the week.*

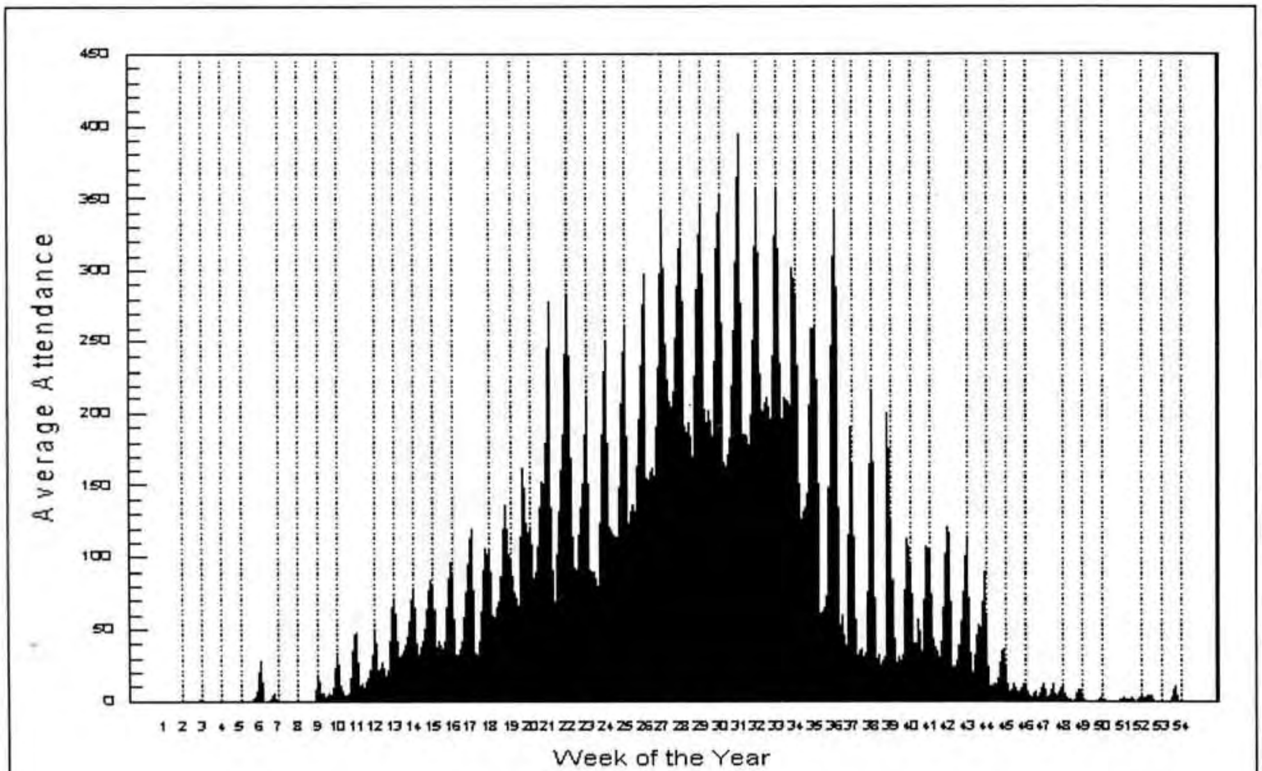

Figure 7. *Weekly cycles of Onondaga Cave attendance through the year.*

There is, of course one other cycle to be superimposed upon this one, the daily cycle of visitor use. However, no concessionaire was ever required to turn in attendance other than by day, and so there are no good figures to predict this pattern. With the power of computers, these figures have been compiled since the Department of Natural Resources began operating the tours on March 1, 1994. Not enough data has accumulated yet to look at each hour of each day of each week of the year separately. However, all days can be lumped together to come up with a typical daily pattern, Figure 8.

By assuming that this day is proportionally a good representation of every day, how many people would be expected to want cave tours at any given time on any given day can be predicted. The mean and standard deviations are used to construct a 95% confidence interval for the upper limit of what this visitor demand might be. By doing this tour size should be regulated and stay below the size limitation. That is: no more than 5% of the tours containing more than 30 visitors.

Results

Thus far, our results have been quite good, although there is still room for improvement. Our 1994 attendance was slightly below average, but up 12% from the concessionaire's last year. There were hopes of reaching our average attendance level in 1995, but repairs to I-44 caused the exit to the cave to be eliminated from May through September. Furthemore, the ten bill boards which were planned to promote the attraction were eliminated. This left only the two directional highway signs at an exit which was closed. Under these conditions, it is a sign of success that 1995 attendance, so far, is down only 1% from 1994.

