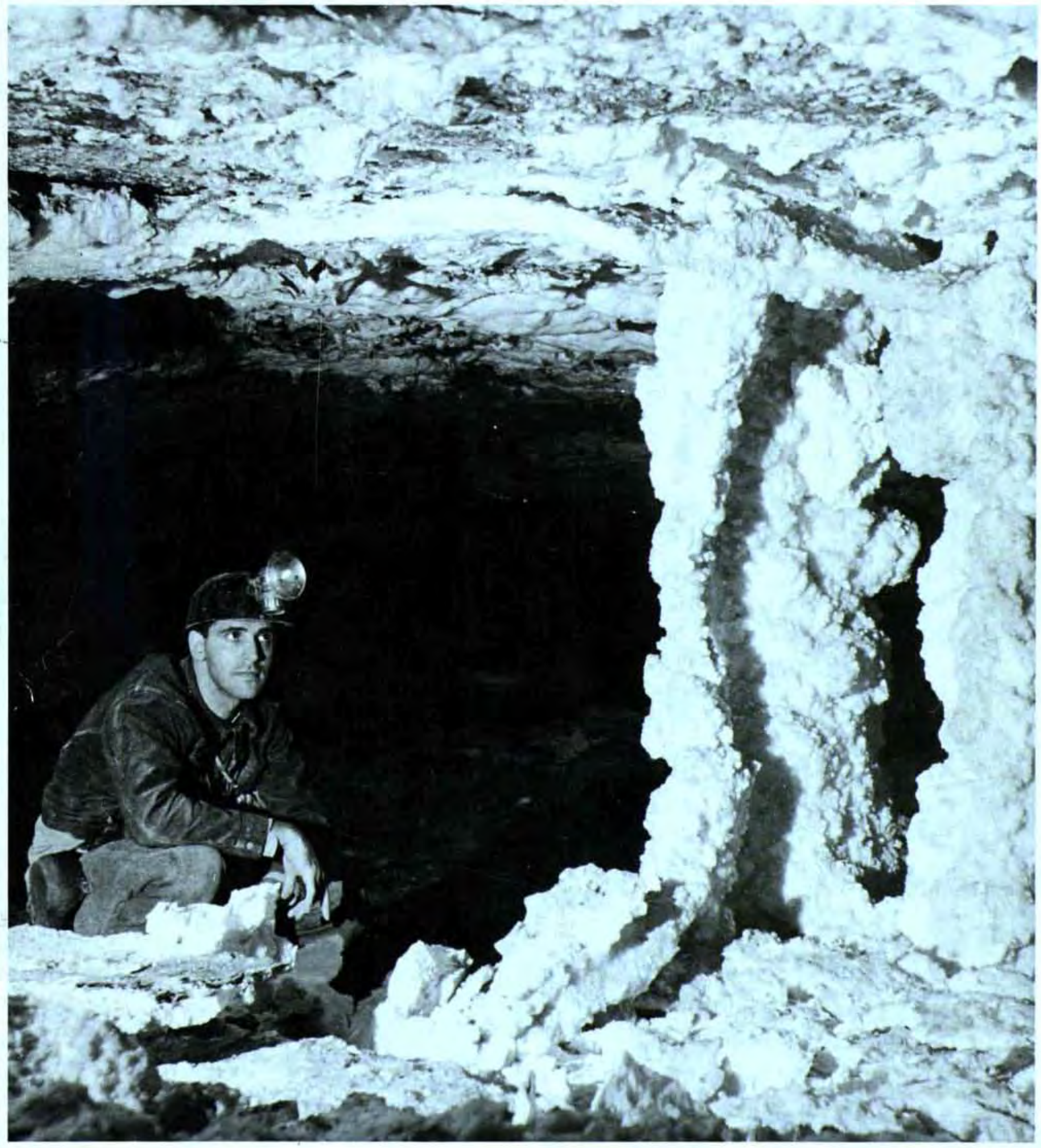
Proceedings of the

National Cave Management Symposium



October 23-26, 1991

Bowling Green, Kentucky

1991
National Cave Management Symposium Proceedings

Bowling Green, Kentucky
October 23 - 26, 1991

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American Cave Conservation Association

Mammoth Cave National Park

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David G. Foster and Ronal C. Kerbo

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Table of Contents

NATIONAL CAVE MANAGEMENT SYMPOSIUM WELCOMING SPEECH

Janet B. Thorne
National Cave Management Symposium/National Speleological Society Liaison

Good morning. I'm pleased to see that so many people were able to come here this morning for the kick-off session of the 1991 National Cave Management Symposium. The organizers must know that I arrived late last night and may have scheduled me to start off this Symposium to make sure that I got here on time.

My name is Janet Thorne, and I am a member of the National Speleological Society, one of the co-sponsors of the Symposium.

I'm curious, how many of you have been to one of the National Cave Management Symposiums before? Would you raise your hand? [Approximately one-third raised their hand -- Editor] Thank you.

Well, those of you who have been to a Symposium before probably have not yet noticed it, but there has been a change of significant proportions made between the last Symposium in 1989 and this one.

The first National Cave Management Symposium took place in Albuquerque, New Mexico, in 1975, and similar conferences have been held at a rate of every two years since then. The process by which a Symposium occurred was extremely informal. At a Symposium someone would volunteer (often because their arms had been twisted!) to organize the next Symposium. The people present who cared about such things would say, "Yeah, do it!", and that pretty much would be the end of it. The person who had taken on the job often ran around trying to get together a group or organization willing to take on the responsibility for the Symposium and to find some friends who could be convinced to help out with the work. They had to scramble to find some "front money" to cover any bills which couldn't be postponed until after registration fees started to come in. They had no mailing list of people who might be interested in attending, no guidance on what the Symposium should accomplish, and often very little idea of how a Symposium should be structured.

Despite the lack of over-all coordination, past Symposia in general have been quite successful. This has been due in no small part to the fact that a number of government agencies and private organizations concerned with caves have recognized the value of participation in a conference like this, focused as it is exclusively on cave management.

The first Symposium in 1975 was the result of participation and support by the National Speleological Society, the National Park Service, the Bureau of Land Management, the U.S. Forest Service, and the Cave Research Foundation. Over the years those organizations have continued their strong support, and they have been joined by a number of other groups.

This past spring several of the organizations which have been involved with past National Cave Management Symposia met to discuss the current status and future goals of the NCMS. The representatives at that meeting decided that it was time for there to be a greater degree of structure to the Symposia so that they could be more responsive to the needs of participants in the future.

Consequently, the participating organizations have created a Steering Committee for the NCMS, and that Committee held its organizational meeting this summer at the NSS Convention. Each organization has one representative on the Committee, and as I name for you each organization which is involved, I would like to have the person who represents that group stand so that you will know who to ask if you have any questions later about this new structure.

The Federal government agencies which initially are participating on the Committee are the Bureau of Land Management, represented by Del Price; the Forest Service, Susan Rutherford; the Fish and Wildlife Service, Joe Murphy; and the National Park Service, Ron Kerbo. From the private sector the organizations which are members of the Committee are The Nature Conservancy, Geoff Roach; the American Cave Conservation Association, Dave Foster; the Cave Research Foundation, Jim Borden; the National Caves Association, Gordon Smith; and, of course, the National Speleological Society, which I represent.

The Steering Committee members have decided that the person who is the representative to the Committee from the NSS also will serve as the Coordinator for the Committee. That is the reason I had to get up early this morning to make these comments!

I don't want to take up much more time, but I do think it important that I touch very briefly on the reasons the participating organizations have taken the step of forming a Steering Committee.

We see many advantages. For example, the Committee will ensure that there is consistent, year-after-year, support for the Symposia from a variety of organizations concerned about caves. The Symposia hosts of the future will have the encouragement and combined resources of the participating organizations behind them as they arrange for facilities, search for speakers, and solicit attendance.

The variety of representation on the Committee is expected to ensure that we continue to meet the original goal of the symposia, which was for it to be a forum at which people from many different backgrounds, but with a common interest in some aspect relating to caves, all meet in one place to exchange ideas, to develop working relationships, and to identify our common goals. Cave owners, cave managers, and cavers all will benefit by talking and gaining a better understanding of each other's interests and attitudes.

Representatives of the various organizations on the Committee are expected to help future Symposia hosts in identifying current cave management issues of special interest to their own members or staffs and in finding appropriate speakers to address those issues.

Also, frankly, the Committee will be a mechanism by which Symposia participants and the concerned organizations can be assured that there exist mechanisms for fiscal accountability and responsibility. We want to try to ensure that the hosts of future Symposia are able to start off with seed money to cover advance financial commitments, and that the hosting organizations do not face a disproportionate financial loss if attendance is unexpectedly light.

These, briefly, are some of the reasons the NCMS Steering Committee was created. I am sure that some of you have questions, and perhaps we can take a couple, but we have a busy schedule today, and we should try to move on to the excellent lineup of speakers and papers which have been arranged for us. Certainly there will be many opportunities over the next few days for me or the other organization representatives to answer any questions you may have. I do want. to ask that, as you participate in the activities of the next few days, you let me or one of the other members of the Steering Committee know of any suggestions you have on ways in which the Symposia can be improved.

One of our goals is to make these meeting responsive to your needs and those of your colleagues, and you can help us a great deal if you give us your ideas.

Does anyone have any question which should be addressed now?

Thank you for coming, and I now would like to introduce to you Dave Foster, Executive Director of the American Cave Conservation Association, who has been carrying the responsibility for all the planning which has gone into this Symposium.

OPENING REMARKS FROM THE CHAIRMAN

David G. Foster
Executive Director
American Cave Conservation Association

It is my pleasure to welcome you to Kentucky for the 1991 National Cave Management Symposium. Cave management in Kentucky involves many challenges. Approximately 40% of the State of Kentucky is underlain by karst. There are approximately 2500 known caves in Kentucky. The Mammoth Cave system is over 300 miles long, more than twice the length of its nearest competitor.

The protection of the world class cave resources of Kentucky presents a variety of problems for the cave manager to overcome. Parts of Mammoth Cave and much of its drainage basin, for instance, extend far beyond the national park boundaries. Development of both urban and rural areas in the Mammoth Cave region threatens the water quality of Mammoth Cave and many other long cave systems in Kentucky.

The National Cave Management Symposium is essentially a networking conference for people who study and who care about caves. We hope that by examining the land use mistakes made in the Mammoth Cave region, you will be better able to prevent similar problems in other parts of the United States. We have brought together a diverse group of scientists, researchers and managers to facilitate the exchange of ideas and concepts in order to promote the development of good cave management policies and the protection of cave resources.

On behalf of all those who helped put this symposium together, I welcome you to the 1991 National Cave Management Symposium. Thanks for joining us!

THE NATIONAL CAVE MANAGEMENT SYMPOSIUM STEERING COMMITTEE

American Cave Conservation Association, David G. Foster
Bureau of Land Management, Del Price
Cave Research Foundation, James D. Borden
National Caves Association, Gordon L. Smith, Jr.
National Park Service, Ronal Kerbo
National Speleological Society, Janet B. Thorne, NSS/NCMA Liasion
The Nature Conservancy, Geoff Roach
U.S. Fish & Wildlife Service, Jim Palmer
U.S. Forest Service, Brent Botts

The Steering Committee wishes to acknowledge and thank those who contributed to the planning for this year's symposium, including the field trip leaders, speakers, and others, who assisted with various conference arrangements.

THE IMPORTANCE OF PARTNERSHIPS IN RESOURCES CONSERVATION

Jeff Bradybaugh
Science and Resources Management Division
Mammoth Cave National Park

First, I would like to welcome you to south-central Kentucky, and its areas of classic karst terrane containing numerous caves including Mammoth Cave. We at the park are excited to be co-hosting the National Cave Management Symposium with the American Cave Conservation Association, because 1991 marks the 50th Anniversary of the establishment of Mammoth Cave National Park, and the 75th Anniversary of the creation of the National Park Service. I would also like to recognize that our sister agency, the United States Forest Service is celebrating its 100th Anniversary this year.

Mammoth Cave National Park is located in an internationally important karst area, containing a splendid diversity of geologic, biological and cultural resources. The Mammoth Cave System is the longest in the world, extending well over 300 miles, and contains most types of limestone cave formations. Of the 200 species of cave fauna found here, 12 are found nowhere else. Many of these species have been isolated from other cave systems for over a million years, resulting in fragile, unique populations. Nowhere else do three species of sightless fish co-exist. Federally endangered fauna include five species of freshwater mussels, Indiana bat, grey bat, and Kentucky Cave Shrimp.

Surface vegetation is highly diverse with 450 different species known from the park. An area of old-growth forest in the park, known as the Big Woods, is one of the largest remaining areas in the state of the ancient forest types of eastern North America. It has been designated a State Natural Area. The state has also designated the Green River within the park as a state Wild and Scenic River, and the Mammoth Cave subsurface streams as Outstanding Resource Waters.

The park contains evidence of four pre-Columbian Indian cultures, with more than 150 archeological sites identified. In the early 1800's, partly in response to the impending War of 1812, cave soils which contain valuable nitrates, were removed from Mammoth Cave. This material was processed into saltpetre just outside the cave, and then shipped to gunpowder factories. An extensive system of pumps and wooden pipes was constructed for this purpose in Mammoth Cave. Remains of these and other human activity can be found in caves and on surface lands throughout the park.

With such a diversity of significant resources, the park was designated a World Heritage Site in 1981, and the park and an adjacent area were declared an International Biosphere Reserve by the United Nations in 1990. A principal concept of the International Biosphere Reserve program is to protect and manage unique resources while encouraging sustainable and compatible economic development. This is most often accomplished through the designation of a Core Zone, receiving the highest level of environmental protection and which usually encompasses the primary resources to be protected, and a Transition Zone where compatible development is allowed, and where secondary or contributing resources are located.

For the Mammoth Cave Area International Biosphere Reserve, the national park forms the Core Zone and the Transition Zone consists of those portions of the Mammoth Cave groundwater basins lying outside the park. The Transition Zone encompasses about 60,000 acres, which is 3/4 of Mammoth Cave's groundwater basins. The Transition Zone is primarily a karst terrane known as the Sinkhole Plain where surface runoff quickly enters the extensive underground stream systems, flowing toward and through Mammoth Cave and then emptying into the Green River.

Obviously, Mammoth Cave National Park and adjacent lands contain some of the best examples of our nation's natural and cultural heritage. However, these resources are threatened directly and indirectly by human activity. Priceless native American hand woven sandals dated as 2000 years old have been stolen from the display area in Mammoth Cave. Elevated levels of ozone and other air pollutants are affecting plant growth. Exotic species of fish compete with native species and the endangered Kentucky Cave Shrimp. Illegal harvest of endangered freshwater mussels threatens their continued existence, and pollution of the Mammoth Cave underground stream system, of which I will speak more, is also of primary concern.

So how do you and I as resources managers, in our various locations, solve these types of problems? Certainly better enforcement of resources statutes is important. But rather than limit public use and participation in activities related to our resources, I believe more public involvement is needed. Through environmental education and participation, the public must develop a sense of ownership and pride in the unique resources which we manage, in trust, for them. As responsible resources managers, working in a world where outside interests have a strong influence on our resources and our management actions, we must develop strong partnerships with industry and the business community, political officials, government agencies, academia and research institutions, special interest groups, neighbors, and the general public in such a way that they understand that they have a stake in the well-being of these unique resources.

PRIMARY THREATS AND PARTNERSHIPS

I would like now to discuss several partnerships in which Mammoth Cave National Park staff are heavily involved dealing with water pollution, a primary threat to park resources. Negative changes in quantity and quality of water flowing through the Mammoth Cave system would be expected to adversely affect the unique aquatic life in these underground streams and alter natural cave development processes.

Mammoth Cave Area Special Water Quality Project

Increased public awareness of water quality problems in south-central Kentucky led to the formation of the Mammoth Cave Karst Area Water Quality Oversight Committee in 1988. The committee was formed for the purpose of achieving coordination among citizens, landowners, and government agencies in monitoring and improving water quality in the area. Membership consists of the Soil Conservation District and county government representatives from each of the five counties in the project area. A multi-agency Technical Committee was then formed to develop a program to address groundwater pollution problems associated with agricultural practices within the five counties, which includes and extends beyond the Biosphere Transition Zone. The Technical Committee designed a program to address three principal concerns:

1) elevated concentrations of herbicide residues

2) high fecal coliform counts from animal wastes which runoff into sinkholes from feed lots and dairies

3) sedimentation due to soil erosion from cropping practices

The Agricultural Stabilization and Conservation Service (ASCS) and Soil Conservation Service (SCS) have provided engineering support and cost-share funds for local farmers to construct solid and liquid animal waste retainers. Thirty facilities have been constructed to date, and the program is continuing. We should note that more farmers signed up for the cost-shared construction program in the first year than the available funds could support. SCS and ASCS are also working with farmers to examine reductions in pesticide use, use of no-till and alternate tillage practices, and reduction of conventional cropping on highly erodible soils.

The Kentucky Division of Water is responsible for designation of demonstration farms and set-up of on-farm water quality analysis programs to collect trend data before and after implementation of new management practices. Hydrologists at Mammoth Cave National Park are assisting the Division, and also are running concurrently a water quality monitoring program downstream, within the park, to assess changes resulting from improved farm management practices.

A number of important advisors including the University of Kentucky College of Agriculture, U.S. Geological Survey, Kentucky Geological Survey, Environmental Protection Agency, Western Kentucky University, and Tennessee Valley Authority are contributing their expertise to the Project as members of the Technical Committee.

But most importantly, the cooperation and interest by the public, elected officials, and particularly farmers, has been, and will continue to be essential to any successes the project achieves.

Caveland Sanitation Authority

Several years prior to the creation of the Area Water Quality Oversight Committee, several local municipalities were struggling with water quality issues related to municipal sewage disposal. Poorly designed or under-sized sewage treatment plants in the cities of Horse Cave and Cave City were releasing effluent into sinkholes, thereby having a direct affect on subsurface water quality in the Hidden River Cave hydrologic system. In nearby Park City, no sewage treatment system exists, and effluent from septic systems, and in most cases raw sewage, is being injected directly into the Mammoth Cave hydrologic system.

With the cities unable to meet federal and state clean water regulations, the Environmental Protection Agency granted funds to prepare a wastewater facilities plan for the cities of Horse Cave, Park City, Cave City and Munfordville, as well as Mammoth Cave National Park. The plan recommended construction of a regional sewer system for the area.

Because of public concerns regarding the quality of the local drinking water supply, impact to cave resources themselves and the economic value they represent to the region, the Caveland Sanitation Authority was formed to implement the plan. The Authority consists of three representatives each from Park City, Cave City and Horse Cave, as well as the Superintendent of Mammoth Cave National Park as an ex-officio, non-voting board member.

Since 1987 various construction projects have been completed to implement different portions of the project, including upgrading the wastewater systems in Cave City and Horse Cave and tying domestic and industrial sources into the system. Major funding has been provided by the Environmental Protection Agency, Commonwealth of Kentucky, and the National Park Service through direct grants. Farmers Home Administration and the EPA have also provided construction loans, which are being repaid through user fees. Just recently, an agreement was reached on implementing the final phases including a sewage collection system for Park City and conveyance lines for remote users including the national park.

This is a splendid example of a partnership involving a number of diverse interests, individuals, and governments. The road has been very rocky, with a lot of disagreement, resignations, legal actions, and grid-lock. But, through the trials and tribulations the Authority board members under the public eye, were able to keep in mind the importance of the project, which at present appears to be headed toward completion.

ENVIRONMENTAL EDUCATION, TOURISM AND ECONOMICS

In both these cases, acknowledgement of a problem vital to the community's well being resulted in forming a partnership to address these issues. This cooperation, of course, followed the public realization that their groundwater supply for agricultural and industrial use, domestic supply and support of the tourism industry, in short their collective livelihood, was threatened in addition to the ecological damages expected. This then was an opportunity to create a public stake in the well-being of the biosphere resources. The next step is to elevate this concern from a personal or financial interest to that of a public or resources welfare issue.

Here is where our responsibilities as environmental educators comes in. Firstly, we cannot simply escort visitors through our precious caves; they cannot just receive a verbal diet of cake and ice cream. If they do, we are missing a prime opportunity to discuss environmental issues faced in our areas. We must be willing to discuss the controversial issues constructively as part of our public programs. All to often in my experience, area managers are reluctant to work these issues into public programs or to assure that staff making the public contacts thoroughly understand the issues; and therefore, are comfortable in discussing them. Environmental education is not only essential for the public, but for our staff as well.

The National Park Service, several weeks ago, convened a national symposium to examine its organization, role in resources stewardship, and direction it must take as the Service heads toward the next century. The conferees consisted of 1/2 National Park Service employees and 1/2 citizens from all sorts of organizations interested in national parks. We received some accolades but also plenty of constructive criticism. Two primary recommendations came out of the conference: the National Park Service must become leaders in resources stewardship and environmental education. Not working alone however, because we all know that funds and manpower are limited, but through partnerships with other agencies, interest groups and the public.

Remember I mentioned earlier that the International Biosphere Reserve concept includes resource-compatible economic development. Mammoth Cave National Park participates in the Barren River Area Development District, a state-chartered organization which coordinates economic, land use, and environmental issues in our region of Kentucky. Active participation in this organization by park managers is crucial to building a consensus with business leaders and civic officials for the protection of biosphere resources through compatible economic development. While not every decision may be favorable to our point of view, we have the opportunity to discuss issues, provide research data, and raise the awareness of local officials to resources management concerns associated with various economic development projects.

We cannot ignore the economic value of tourism and its potential for resource-compatible economic growth. As it relates to the resources we manage, economic considerations must be included when building our partnerships, a point which Stephen Biggers will be discussing with us more in a few minutes. While we, as park managers, are primarily concerned with the well being of the resource, our neighbors are often heavily dependent on the tourism income the resource generates. For example, I recently saw some data from the Kentucky Department of Travel Development which showed that visitors to Mammoth Cave National Park generated $98 million in total expenditures to the benefit of the statewide and local economies in 1990. These expenditures had an additional tax impact of $6.8 million and resulted in employment of 2,800 persons. The modern day resources manager needs to be armed with this data, as well as natural and cultural resources data, to build partnerships with the local business community in order to achieve resources protection and compatible economic development.

I believe this concept of partnerships and public involvement holds true for all of us here. It may be disconcerting to many of us to imagine the public with greater influence in management of our national, state and regionally significant resources. But the public has demonstrated their commitment to resources protection issues ranging from endangered species, to oil spills, to air and water pollution, to antiquities, all of which, as you know, can be associated with cave systems. I believe that greater public participation in management of our parks, forests, monuments, or what-have-you, through partnerships, will enhance public responsibility for them, and ultimately better provide the means for better protection of our natural and cultural heritage.

THE EVOLVING RELATIONSHIP BETWEEN MAMMOTH CAVE NATIONAL PARK AND ITS HYDROGEOLOGIC SYMBIONTS

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Minneapolis, MN 55455

June 1992

And Noah he often said to his wife when he sat down to dine,
"I don't care where the water goes if it doesn't get into the wine."
from Wine and Water
by G.K. Chesterton

TABLE OF CONTENTS

1
INTRODUCTION

The National Park Service (NPS) is mandated to protect and preserve the physical, biological, and historical resources placed in its care. Each unit in the National Park System contains portions of or entire single and multiple ecosystems. The NPS is required, therefore, to assume a complex, interdisciplinary approach to its management philosophy. Additionally, each unit is part of a local and regional geographic area, often with cities and other governmental units nearby, and each unit is enmeshed in complex, physical, biological, and political symbiotic relationships with its neighbors. The NPS management philosophy is beginning to consider social and political interactions and partnerships with residents and governmental agencies that co-inhabit the units' geographic regions.

Mammoth Cave National Park (MCNP) in Kentucky is a prime example of how complex this process can become. At MCNP, the NPS manages both the complex surface ecosystems and the Mammoth Cave System (MCS), the longest cave in the world, and the major component of the Park. This system of cave passages and underground rivers supports its own rich and diverse flora and fauna. These biota are intimately interconnected in complex ecological relationships and are coupled to conditions on the land surface. The management of such resources is dependent on knowledge of the biological and physical aspects of both the surface and subsurface environments and consideration of the economic and social needs of region's inhabitants.

This paper examines the interplay of scientific research, social interactions, and natural resource management in the Mammoth Cave Region. During the summer of 1991, about two dozen individuals connected with MCNP were interviewed and many of this paper's observations and conclusions are based on those interviews. The published results of the scientific research are reviewed as are written plans for future research projects. Social issues that impact the hydrogeologic research in MCNP and the neighboring communities are explored. The origin, development, and impact of NPS's evolving management decisions and policies at MCNP on hydrogeologic and other research in the region are reviewed. Finally, recommendations are made concerning how to improve the interactions of science and management.

GEOGRAPHIC LOCATION AND GEOLOGIC SETTING

MCNP lies within the Central Kentucky Karst, a region of 970 square miles (2,510 km^2) with over 450 miles (720 km) of mapped cave passage. Many long-time workers in the area believe that there will be at least 1,000 miles (1,600 km) of cave passage that are humanly passable when all such passages are discovered and mapped. Over 325 miles (520 km) of mapped cave passage are contained within the MCS itself. The Park contains 52,713 acres (21,332 ha), approximately 74% of the 70,618 acres (28,578 ha) originally authorized. The Green River flows westward through the Park, and the towns of Munfordville, Horse Cave, Cave City, Park City, and Brownsville are nearby.

The MCS occurs within the upper St. Louis Limestone, all of the Ste. Genevieve Limestone, and the Girkin Formation. Located below the St. Louis Limestone, the Salem-Warsaw Formations and older rocks act as a regional aquiclude. The rocks in the region dip gently toward the west, northwest and north. In general, surface water flows across the lower St. Louis Limestone into swallets in the middle St. Louis Limestone. The water then flows through the aquifer, and down the potentiometric gradient to the Green River, which is the regional base level.

Twenty-eight groundwater drainage basins and seven sub-basins south of the river have been defined by Dr. James F. Quinlan and his research associates by utilizing the data from more than 400 dye traces, 1,500 water-level measurements, and mapping of approximately 450 miles (725 km) of cave passages by various groups active in the park and in the region. These results are shown on the map by Quinlan and Ray (1989).

2
MAMMOTH CAVE NATIONAL PARK AND ITS REGIONAL NEIGHBORS - A STUDY IN CONFLICT ANALYSIS

Recognizing that resource management requires a comprehensive understanding of the nature and extent of the resource, including the susceptibility of its various components to adverse impacts, the NPS, scientists, and cavers intensified research in the biological and physical settings of MCNP in the mid-1960s. This work demonstrated that the cave extended far beyond the Park boundaries. The underground rivers on which the subterranean ecosystems (and eventually the surficial ecosystems) depend so heavily also extend beyond Park boundaries and drain the adjacent Sinkhole Plain and the communities built on it.

These new insights encouraged the NPS to adopt the concept of regional watershed protection, rather than Park-bound schemes, and to begin working in cooperation with local governments and with the U.S. Environmental Protection Agency to gain protection for the underground rivers of the entire region. The NPS is moving from the role of quiet neighbor to the role of an active partner in the development of the region surrounding MCNP. This change necessitates more specific and larger-scale research to define and understand the nature of groundwater flow in the region.

The metamorphosis of MCNP's role in the region has not been an easy change to accept for any of the groups involved, however, because of long-term conflicts in the Mammoth Cave Region. These conflicts are rooted in history and in politics at a variety of levels, and to understand the evolving relationship between MCNP and its regional neighbors, the various components of this conflict must be appreciated. Figure 1 is a visualization of these complex levels of conflict and the relationships of the various components within each level. The following analysis will utilize the phraseology of this illustration.

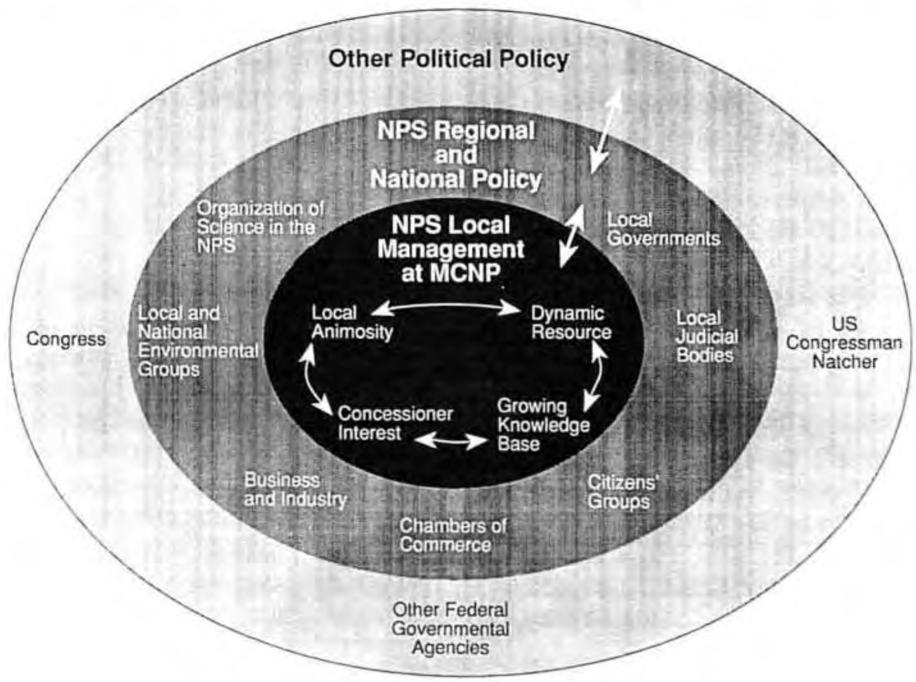

Fig. 1: Diagrammatic representation of nested levels of conflict for MCNP. (Roger Brucker, personal communication 1991)

LEVEL I - SEEDS OF REGIONAL CONFLICT

The components of this level comprise the fundamental basis for conflict between MCNP and the citizens of the Mammoth Cave Region. This conflict is rooted in the history of both the region and Mammoth Cave, but also includes the dynamic nature of the region's cave and groundwater resources and the contributions that various scientific studies have made to increasing the understanding of that dynamic nature. Another critical component involves the interests and influence of the MCNP concessionaire, a powerful resident of the area, in the region's politics and in the management of the resources of MCNP.

Each of these components is complex, and a detailed examination is beyond the scope of this paper. Brief summaries of the salient points, however, will be presented in the following discussion.

Local Animosity - The Creation of MCNP

In 1790, John and Patty Houchin settled on the south bank of the Green River just downstream from what would become known as Mammoth Cave and its Historic Entrance. Legend states that this entrance was discovered sometime during 1798 or 1799 by John Houchin while hunting. In 1798, Valentine Simmons purchased 200 acres, including two caves that would become known as Dixon and Mammoth Caves. In 1799, Simmons sold the property and both caves to John Flatt, and the larger cave (Mammoth Cave) became known as Flatt's Cave. Mammoth Cave was referred to as "Big Cave" in Jonathan Clark's diary in 1802. On January 21, 1810, the name "Mammoth Cave" was first used in print by a newspaper in Richmond, Virginia.

The first map of Mammoth Cave was made shortly before 1811. The cave and others in the region became vital sources of saltpetre during the War of 1812; this domestic source helped the U.S. to win the war. Without it, the country probably would have lost quickly. Despite this role, it was Nahum Ward's published descriptions in 1816 that made Mammoth Cave famous. Edmund F. Lee made the first instrument survey and map of Mammoth Cave. During the period from 1838 to 1839, the slave-guide, Stephen Bishop, made many important discoveries in Mammoth Cave.

Ownership of the land containing the entrances to the two caves changed several times before the property was purchased by Dr. John Croghan in 1839. In 1842, Stephen Bishop, with the assistance of George Croghan, prepared a new map of Mammoth Cave, which was published in 1845. Stephen Bishop continued to make discoveries in Mammoth Cave for Dr. Croghan, and, in gratitude, Dr. Croghan eventually gave Stephen his freedom. When Dr. Croghan died in 1849, the property was placed in trust for heirs and was known thereafter as the Mammoth Cave Estate. When Stephen died in 1857, exploration of Mammoth Cave was continued by slave-guides Mat and Nick Bransford.

The process of making Mammoth Cave and vicinity into a national park was initiated in 1905 by members of the Kentucky Congressional delegation to the U.S. Secretary of Interior. Bills to create MCNP were subsequently introduced in Congress, but no action initially resulted.

In 1906, Lock and Dam #6 was built on the Green River at Brownsville, downstream from Mammoth Cave. This dam raised the water levels at Mammoth Cave approximately six feet and flooded significant parts of the cave. However, the dam also allowed excursion-class steamboats to bring visitors to the cave via the Green River.

In 1908, Max Kaemper secretly mapped much of what was known of Mammoth Cave for its managers, and discovered another significant portion of Mammoth Cave with guide Edward Bishop. In 1916, George Morrison opened the Cox Entrance to Mammoth Cave on land outside of the cave property. He then opened the New Entrance under similar circumstances in 1921. In 1924, Roy Jaggers, Earl Lee, and L.L. Lee discovered the Frozen Niagara section of Mammoth Cave, and opened the Frozen Niagara Entrance to access it. In October 1924, the Mammoth- Cave National Park Association, a private subscription organization, was organized in Bowling Green, Kentucky, to purchase or accept donation of the necessary land and to clear the titles for what was hoped would be the future MCNP.

On January 30, 1925, Floyd Collins became trapped in Sand Cave, a small cave located on the far southeast end of Mammoth Cave Ridge that Floyd hoped could be made into a successful commercial venture. The importance of Sand Cave was its location, which would have allowed direct competition with Mammoth Cave. Floyd's plight and the attempts of his would-be rescuers became front-page, headline news throughout the country. Somewhere between ten and fifty thousand people clogged the site of the tragedy. On February 15, 1925, rescuers finally reached Floyd's body and doctors decided that Floyd had been dead at least 24 hours (Murray and Brucker, 1979, p. 211). The publicity surrounding the attempt to rescue Floyd and the failure of these efforts fed the enthusiasm for the national park concept.

On April 18, 1926, the U.S. Secretary of the Interior received the report of the Southern Appalachian National Park Commission. This report recommended national park status for the Mammoth Cave region for the following reasons.

> The limestone caverns that contain "beautiful and wonderful formations," the "great underground labyrinth" of passageways "of remarkable geological and recreational interest perhaps unparalleled elsewhere," and the "thousands of curious sinkholes of varying sizes through which much of the drainage is carried to underground streams, there being few surface brooks or creeks...." The rugged topography and "areas of apparently original forests which, though comparatively small in extent, are of prime value from an ecological and scientific standpoint, and should be preserved for all time in its virgin state for study and enjoyment...." The "beautiful and navigable Green River and its branch, the Nolin River," which flow through the forests of the area. "All of this offers exceptional opportunity for developing a great national recreational park of outstanding service in the very heart of our Nation's densest population and at a time when the need is increasingly urgent and most inadequately provided for."

On May 25, 1926, pursuant to this recommendation and the endorsement of the citizens of Kentucky, the U.S. Congress authorized the establishment of MCNP, which was to contain 70,618 acres (28,578 ha). The act, signed by President Calvin Coolidge, stipulated that only donated lands conveyed in fee simple could be accepted by the Secretary of Interior for the creation of MCNP. Later, the U.S. Congress appropriated Federal funds to speed land acquisition. The act also required that a minimum of 45,310 acres of land including and surrounding Mammoth Cave would be donated to the Federal government before the area could be accepted as a national park.

By the close of the 1920s, no less than 15 different commercial caves were competing for tourist business in the Mammoth Cave Region. In 1929, the Mammoth Cave National Park Association purchased two-thirds interest in the Mammoth Cave Estate. In 1930, the Cathedral Domes Entrance was opened and the remaining one-third interest outstanding in the Mammoth Cave Estate was condemned and purchased.

Upon the recommendation of the Mammoth Cave National Park Association, the Commonwealth of Kentucky created the Kentucky National Park Commission in 1928. The Commission was authorized to use legal condemnation of land through the Commonwealth's right of eminent domain to speed land acquisition for MCNP. This same legislature also appropriated funds to be used for land acquisition at Depression-era price of $30/acre, rather than the then-normal $60/acre. Kentucky also ceded to the Federal government exclusive jurisdiction over park lands. Initially, the Commission lost many condemnation suits in the local courts, especially in Edmonson County. It seemed doubtful that enough land would ever be obtained to create a National Park.

The Association and the Commission each operated the respective cave properties acquired. On January 5, 1931, George Morrison sold the New Entrance to the Kentucky National Park Commission. The Carmichael and Violet City Entrances to Mammoth Cave were opened the same year. The Civilian Conservation Corps (CCC) came into the region in May, 1933, when CCC Company 510 began to build the Flint Ridge Reforestation Camp. At this time, Mammoth Cave was operated by a joint committee with the profits earmarked for further land acquisition. [It is important to note that, through May 1934, all of this action was taken by the Commonwealth of Kentucky and powerful Kentucky residents, not the Federal government.]

"On May 28, 1934, National Park Service officials met with the Mammoth Cave National Park Association and the Kentucky National Park Commission. The NPS agreed to assume the obligation of purchasing the necessary land. Thus, local landowners who had 'beaten' park proponents in the local courts now had to fight the Federal government . . . and lost . . . Only when the responsibility for obtaining land was assumed by the National Park Service in Federal court was it able to successfully utilize the power of eminent domain. Thereafter, land acquisition proceeded quickly" (Sides, 1992).

The Salts Cave and Colossal Cave properties were purchased for MCNP in 1935. In 1936, H.D. Walker surveyed Mammoth Cave for the United States Geological Survey. By May 22, 1936, 27,402 acres (11,089 ha) of land had been acquired by various means and was accepted by the U.S. Secretary of Interior. In 1940, the New Discovery Entrance was opened. Finally, on July 1, 1941, 45,310 acres (18,340 ha), composed of over 600 deeds, had been assembled, and Mammoth Cave was accorded full national park status.

In the end, more than 2,000 people were displaced. The forced abandonment of homes and schools, and the displacement from churches and ancestral cemeteries were difficult pills to swallow. Titles to the land containing the churches and cemeteries were conveyed in fee simple to the United States, but the titles are subject to continuing ingress and egress with the right of burial in the cemeteries for the members of the churches and their families. Interments, however, are not to exceed the individual burial capacities of each cemetery as specified at time of acquisition. On June 5, 1942, the U.S. Secretary of Interior was given authority to accept exclusive jurisdiction over park lands (Act 56 Stat. 317). The U.S. Secretary of Interior was now empowered to make rules and regulations for the proper management and care of the new national park and for the protection of the property contained therein, including all flora and fauna.

Sometime during 1943, Hidden River Cave, a commercial cave owned by Dr. Thomas beneath the town of Horse Cave, became the first cave in the region to be closed as the result of groundwater pollution.

The U.S. Secretary of Interior accepted exclusive jurisdiction over park lands on May 1, 1944, as ceded by Kentucky on March 22, 1930. On June 18, 1945, a deed reservation for certain roads to remain open for the usual use of the public was recorded in Edmonson County (Deed Book 45, Deed No. 262, p. 604-607.)

On September 18, 1946, after World War II had ended, MCNP was formally dedicated. Many of the cave's guides and most of the cave's tourist practices and routes were retained by the NPS. Many of the surnames that are on the MCNP payroll today have been there for over a century. However, many of the African-American guides, who outnumbered the Anglo-American guides prior to NPS takeover, were "furloughed". This ended the proud tradition of cave exploration and guiding at Mammoth Cave by African-Americans that had begun with Stephen Bishop. This policy also created a lasting sense of distrust and hatred toward the Park Service in much of the local African-American community.

The NPS continued to charge a substantial entrance fee to Mammoth Cave itself while keeping closed all the other, formerly commercial, now government-owned caves within NPS boundaries (e.g., Colossal and Salts). However, the NPS did not yet own Great Onyx Cave or Floyd Collins' Crystal Cave, and the owners of these caves fought "cave wars" with each other and with Mammoth Cave to gain as large a share as possible of the 500,000 tourists who annually visited Mammoth Cave.

These cave owners fought pertinaceously against government take-over. These in-holdings were not only competition for Mammoth Cave, they were viewed as a threat to bureaucratic survival by Park management for several reasons. They consumed maintenance appropriations via road use, and they used general resources supplied by the Federal government for MCNP. In addition, subsidies were budgeted and administrators were paid according to the number of visitors at MCNP each year (Murray and Brucker, 1979, p. 240). The more successful the in-holders were in diverting visitors from Mammoth

Cave, the lower the park was rated. With fewer visitors at MCNP, less was spent at the concessionaire's facilities and stands.

For fear of connection of other caves to Mammoth Cave and for fear of accidents like that which killed Floyd Collins, the NPS prohibited all exploration off established tourist trails. Thus ended the proud tradition of guide-explorers, and more hard feelings toward the NPS were created.

From February 14 to 20, 1954, the National Speleological Society sponsored the "C3" (Collins' Crystal Cave) Expedition, which was hosted by the Thomas family, the owners of Floyd Collins' Crystal Cave. Coincidentally, on February 16, 1954, during this expedition, the U.S. House Interior Committee approved a bill to acquire Great Onyx and Floyd Collins' Crystal Caves. Additional explorations were sponsored and supported by the Thomas family during 1955 to 1956 in Floyd Collins' Crystal Cave. The results of this work were published copiously in the National Speleological Society News and in various local and regional caver newsletters, and this generated much national publicity for the cave property.

Some of the individuals involved in the exploration and mapping of Floyd Collins' Crystal Cave formed the Cave Research Foundation (CRF), which was incorporated in the Commonwealth of Kentucky in 1957. CRF was formed to support scientific research and exploration in caves, in general, and in what would eventually grow from Floyd Collins' Crystal Cave to the Flint Ridge Cave System, in particular. Joe Lawrence and Roger Brucker, C3 expedition members and founders of CRF, published a book about the expedition in 1959, The Caves Beyond. The sale of this book generated more publicity for Floyd Collins' Crystal Cave. On October 20, 1959, CRF signed a Memorandum of Agreement with NPS to allow CRF to explore, study, and map all caves within MCNP. This caused further animosity on the part of the MCNP guides, who were banned by the NPS from exploring during their off hours. CRF encouraged MCNP guides to join its work trips into the caves, but that did little to ease the anger of the older guides, who remembered through their own experience or that of one of their family members, being denied access to Mammoth Cave.

By 1961, through continued efforts by CRF and others and with support of the Thomas Family, Floyd Collins' Crystal Cave had expanded to become the Flint Ridge Cave System. In that same year, Great Onyx and Floyd Collins' Crystal Caves were sold to the NPS, giving MCNP the approximately 52,000 acres currently contained in the park.

[NOTE: The preceding historical material is from Sides (1991), Meloy (1979), Murray and Brucker (1979, p. 211, 238-240, and 317), MCNP (1983), and interviews of various individuals by the authors.]

Dynamic Resource

If one were to occasionally visit MCNP or the MCS, one might feel that the resource never changes. However, if one were to visit the resource regularly and were to become well acquainted with it, one would realize that the resource changes constantly. In other words, the cave and the park are each a dynamic, not a static, resource. For years, it was popular for both the tourists and park managers to consider the cave as an unchanging, 150-mile long labyrinth of mystery, reflecting an attitude that dated back to the early 1800s. However, these dynamic resources are simultaneously being created and destroyed by the same processes.

Growing Knowledge Base

The final historical component is that the dynamic nature of the resource was revealed by both scientific and systematic cave mapping investigations. The scientific studies and mapping created a growing knowledge base that documented the dynamic resources of the park and cave system. As that knowledge base grew in size and sophistication, the following became evident: 1) the dynamic resource was changing at a much greater rate than initially thought; 2) the resource was much larger than originally thought; and 3) the resource was an integral part of a system that extended well beyond the park boundaries.

This growing knowledge base has created and continues to create several conflicts. First, it revealed that both the MCS and the park were regularly impacted by a variety of human activities occurring in the region, but outside of the park. This discovery destroyed the myth that MCNP and the MCS could be managed by the NPS as isolated, autonomous units. Second, the individual scientists and cavers took a personal pleasure and pride in participating in the growth of the knowledge base. These feelings grew into a strong sense of loyalty to the resources that superseded the loyalty of these individuals to the NPS. Finally, it revealed the additional conflict between the scientific view that demonstrates what reality is and the management view that tries to determine what reality should be.

Concessionaire Interests

National Park Concessions, Inc. (also called NPC or the concessionaire), the concessionaire at MCNP and four other National Parks, developed directly out of the Kentucky National Park Commission. The individuals that were active in the Commission, such as Judge Coleman, helped to form the NPC. In this sense, the concessionaire actually predates the park. MCNP, rather than the other parks in which NPC operates, has always been its business base, and NPC's corporate headquarters are located in Cave City. The concessionaire, like all concessionaires operating in national park units, is essentially a protected monopoly (Public Law 89-249, Section 5, currently governs the preferred renewal of contracts which the concessionaires enjoy). NPC has become entrenched in the Mammoth Cave region with successive generations of employees. It maintains deliberate ties into the regional community and to the Congressman in the region, Congressman William Natcher. At one time, and probably still today, the policy of the concessionaire was to employ residents of each of the counties containing and/or surrounding MCNP. These local people could, in effect, create a network to protest strongly any actions taken by the park management that are seen to conflict with the interests of NPC. Successive MCNP Superintendents have said that their toughest battles are with the concessionaire. The interests and activities of the concessionaire are often perceived to be in direct opposition of the efforts to manage and protect the resource. However, because of the protected monopoly within the NPS, the NPC has enormous powers, allowing it to take actions that the Superintendent has no power to control.

LEVEL II - NATIONAL PARK SERVICE REGIONAL AND NATIONAL POLICY

This level contains all entities and characteristics that impact upon policy making in the NPS at the regional and national levels. Included for consideration are the general characteristics and structure of the NPS organization, local entities in the Mammoth Cave Region, the interests of local and national environmental groups in the management of the natural resources of the Mammoth Cave Region, and the management structure for scientific research activities in the NPS.

General Organizational Characteristics

There are several organizational characteristics of the NPS that are critical to how the resources of the National Park System are managed. According to Smith (1968) and Everhart (1983), the basic organizational structure introduced when the NPS was established in 1916 is fundamentally unchanged today. In the NPS, responsibility for administration is vested with rangers who advance up the line of command, whereas staff functions are filled by the naturalists, engineers, scientists and other specialists who make recommendations concerning management. The rangers usually hold degrees in a variety of subjects and skills in a variety of activities. In contrast, staff officers include scientists and interpreters who have professional training and experience in specific disciplines.

Smith (1968) pointed out four reasons for the initial adoption of such a line and staff system of administrative management and control. First, the original park units were under the control of the military in the years prior to the establishment of the NPS. Some of the park personnel, then in the military, transferred to the NPS. Second, when the NPS was organized, the leaders of the new organization found that veterans of the Spanish-American and First World Wars were among those who were the most qualified to administer what were then remote areas. Third, protection by a quasi-military ranger force was a major responsibility in the earliest days of the Service because the Parks were remote and difficult to reach. Fourth, the NPS was established in an era when the regulatory function of the Federal government was in new vogue.

To assure loyalty primarily to the Service and not to the individual park unit, the NPS adopted the military's philosophy of transferring key personnel on a time scale of approximately every three to four years. Such transfers have been and continue to be the key to promotion.

Finally, according to Everhart (1983): "Undeniably, the threat of crime has caused a substantial shift of emphasis toward the direction of law enforcement. Rangers now receive 400 hours of intensive law enforcement training at the Federal Law Enforcement Training Center, plus periodic refresher courses.... At a conference of park Superintendents, the moderator of a session on law enforcement noted that 'hardly anything has been more talked about' within the Park Service, concluding that 'our people are undertrained in resource management and overtrained in law enforcement. A tremendous imbalance has been created.'"

Local Entities

These include local governments, judicial bodies, business and industry, citizen groups, and Chambers of Commerce, all of whom try to give input to the NPS unit near them. Most park units contain parts of resources and ecosystems that are regional in extent and, therefore, are not protected by the land owned by the park. Despite this, there is no local advisory representation to the park unit to facilitate the local input that would permit cooperation between the NPS and local agencies in managing and preserving the shared resources. Hence, decisions made by these organizations will impact on park resources without any NPS input into those decisions, and vice versa. If there is strong local animosity, these decisions will be made either by ignoring the park or in spite of the park.

Environmental Groups

Because of the interest of local and national environmental groups, there is always some degree of oversight when the sensitivity of the resource has been identified. These groups can bring pressure to bear on the NPS and on local park unit management. However, such efforts often aggravate both the NPS managers and the local citizens. The NPS resents the environmental groups' successful attempts to establish policy because it is seen to be an infringement on the managers' prerogatives. The local citizens often view the environmental groups as "outsiders" trying to influence local issues.

Science in the National Park System

Science in the NPS is performed by staff officers with no command authority. Park scientists report either to the park Superintendent or to the Regional Chief Scientist. Regional Chief Scientists report to Regional Directors and to the NPS Senior Scientist in the Washington, D.C., office. This Senior Scientist reports to the Associate Director for Science and Technology, who, in return, reports to the NPS Director. Table 1 shows this current management structure.

Science in the NPS in general and at MCNP in particular is now supervised by the park Superintendent, who has historically been a line officer, not a scientist. An important result of this organizational structure is that, if a conflict arises between management and science, the management command structure takes precedence. Exceptions to this are extremely rare.

NATIONAL HEADQUARTERS IN WASHINGTON, D.C.:

NPS DIRECTOR
DEPUTY DIRECTOR - OFFICE OF PARK PLANNING AND ENVIRONMENTAL QUALITY
ASSOCIATE DIRECTOR - SCIENCE AND TECHNOLOGY
SENIOR SCIENTIST
Air Quality Division
Energy Conservation and Technology Transfer Division
Natural Science Division
Natural Landscape Division
Water Resources Division
Special Science Projects Division

SOUTHEAST REGIONAL OFFICE IN ATLANTA, GEORGIA:

REGIONAL DIRECTOR
DEPUTY REGIONAL DIRECTOR
ASSOCIATE REGIONAL DIRECTOR, OPERATIONS
DEPUTY ASSOCIATE REGIONAL DIRECTOR, SCIENCE AND NATURAL RESOURCES
Natural Resource Management and Policy Division
Terrestrial Ecosystem Research Division
Coastal and Marine Ecosystem Research Division

MAMMOTH CAVE NATIONAL PARK, MAMMOTH CAVE, KENTUCKY:

SUPERINTENDENT
CHIEF, DIVISION OF SCIENCE AND RESOURCE MANAGEMENT
CULTURAL RESOURCES SPECIALIST - Museum Technician (seasonal)
NATURAL RESOURCES SPECIALIST
Air Quality Technician - Radon Technician (seasonal)
Biology Technician
HYDROGEOLOGIST
Hydrologic Technician

Table 1. 1992 organizational structure for the management of scientific research in the National Park Service in the Southeast Regional Office and in Mammoth Cave National Park (Mihalic, 1991; Deskins, 1991).

LEVEL III - POLITICAL POLICY MAKING

The U.S. Congress can impact on NPS policy and resource management through legislation initiated by any of the following: local and/or State citizens, local and/or State business, local and/or State government, national environmental groups, national industrial interests, etc. Further, and more pertinently, the local U.S. Congressmen seem to be the most expedient route to get the NPS to do something desired by the local groups identified in Level II and/or by the Park Superintendent. This completely circumvents the regional and national NPS command structures.

CONFLICT SYNTHESIS

When a new Superintendent, usually someone with a ranger (line officer) background, arrives at MCNP, he or she quickly realizes that there are elements of conflict which interfere in his or her ability to manage the resources of MCNP. The first introduction to this is often when the concessionaire proposes to pursue some activity that is inherently or potentially damaging to the resource. The Superintendent will, of course, resist such a proposal. He or she then discovers the entrenchment of NPC's protected monopoly within the NPS and that the proposed activity falls outside of the Superintendent's jurisdiction to change or control.

The Superintendent then discovers that scientific research is being performed at MCNP by academic scientists, independent organizations like CRF, and NPS scientists. The results of this research have demonstrated that there is a great deal of resource lying <u>outside</u> the boundaries of MCNP which must be considered to protect the resources <u>inside</u> MCNP. The NPS, however, has the tendency to consider only that which lies within their boundaries, even though those boundaries were drawn for practical and political, not environmental, reasons. The entire resource in the Central Kentucky Karst is an intimate linkage of many resource elements, and events outside of MCNP boundaries can quickly impact the resources inside MCNP boundaries. Therefore, the Superintendent quickly realizes that he or she must consider all the Mammoth Cave Region not just the resources in MCNP.

The last issue that the Superintendent is likely to encounter is local animosity, usually as the result of some activity in which the NPS at MCNP must interact and cooperate with local citizens, Chambers of Commerce, churches, industry, and city governments. The Master Planning process, now referred to as the General Management Planning (GMP) process, will be used here as a illustration.

At the commencement of the GMP process, the Superintendent and the park staff used the existing knowledge base of the resources plus some generalized views of what the NPS at MCNP should be doing to serve the public, both in protecting the resource and interpreting it, to start the planning process. This review of the available science (the knowledge base) illuminated some of the dangers and potential risks to the resource, and appeared to indicate the necessity, in some situations, of less, not more, development. This immediately placed the GMP process in direct conflict with the concessionaire's interests.

Since public input was part of the GMP process, the concessionaire, feeling threatened, organized all the surrounding counties through a network of employees. Resolutions were made in all of the fiscal courts in these counties. The actions of the concessionaire also gained the involvement of local Chambers of Commerce, local civic groups, local church groups, and an impressive array of people that the concessionaire could turn out on command. Again, the concessionaire, understanding well the four-fold conflict setting (local animosity, concessionaire interests, dynamic resource, and growing knowledge base) simply fed the conflict with inflammatory comments such as, "these outsiders are coming in and they want to change YOUR park, and they want to close it down, and they want to lock it up and make it into wilderness." All of these were fighting words to the local communities surrounding MCNP, and so the ensuing battles intensified. The NPS retreated to the planning room and attempted to revise the GMP, promising less controversial items, hoping that the revised GMP would be accepted by the local populace. The likelihood of this occurring, however, depends upon the concessionaire and his perceptions that his interests are being protected.

In the last three decades, a new constituency has grown as the scientific knowledge base has expanded. This constituency includes CRF, the Wilderness Society, the Sierra Club, the National Parks and Conservation Association, and other environmental groups who act as advocates of preservation of the resources of MCNP and the MCS. These groups have, through participation in past battles at MCNP, become very aware of the elements of conflict in the region, and have become as effective as the concessionaire in these battles. The Superintendent may have less experience than either the concessionaire or the environmental community in dealing with what can be a hostile, loud, vociferous, local populace who tends to oppose the actions of the NPS at MCNP. Meanwhile, knowledge of the cave and groundwater resources expands, and the understanding of the threats becomes more detailed and comprehensive.

Finally, the last potential conflict is national political policy. The Congress of the United States makes numerous decisions which affect MCNP. Budgetary decisions regarding the NPS are particularly critical. Congressman Natcher represents the area that includes the Central Kentucky Karst, and he is one of the five most senior U.S. Congressmen. He is very powerful, and is chairman of the Appropriations Committee. Local citizens and the concessionaire successfully lobby Congressman Natcher to their benefit, often to the detriment of the NPS and the resources of MCNP.

The Superintendent may take three to four years to comprehend all of these elements, while being distracted by all of the other tasks required of him or her on a daily basis. These short term necessities leave little time for larger, long-term issues which may be vital to preservation of the resource. Just when the Superintendent is getting a grasp of the elements of conflict that must be addressed to manage the resource, he is transferred to another park unit to start over again.

3
RECOGNITION OF REGIONAL SYMBIOSIS

Recognition of the symbiotic relationships between MCNP and its regional neighbors has been the result of years of cave exploration and mapping, long-term resource monitoring and inventory, and patient scientific research. Many dedicated individuals have contributed to this effort.

RESEARCH MODES

Hydrogeologic research has been performed in four modes at MCNP. These are: 1) individual scientists,
2) volunteer organizations such as CRF and others,
3) a NPS Research Geologist assigned to MCNP,
4) and other individuals and agencies.

Individual Scientists

Individual, non-NPS scientists (primarily academic and often members of CRF) have made long-term, career commitments to study the resources of MCNP and the MCS. If an academic scientist is involved, the effort has often included obtaining funding (non-NPS) and funnelling graduate students into appropriate research projects in the park and region to continue the professor's long-term research program. Examples of this include but are not limited to the following.

a) The hydrogeological, geomorphological, and mineralogical work in the Central Kentucky Karst by Drs. William and Elizabeth White and their students and associates (1960 to present) that culminated in two theses and in the White and White (1989) book summarizing karst geomorphology and hydrology of the park area.

b) The geological, stratigraphic, speleogenetic, and hydrogeological research in the MCS by Dr. Arthur Palmer and Ms. Margaret Palmer (1960 to present) that culminated in Palmer (1981; 1989a,b).

c) The hydrogeologic research in the MCS by Dr. Ralph O. Ewers and his students (Ewers and Ford, 1978; Recker and others, 1988; Recker, 1989; Meiman and others, 1988; Meiman, 1989; Estes, 1989)

d) The surface and in-cave archaeological research by Dr. Patty Jo Watson and her students and associates (approximately 1963 to present), which resulted in two books (Watson, 1969; 1974) and a long series of articles (e.g., Watson 1989; 1991). Professor Watson's research played a major role in garnering the recognition for Mammoth Cave archaeology that culminated in her election to the National Academy of Sciences.

e) The biological research (approximately 1955 to present) by Dr. Thomas Barr (Barr, 1967; Barr and Kuehne, 1971), Dr. Thomas Poulson and his students (e.g., Poulson, 1967; 1990; Poulson and White, 1969; Poulson and Kane, 1981), and Dr. Julian Lewis (e.g., Lewis, 1981; 1990).

Volunteer Organizations

For decades, a major part of the scientific research, the bulk of the resource inventory, and most of the cave exploration and mapping in MCNP and the MCS has been done by volunteers. This volunteer pool is national and international in origin and contains individuals from many different professions. Their efforts are largely self-motivated, self-directed, and self-financed. The quality and professionalism of this volunteer work is, on average, excellent and the best of it is without equal.

The lead organization in the volunteer effort has been the CRF, but other organizations have made sizable contributions. Other volunteer organizations involved in MCNP and the region include the Central Kentucky Karst Coalition, the Fisher Ridge Project, the North Shore Project, various National Speleological Society Grottos, etc., as well as numerous individual volunteers.

Much of the work done by Drs. White, Dr. and Ms. Palmer, Dr. Watson, Dr. Poulson, Dr. Lewis and a number of other scientists were done under the aegis of CRF. Dr. White was CRF Chief Scientist from 1962 to 1973 and Dr. Poulson has served in the same role from 1979 to present.

National Park Service

James F. Quinlan was hired by MCNP on July 26, 1973, as the result of a request by the MCNP Superintendent, Joseph Kulesza. According to his position description, he was to coordinate all research activities in MCNP and was to emphasize what were identified as critical research needs. The identified critical research needs included complex, long-term studies of regional karst geomorphology, speleology, park and regional hydrology, geochemistry, petrology, mineralogy, sedimentology, cave climatology, and paleontology. He was to identify and correlate research needs in each discipline based on acquired knowledge and appraisal of physical data and literature. Dr. Quinlan was to perform geological studies and to establish monitoring systems of physical resources, including water drainage patterns, particularly those vulnerable to outside influence. He was to receive general administrative supervision from the MCNP Superintendent, but was to have wide latitude for professional, independent judgment and action. He was to maintain close ties with the Regional Chief Scientist.

Dr. Quinlan's tenure at MCNP was scientifically productive. The contributions of his scientific work are reviewed below. Dr. Quinlan's tenure was also controversial. As a result of disputes with NPS management, Quinlan (1975) filed a formal grievance against MCNP Superintendent Kulesza. The successful resolution of that 1975 grievance permitted a decade of fundamental scientific work at MCNP until the underlying conflict between science and management resurfaced. After a bitter clash of wills with NPS management, Dr. Quinlan resigned in 1989. With Dr. Quinlan's departure, the NPS lost much of the knowledge that he had gained during his 16 years as the Research Geologist at MCNP and his 30 years of experience in the Central Kentucky Karst. This situation will be discussed in more detail in the section, "The tenure of the National Park Research Geologist", later in this paper.

A new research structure was established in the fall of 1988. The position Dr. Quinlan vacated in 1989 has not been filled. The Research Geologist position was held and funded by the Southeast Regional Office, and duty-stationed at MCNP. The park requested that the position be filled again following Dr. Quinlan's resignation. The Regional Chief Scientist chose to reassign the position elsewhere in the region. In October 1990, MCNP requested the regional office to establish a Hydrologist position at Mammoth Cave. In November 1990, the Regional Office approved this position in lieu of a research scientist and the position was filled, at a full performance level of GS-11, in January 1991. This new staff is conducting hydrogeology research programs as directed by the Superintendent.

Others

State and Federal governmental agencies and private industry have performed research in MCNP or in the Central Kentucky Karst. Examples of this include the first dye trace in the region, performed by Anderson (1925) of Louisville Gas and Electric, geologic mapping efforts by the Kentucky Geological Survey, and hydrogeological studies by the U.S. Geological Survey. Several of the latter efforts were part of larger State and Federal programs and involved MCNP only because it was located in the study area. These studies, however, provided useful background information on MCNP and the MCS.

MCNP is currently involved in or developing inter-agency projects with several State and Federal agencies. These projects involve environmental issues that directly impact MCNP and are issue oriented. This mode of research appears to be growing, both at MCNP and throughout the NPS, and represents a distinctly new style of research in the National Parks.

Summary

The professionals involved the exploration and scientific study of MCNP and the MCS represent a significant reservoir of knowledge and varied expertise which is available to the NPS on a volunteer basis. With this overview, we would now like to review some of the highlights of the geologic and hydrogeologic research that has been undertaken at MCNP. [This review is not meant to be all-inclusive and, for brevity, will not mention many of the researchers who have contributed to the current scientific understanding of the resources of the Central Kentucky Karst.]

RESEARCH ACTIVITIES

The exploration, mapping and scientific study of MCNP, the MCS, and the Central Kentucky Karst have been at the leading edge of U.S. speleology and karst hydrogeology for almost two centuries. Cave exploration, mapping and scientific observations in the area began in the 1800s. Scientific research began in the 1920s and continues to the present. The modern research effort and its results can be understood by first describing how a research plan was developed, and then how it was implemented, modified, and expanded. It is most convenient to divide the research from the 1950s to 1991 into three parts: (1) that done from the 1950s to 1973, prior to a NPS Research Geologist being placed in MCNP, (2) from 1973 to 1989, when the NPS Research Geologist was at MCNP, and (3) from 1989 to 1991 (when this paper was written) after the Research Geologist resigned from the NPS. The research's value is defined by the impacts it has had on the management of MCNP, the policies and actions of the residents and governments of the Mammoth Cave Region, and finally on karst science in general.

1950s to 1973

Objectives

The first documented speleological research plan for the Mammoth Cave Region was outlined by CRF (1960) included the following items:

(1) Exploration and Cartography, which were considered "basic to an integrated speleological study...to provide data for mapping, geological study, archaeological work, and other investigations...."

(2) Geology and Hydrology: "Little is known about the hydrology of the Mammoth Cave Region. Studies undertaken in 1925 [by Anderson] showed the need for systematic tracing of water from the ridges and from the Sinkhole Plain. A complete study of water movement, both in accessible streams and in flooded

cave passages, requires new techniques and extensive support. Springs along the Green River should be located and described in detail."

A specific hydrologic research plan was then formulated by various CRF scientific personnel, including the CRF Chief Scientist, Dr. White. A more detailed description of the envisioned hydrology program was presented in CRF (1968), as follows:

1. Drainage Net Behavior: would include examination and careful mapping of the cave passages as representatives of paleoconduits.

2. Hydrology: would encompass all of the quantitative measurements usually associated with water research, such as: gaging stations on all identified springs to measure discharge, hydrographs, rain gauges, refinements to measure infiltration, determination of the existence and characteristics of a storage component of the karst aquifer, and dye tracing to connect various parts of the drainage network not accessible to direct examination.

3. Hydrogeologic Controls: would consist of careful mapping of the stratigraphic, lithologic, and structural characteristics of the aquifer and comparing these with known cave patterns and known groundwater flow paths.

4. Geochemical Mechanisms of Solution: could be accomplished via two methods of examination. First, "...hydrochemical facies mapping consists of doing fairly complete analyses of dissolved ions (Ca, Mg, Na, Cl, HCO_3) in wells, underground streams, and springs. From the distribution of these constituents in space...one can learn much about the residence time of the water, of the general flow paths in the diffuse flow parts of the aquifer, and the prior history of the water before it reached the sampling point." Second, "the chemical hydrograph technique measures the same variables but determines them as a function of time. By looking at the variation of the chemical parameters with season and with discharge, information can be gained about whether the water is flowing through open channels or by diffuse flow."

5. Theory: "...New mathematical models for groundwater motion in limestone must be invented...."

6. Pollution Transport Mechanisms: "A full program of hydrologic research...must be concerned with the various pollutants which can be transported by underground flows.... Are natural clean-up processes operating? Cave streams have a well known aquatic life. Does the cave life succeed in scavenging the pollutants? How is the pollution dispersal pattern related to the nature and geometry of the drainage net? This is an area where there is an interface between the biological programs operating in cave systems and the hydrological research.... One is meaningless without the other and it is becoming an absolute necessity that some sort of quantitative measurements be started. The research on the drainage net itself cannot be ultimately tested until the quantitative flow data are available."

Projects

[NOTE: During this time, various State and Federal governmental agencies and private industries were involved in research projects in the Mammoth Cave Region. Space does not permit addressing these projects here, but that research formed a foundation upon which the following was built.]

Various aspects of this hydrogeologic research were performed by Dr. White, his graduate student, John Hess, and graduate students recruited from other institutions by CRF. This occurred primarily from 1957 to 1974 and can be traced through the following publications: CRF (1961), Reams (1963; 1965), Deike (1967), Deike and White (1969), White (1969), Harmon and others (1972), and Wells (1973). Other research occurring during this period at MCNP can be traced through the various CRF Annual Reports for 1957 to 1973 or the regular scientific literature. The reviews by Poulson and White (1969), Quinlan (1970), White and others (1970) are useful syntheses of the information available in the later 1960s.

In CRF (1961), the following research activities were discussed: (1) Physical Geology, (2) Karst Geomorphology, (3) George Deike's Ph.D. research on cavern development and paleohydrology of the MCS, and his publications on these topics with Dr. White, (4) Mineralogy, and (5) Hydrology (though it was noted that dye tracing and the chemical analyses of water samples in Flint Ridge had to be suspended due to lack of funding and available manpower). "The work is time-consuming since tracing dye-laden water often necessitates continuous observations for periods extending over several weeks before dyed water appears at accessible points."

Reams (1963; 1965) examined, with CRF support, the origin of vertical shafts. He confirmed that these features, which rapidly conduct water vertically downward in the aquifer, were vadose in origin (Pohl, 1955). He also tentatively assigned ages to the vertical shafts in the Central Kentucky Karst based on time of formation determined from simple laboratory models (Reams, 1963; 1965).

Deike (1967) concluded that "the role of the trunks was to carry water from the Sinkhole Plain to the Green River.... The spring locations seem to have shifted very little since the caprock was breached. Trunk gradients are very low. This implies a very flat water table...." He also discussed the speleogenesis of the MCS relative to the control of various structural elements.

Deike and White (1969) determined that two types of conduit non-linearity were present in the MCS: "an angulate form generated by water flow down a hydraulic gradient diagonal to a rectangular joint set, and a curvilinear form with sweeping S-bends apparently related to meanders of surface forms." They then performed a statistical analysis of such forms in the MCS.

White (1969) proposed a classification of three types of carbonate aquifers in regions of low to moderate flow. Each flow type (and sub-type) had particular hydrologic controls, mainly the depth of soluble rocks beneath the land surface, and each flow type (and sub-type) had associated cave types, input settings, and degrees of sediment load.

Independent but interacting reviews by Poulson and White (1969), White and others (1970), and Quinlan (1970) reviewed the state of karst hydrogeology as of the late 1960s. These reviews discussed what was known, what remained to be learned, and synthesized much of the earlier work. These reviews and the community of scientists they helped build were particularly important in guiding the subsequent research efforts of CRF and the NPS Research Geologist.

Harmon and others (1972) characterized the waters of the Central Kentucky Karst based on chemical parameters. Water samples were grouped according to the calcite saturation index and the equilibrium pressure of CO_2.

Wells (1973), a student recruited by CRF from the University of Cincinnati, studied the geomorphological development of the Sinkhole Plain. Wells (1974) utilized equations of best fit curves to examine the relationships between: (1) current surface stream profiles prior to their capture at swallets, and (2) underground conduits between the swallets and the springs. He extended this information into a preliminary model of the origin and development of groundwater drainage patterns.

Dr. Franz-Dieter Miotke's pioneering work in the Central Kentucky Karst culminated in Miotke and Palmer (1972), Miotke and Papenberg (1972), and Miotke (1975). Miotke and Palmer (1972) noted chemical data indicate that "...most infiltration into the caves reaches the phreatic zone while still unsaturated...." Miotke and Papenberg (1972) reported the results of the first significant dye-tracing results, as follows.

> "The Sinkhole Plain in the vicinity of Pilot Knob drains both to the Green River and the Barren River. It is a potential source of groundwater pollution in MCNP and other intervening areas.... The pre-karst drainage pattern still influences the subterranean drainage.... Although the relationship between the pre-karst drainage pattern...and the subterranean drainage is obvious, the lack of springs occurring along the Barren River southeast of Bowling Green -- particularly to the south of the swallets of the sinking streams, from where the hydraulic gradient is steepest -- shows that the influence on the groundwater hydrology of not only the strike and dip of the beds, but also the lithology, cannot be denied.... A subterranean drainage divide lies between Little Sinking Creek and Sinking Creek.... If the subsurface flow

direction of water from the several sinking streams east of Gardner Creek is similar to that from the Creek..., it is most probably to River Styx Spring, Echo River Spring, and other springs east of Turnhole Bend Spring. Consequently, part of the water supply of MCNP may be polluted by water that enters the aquifer as much as 6 km south of the MCNP boundary...."

Significance of Research

Deike and White examined the origins of the caves within MCNP and performed some of the first morphometric studies of caves in the United States. White contributed the beginnings of an American synthesis concerning the types and characteristics of karst aquifers, an aquifer type little understood at that time. Both Wells and Miotke and Papenberg performed some of the first successful, modern dye traces in the region and also provided the first links between the development of the MCS and that of the Sinkhole Plain.

The results of this research provided the foundations for the research that would be done after 1973. The work of the Research Geologist (Quinlan, 1992, personal communication) at MCNP was most strongly influenced by: (1) Miotke's dye traces, (2) Hess's knowledge of springs, and (3) the review papers by White and others (1970) and Quinlan (1970).

1973 to 1989

Objectives

Individual scientists and CRF continued to pursue various research projects between 1973 and 1989. CRF continued work in support of its 1968 research plan. Various State and Federal agencies also performed research that included the Mammoth Cave Region and MCNP based on their own agency agendas. The North Shore Task Force, a group of volunteer cavers from Louisville, Kentucky, obtained permission from MCNP to carry out systematic exploration and mapping of the caves on the north side of the Green River in the park.

In 1973 MCNP hired a Research Geologist, James F. Quinlan, a scientist already familiar with the research being performed in the Mammoth Cave Region. This familiarity resulted from his own independent research in the region and in karst areas elsewhere and from his involvement with CRF. Quinlan (1977, 1991) retrospectively summarized his own research plan as follows:

> Principal research needs identified were: (1) delineation of groundwater basins in the park north and south of the Green River utilizing dye tracing and chemical hydrograph studies, and (2) determination of the variable times of travel from points outside the park to cave streams and springs inside the park. The research results "will be applicable to protection of cave fauna, including [endangered and threatened species],...visitor health and safety, and water quality.... The results are urgently needed in order to know the response time for the following: (1) reaction to accidental spills of hazardous materials along the nearby Interstate highway, other roads, and the major rail line between Louisville and Nashville, and (2) planning NPS responses not only to such accidental spills, but also to existing and proposed oil and gas production, drilling, and waste-disposal practices."

The work plan consisted of four major sub-projects (Quinlan, 1991). Phase I: dye tracing would be performed in order to: (a) delineate groundwater basins north and south of the Green River, and (b) refine the results of such dye-tracing. Phase II: regular chemical analysis of water quality at selected springs and cave streams would be undertaken in order to: (a) determine the natural variations that occur, (b) interpret what chemical processes and mixing processes occur in the aquifer between where water and pollutants enter the ground and where they are discharged at springs (which would allow prediction of dilution to be expected for spilled materials), and (c) calibrate instrumentation used for monitoring water quality -- and thus gain greater reliability for interpretation of water quality data. Phase III: the skills of Arthur Lange, who is a pioneer in the natural-potential method of locating conduits from the surface (Lange, 1988; Lange and Quinlan, 1988), would be utilized. Such remote location methods would assist in not only locating conduits that were inaccessible to human inspection and mapping, but also the siting of instrumentation in these cave rivers. Phase IV: computer-aided mathematical analysis and interpretation of data would be performed -- first using ground truth to model real data, and then, when the model accurately modelled these conditions, to using hypothetical situations to model adequate aquifer behavior and spill response. In 1988, Dr. Quinlan had begun negotiations to initiate a collaboration with Dr. Shirley Dreiss, a nationally recognized scientist in this aspect of hydrogeologic data analysis.

Projects

Many of the research projects that occurred between 1974 and 1989 are summarized in the Superintendent's Annual Research Reports, and in the CRF Annual Reports, including some of the projects that were not part of CRF's sponsored research Program. The work of the Drs. White and their students and coworkers is summarized in White (1988) and White and White (1989). The North Shore Task Force's effort expanded into scientific research concerning: 1) the distribution of caves and karst features north of the Green River (George, 1973; 1975; 1979), 2) other geomorphic and paleo-topographic features (George, 1982), 3) the geologic factors controlling cavern development (George and Schmidt, 1977), and 4) water quality issues (George, 1977). George (1985, 1989) are overviews summarizing this body of work.

Hess (1974), in his Ph.D. dissertation, presented the work that both he alone and he and Dr. White had performed in the Central Kentucky Karst on the following topics: (1) analysis of karst aquifers from spring hardness hydrographs, and (2) seasonal variations in the carbonate geochemistry of the waters of the Central Kentucky Karst. He examined spring hydrographs to investigate the flow system of the Central Kentucky Karst and the seasonal changes in the chemistry of the various waters in the area. Flood pulses were monitored for temperature and specific conductance, and variations were attributed to aquifer storage and back flooding by the Green River. Hess noted that when the precipitation input pulse was very sharp and well-defined in time, a considerable amount of resolution of fine structure from the different local inputs was observed. The fine structure found on the hydrographs could then be correlated with the various inputs arriving after different time delays. Finally, he concluded that: (1) the distinction between the local and the regional springs, drawn originally on geologic grounds, is also manifested in the water chemistry, (2) the thick soils of the Sinkhole Plain are the most significant source of CO_2 in the groundwater system, and (3) all waters trend toward a common level of undersaturation. Both vadose and base level (shallow phreatic) waters appeared to be undersaturated most of the time.

Hess and others (1974) identified 81 springs along the Green River using temperature and specific conductance measurements. Discharge was estimated for each spring so identified. The location of these springs became critical for the success of Dr. Quinlan's subsequent dye tracing.

Dr. Quinlan recognized immediately upon his arrival at MCNP that a study of the pollution in Hidden River Cave in Horse Cave, Kentucky, could provide not only insight into the groundwater hydrogeology of the region, but would also provide data to justify the comprehensive research that he envisioned for the region. This work was supported in part by the Water Resources Research Institute at the University of Kentucky and by local and regional banks and businesses, and it resulted in the publications of Quinlan and Rowe (1977; 1978) and Quinlan and Ray (1981; 1989). These results showed that heavy-metal-laden water from the cave, instead of going to the expected one or two springs, actually appeared at 46 different springs at 15 locations along a five-mile (8-km) reach of the Green River, the first documentation of a distributary system in a karst region. By 1978, after more than 250 dye traces, Quinlan and Rowe had also partially delineated 15 groundwater basins in the Central Kentucky Karst, 11 of them characterized by distributary flow.

In 1979, Dr. Quinlan determined that effluent from Park City flowed into portions of MCS in MCNP through a major drainage trunk for the region, and that flow conditions determined which route was utilized. Under conditions of low flow, the water flowed northwest and then west just to Cedar Sink and Turnhole Spring via Proctor Cave and Logsden River. During moderate flow and flood-flow conditions, however, water took a high-level overflow route downstream from Proctor Cave and also flowed to both Echo River (within the tourist section of the MCS in MCNP) and Sand Cave on Turnhole Bend in MCNP (Quinlan, 1979; Quinlan and others, 1983). This was the second documentation that groundwater flow routes varied with base-flow and flood-flow conditions, and that effluent could cross groundwater drainage divides during flood conditions.

Quinlan (1980a; 1982a,b) described: (1) the occurrence and movement of groundwater in the karst aquifer of the Central Kentucky Karst, (2) the flow of heavy-metal-laden and creamery-waste effluent through the aquifer, (3) the various tracers utilized, (4) the construction of a potentiometric-surface map based on water levels in 1,500 wells during base-level conditions, and (5) the delineation of 27 groundwater basins within the karst aquifer in the 740-square-mile (1,900-km^2) area south of the Green River. These basins were delineated by utilizing the results of more than 400 dye traces, 1,500 water-level measurements, and mapping of approximately 300 miles (480 km) of cave passages by CRF, the Central Kentucky Karst Coalition, Dr. Quinlan's research group, the Fisher Ridge Project, and several others. He also described the beginning of instrumentation efforts in five different cave streams, several springs, and along the Green River to monitor stage, temperature, conductivity, flow velocity, precipitation, and chemical hydrology. He concluded that such information would: (1) be valuable for the examination of aquifer properties, (2) facilitate the prediction of flow rates, and (3) expedite the computer simulation of aquifer behavior under a variety of conditions.

The publication of Quinlan and Ray (1981; 1989) was the initial culmination of what Quinlan conceived as Phase I of his research plan. This map delineated the groundwater characteristics in the Central Kentucky Karst. Constructed using techniques described in detail in Quinlan (1981; 1982b), the map showed the potentiometric surface, inferred groundwater flow paths (based on tracer flow routes drawn perpendicular to potentiometric contours), springs, cave passages, and the boundaries of 28 groundwater basins and seven sub-basins.

This map could be used to identify catchment areas that might affect the water quality of any of the springs and cave streams shown. It could also be used to predict not only the dispersal route of any hazardous material that might be discharged into the ground or spilled accidentally, but also what water supplies might be adversely affected by such discharges or spills. For example, the map shows that MCNP and the MCS within MCNP could be affected by anything that pollutes groundwater in the following basins: the Turnhole Spring, the Echo River, and the Pike Spring groundwater basins, and any associated sub-basins. The map demonstrates that troughs in the potentiometric surface correspond to zones of maximum groundwater flow, and the coincidence of major underground rivers with such troughs in four instances serves to strengthen that conclusion. Finally, this map set a new standard for the mapping and management of groundwater drainage basins in karst regions. To our knowledge, it has not yet been equalled by any other workers in the world.

Quinlan and Ewers (1981a,b) and Ewers and Quinlan (1981) synthesized the current state of knowledge of the groundwater hydrology of the Central Kentucky Karst by addressing the development of the MCS through time. They also described the development and characteristics of the largest groundwater drainage basins in the region (Graham Springs, Bear Wallow, and Turnhole Spring). They documented the headward capture of drainage from one basin to another in several of the groundwater drainage basins. Palmer (1975; 1981), contributed valuable information concerning the lithologic and structural controls on the paleoconduits. This information guided Quinlan and Ewers (in their various publications of 1981) to describe a possible scenario for the development of the currently active groundwater conduit networks.

Quinlan and others (1983) added further insight into understanding the groundwater drainage basins and springs in the Central Kentucky Karst by describing Waterworks Spring in the Graham Spring groundwater drainage basin, the only known perennial, diffuse-flow spring in the region. Their recommendation for the emphasis of future work was "...on interpreting the results of instrumentation to monitor the stage, discharge, and water chemistry of cave streams that drain to the park. This data will be coupled with data from a rain-gauge network and soil-moisture records and various other computer-assisted procedures. It is expected to yield a unique understanding of how groundwater moves within this aquifer and of specific characteristics of its individual conduit elements."

Palmer (1985) provided a synthesis of the geologic setting of the Mammoth Cave Region. He also presented information concerning hydrologic controls of cave patterns, describing the general characteristics of the caves based on their occurrence: (1) in high-level recharge areas, (2) along major phreatic drainage lines, and (3) at the downstream ends of catchment areas. He described the relationship of the karst features and caves to the geomorphic development of the Mammoth Cave Region, including dates of formation of the various vertical levels of the cave passages. Based on his analysis of the linkage between karst and surficial features, Palmer determined that the oldest passages in the MCS began forming during the late Tertiary and early Quaternary periods, He further proposed that the Sinkhole Plain also formed during the Tertiary period.

Quinlan and Ewers (1985), was a synthesis of observations made in the Central Kentucky Karst and elsewhere. It was a major effort to expand the monitoring of groundwater in karst terranes into a more standardized, utilitarian procedure. In this paper, they discussed the nature and characteristics of flow in karst aquifers, and observed that "...springs, rather than wells -- are the most logical, efficient, reliable, and economical places to monitor for pollutants in limestone terranes [from the abstract]." The oft-quoted analogy made in this paper has done much to convey the perplexing nature of designing a monitoring program in a karst aquifer to someone not familiar or experienced with such things: "The probability of a randomly-drilled monitoring well intercepting the trunk conduit which drains a groundwater basin is similar to the probability of a dart randomly thrown at a wall map of the United States hitting the Mississippi River!" This paper's unambiguous and lucid explanation of the problems of groundwater monitoring in karst terranes made a major change at the national level in groundwater monitoring in karst areas.

Quinlan and Ewers (1989) was the next major synthesis of the groundwater data and included not only results of the continuing dye tracing, but also results of the initial information gathered from the instrumentation network. Furthermore, they detailed the effects of the May 1984 flood on the Turnhole Spring groundwater basin's flow patterns, which basically involved the shunting of water from a once-active spring (Turnhole Spring) to an adjacent set of springs that used to drain a separate groundwater basin (Sandhouse Cave Spring, Stilling Well Spring, Notch Spring, and Knob Spring). This event also affected the Turnhole Spring in that, since the May 1984 event, it periodically closes with sediment and re-opens, affecting the stage of base-level streams in the MCS and elsewhere by as much as 12-35 inches (30-90 cm) during a 48-hour period.

Hess and White (1989) described the water budget and physical hydrology of the Central Kentucky Karst, noting that base-level backflooding provides a major source of recharge to the karst aquifer. Backflooding was observed to extend to a distance between 0.3 to 1.1 miles (0.5 and 1.7 km) into the MCS from the Green River. They elaborated on the observations made by Hess (1974) concerning storm hydrograph response in the Central Kentucky Karst aquifer, and noted that the hydrographs reveal a considerable amount of detail, including "...a surprising amount of fine structure." Aquifer relaxation and storage were examined, and it was determined that aquifer recovery times were approximately two to three weeks for the Turnhole Spring groundwater basin. The amount of water held in temporary storage in this basin was calculated to have been between 663 and 1,080 million ft^3 (18.8 and 30.6 million m^3) respectively for two separate storm events.

Significance of Research

The significance of the research has been multifaceted, as the research itself has been. The research has proven its value in the protection and management of MCNP, the MCS, and the Central Kentucky Karst, and has won national and international recognition. The principles of groundwater movement in a karst terrane that were discovered during this time are being applied to the protection of the many other karst aquifers throughout the U.S. and the world. This applicability is also true for the techniques and technology developed to perform the research, and these are serving as guides for other researchers in many karst areas.

Drs. Quinlan and Ewers were awarded the Geological Society of America's 1986 E.B. Burwell, Jr., Memorial Award for their paper, "Groundwater flow in limestone terranes: Strategy, rationale and procedure for reliable, efficient monitoring of groundwater quality in karst areas" (Quinlan and Ewers, 1985). This award is given annually for a published paper of distinction which advances knowledge concerning the principles and practices of engineering geology (Beck, 1987). As approximately 20% or more of the United States is underlain by karst terrane, the paper not only impacted research efforts at MCNP and in the NPS, but also nationally (Quinlan, 1989) and internationally.

Applications of the Research

The applications of the recent research have been as follows (quoted directly from Quinlan and Ewers, 1989).

1. Design of a $14 million regional sewage-treatment system for MCNP and the towns of Horse Cave, Cave City, and Park City. [Work on this project is halfway completed, with Park City and MCNP still to be connected.]

2. Response to spills of hazardous materials among Interstate 65 (an average of 1.5 per year, described in Quinlan, 1986b).

3. [Development of] a strategy for reliable monitoring of pollutants in karst terrains (Quinlan and Ewers, 1985).

4. Interpretation of the geomorphic history of the Mammoth Cave area.

5. Environmental protection for MCNP.

6. Regional planning for solid-waste disposal and concomitant protection of groundwater supplies and the blind Kentucky Cave Shrimp, Palaemonias ganteri (Hay), which is on the Federal Endangered Species List.

Contributions to the Body of Scientific Knowledge

In addition to the above, there are four concepts of groundwater movement that have been recognized previously in other karst terrains, but are now described in the Mammoth Cave Region in more extensive and detailed nature than anywhere else. These are as follows (quoted from Quinlan and Ewers, 1989):

1. Distributary flow.

2. Shunting of water by high-level overflow routes [often into adjacent groundwater drainage basins].

3. Shared headwaters [of groundwater drainage basins].

4. Location of all major stream caves in troughs on the potentiometric surface and, likewise, association of all major troughs with axes of trunk drainage in the subsurface.

New Hydrogeological Concepts Resulting From National Park Service-Sponsored Research

The first concept involves a new technique, rather than a new concept, and has made a significant impact on the practice of dye tracing in karst terranes. "The Hidden River groundwater sub-basin of the Bear Wallow groundwater drainage basin was the site of the first attempt, in 1977, to use the presence of optical brighteners and heavy metals in spring water as a prospecting tool in the search for effluent from a sewage-treatment plant (Quinlan and Ewers, 1989)."

The remaining concepts represent significant first-discovery situations in the field of karst hydrogeology (quoted directly from Quinlan and Ewers, 1989). They are:

1. Deliberate injection in North America of optical brightener as a tracer.

2. Application of CI Direct Yellow 96 as a tracer (Quinlan, 1977).

3. Published maps showing the relations between surface drainage, numerous dye traces, the potentiometric surface, springs, mapped caves, and groundwater basins in a karst terrain (Quinlan and Ray, 1981; 1989).

4. Use of low-frequency electromagnetic induction equipment to locate sites for successful drilling of wells to monitor cave streams at depths ranging from 130 to 470 ft (40 m to 143 m).

5. Continuous monitoring for stage, conductivity, velocity, temperature, rainfall, and soil moisture at a genetically related series of sites. (Pioneering work on continuous monitoring of conductivity and temperature of a spring and a cave stream, plus stage of the Green River....). [NOTE: This system, designed by Dr. Ralph Ewers and Dr. Quinlan, is known as the Karst Waters Instrumentation System or "KWIS".]

6. The discovery of aquifer storage in bedrock in karst aquifers. This discovery was made by interpretation of water level data from wells drilled into and near Mill Hole [one of the first applications of digital data acquisition at MCNP].

7. The strategy of monitoring for pollutants in karst terrains at springs and cave streams (begun by Quinlan and Ewers, 1985, 1986a) and continued by the creation of the U.S. Environmental Protection Agency standard guidelines for monitoring in a karst terrain (Quinlan, 1989).