From March 1, 1994, through October 16, 1995, only 4.76% of the tours went over 30 visitors, 0.12% over 40 visitors, and just one over 50 visitors. That one tour was a school group which, upon showing up, demanded that the whole group be taken as one tour. It was miserable, and they probably will not be back. A lesson from this is never to give poor service to visitors even when they demand it.

The budget for the cave operation in 1994 was $118,525 and spending did go slightly over budget. However, revenue was $175,699.45, for a net profit of $57,174.45 which is more than twice the revenue ever received from the concession contract. In other words, the Onondaga Cave Tours and gift shop are taking in about $1.50 for every $1.00 spent.

More can still be done to improve the quality of the tours for visitors and to handle a limited increase in visitor use while still providing good stewardship of Onondaga Cave State Park. But as much as an understanding of our challenges can

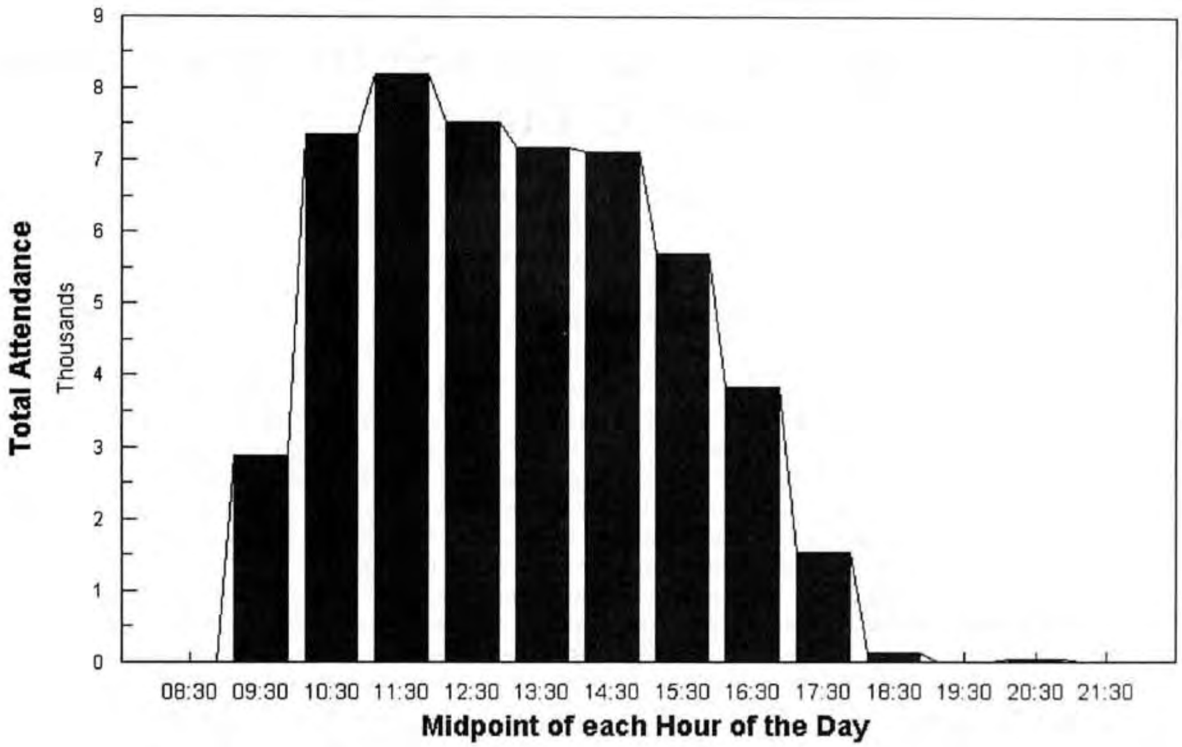

Figure 8. *Onondaga Cave attendance by hour of the day.*

do, the people who implement our plans are the reason for our success, and so I would like to recognize Richard Risor, our cave manager, and his staff for their continuing efforts to maintain quality of interpretation and quality of stewardship of the resource.

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The Missouri Caves and Karst Conservancy—Its Mission and Its Voice, The MCKC Digest

H. Dwight Weaver
Editor
MCKC Digest

Abstract

The Missouri Caves and Karst Conservancy was established to encourage the preservation of all high-value caves in Missouri, to promote good communication between public and private cave owners and the Missouri caving community, to lend cave owners a helping hand in the management of their caves, to foster a sense of resource stewardship within the caving community, to own and manage caves to encourage scientific research, to ensure that the caving community continues to have access to caves, and to benefit the resource.

To accomplish its mission in a state with more than 5,400 recorded caves, the Missouri Caves and Karst Conservancy has begun an inventory of Missouri's most significant caves, adopted an activity plan that focuses on member involvement and cave owner/manager needs, and created a quarterly magazine called the *MCKC Digest.* The magazine is designed to provide timely and educational information about Missouri caves, to serve as a public forum for cave management topics, and to network with all public and private entities in the state that own and manage caves.

The Missouri Caves and Karst Conservancy is the newest initiative of the Missouri Speleological Survey. The Survey was established in 1956. Its mission is to locate, record, explore, study, and conserve the caves of Missouri and to disseminate knowledge about Missouri caves. The Survey's Board of Directors is composed of representatives from affiliate Missouri caving organizations. Most are grottos of the National Speleological Society.

The success of the Missouri Speleological Survey in accomplishing its mission through four decades can be easily measured by the growth and comprehensive nature of its master cave files. The cave files began in 1963 as eight, three-ring binders containing very little information on 437 recorded caves. Today, the master cave files fill 14 legal-size, five-drawer filing cabinets that store information on nearly 5,500 recorded caves in Missouri. Map cabinets hold nearly 2,500 cave maps. Every kind of document imaginable from cave notes on scraps of paper to photographs, news clippings, and scientific reports can be found in the master cave files. The size of the files illustrate how well the survey has accomplished its mission to locate, record, and study Missouri caves.

The Missouri Speleological Survey has also published a monthly newsletter, *Liaison*, and a quarterly journal, *Missouri Speleology*, for more than 30 years. In this way the Survey has disseminated knowledge about Missouri caves.

These accomplishments also demonstrate the commitment of Missouri cavers to the Survey's mission. While the basic mission of the Missouri Speleological Survey is not apt to change in the foreseeable future, there are new initiatives by affiliates that reflect changing times.

Several years ago some members of one of the Survey's long-time affiliate groups, Lake Ozark Grotto, decided while the Missouri Speleological Survey was doing an excellent job in accomplishing its original mission, it wasn't making a conscientious effort to manage the resource itself. Seasoned members of Lake Ozark Grotto felt that the Survey was not doing enough to educate public and private cave owners about the value of their caves; not providing enough technical assistance; and not making an effort to acquire significant caves for management, access, and protection purposes.

When the Missouri Speleological Survey was established, most caves in the Missouri were privately owned by non-corporate, non-government land owners, most of whom were farmers. Today, an estimated 20 percent of all caves in the state are owned or managed by federal and state agencies or other government entities. A substantial majority of the remaining 80 percent are owned by people who do not farm the land upon which they live.

By contrast, you can count on one hand the number of Missouri caves managed by individual cavers or groups of Missouri cavers, and no Missouri cave is owned by the Missouri Speleological Survey or one of its affiliates. One would assume that if any organized groups within the state had good reasons for owning and managing caves, it would be organized cavers.

Forty years ago the only types of people with a desire to know about Missouri caves were show cave operators, academics studying cave life and cave origins, and spelunkers. Today, thousands of caves belong to people and corporate entities who really need to learn about the resource but who have no expertise in cave management, no management plan for their cave, little or no desire to explore the caves they own, and not even the foggiest notion of the natural value of the caves they possess. Is it any wonder then why nearly every endeavor of mankind and every kind of development that comes along seems to take precedence over the protection and preservation of caves?

In 1993, Lake Ozark Grotto led the effort to establish the Missouri Caves and Karst Conservancy arm of the Missouri Speleological Survey. The Missouri Caves and Karst Conservancy is administered by a self-electing Board of Directors separate from the representative Board that governs the Missouri Speleological Survey. The Survey Board does have approval over individuals nominated to the Missouri Caves and Karst Conservancy Board and the Survey is seated on the Conservancy Board.

The purposes of the Missouri Caves and Karst Conservancy are to:

- encourage the protection of all high value caves in the state,
- promote good communication between public and private cave owners and the Missouri caving community,
- lend cave owners a helping hand in the management of their caves,
- foster a sense of resource stewardship within the caving community, and
- own and manage caves to encourage scientific research and ensure that the caving community continues to have access to caves.

Goals require tools—a means to accomplish purpose. The first goal of the Missouri Caves and Karst Conservancy mentioned was the protection of all high-value caves in the state. But how can high-value caves be preserved if there are no established yardsticks for measuring cave value and no existing list of significant caves?

To maximize protection for caves when you have only a limited amount of money and manpower, you need certain basic information about the caves. You need to know which ones are the most significant in terms of recognized cave values. You need to know which of the significant caves are the most threatened or in need of some kind of remedial action or management effort.

All caves are significant to one degree or another but no organization can afford to spend the same amount of time, effort, and money to keep every cave pristine and out of the reach of harm. This is especially true when the number of existing caves totals in the thousands and the number of people willing to spend their own precious time and hard-earned money in the effort to protect caves is very insignificant. Some caves—by virtue of the quality of their archaeological, biological, commercial, geological, historical or paleontological values—are considered more significant than others.