Other Benefits

The NPS's Southeast Regional Chief Scientist Dr. Dominic Dottavio, and Assistant Regional Director Robert Deskins both commented on the importance of a subtle benefit of Dr. Quinlan's stay at MCNP (Dottavio, 1991; Deskins, 1991). The resolution of Dr. Quinlan's 1975 grievance had an impact on how science was done throughout the entire NPS. One of Dr. Quinlan's grievances was that the MCNP Superintendent at that time would not allow Dr. Quinlan to conduct any research outside of MCNP boundaries (in accord with NPS management policies in force at the time). This policy was enforced even though his position description specified that Dr. Quinlan was to extend his research beyond park boundaries, and he could demonstrate that water and pollutants in the MCS within MCNP came from outside MCNP. The resolution of that particular grievance gave Dr. Quinlan permission to perform his dye tracing wherever he felt it was necessary, in other words, wherever the water led him. The decision, based on an opinion rendered by the Regional Solicitor, that Dr. Quinlan did indeed have the right to perform scientific research outside a park unit when justified became a precedent for other NPS scientists when they encountered managers who were similarly opposed to work outside of park boundaries.

Future Research Objectives

Dr. Quinlan had planned to continue his research objectives, but in an expanded form. According to Quinlan and Ewers (1989) and personal communications with Dr. Quinlan in 1989, the highest-priority research at that time was Phase II of his research plan: the maintenance and interpretation of data from the KWIS network. It was Dr. Quinlan's goal to have 18 or more KWIS instrumentation packages installed within one to two years in a variety of locations to cover different land-use practices, different areal geology, different surficial recharge and discharge characteristics, different aquifer characteristics such as diffuse-and conduit-flow regimes, and other categories. A rain-gage network was scheduled to be installed. The information generated by these networks would provide specific information on the movement of pulses of water (and therefore pollutants) through the aquifer in response to various environmental conditions (type and amount of precipitation, stage of both the Green River and groundwater, hydrogeochemical facies setting, physical and chemical nature of the pollutant, etc.). These results would provide invaluable insight into not only how this particular aquifer behaves, but also would provide the information necessary to develop specific response protocols and modelling for toxic or other pollutant spills in the region.

Karst aquifers cannot be modelled using standard, porous-media computer methods, and efforts to simulate karst groundwater systems are still in their infancy. Without verified models, groundwater flow velocities and pollutant movements in karst terranes are impossible to predict. The information provided by KWIS would give further insight into the operative physical processes and would provide necessary data for model calibration and verification. It was Dr. Quinlan's goal to gather a substantial, statistically significant body of KWIS data, and then to arrange for others skilled in mathematical interpretation of water quality data, such as Dr. Shirley Dreiss, and several modelers to create an accurate computer model for the Central Kentucky Karst. This collaboration could have provided not only the first such simulation and model of its kind in the world, but also a management tool without equal for the NPS and the governments of the Central Kentucky Karst in protecting their shared groundwater and cave resources.

Of the 18 KWIS instrumentation units that had been planned, four had already been installed by Drs. Quinlan and Ewers, and the parts for much of the rest remained in storage, awaiting assembly and installation. As will be detailed in the section, "The Interaction of NPS Karst Hydrogeologic Research and Management", Dr. Quinlan left the employment of the NPS in 1989. At Dr. Quinlan's departure, implementation of his research plan ceased. Without the KWIS network fully installed and operating, computer modelling to meet the NPS goal of creating spill response protocols, therefore, is no longer feasible on any reasonable time scale or with any reasonable accuracy.

1989 to 1991

The previous 16 years of karst hydrogeologic research was conceived and implemented by a Research-grade scientist with an extensive education and broad experience who was able to conceive and visualize long-term research needs within MCNP and the surrounding region. In the fall of 1988, the Superintendent established a new research structure which he directs. The new structure was initially titled the Office of Science and Resource Management. The Office was formally approved by the Southeast Regional Office in January 1989 and was elevated to full Division status in January 1991. The Division's activities are planned and executed by individuals with B.S. or M.S. degrees and substantially less experience in karst hydrogeology than Dr. Quinlan possessed.

The four KWIS units installed by Drs. Quinlan and Ewers are in the field, but two are non-functional from storm damage and there are no plans to repair them (Meiman and Ryan, 1991). The data set generated by the operating units (a stack of computer disks approximately two feet tall) is an invaluable data set that, if analyzed, could improve the understanding of how pulses of water and pollutants move through the aquifer system under various conditions. The data disks are stored, unanalyzed, in a file drawer.

Data loggers and platinum resistance thermometers have been installed in one of the small caves in the park. This cave contains a large colony of bats and is recognized to serve as an important bat habitat. Parts of a KWIS unit is being used to monitor atmospheric conditions. Portions of two other KWIS units are in the MCS on a tourist route, monitoring environmental conditions there, primarily the atmospheric impacts of a food service operation in that part of the cave. One customized KWIS unit was used for a temporary project at Cumberland Gap National Historical Park in 1990. The components of the rest of the KWIS units are in storage at MCNP. Knowledge of instrument installation, design, and programming of data loggers and related probes will and is being exported to other park areas (Meiman and Ryan, 1991).

Other scientists are continuing their research programs at MCNP and in the Mammoth Cave Region. Much of this work is not yet published, but a number of summaries can be found in the Annual Reports for CRF for the years 1989 to 1990.

Objectives

<u>MCNP Water Quality Monitoring Program:</u> This new program was initiated in 1990, with the intention of monitoring water quality in MCNP (Project # MACA-N-020 - funded, and MACA-N-021 - unfunded) (MCNP, 1990; Meiman, 1990a,b). It is these programs that are currently the primary thrust of karst hydrogeological research at MCNP.

MACA-N-020 was designed to determine the existing water quality of the Green River drainage basin (surface and subsurface) and to monitor trends in base-flow and event-related water quality. Included in this is the identification of: (1) existing base flow ("chronic") and event-related ("acute") water quality problems in the Green River drainage basin, and (2) the potential pollution sources and problems. Part of the goals of the study is to determine the level of compliance with government water quality standards, and to collect data that will assist in the determination of existing water quality impacts on the biological, aesthetic, and recreational resources of MCNP.

In addition to the water quality monitoring program described in the preceding, delineation of the primary groundwater basins on the north side of the river is a high priority. Additional instrumentation is to be developed and added to the monitoring network, and a generalized aquifer vulnerability map is to be created. Sampling methods will be evaluated and modified as needed. Also, the project is to develop methods for determining whether or not specific high bacterial "events" are attributable to human sewage inputs, and to determine sample parameter(s) and analytical method(s) to reliably establish when a public health threat exists. Supplemental to this program will be the monitoring of herbicides utilizing the same sampling sites and methodologies.

These are all valid goals, that echo Dr. Quinlan's research plans, particularly those utilizing the KWIS network. However, the methodology, sampling intervals, and analytical standards will neither meet these goals nor current "industry" standards set by the U.S. Environmental Protection Agency and leading researchers in karst hydrogeology around the country. For example, sampling frequencies of once a month will not provide the information necessary to make detailed and accurate observations concerning this exceptionally dynamic aquifer. These sampling intervals are prone to miss significant events on a regular basis. Hence, the generalized studies proposed will not produce the specific products both proposed and required for resource management and protection (i.e., aquifer vulnerability maps). Without expanding the KWIS network, the event-specific goal cannot be met.

MACA-N-021's goals are to further develop methodology that would be effective in pollutant remediation where access to the polluted conduits is possible. Effective methods to locate additional primary conduits will also be developed and utilized. To further the research plan, adequate access to all known primary conduits is proposed to be developed and/or secured. Finally, emergency spill-response capability will be developed in MCNP.

Quinlan and others (1990) clearly stated doubts that the goal of pollution remediation in a karst aquifer as described above could ever be possible. The goal of locating additional primary conduits is a direct statement of one of Dr. Quinlan's research goals, utilizing the skills of Arthur Lange. There is an ongoing concern, however, that drilling new entrances into a conduit might enhance the vertical flow into it via the new entrance or monitoring wells.

Current Projects

The delineation of groundwater basins on the north side of the Green River is a project that Dr. Quinlan estimated was approximately 70% complete in early 1989 (Quinlan and Ewers, 1989, p. 66). This information was obtained to construct a regional-scale map, to compliment the Quinlan and Ray (1981; 1989) maps. A draft manuscript of that map exists and has been sent to MCNP (Quinlan, private communication, 1992). However, little of that tracing was done inside MCNP north of the Green River. Between March 1990 and January 1992, MCNP staff have conducted over 65 traces designed to delineate the groundwater basins north of the Green River, inside MCNP (Ryan, 1991, 1992; Meiman and Ryan, 1991). This major effort is continuing.

Another emphasis of the current research program is technology development. Ryan's (1991a, 1991b) development of a submersible, filter fluorometer instrumentation to allow continuous, quantitative monitoring of dye pulses is a noteworthy effort. This will aid in the dye tracing activities north of the river and other dye tracing activities south of the river. The dye tracing efforts that resulted in Quinlan and Ray's (1981; 1989) maps was qualitative, with limited time resolution. Ryan's (1991a, 1991b) initial results demonstrate that quantitative tracing with KWIS-based, continuous data acquisition represents a significant new step in understanding the conduit systems of MCNP.

The final research program in karst hydrogeology, as identified by the Park Hydrologist (Meiman and Ryan, 1991), is to document the flow reversals between the River Styx and Echo River based on Green River stage. This is considered to be a part of the emphasis on emergency spill response. This phenomenon has been documented in reasonable detail in Quinlan and Ewers (1981a), but it will be useful to know at what stage of the Green River that overflow occurs into Echo River.

A related research emphasis on "bio-monitoring" is described in MACA-N-020 and 021. Bio-monitoring is defined to be the identification and study of fauna both within the base-level rivers of the MCS and the Green River that are sensitive to various pollutants and which, therefore, may be indicators of the presence of that pollutant by population changes or complete disappearances of the species. It is a highly useful and validated technique. However, bio-monitoring research at MCNP was initiated 30 years ago and continues currently in the scientific studies by both Dr. Thomas Poulson and his graduate students and Dr. Julian Lewis, and has been copiously reported on in print. A summary may be found in Poulson (1990) and Lewis (1990). This is a funded project, but the absence of any reference to this relevant background material raises a concern about the current park staff's lack of knowledge of pre-existing and/or ongoing research in pertinent research fields.

Significance of Current Research

It is too early to evaluate the ultimate impact of the current research, because it is ongoing and only time will show how valuable it will prove to be. Much of the current research is focused on what are perceived to be immediate management concerns, but useful results are beginning to appear at appropriate professional meetings (Meiman, 1990a,b; 1992; Ryan, 1991, 1992). However, the change in emphasis from long-term research conceived by a highly qualified set of scientists to short-term research conceived in large part by the park Superintendent and two scientists with far less experience raises concerns about the long-term significance of the current research.

4
THE IMPACT OF RESEARCH ON NATIONAL PARK SERVICE MANAGEMENT

Scientific research and long-term resource monitoring have profoundly affected the management and managers of MCNP. Research has totally changed the boundary conditions of the management task facing the Superintendent. In the 1960s, it was possible for the Superintendent to believe that the rest of the region had no affect on the Park. Therefore, the Superintendent was able to manage in isolation what many assumed to be a nondescript show cave in Central Kentucky. In the 1990s, however, the MCNP Superintendent faces the daunting task of administering a National Park that has the following attributes and management challenges.

(1) It is a world-class resource that is part of the longest and best-documented cave system in the world.

(2) It contains unique, rare, and threatened biota.

(3) It is being profoundly impacted by NPS activities, concessionaire operations, visitors, and human activities in the region outside of the Park.

In addition, researchers have shown that many of the technical and regulatory tools used by society to manage resources are not effective in karst regions. Finally, the results of scientific research often seem to change the rules with new discoveries faster than the managers can assimilate and react. As a result of these new boundary conditions, the Superintendent has only a limited ability to "preserve and protect" the resource he or she is charged to manage.

The reactions of the individual Superintendents to the research performed at MCNP, the MCS, and in the Mammoth Cave Region have depended upon their individual skills, philosophy, and management style. Although none of the MCNP Superintendents thus far have had a scientific background, two MCNP Superintendents, Amos Hawkins and Robert Deskins, both recognized the value of the research being done both prior to and during their tenures. These men maximized the results of this research by initiating and then solidifying a regional partnership in the Central Kentucky Karst. The research, and specifically the dye tracing, performed by Dr. Quinlan demonstrated clearly the need for a regional sewage treatment project to protect the groundwater resources and, hence, the caves, of both the region and MCNP. This resulted in the creation and development of the Caveland Sanitation Authority (CSA), a regional sewage treatment authority designed to serve Horse Cave, Cave City, Park City, and MCNP. The system for Horse Cave and Cave City was completed in 1989.

Neither MCNP nor Park City, the primary source of pollution for the MCS within MCNP, have been hooked into the system yet. Details of this cost-sharing partnership may be found in Mikulak (1988).

The successes of these two individual Superintendents demonstrate that productive partnerships between management and scientific research are possible within the NPS. In both cases, the Superintendents did not try to manage the research. Rather, they allowed the scientists involved to manage the details of the scientific research, and the Superintendents only managed the administrative details. They used the scientific results as a basis for innovative management of the resource by seeking out the best available scientific information from their own and outside sources. They welcomed that information and assimilated it into their management decisions. Finally, they forged effective partnerships by enlisting the participation of scientists and other skilled professionals in their management teams. The successes of Mr. Hawkins and Mr. Deskins can be measured in the increased prestige and value of MCNP at the local, regional, national, and international levels.

The attempt to relocate the MCNP headquarters buildings and visitor center onto Joppa Ridge is a specific illustration of the use of scientific research results in complex management decisions. Since the dedication of the visitor center and headquarters complex in 1966, visitors have been concentrated at these facilities, which are located near the Historic Entrance to the MCS and directly above the cave itself. According to the General Management Plan (MCNP, 1983, p. vi), "from 1965 to 1975, the Historic Entrance area was heavily congested with cars and people throughout the summer season and on peak travel days in spring and fall. In an attempt to relieve congestion occurring at that time, the 1976 Master Plan evaluated several alternative solutions. Based on existing conditions and available information, a preferred alternative was selected that proposed developing a staging area at the periphery of the park near Union City [on Joppa Ridge]. In concept, this staging area would concentrate parking and basic visitor services in a less fragile area of the park away from the entrances to the primary cave system [i.e., the MCS]."

However, the discovery of Logsdon/Hawkins River underneath Joppa Ridge in 1979, demonstrated that a major cave system lay beneath the proposed staging area. Both Roger Brucker and Bob Deskins (personal communications, 1991) stated that in 1979, Dr. Quinlan had proposed keeping the visitors center and headquarters complex near the Historic Entrance in the downstream portion of the groundwater basin. Relocating the staging area to Joppa Ridge would have moved it into the upstream portion of the groundwater basin. Pollution associated with the staging area would then affect a larger section of the cave system. If pollution occurred, it would be better to have it occur closer to the Green River, thereby minimizing the travel distance through the cave and impact on the cave system. In light of the difficulties identified by research, the concept of a staging area on Joppa Ridge was removed from the 1983 General Management Plan. The new cave discoveries and a drop in visitation were cited as the reasons for the change. The 1983 General Management Plan was developed by an NPS planning team from the park, region, and Denver Service Center (DSC). The planning team captain was W. Drew Chick, Jr., of DSC. Mr. Deskins was a team member and, as Superintendent, the Recommending Official.

In contrast to the successes, other Superintendents were disinterested or hostile to research performed by various groups at MCNP. In the absence of productive partnerships, research was often done in spite of park management. When the park management did utilize research results, they were not utilized as fully as the various researchers involved would have preferred. Dr. Quinlan, for example, often had to perform his research in the face of NPS management support that ranged from minimal to hostile. This situation existed with the current Superintendent, who occupied this position prior to and during the time when Dr. Quinlan resigned. On the other hand, this Superintendent is supportive of the current activities of the Division of Science and Resource Management (which he created). The Division Chief and the Division employees are generally satisfied with management support, though they are continually faced with less funding than they would like and feel they need.

A MCNP management stratagem employed by several Superintendents has been to try to ignore the research results. For example, CRF would often approach a MCNP Superintendent with information in the form of cave maps produced by their cartographic program and the Superintendent would expressly tell the CRF members that he did not want to know -- he already knew more than he cared to about the cave. One Superintendent early in the history of CRF's involvement at MCNP told CRF that he would just as well prefer to have "the damn entrances blown shut" (Roger Brucker, 1991).

Another example involves the pretense that the cave does not extend beyond the park boundaries, which allowed park management to avoid confronting the controversial land acquisition issue for several decades. However, this pretense is no longer viable. In the current Resource Management Plan (MCNP, 1990), Project #MACA-N-052 (proposed but unfunded) involves development of specific strategies to protect external cave resources (i.e., those that lie outside of MCNP boundaries but are integrated parts of the MCS). This project represents an attempt to begin addressing the land acquisition issue. NPS management is acknowledging that many miles of the MCS and several entrances are in unacquired lands that lie within the originally authorized boundary. The present Land Protection Plan does not address this issue. The Southeast Regional Office, citing the policy of the Secretary of the Interior to only address "perceived inholdings", deleted the park's proposal to include this issue in the Land Protection Plan. Although the enabling legislation for MCNP indicates that the legislative intent was to protect "all the caves," several cave systems that are now connected with the MCS lie outside the authorized boundary. MACA-N-052's recommended action is stated as follows.

> "The Land Protection Plan should be updated to propose acquisition of appropriate interests to insure the protection of all of the lands within the authorized boundary of MCNP and those interests should be acquired. This action would complete the intent explicitly expressed by Congress in establishing the park, and would provide for protection of perhaps more than 100 miles of currently unprotected [sections of] the MCS, several cave entrances, and a relict plant community.... Additionally, alternatives for appropriate protection of the portions of the MCS that lie outside of the authorized boundaries should be developed."

Management has recognized that it can not protect that which it was mandated to protect, and has decided to pursue additional land acquisition to fulfill its mandate. (MACA-N-052's proposed budget is $4 million over four years.) Such attempts will increase the local conflicts for MCNP and the NPS, because the human infrastructure surrounding MCNP has significantly expanded in the years since Mammoth Cave became part of the National Park System. The ultimate resolution of these plans will be more financially and politically expensive than it would have been in earlier decades.

The ignore-the-research management approach can succeed <u>for the Superintendent</u> if he or she is rotated to a new position before any detrimental effects revealed by the research have an impact on the resource. This approach fails <u>for the Park</u>, however, because it leads to reversals of management decisions, squanders valuable time and resources, and allows others, usually non-NPS personnel, to manipulate the park to their advantage.

The NPS often expends its limited resources repeating the research of other (previous and/or contemporaneous) workers. Several proposed and/or active NPS research projects at MCNP will repeat the research that has been done by individual scientists, volunteer organizations, Dr. Quinlan, and researchers with other agencies and industry. MCNP management appears to lack interest in or knowledge of many non-NPS research projects conducted in the Park. Much of this outside scientific expertise is readily available to the NPS management for little or no cost.

During an interview in July 1991, Roger Brucker stated an excellent summary of the interactions of scientific research and management that is worth repeating here. He felt the resources at MCNP and in the MCS were an excellent metaphor for the difficulty of science and management interactions because "all of it is underground and remains hidden from view most of the time," which is the "central characteristic of these particular resources." In other words, science/management interactions are more susceptible to conflict because "out of sight, out of mind - if you can't see the impact, it, in fact, doesn't exist."

5
THE IMPACT OF NATIONAL PARK SERVICE MANAGEMENT ON RESEARCH

Some impacts of NPS management on long-term scientific research and monitoring have been positive, however, the impacts have often been negative. Arguably, the most positive impact was the original decision to hire a Research Geologist at MCNP. While the Research Geologist produced the outstanding scientific results outlined above, he also was the center of two long-term disputes with NPS management. This conflict between Superintendents and the Research Geologist appears to be a fundamental consequence of the current NPS management structure and recurs at a variety of scales and intensities. Some of the particulars of this conflict at MCNP are reviewed below to illustrate the pitfalls associated with the current management structure that does not naturally produce the continuity required by long-term research, and to help identify solutions that will encourage successful long-term monitoring and scientific studies in the NPS.

THE CREATION OF THE RESEARCH GEOLOGIST POSITION

According to NPS Assistant Southeast Regional Director Robert Deskins (personal communication, 1991), the MCNP Research Geologist position resulted from discussions between the MCNP Superintendent, the Chief Naturalist, and himself, then MCNP's Assistant Superintendent. These meetings began in 1972 because of park management's recognition of the need for scientific research to facilitate and improve resource management within the park. The decision reached in these meetings was to create a Research Geologist position. The position itself and the funding for it, however, have always come from the Southeast Regional Office. According to the position description (Quinlan, 1975), the Research Geologist was to be supervised in the following manner.

> "...receives general administrative supervision from the Superintendent, GS-14, but has wide latitude for professional independent judgment and action. Plans, executes, and evaluates research independently, [emphasis added] subject to management review by Superintendent and Regional Director. Exercises initiative and assumes responsibilities with limited technical supervision from Regional Scientist. Maintains close functional ties with the Regional Chief Scientist, Southeast Regional Office."

Three candidates applied for the position, two NPS employees and one geologist from outside of the NPS, James F. Quinlan. Before making his final selection, the MCNP Superintendent solicited the review and input of the scientific staff of CRF. CRF offered the opinion that James Quinlan was the best qualified candidate of the three for the position (Sides, personal communication, 1991). He was offered the position in late 1972. However, due to personnel ceilings and a hiring freeze, he was not officially hired until July 26, 1973. [James Quinlan had completed all but the thesis requirements for his Ph.D. and had finished a three-year post-doctoral research appointment before he began to work at MCNP. However, his thesis was not finally completed and his Ph.D. granted until 1978.]

THE TENURE OF THE NATIONAL PARK SERVICE RESEARCH GEOLOGIST

Dr. Quinlan's initial grade was a GS-11 (subject to furlough). He reported directly to two individuals: (1) the MCNP Assistant Superintendent (GS-13), who was his administrative supervisor, and (2) the Regional Chief Scientist, who acted as his technical and scientific supervisor.

Dr. Quinlan (1991) quickly realized the regional nature of the groundwater and cave resources, but MCNP Superintendent Joseph Kulesza (GS-14) (Superintendent from 1970 to 1976) constrained him to perform research only within the boundaries of MCNP. This was the same constraint that CRF worked under at this time in their investigations and mapping in the MCS and was consistent with NPS management policies in force at that time. There were other administrative needs for science that management was unresponsive to according to Dr. Quinlan. These conflicts escalated into a formal grievance (Quinlan, 1975) against MCNP Superintendent Kulesza. In addition to the Superintendent's refusal to allow research outside of park boundaries, other major grievances involved what Quinlan (1975) felt were instances of censorship and suppression of scientific reports by the Superintendent, cases where Quinlan was forbidden to and prevented from contacting the Regional Chief Scientist, difficulties in accommodating the flexible schedule required by the research, etc.

The Regional Chief Scientist, Dr. Ray Herrmann, supported Quinlan's (1975) grievance and Quinlan believed that he won 99% of it. In the resolution, he was assigned to the Uplands Research Laboratory at Great Smoky Mountains National Park, with his work location at MCNP. His direct supervisor became the Regional Chief Scientist, who also was to review research objectives with Dr. Quinlan. Only general administrative supervision was provided by the MCNP Superintendent. Dr. Quinlan was thus able to independently develop and conduct the research program within the limitations of the resources made available (Quinlan, 1986a).

There is disagreement on the format of the grievance resolution, however. Mr. Deskins (personal communication, 1991) believes that the resolution was informal and not written. Conversely, Dr. Quinlan (1991) believes that there was a formal, written resolution, but efforts by Dr. Quinlan, Mr. Deskins, and the authors to obtain a copy of this document have been unsuccessful. This lack of clarity concerning the nature of the resolution has plagued the relationship between Dr. Quinlan and the NPS since 1975.

Dr. Quinlan filed his grievance against Superintendent Kulesza. According to Mr. Deskins (personal communications, 1991), once Superintendent Kulesza left MCNP in 1976 and a new Superintendent, Amos Hawkins, took over, direct supervisory control of Dr. Quinlan returned to the MCNP Superintendent and remained there until Dr. Quinlan received a second grade promotion in 1986 (his first grade promotion was in 1979). This change in supervision, Mr. Deskins believes, was primarily a result of personnel ceilings imposed within the Regional office during the administration of President Jimmy Carter (1976-1980). President Carter was committed to decentralizing government, and so regional office staffs were cut and park unit staffs were increased.

When Superintendent Hawkins was transferred in 1979, Robert Deskins became MCNP Superintendent. President Reagan (1980-1988) dropped the decentralization policy of President Carter. At that point, Dr. Quinlan could have been transferred back to the supervision of the Southeast Regional Office and the Chief Scientist, had he filed for such action. However, during the tenures of MCNP Superintendents Hawkins (1976-1979), Deskins (1979-1985), and Pridemore (1985-1988), the value of Dr. Quinlan's research was recognized and the peculiarities of his schedule and work were understood and/or tolerated. This minimized the conflicts between Dr. Quinlan and these park Superintendents, and he did not feel the need to invoke the 1975 grievance resolution. He continued to operate with the belief that the 1975 resolution was in effect. During the tenures of these three Superintendents, Dr. Quinlan continually received extremely high ratings for his annual performance reviews (Level I -- Far exceeded all performance standards on a sustained basis).

In 1986, Dr. Quinlan was evaluated for promotion by an independent panel of scientists (standard procedure for a Research-Grade appointment). The panel recommended promotion, and Dr. Quinlan was upgraded to a GS 13/5. According to the position description for the Research Geologist (GS-1350-12), Dr. Quinlan's supervisor was once again the NPS Southeast Region's Chief Scientist, though the MCNP Superintendent provided general administrative supervision.

The subsequent history of Dr. Quinlan's supervision is unclear but is critical in the subsequent events. According to Mr. Deskins (1991), sometime during 1986 after his promotion, Dr. Quinlan's supervisor once again became the MCNP Superintendent. Mr. Deskins recalls that this occurred as the result of personnel ceilings imposed in the Regional Office. In contrast, Dr. Gary Hendrix (personal communication, 1992) remembers that when he was transferred to the Southeast Regional Office in 1989 one of his first assignments was to be Dr. Quinlan's supervisor.

As the result of this ambiguity in Dr. Quinlan's supervision, when the current MCNP Superintendent took over in 1988, the stage was set for a conflict that would ultimately result in Dr. Quinlan's resignation. Both individuals have strong personalities and both agree that personality conflicts played a major role in many of their difficulties. "Quite frankly I tried to fire him. We had tremendous personal problems." (Mihalic, 1991).

Dr. Quinlan believed that he was still directly supervised by the NPS Southeast Region's Chief Scientist, not the MCNP Superintendent. The Superintendent, however, believed that he was Dr. Quinlan's direct supervisor. The Regional Chief Scientist did not support Dr. Quinlan's position and the Superintendent's beliefs prevailed. Several individuals interviewed by the authors in during the summer of 1991 agreed with the speculation that another contributing factor to the escalating dispute might have been Dr. Quinlan's grade (GS-14/5 in 1989) relative to the Superintendent's grade.

The current Superintendent decided that Dr. Quinlan should be restricted to working regular hours in the office, and believed that Dr. Quinlan was not performing the type of water quality research that had been funded. The Superintendent perceived the KWIS-based research to be more dye tracing research, what the Superintendent calls conduit research (i.e., where water flows in the region). He questioned Dr. Quinlan's management of his staff, and a number of other administrative issues that had been raised during Quinlan's 1975 grievance re-emerged. "... He'd been operating for fifteen to twenty years doing what...he thought was right. I came in and I said: 'We can no longer go in this direction. We have to go over here and do these types of things.' ... He was reluctant to do this" (Mihalic, 1991).

A contributing factor to the dispute appears to be the current Superintendent's lack of knowledge of not only the scientific research that had been done in the Park, but also the scientific research that Dr. Quinlan was performing and would have continued to perform. Despite repeated invitations, the Superintendent never agreed to spend a day in the field with Dr. Quinlan to review the groundwater hydrogeology of the region -- an opportunity that each preceding Superintendent had taken advantage of. The Superintendent never saw first-hand what actually constituted Dr. Quinlan's research. The Superintendent incorrectly characterized Dr. Quinlan's research as conduit research, not water quality research, which, in the Superintendent's view, contributed nothing to understanding how pollutants move through the system (Mihalic, 1991). The Superintendent believed that Dr. Quinlan possibly was misdirecting his water quality grants to some inappropriate category of research.

This clash of science and management perceptions led to the end of Dr. Quinlan's research at MCNP. Dr. Quinlan's tenure at MCNP was traumatic for both MCNP management and Dr. Quinlan. From the beginning, MCNP had no experience managing a scientific research project. No provision had been made to provide the Research Geologist's position with a research budget that was both adequate and could expand as needed. No equipment or supplies existed until Dr. Quinlan obtained outside grants, from local banks, the Commonwealth of Kentucky, and the University of Kentucky. The NPS funds that were eventually made available came from Regional and National NPS sources and programs. Dr. Quinlan's schedule, demeanor, personal philosophy, and strength of conviction, clashed with the employee qualities acceptable to the NPS.

As the clash of wills between Dr. Quinlan and the Superintendent intensified, the Superintendent filed a civil service adverse action against Dr. Quinlan. Dr. Quinlan filed a grievance. The Regional Chief Scientist proposed a compromise that would have transferred Dr. Quinlan to a Cooperative Park Study Unit (CPSU) at the University of Tennessee in Knoxville. Dr. Quinlan called this the Geologist-in-exile option. Another NPS scientist offered a blunter characterization: "Had Quinlan accepted a transfer to the CPSU in Knoxville, he would never have been has allowed to set foot in MCNP again." In the absence of support from the Regional Chief Scientist, Dr. Quinlan decided that his only option was to resign from the NPS and he did so in August, 1989.

OTHER SCIENTIFIC RESEARCH IN THE MAMMOTH CAVE REGION

The current Superintendent's philosophy concerning the most appropriate management of scientific research has not been restricted to Dr. Quinlan. An early indication of the relationship to come was when this new Superintendent refused to go into the MCS with CRF upon his arrival at MCNP. CRF has made such an offer to each new Superintendent, and the current Superintendent is the only one to have declined. Several past MCNP Superintendents, Assistant Superintendents, or Administrative Assistants have participated in regular work trips with CRF into the MCS. This refusal to view CRF's on-going research was consistent with the current Superintendent's refusal to go into the field with Dr. Quinlan.

An example of the interaction between volunteers and this management philosophy is illustrated by the current Superintendent's comments about Dr. Patty Jo Watson, an internationally renowned archaeologist (Mihalic, 1991). "Patty Jo Watson is an archaeologist, so she's doing the archaeology that she's interested in, but she's not necessarily doing the archaeology that the National Park Service is interested in...." When asked if MCNP had ever provided a list of archaeological research needs to Professor Watson, the Superintendent responded, "To my knowledge, we have not." The current Superintendent made similar comments about the work of Dr. Poulson (1990).

A different sort of example of NPS management's impact on long-term scientific research and monitoring at MCNP was recently described by Hagan and Sutton (1991) and Dr. Julian Lewis (personal communication, 1991) of the University of Louisville and a long-time researcher in the MCS. Recently, the MCNP Resource Manager undertook efforts to clean up and restore parts of the MCS. The Resource Manager contacted Dr. Lewis about a site he was studying in a remote section of the MCS within MCNP. Dr. Lewis had chosen this area as a research site in the early 1980s for a long-term study to document and observe the dynamics of its ecosystem, which was based on the wood remains of old tourist trails. Dr. Lewis was secure in the knowledge that it was in a remote location in a cave in a national park where there was no chance of the habitat being disturbed.

The Resource Manager, knowing of Dr. Lewis's research, requested Dr. Lewis's opinion regarding whether the site was a candidate for restoration. Dr. Lewis advised the Resource Manager that the area should not be restored since: (1) the area was only seen by explorers with CRF and a few tourists on NPS wild-cave trips, (2) the area offered a valuable opportunity for research not often available in the MCS, and (3) Dr. Lewis had already invested several years of time and money, and he planned to continue this research. The Resource Manager asked Dr. Lewis to put his response in a written memorandum to the park and to post a sign at the entrance to the area stating it was a scientific research area and should not be entered or otherwise disturbed. Dr. Lewis immediately complied with both requests. Several months later, a CRF crew working in the vicinity discovered that the area had been restored, and they notified Dr. Lewis. The removal of the wood and the severe trammelling of the area destroyed that local biological community and, therefore, Dr. Lewis's research.

In addition to the individual examples described above, the fundamental nature of the NPS constrains the range of scientific research done and scientists who are willing to work at MCNP. The NPS is a large, governmental bureaucracy administered by a military line-and-staff organization which has promulgated numerous rules and regulations regarding the resources of MCNP. Some individuals choose not to deal with this system and MCNP looses the potential contributions of such individuals.

Other individuals and organizations successfully adapt their programs and activities to the NPS system. For example, to obtain its Memorandum of Agreement with the NPS, the CRF adopted a highly-structured, military-like organization and discipline. CRF's growth, long-term stability, successful exploration and mapping programs, and its support of scientific studies demonstrate the utility of their approach.

The success of CRF, however, led to a misperception by some that cave exploration, mapping and to a lesser extent scientific research in the MCNP portion of the MCS could only be performed under the auspices of CRF. That perception was and is incorrect, particularly for scientific research. The option of performing scientific research at MCNP without CRF's help has always existed and several individuals and organizations have done so. A combination of approaches is also possible. One of the authors (EKE), Angelo George, and others, have performed research in MCNP both with CRF's assistance and strictly through the NPS regulatory system. One of us (ECA) notes, however, that the misperception exists and has contributed to personal decisions by some scientists to conduct their karst hydrogeologic research elsewhere.

6
THE FUTURE - WHAT IS GOOD FOR THE REGIONAL SYMBIOSIS?

RECOMMENDATIONS FOR FUTURE SCIENTIFIC RESEARCH

The importance of scientific research at MCNP should be clearly understood to define and support recommendations for future work. There are two definable, but ultimately overlapping, categories of research which augment National Park functions: long-term (usually basic) research, and short-term (usually applied) research. Basic research helps to define the nature of the National Park resource and the systems which do or may impact the resource. Applied research helps determine the state of the resource with respect to recognized impacts, or in response to plans for development, both internal and external to the park.

Basic research studies may require years or decades to complete given the complexity of natural systems, the physical dimensions involved in the parks, and the necessity of examining time variations of natural phenomena and processes. Indeed, successive discoveries as basic research proceeds invariably necessitate additional studies. The basic research activity itself, and the expertise engendered by the pursuit of basic research, are invaluable in designing and carrying out applied research to understand and solve applied problems. To the extent that we develop an improved understanding of the general processes acting, and produce a clearer picture of the National Park resource, we are able to find better solution to practical problems.

Applied research programs must be timely and responsive to the immediate needs of the park and the park managers. While it would be shortsighted to let applied research needs disrupt the continuity of long-term research, it is essential to the well-being of the park that resources (including staff time) be allocated to practical problems when they arise.

There is another consideration in promoting scientific research in National Parks. They represent, to a large extent, relatively pristine areas and are invaluable resources for basic studies of the regional, national, and global environment. Even in those parks most strongly affected by human activities, the current state of restricted development and cultural change is an invaluable resource for environmental investigation. The very act of preservation produces a significant scientific resource. This aspect of national parks is recognized world-wide.

With this background in mind, and considering the history of scientific activity at MCNP outlined above, we would like to make recommendations for future research at MCNP. These recommendations fall into two areas: a general policy approach to support scientific research in the park, and specific recommendations for research areas which we think will provide knowledge of benefit to the park and support the objective to preserve and protect the resource.

History shows that long-term research programs can exist at MCNP, but also reveals that these activities can be seriously impacted by misunderstanding, lack of communication, and even a lack of knowledge. All of these problems can be overcome, but their probable origins should be recognized if they are to be minimized.

The management structure of the NPS is certainly a factor which exacerbates these problems. The rotation of Park Superintendents has a sound management basis, which we do not criticize. However, the growing importance of scientific research, both for purposes of park management and in the use of National Park environments for broader scientific discovery, places a new Superintendent in a difficult position with respect to a professional NPS staff scientist with many years of experience at a given park. A new Superintendent, who has responsibility and authority, will typically have less factual knowledge about the park resource than most of the permanent staff. This situation is likely to be even more profound with respect to technical scientific information held by a senior-level scientist. This can be (or lead to) a highly uncomfortable situation for both the new Superintendent and for the park scientists. It is clearly in the interest of the NPS to develop an appreciation of this problem among its senior personnel in both management and staff lines, and to develop and promote procedures to overcome the implicit difficulties.

One approach we specifically and strongly preclude is rotation of scientific personnel. Scientific understanding of natural systems is time-consuming. Ongoing research in National Parks would be adversely affected by changing the personnel directly responsible for carrying out the research. Even if most or all of the research is by external (volunteer) researchers, with the park scientist in an oversight role, rotating park scientists will lower the efficiency of the research operation if a new scientist has to get up to speed after each transfer. It is probably essential to the success of research in a park to have the NPS scientist actively involved. Perhaps a more important reason for not rotating park scientists is their value as part of the park resource which inevitably results from many years of active research in a park. The roles of Superintendent and park scientist are, ideally, complementary. The Superintendent has a more disinterested managerial position and the park scientist develops the essential depth of knowledge based on long experience with the park. The challenge is to find a mechanism to bring these two views together in a harmonious partnership that benefits the park. This suggestion obviously applies to all National Parks, not just MCNP.

Based on a consideration of the long recognized special hydrogeological regime at MCNP we can make specific recommendations regarding future research in the park. The tremendous amount of research accomplished in the last few decades had helped provide the basis not only for practical responses to problems in and around the park, but for the design of future research programs. In particular, the hydrogeologic work has defined the boundaries of the groundwater drainage basins and the dynamic nature of the groundwater system. Based on that knowledge, and with the goal of providing information useful in management of the park, there are three major research programs we can suggest:

1. In order to understand more fully the natural variation in water chemistry and discharge (and the relationships between chemistry and discharge) it is essential to gather comprehensive data at major points in the hydrologic system. It is essential to gather that data with a time-resolution of sampling that is short compared to the variations in these systems. The water quality and quantity changes significantly on time scales of minutes to hours in MCNP. Automatic data gathering systems such as the KWIS instrumentation which was being installed in 1988 and 1989 provide precisely the kind of information necessary for a complete understanding of chemistry of the hydrologic system at MCNP. It makes sense to restart and complete the KWIS program, and begin analysis of this important data set.

2. As analysis of the data collected above proceeds it will become possible to produce models of the groundwater flow systems at MCNP. It is important to begin this modelling effort for two reasons. First, it is an exceptional opportunity to develop and refine the first well-constrained hydrologic model for a karst system anywhere. Such a model will represent the kind of basic scientific effort at MCNP which will contribute to a general understanding of a significant scientific problem. Second, a functional geohydrologic model of MCNP will provide potentially the most important tool in any plan for emergency response to pollution events,

such as a surface spill. It may also provide the basis for responding to unusual meteorological events which may result in flood surges capable of endangering visitors in the cave and/or to park infrastructure. Such a model would be invaluable to evaluate the impacts of future surface and subsurface developments anywhere in the drainage basins.

3. A biologic/biomonitoring research and monitoring program may be vital to the long-term health of the MCS. Using the data collected over the past twenty years or so, it should be possible to develop a biomonitoring program which can detect subtle changes in the subsurface environment. An ongoing biomonitoring program also presents the opportunity to investigate natural changes in the microenvironments of the cave through examination of biologic changes. In the process it should also be possible to define especially secure parts of the underground biosphere which may serve as refuges for species preservation, from which restocking of damaged environment could take place following possible future destructive events.

These three programs should be coordinated with one another. By listing these particular research programs, we do not wish to imply that they are the only ones important enough for NPS attention, rather that they are the logical extensions of previous research efforts, and will likely provide the most immediately useful data for managing the resource at MCNP.

AGENDAS

The Local Symbiont Level

During our interviews with various citizens of the Mammoth Cave region, a number of themes or agendas repeatedly emerged (Austin and Austin, 1991; Gunn, 1991; Kelley, 1991). This local agenda can be summarized as a set of questions:

1. Will a fully implemented CSA truly preserve the MCS and the groundwater resources by reducing pollution? Since CSA can't service every sinkhole that is receiving waste on the Sinkhole Plain, is the regional sewage plan going to work? Was all of this worth it?

2. NPS scientists tend to talk over everybody's heads. Would the NPS please translate existing scientific research results at MCNP into lay terms for the local citizens? What has NPS research discovered that may be helpful to the local area now or in the future? There needs to be continual and on-going communication concerning this.

3. Will the NPS continue to provide technical support to CSA and the region? Such support has been a great help.

4. May the local region make research requests of the NPS to assist in joint issues?

5. Would the NPS consider creating a local advisory board to MCNP to allow local input into the management of park resources since that management might impact the other symbionts?

The National Park Service Local Level

In our interviews, the MCNP Superintendent and the members of the staff of the Office of Science and Resource Management voiced a number of goals and ideas (Mihalic, 1991; Bradybaugh, 1991; Meiman and Ryan, 1991) which can be summarized as:

1. CSA, the regional sewage treatment project, should be completed with all haste to protect MCS and the groundwater resources of the symbionts.

2. MCNP should utilize its Resource Management Plan in creating an academic wish-list to solicit the participation of academic scientists in research.

3. MCNP needs to hire and adequately support a biologist, geologist, and other professional scientists, including a cultural resource specialist for archaeological and historical research (Native Americans, War of 1812, Floyd Collins, Cave Wars, etc.). These should be Research-grade positions like the one Dr. Quinlan occupied. All scientists should be supervised by the NPS Chief Regional Scientist.

4. There should be a realignment of NPS staff. MCNP currently has more visitor-protection/control

rangers than it has resource-protection rangers by a factor of least two. This ratio should be reversed or at least brought into balance.

5. MCNP should develop and obtain funding for a world-class karst research institute, which will include programs for visiting national and international scientists.

In addition, the existing water quality program MACA-N-020 is funded for three years, but it cannot possibly be completed in this time, and should be expanded and funded on a long-term basis. This program requires implementation by one or more Research-grade scientists with much greater experience than the current MCNP science staff.

The National Park Service Southeast Region Level

Mr. Deskins (1991) expressed the following goals for the Region:

1. Develop and strengthen the existing and new CPSU's to a level of involvement found in the CPSU's of the NPS Western Region. Add another 20-25 CPSU's to perform much of the proposed and on-going research.

2. Create a functional, complete information management system (both paper- and computer-based) and a standard operating procedure for data storage and retrieval protocols. These will facilitate use of data.

SCIENCE IN THE PARK AND THE REGION

Much of the scientific research in the MCS, at MCNP, and in the region has been done by volunteers. That pattern probably will continue for the foreseeable future given the intrinsic attractiveness of the resource and NPS's limited funds. Volunteer scientists should be recruited, encouraged and supported in their work in MCNP. However, the current Volunteer In Parks (VIP) program was not established to encourage or manage scientific research, and the VIP Coordinators are not qualified to supervise and interact with volunteer scientists. A new structure needs to be created. Specifically at MCNP, cooperation with academic scientists and volunteer groups and their supported scientists should be increased and encouraged.

The NPS needs and desires to continue doing research within its aegis, both to fulfill its own priority needs and to coordinate, manage and use the volunteer scientific research. However, in order to do successful long term science and resource monitoring in National Parks, major structural changes need to be made. Phraseology is needed in the NPS enabling legislation to authorize and require scientific research, long-term monitoring, and resource inventorying. This will enable the NPS to establish research programs and obtain Congressional funding specifically for that research.

The NPS will then need to establish both a budget and an organizational structure that are dedicated strictly to research. Currently approximately 2% of the NPS budget goes to scientific research (Dottavio, 1991; Bishop, 1991; Bradybaugh, 1991). That amount needs to be substantially increased because the results of research are critical to resource management. The budget and structure needs to be separate from both political climates and personal whim.

A NPS Director of Scientific Research should be created at the Washington, D.C., level, and he or she should be given line authority. Chief Scientists already exist at the regional level, but are completely removed from the management line. Chief Scientist positions will be useful in any park unit that requires more than one scientific discipline to be represented on its staff. MCNP, in requiring a biologist, geologist, and cultural resources scientist at the research grade, needs a Chief Scientist to oversee and administer the entire science program. Increasing the grades and pay structures for scientists will help attract top-quality researchers.