The members of the Missouri Caves and Karst Conservancy are in the process of developing and will soon implement an inventory of the significant caves of Missouri. The inventory will identify those caves that are most significant in various value categories on a subjective scale of 1 to 10, ten being the rating of highest value. This will permit the Conservancy to focus its greatest effort on those caves that most people in the caving community consider to be of the greatest identified value, caves with ratings between 5 and 10. But this does not mean that the Missouri Caves and Karst Conservancy cannot nor will not respond in any way when it sees that a cave of lesser value needs attention.

The mechanism that will drive the inventory is called the Great Caves Challenge. It will have built-in incentives to encourage cavers to participate. With nearly 5,500 caves scattered across 80 of Missouri's 114 counties, caves are at risk from, among other things:

- highway construction,
- oil and product pipelines ruptures,
- hazardous substance spills,
- industrial development,
- residential expansion,
- non-point-source pollution,
- vandalism, and
- over use.

It is important that potential threats to the most significant caves be identified as early as possible. Sponsoring the development of watershed maps and environmental-risk maps and studies for significant caves is a project that will give the Missouri Caves and Karst Conservancy valuable tools for both proactive and reactive efforts.

The Conservancy is very much about providing cave owners and managers with volunteer management help and technical assistance. This will materialize in a variety of ways in the years ahead. The Conservancy is planning to development a variety of cave owner assistance programs and educational tools. These include:

- printed educational materials as well as educational slide and video presentations;
- cave stream-teams;
- cave management plans;
- cave gating, monitoring, and clean-up programs;
- educational cave signage;
- cave visitor liability forms, report forms and caver log books for cave owners to use to monitor their cave traffic and foster a sense of stewardship among their cave's visitors; and
- a cave owner's handbook with text that is linked to topic-specific technical assistance primers and reports.

The operative words are "partnership agreements," especially with government agencies who own and manage cave resources. In Missouri, budgetary constraints have robbed some government agencies of the funds and staff they need to manage their caves properly.

The Missouri Caves and Karst Conservancy also hopes to acquire caves through purchase, lease, donation, and bequests for protection and management purposes. Once a cave has been acquired, a management plan will be developed and a cave management team composed of cavers, preferably local cavers, will be established to implement the management plan. Eventually, the Conservancy hopes to have training programs and workshops available to teach cavers and others how to manage caves.

From its inception, the Missouri Caves and Karst Conservancy recognized the need for a high-quality quarterly magazine designed to promote its mission, programs, successes and needs, as well as the need for a publication that would network with all public and private entities throughout the state that own and manage caves. This need gave birth to the *MCKC Digest.*

Missouri has had three types of cave-oriented periodicals over the years—newsletters published by Missouri caving groups; *Missouri Speleology*; and *Liaison,* published by the Missouri Speleological Survey. *Liaison* carries brief reports of the activities of Missouri Speleological Survey affiliate groups, announcements, and actions of the Survey Board. *Missouri Speleology* is a technical journal which publishes research papers, cave maps, and cave descriptions. These publications are produced largely by cavers for cavers, which is clearly recognizable in their style and content.

Since the Missouri Caves and Karst Conservancy needs to target cave owners and managers who are not active members of the caving community, and in particular professionals who are employed by federal and state agencies, it was necessary to create a new kind of publication. What evolved is the *MCKC Digest.* The most professional volunteer staff possible has been assembled for its production. Every effort is made to make it reflect the expertise of its staff because accuracy, good design, good writing, professional editing, and quality production are considered important to credibility and reader appeal. Extra effort is made to make the magazine interesting, informative, and as non-technical as possible. Effort is also expended to make it dependable so that it comes out on time every time, not months behind schedule. So far the staff has performed these tasks exceptionally well and they take pride in every issue that appears. Hopefully, this level of competence will continue well into the future. The content of the *Digest* is carefully constructed with the long-range goals and the mission of the Conservancy in mind.

To educate readers about cave value so they will be better able to help the Conservancy create an inventory of significant caves, there is an ongoing feature often referred to as the "cave value recognition series." The experts are teaching our readers and members how to evaluate caves and determine their archaeological, biological, geological, commercial, historical, and paleontological value. When the series is complete, the Missouri Caves and Karst Conservancy will be able to excerpt the segments and package them as a separate publication for use as an educational handbook.

Missouri cavers and grottos are being encouraged to sponsor subscriptions to the *Digest* for private cave owners. To enhance relations with private cave owners, the *Digest* is profiling private owners and their caves. There are hostile cave owners out there, but there are also owners who take pride in cave ownership and who go out of their way to work with cavers and to manage their resource the best way they know how.

The *Digest* is also recognizing the skills and hard work done by resource managers who are employed by federal and state agencies—men and women who seldom get recognition from the caving community, and who often get little recognition from their own employers.

To teach cavers how to restore caves that have been damaged and vandalized, the *Digest* has a department called "Speleotech." To discuss subjects related to geology, it has a department called "Geotalk." There is a section exclusively for showcaves and the *Digest* will soon begin a department called "Showtech," which will focus on the development, maintenance, and promotion of show caves, as well as techniques of presentation and interpretation. The *Digest* also has a section called "In the Public Domain" where caves and cave management on public lands are highlighted.

The *Digest*, its readers, and the Missouri Caves and Karst Conservancy are now benefitting from input from government agencies that own and manage caves in Missouri. These include the Missouri Department of Natural Resources, the Missouri Department of Conservation, the USDA Forest Service, and the National Park Service.

The Conservancy has accepted an enormous challenge. It will be years before the measure of its success can be taken. But if the accomplishments of its associate organization—the Missouri Speleological Survey—are a good yardsticks for measuring success, then the Missouri Caves and Karst Conservancy can look forward to a bright and productive future.

Proven Techniques for Repairing Formations

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Abstract

It is timely to produce a handbook of proven techniques for formation repair and cave restoration. This paper presents speleothem repair techniques. Topics include environmentally-safe materials and longevity. The goal is to initiate a forum for gathering procedures that have been successfully implemented in cave environments. Information exchange will become the catalyst for a collection of cave restoration data.

Increased human impact on caves is resulting in the need for more frequent repair of formations. This paper suggests ways to repair formations and the materials and equipment needed to facilitate repairs.

As with any project of this kind, it is necessary to consider the environmental impact of the materials being used and the safety of the people doing the work. Before using epoxies, hardeners, cyanoacrylates, solvents, or metal fixtures, it is important to obtain data sheets from the manufacturer detailing the chemical properties of the materials. Material Safety Data Sheets are often available that discuss any hazards connected with the materials. It is also advisable to consult with a biologist or geologist to ascertain the effect of the material on the cave environment. Failure to do so could result in considerable damage or introduction of toxins to the cave environment.

The following materials have been most effective for repairing cave formations:

Epon Resin 828® combined with Versamid 40® curing agent works in dry environments. When combined with Versamid 28® curing agent, Epon Resin 828 can also be used for wet applications. These adhesives develop a strong bond with a shear strength of up to 6,000 psi. Shrinkage is minimal and the bond is resistant to a broad range of chemicals. Epon 828 with Versamid 25® curing agent can be used to bond formations under water.

Fast-setting cyanoacrylate adhesives such as Special "T" that have a setting time of 50 to 60 seconds can be accelerated with Kick-It®. These adhesives are useful for repairing small formations such as soda straws, helectites, and thin draperies. They can also be used for repairing stalactites up to two inches in diameter by carefully applying a small amount of the instant adhesive in the center and a ring of Epon epoxy around the outer edge.

Metals that have worked best in the cave environment are stainless steels, particularly Types 304 and 316, which are both highly resistant to corrosion. These may be purchased in round stock and cut to the length of pin required.

Stalactite Repair

First, install the pin in the upper section by drilling a hole the same size as the pin and epoxying the pin in place. Then drill a slightly oversized hole in the lower section to allow for alignment of the formation and the pin. Fill the hole with epoxy and join the lower section to the upper section using wire, as shown in the drawing, inserted through the horizontal holes to hold the formation in place while the adhesive dries.

Allow the Epon 828 epoxy to set for at least 24 hours. Then remove the wire and fill the small holes with epoxy and ground-up material of the same type and color as the speleothem being repaired. The best source of ground-up material is the powder that results from drilling the hole for the stainless steel pin. The dust can be retained in a plastic bag and applied after the epoxy dries. The same mixture can be used to fill any voids in the fracture area.

Hold the formation in place with wire until the epoxy has set. Afterward, remove the wire and fill the holes. In the event that the formation section is too thick to drill holes for wires, one should drill the holes for pins as shown in the drawing for the alternate method of repair. Wire the pins together on the outside to hold the formation in place.

Stalagmite Repair

Drill a larger hole in the lower section of stalagmites to allow for misalignment. It is important to epoxy the pin into the upper section first. After aligning, fill the hole in the lower section with epoxy and attach the upper section to the lower section. Be sure to check the alignment prior to filling the large hole with epoxy.