The new research organizational structure should be integrated with other existing organizational structures so that research and management are encouraged to work together. The research structure should have long-term continuity. Good scientific research cannot be accomplished if science is managed either by non-qualified managers or by managers who rotate through the park every three to four years. Such transient management techniques tend to reward people who go along with the system and do not challenge it.

The "get it done today" management philosophy as it has been applied to research needs to be eliminated. This has impacted negatively on park-paid research by forcing researchers to do "dip-stick" investigations. The NPS should learn to take advice from scientists and other professional volunteers who collect, and therefore understand, the data for NPS, so that the non-scientist NPS managers can make proper use of such data. The NPS should develop both a partnership attitude and a contractual working relationship with these professionals. Most importantly, the NPS should recognize the research currently being done by volunteers. A case in point: Dr. Poulson and Dr. Lewis have been doing bio-monitoring (biota inventory and temporal monitoring) for years at MCNP. It is not cost-effective to reinvent biomonitoring, when it already exists in great detail at MCNP.

The NPS needs to stop making management decisions without first investigating the possible impacts of those decisions on the cave resources. Volunteer and staff scientists should be consulted first. The NPS should approach these scientists for more information and for the creative application of that knowledge to the problem. This requires open, honest, frequent communication between science and management.

Finally, other national parks have excellent programs for the communication of the latest research results to the visiting public. Such programs usually work to the parks' advantage. Such programs are missing at MCNP. For example, the interpretative signs in the cave and on the surface are outdated and, in many cases, incorrect.

The bottom line for scientific research at MCNP is that the current managers at MCNP seem to be so divorced from the park's resources that: (1) they don't know what to ask the volunteer scientists for, and (2) they don't know how to use the data that the volunteer scientists provide. Protecting and studying a resource requires a strong affinity for and commitment to the resource and an appreciation for how special it is. Dr. Quinlan had such a commitment, but he is gone. Numerous volunteer scientists, long-term cave explorers and mappers, and other interested individuals have these qualities, but they are ignored.

7
SUMMARY AND CONCLUSIONS

Karst hydrogeologic research has a long and distinguished history at MCNP. Research and resource monitoring in the last 30 years have been particularly productive, and have demonstrated that MCNP, the MCS, and their regional neighbors are linked together in a symbiotic relationship. MCNP and the Central Kentucky Karst contain the longest cave system and the best documented, conduit-flow, karst groundwater system in the world. Information and scientific concepts developed during the study of the MCS and the Central Kentucky Karst form the basis for karst monitoring and regulation throughout the rest of the United States. Such documentation has resulted in MCNP being designated a World Heritage Site in 1981 and in the Mammoth Cave Region being designated an International Biosphere Reserve in 1990. Also, the underground rivers of the Mammoth Cave Region have been designated by the Commonwealth of Kentucky as Outstanding Resource Waters.

The scientific research and resource monitoring at MCNP have been accomplished by four different groups. First, a number of individual university scientists have dedicated major portions of their research careers to the study of the Central Kentucky Karst. These efforts have been successful both professionally and scientifically. Second, a number of volunteer organizations have assumed primary responsibility for the exploration and mapping of the MCS. The decades-long efforts of these dedicated individuals resulted in the discovery and integration of many individual caves into the longest system in the world. These same volunteer groups have also supported scientific research and resource monitoring efforts at many levels. Third, a NPS Research Geologist worked at MCNP from 1973 through 1989. The Research Geologist's efforts were highly successful and have been the basis of a number of fundamental changes in the environmental management of MCNP and the Central Kentucky Karst. His efforts have brought national and international recognition to the Park and the Mammoth Cave Region. Fourth, a number of private, State and Federal agencies have performed a number of important studies covering the area.

The MCNP management support of, and response to, this research has varied. A few Superintendents have supported the scientific research and have successfully incorporated the growing knowledge base into management decisions that have often impacted the park and the region. Park managers decided to hire the Research Geologist and thereby initiated a very successful and productive period of research. One Superintendent successfully initiated a regional partnership, CSA, between MCNP and its neighbors to deal with a major threat to the groundwater quality in region, the cave, and the Park.

More often, however, Superintendents have grudgingly utilized research findings or ignored them entirely. Much of the research and resource monitoring was done in spite of MCNP management, without NPS support or funding.

The Research Geologist was actively opposed by two Park Superintendents. He had to file a formal grievance to be able to carry out the research he was hired to perform, and, despite the success of the grievance resolution, continued to work in an often hostile, unsupportive, management environment. The Research Geologist's direct supervision was shifted from the MCNP Superintendent to that of the Regional Chief Scientist and back again several times for various management reasons. In 1989, his direct supervision was again the MCNP Superintendent and a bitter clash of wills with the Superintendent resulted in the resignation of the Research Geologist.

The full impact on MCNP of this resignation is only now becoming evident. The direct effects include the cancellation or abandonment of highly productive, visible, and immediately useful NPS research programs. During his tenure at MCNP the Research Geologist produced about 120 karst-related publications. MCNP also lost the 35 years of accumulated knowledge and experience of the Research Geologist.

The indirect effects are potentially even more damaging. The Superintendent now firmly controls the nature and direction of scientific research at MCNP. The implications of this action are chillingly clear to any NPS employee performing scientific work at MCNP. It will take a very committed individual to tell a Superintendent that scientific results conflict with management policy.

Can and will long-term scientific research and monitoring be performed at MCNP? We believe that it can. The record clearly demonstrates that the MCS and Central Kentucky Karst is of such importance and attraction that university scientists and volunteer organizations will continue their dedication and commitment to furthering scientific study and systematic exploration in the Mammoth Cave Region. These motivated and creative individuals will strive to succeed with or without MCNP management support and encouragement. The researchers will productively use whatever resources are made available by supportive park managers, or they will creatively seek out effective ways to continue their research when faced with unsupportive and/or hostile park managers.

Will NPS scientists be able to participate meaningfully in the long-term scientific research and monitoring at MCNP? We do not believe that this is possible under the present NPS management system. The deliberate destruction of the productive and successful karst hydrogeology research program at MCNP accompanied by the forced resignation of the Research Geologist is stark evidence of the problem. While non-NPS volunteer researchers have some ability to protect their work from the uninformed actions of a hostile management scenario, the NPS scientists do not. These events are not just the isolated product of an unusual personality conflict. The pattern spans several Superintendents and analogous events have occurred in other National Park units. The problem is a fundamental structural flaw in the NPS management organization. While some Superintendents can be supportive managers, other Superintendents' management techniques can destroy the continuity required by scientific practices.

Therefore, we believe that a major reorganization of the NPS is necessary before NPS personnel can successfully perform effective, long-term scientific research and resource monitoring. The NPS should have a Science Division that is managed and directed by scientists, rather than by administrative personnel with no scientific training or experience. The Science Division should extend throughout the NPS structure, from the Washington, D.C., headquarters with a NPS Chief Scientist, to the regional offices with Regional Chief Scientists who report to the NPS Chief Scientist, and into the individual park units with Chief Park Scientists, each of whom would administer in toto the scientific programs within their individual parks. The Science Division should not be eliminated from the command structure, but rather it should be an integral, co-equal part of that structure. Mechanisms should be established: (1) to encourage and reward cooperative decisions for good resource management between park managers and the scientists, and (2) to protect NPS scientists from NPS managers and vice versa. NPS scientists should not be required to change their base of operation every three to four years for promotion or advancement purposes.

We recognize that implementation of such sweeping changes in the NPS structure will be complicated, costly, and will undoubtedly necessitate a concise, specific, Congressional mandate. Such a mandate will require changing the NPS enabling legislation and will also require a concurrent increase in base funding. If and until such legislation and funding are available, we believe that the NPS should actively pursue partnerships with: (1) university scientists via CPSU's and other appropriate mechanisms, and (2) volunteer organizations such as CRF. The university scientists will provide access to state-of-the-art equipment and techniques and will keep NPS science programs in the mainstreams of their respective disciplines. The volunteer organizations will provide a proven, long-term commitment to science and resource inventory and access to highly qualified and motivated individuals willing to contribute their expertise and labor. The NPS should not only seek cooperative agreements with such organizations, but should actively and financially support their activities. Finally, the NPS should seek and encourage university, volunteer, and local advisory groups to contribute to the evaluation of park management decisions.

The NPS must also be aware of its regional symbionts and MCNP's obligation to them. This awareness can be acknowledged by the creation of a local advisory board to MCNP management, continued participation in the completion of CSA, and the sharing of research results with local and regional citizens and other entities.

In closing, we quote from the report resulting from an investigation performed by the Commission on Research and Resource Management Policy in the National Park System (1989).

> "Research is basic to the mission of the NPS. Yet, the Park Service, unlike other Federal agencies such as the U.S. Forest Service, lacks an explicit mission for research. Without a sufficient knowledge base, it is impossible to make wise management decisions or to design effective education programs. Research must be broad-based because the National Park System is huge and diverse and because its units have both cultural and natural resources which are affected by many factors. Research must also be ongoing, incorporating new techniques and interpretations as appropriate .... The NPS cannot manage what it does not understand."

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KARST MANAGEMENT THROUGH ZONING AND SUBDIVISION ORDINANCES

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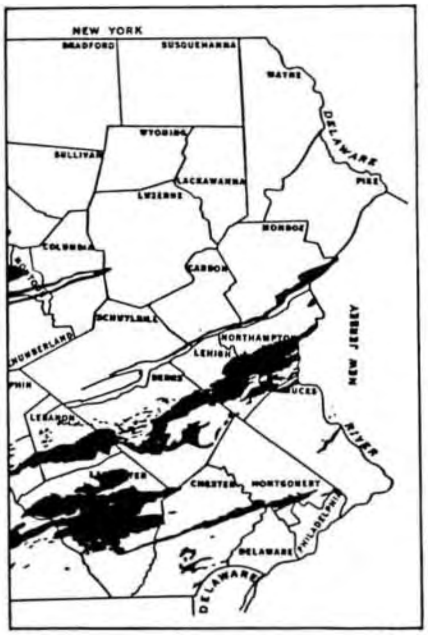
ABSTRACT

Sinkhole formation results in excess of $1,000,000 damage annually in the Lehigh Valley of Pennsylvania, a portion of the Great Valley of the Appalachians. In the United States, this loss is second only to that occurring in Florida. The Lehigh Valley contains five limestone formations, forming a great structural valley, ranging in age from Cambrian to Ordovician. The fertile limestone soils and the lowland transportation route have resulted in a high density of population, with nearly a million people living in the metropolitan areas of Allentown, Bethlehem, Easton, and Reading. In addition, the area continues to grow because of its proximity to New York and Philadelphia. Therefore, the area is faced with a growing threat of a potential loss of human life and damage to property by sinkhole formation.

It is proposed that the best way to safeguard lives and reduce the amount of property damage is to not allow development on sinkhole prone areas in the first place. It is too late for the already built-up areas of the cities, but the growing suburban areas can and must be safeguarded today. This can be best accomplished by the use of state mandated planning documents including the comprehensive plan, zoning ordinance, and subdivision ordinance. All new housing, commercial, and industrial developments must be reviewed under these documents; therefore they should contain language that is tough enough to keep development from occurring on sensitive sites such as karst features. This may appear to be a simple task from a karst geomorphology perspective, but it is complicated for one must also deal with politicians, lawyers, and special interests groups such as environmentalists and builders. This paper presents a model ordinance and discusses problems encountered in passing such legislation. The model ordinance is the Lower Macungie Township Subdivision Ordinance which was in preparation for over two years when finally adopted.

Newspaper headlines and other news media in the Lehigh Valley contain numerous references to "sinkholes" and karst collapse. Over $1,000,000 damage is done yearly in the Lehigh Valley, the portion of the Great Valley of the Appalachians that cuts diagonally from northeast to southwest across Pennsylvania. In the United States, this amount of damage is second only to the much larger karst prone area of central Florida. Some collapse episodes within the past five years have resulted in loses in excess of $500,000 each: the Macungie sinkhole (Dougherty and Perlow, 1987), the Vera Cruz road collapse (Bonaparte, 1987), and the Allentown church disaster (Clark and Reaman, 1988). Because of the high density of population, there is also a danger to human life. Three lives were lost in a 1925 collapse in the City of Allentown (Wittman,1988), and another death and seven injuries resulted from the collapse of two townhouses and an accompanying gas explosion on August 29, 1990 (Casler, 1990).

It is not unusual to see headlines in local newspapers like "Residents flee street-gobbling Macungie sinkhole" (Buzgon, 1986), "Another day in the Valley, another sinkhole" (Whelan, 1986), "30 foot sinkhole opens in shopping center" (Morning Call, August 4, 1986), "Emergency work at Upper Saucon sinkhole complete" (Morning Call, November 4, 1986), "PennDOT says it's not to blame in latest Upper Saucon sinkhole" (Darrah,



MAP 1. Location of the Great Valley of the Appalachians. The shaded area in Northhampton and Lehigh counties shows the limestone outcrops of the Lehigh Valley, extending into Lebanon County as the Lebanon Valley. The other major limestone region is the Lancaster Plain.

Source: Pennsylvania Topographic & Geologic Survey, 1981

1987), "Another U. Saucon road is affected by sinkhole" (Morning Call, March 7, 1987), "Sinkhole threatens to undermine Northampton home" (Berton, 1987), "Muhlenberg dormitory get that sinking feeling" (Youngwood, 1988), "City church collapses into sinkhole" (Clark and Reaman, 1988), "City firm hired to fill sinkholes at Allentown Airport" (Cowen, 1988), "Lower Nazareth woman files lawsuit over sinkholes" (Morning Call, July 27, 1989), and many more. The news reports only indicate the largest and most disastrous sinkhole occurrences in the area since most collapses are not reported in the news media. Perusal of roadmaster records in suburban and rural townships show the problem to be much greater than indicated by the news media. Local residents are also eager to share accounts of their favorite neighborhood sinkhole collapse including stories about missing dogs, disappearing back yards, and even a humorous account of a football coach at a high school football game, who while pacing the sidelines, was engulfed waist deep in a sinkhole. The above referenced and personal accounts show that there are numerous collapses in this region which bear investigation because of their economic and life threatening impact.

In order to minimize the loss of life and the destruction of property, local government officials must know what causes such episodes. Clues to the formation of collapses can be found in an analysis of their spatial and temporal distribution. It is important from a planning perspective to know what areas are the most prone to collapse so that zoning and subdivision ordinances can be written in such a way as to minimize the danger from subsidence. The temporal aspect is also important so that emergency service organizations can plan for the possibility of a period of greater collapse activity. Therefore, it is the purpose of the current research to investigate the causes of karst collapse, the spatial distribution of occurrences, and the temporal aspects in the Lehigh Valley. Since the Lehigh Valley is a representative sample of the Great Valley of the Appalachians, information from this study can be applied to the Lebanon Valley, East Penn Valley, Shenandoah Valley and other similar areas in the Great Valley of the Appalachians. This is especially true of the Reading, Harrisburg, and Hershey urban areas which have a similar stratigraphic profile.

The Study Area

The Lehigh Valley is generally considered to be that portion of the Great Valley of the Appalachians that extends from the Delaware River on the east to the Schuylkill River on the west (Map 1). This

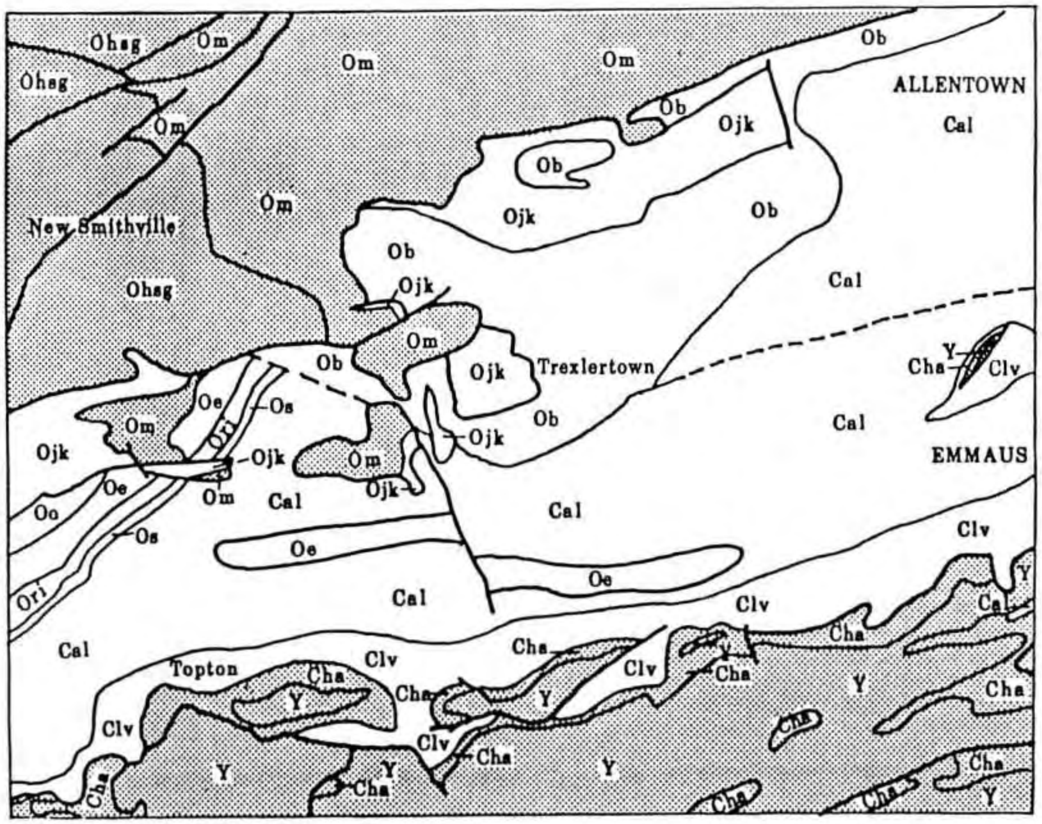
MAP 2. Urban Land-use in the Lehigh Valley: Lehigh and Northampton Counties, PA.

Source: Joint Planning Commission, 1991.

encompasses Lehigh and Northampton counties which contain the Allentown/Bethlehem/Easton metropolitan area with nearly three-quarters of a million population (JPC, 1991). If nearby Reading is included, the urban area exceeds one million people, most of whom live on the limestone areas of the Lehigh Valley. Contrary to the negative publicity the area received from the song "Allentown" by Billy Joel, the area is not depressed and withering on the vine. It is a dynamic urban area that has been stimulated by the recent completion of Interstate 78. The area already contains the Northeast Extension of the Pennsylvania Turnpike and other major highways such as routes 22, 100, and 309. With easy access to New York City and Philadelphia, the areas has experienced substantial growth as a warehousing center. Cheap office space has also resulted in an influx of tertiary activities that have replaced the jobs lost in the shrinking heavy industrial base. This expansion has resulted in a 8.1% increase of population over the past ten years (JPC, 1991). That increase plus the movement from the core cities to the suburbs is resulting in increased urban sprawl. Map 2 shows the urban land use which is concentrated on the limestone lowlands, a use which may not be compatible with the karst landscape (JPC, 1982).

The Lehigh Valley is a distinct physiographic region located between South Mountain of the Blue Ridge Province composed of Pre-Cambrian and Cambro-Ordovician granitic gneisses, quartzites and sandstones; and Blue Mountain, the first ridge of the Appalachians, which is composed of Silurian sandstones and conglomerate which is partially metamorphosed to quartzite. Between the two resistant ridges one finds a 25 km wide valley with over 400 m relief. The valley floor is composed of Martinsburg Formation shales which form a higher structural bench of undulating topography on the northwestern side of the valley, and limestones on the southeastern side of the valley which form a flat agricultural plain stretching to the base of South Mountain (Miller, 1934). Map 3 shows the geologic formations of the Lehigh Valley west of Allentown, extending from Kutztown in the south to Slatington in the north (Lash, et. al., 1984).

Lower Macungie Township is well situated to participate in the rapid growth of the region because of its location at the intersection of route 222 and the new Interstate 78. It is transected by routes 309, 100, and the Northeast Extension of the Pennsylvania Turnpike. As long as the Township remained rural,



MAP 3: Geologic formations of the Lehigh Valley west of Allentown, PA. Shaded areas to the northwest are the shale hills composed of the Hamburg sequence (Ohsg) and the Martinsburg Formation (Om). The limestone lowland of the Lehigh Valley is in white and is composed of the Jacksonburg Formation (Ojk), Ontelaunee Formation (Oo), Epler Formation (Oe), Rickenbach Formation (Ori), Stonehenge Formation (Os), Allentown Formation (Cal), and the Leithsville Formation (Clv). The shaded areas to the southeast are the Hardyston Formation (Cha) and the undifferentiated gneisses of South Mountain.

Source: Berg and Dodge, 1981; Dougherty, 1991

there were few problems with subsidence, but with urbanization the problems were exacerbated by stripping of the land (Myers and Perlow, 1986), drawdown of the water table (Wood, et. al., 1972), and filling of karst features (Kochanov, 1988). Between 1950 and 1984, the Township grew from 2,997 people to 14,081 (Lower Macungie, 1988). The recent census shows over 16,000 people in 1990 and over 2000 housing units approved for sub-division. By the year 2000, the population will exceed 25,000.

Lower Macungie's location in Pennsylvania causes further problems in karst management. Planning, zoning, and subdivision are done by the local municipality--not the county or state. Pennsylvania has over 1,600 minor civil divisions doing their own thing under the Pennsylvania Municipalities Planning Code, Act 247 (Commonwealth of Pennsylvania, 1989). The result is fragmentation and numerous legal challenges to the local codes. The positive side of the situation is it is easier to change local codes in the favor of karst hazard mitigation than it is to change state or county codes where karst landscapes may form only a small percentage of the total area. It must be realized that the material in this paper reflects the vagaries of Act 247 and cannot be used directly in other states. The

Formation (Age)	Thickness (m)	Formation Description and Weathering Characteristics
Jacksonburg Formation (M.Ord.)	170-460	Dark-gray shaley limestone grading downward into crystalline, high-calcium limestone. Low to moderate porosity and permeability; thin soil mantle; relatively few solution features.
Ontelaunee Formation (L. Ord.)	0-200	Medium-gray, finely crystalline dolomite; cherty at base; missing at many locations. Solution-enhanced porosity and bedrock pinnacles characteristic. Moderate to thick soil mantle.
Epler Formation (L. Ord.)	270±	Interbedded very fine grained, medium-gray limestone and gray dolomite. Solution-enhanced porosity; few bedrock pinnacles; very thick soil mantle.
Richenbach Formation (L. Ord.)	220	Gray, fine to coarse dolostones, thin bedded at top to thick bedded toward base. Solution-enhanced porosity and bedrock pinnacles characteristic; moderately thick soil mantle.
Allentown Dolomite (U. Camb.)	575	Alternating bed of light- and dark-gray weathering dolomite; stromatolites and oolites common; some orthoquartzite beds. Solution-enhanced porosity and bedrock pinnacles characteristic; soil mantle generally thin.
Leithsville Formation (Uppermost L. M. Camb.)	350	Interbedded fine- to coarse-grained dolostones and tan phyllite; few thin sandstone beds. Solution-enhanced porosity; bedrock and pinnacles common; commonly covered with thick colluvium near uplands.

Table 1: Characteristics of Lehigh Valley Carbonate Rocks. Source: Myers and Perlow, 1986.

Formation	Total Area (mi^2)	Total No. of Sinks	Average Sinkhole Density (No./mi^2) (all occurrences)	Average Sinkhole Density (sinks/square mile)			
				Naturally Occurring	Construction Related	Utility Related	Structure Related
Jacksonburg	24.0	054	2.2	1.8	0.3	0.1	–
Ontelaunee	06.4	028	4.2	1.4	1.4	1.4	–
Rickenbach	18.7	174	9.3	4.5	4.0	0.8	0.05
Epler	74.5	518	6.9	4.0	2.5	2.5	–
Allentown	85.0	731	8.6	2.2	2.2	4.2	–
Leithsville	32.0	069	2.1	1.0	0.2	0.9	–

Table 2: Average Sinkhole Density for various geologic formations and sinkhole types. Source: Myers and Perlow, 1986.

concepts can be modified to fit the planning codes of other states on either the municipal or county level.

Spatial Attributes of Karst Collapse

Karst collapse in the Lehigh Valley is restricted to the limestone belt on which most of the urban development is located. There are six limestone formations within this zone, starting with the shaley limestone of the Jacksonburg Formation with its Portland cement quarries in the northwest. This is followed in sequence by the progressively older Epler, Rickenbach, Allentown, and Leithsville formations. Table 1 shows the thickness and characteristics of the formations in the Allentown area (Myers and Perlow, 1986). From a cursory examination, one should expect to find many sinkholes in the Allentown Formation because of its greater thickness and larger geographical coverage. Fewer sinkholes should occur on the shaley Jacksonburg Formation because of its thin bedding and impure nature. In addition, one should find few sinkholes on the Leithsville Formation because it is highly dolomitized and it is covered by an extensive South Mountain colluvium (exceeding 30 meters in places). The Ontelaunee is a minor formation in areal extent and therefore has few sinkholes present.

Table 2 shows the results of a study of sinkhole occurrence in the Lehigh valley (Myers & Perlow, 1986). Data for the study was taken from topographic maps, air photos, utility company records, and records of local government and engineering offices. A total of 1574 sinkholes were identified. It is not surprising to find the largest number of sinkholes on the Epler and Allentown formations which cover the greatest geographic area and the least number on the Jacksonburg and Ontelaunee formations which cover a small area. The most significant figure on the table shows the Rickenbach Formation has the highest density of sinkholes per unit area at 9.3 per square mile, followed by the Allentown Formation with 8.6, and the Epler Formation with 6.9. An attempt to break down the sinkholes into categories based on their cause shows the Rickenbach and Epler formations have the highest density of naturally occurring sinkholes, while the Allentown Formation has a high utility related component. Several recent sinkhole episodes, not reported by the media, have occurred on the Allentown Formation after it was stripped during housing development construction. This means that human action aggravates sinkhole formation in an area that otherwise does not have a significant number of naturally occurring sinkholes. Therefore planners should pay more attention to the previous three formations because of the greater likelihood of sinkholes formation.

Investigation of newspaper clippings of sinkhole formation and field visits to sinkhole sites add further information to the previous study that is not apparent from the table (Dougherty, 1991). Although the Allentown Formation has a larger number of sinkholes than most other formations, the individual sinkholes are small because of the thin overburden and the small size of the joint controlled groundwater entries. Sinkhole "eyes" are close to the surface and are easily repaired. The Leithsville Formation on the other hand has the lowest density of sinkholes, 2.1 per square mile, but it is the site of some of the most disastrous collapses in the area. The Macungie sinkhole formed on June 24, 1986 resulting in a hole 40 meters across and nearly 20 meters deep which cost in excess of $700,000 to repair (Dougherty & Perlow, 1988). The reason for the humongous size is related to the deep colluvial cover of the formation allowing for the development of suffosion sinkholes. This is also the location where the allogenic waters from the Hardyston sandstone and undifferentiated gneisses of South Mountain come in contact with the first limestone of the Lehigh Valley. Larger more persistent sinkholes form at this location, although the overall density of sinkholes is lower in the Leithsville than in any other formation in the Lehigh Valley.

Methodology and Analysis

Using the old adage that an "ounce of prevention is worth a pound of cure," existing ordinances in the Lehigh Valley were investigated to find what provisions were used to minimize the danger of karst collapse. It was the intent to take the best of existing ordinances and create a new zoning ordinance for Lower Macungie Township incorporating the best of the rest. In addition, a karst overlay district similar to the flood plain overlay districts common in most zoning ordinances was planned. Several existing bases were used including a detailed fracture trace analysis and sinkhole location study done for the Delaware River Basin Commission (DRBC, 1985), a study done for the Pennsylvania Power and Light Company by VFC, Inc. (Perlow, on-going), and interviews with Township officials. To this base were added sites known through personal knowledge and through having a Joint Planning Commission intern identify sinkholes from aerial photographs. This resulted in a data base of existing karst features that can be updated periodically in order to provide a historic basis of past activity in the problem area.

Only two other ordinances were found in the Lehigh Valley that contained karst language. Both were subdivision ordinances. The one from Upper Saucon was very restrictive and was thought to be anti-development and unenforceable in court (Donald Miles, Lower Macungie Township Solicitor, personal communication, 1989). In addition, it made extensive use of fracture traces and lineaments, generally accepted karst features but a legally indefensible concept in court. If any three karst experts were asked to draw their interpretation of fracture traces from the same air photo, three entirely different spatial patterns would result. Some of the traces could be cultural features such as utility line scars, cropping patterns, or excavations. It was decided to delete the use of fracture traces in the current ordinance because of the legal problems that could arise. Another subdivision ordinance is one developed by the Joint Planning Commission of Lehigh and Northampton counties (JPC, 1988). It is not detailed enough to restrict development near karst features and it does not allow for developers to make an appeal by performing geotechnical investigations to show there is no danger in developing a particular piece of property. No individual may be restricted from developing his/her property unless a just cause is shown. This is the result of the famous Seventh Day Adventist Case in

California where "taking" or illegal restriction on the development of one's land has been ruled illegal by the Supreme court.

There is a debate over where a karst hazard code should go, the zoning ordinance or the subdivision ordinance. If placed in the zoning ordinance it is in the company of such issues as floodplains, historic places, wetlands, hydric soils, and steep slopes. In addition, developers have to file an application to go before a Zoning Hearing Board to have any changes made by a special exception or they must have the ordinance changed in their favor--both of which are long and tedious procedures. The subdivision ordinance, on the other hand, is administered by the local planning commission which may make waivers upon application. The governing body can also make exceptions if pressured by developers. Unfortunately, in the case of Lower Macungie, the ordinance became part of the subdivision process. It has been tested several times but has not been waived or changed.

The heart of the ordinance is the Karst Overlay District and the Karst Hazard Overlay Map. Developers seeking a building permit, conditional use, or a special exception must submit a map at a scale of at least 1"=100' showing the karst features listed in the Ordinance. The Zoning Officer has the responsibility of informing applicants that they have karst features on their property; and, if necessary, may perform a site visit and delineate such features, or procure the necessary expertise to delineate such features. The applicant is also required to have an engineer visit the site and assess the presence of karst features. If further testing is necessary, the result should be submitted to the Township Engineer who will report to the Zoning Officer and Planning Commission on the adequacy of the report. In special cases the Township Engineer may request further testing by the applicant's engineer.

A set of performance standards is also adopted in the ordinance. These include the provision of having no stormwater detention facility within 30 m of a karst feature. This is necessary for many developers try to site detention basins in dolines with disastrous consequences. The eye of the sink can open due to the excess water and added pressure. In addition, no stormwater swale or sewer pipe may be constructed within 30 m of a karst feature unless special precautions are taken including the installation of liners or impermeable bed. No throughflow is allowed along utility trenches and impervious dikes are required at 10 m intervals. No buildings or accessory structures are allowed within 15 m of a karst feature unless detailed geotechnical work shows there will be no negative impact. No blasting, well enhancement activities, gasoline or other chemical storage is allowed within 30 m of the karst features. To guard against the stripping of land cover and the associated opening of dolines, a soil conservation plan must be submitted to the County Soil Conservation Service showing safeguards. When there is a disagreement over the delineation of a karst feature, the applicant shall bear the burden of showing that such conditions do not exist on the property in question. This may require expensive field surveys and geotechnical work, the expense to be borne by the applicant. An appeal procedure is set up in another section of the ordinance for use by the applicant.

Development within 30 m of karst features such as sinkholes, sinking streams, ghost lakes, cave entrances, closed depressions, lineaments, faults, and any other recognizable karst feature is expressly forbidden unless expert geotechnical work shows that it can be done safely. In addition, the same restriction applies to limonite excavations, the remnant of the mining legacy responsible for Bethlehem Steel and over fifty blast furnaces in the Lehigh Valley in the late 1800's. Many of the iron pits are undoubtedly old sinkholes where the iron ore was concentrated and still continue to channel water to the hidden karst plumbing network. Seasonal high water tables and clumps of trees are also to be shown on the developer's map for both have been found to be good indicators of karst features in the study area.

A subdivision applicant must come before the Township Planning Commission for several reviews: sketch plan, preliminary plan, and final plan. At each step, there is ample opportunity to discuss the karst hazards on the property. In fact, at the preliminary plan stage, the Township Engineer is expressly directed to flag any such zones on the applicant's property and/or tell the applicant that there is a potential for karst features on the land in question. The Planning

Commission can deny the application for subdivision or conditional use if the applicant fails to go before the Zoning Hearing Board for a zoning variance.

Summary and Conclusions

Although it is stated that zoning and subdivision ordinances are a good way to avoid problems associated with karst subsidence, there are many shortcomings with this approach. Most karst researchers will undoubtedly feel the wording is not strong enough. Any debatable language or legal uncertainty, like the identification of fracture traces, has to be left out of the Ordinance. Only language that can be defended by the Township Solicitor in court and only features readily identifiable by non-experts can be kept in an ordinance. A great problem is the fact that karst science is still in its infancy and detection methods are primitive at best. Until we get better methods of delineating karst features and identifying incipient sinkholes, we can not make the language or requirements in the ordinances any tougher. There is also a problem with the public and government officials not realizing the threat of karst subsidence to life or property. Education must also accompany the push for implementation of codes or else the effort is bound to fail. Developers can present a convincing argument against the implementation of codes because of the extra expense they have to pay. Probably the biggest problem with karst hazards codes, be it subdivision or zoning, is the lack of enforcement. Many municipalities have no way to follow up on developers to ensure that the provisions agreed upon are followed. Many of these problems only come to light if there is a collapse or if a resident protests.

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DEVELOPING URBAN NONPOINT SOURCE MANAGEMENT PLANS IN KARST AREAS OF SOUTH-CENTRAL KENTUCKY

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ABSTRACT

The presence of urban nonpoint source impacts has been clearly documented for South-central Kentucky caves, groundwater and connecting streams. This paper discusses the informational needs for conducting preliminary nonpoint source assessments and a methodology for preparing a phase one plan to address remedial and preventative nonpoint source pollution control. The nature of karst use impairment is emphasized, using a watershed-based approach. The paper recommends ways to use available information in complex groundwater basins to justify or preclude potentially expensive remedial programs.

INTRODUCTION

National research, particularly from the Nationwide Urban Runoff Program (USEPA, 1983), has shown that urban runoff is contaminated with pollutants whose concentrations may exceed accepted water quality standards. Likewise, studies in Kentucky have found that water quality in urban karst groundwater basins such as in the vicinity of Bowling Green is adversely affected by urban nonpoint source pollution (Crawford, 1990, 1989). Domestic water supply and recreational uses in connecting surface streams and caves are believed to be threatened or significantly impaired by sediments contaminated with oils, pathogenic bacteria, heavy metals, and organic compounds derived principally from urban runoff (Kentucky Division of Water, 1990).

Urban storm water in Bowling Green, for example, is disposed of by means of karst sinkholes, dry wells and swallets where untreated urban runoff is allowed to quickly penetrate shallow aquifers, potentially contaminating domestic water supplies, impairing cave uses and discharging pollutants at springs to surface watercourses downstream such as the Barren River and the Green River.

It is clear that nonpoint sources, sometimes in combination with industrial point source effluents and substandard sanitary sewer connections result in impairments of cave and groundwater uses. In newly urbanizing groundwater basins, nonpoint problems can be minimized by requiring relatively inexpensive "best management practices" (BMPs) and environmental ordinance controls for new development. In already developed watersheds with identified use impairments, it will be more difficult and expensive to identify and implement the kinds of controls necessary to fully remedy the observed impaired conditions.

Another important issue which should be considered in addressing existing cave and groundwater use impairment problems is the unfamiliarity and lack of financial resources of local officials and citizens regarding nonpoint sources and water quality. Because of the long-term historical degradation of urban cave streams in Kentucky, there exists a common perception that there is little potential for beneficial uses, other than drainage and wastewater disposal. As a result, local officials may be reluctant to voluntarily implement control programs and invest limited resources in solving a problem which is not a high priority. Even with the encumbrance of federal storm water regulations (U.S. EPA rules mandating storm water quality controls for construction sites of five acres of more), it appears that local government officials will need clear and conclusive information from groundwater basin assessments before they are likely to embrace potentially expensive nonpoint source control programs.

INFORMATION NEEDS

One of the objectives of this paper is to define a realistic methodology to address the problems raised above. The purpose of this methodology is to accurately define the causes, effects and practical solutions of urban nonpoint source impairments in specific cave and groundwater basins. This methodology will require the collection and analysis of site specific data from demonstration project areas within designated urban groundwater basins. As the knowledge of nonpoint source cause and effect relationships increases, the level of necessary data collection and analysis can be reduced to address primarily those factors which are unique to other basins.

Several important elements are needed in developing an urban nonpoint source management plan for karst South-central Kentucky:

> Demonstration of groundwater basin-specific cause and fact relationships between nonpoint resources and impairments of cave stream uses,
>
> Prototype studies performed in "representative" groundwater basins that identify critical nonpoint source effects and demonstrate successful best management practices programs, serving as examples of cost-effective nonpoint source management for karst areas of South-central Kentucky,
>
> Regional guidelines for groundwater basin analysis criteria, monitoring methods, intergovernmental agreements, and strategies for watershed-based planning programs developed to assist local units of government, and
>
> BMP design criteria, facilities construction guidance, cost criteria, and maintenance needs.

Cave use and groundwater quality enhancement should be the primary goal as well as the critical measure of the effectiveness of a nonpoint source management plan. Other measures of the plan's effectiveness can and should be used, e.g. location and elimination of substandard sewer connections, location and cleanup of abandoned underground chemical storage tanks, comprehensive testing and remediation of failing chemical storage and septic tanks, water quality improvement, etc.

RECOMMENDED METHODOLOGY

The recommended methodology for developing urban nonpoint source management plans is based on two basic principles. The first is that effective planning must be watershed-based. The second is that the primary goal of the planning process should be the restoration and protection of desirable cave stream uses.

The methodology is two-phased. The first phase involves the collection of available information on the selected groundwater basin and its adjoining surface streams. This information will typically be adequate to draw significant conclusions about the nature of nonpoint source impacts, make preliminary recommendations for effective BMPs, and to determine additional monitoring and assessment needs. It is important to note that this information may lack storm event-related water quality data and therefore be inadequate to justify to local officials significant expenditures for remedial measures, such as retrofitting detention basins for pollutant removal.

The second phase of the recommended urban nonpoint source planning methodology involves more intensive data collection and assessment. Several representative groundwater basins should be selected for more thorough water quality assessments (e.g. Turnhole Spring, Lost River, and Harris Spring) in a phase two analysis. The knowledge gained in these demonstration watersheds, in combination with existing information, may be adequate to characterize and control nonpoint problems in most remaining watersheds.

The following are the key elements of a recommended nonpoint source management planning methodology:

Define Water Resource Objectives

Collect Groundwater Basin Data

- Water Quality, Biological and Sediment Date
- Point Source Effluent Date
- Physical Conditions
- Cave Habitat
- Drainage Maps/Sinkholes
- Land Use Maps
- Land Cover Maps/Orthophotos
- Soils Maps
- Existing Nonpoint Control Programs

Perform Nonpoint Source Assessment

- Use Assessment
- Impact Assessment
- Cause Assessment
- Source Assessment

Prepare Nonpoint Source Management Plan

- Identify Remedial Measures
- Identify Preventative Programs
- Develop Implementation Mechanism
- Develop Plan Evaluation Program

DEMONSTRATION WATERSHED

The Harris Spring Groundwater Basin is located within the Bowling Green corporate limits, and much of it is under new or recently built commercial and residential developments. Numerous sinkhole drainage wells, more than fifty small storm water detention facilities, and one large regional detention basin are located there. The functioning of these facilities could be threatened if sediment forms blockages in subsurface streams.

In addition, aquatic life and associated recreational benefits of the Barren River should be protected or restored by implementing nonpoint source BMPs in the basin. Damages from any chemical spills in the highly traveled Scottsville Road and Interstate 65 area should be mitigable as well.

Sources of Impairment

Once the use impairment or potential impairment is determined, using available information outlined above, and the specific pollutants which are causing the water quality problem are identified, then those pollutants can be traced to their sources, and critical areas can be defined. If the available information is inadequate to draw cause-and-effect conclusions, a monitoring strategy should be developed as follows.

Water Quality Monitoring

An adequate monitoring strategy should include:
1) weekly surface and groundwater monitoring at Harris Spring and other selected locations in the basin, 2) quarterly benthic macroinvertebrate sampling of selected perennial and wet weather springs, 3) hourly chemical analysis at Harris Spring for at least twelve storm events, and 4) dye tracing to develop a clearer understanding of the subsurface flow patterns.

Chemical tests should be performed by a water quality lab certified by the Kentucky Division of Water for quality assurance. Tests should be run for constituents including but not limited to: fecal coliform, suspended solids, conductivity, nitrates, total phosphorus, copper, cadmium, chromium, oil and grease, lead, pH, dissolved oxygen, triazine and volatile organic compounds.

For demonstration purposes, monitoring stations should be set up to correspond with anticipated BMPs and adjacent sub-basins in order to utilize the EPA-recommended "paired watershed" approach in lieu of the traditional "before and after" monitoring. Documentation and data reduction of all water test results should indicate any significant cause and effect relationship between BMPs, water quality and use support.

BMP Implementation

The means of controlling or eliminating pollutants in critical areas should be through the use of best management practices (BMPs). BMPs prescribed for residential, commercial and industrial land uses should include silt traps, infiltration basins, rock outlet protection, grassed waterways, straw bale dikes, ditch checks, diversions, plantings, seedings, mulching, underground storage tank leak detection and remediation, septic system inspection and ongoing maintenance on all installations for the lifetime of each practice.

To treat sediment and nutrient problems in selected new and existing storm water detention basins, small constructed wetlands should be installed above drainage wells to increase detention time, encourage infiltration, and facilitate settling of solids before they enter the karst aquifer.

These practices along with other standard sediment control procedures such as the use of erosion control blanket, straw bale dikes and ditch checks, and temporary sediment traps and diversions during construction with permanent vegetation establishment after construction are proposed for each BMP installation. Design guidance on these practices should be modeled after those specified by the Soil Conservation Service Technical Guide and supplemented by locally accepted engineering practices.

Cost and Benefit Analysis

A complete evaluation of the project should be made, linking an assessment of water quality improvements with the economic impacts of BMPs and the overall project's impact on participating landowners, the community, and users of important groundwater resources.

CONCLUSIONS

The recommended approach for addressing existing cave stream use impairments is to develop a watershed-based nonpoint source management plan. The first phase of this approach is the collection of existing information and the assessment of watershed conditions. Collection of additional watershed-specific data and in-depth nonpoint source assessment is recommended for representative demonstration watersheds. This information can then be used to develop management plans for other similar watersheds within the region. A critical element of this approach is the evaluation of management practices after they are implemented, ideally in demonstration watersheds, to determine the effectiveness in reducing identified problems and to modify management plans, as appropriate.

It is hoped that impending U.S. EPA storm water regulations will recognize the appropriateness of a flexible approach to nonpoint source control. Likewise, it is hoped that the regulations will place greater emphasis on the attainment of desirable cave stream uses rather than strictly on controlling the quality of storm water discharges.