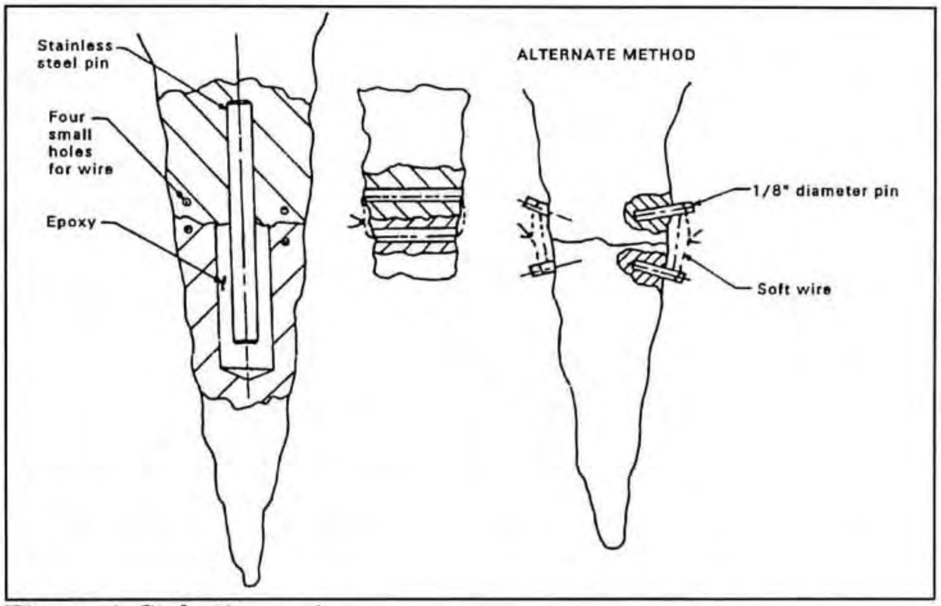

Figure 1. *Stalactite repair.*

Drapery Repair

Draperies can be repaired by applying instant adhesive to thin sections or by applying pins and epoxy, much the same as for stalactites.

Drapery pieces should be gathered and pieced together like a puzzle before beginning the repair. A flat, dry surface is useful. Fast-drying Super "T" on one edge with Kick-It sprayed on the matching edge works if the pieces match exactly. For alignment, mark each matching edge with a felt marker, making only a small tick across the fracture. This mark will aid in quickly fitting the edges after applying the fast-dry adhesive.

After the epoxy sets, the drapery section can be reattached. Small holes can be drilled and the pieces can be epoxied and wired together for drying.

Rimstone Dams

(Method developed by Jerry Trout.) Rimstone dams can be rebuilt using Quick-Patch cement mixed to a workable consistency. Using hands and a brush to add texture, shape the cement as required to fill in missing pieces. To speed up the curing process, add lime. If coloring is added, it is best to match the color outside in the daylight. It is very difficult to match color with only your cave light. Be sure to wear rubber gloves when working with cement. Also, be certain that coloring agents contain no toxic chemicals.

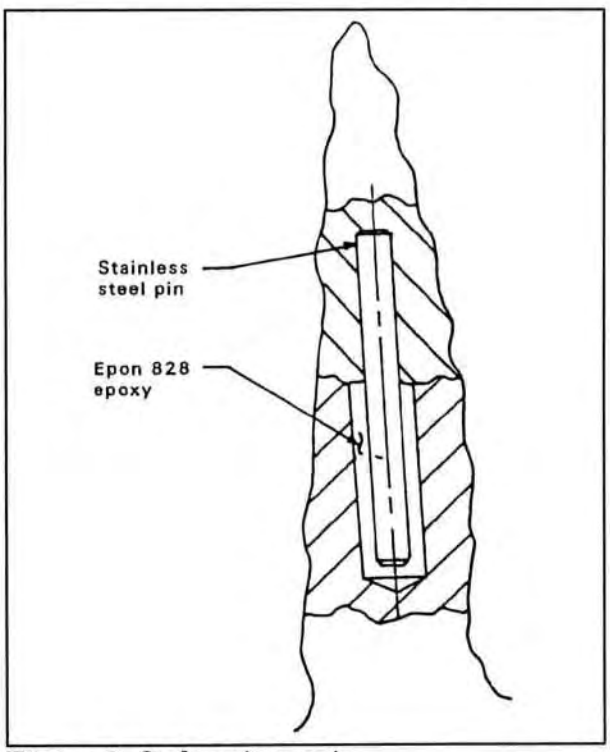

Figure 2. *Stalagmite reapir.*

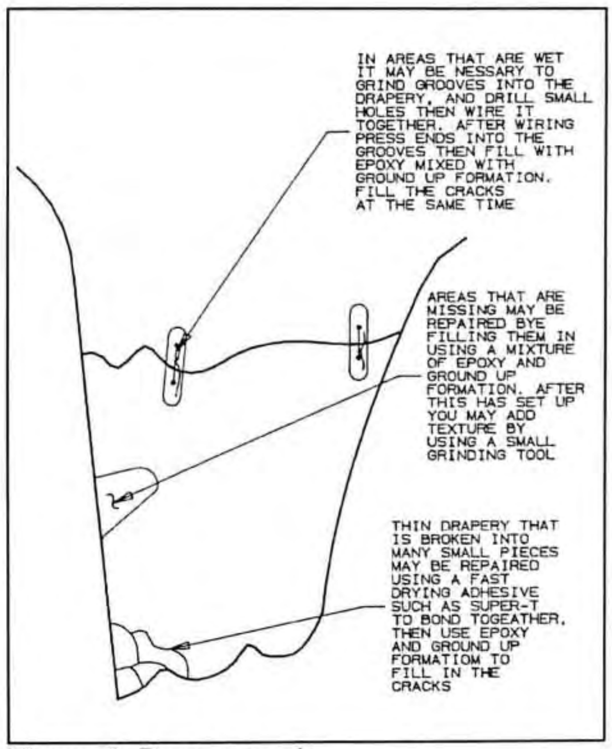

Figure 3. *Drapery reapir.*

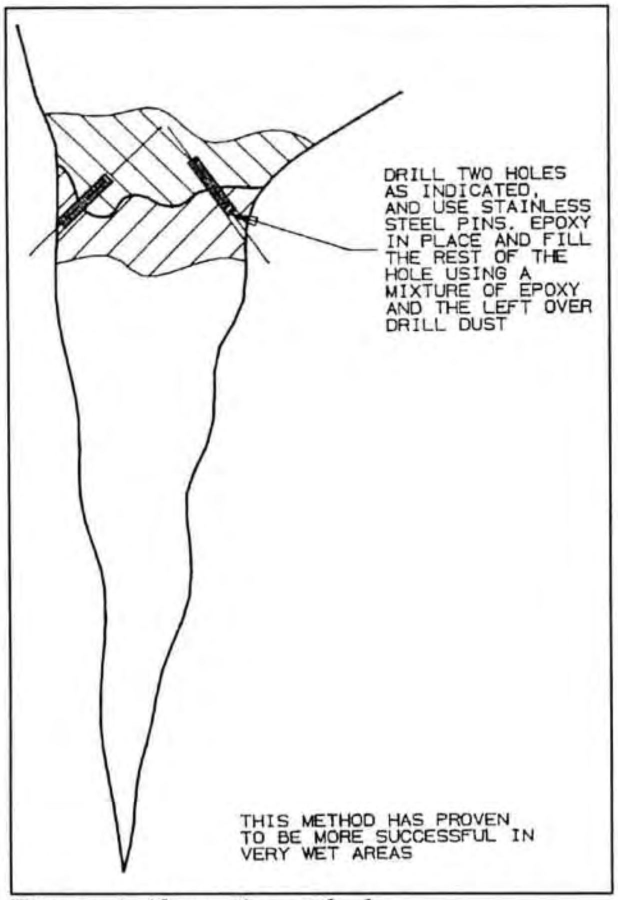

Figure 4. *Alternative method.*

Repair Notes

For drilling holes, a small, battery-powered drill and metal bits are sufficient for little formations up to four inches in diameter. For larger formations, a Hilti battery-driven hammer drill is capable of drilling much larger holes to greater depth. Caution is essential, as it is very easy to shatter the formation.

To obtain the approximate location of the holes on both the upper and lower portions of a formation, drill a hole in the center of one section. Cut off a small chunk of felt marking pen. Place the inked felt chunk at the drilling site on one section and fit to the second section of formation. The resulting marks will provide guides for your drill. Again, be sure to fit the pieces together and check alignment before applying epoxy. After the hole is drilled, canned air with a nozzle is useful for blowing dust out of the hole.

In dry caves, fracture sites on repaired formations can be filled with a mixture of epoxy and drilling dust. If repairs are done in a part of the cave that is still active, it is not necessary to fill small voids or fractures with epoxy, as nature will most likely take its course and cover them with new calcite deposits.

Author's note: If I can be of further assistance, or if anyone has any new methods, materials, or techniques, please contact me. I would like to thank Jerry Trout for the information on rimstone dams, and Linda Doran for help in preparing this paper.

New Improved System for Photomonitoring

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Abstract

A faster, easier photomonitoring system has been developed. It offers more accuracy and repeatability, streamlines labor and tedium, and reduces cave impact. This new photomonitoring system has been installed in Carlsbad Caverns National Park, Bureau of Land Management caves in New Mexico, and Forest Service caves in New Mexico and Arizona. This paper presents the efficient, unobtrusive, permanent system and compares the new technique with traditional methods. Discussion includes speleothems and impact areas that should be photographically monitored, recommended equipment for repeatability, and procedures for minimizing cave impact.