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APPENDIX

Urban Nonpoint Source Variables and Components

- Source Category
  - Point Sources
    - Municipal
    - Industrial
  - Nonpoint Sources
    - Construction
    - Urban Runoff
    - Resource Extraction
    - Land Disposal
    - Industrial Activity
    - Filling and Raining
    - Atmospheric Deposition
    - Golf Course Runoff
    - Fertilizer Application
    - Herbicide/Algicide Appl.
    - Leaky Storage
    - Spills
- Cause Category
  - Contaminants
    - Sediments
    - Pesticides
    - Toxic Organics
    - Metals
    - Ammonia
    - Chlorine
    - Nutrients
    - Biological Oxygen Demand
    - Salinity
    - Pathogenic Bacteria
    - Radon
    - Oil and Grease
    - Volatile Organics
    - Suspended Solids
  - Other Causes
    - Modified Hydrograph
    - Streambank Erosion
    - Habitat Alteration
    - Low Dissolved Oxygen
- Impact Category
    - Turbidity
    - Sedimentation
    - Odors
    - Taste
    - Noxious Plants
    - Abnormal Water Temperature
    - Fish Kills
    - Skin Irritation
    - Other Health Impacts
- Designated Uses
    - Aquatic Life
    - Fishing
    - Water Supply
    - Swimming
    - Boating
    - Passive Recreation
    - Navigation
    - Industrial Cooling Water
    - Education
    - Research
    - Land and Nature Preservation
- Best Management Practices
    - Detention Basins
    - Vegetative Stabilization
    - Rock Outlet/Inlet Protection
    - Sediment Traps
    - Silt Fences
    - Grassed Waterways
    - Ponds
    - Diversions
    - Infiltration Basins
    - Straw Bale Dikes
    - Leachate Collection Systems
    - Channel Restoration
    - Mulching
    - Erosion Control Structures
    - Storage Tank Inspection
    - Tree Planting
    - Setbacks/Buffer Strips
    - Permit Requirements

(adapted from Taylor and Dreher, 1990)

ENVIRONMENTAL EFFECTS OF ACID MINE DRAINAGE IN KARST TERRAIN

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ABSTRACT

A common geologic situation occurs along the margins of the southern Appalachian Plateaus in which karst-forming carbonate rocks are overlain by sequences of Pennsylvanian clastic rock. In some locations mining of this coal has resulted in acid mine drainage (AMD) contamination of streams entering the karst below, creating potential environmental threats to these flow systems. In the study detailed geochemical sampling and analysis along such a system (Camp's Gulf Branch in Van Buren County, Tennessee) was undertaken in order to understand the interactions between the AMD waters and the carbonate rocks, as well as environmental implications for the karst as a result of these interactions.

Initially, AMD waters are characterized as very low in pH and high in sulfate, iron, and manganese. Upon contact with the carbonates, buffering due to calcite dissolution as well as dilution from input of noncontaminated groundwater causes a rapid pH rise to approximately neutral levels. The waters of Camp's Gulf Branch, for example, range in pH from 3.3 to 7.7 along the study reach. This pH change, in turn, controls many of the other accompanying chemical changes impacting water chemistry. By the time Camp's Gulf Branch emerges from a large spring at the base of the plateau, these naturally occurring reactions have brought each of the serious contaminants (sulfate, iron, and manganese) to within drinking water standards. An environmental gradient also exists with respect to varying types of aquatic life observed along the flowpath during sampling trips.

Please contact the authors for further information on this paper.

WATER QUALITY IMPACTS OF AGRICULTURE ON KARST CONDUIT WATERS GREENBRIER COUNTY, WV

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ABSTRACT

Weekly samples were taken beginning in the Fall 1990 from four springs draining two Karst basins to determine the impact of animal grazing agriculture on conduit waters. Atrazine and its metabolites were detected in all springs at low levels ($< 0.2 \mu g/l$) during and after the period of application. Mean nitrate levels were 13.6, and 10.8 mg/l from the two basins. Mean bacterial levels for the two respective basins were 101, and 139 colonies per 100 ml for fecal coliform, and 266, and 276 colonies per 100 ml, for fecal streptococcus. Samples were taken from nine sites in cave streams which underlie one of the basins. Mean nitrate levels ranged from 13.4 to 63.7 mg/l, with three sites above 40 mg/l, and four below 20 mg/l. Fecal coliforms ranged from 110 to 28,588 colonies per 100 ml. One site, which had the highest nitrates and fecal coliforms, receives flow from a sinkhole which is immediately adjacent to a feedlot on the surface.

1 Introduction

The impact on water quality by agricultural activity in Karst terrain is an important consideration for resource management within the Appalachian Region. Karst areas comprise about eighteen percent of the Regions' land surface, upon which is located an estimated one-third of its farms and cattle. About one-third of the Regions' agricultural market value production occurs on Karst terrain.

Because of the interrupted surface drainage and conduit flow in mature Karst terrain, a relatively rapid and direct connection exists between surface water and groundwater ([9]). Sources of contamination may be detected miles from their origin within very short travel times. Large variations in groundwater quality can occur over short time spans ([5]).

Researchers have demonstrated the potential for acute groundwater contamination in Karst areas. Average well water quality has been shown to degrade with increasing proximity to agricultural activity ([8], [11]). Significant localized increases in well contamination have been shown to occur due to inflow from barnyard wastes ([3]). In extensively row cropped areas, high levels of nitrates and pesticides have been found in major springs ([5]).

Livestock agriculture presents a unique combination of potential impacts on groundwater quality. Compared to row cropping, livestock management utilizes less land area for crops, and therefore less agrochemical per acre of farm. However, livestock wastes constitute a significant source of nitrogen and bacteria ([1]). Some animal waste is concentrated in feedlots or barns, where periodic washings may enter nearby sinkholes. It is important to understand how these factors affect ground water quality.

The present study focuses attention on the impact animal grazing systems have on conduit water quality. Conduit waters may have characteristics quite different from water in the surrounding fractured material. In mature Karst basins, a portion of surface runoff is transported to the conduit system through surface features such as sinkholes and sinking streams. These collected flows typically resurge at identifiable base level springs ([9]). Such springs are therefore logical locations for obtaining a composite conduit water sample. This work presents data from several such springs which drain from agricultural areas.

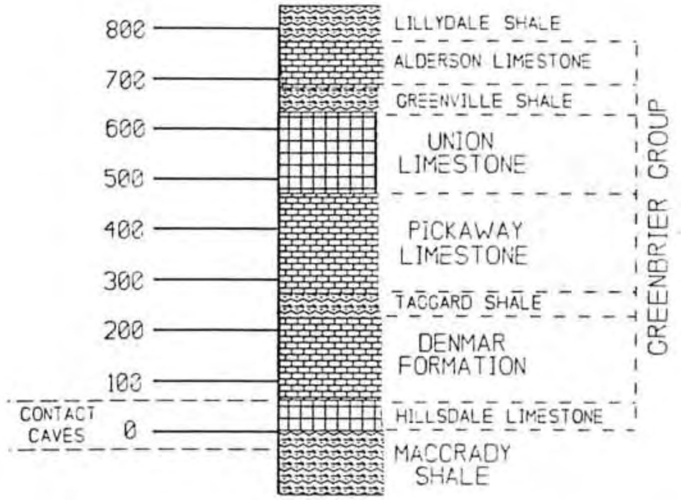

Figure 1: GENERALIZED STRATIGRAPHIC SECTION OF THE GREENBRIER GROUP IN GREENBRIER COUNTY (FROM HELLER, 1980)

2 Study Area and Sampling Procedures

The stratigraphic setting of the study area is the Greenbrier Group, which is of Mississippian age, and predominantly comprised of limestone with interbedded shales ([6]). The generalized stratigraphic section is presented in Figure 1. The surface is replete with mature Karstic expressions. The predominate location for cave development in this area is along the basal contact between the Hillsdale Limestone unit and the Maccrady Shale. This topography, lying on the Karst plateau of the Central Greenbrier Valley and termed the "Great Savannah", is as well developed as any other Karst region within the United States ([2]).

The principal study area is The Hole Basin, an approximately 5.6 square mile agricultural area located south of Spring Creek and west of the Greenbrier River (Figure 2). Human enterprise within this basin is almost exclusively agricultural. There are 38 farms in The Hole Basin. According to a recent land use survey, about 68 percent of the area is in pasture, 10 percent is in crops and hay, and 20 percent is forested. The Hole, an extensive contact cave system, underlies the basin, and resurges out of several springs which immediately enter Spring Creek ([7]). Three resurgence points were monitored from The Hole Basin: Burns Cave, Legg Spring, and Blue Hole.

A second study area is Davis Spring Basin, a 76 square mile area located south of, and adjacent to The Hole Basin (Figure 2). Davis Spring is the resurgence point for the basin, which is known to receive flow from all of the contact cave systems south of The Hole, and north of the Greenbrier River. These include Ludington, McClungs, Maxwelton, Benedicts, and Wades caves ([2]). Davis Spring is the largest known spring in the state of West Virginia ([7]). A land use survey was not available for Davis Spring Basin at the time of writing. However, animal agriculture occupies a major portion of the land area. Population centers are relatively small.

Weekly water samples were taken from the four springs, and from sites within Spring Creek which are upstream and downstream of the three resurgence points. Samples were analyzed for triazine herbicides, nitrates, fecal coliform (FC), and fecal streptococcus (FS).

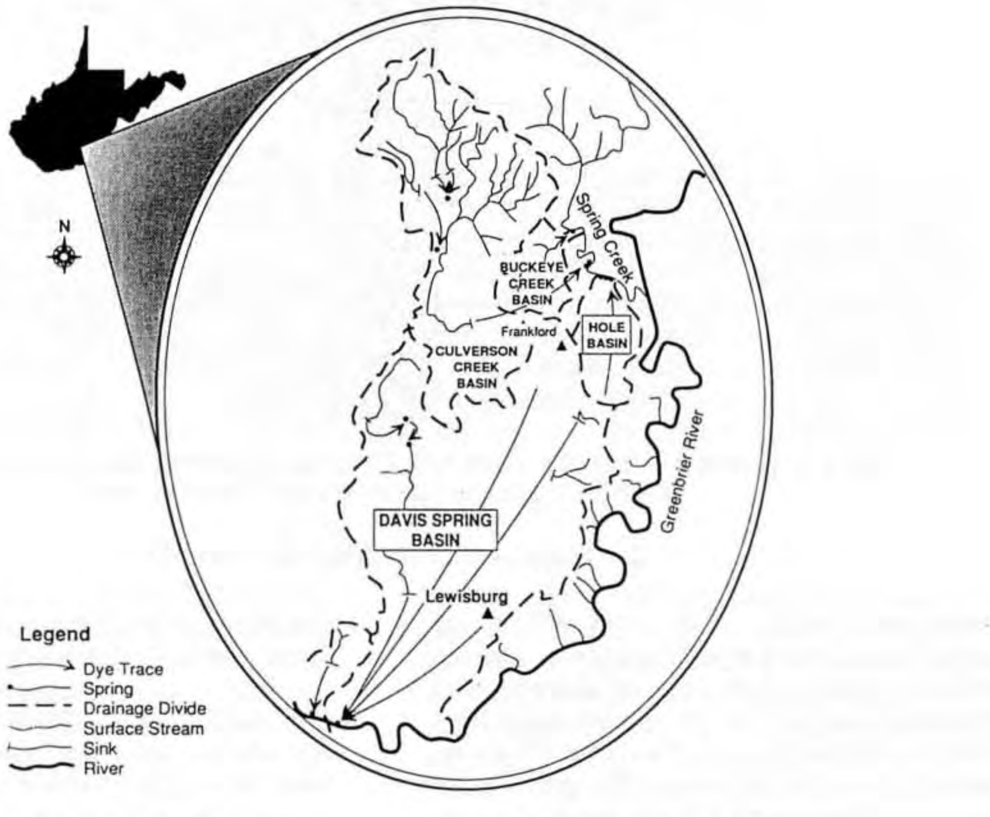

Figure 2: Drainage Basin Boundaries and Principle Dye Traces, Jones, 1973

Attention was given to triazine herbicides because atrazine is widely used on corn crops which are harvested as feed for livestock. Elevated concentrations of nitrogen and fecal bacteria are good indicators of fecal contamination ([1]).

Triazine herbicides were determined using gas chromatography/mass spectrometry. Nitrates were determined by cadmium reduction ([10]). Bacteria were enumerated using the membrane filter technique, and verified by gas production in lauryl tryptose and EC broth ([10]).

The present work was initiated in several phases. The nitrate, FC, and FS data analyses were begun in October 1990, February 1991, and March 1991, respectively. Sample analyses for triazines began in April 1991, one month prior to the principal period of application.

The data presented below almost exclusively represents baseflow conditions. Because of this, it was not possible to develop correlations between any of the measured parameters and either rainfall or spring level. However, such relationships will likely emerge once a more complete data set is assembled.

	Atrazine				Nitrate			
Site	mean (μg/l)	range	CV (%)	n	mean (mg/l)	range	CV (%)	n
Upstr. Spring Ck.	0.00	0.00-0.00	-	11	3.2	1.5-5.6	35	46
Downstr. Spring Ck.	0.00	0.00-0.00	-	9	4.2	1.5-7.0	34	46
Burns Cave	0.07	0.01-0.16	68	10	13.3	10.6-15.9	10	46
Legg Spring	0.03	0.00-0.09	83	10	14.0	10.6-16.7	11	45
Blue Hole	0.02	0.00-0.06	172	11	12.6	8.7-17.3	15	46
Davis Spring	0.05	0.00-0.16	93	12	10.8	7.4-13.1	14	46

Table 1: Summary of Water Quality Data: Nitrate and Atrazine

3 RESULTS AND DISCUSSION

In Tables 1 and 3 are presented the mean, minimum-maximum, coefficient of variation (CV), and number of data (n) for atrazine, nitrates, fecal coliform, and fecal streptococcus.

The presence of atrazine and its metabolites in conduit waters presents the most certain evidence of agricultural impacts (Table 1). Based on these preliminary investigations, it appears that atrazine levels are well below the EPA action limit of 3 ppb. On the other hand, the presence of any atrazine constitutes cause for reasonable concern, since it is applied to less than 10 percent of the watershed land area. To the authors' knowledge, there are no cropping areas which immediately adjoin Spring Creek anywhere above the downstream sampling site. Therefore, any atrazine entering Spring Creek is likely derived primarily from groundwater rather than surface runoff. These small concentrations are apparently diluted in Spring Creek to levels which are below the minimum detection limit of about 0.01μg/l.

The consistently high nitrate levels in all four springs demonstrates the potential impact of surficial Karst features on the quality of water in the conduit system. In Table 2, mean nitrate values are listed from the present work, and for waters from portions of the Greenbrier Group, as measured in well water samples by Heller ([6]). The nitrate levels from Burns Cave, Legg Spring, and Blue Hole are averaged together to yield the mean for the "Hole Springs". Well samples generally characterize the diffuse, or fractured portion of the aquifer. Heller's data is therefore considered representative of diffuse flows within each formation. Nitrate levels in the Maccrady-Hillsdale aquifer are about one fifth of those in the Hole Springs, and one fourth of those in Davis Spring. The higher nitrates in the springs are interpreted as being derived from nitrate enriched runoff from pastures, feedlots, etc. which is captured by Karst features and delivered directly to the conduit system.

As seen in Table 3, fecal bacterial levels are high enough to indicate significant animal and/or human impacts. Their almost continuous presence at all sites suggests that elevated nitrate levels are closely associated with fecal pollution. Both FC and FS in the springs are of the same order of magnitude as in Spring Creek. This is in contrast to the marked differences in nitrate concentrations between the two.

	Alderson Limestone	Pickaway-Union	Taggard Shale	Maccrady-Hillsdale	Hole Springs	Davis Spring
$n =$	3	18	11	39	138	46
NO_3^- (mg/l)	1.4	5.9	11.9	2.7	13.6	10.8

Table 2: Mean Properties of Formation Waters (Heller, 1980), compared to Mean Properties of Hole Springs and Davis Spring (present work).

	Fecal Coliform				Fecal Streptococcus			
Site	mean (#/100 ml)	range (#/100 ml)	CV (%)	n	mean (#/100 ml)	range (#/100 ml)	CV (%)	n
Upstr. Spring Ck.	116	0-633	108	29	660	16-2093	90	24
Downstr. Spring Ck.	183	0-520	80	29	517	13-1920	103	24
Burns Cave	134	0-1000	152	29	441	20-3793	203	24
Legg Spring	104	4-540	116	28	241	11-1453	157	24
Blue Hole	66	0-980	268	29	117	1-535	121	24
Davis Spring	139	6-1434	199	29	276	13-2333	182	24

Table 3: Summary of Water Quality Data: Fecal Coliform and Fecal Streptococcus

4 Preliminary Cave Survey

Another aspect of the present work which has just begun, is to determine the impact of agricultural activity on the cave environment. Two different systems are being studied, each of which consists of a main stream receiving several feeder streams. Sampling sites include each feeder stream, and points within the main stream which are upstream and downstream of the feeders. Samples have been analyzed for nitrate and fecal coliform concentrations.

The results of the survey are presented in Tables 4 and 5. Sampling began in July, 1991, and each of the values in the table are based on two sample sets from different sampling dates.

Nitrate levels in the System I main stream decrease in the downstream direction. This decrease is not due to dilution by the feeder streams. The main stream is visually observed to be larger than any of the feeders, and all three feeders have nitrate levels close to or above the 13.6 mg/l level at the downstream site. This decrease is apparently caused by dilution from unseen sources, such as infiltration waters.

Neither the three feeder streams, nor any unseen input produce a measurable change in the System I main stream fecal coliform counts. All FC levels are quite close, with the mean count in the three feeder streams at 135. Given the inherent variability in the

site description	Nitrate (mg/l)	Fecal Coliform (#/100 ml)
Upstream	17.2	154
Feeder 1	15.9	170
Feeder 2	13.4	110
Feeder 3	40.1	124
Downstream	13.6	153

Table 4: Cave Stream System I - Nitrates and Fecal Coliforms

site description	Nitrate (mg/l)	Fecal Coliform (#/100 ml)
Upstream	20.4	114
Feeder 1	28.1	1430
Feeder 2	63.7	28,588
Downstream	42.3	>1867

Table 5: Cave Stream System II - Nitrates and Fecal Coliforms

enumeration technique, it is not contradictory that measured FC along the main stream remains nearly constant while nitrates decrease. Nitrate values are generally assumed to be accurate to within 5 percent, while fecal coliform levels are considered significant to within 100 percent.

In contrast to System I, the main stream in System II was substantially degraded by its feeder streams. Nitrates were about doubled, and fecal coliform levels increased at least one order of magnitude[1], from upstream to downstream. In both feeders, the fecal coliform levels were at least one order of magnitude higher than for any of the sampling sites in System I. Feeder 2 contains both the highest nitrates, and the highest fecal coliform levels among the nine sites. Nitrates in both samples from Feeder 2 were above the EPA action level of 44.5 mg/l. This stream originates from a sinkhole which is located near, and downslope from a feedlot. The marked contamination levels may arise from washing of animal waste into the sinkhole.

The state of aquatic fauna in the cave provide another indicator for the presence of pollution. Enumeration of aquatic invertebrate species were performed at all sampling sites (data not shown). The results were indicative of a nutrient enriched environment. Species diversity of troglobites was substantially reduced from that found in other, less contaminated contact caves in the same county ([4]).

Cattle are periodically present at, or near, all spring and surface water sites mentioned in the previous section. The present data suggests, however, that a major portion of the fecal bacteria in springs is carried there by conduit waters. This is supported by the fact that the portion of the cave system sampled contained fecal coliform at levels consistent with, or greater than those discovered in the springs.

[1]The fecal coliform count for the downstream site could only be given a lower bound because levels were too high on the plate to enumerate. This value is calculated from the highest allowable plate count (200 colonies according to [10]), and the dilution used. Higher levels were discernable in Feeders 1 and 2 because they were anticipated, and higher sample dilutions were employed.

5 Concluding Remarks

A better understanding of the movement of agricultural contaminants in Karst terrain is essential in order to safeguard groundwater in such areas. Nitrate and atrazine were below EPA action levels in the springs and surface waters studied. However, the sensitivity of the Karst system to potential contamination is apparent. For example, although the percent land use for crops is small, atrazine was discovered in all four springs. The nearly continuous presence of fecal bacteria suggests that untreated spring waters cannot be assumed to be safe sources for domestic use. Also, acute fecal pollution was observed in localized areas within some cave streams. Efficient and affordable management practices must be developed to aid farmers in minimizing these impacts.

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HYDROLOGIC FLOWNET MAPPING AND KARST-CONDUIT DETECTION USING THE NATURAL ELECTRIC FIELD

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ABSTRACT

When water flows through conduits or a porous medium, an electric current is generated whose potential gradient is proportional to the driving pressure. This *electrokinetic* effect occurs wherever water flows in the ground and gives rise to a voltage distribution on the surface corresponding to the horizontal component of the underlying hydrologic flownet. Thus the surface *electric current pattern* produced from a natural-potential survey can be interpreted in terms of the subsurface *fluid-flow regime.*

Examples of flownet interpretations from natural-potential (NP) surveys around wells in non-karstic terrain are shown. In karst, caverns and active conduits give rise to characteristic electric signatures on the surface expressive of the nature of the underground flow. These signatures form discrete anomalies in the deduced karst flownet that correspond in location to the subterranean voids and streams.

The natural-potential technique is of particular value for mapping karst conduits between the endpoints of tracer tests in karst. Thus it is an effective tool for targeting monitor wells and for detecting and mapping caverns beyond their known extents.

Introduction

Patterns of d.c. electric potentials occur everywhere upon the ground surface and beneath it. These are the result of ambient electric currents generated by natural phenomena, including oxidation/reduction reactions around mineralized bodies, localized thermal heating, mixing of fluids, and the flow of groundwater through pores, fissures and conduits of earth materials. The production of a natural-potential (NP) field by moving fluids constitutes the family of processes referred to as *electrokinesis*, or *electrofiltration.* In this report, we shall focus on the means by which measurements of electric potential on the ground surface can illuminate active karst conduits in the subsurface. First, however, it is necessary to summarize more generally the principles underlying the electrokinetic, or *streaming*, phenomenon.

Basic electrokinetic process

Figure 1a illustrates the relationship between the driving pressure and the resulting electric potential gradient in the simple one-dimensional laboratory case of a liquid solution passing through two separated permeable plugs subjected to equal pressure gradients. A charge separation is normally present around material grains immersed in an electrolyte, such that, in the case of silica, a double layer of ions develops as the grain surface, where negative ions attach to the solid, and positive ions surround the grains within the fluid. With fluid flow, the most mobile positive ions are displaced from the double layer, leaving an unbalanced negative charge on the grains. The cumulative effect of charge separation is a potential gradient positive in the direction of flow. In Figure 1a, fluid movement generates a greater potential in the

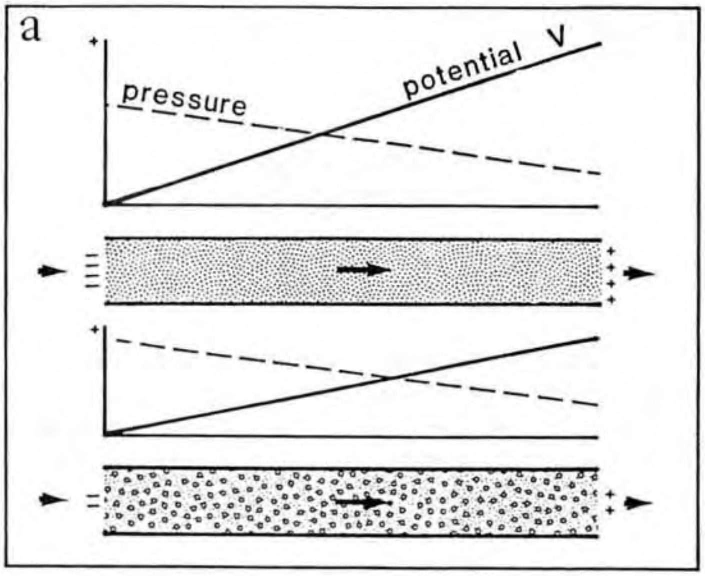

Figure 1a. A liquid forced through a tube containing silica sand (upper example) generates an electric potential gradient positive in the flow direction and proportional to the gradient of driving pressure. The lesser potential gradient developed in the lower example of a gravel-filled tube is the result of a lesser coupling coefficient associated with the larger grain-size of the gravel.

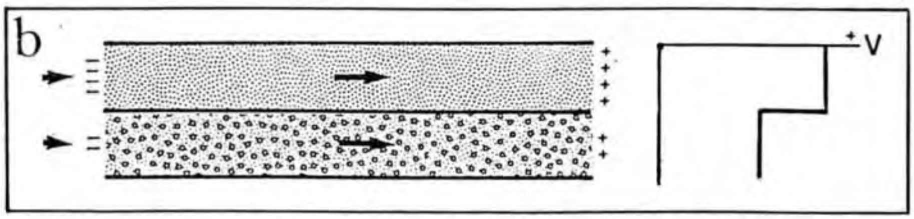

Figure 1b. If the two above conduits abut one another, but remain partitioned, the voltage profile measured across the downstream ends relative to the influx is a positive step function, corresponding to the potential gradients of Figure 6a.

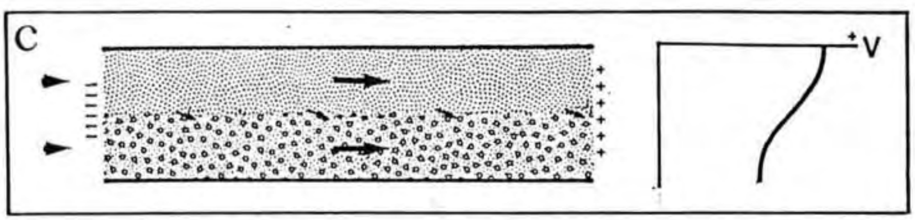

Figure 1c. Upon removing the separator between the above channels a portion of the flow of the sand medium is refracted toward the medium of greater hydraulic conductivity, but of lower coupling coefficient, so that the terminal voltage profile is gradational.

tube of quartz sand (upper case) than in the lower example of gravel. Under normal circumstances the relationship between potential and pressure differentials is linear; the slope of the line is the *coupling coefficient.* The coefficient is the result of chemical and hydrologic properties of both the solid and the fluid; for example, in the case illustrated, coupling is inversely related to grain size, permeability and salinity (Ahmad, 1964)[1]. The effects of temperature and pH are more complex (Ishido & Mizutani, 1982); thus, in the case of a carbonate in water that is acidic, the coupling is inverted; that is, the potential becomes more negative in the direction of flow, according to Scherer & Ernstson, 1986. In the case of fissure-flow, Bogoslovsky & Ogilvy (1972), using glass plates, measured a decrease in coupling coefficient with increasing aperture.

In Figure 1b, the previous sand and gravel conduits are juxtaposed and subjected to the same pressure gradient. Their differing coupling coefficients give rise to a sharp change in voltage across their downstream ends, relative to the upstream ends, provided the conduits are separated. Removing the partition (Figure 1c) results in some refraction of flow towards the lower medium of higher porosity, and a smoothing out of the voltage profile at the downstream end of the system. In effect, the natural potential, measured at the surface can, under relatively uniform conditions, provide an approximation to the flownet of the hydraulic regime (Lange, 1991). The NP technique has found widespread application in the mapping of leakage in dams and pipelines and in the search for thermal and meteoric water plumes (Ogilvy, et al., 1969).

Flow-net mapping in a near-homogeneous terrain

In order to demonstrate the nature of the potential gradients arising from meteoric water infiltrating the ground, we cite an example from the nearly homogeneous loess terrain of western Kansas, where a natural potential grid was measured over a block of ground approximately 2.5 x 9.7km (1.5 x 6mi). Total relief between the high ground and arroyo bottoms is about 37m (120ft), as depicted in Figure 2a.

The survey of natural potential resulted in the contour plot of Figure 2b. According to the rules developed above, we expect water to move from the regions of lower potential towards those of higher potential; i.e., to the more positive ground. Thus, we can construct arrows at right angles to the contours and directed toward the positive zones. When these arrows are superimposed on the topography (Figure 2c), we see that the deduced flow is consistently directed from the higher recharge areas towards the drainages or discharge zones, which is the normal hydraulic behavior in such an environment. In effect, the potential contours are inversely related to elevation; but by virtue of the groundwater movement, rather than by the altitude directly.

The flow net around a pumped well

A well on the Kilty ranch of Goshen County, Wyoming, has a total depth of 43m (140ft), of which the upper 6m (20ft) have a metal casing. Alluvium here averages about 6m (20ft) in thickness and is underlain by siltstone of the Oligocene Brule formation. The water table occurs normally at around 7.6m (25ft). The well had been pumping for irrigation purposes during most of the summer, but was turned off approximately two weeks prior to our tests.

The potential pattern appears as the typical inverse cone of depression seen in NP data around pumped wells (Bogoslovsky & Ogilvy, 1973). In Figure 3, I have constructed current arrows (dashed) drawn orthogonally to the equipotentials. They provide a reasonable pattern for the hydraulic flow lines during the recovery phase. Two centers of attraction are evident: the well itself, and a second center to the northeast. The latter likely connects to the well via a deeper path, possibly through piping, that was not resolved in the surface expression.

[1]Schriever & Bleil (1957), using glass beads, observed a *decrease* in coupling coefficient with decreasing grain size, but no measurable effect due to porosity variations within the range of 0.392 and 0.432. Abazo & Clyde (1969), on the other hand, confirmed the relationships observed by Ahmad.

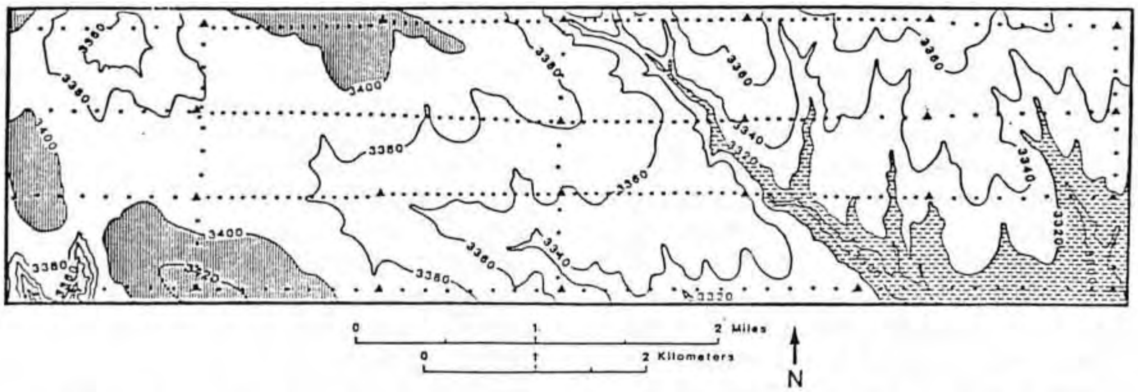

Figure 2a. Topography and grid of a reconnaissance natural-potential survey in loess of northern Logan County, Kansas. Contours in feet; shadings highlight the higher and lower regions. (TGG data).

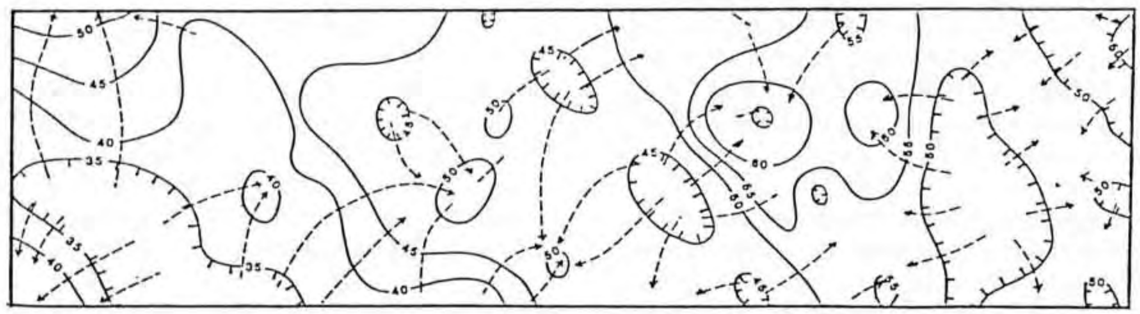

Figure 2b. Natural-potential pattern in millivolts contoured from the above grid. In this very homogeneous medium, a strong inverse correlation has resulted between NP response and elevation. Orthogonal arrows (directed toward the positive potential) are here superimposed on the electric potential. These arrows correspond to the horizontal component of potential gradient, or current lines. The current pattern, in turn, approximates the horizontal projection of hydraulic flow paths of the flow net.

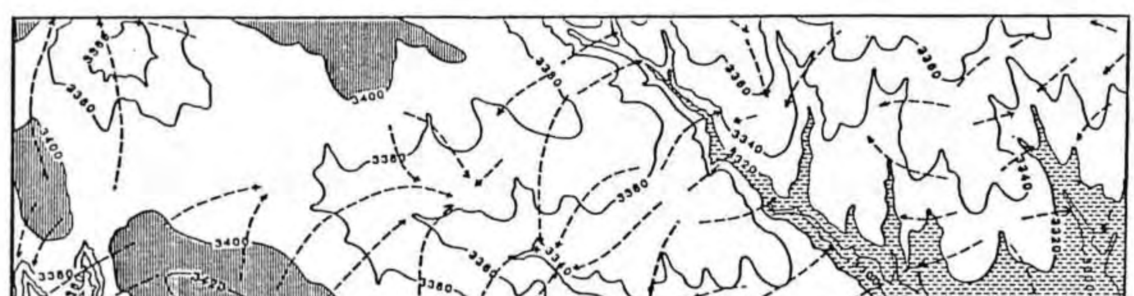

Figure 2c. Current arrows superimposed on topography demonstrate a strong positive attraction toward the drainages (loci of discharge), typical of hydraulic flow paths in a homogeneous medium.

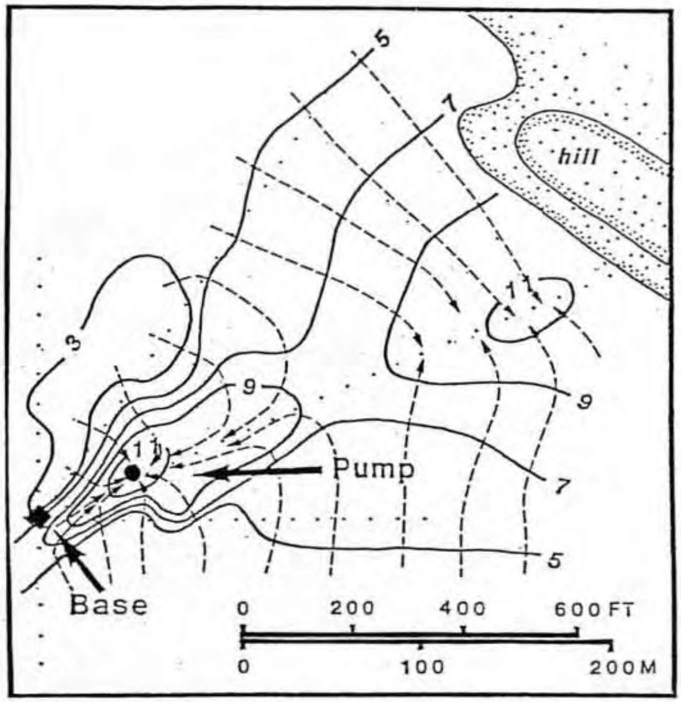

Figure 3. Natural potential distribution (solid contours) corresponding to the cone of depression around a pumped well on the Kilty ranch, Goshen County, Wyoming. The orthogonal arrows (dashed) depict the configuration of the electric gradients, which approximate the hydraulic flow paths during recovery. (TGG data, courtesy of Kevin Kilty).

Field instrumentation and procedures

Ostensibly simple, the natural potential apparatus used by the author consists of a pair of sealed non-polarizing copper/copper sulfate electrodes, an 800m reel of cadmium-bronze wire (color-calibrated by distance) and a digital multimeter of ultrahigh $(1000 M\Omega)$ input impedance. A base electrode is buried at a point central to the area being surveyed, and a connecting wire is unreeled out to the starting points of successive lines. It is preferable to refer all readings to one common base, if at all possible; if not, secondary electrode bases must be established by multiple ties. Four readings in shallow holes (≈ 10 cm) are read within a radius of about one meter around the base at the beginning and end of each line traverse.

Readings are then made at successive points along a line; usually two holes are sampled and averaged at each station: more, if they exceed a designated threshold; e.g., 4 millivolts. Typical spacings used for detecting karst conduits is 7.5m (25ft) or less, with line separations of 30 to 60m (100-200ft). Occasional resistance readings are made to insure continuity of the wire. Following completion of a line segment or the complete line, the operator returns to the base station and rereads its four holes. The voltage differences in any two base observations represents temporal drift, for which the line data must be compensated.

Data are entered into a computer at the end of each day and drift corrected. Plots of voltage versus distance can then be generated using a graphics program either on the screen or as a printout. Additional data treatment may be required, such as removal of elevation effects, cathodic protection trends, etc. Finally the NP data are contoured to provide an areal map of potential distribution, which may be translatable into an approximate flow net, as demonstrated above.

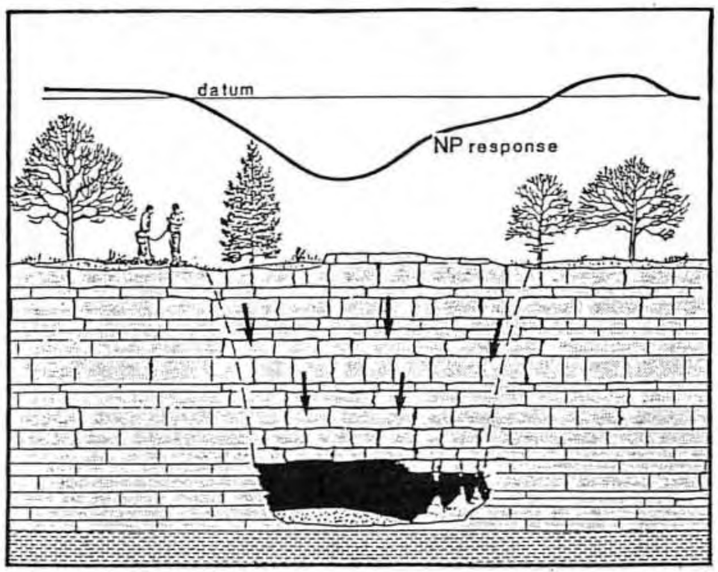

Figure 4. Natural-potential response arising at the surface due to water infiltrating the roof of a cave. The electrokinetic anomaly is expected to be negative in polarity if the water is basic, and positive if acidic.

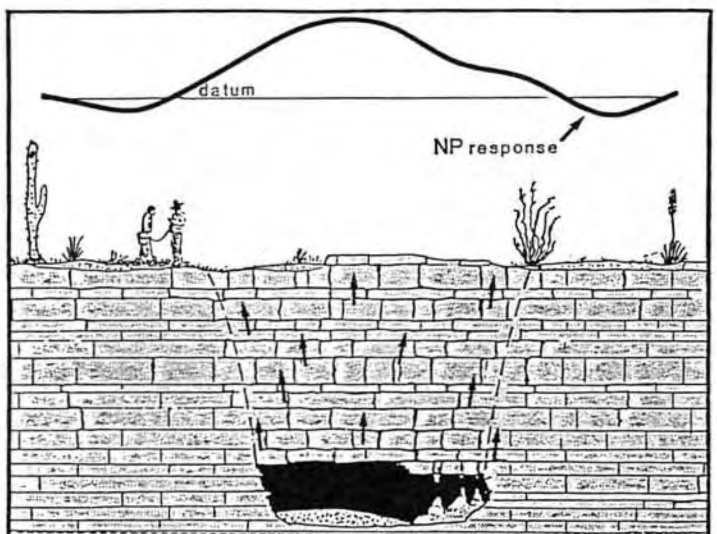

Figure 5. Natural-potential response resulting from upward migration of water under capillary action, from the moist environment of the cavern to the arid surface terrain where evapotranspiration takes place. In this case a positive surface anomaly is expected in the case of basic water.

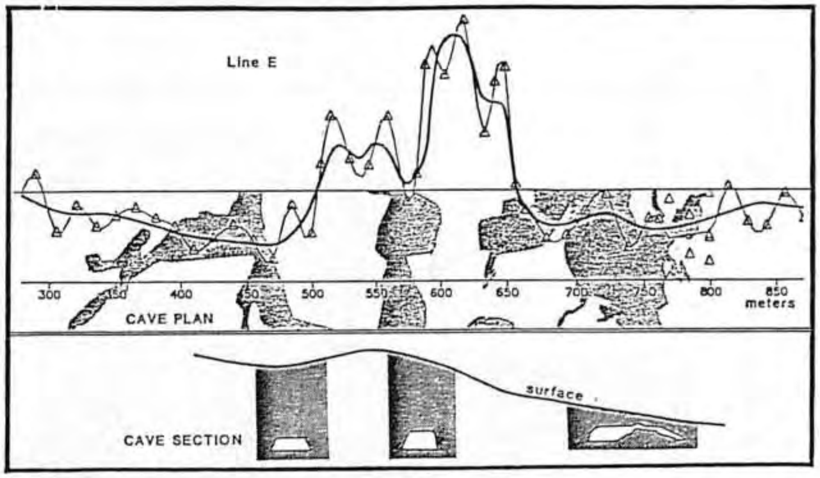

Figure 6. NP response over the main passages of Kartchner Caverns State Park, Arizona. The anomaly here is a compound feature consisting of a double positive flanked by lows, possibly the result of upward migration of water from the very moist cave environment. (From Arizona Conservation Projects, Inc., funded by the Arizona State Parks Department).

ORIGIN OF CAVERN ANOMALIES

The infiltration model

Before addressing the relationship between the natural electric field and karst streams, we shall consider the more general case of the effect of an empty void on the electric field at the surface. In a carbonate environment, infiltration occurs primarily through joints and fissures. In the roof of a cave, downward flow is preferentially favored, but because of the difference in rock chemistry, an anomaly can be expected whose polarity depends on the pH of the electrolyte (Scherer & Ernstson, 1986). A negative anomaly, corresponding to a pH>7 is illustrated in Figure 4. In the case of acidic water, a positive anomaly can be expected over the void.

The preceding mechanism is but one of several that might be invoked to explain the NP anomalies observed over actual caverns. The report by Lange & Quinlan (1988) summarizes several other likely explanations. In addition, the possibility that water is moving from the cave upward towards the surface under capillary flow must be seriously considered as an explanation of positive anomalies observed over caves in desert environments (Figure 6).

Previous NP surveys over caves

The Geophysics Group previously mapped NP responses over caves in Missouri, Kentucky, Arizona and Nevada; however, polarities of the anomalies did not always conform to the simple rules outlined above. For example, while the responses along two lines over Cave Valley Cave, Nevada exhibited sharp positives superimposed on broad lows, typical of a limestone overlain by alluvium, there occurred here at most only a few centimeters of soil over the rock. At the Ozark Underground Laboratory, Missouri, negative anomalies coincided with underlying cave passages (Lange & Quinlan, 1988), where the country rock is a dolomite. At Kartchner Caverns State Park, Arizona a compound anomaly is observed (in summer) over the cave as a whole (Lange et al., 1990) (Figure 6). Lange and Wiles (1991) found an overall low zone characterizing the maze of Jewel Cave, South Dakota. Meanwhile, the NP profile over Inner Space Cavern, Georgetown, Texas, produced prominent *positive* anomalies developed over the mapped cave passages (Figure 8). Clearly, different rock or fluid properties are influencing the resulting surface expressions in the different environments.

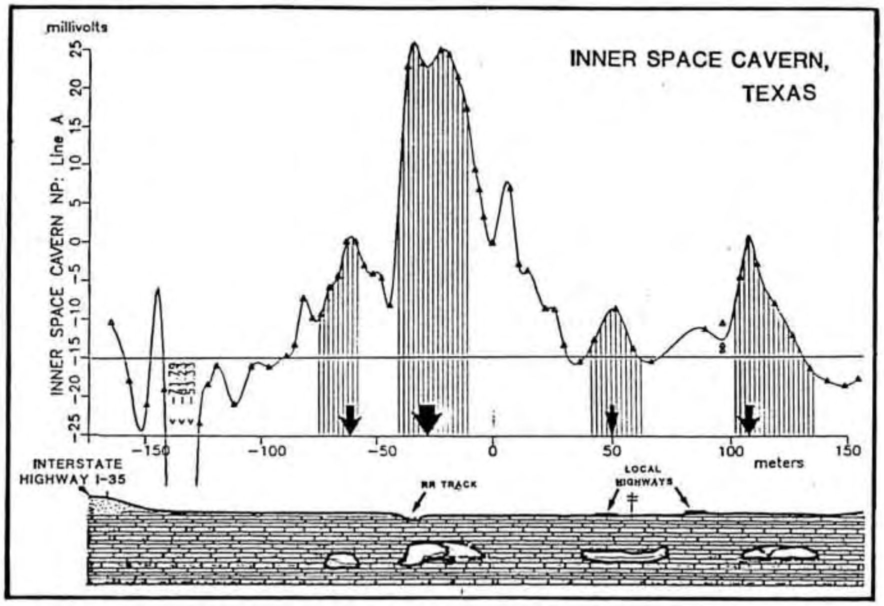

Figure 7. Positive NP anomalies corresponding to passages in Inner Space Cavern, Texas. The extreme negative anomaly alongside the highway is due to a buried pipeline.

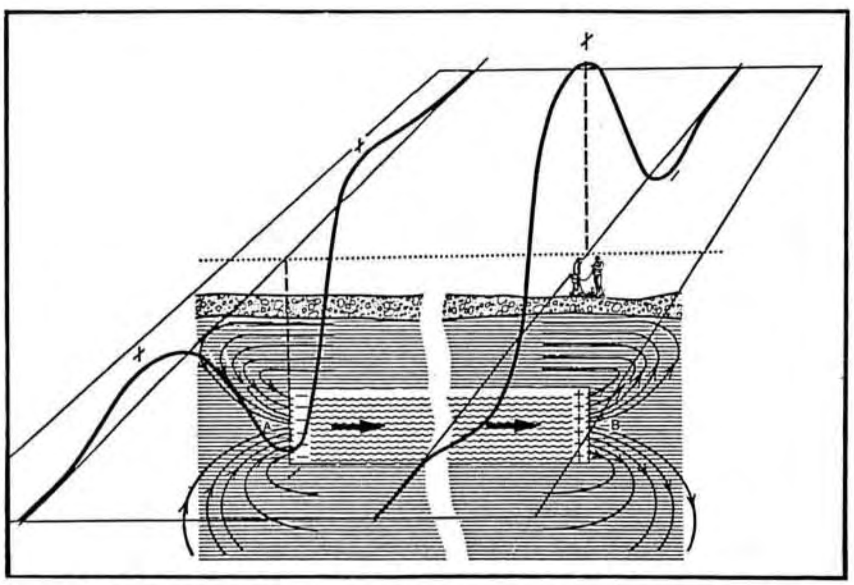

Figure 8. Electric flowlines wrapping around a karst conduit as a result of a potential gradient set up by water flowing from a source at *A* to a discharge point at *B*. The resulting NP surface profiles measured over the two conduit ends are of opposite polarities. Theoretically, across the midline of the conduit, no anomaly would appear.

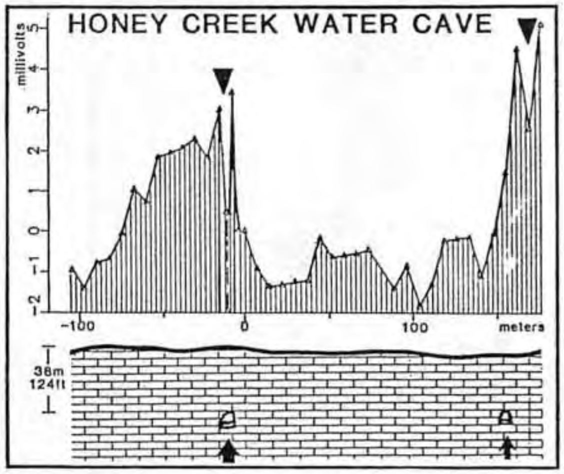

Figure 9. Compound anomalies over segments of the longest cave in Texas. Here each conduit is expressed as a sharp M-shaped positive.

The cave stream model

Laboratory experiments have demonstrated that measurable potential gradients can be generated by an electrolyte flowing through fissures (Bogoslovsky & Ogilvy, 1972). It is therefore reasonable to expect a response from a flowing cave stream, wherein a separation of ions can occur along the conduit walls. Thus, referring back to Figure 1a, if we empty out the sand and gravel from the tubes, negative ions still collect around the walls of the conduit, while the positive ions align themselves towards the discharge end, resulting in a downstream opening that is more positive than the upstream intake. The tube becomes a charged half cell of a battery, which, because the surrounding earth is somewhat conductive, sets up a return, or conduction, current following the flow paths that wrap completely around the conduit.

The process is illustrated in the simplified conduit of Figure 8. Water enters the constricted underground conduit at A and moves (either under free-flowing or tube-full conditions) to the discharge end B, where it can form an underground pool or a surface rise. The potential measured at the surface over the downstream end is positive relative to the mid-line of the system; and at the upstream end, negative. These peaks of opposing polarity are accompanied by lesser contrary excursions to either side of the conduit as a result of the electric field pattern generated by the flow. Because the peak response on a profile over the downstream end is positive, and that over the upstream end, negative, it stand to reason that, as we read successive profiles towards the middle of the system, these amplitudes decline. Somewhere, about the mid-line of the conduit, response should be flat! This effect may explain why different polarities can be observed over different segments of the same cave system. And if somewhere the signal dwindles away to nothing, one may be standing over the electrical midriff of the system.

Natural-potential anomalies observed over cave streams

In his penetrating monograph on geo-electric phenomena, Krajew (1957) concludes that electrokinetic effects over stream channels develop only along the axis of the stream, not transverse to the flow. A number of traverses carried out by us over mapped cave systems demonstrate that Krajew's conclusion is incorrect; very clear-cut NP anomalies have been observed over karst streams. Texas' longest cave system--Honey Creek Water Cave--produces sharp anomalies both positive and negative over different segments of the system (Figure 9). Strong signals are detected through more than 94m (310ft) of overburden above Big Spring, Missouri, the nation's largest spring (Figure 10). A small limestone spring in Cave Valley, Nevada (0.025m3/sec; pH=5) produces a 20mV very sharp negative anomaly some 75m (250ft) from the orifice (Figure 11).

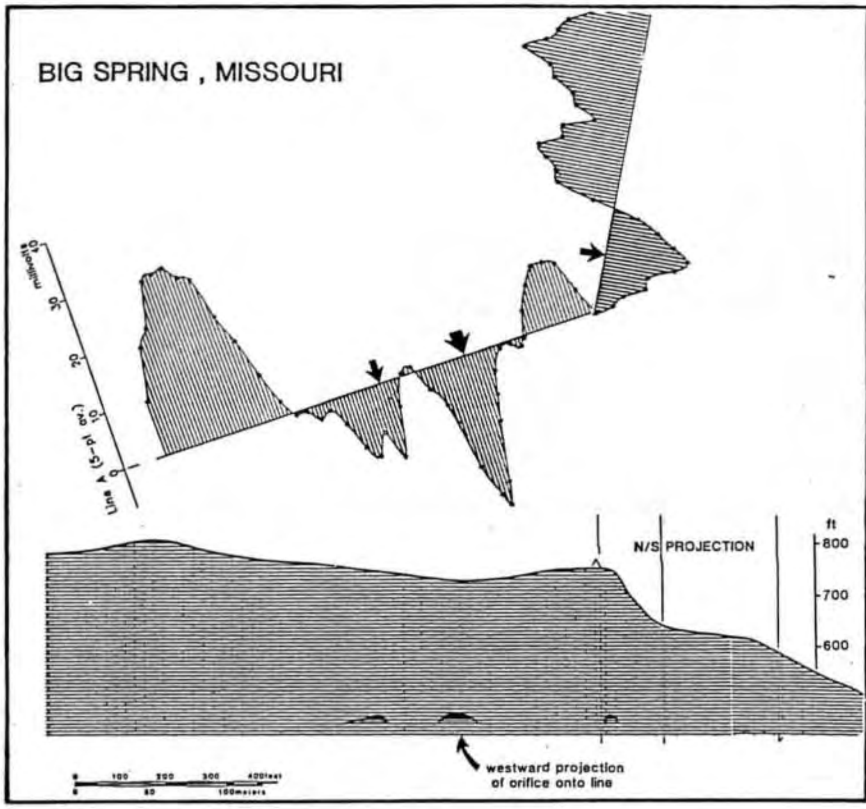

Figure 10. NP anomalies over possible conduits of the nation's largest spring--Big Spring, Missouri. Prominent negatives appeared along the ridge, 95m (315ft) above the orifice. (Courtesy of Ozark National Scenic Riverways).

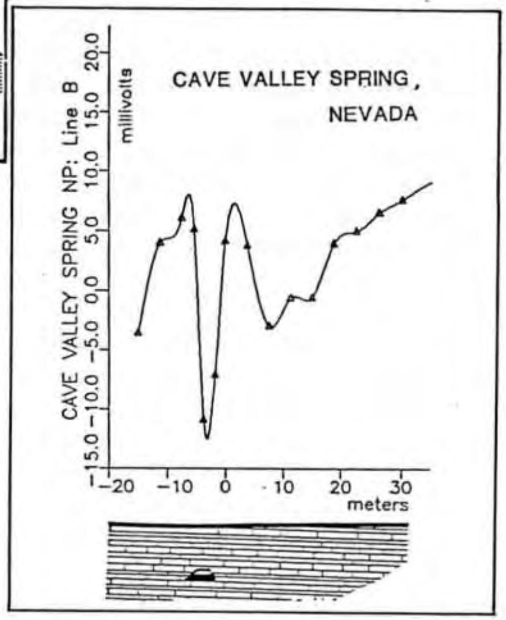

Figure 11. Sharp NP compound anomaly recorded over a small underground stream in Cave Valley, Nevada.

During June of 1991, I ran three traverses over cave streams in karst of the Central Lowlands. Lost River in Bowling Green, Kentucky winds around beneath the city and discharges at a park in the northwest part of town. A profile run about 45m (150ft) back from the entrance yielded a double-peaked positive anomaly less than 10mV in amplitude (Figure 12). Parker Cave, outside of Mammoth Cave National Park, Kentucky produced a sharp 10mV low over the likely extension of Brown River (Figure 13), which farther downstream appeared as a positive in the survey of winter 1988 (Lange & Quinlan, 1988). Finally, at Lost River, Indiana, I ran a traverse along State Rte 37, 6.4km (4mi) south of Orleans, where the highway crosses over the dry surface channel of Lost River Cave. Figure 14 depicts the 45m-wide positive expression of the underlying river.

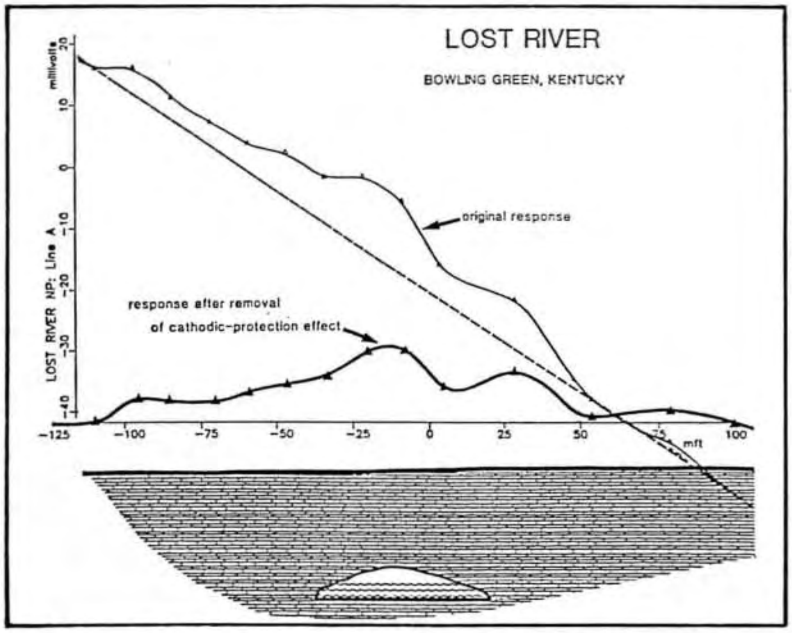

Figure 12. Response over the cave passage near the discharge of Lost River, Kentucky. Information on the exact location of the passage is not yet in hand.

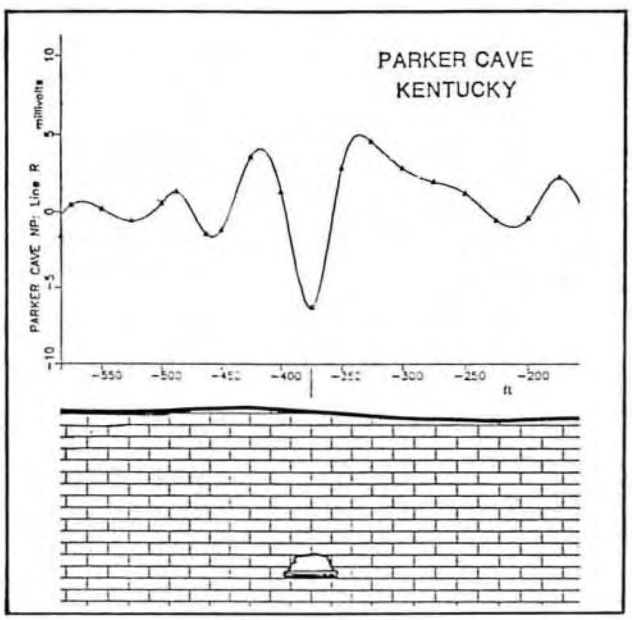

Figure 13. NP profile along the road crossing over Brown River of Parker Cave, Kentucky.

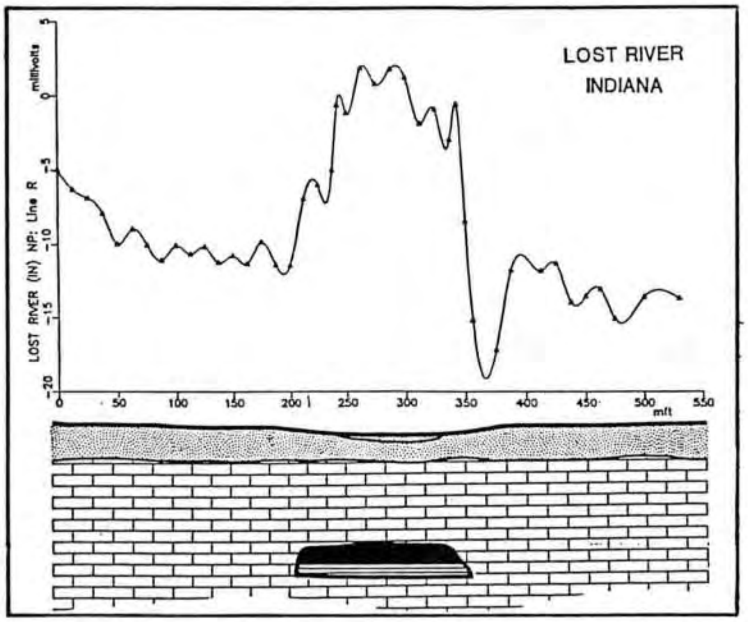

Figure 14. Natural potential along Highway 37 crossing the dry channel of Lost River, Indiana. The cave depth and location are estimated.

Conclusions

The basic principles of flownet mapping in clastic rocks still apply in a karst environment, or in situations of localized channeling. Thus under normal conditions water moves from the negative NP region towards the positive; that is, towards the discharge points. Where the flow is concentrated along a particular conduit or channel, however, we expect to see parallel fringe effects around the conduit walls; thus, near the downstream end of the tube, the positive anomaly characterizing the convective current is accompanied by lesser negatives on either side (see Figure 9); and vice versa at the upstream end. As a result, we cannot simply draw flow vectors from negative to positive regions as in the case of distributed flow. Hence, construction of the flow paths becomes an interpretive process rather than an automatic one; and while this might sound like an encumbrance, the interpretation is greatly facilitated by the diagnostic signatures observed in the successive profiles over the stream courses.

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DEVELOPMENT OF A FLOW-THROUGH FILTER FLUOROMETER FOR USE IN QUANTITATIVE DYE TRACING AT MAMMOTH CAVE NATIONAL PARK

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ABSTRACT

A series of quantitative traces were completed in the Buffalo Spring ground water basin in Mammoth Cave National Park as part of the field testing of a newly developed filter fluorometer. The RME flow-through filter fluorometer is an inexpensive, labor-saving, battery-operated, submersible device that, when interfaced with a digital datalogger, is capable of precisely measuring the travel time of two dye slugs (rhodamine WT and fluorescein) simultaneously. It is also able to measure the approximate dye concentrations passing a recovery point. Interpretation of RME data yielded unprecedented information concerning the hydrology of the Buffalo Spring basin--including the unanticipated discovery of a major flow-route.

INTRODUCTION

Fluorescent tracer dyes are commonly used in the study of ground water movement in karst terranes. Qualitative dye tracing, using passive dye-detectors like cotton and activated charcoal to recover the dye, is frequently employed to approximate ground water flow-routes and define ground water basin boundaries. Quantitative dye tracing, which requires the measuring of changing dye concentrations at a recovery point, is useful in the determination of ground water velocities, conduit condition (phreatic or vadose), unexpected flow routes, and water "budgets" (for basins with multiple discharge points). If the flow of dye through an aquifer is closely documented using quantitative tracing, models of soluble point source contamination events may be generated. Such models may be used by ground water managers to aid in drafting contingency plans for dealing with acute ground water pollution.

Quantitative dye tracing--much more expensive and labor intensive than qualitative tracing--is generally performed only as a supplement to qualitative tracing. Typical methods used to recover dye include grab sampling, automatic sampling, and flowthough fluorometry. Each of these methods has inherent drawbacks. Grab sampling is enormously labor intensive. Automatic sampling is moderately labor intensive and costly--automatic samplers cost over $2000 each. Samples obtained using grab or automatic sampling must be quantitatively analyzed on a fluorometer. Fluorometer prices start at around $7000. Flowthrough fluorometers are able to directly measure concentrations of dye at a recovery point; however, in addition to being expensive, they require a pump to generate flow through the instrument. The energy requirements of the pump and fluorometer make this method impractical in remote areas where electrical service is not available. A need exists for the development of cheaper and easier techniques capable of obtaining results of similar precision.

THE RME FILTER FLUOROMETER

An alternative to conventional dye recovery methods has been developed and is being used extensively at Mammoth Cave National Park. The RME flow-through filter fluorometer is an inexpensive, battery-operated, submersible probe, supported by a digital datalogger. It may be deployed in the field for

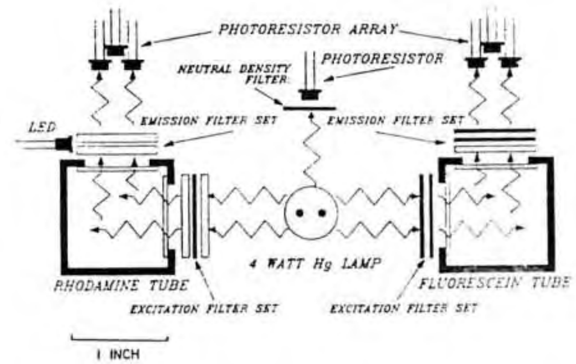

Figure 1. Diagrammatic cross-section of the RME filter fluorometer.

extensive periods of time, and requires only occasional servicing. The RME uses 6 volts DC and draws less than 100 ma/hr. Since it is submerged into the spring and is designed to slowly draw water through itself, no pump is required. The RME is capable of continuously measuring small concentrations of two dyes simultaneously--rhodamine WT (C.I. Acid Red 388) down to 0.5 ppb and fluorescein (C.I. Acid Yellow 73) down to 5 ppb. The material cost of building an RME is approximately $175 per unit. A datalogger with versatile programming is required to execute and record the data measurements. The datalogger and RME battery power supply, attached to the RME through waterproof wire, must be placed above the highest possible water level in a weatherproof enclosure.

The RME fluorometer is two filter fluorometers in one package. It has one light source, a 4-watt clear quartz mercury ultraviolet lamp, sandwiched between two flow-through sample tubes (Figure 1). The flow-through tubes are made of 6 inch sections of 1-inch ID aluminum box tubing. Two elongate windows are milled into each tube at right angles to each other. Clear microscope slide glass is mounted across each window from the inside using a silicone sealant.

LIGHT FILTER SETS

Situated between the lamp and the rhodamine sample tube is an excitation filter set, composed of a Kodak Wratten 61 gel filter sealed between two Corning I-60 colored glass filters (recommended in Smart and Laidlaw, 1977). This filter set is designed to allow only the 546nm mercury line light to illuminate the inside of the sample tube. The other major spectral lines emitted by the mercury lamp (578nm, 436nm, 405nm, 365nm, and 254nm) are absorbed by the filter set. The 546nm light illuminating the interior of the rhodamine tube is within the excitation spectrum for rhodamine WT (its excitation maximum is about 555nm), so if that dye were present in the sample tube, it would be induced to fluoresce. An emission filter set, composed of a Corning 3-66 and a Corning 4-97, is located between the other window and the photodetective array. The secondary filter set is designed to transmit a spectrum that has peak nearly coinciding with the emission maximum of rhodamine WT (about 580nm); the filters are nearly opaque to wavelengths outside this relatively narrow spectrum.

The excitation filter set for the fluorescein tube is a combination Wratten 2A and a Wratten 47B. It transmits the 436nm mercury line, which is within the excitation spectrum of fluorescein (the excitation maximum is 490) and is nearly opaque to the other lines. The emission filter, located between the emission window and a photodetective array, is composed of a Wratten 2A, a Wratten 12, and a Corning 4-97 (recommended in Turner Designs, 1983). This filter set transmits a portion of the excitation spectrum of fluorescein (the maximum is about 520nm) to the photodetective array. All Wratten filters are sealed inside clear glass to help preserve them.

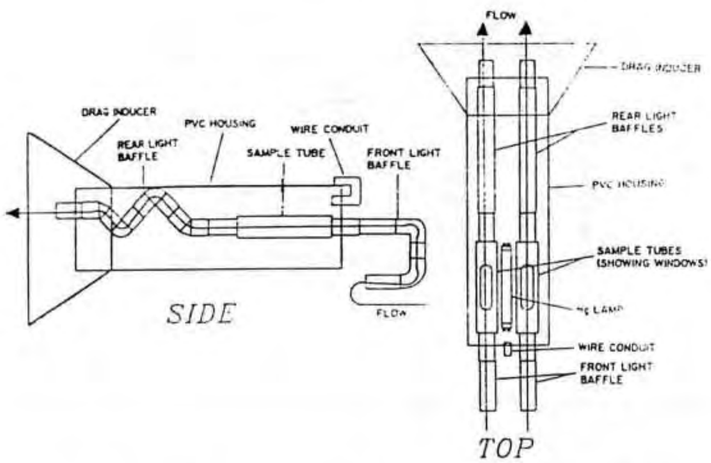

Figure 2. Diagrammatic cut-away views of the RME.

THE PHOTODETECTORS

The RME uses cadmium sulfide photoresistors as photodetectors. The electrical resistance of a CdS photoresistor varies--in an inverse log relationship--with the intensity of light striking it. The photoresistors are extremely sensitive even to tiny changes in light intensity--especially in the 500nm to 600nm range. Both of the RME's sample tubes have an array of three photoresistors, connected in parallel and located outside the emission filter (Figure 1). Another photoresistor, along with a protective neutral density filter, is used to monitor intensity fluctuations in the mercury lamp.

PROGRAMMING THE RME

To conserve battery power and to extend the life of the heat sensitive Wratten filters, the lamp, and the lamp circuitry, the lamp is only operated periodically. The datalogger (Campbell Scientific 21X microloggers were used by this investigator), via a relay, switches the lamp on for one minute out of every ten. At the end of that one minute the resistances of the rhodamine array, fluorescein array, and the lamp reference are measured, using a DC half bridge, and stored. If dye above a pre-chosen concentration is sensed, the sampling interval will change to once per five minutes and then revert back to ten minutes when that concentration is no longer exceeded. This insures a better probability of documenting short duration features.

Cadmium sulfide photoresistors have an undesirable inherent behavior called a memory or light history. If they are placed in total darkness for even a brief period of time (as they are when the lamp is off), they will become "stuck" in this very high resistance dark state; small increases in illumination will not cause any change in electrical resistance. Minute increases in dye concentration above background would therefore go unnoticed. To counter this, an LED that keeps the rhodamine array slightly illuminated is switched on when the lamp is switched off. The fluorescein array receives enough exciting light through its secondary filter (an otherwise negative trait) that, when the lamp is switched on, the array is quickly "snapped out" of the memory state.

RME ENCLOSURE

The electronics and optics of the RME are enclosed in a watertight 4-inch schedule 40 PVC pipe compartment. The sample tubes are connected to 3/4-inch PVC pipes which pass through the endcaps of the compartment. To prevent ambient light from reaching the sample tubes, light baffles made of 45 and 90 degree ells are inserted between the sample tubes and the outside (Figure 2). The front light baffles are removable to facilitate cleaning the sample tubes. All piping and the enclosure itself are painted black as further protection against ambient light. On the downstream end of the RME exterior is an inverted funnel-shaped feature called a drag inducer. When the RME is properly oriented in a flowing stream, the drag inducer produces a vacuum effect which draws water through the sample tubes. This insures that the RME is taking a sample representative of the water around it at any given time.

SUMMARY OF HOW THE RME MEASURES DYE CONCENTRATION

The following is a very basic summary of the physical relationships employed by the datalogger and the RME to measure dye concentration:

1) A change in dye concentration results in a directly proportional change in fluorescence.

2) A change in fluorescence results in a directly proportional change in the amount of illumination striking the CdS photodetector.

3) A change in the amount of illumination striking the photodetector results in an inverse logarithmic change in the electrical resistance of the photodetector.

4) A change in the electrical resistance of the array is measured as a proportional change in the output voltage of a DC half bridge by the datalogger.

The datalogger records the output voltages of DC half bridge measurements, which are downloaded from the logger onto a cassette tape or into a data can and then loaded into a PC spreadsheet where the following transformations may be made to it:

1) Using a conversion formula, output voltages are converted to resistances.

2) Resistances are converted into dye concentrations by interpolating from a calibration curve--calibration curves are created prior to field deployment by plugging one end of an RME's flow-through tubes, pouring in a series of standards, and recording the resultant resistances.

3) Concentrations are temperature compensated using the formula provided by Smart and Laidlaw (1977).

4) Instrumentational background is subtracted out by "zeroing" data immediately proceeding the leading edge of a dye slug.

5) Temperature compensated dye concentrations are multiplied by the discharge of the spring or stream to determine dye load.

6) The area under a dye load curve is calculated to determine the total amount of dye recovered.

Because of deficiencies in the present RME design (primarily in the light filter sets), fluorescein concentrations may only be roughly determined; therefore, fluorescein may only be reliably used with the RME in ground water time of travel study.

THE DETERMINATION OF THE HYDROLOGY OF THE BUFFALO SPRING GROUND WATER BASIN USING RME FLUOROMETRY

INTRODUCTION

The Buffalo Spring ground water basin occupies about a $20 Km^2$ portion of Mammoth Cave National Park, Kentucky. It is located north of the Green River, just west of its confluence with the Nolin River within the Hilly Country of the Chester Upland (George, 1989). Buffalo Spring is stratigraphically located near the middle of the Girkin Formation, the uppermost unit of a thick section of highly karstifiable Mississippian limestone. An alternating sequence of relatively thin Mississippian sandstones and limestones and the basal Pennsylvanian Caseyville Formation are located above the Girkin Formation. The regional dip is a relatively gentle 5 to 15 m/Km to the west-northwest. The Buffalo Creek surface drainage splits into its two main tributaries, the Wet Prong and the Dry Prong, about lKm from the Green River. Surface flow is absent in both of these branches where the Girkin Formation crops out, except under high flow conditions. The surface streams are lost through a series of sequential ponors downstream from the upper Girkin contact.

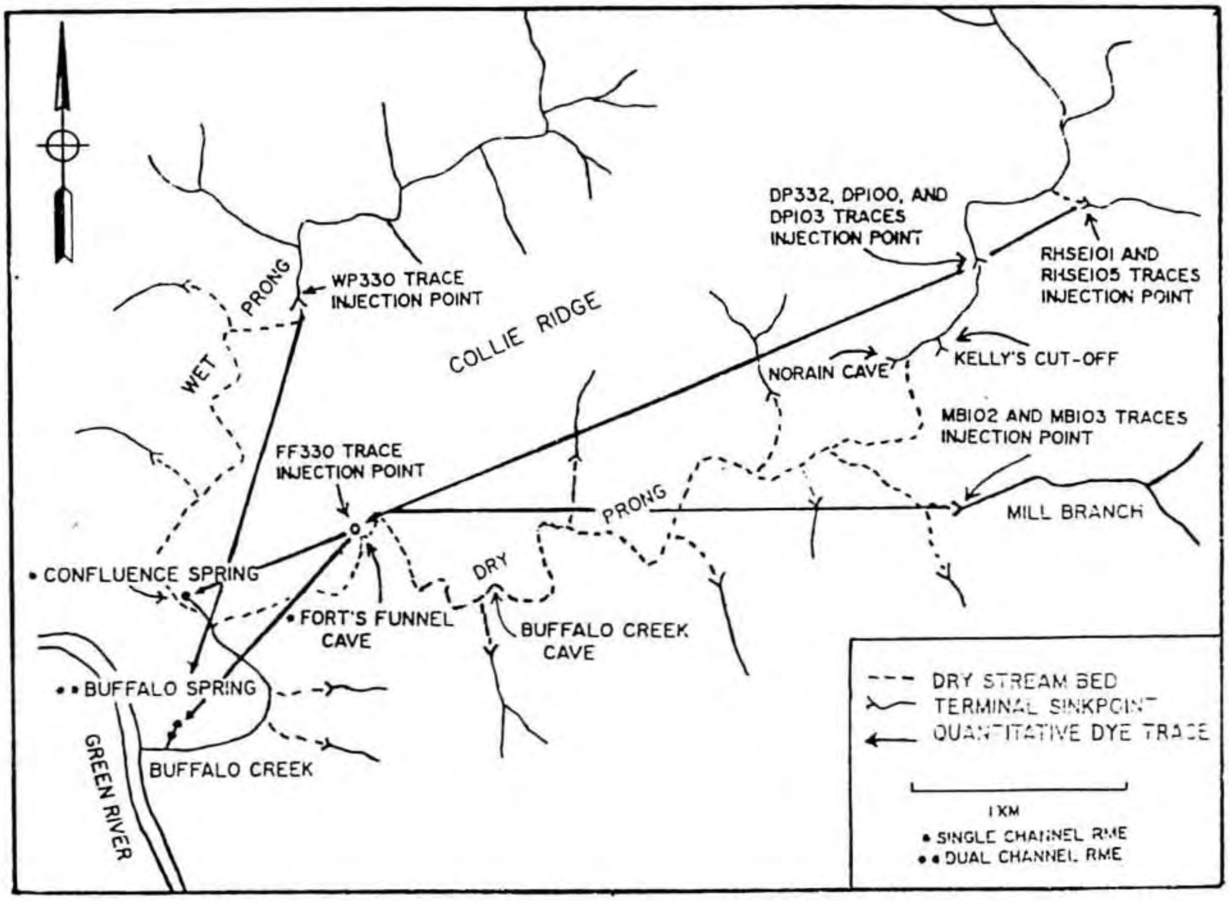

Figure 3. Map of the Buffalo Spring ground water basin.

Many of the tributaries to both the Wet and Dry Prongs also sink into the upper Girkin.

Buffalo Spring is a rise pit type spring. It has a highly variable discharge that ranges between about 60 and 1800 l/s, with an average discharge of about 500 l/s. Qualitative dye tracing by Meiman and Ryan (1990) confirmed that sinking water from the Wet Prong and Dry Prong sequential ponors resurges at Buffalo Spring (Figure 3). A large tributary to the Dry Prong, Mill Branch, and numerous smaller tributaries to both Prongs were also traced to Buffalo Spring. Qualitative dye tracing showed that Confluence Spring was an overflow spring for Buffalo Spring. Fort's Funnel is a cave located on the flank of Collie Ridge just northwest of the Dry Prong (Figure 3) and containing a large stream. The discharge of the cave stream is roughly half that of Buffalo Spring. Every qualitative dye trace performed in the basin was recovered with positive results at Fort's Funnel as well as at Buffalo Spring and Confluence Spring (if Confluence Spring was flowing). Since the discharge at Fort's Funnel was considerably less than Buffalo Spring, the exact relationship between the Wet and Dry Prongs and Fort's Funnel remained problematic even after recovering numerous qualitative traces.

Table 1. Summary of quantitative dye traces performed in the Buffalo Spring basin using the RME.

Trace number	Injection date	Injection site	Recovery point(s)	Dye used/ Quantity
DP100	4-10-91	Dry Prong base flow sink point	Buffalo Spring Confluence Spring Fort's Funnel	Rhod. WT/ 150g
DP103	4-13-91	Dry Prong base flow sink point	Buffalo Spring Confluence Spring Fort's Funnel	Rhod. WT/ 150g
DP332	11-28-90	Dry Prong base flow sink point	Buffalo Spring	Rhod. WT/ 119g and Fluor./ 150g
MB102	4-12-91	Mill Branch quarry ponor	Buffalo Spring Confluence Spring Fort's Funnel	Rhod. WT/ 150g
MB103	4-13-91	Mill Branch quarry ponor	Buffalo Spring	Fluor./ 150g
RHSE101	4-11-91	Raymer Hol. SE terminal sink point	Buffalo Spring	Fluor./ 150g
RHSE105	4-15-91	Raymer Hol. SE terminal sink point	Buffalo Spring Confluence Spring Fort's Funnel	Rhod. WT/ 150g
WP330	11-26-90	Wet Prong base flow sink point	Buffalo Spring	Rhod. WT/ 119g
FF330	11-26-90	Fort's Funnel cave stream	Buffalo Spring	Fluor./ 100g

Table 2. RME-determined results of the Buffalo Spring basin quantitative traces.

Trace number	*Recovery point(s)	Apparent travel distance (meters)	Discharge (l/s)	Time to leading edge (hours)	Time to peak conc. (hours)	Approx. peak conc. (mg/l)
DP100	BS	4320	875	12.83	14.38	.002
	CS	4000	150	11.13	14.18	.005
	FF	3120	395	8.23	9.38	.004
DP103	BS	4320	950	10.00	11.90	.002
	CS	4000	460	8.90	10.65	.006
	FF	3120	770	5.75	7.50	.010
DP332	BS	4320	280	28.75	34.75	.007
MB102	BS	3980	940	11.27	12.37	.004
	CS	3630	360	9.77	11.02	.011
	FF	2780	700	7.67	8.37	.024
MB103	BS	3980	960	9.50	10.50	-
RHSE101	BS	4850	930	14.72	17.22	-
RHSE105	BS	4850	1090	12.25	16.75	.0005
	CS	4600	330	11.85	14.75	.001
	FF	3750	595	7.25	11.85	.0025
WP330	BS	2000	280	11.92	13.82	.100
FF330	BS	1200	280	18.20	20.75	-

*Buffalo Spring = BS
Confluence Spring = CS
Fort's Funnel = FF

QUANTITATIVE TRACES

Table 1 is a summary of the quantitative tracer tests performed in the Buffalo Spring basin using the RME filter fluorometer. A dual channel RME, capable of recovering rhodamine and fluorescein simultaneously, was placed at Buffalo Spring during all the traces. Single channel RMEs, rhodamine sensitive only, were placed in Fort's Funnel and Confluence Spring only during the April, 1991 traces. Figure 3 shows the injection points, recovery points, and straight line travel routes for each trace and Table 2 summarizes the results of each trace.

November Traces

Three quantitative traces were recovered at Buffalo Spring in November, 1990. Flow conditions were low and relatively stable during this period, and Confluence Spring was not flowing. Figures 4 and 5 show the recovery curves of traces initiated simultaneously from Fort's Funnel and the Wet Prong terminal sinkpoint. The dye slugs were recovered using both a dual channel RME and an automatic sampler. Surprisingly, the rhodamine injected in the Wet Prong (WP330 trace) arrived at Buffalo Spring more than six hours before the fluorescein from the much closer Fort's Funnel (FF330 trace) (Figures 4 and 5, and Table 2). This shows that a primary flow-route exists between the Wet Prong sink and Buffalo Spring with a gradient that is significantly steeper than the flow-route between Fort's Funnel and Buffalo Spring. Consequently, a difference in head must exist between this newly discovered trunk conduit carrying Wet Prong water and the Dry Prong trunk visible at Fort's Funnel. Enough of the Wet Prong trunk is apparently pirated by the Dry Prong trunk above Fort's Funnel to be detected using qualitative dye tracing methods, but not enough to cause a noticeable secondary dye slug to appear at Buffalo Spring while using quantitative methods.

The RME results (Figure 4) compared favorably with the ISCO sampler/Shimadzu spectrofluorophotometer results (Figure 5). The ISCO sampler, which was programmed to draw a sample hourly, failed to sample the peak rhodamine concentration. The higher resolution RME data shows that the peak rhodamine concentration was considerably greater than what was determined by the ISCO/Shimadzu methods. Figures 4 and 5 prove that the RME is a capable alternative to conventional dye recovery methods. RME and ISCO/Shimadzu results were also similar for a simultaneous two-dye trace from the Dry Prong sinkpoint to Buffalo Spring (DP332).

April Traces

Six quantitative traces--two using fluorescein and four using rhodamine--were performed in the Buffalo Spring basin in April, 1991. Flow conditions were much higher than in November and fluctuated due to several moderate rainfall events received during the study period. During the six day study period the discharge was measured, using a tape measure, a survey stick, and a Marsh-McBirney flow meter, five times at Buffalo Spring, four times at Fort's Funnel, and five times at Confluence Spring. Discharges listed in Table 2 for each dye slug at each recovery site were interpolated from these measurements and are presumed to be only moderately accurate.

If automatic sampling had been used as the dye recovery method at all three sites for six days with a sampling interval of one hour, it would have required changing 432 sample bottles and analyzing 576 samples on the spectrofluorometer. All this toil would have produced only mediocre results because each dye slug would have been sampled only a few times (due to temporal compactness of the slugs) and only a vague picture of a slug's true shape would have resulted. The ten (or five) minute sampling frequency of the RME insures that a more realistic view of the dye recovery curve will be recorded.

MB102 Trace

Rhodamine trace MB102 was initiated at a discrete sinkpoint in Mill Branch and was recovered at Fort's Funnel, Confluence Spring, and Buffalo Spring. The resultant recovery curves are shown in Figure 6. It is apparent in that the peak concentrations of Confluence Spring and Buffalo Spring are much lower than Fort's Funnel. The Wet Prong trunk converges with the Dry Prong trunk somewhere between Fort's Funnel and Buffalo Spring and dilutes the dye-laden Dry Prong

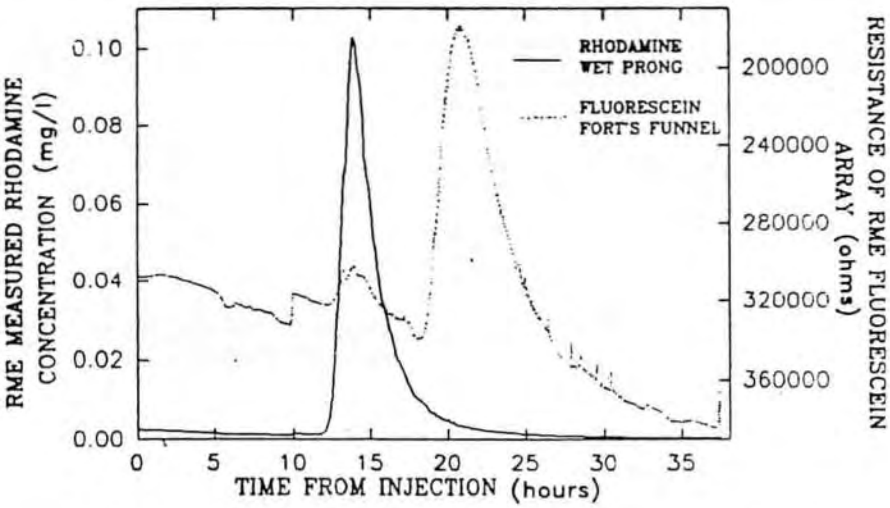

Figure 4. Recovery curves of FF330 and WP330 simultaneous traces created from RME data.

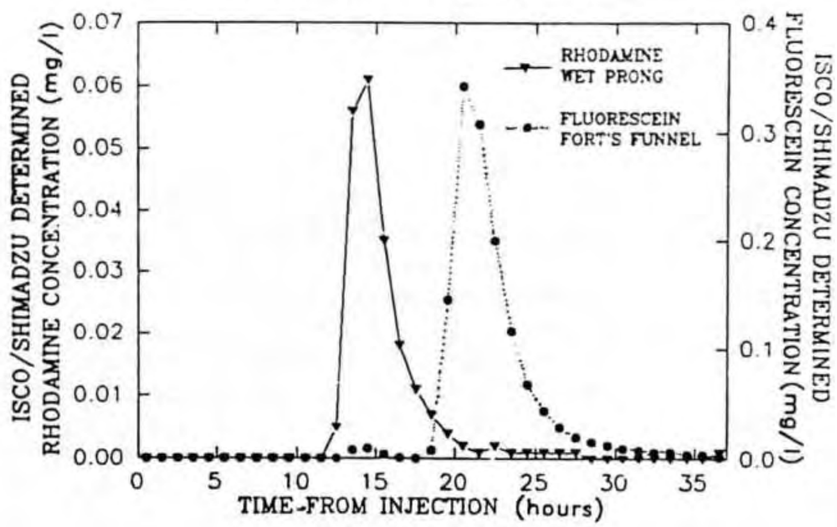

Figure 5. Recovery curves of FF330 and Wp330 simultaneous traces created from automatic sampler/spectrofluorometer results.

waters. Further longitudinal dispersion was probably also a factor in this reduction. Hubbard et al. (1982) contains an excellent description of dye dispersion in streams during quantitative traces. Evidently, an input from the Wet Prong trunk exists between Fort's Funnel and Confluence Spring, as well, and it is responsible for the sizable drop in concentration at Confluence Spring. Helpful "black box" type models of conduit systems like these were presented and discussed by Brown (1973).

The total mass of dye recovered at Fort's Funnel during the MB102 trace was 122g, or 81% of the 150g injected. Only 45% of that 122g was recovered at the two terminal springs; the remaining 55% was unaccounted for. Since the total discharge of the Buffalo Spring system was above average and increasing, a plausible explanation is that dye-laden conduit water moved into diffuse storage adjacent to the conduit--like river bank storage. Atkinson et al. (1973) describes this analogy in some detail. Significantly, very strong positive results for rhodamine and fluorescein were still being found on the passive dye detectors at Buffalo Spring under low flow conditions more than three months later. It is possible that dye in conduit adjacent diffuse storage was slowly released as the summertime base flow condition was approached. Other factors that may have contributed to the apparent dye loss may have been adsorption or the use of inaccurate (too small) discharge values.

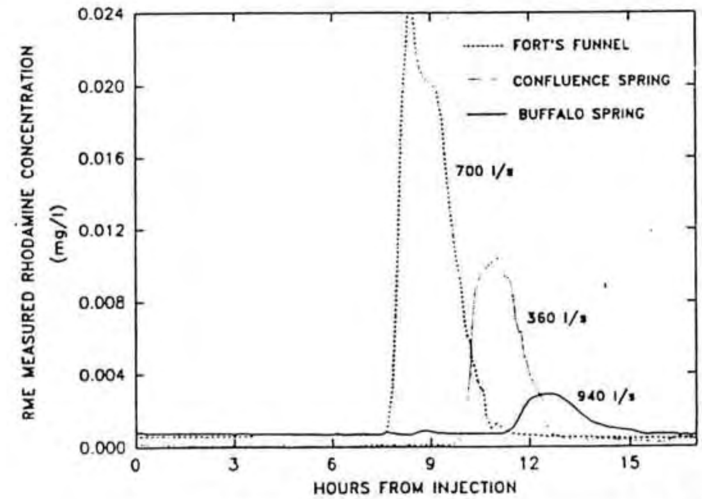

Figure 6. Recovery curves from MB102 trace.