A faster, easier photomonitoring system has been developed. Installed in Carlsbad Caverns and in several New Mexico and Arizona caves, this system is designed to create less impact, consume less time, and provide more consistent photos. This new approach is streamlining the tedium and hassles of traditional methods. The new photomomitoring installations offer more accuracy and repeatability, minimize labor and tedium, and reduce cave impact. This permanent photomonitoring system offers years of efficiency, longevity, and redundancy.

Historically, photomonitoring has involved laborious and repetitious use of tripods, levels, plumb lines, measurements, compass readings, and camera settings, often yielding inaccurate results and increased impact to cave resources. Contemporary technology reinforces the need for faster, more consistent photographic documentation. With current advances in computer imaging, advanced systems will easily convert information from visual images to data for graphs and statistics. New avenues will open for research as well as resource management. Installation of permanent photo stations makes possible the accurate alignment, angle, and focal distance of each photograph every time it is shot.

Permanent stations, which accept a special camera mount, make possible the same exact photograph on subsequent shooting sessions. Time-based data can be accurately recorded. Photo-documentation projects provide visual tools for cave management. Trails, geologic features, formations, human impact, environmental change, and pristine areas can be more accurately monitored. Changes in cave environments, water levels and conditions, trail maintenance or damage, restoration projects, growth and decline of speleothems, and other visual data can be photographically recorded to provide monitoring data.

The photomonitoring system was designed by the authors. The concept of installing permanent systems for photomonitoring first came to Val, a professional photographer and multimedia producer, when she became involved in the tedium and repeated cave impact inherent in classic photomonitoring techniques. Jim, applying his years of experience in design, tooling, and engineering, and his interest in cave conservation and formation repair, designed and built the prototype. Together, they worked to develop the complete system, from installation through archiving, and implemented permanent photomonitoring in several caves of the southwestern United States. A patent is pending.

Photo stations are placed in cave floors, ceilings, and walls. A hole is drilled to accept a stainless steel sleeve. Using a Hilti battery-powered drill, one hole per station is placed to accept the stainless sleeves. The sleeves are machined for proper fit of the monorod. After alignment and positioning of the sleeve, monorod, and camera, each point is epoxied in place using Epon Resin 828® mixed with Versamid 40® Hardener. Both products are manufactured by Shell. Research and experience during the past eight years support the safety and stability of these products in cave environments.

Photo points are allowed at least 24 hours to set up. After the epoxy sets, photographs are made. The system is designed for use with the Pentax IQ Zoom camera series. The IQ Zoom was chosen for its adequate lens quality, flash characteristics, bulb setting, and mounting position. Additional flash is provided with slave units on Vivitar 285/385 and Metz 45CT series flashes. For each photo, one flash is held at arm's length to one side of the camera while the second flash is positioned to show in the image area, thus facilitating the repeatability of the photo. The system can be adapted to other equipment.

Integral to the photomonitoring system is the specially-designed monorod. The camera is mounted on the stainless steel monorod which is inserted in the sleeve at each photo station. The monorod is small enough to carry through the cave in a fanny pack, eliminating the potential impact of bulky equipment.

Stations are covered with numbered nylon caps that are unobtrusive to the casual observer. Locations are provided on maps and are surveyed into existing points when feasible. Photographic prints are made of each location with the monorod, camera, and flashes in place to help document the locations of stations. Detailed notes, photo prints, and maps are included in the final archival slide books.

This photomonitoring system is not limited to cave environments. It can be installed to monitor hiking trails, sea walls, waterways, and other environmental assessments.

Photographic documentation can tell a story. Photomonitoring can tell a series of stories enhanced by a visual display of time and change. Through the aid of permanent photomonitoring installations, pictures from different photo sessions can be identical. Improved data will be recorded and archived for future analysis. Photographs will be easily compared on a light table or projectors. Multi-image dissolves will dynamically display differences and change. The slides will provide data for computerized comparison through advanced digital technology.

Information sequences can be revealed through visual documentation. Data collected through scheduled photomonitoring can enhance management of cave resources. Visual inspection can quickly reveal time-based information for monitoring changes, growth, and impact. Documentation through accurate photomonitoring can provide easily-accessible tools for management and protection of unique, irreplaceable, non-renewable, fragile cave resources.

There will be no further need to reestablish points with tripods, levels, tape measures, or plumb bobs each time a photograph is made. The point is established once and remains in place waiting for the next photo session. After painstakingly establishing a point the first time, each subsequent photo is easily repeated. Simply mount the camera on the monorod, place the entire assembly into the permanent photo point and expose the film. Photo monitoring is now easier, faster, more consistent, more accurate, and perpetually repeatable. Make the same photo today, tomorrow, next year, or 50 years from now.

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