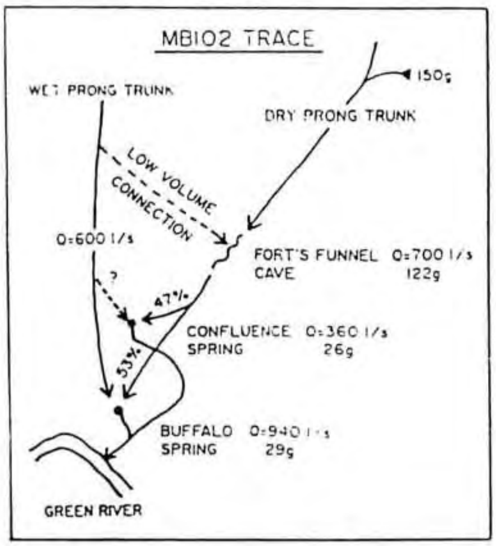

Figure 7. Summary of MB102 trace.

Figure 7 summarizes the dye recovery results for the MB102 trace. The percentage of dye (and flow) going to each spring was computed by considering the total mass of dye recovered at both terminal springs 100%, then the mass recovered at either one of the springs was divided by the total recovered at both springs and multiplied by 100. The discharge of the Wet Prong trunk was computed by subtracting the discharge at Fort's Funnel (which was assumed to be the entire Dry Prong trunk flow) from the combined Confluence Spring and Buffalo Spring discharges. Based on this, approximately 47% of the discharge from Fort's Funnel resurged at the overflow route--so about 329 l/s of Confluence Spring's 360 l/s discharge came from the Dry Prong trunk. The remainder of the Dry Prong trunk flow and nearly all the Wet Prong trunk flow resurged at Buffalo Spring.

DP103 Trace

Figure 8 shows the recovery curves at the three recovery sites for the DP103 dye trace. When compared with the recovery curves from the MB102 trace, in which the same amount of rhodamine was injected, several differences are discernable: the peak concentrations are all lower, the travel times are less, and the slugs are more dispersed longitudinally. Because the discharge was greater during this trace, the first two are believable--even though the reduction in concentration was larger than such an increase in discharge would warrant. An increased longitudinal dispersion, however, is the exact opposite of what would typically be expected for a trace initiated under higher flow conditions.

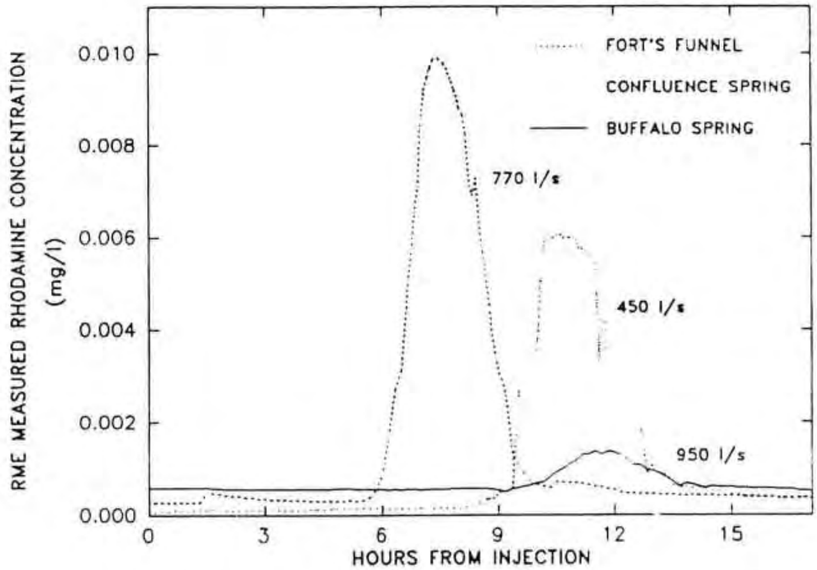

Figure 8. Recovery curves from DP103 trace.

The reason the DP103 slugs were more dispersed than the MB102 slugs may be related to the fact that DP103 dye entered the subsurface through three widely spaced sequential ponors instead of through one discrete ponor. All three Dry Prong traces were initiated from the same point--just above the Dry Prong base flow terminal sinkpoint. However, the flow conditions were very different for each trace: the terminal sinkpoint for the DP332 trace was the base flow sinkpoint, the terminal sinkpoint for the DP100 trace was about 600 meters downstream at a ponor called Kelly's Cut-off, and for the DP103 trace the terminus of surface flow was a huge ponor 250 meters further downstream called Norain Cave (Figure 3). Dye from the DP103 injection entered the subsurface at all three of these major ponors. As a result of this the injected slug was split into three separate slugs, each with a slightly different route to follow at first. Flow from the three separate inputs eventually reunited and the three slightly out of phase dye slugs were fused back together--slightly more dispersed and with a lower amplitude than a single input slug would have been.

Only 75g of the 150g of dye injected (50%) was recovered at Fort's Funnel. The amount of that dye which was recovered at the terminal springs was 73%. The results, summarized in Figure 9, suggests that 55% of the total discharge passing Fort's Funnel went to the Confluence Spring (about 423 l/s) and 45% went to Buffalo Spring (about 347 l/s). The remainder of each was supplied by the Wet Prong trunk.

When the DP103 trace results (Figure 9) are compared to the MB102 results (Figure 7) several important insights into the behavior of this aquifer may be gleaned: the Confluence Spring waters are mostly derived from the Dry Prong trunk, and the Wet Prong trunk is not well connected to Confluence Spring. Thus the Confluence Spring is predominately an overflow spring for the Dry Prong trunk. If the discharge were increased in both the trunks simultaneously, hydraulic damming by Wet Prong waters, which basically have no place else to go but Buffalo Spring, would cause a decrease in the percentage of Dry Prong water resurging at Buffalo Spring and an increase in the percentage overflowing at Confluence Spring.

Repeated Quantitative Traces as a Predictive Tool

The input-to-resurgence travel time of a dye slug decreases with increasing discharge. Peak concentrations often decrease with increasing discharge because dilution increases, and longitudinal dispersion decreases due to decreased dye slug travel time. Figure 10 illustrates the results of a trace from Dry Prong to the terminal spring(s) repeated three times under

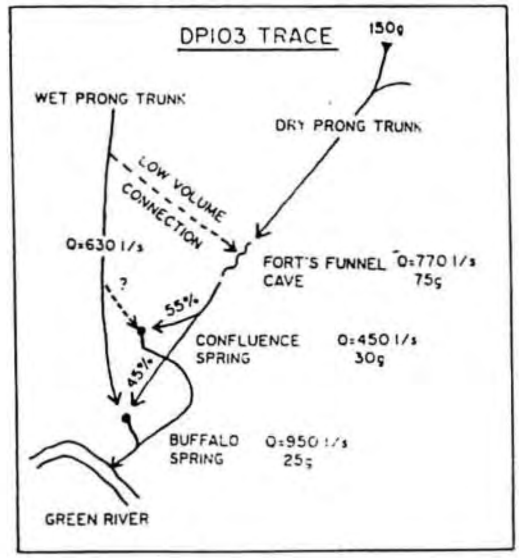

Figure 9. Summary of DP103 trace.

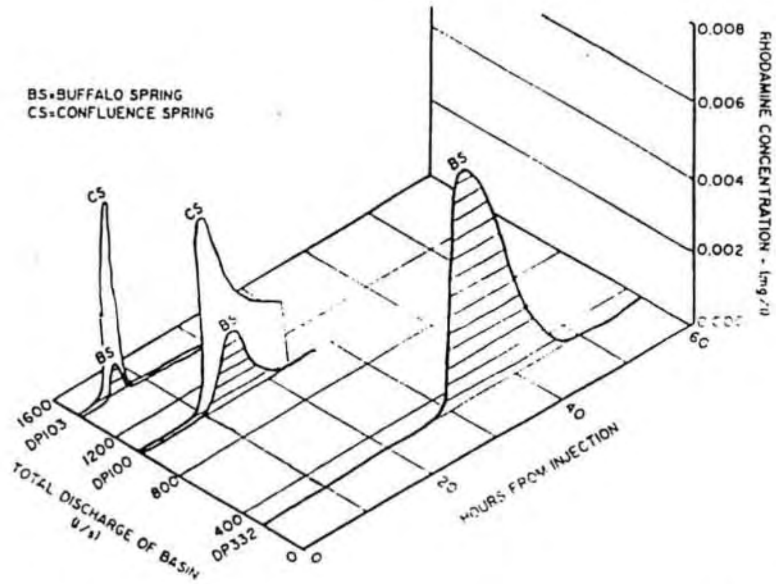

Figure 10. Recovery curves of Dry Prong to the terminal spring(s) traces.

different flow conditions. The aforementioned effects of increased discharge are very clear. Using results from these three traces, reliable predictions for almost any set of flow conditions could be made concerning travel time, peak concentration, and dispersion for a soluble contaminant accidentally injected into the Dry Prong. Mull et al. (1988) gives a detailed discussion of this important topic.

Determination of Conduit Condition

Conduit condition may be resolved even if a conduit is inaccessible by using quantitative tracing; this was done for segments of the Dry Prong trunk using the RME. The discharge of a vadose conduit is increased by increasing the flow velocity and/or the cross-sectional area of the channel (by increasing stage). The only way to increase the discharge of a phreatic conduit, since it is completely full and stage cannot be increased, is by increasing the flow velocity. So, when log discharge (X) is plotted versus the log travel time (Y) for a series of traces through a phreatic conduit the result would be a line with a slope of nearly -1 (Smart, 1981). A plot of traces through a vadose conduit would be a line with a slope of less than -1.0 (but probably greater than -0.3). Figure 11 shows first order linear regressions of log discharge versus log travel time for the three Dry Prong traces recovered by the RME for, the entire Dry Prong, the segment of the Dry Prong trunk upstream from Fort's Funnel, and the segment of Dry Prong trunk downstream from Fort's Funnel. Judging from their slopes, which are admittedly based on a paucity of data, the segment downstream from Fort's Funnel is apparently mostly phreatic and the segment upstream is mostly vadose.

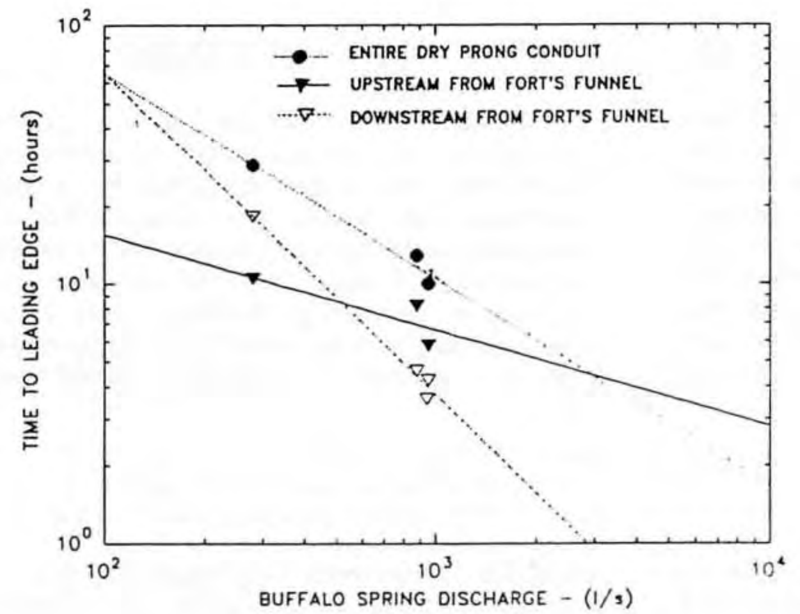

Figure 11. Log-Log plots of discharge vs. time of travel for various segments of the Dry Prong trunk.

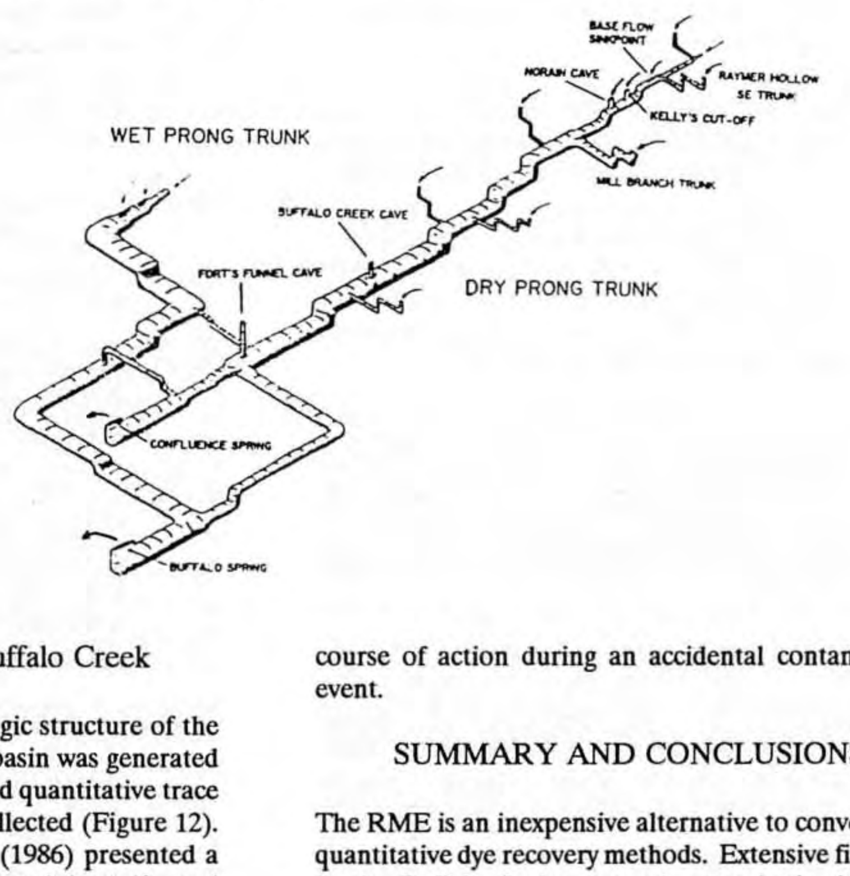

Figure 12. Hydrologic structure of the Buffalo Spring ground water basin.

Hydrologic Structure of Buffalo Creek

A pictorial summary of the hydrologic structure of the Buffalo Spring karst ground water basin was generated by synthesizing all the qualitative and quantitative trace data and geomorphological data collected (Figure 12). Smart (1988) and Smart and Ford (1986) presented a structural model of the Castleguard conduit aquifer and laid the groundwork for this type of aquifer representation. Models like these could be quite useful to ground water managers charged with determining a course of action during an accidental contamination event.

SUMMARY AND CONCLUSIONS

The RME is an inexpensive alternative to conventional quantitative dye recovery methods. Extensive fieldwork in the Buffalo Spring ground water basin, including some in conjunction with traditional dye recovery methods for comparison, proved that the RME is a useful dye quantification tool for field study.

Through use of the RME, subtle details concerning the hydrology of Buffalo Spring basin were recognized and described including several previously unknown ground water flow routes. Also generated was new information about the relationships of the primary spring and the over-flow spring to the two primary feeder trunks and the response of aquifer transmissivity to changes in discharge. Interpretation of RME data helped to identify the phreatic and the vadose portions of the Dry Prong trunk conduit. A structural model of the Buffalo Spring basin was produced using all the available dye tracing data.

ACKNOWLEDGEMENTS

Dr. Ralph Ewers of Eastern Kentucky University provided to me the initial idea of developing a submersible fluorometer supported by a digital datalogger. Joe Meiman, my colleague at Mammoth Cave, wrote the datalogger program used by the RME and contributed many hours of assistance during development and testing. Mammoth Cave National Park provided financial support, laboratory facilities, and other resources. I am extremely grateful to them all.

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THE EFFECTS OF RECHARGE BASIN LAND-USE PRACTICES ON WATER QUALITY AT MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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ABSTRACT

A water quality monitoring program was designed at Mammoth Cave National Park to determine if there exists any influence on the water quality of the Mammoth Cave karst aquifer within the park from various land-use practices of the recharge area. These land uses primarily include: heavy agriculture (row crops and livestock), logging, oil and gas production, and residential areas. The program, initiated in March 1990 and extending through September 1992, samples two rivers, and eight springs recharged by lands with varying land-use. Monthly nonconditional synoptic sampling monitors 36 parameters, including site discharge. The first 19 months of data demonstrate a strong correlation between drainage basin land-use and water quality. Contaminant entrainment mechanisms and relative pollutant input rates can be discerned when the mass-flux of selected parameters is calculated. By use of these data, effective resource management decisions can, and are being made to conserve and protect the irreplaceable natural resources of Mammoth Cave National Park.

INTRODUCTION

For what purpose do we monitor the quality of water at Mammoth Cave National Park? Aside from pure stoichiometric data to satisfy our curiosity of the water's chemical composition, spatially and temporally, the fundamental mission of this monitoring program is to better understand, and thus better manage, the aquatic natural resources of the park. During the three year course of this program, data will be collected and interpreted to provide information on the current state of the surface and subsurface water of the park. This data set will be used as a datum from which to compare past and future studies. As the author is not a biologist, no claims, speculations, conjectures, or theories pertaining to the present health or future of the aquatic ecosystems will be made. However, before trained personnel can accurately assess the condition of the park's aquatic life, a broad database of the physical and chemical properties must be available.

Although this phase of the monitoring program is far from complete, there appear to exist a few trends and correlations which deserve mention. The following pages will concern the first nineteen rounds of monthly sampling.

BRIEF DESCRIPTION OF MONITORING PROGRAM

The monitoring program is largely based upon synoptic samplings. Synoptic, as defined by Webster, is "relating to or displaying conditions as they exist simultaneously over a broad area". Although the water quality monitoring program includes two different synoptic approaches, conditional and non-conditional, the latter comprises by far the bulk of monitoring activities for the first years of the study. The program also includes topical sampling which provides a detailed evaluation of a particular flow condition, contaminant, basin or river reach.

Choosing synoptic stations within a karst aquifer differs greatly from the same task preformed on a surface drainage. In a surface drainage one can choose sites based upon stream reaches (every 20 miles for example) to improve spatial distribution, or install a station exactly where a known pollutant source is located. The monitoring sites of this program were chosen with respect to land-use practices of the various recharge basins. These practices range from the naturally wooded park-land groundwater basins where human influence has been absent for at least 50 years, to highly agricultural lands with a share of urban use and oil and gas exploration.

The ten non-conditional synoptic stations are sampled, regardless of flow or weather conditions, on the 10th of each month for the duration of the study (Figure 1). The sites are sampled during a single day by one field crew. The need for repetitive sampling (each month for three years) at each non-conditional synoptic station arises from the considerable temporal variability of karst and surface water quality. This variability is largely a result of sudden changes in discharge, and seasonal availability of contaminant sources. Over the course of the study each end of the flow continuum (base and flood conditions) and each growing season will have been encountered several times, as by program design.

The primary use of conditional synoptic surveys is to provide a finer degree of spatial resolution to the descriptions of discrete water quality and flow conditions than would be attainable from the non-conditional synoptic station network. One of the goals of the conditional synoptic surveys is to identify relatively short reaches of drainage basins which have demonstrated (by data from the non-conditional synoptic station network) chronic water quality problems.

Although the program is designed to allow the park to determine the effects of land-use practices on water quality after three years of sampling, we can, at this juncture, observe various traits which may be attributed to types of land-use in the recharge areas. Each time a sample is extracted, discharge at the site is recorded. Parameter concentration, coupled with discharge will yield flow-weighted values. These values will allow us to determine the mass flux (loading) of a particular parameter at various flow conditions. These data will allow us to better determine contaminant source as it pertains to constituent availability, release, and entrainment into the water, and mechanisms of transfer from the surface to the subsurface.

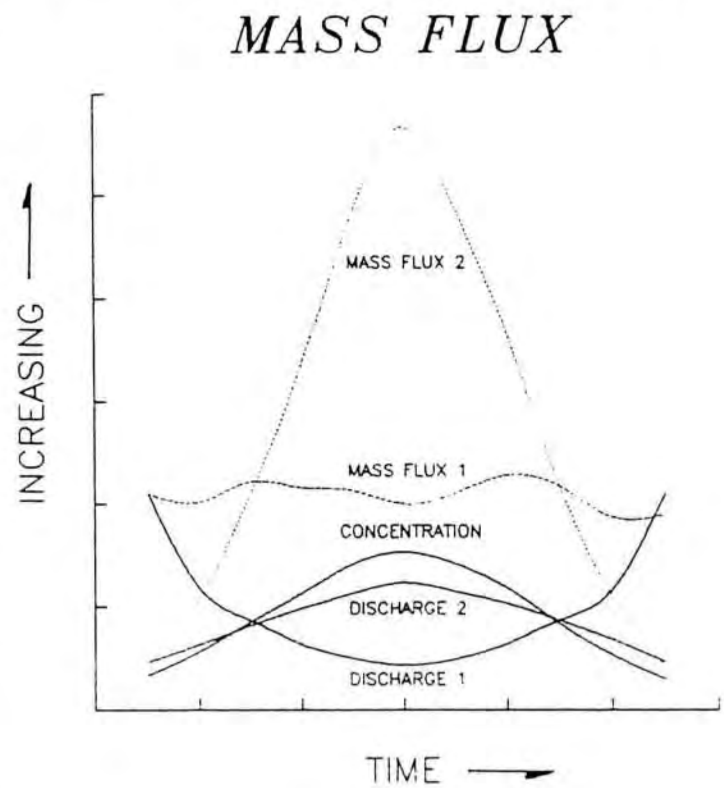

Figure 1. Hypothetical mass flux signatures.

A DISCUSSION CONCERNING MASS FLUX AND FLOOD PULSES

It would be difficult to continue this discussion without first examining mass flux and flood pulses. Mass flux is simply the amount (mass) of a particular parameter passing a point in a given time interval (flux). A flood pulse is the portion of water propagated along a channel and/or conduit as result of a recharge event, most commonly, rainfall. With an understanding of flood pulse movement, one might better understand mass flux signatures of various contaminants.

MASS FLUX

If a contaminant is released into a stream of water at a constant rate, and at some point downstream its concentration and the stream's flow can be measured, the mass flux of the contaminant can be calculated (Figure 1). If flow (Discharge 1) decreases or increases, the contaminant's concentration will proportionally increase or decrease, respectively

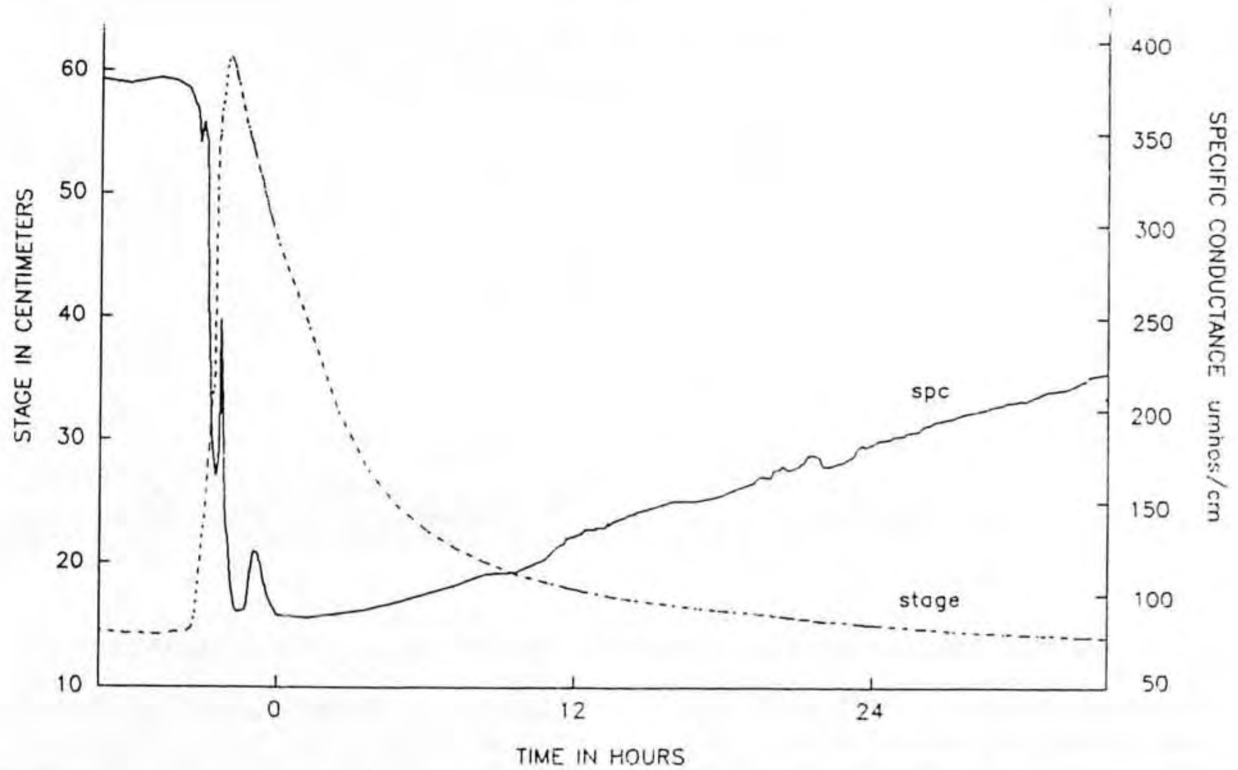

Figure 2. Stage and specific conductance responses of a flood pulse in a surface stream, Turnhole Spring groundwater basin.

(Concentration). That is, at times of high flow the contaminant will experience a greater amount of dilution. The resultant mass flux signature (mass flux over time) of a constant source release will consist of a relatively low amplitude disturbance (Mass Flux 1). One may think of this mass flux signature as a type of destructive wave form interference.

Suppose a contaminant is released into a stream only when specific hydrologic conditions are met, a rainfall event of a certain intensity and volume for example. Therefore, if flow (Discharge 2) increases, contaminant concentration also increases (Concentration) as these stores are displaced into the streams during flood pulse activity. That is during the times of peak flow, peak (or near peak) concentrations also occur. The resultant mass flux signature of a precipitation-triggered release will be of relatively high amplitude, perhaps several orders of relatively high magnitude greater than the pre-pulse mass flux (Mass Flux 2). This mass flux signature may be likened to constructive wave form interference.

FLOOD PULSES

Flood pulses in the Mammoth Cave area may raise a basin's discharge a couple liters per second following minor rainfall, to several thousand liters per second after major rainfall. Research by Meiman (1988 and 1989) has demonstrated that a flood pulse is comprised of two chemically and physically distinct components: displaced stores and freshly input recharge. The former, which usually occurs as the leading edge of a flood pulse and is characterized by high specific conductances, can be thought of as easily displaced vadose storage. Freshly input recharge, which comprises the bulk of a flood pulse, is characterized by low conductances, as there is little time for interaction between its waters and ionic sources. These relationships are also manifested in water temperature, as displaced stores, with longer residence times, will reflect the antecedent system temperature, and freshly input recharge correlative to surface temperature (Meiman, 1988 and 1989).

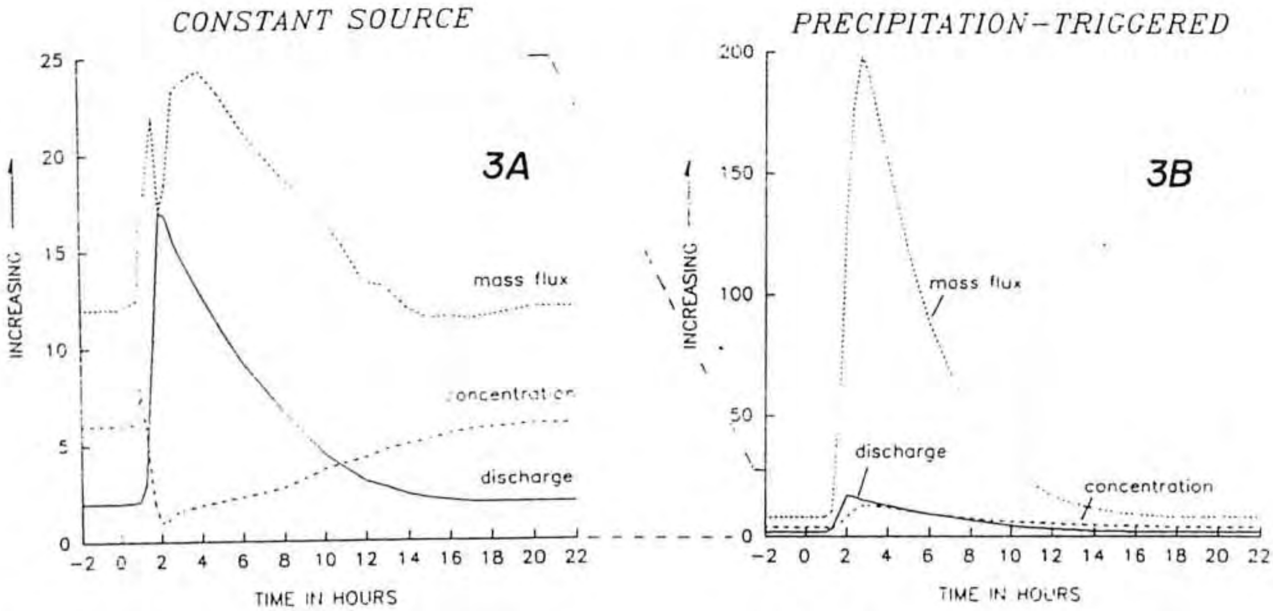

Figure 3. Hypothetical mass flux signatures of constant source release (3A) and precipitation-triggered release (3B).

Consider the flood pulse displayed in Figure 2. This pulse, documented over approximately 42 hours in the fall of 1987 at a sinking creek of the Turnhole Spring groundwater basin, clearly indicates the arrival of three highly conductive sources during the course of floodpulse activity. The majority of flow generated from this rainfall event was of the low-conductance, run-off variety. If water provenance suddenly changes, one may expect to see a similar change in water quality with respect to available water-borne constituents. Hallberg, et al (1985) identified an acute, albeit brief, water quality degradation associated with this run-off component in the karst of northeastern Iowa.

WATER QUALITY, EXPRESSED BY MASS FLUX, AS IT RELATES TO FLOOD PULSES

Important water quality information may be gained if knowledge of flood pulses is combined with mass flux signatures. As rainfall occurs, flood pulses are generated and propagated through the karst aquifer. Just as stage may suddenly vault from its base condition, water quality may also undergo rapid and drastic change as a flood pulse passes. If a significant amount of constituents are released by the precipitation event (entrained in run-off), the mass flux of these elements may rise tremendously.

Contemplate the two hypothetical mass flux signatures of Figure 3. It is vital to note the relative, unitless scales of the two graphs. Although the X-axis scales are equal, the Y-axis of 3a is 1/8th that of 3b. Also note that "Time 0" indicates the advent of precipitation. The same discharge hydrograph is employed for both graphs. Remember, data used in these graphs are hypothetical. Numbers were derived by noting the timing, duration, and wave-form characteristics of years of continuous data (stage, specific conductance, water temperature and discharge) and months of water quality data. Mass fluxes are actual products of discharges and concentrations.

If a constant source parameter is monitored through a flood pulse, oil-field brine chlorides from a leaking well casing for example, a response similar to that of Graph 3A might be expected. Following an initial upward spike in concentration, perhaps caused by a flushing of vadose stores, chloride concentration is diluted as the pulse's freshly input recharge component dominates the flow. The resultant mass flux signature, although not without structure, displays relatively low amplitude disturbance.

If the same discharge is used with a precipitation triggered release parameter, certain pesticide residues

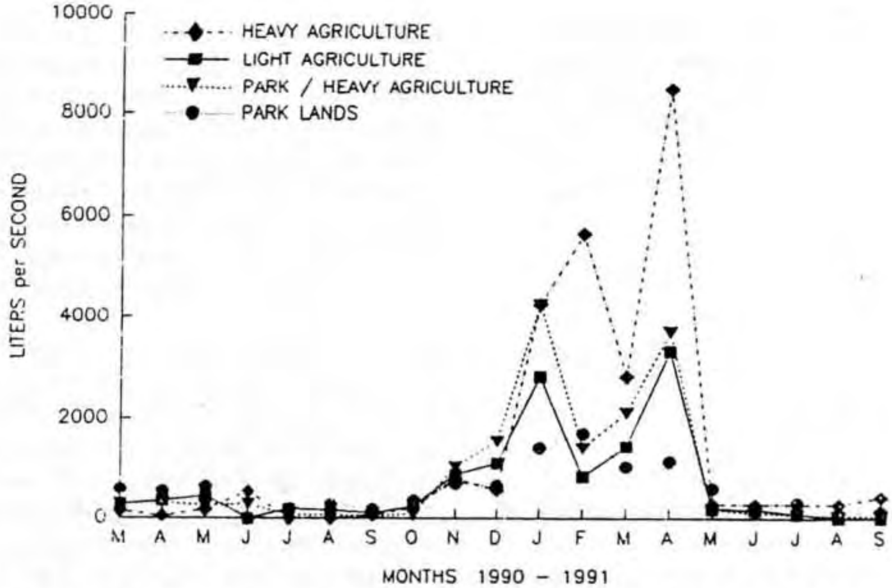

Figure 4. Discharge values, March 1990 through September 1991, of four monitoring sites.

for instance, a totally different mass flux signature results (Graph 3b). Again, note the Y-axes scales. The effects of constructive wave-form interference are noticeable as a high amplitude mass flux signature is generated. The passage of the leading edge of the pulse may be reflected in a sharp drop in pesticide residue concentration, as long-residing stores are displaced. This effect will be far overshadowed by the arrival of the freshly input recharge. Not only does this flow component comprise the majority of the flood pulse discharge, it also contains the bulk of surface run-off with entrained herbicides. The resultant mass flux signature may be several orders of magnitude higher than pre-pulse values.

There are many factors that may control the shape of the mass flux signature: availability of constituents, entrainment method, transfer mechanism from surface to subsurface, rainfall volume and areal distribution, time since last rainfall, and conduit condition, to name a few. It should be noted that the conduit condition used in this example is highly vadose. A different signature, especially with respect to temporal lags of concentrations and discharge peaks, will occur when dealing with a phreatic conduit system (Meiman 1988, 1989). Current research at Mammoth Cave specifically addresses flood-pulse water quality.

Perhaps by close examination of mass flux signatures of fecal coliform bacteria, dominant waste sources, human or animal, may be discerned. Human waste, for the most part, should behave as a constant release source. Human waste is injected directly into the aquifer via leach fields, leaking septic tanks, or dry-wells, at a relatively constant rate. A constant mass flux signature should result. Animals, not nearly intelligent enough to defecate down wells, will deposit waste on the surface. Without rainfall (or a major snow-melt), this waste will not be transferred into the aquifer. Following a significant recharge event, animal waste will be washed into the aquifer, producing a mass flux signature characterized by a very high amplitude disturbance.

RESULTS OF MARCH 1990 THROUGH SEPTEMBER 1991

The following data (based upon non-conditional samples) was run from March 1990 through September 1991. The summer months, which comprise a disproportionally large percentage of the data, will skew the data toward low-flow conditions. Non-conditional synoptic sampling covers a wide spectrum of flow conditions, ranging from flood-pulses to flow-reversals. If river water is back-flooded into the spring, it is considered to be representative of the

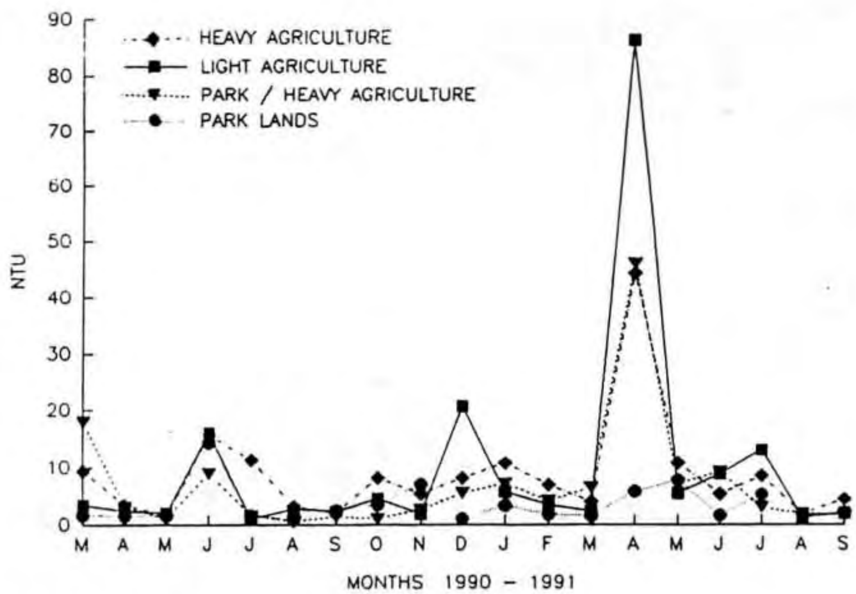

Figure 5. Turbidity values, March 1990 through September 1991, of four monitoring sites.

spring's water at that moment in time. The sample will be taken and analyzed regardless of water provenance (river or cave derived). The aquatic communities of the spring and related conduit must live in the waters, regardless of the source, therefore the sample is representative of their environment.

The presentation of water quality data in the following discussion will be in two forms: statistical graphs (bar and whisker) and XY graphs depicting trends at selected sites of selected parameters. The four selectedsampling sites for this document are: Light agriculture (Pike Spring, PSPS), Park/heavy agriculture (Echo River Spring, ERES), Heavy agriculture (Turnhole Spring area, THNS), and Park lands (Buffalo Creek Spring, BCGR).

DISCHARGE

Discharge depends, of course, upon precipitation events. The summer and fall months are traditionally characterized by low discharge, with higher discharge through the winter and spring (Figure 4). Overall the largest discharges during sampling occurred on April 10, 1991. On this date flood-pulse activity was high as the aquifer quickly responded to the rains of the previous day. This sampling round is of specific importance as samples were extracted near peak discharge times of the flood-pulses. Although other rounds saw relatively high discharges, samples were, as dictated by monitoring program, taken either well before or well after pulse peaks.

During the first nineteen months of the study a major backflooding event was sampled on June 10, 1990. At this time all springs, with the exception of THNS, were in a state of flow reversal - water from the Green River flowing back into the aquifer.

Notice that Echo River Spring is referred to as "Park/heavy agriculture". During times of high discharge, flow from the heavy agriculture basin is shunted through a high-level overflow route into the Echo River basin, which is normally recharged by park lands. When this route is activated, water quality in Echo River may, nearly instantaneously, degrade. Research in the next year will document the conditions needed to conduct flow through the overflow route.

TURBIDITY

Turbidity, correlative to the amount of suspended sediment in the water, is highly variable through all non-conditional synoptic sites (Figure 5). As expected, basins dominated by agricultural land-use, discharge more turbid waters than those dominated by undisturbed forests. Generally one would expect the higher turbidities associated with areas of high soil loss. Although the Turnhole basin (Heavy agriculture) contains by far the greatest area of tilled crop-lands, its turbidities, albeit high, were not the highest recorded; that honor goes to the light agriculture Pike Spring basin. Although containing far fewer acres of tilled land, the rugged topography of the Pike Spring basin amplifies soil loss when disturbed.

Displayed in turbidity are the back-flooding and overflow described in the preceding section. The back-flooding event of June 1990 is evident in turbidity, as back-flooded springs display turbidities close to that of the Green River. The Echo River basin (Park/heavy agriculture) exhibits low turbidities, associated with low to moderate discharges when the spring is recharge by park lands, and high turbidities when the overflow route from the heavy agriculture basin is activated.

CHLORIDE

Chloride may be indicative of animal/human waste and oil field brines. Figure 6a shows the chloride concentration trends of the four selected sites, while Figure 6b demonstrates the mass flux of the chloride ions. Both graphs exhibit interesting data. Figure 6a shows elevated concentrations of chloride in the heavy agriculture basin.

Oil field brines seem the prime suspect for two reasons: presence of associated brine ions, and mass flux signatures. Within the headwaters of the basin, and adjacent to the Park City oil-field, is Parker Cave. On a low-flow conditional synoptic survey (September, 1990), Parker River (a stream passage within Parker Cave) had chloride levels of 1476.1 ppm. Further down-basin, Mill Hole chloride was 59.9 ppm, as the Parker River water was diluted. At the basin's terminal spring, chloride was further diluted to 31.6 ppm. Bromide and sulphate, also suggestive of brines, were found decreasing at similar rates at the same sites. Similar results were reported by Meiman (1989), and Quinlan and Rowe (1978).

The mass flux signature of chloride may also indicate brine contamination instead of animal waste. Figure 6a displays a variable, yet predictable pattern of chloride concentrations. One may assume that the chloride source is of relatively constant delivery as chloride concentrations are higher during low flow periods of summer and early autumn, and lower, more dilute, during the high flow periods of winter and spring. Figure 6b indicates an apparently dramatic increase on the mass flux of chloride during months of high discharge. This increase, some eight times the mass flux of low discharge periods, may not be as severe as it may seem. This variation may be normal, even for this relatively constant source parameter. One might expect a much greater (several orders of magnitude) rise in the mass flux signature if a source is released by run-off from a precipitation event.

A certain portion of chloride can be considered as a natural, background concentration. Observe the chloride trends of the Park land basin. Not only are chloride concentrations low (Figure 6a), they remain at approximately the same mass flux throughout the year (Figure 6b). Upon closer examination, notice the slight increase in mass flux through the winter months. Although seemingly small and insignificant, the relative changes between seasonal mass fluxes in the Park land and the Heavy agriculture basins are very similar. This trend may be an inherent wave-form signature due to the vast increase in discharge.

Road salts as a potential chloride source must be recognized. Although the use of road salts have been prohibited within the park since 1987, they are used throughout several of the park's groundwater basins. The amount of road salt contributing to chloride levels found in parks waters is yet unknown. Since the first month of sampling there has not been a significant snow fall to warrant the use of much salt. Perhaps this unnatural source will be manifested in a "unique" mass flux signature, representative of seasonal application and recharge.

FECAL COLIFORM

Fecal coliform bacteria is found at all sampling sites (Figure 7). These bacteria are common in wastes of all healthy warm-blooded animals. By far, basins with high occurrences of dairies, feed-lots and urban areas are characterized by high levels of fecal coliform.

A certain amount of fecal coliform can be attributed to wildlife. Note that the Park land basin (BCGR),

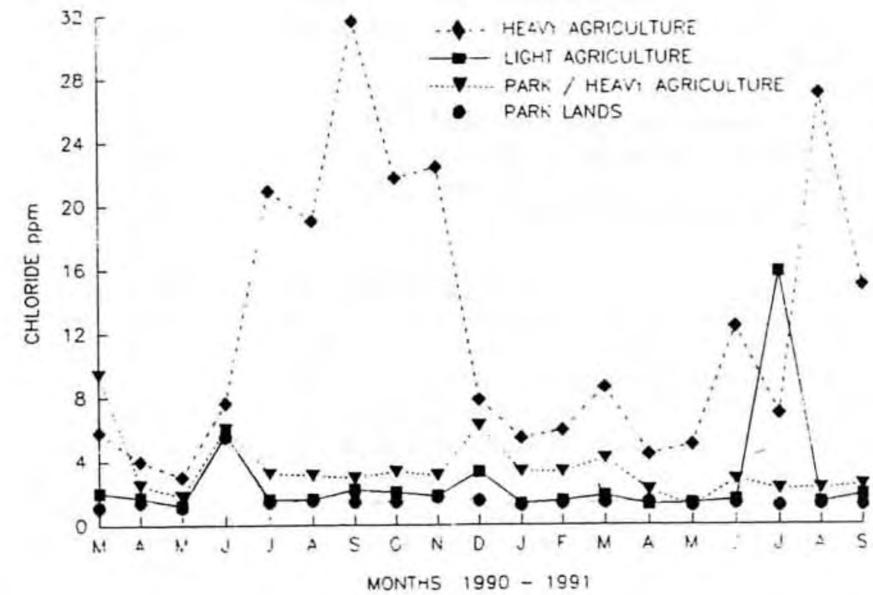

Figure 6a. Chloride concentrations, March 1990 through September 1991, of four monitoring sites.

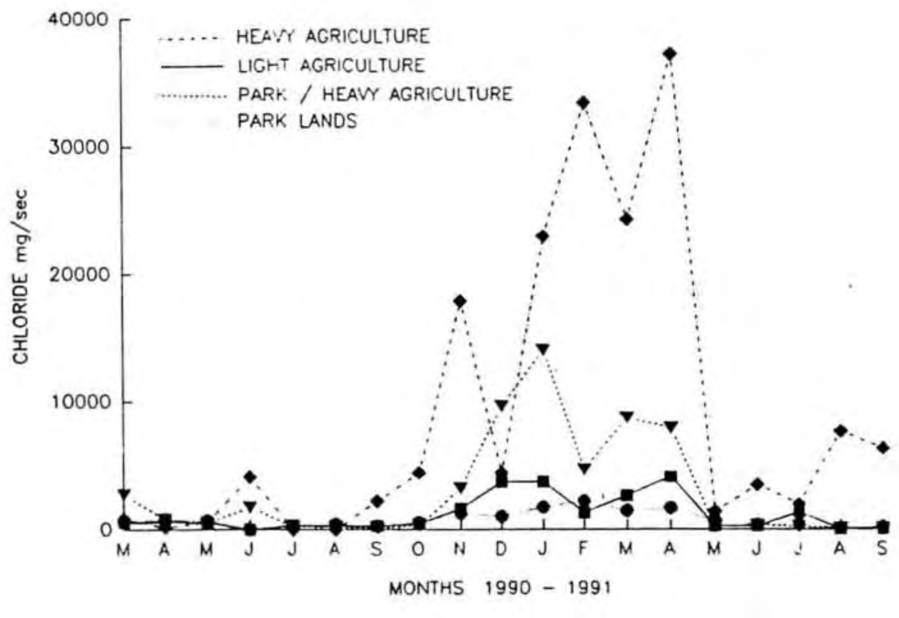

Figure 6b. Chloride mass flux, March 1990 through September 1991, of four sampling sites.

representative of pristine conditions, contains a fair amount of fecal coliform bacteria (mean of 67 colonies per 100 ml), and discharges a relatively stable 1.5 million colonies per second (not shown). Although the latter number may appear high, a single gram of feces may contain tens of millions to tens of billions of cells (Feachem, et al., 1983).

The heavy agriculture basin (THNS), with hundreds of homes without proper waste treatment facilities, and scores of dairies and feed-lots where live-stock waste flows as sinking-creeks into the aquifer yielded the highest overall fecal coliform levels. Feachem et al.

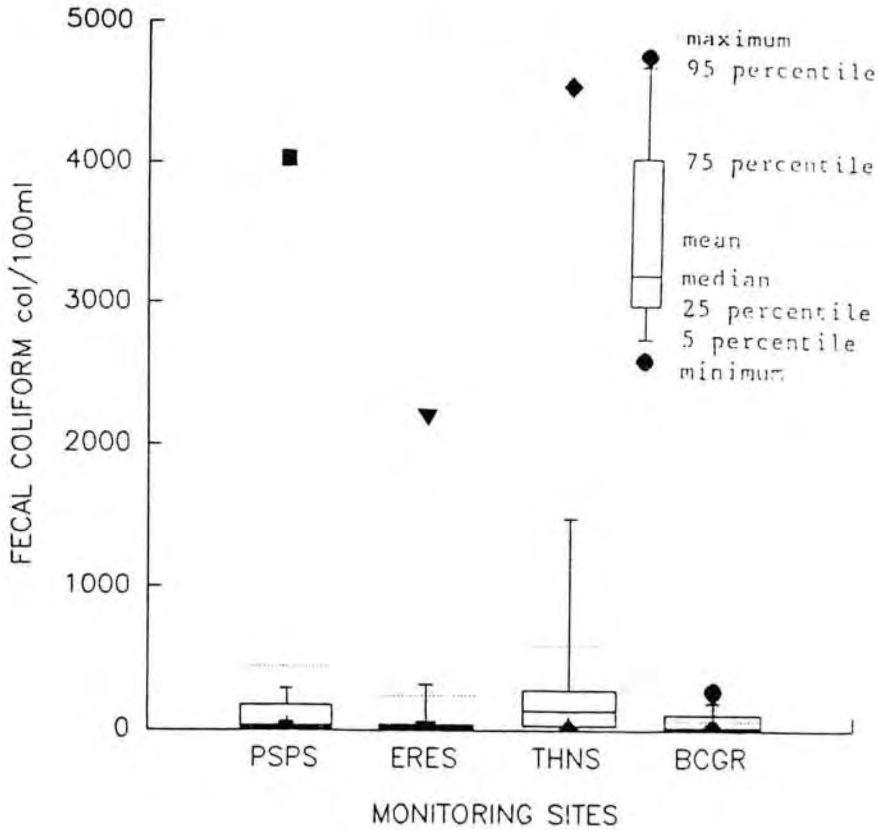

Figure 7. Statistical examination of fecal coliform bacteria levels, March 1990 through September 1991, of four monitoring sites.

(1983) reports that although fecal coliform density per gram of feces of man and livestock are comparable, a human may excrete 150 grams of feces per day compared to 15 to 20 kilograms for a cow. The highest flow weighted value, greater than 535 million colonies/second, was observed at this spring on April 10, 1991. As samples are taken on a set monthly date, regardless of weather or flow conditions, over the three-year period of monitoring some flood pulses are likely to be sampled. April 1991 was such an occurrence. It is important to note the relative temporal position within the flood pulse from which the sample was taken. A great amount of variance in parameter concentration may exist throughout high discharge periods of a flood pulse. It is not possible to tell from one sample its temporal relationship to concentration or mass flux peaks of a particular parameter.

The chance occurrence of flood pulse activity coinciding with a predetermined sampling date tends to create a large variance in reported concentrations and mass fluxes of fecal coliform bacteria. A high variance may indicate, as in the heavy agriculture basin, the presence of large amounts of animal waste stored at the surface, awaiting release by a rainfall event.

Notice that low values dominate the data set in the park land/heavy agriculture basin (ERES). Occasionally these low levels of fecal coliform are interrupted by brief periods of very high concentrations, as expressed in the elevated mean and maximum values. Recall the overflow route mentioned earlier. During high-stage times, a portion of the bacteria-laden waters of the heavy agriculture basin are shunted into the relatively clean park basin.

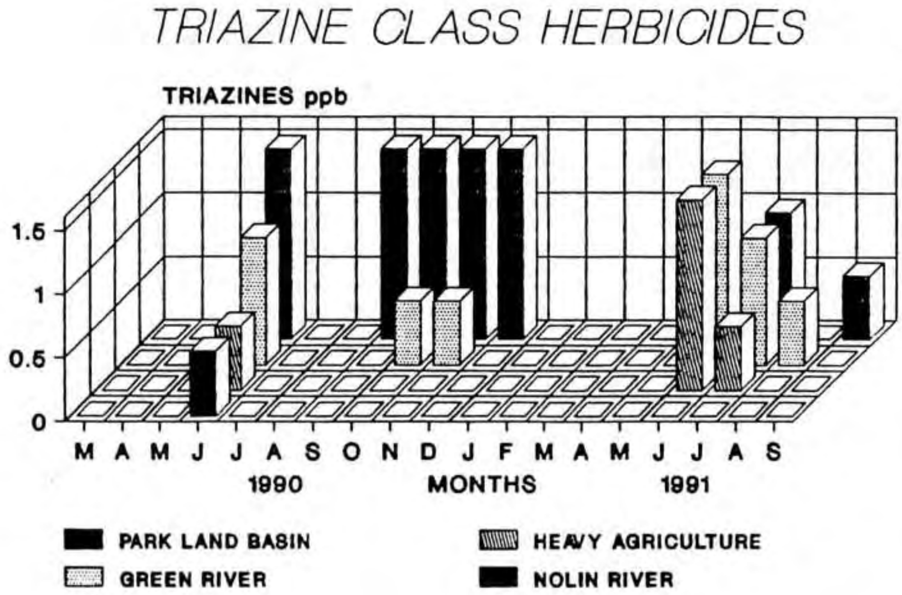

Figure 8. Temporal occurrences of triazine-class herbicides using immuno-assay methods, March 1990 through September 1991, at four monitoring sites.

TRIAZINE-CLASS HERBICIDES

The monitoring program indicates the presence of triazine-class herbicides (greater than 1 part per billion) within the surface and ground waters of the park. The occurrence of these compounds generally coincided with the peak application period. To avoid costly organic laboratory testing for these compounds, the program employs assay screening tests. Although gas chromatography analysis would indeed be desired, laboratory costs of a couple of sampling rounds would destroy the monitoring budget. Assay-screening can not be thought of as a quantitative analysis. It is used primarily as a "hit-or-miss" technique, with semi-quantitative values (ie, greater than 1 ppb).

The spatial and temporal occurrence of triazine-class herbicides reflect land-use, herbicide application periods, and perhaps the mechanism of transfer between the surface and subsurface (Figure 8). With the exception of a back-flooding of triazine tainted river water, the only groundwater sampling site in which triazines were found was the heavy agriculture basin (THNS) spring. Additionally, triazines were only found in months (June 1990, June and July 1991) following peak application periods within the basin. Triazines are also found at both river sites following peak application.

For the remainder of the year no triazine-class herbicide residues were found in the sampled springs. Although rapid transport of these residues through the karst system is expected, one may not assume that all, or even the majority of these compounds that will move through the aquifer have done so. Research in Iowa by Hallberg et al. (1985) found that although large amounts of herbicides are quickly transported through the karst system via run-off following rainfall, the bulk of these materials are slowly released through infiltration in low concentrations. It would not be surprising to see a similar pattern of pesticide transfer through the Mammoth Cave aquifer.

Aside from occurrence following peak application periods, triazine-class herbicides were found in both the Green and Nolin rivers in the fall of 1990, and possibly in the fall of 1991. Two scenarios may be possible: 1) There was a late application of these compounds in the fall, or, 2) The residues were slowly transferred through a less permeable media (clastic strata).

As triazines are applied as pre-plant or pre-emergence herbicides, there is no reason to believe that there was a late application, as crops that receive triazines (corn, and to a lesser degree, soybeans) were near harvest.

River flood plains, with associated unconsolidated fluvial deposits, are favored lands for row-crop production. It may be possible that these persistent compounds may: 1) become entrained in run-off shortly after application, and 2) slowly infiltrate through the fluvial materials and leach into the river following fall rains. The "half-life" of these compounds (3-12 months) is certainly sufficient to cause such persistency.

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DELINEATION AND HAZARD AREA MAPPING OF AREAS CONTRIBUTING WATER TO SIGNIFICANT CAVES.

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ABSTRACT

The recharge area for a cave is that area which contributes water to the cave. In some cases the recharge area is little more than the land which overlies the cave. However, in many cases (and especially when the cave contains streams or lakes) the recharge area may encompass several square miles.

Groundwater tracing is a fundamental tool for recharge area delineation. The general approach is to introduce fluorescent tracer dyes at points where surface waters sink into the groundwater system and then sample for these dyes at springs, significant caves, and other relevant points.

Hazard area assessment and mapping is a management approach for identifying and characterizing those areas which pose the greatest water quality threats to significant caves. Hazard area delineation integrates the hydrologic functioning of particular units of land with the uses of those lands. This paper will help resource managers understand the benefits of recharge area delineations and hazard area mapping and understand characteristics of technically sound investigations.

Introduction

The area which contributes water to a cave is called the recharge area. With few exceptions, identifying the recharge area for a significant cave represents fundamental management information. Recharge area delineations are particularly important for caves with important aquatic cave faunas.

The purpose of this paper is to provide resource managers with a workable understanding of how cave recharge areas are delineated and how hazard area mapping is done. While there is no single "right" way, there are clearly many ineffective or undesirable ways to accomplish this work.

Methods for Delineating Recharge Areas

Cave Mapping and Topographic Studies

While cave maps can provide useful data, they seldom provide an adequate basis for recharge area delineation. We sometimes see assumptions that the area overlying a cave plus some arbitrary narrow "buffer zone" on the order of 100 to 300 feet is the sole source of recharge waters for that cave. This assumption is questionable (and often wrong) even when the cave contains neither streams nor lakes, and where only drippage waters are present. This assumption is frequently wrong even when the dip of the bedding is taken into account. A major reason that this approach is often in error is that flow paths in the epikarstic zone (the weathered and corroded zone beneath the soil) are highly complex, may be dramatically different from the dip, and may involve lateral water movement over substantial distances.

Water infiltrates the epikarstic zone more rapidly than it infiltrates beneath it; this results in appreciable water storage in the epikarstic zone and lateral water movement through the zone since lateral permeability is routinely much greater than vertical permeability.

It is sometimes assumed that groundwater flow directions and divides are identical, or very similar to, surface flow directions and topographic divides. In our experience this assumption is commonly false. An exception could be a cave in the bottom of an intermittent surface stream channel, although such caves may also receive water from points not tributary to the surface stream. Even when it appears that the recharge area for a cave may be estimated from surface features, actual delineation studies should be conducted for verification.

Equipotential maps, which are contour maps of the water table elevation, can be developed for areas. In most (but not all) karst areas these maps are not of great utility in delineating cave recharge areas. One reason is that the data points are generally widely scattered and poorly distributed; the resulting maps are thus gross generalizations. Well depths vary substantially in many karst areas, and water level elevations are significantly affected by the geologic units in which the well is developed. In one cave area we routinely encountered differences in water level elevations of over 100 feet between nearby wells 125 feet deep and those 300 feet deep. Differences are generally not this great, yet the differences are commonly sufficient to readily produce incorrect interpretations.

Groundwater Tracing

Realistic recharge area delineation requires groundwater tracing. The tracing is generally conducted with fluorescent tracer dyes. Other tracing agents exist, but their use is substantially more difficult than tracing with the fluorescent dyes. Some of the other tracing agents, such as sodium chloride, are likely to create adverse impacts. Groundwater tracing techniques are described in detail by Aley and Fletcher (1976) and by Aley et al. (1992; in preparation). There have been major improvements in analytical techniques since the Aley and Fletcher (1976) publication.

The most effective and most commonly used tracer dye is sodium fluorescein (Acid Yellow 73, Color Index [CI] Constitution Number 45350). It is commonly simply called fluorescein in the United States; it is sometimes called uranine (especially in Europe). It is most commonly sold in a powder form which has a strong reddish color. When added to water the dyed solution is a brilliant yellow-green color. Visual detectability is significantly affected by background color in the dyed water and other factors. An experienced observer can commonly detect fluorescein in the field in concentrations as low as about 30 micrograms per liter (parts per billion).

The concentration of fluorescein in dye mixtures sold by various supply houses varies substantially. Some of the liquid mixtures contain less than 5% fluorescein. Powder mixtures generally contain more fluorescein than liquid mixtures, but they also vary widely. In order to achieve a uniform product and, in some cases, to enhance the ease of dyeing a product, it is conventional to add diluents (cutting agents) to technical grade dyes. This is standardization, not adulteration. The diluent most commonly used with fluorescein is sodium sulfate.

Rhodamine WT (Acid Red 388) is also a commonly used tracer dye. Rhodamine WT should not be confused with other Rhodamine dyes; some of the other Rhodamine dyes have undesirable properties. Rhodamine WT is commonly sold as a 20% dye solution. When added to water the dyed solution is pinkish orange. As with fluorescein, visual detectability of Rhodamine WT is affected by background color in the dyed water and other factors. An experienced observer can commonly detect Rhodamine WT in the field in concentrations as low as about 50 micrograms per liter (parts per billion).

Various optical brighteners have also been used in groundwater tracing. These are pale blue fluorescent dyes commonly used in laundry soaps and detergents to make "whites appear whiter". Because of their use in soaps and detergents the optical brighteners may already be present in cave waters; this limits their utility for recharge area delineation studies. However, sampling for background concentrations of optical brighteners can be useful in indicating sewage contamination of the cave waters (Aley, 1985). We find background sampling for optical brighteners to be a very useful approach during a recharge area delineation study. It should be noted that the absence of background optical brighteners in cave waters may result from their adsorption onto fine textured soils; sewage effluents may be present even if optical brighteners are absent.

Direct Yellow 96 (Diphenyl Brilliant Flavine 7GFF) is a fluorescent yellow dye which has been successfully used in a number of groundwater traces in Kentucky. Other fluorescent dyes which have received some use in the United States include Pyranine (CI 59040; CI solvent green 7, D&C green 8); Lissamine FF (CI 56205; CI acid yellow 7); and Eosine Sodium (CI 45380). Amino G Acid, a dye intermediary, has also been used. Anyone competently using any of these dyes will almost certainly also be using fluorescein, Rhodamine WT, and probably optical brighteners.

Of the four most commonly used dyes, fluorescein is generally the best for groundwater tracing and Rhodamine WT is the second best. Fluorescein is more subject to destruction or alteration in sunlight than is Rhodamine WT, optical brighteners, or Direct Yellow 96. Significant dye losses by adsorption onto charged soil particles can occur with any of the dyes; in our experience dye losses to adsorption increase in the order of fluorescein, Rhodamine WT, optical brighteners, and Direct Yellow 96. Use of optical brighteners and Direct Yellow 96 is unlikely to be successful in groundwater systems where appreciable adsorptive losses occur. Other considerations are also involved in the selection of the dye or dyes to use.

There are sometimes sources of background fluorescence which can interfere with the detection of tracer dyes. Additionally, the tracer dyes (or similar dyes) may be components of compounds already present in the area. Fluorescein is used in a few household products and as the coloring agent in antifreeze. It can sometimes be detected in runoff waters from parking lots and city streets. Pyranine is used in more household products than fluorescein; these dyes cannot be readily separated visually or with a fluorometer, but they can be separated with a spectrofluorophotometer operated with a synchronous scan protocol. A dye which cannot be fluorescently distinguished from Rhodamine WT (it is probably Rhodamine B) is used as the coloring agent in many hydraulic fluids. It is routinely present in the waste water from manufacturing plants which use hydraulic equipment. Additionally, Rhodamine B has also been used to color seed corn to prevent it from accidentally being fed to livestock.

Cumulative samplers capable of adsorbing passing dyes are commonly used in recharge area delineation studies. Activated carbon samplers are used to adsorb dyes such as fluorescein, Rhodamine WT, and some of the less commonly used dyes. Cotton samplers are used to adsorb optical brighteners and Direct Yellow 96. "Grab samples" of water can be collected for dye detection, but the frequency of sampling necessary to insure that a pulse of tracer dye is not missed limits the general utility of this approach. Grab samples of water collected simultaneously with the collection of activated carbon samplers can provide valuable data on actual dye concentrations at particular points in time if the analysis protocol is capable of providing credible quantitative results.

Cumulative samplers are typically collected and new samplers placed about once a week, although the frequency can be varied depending upon the nature of the study. Activated carbon samplers are eluted with a strong base, alcohol, and water solution. Moderate to large concentrations of fluorescein can be detected visually in the eluting solution. Visual detection of Rhodamine WT in the eluting solution is difficult; this dye should not be used in groundwater tracing unless analytical equipment is available. Simultaneous tracing with fluorescein and Rhodamine WT can be done with the use of a spectrofluorophotometer operated in a synchronous scan mode. It should not be attempted with a fluorometer since large concentrations of one dye will create an apparent detection of the other dye with this type of instrument.

Cotton samplers are washed with jets of clean water and then examined either under an ultraviolet light or in an appropriate analytical instrument. Experience and care are essential in visual analysis. Optical brighteners and Direct Yellow 96 can mask one another unless both are present in large concentrations.

These dyes can be used simultaneously if analysis is done with a spectrofluorophotometer operated in a synchronous scan mode.

The common groundwater trace utilizes cumulative samplers. Background sampling, prior to any introduction of tracer dyes, is generally conducted to demonstrate the absence of fluorescence interference or to characterize the magnitude of the interference. The extent of background sampling is largely determined by the nature of land use in the area.

A well designed delineation study for an important cave is characterized by thorough field work to identify potential dye injection sites and caves or springs through which the injected dye may subsequently pass. Simply studying topographic maps and aerial photos alone will seldom be sufficient. These approaches generally miss many important springs. Groundwater tracers seem to have a propensity to discharge from springs that were not sampled. Some of the missed springs may be in the channel of surface streams. As a result, surface streams must be sampled to address this possibility. Multiple sampling stations are routinely needed along surface streams since tracer dyes deteriorate and are adsorbed as they are transported down the stream channel. In delineation studies, a trace that goes to the "wrong" spring provides valuable data for the delineation of the cave or spring of concern. It is always better to know where the trace went than to simply know where it did not arrive. This is not always possible; an example would be an area where many springs are beneath the surface of large lakes.

The easiest sites for injecting tracer dyes are points where water always or almost always sinks into the groundwater system. Sites near roads, on public land, or on property of landowners known to be friendly are always nice. The easiest sites are frequently not those most useful for a good delineation study. The good delineation study must gather the data needed rather than the data that are more easily available.

A good delineation study must be dynamic; one should seldom plan more than one or two traces in advance. The results from one trace must be incorporated into the planning for the next. Tracing should take advantage of weather conditions. Some highly desirable tracer injection sites have flowing water only a few days out of the year. Unless one can haul substantial volumes of water, these sites must be used when the water is present. Sometimes one can place the tracer dye where it will enter the water the first time flow occurs; this must be done very carefully.

Another characteristic of a good delineation study is that many of the dye injection sites are located in areas where contaminants enter (or might enter) the groundwater system. We routinely select injection sites which receive waters from dumps and landfills; sewage and sewage effluent discharges; commercial and industrial operations; highways, railroads, and product pipelines; and major sources of animal wastes. The failure to recover dye from such traces in the cave of concern is always an important finding; however, important caves are not immune to impacts from these types of land uses.

A good delineation study should include groundwater traces which are recovered in the cave of concern plus some traces which are recovered at sites other than the cave. If all of the traces are recovered in the cave of concern you have probably not identified the boundary of the recharge area.

Water that enters the karst groundwater system at a particular point does not always flow only to one cave or spring. The flow may be to two or more caves or springs. In one study Aley (1988) found radial groundwater flow throughout a large area in northwestern Arkansas. Not only can the flow be shared among several caves or springs, but the relative quantity moving to each site can vary with flow rates and other groundwater conditions.

We often find that a particular cave (or spring) has some recharge areas which contribute waters only to that cave. Often there are some recharge areas which share water between the cave of concern and other caves or springs. The total recharge area includes both the exclusive recharge area and the shared recharge area. Where feasible, each should be delineated separately and their hydrologic interactions characterized. Shared recharge areas are commonly located near recharge area boundaries, however, distributaries can exist closer to the discharge points for the groundwater system. An illustration of distributaries is provided by the springs which drain the main stream in Tumbling Creek Cave, Missouri. These springs extend for 2,000 feet along Big Creek; none of these springs is more than a mile from the cave stream.

Identification of shared recharge areas routinely requires more comprehensive sampling, good analytical approaches, and project direction by experienced groundwater professionals. Some shared recharge areas deliver water to a cave of concern only during moderate to high flow conditions. Fantastic Caverns near Springfield, Missouri is an illustration of this condition. During low flow conditions the recharge area comprises about 7 square miles. During high flow conditions the recharge area comprises about 20 square miles; at least six springs share portions of this recharge water.

Even a small cave stream may have a large recharge area because of shared recharge areas. Fire Hydrant Cave on the Current River in Missouri is an illustration. This cave shares water with Pulltite Spring and other springs in the area. While the mean flow rate of this spring is relatively small, dye injected in a losing stream segment of Big Creek 13.1 miles straight line distance from the cave was recovered in the cave.

How large are recharge areas for significant caves likely to be? This is a bit like asking the length of a typical piece of string, yet resource managers concerned with potential recharge area delineation investigations need some understanding of the size of areas likely to be involved.

The caves with the largest recharge areas are generally those which contain cave streams or lakes. As a general rule, the greater the mean annual flow of water through the cave the larger the recharge area. If a recharge area is shared by multiple caves and springs the recharge area is likely to be larger than if the cave has an exclusive recharge area. Caves which receive recharge waters from a significant surface stream have recharge areas which include the entire topographic basin of the stream upstream of the recharging point plus any other areas contributing water to the cave stream.

We have delineated the recharge areas for about 25 caves in seven states. Six biologically significant caves had recharge areas of 0.2 to 2.5 square miles; none of these received recharge waters from any appreciable surface streams. Six other biologically significant caves had recharge areas of 7 to 24 square miles; all but two of these involved either appreciable surface streams or recharge areas shared with other caves or springs. Caves in the Western United States do not necessarily have larger or smaller recharge areas than caves in the Midwest or East.

Hazard Area Mapping

The hydrologic functioning of the land is not uniform. The hydrologic impacts of land use are also not uniform. It is clear that the combined impacts of these conditions on a cave or spring are also variable. Because of these conditions we can develop maps which depict qualitatively different groundwater quality risks posed to a significant cave. This is the foundation for a karst-specific approach which we call hazard area mapping.

We initially developed the approach in 1976 for use in recharge area delineation studies for major springs on the Ozark National Scenic Riverways in Missouri (a National Park unit). We have subsequently applied the approach in many of the delineation studies we have conducted over the last 15 years, and believe it to be a very useful management tool. It has been applied elsewhere in Missouri and in Arkansas, Oklahoma, Wyoming, Kentucky, and Alabama.

A nationally used mapping approach for assessing groundwater contamination risks was developed by the National Water Well Association and the U.S. Environmental Protection Agency (Aller et al., 1987) and is called "DRASTIC". It is a useful approach, but is neither a karst specific nor a cave resource-sensitive approach. The DRASTIC approach demonstrates that karst areas are readily subject to groundwater contamination but does not provide for more detailed discrimination nor for integrating land use conditions.

We develop somewhat different criteria for hazard area classes for each region (and sometimes for each cave) studied. We typically use three or four categories, although one or more may be absent in particular recharge areas. In a typical hazard area mapping project the categories will include low, moderate, high, and extremely high groundwater contamination hazard categories. Situations associated with the higher risk categories include:

1) Areas in close proximity to the cave.

2) Sinkhole areas, losing stream segments, and areas within 300 feet of mapped fracture traces and lineaments.

3) Localized areas where substantial volumes of water enter groundwater.

4) Areas with shallow or very rocky soils.

5) Areas where land uses of concern exist or are likely to exist. Point sources are routinely identified, assessed, and shown on the maps with an index number.

6) Areas which exclusively recharge the cave of concern.

Summary of Good Recharge Area Study Characteristics

1. The study should be conducted by, or be under the technical direction of, a karst hydrologist who has successfully conducted previous recharge area delineation studies. A person who has previously conducted groundwater traces does not automatically quality since recharge area delineation and hazard area assessments requires more than simple groundwater tracing. However, the person directing the study should have background or experience in groundwater tracing. Once a year the National Water Well Association offers a week-long professional short course entitled "Practical Karst Hydrogeology with Emphasis on Ground Water Monitoring". This course provides the type of background needed to supplement the conventional background of most groundwater hydrologists. Recharge area studies lie well outside the field of expertise of the typical registered geologist or engineer.

2) Thorough field reconnaissance precedes the start of groundwater tracing. Background sampling is conducted before tracer dyes are injected. Numerous sampling stations are established to insure that the injected dyes are recovered. Dyes appropriate to conditions in the study area are selected and the quantities used are adequate to insure that the failure to recover dye at the cave of concern is credible evidence that a hydrologic connection does not exist. Depending upon conditions, adsorptive losses may cause the failure of groundwater traces conducted with Direct Yellow 96, optical brighteners, and Rhodamine WT.

3) The delineation study should be adequate to detect and assess recharge areas which the cave of concern shares with other caves or springs. The good study will not be limited to just the simple and easy groundwater traces, but will instead include traces from areas where data are needed. The good study will routinely conduct traces to assess sites which pose potentially significant water quality threats to the cave or spring being studied. The study will be dynamic; the results from previous traces must be incorporated into the planning for those subsequently conducted.

4) State of the art analysis for tracer dyes uses a scanning spectrofluorophotometer operated with a synchronous scan protocol. Successful groundwater tracing can be done using visual and fluorometric methods, but these approaches slow the tracing program because of dye interferences and the necessity of using more dye to insure positive results. Increasing the quantity of dye increases the duration of the dye pulse and, in turn, the time between traces. Field time is generally the most expensive part of a recharge area study. In our experience, state of the art analysis generally maximizes the number of groundwater traces conducted; it also produces the most credible results. Several firms have this type of equipment; at least two of these firms will routinely conduct dye analysis work on samples shipped to them. Similar equipment exists

at a few universities or other state agencies, yet experienced operators and acceptable protocols for dye analysis often limit the utility of this equipment.

5) Hazard area assessments and the development of hazard area maps should be a routine component of recharge area delineations.

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NATURAL AND CULTURAL LANDSCAPE INTERACTIONS IN THE KARST OF BATUAN, BOHOL, THE PHILIPPINES

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ABSTRACT

Population pressure, periodic drought, insurgency and the nature of the karst landscape have combined to degrade Batuan's soil and water resources. Decreased fallow times and slash and burn agriculture have greatly diminished aquifer recharge rates and increased soil erosion. This degradation implies that changes in the cultural landscape are altering the natural landscape. This interaction between man and land forms the basis for the environmental problems which currently exist in Batuan.

Introduction

This manuscript examines the relationships that exist between man and land in the limestone terrain on Bohol in the southern portion of the Philippine archipelago. Examples are cited from the municipality of Batuan, which is located in the Central Limestone Plateau Region of the island. Batuan's natural landscape includes abrupt isolated limestone hills (mogotes), rugged uplands, broad flat alluvial valleys, springs, caves and dense jungle.

How man relates to the land, changing it and being changed, is the central theme of classical cultural geography (Sopher, 1973). "Its focus is on the systemic links between man and culture expressed in the appearance of the cultural landscape- the land remolded by culture" (Sopher, 1973). The man/land relationship which exists on Bohol (specifically Batuan) was examined from antiquity to the present using historical records, scientific writings, folklore, and personal communications to develop a model of human interaction and exploitation of the natural landscape.

Population expansion and the proliferation of agriculture after settlement have degraded soil and water resources on Bohol. How man has dealt with this degradation was studied in the context of natural landscape exploitation shaping cultural attitudes thus forming an evolving cultural landscape. Agricultural development in tropical karst areas is related to the nature of specific karst resources including the spatial orientation and interaction of bedrock, soils, sediments, springs, tufa dams, zones of saturated bedrock and swallets (Urich, 1991a). The inter-relationships between these resources often determine the evolution of indigenous agricultural systems (Urich, 1991a), with groundwater quantity and quality being paramount in the operation of these systems (Urich, 1991b).

The natural landscape of Batuan has supported a culture dependent upon intensive wet rice cultivation for a millennia or more and continues to maintain mature and sophisticated wet rice irrigation systems (Urich, 1989, 1990). But in contrast to the pristine natural landscape of the first settlers, today's landscape is greatly disrupted. The heavily forested, perhaps somewhat ominous natural landscape of the original settlers has evolved into the deforested, largely cultivated natural landscape of contemporary Bohol. Through time, the evolution of the man/land relationship influenced the attitudes, perceptions and customs specific to Bohol and served as building blocks for the societal structure which currently exists.

Figure 1 - The location of the island of Bohol, The Philippines.

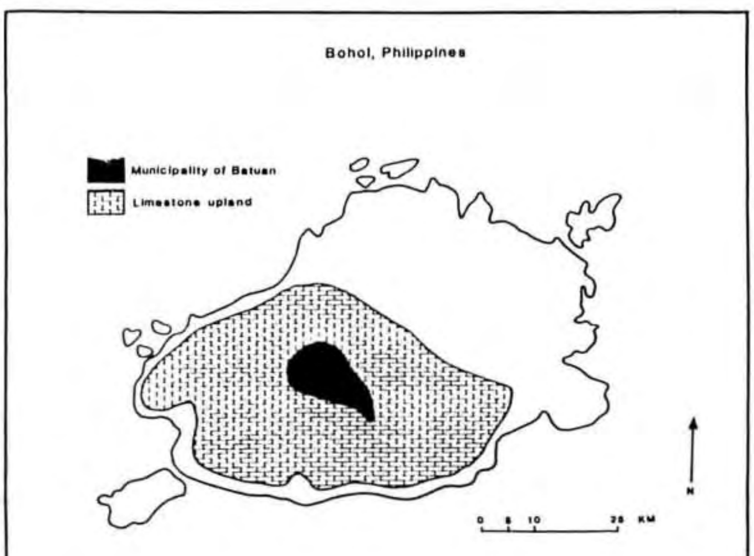

Figure 2 - Location of the Limestone upland and the Municipality of Batuan, Bohol, The Philippines.

General Overview of Batuan, Bohol

The island of Bohol is located in the south-central Philippine archipelago about 500 kilometers southeast of Manila (figure 1). Batuan is located in the Central Plateau Region of the island and is almost exclusively underlain by the Pleistocene aged Maribojoc Limestone. Batuan is one of 47 municipalities which comprise Bohol (figure 2). It has a population of about 11,000 people and a total land area of nearly 8,000 hectares, of which 60% is cropland and 25% is pasture, with about 35% of the cropland used for lowland rice cultivation. The other principal crops grown in Batuan are corn (16% of the total land area) and coconuts (7%). A total of 1,771 hectares are cultivated with lowland rice varieties, of which 619 hectares are irrigated, with the remaining 1,152 hectares being rainfed. Production data indicates that yields from irrigated fields are double the output from the rainfed plots (Virador, 1988). Fields are irrigated by spring resurgences which discharge into a system of channels that have evolved over the centuries into a well integrated network which irrigates about 33% of the lowland rice fields.

Evolution of the Cultural Landscape

The first population migration to affect the southern Philippine archipelago brought people from northern China who had migrated through southern China, across mainland southeast Asia and into the Malay Peninsula by around 4,500 B.P. Then, traveling mainly by water, they migrated east through the Indonesian islands, moving north through Borneo and Sulawesi into the Philippines (Heine-Geldern, 1932). Beyer and de Veyra (1947) note that the southern Visayas, including Bohol were settled by people who had come from Borneo between 2,200 and 2,300 B.P. These settlers brought with them the technology to grow wet rice crops in terraced fields.

At the time of settlement, Bohol was probably heavily forested, which proved inviting to the new settlers' machetes. From the first footsteps on the beach, to the crudely fashioned homes of the settlers, to the trails cut through the jungle to penetrate the island's interior, man's mark was immediately put upon the natural landscape. The development of the wet rice culture on Bohol probably began with the cultivation of small family plots. As the island's population increased, more land was cleared for sustained agriculture.

Along with accelerated soil erosion due to land clearance, essential water resources necessary to keep the land fertile and producing crops were also degraded. The availability of fertile soil and irrigation water induced settlement in areas which had the greatest potential for agriculture. Then a cycle of land development, degradation and abandonment occurred which constantly redistributed the island's population. Throughout these episodes of degradation and population migrations, Boholanos maintained the indomitable spirit for which they are legendary (Borja, 1989).

"It is comforting that far from being portrayed in history books as belligerent and easily given to pugnacity, the Boholano is indeed a man of peace with a deep sense of respect and affection towards others" (Borja, 1989 p. 2). Behind the timid facade of the Boholano is a fervor which can transform disappointment into righteous indignation, then a prolonged burst of anger and finally, to unbridled fury (Borja, 1989). The nature of the Boholano is typified by the events associated with the signing of a blood compact (sandugo) on March 16, 1565 between Datu Sikatuna, the ruling chieftain of Bohol, and Miguel Lopez, a representative of the Spanish government. This represents a significant milestone in Filipino history, the development of international understanding. But it was also on Bohol that the first and most significant armed resistance against the abusive Spanish took place. For 85 years, between 1744 and 1829, the Dagahoy Rebellion occurred, which was the longest such rebellion in Philippine history. The final result was freedom for the Boholanos to proliferate their culture.

Throughout Philippine history Boholanos have always been ready to defend their homeland and way of life. Boholanos were noted to be the fiercest fighters in the American-Filipino War and World War II. It is this spirit which can be traced through history and which still exists in today's Boholano. Although a civil war of sorts is currently being fought throughout the

Philippines, with Bohol being no exception, most Boholanos still remain humble farmers who relish their freedom and their way of life. The armed insurgency and counter-insurgency has prompted families and clan groups to move from traditional, highly decentralized ancestral house sites to relocation sites near village cores or along roads (Urich, 1991b). This centralized and intensified the pattern of degradation. The intensification of land degradation and the lack of any social mechanism to check this problem could greatly affect future preservation of the Boholano way of life, more so than even the violence of the current civil war between the New Peoples Army (communist rebels) and the Aquino government.

Degradation of the Natural Landscape

Batuan's natural landscape is dominated by residual limestone hills (mogotes) and ridges separated by broad, flat alluvial valleys. Other karst phenomena include channels which carry ephemeral storm water, sinkholes, caves and springs (Reeder and others, 1989). The unique nature of the karst landscape and the lack of understanding of the complex systems which exist in such terrain has led to degradation of the natural landscape. Current environmental problems include 1) periodic drought, compounded by the dominantly underground drainage, 2) soil erosion from valley sides and floors, 3) land subsidence, particularly sinkhole collapse, and 4) groundwater contamination (Reeder, 1990). These problems affecting the natural landscape and subsequently the cultural landscape, have been accelerating since settlement, and are directly related to man's impact upon the land.

Hillslopes have a thin, patchy soil cover (less than 10 cm deep) and are used mainly for pasture. The valley floors are used for intensive rice cultivation, although soil depth averages only about 15 cm. Batuan's economy is almost totally dependent on agriculture, but production is limited severely by natural landscape constraints: 1) surface water for irrigation is ephemeral and unreliable, 2) underground water is not readily accessible, and 3) the thin soils are eroded easily (Reeder, 1990).

Paralleling these problems, Batuan has difficulty maintaining reliable domestic water supplies. Springs resurge and sink at thousands of locations throughout Batuan. Spring resurgences are typically used for irrigation, the watering of draft animals, laundry and bathing. Certain spring resurgences are used only as drinking water supplies. But the complexities of the karst drainage systems are not well understood and often spring resurgences used as drinking water supplies are discharging waters previously used for irrigation, laundry, etc. Water quality determinations indicate that many domestic water supplies are contaminated by fecal coliform bacteria. Gastrointestinal illnesses are common (there were 16 deaths due to severe diarrhea between 1978 and 1980) and there is a threat of typhoid and hepatitis. It is also probable that organic contaminant levels are elevated because of the use of fertilizers to increase crop yields which has become a necessity because of expanding population pressures (Municipal Development Staff, 1982). The "Masagana 99" program was introduced in 1973 and provided farmers with fertilizers, pesticides, and herbicides (Urich, 1991b).

Natural and Cultural Landscape Interactions

The environmental degradation and associated problems which currently exist in Batuan reflects the transgression of the cultural landscape affecting the natural landscape. As the population expanded, more land was cleared and the natural balance of nature (and the natural landscape) was altered. This led to severe degradation in some places causing the abandonment of land because of poor land management practices. The degradation of the land resource affected the cultural landscape in that population outmigration occurred from degraded areas to other areas where fertile land was still available. Some of the migrants choose to go to surrounding islands such as Cebu, Negroes, or Mindanao, while others attempted to find new land suitable for agriculture on Bohol. But because of poor management practices these lands were eventually degraded and other population redistributions occurred. In many instances the cycle of land development, degradation and abandonment ran full circle and once degraded lands were again used for some type of agriculture. The population outmigration from Bohol to other islands served to alleviate some destructive impacts upon the natural landscape, but because most contemporary Boholano's choose to stay on Bohol, population pressure has further strained the land resource by reducing or eliminating fallow time. In an attempt to curb the escalating population throughout the Philippines, the national government has established a moratorium on family size which states that a married couple may only have four children. Any children beyond the limit are taxed thus applying an economic burden upon the family unit impelling families to limit their siblings to four.

Since the Central Limestone Plateau Region of Bohol was raised from the sea less than 1.8 million years ago, people have stripped the natural ground cover, channelized the flow of streams, plowed the land, blazed trails, built towns and roads, fought battles and generally disrupted the natural landscape. This uninterrupted disruption has led to the degradation of Batuan's soil and water resources, which is the root of Batuan's agricultural development problems. Batuan currently has no established soil and water management policies, hence, resource degradation continues essentially unchecked.

The practice of kaingin (slash and burn) agriculture has greatly contributed to the degradation of Batuan's soil and water resources. Only 29% of Batuan's population is gainfully employed in agriculture and unemployed landless people go to the highlands to cultivate small plots using the kaingin system. This poses problems for the lowland rice and corn areas, where agriculture is most intense, because the kaingin method greatly affects the hydrologic regime. It was noted by a long time local resident that area spring discharges have decreased approximately 40% (Virador, 1989). This is likely a result of land clearance in the upper portion of the drainage basin diminishing aquifer recharge rates and hence decreasing spring discharges. Only recently has the link between deforestation and the volume of discharge at lowland springs been officially recognized. But to date only 111 hectares of Batuan's 7,908 hectare land area has been replanted in forest.

The kaingin system also greatly accelerates soil erosion. This system has been practiced on Bohol since settlement and thus the degradation caused by these methods has been altering the natural landscape for several thousand years. But now with growing population pressures, the ramifications of such practices are being vaulted to paramount importance.

Only recently has the full extent of Batuan's soil and water resource management problem been recognized, thus prompting a call for the development of resource management strategies (Municipal Development Staff, 1982 and Day and others, 1989). The complexities of the karst landscape, the severity of degradation, increased population pressures, the well established cultural attitude which accepts degradation, and the lack of previous management policies will make reversal of the negative environmental spiral difficult.

Summary and Conclusions

From evidence and ensuing discussions presented in this manuscript, a number of points become apparent. Firstly, Bohol, and Batuan specifically, face severe environmental degradation problems which have greatly altered the natural and cultural landscapes. The combined alteration of these landscapes point to the fact that they evolve simultaneously. What affects the natural landscape eventually affects the cultural landscape, although a certain lag time may exist.

Man has altered the natural balance by stripping the ground cover, channelizing the flow of streams, building towns, houses and roads, plowing the land, and blazing trails. These features represent culturally based alterations of the natural landscape thus forming an evolving cultural landscape. This points to the almost inseparable relationship that exists between these landscapes. These landscape interactions can produce barren hillsides too degraded for agriculture, or lush fertile fields which produce enough crops to feed the populous.

It was perhaps a series of unconscious decisions made during the infancy of Boholano society which set the course which future generations followed. During early settlement land was perhaps indiscriminately cleared and resource conservation was unimportant because resources were so abundant. Through time, as the population grew and more strain was put upon the land resource, the level of conservation stayed the same. Even now, 2,500 years after settlement, concepts of environmental conservation and soil and water preservation are little known to Boholanos. This lack of resource conservation has led to severe environmental degradation problems which have perched Bohol on the precipice of disaster. If sound management plans are not implemented in Bohol, the environmental degradation may become irreversible destroying the natural and cultural landscapes in its wake.

Acknowledgements

Data for this investigation could not have been gathered without the assistance of the National Irrigation Administration, the Philippine Department of Agriculture and the Mayor and people of Batuan. Appreciation is also expressed to the National Speleological Society which provided some financial support and to Apolonio "Pol" Virador the Municipal Agricultural Officer for Batuan whose assistance was invaluable.

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IT'S AN OPEN AND SHUT CAVE: PLUGGING ARTIFICIAL ENTRANCES AT ONONDAGA CAVE STATE PARK

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ABSTRACT

Onondaga Cave is located in Onondaga Cave State Park at Leasburg, Missouri. The cave has been managed by the Missouri Department of Natural Resources since 1981, but it was commercially operated and developed for the previous ninety years. During one hundred years of operation, numerous artificial openings have been created. These openings have increased opportunities for illegal entry and vandalism and have altered the airflow and climate of the cave, affecting wildlife and speleothems. An ongoing program to secure and seal these artificial entrances and restore natural conditions to the cave has utilized bat compatible gates, hermetically sealed doors, airlocks, and sewer plugs. Work was accomplished using state park employees and caver volunteers from the Missouri Speleological Survey.

Onondaga Cave State Park is located 90 miles southwest of St. Louis in the Ozark Region of Missouri. It features Onondaga Cave, a show cave located along the Meramec River and formed in the Gasconade and Eminence Dolomites. The cave has been protected as a state park since 1981.

The story of the cave begins at the Davis Mill in 1886. The Mill Pond was created by damming the spring, and a small gap above the water was the natural entrance through which the original explorers entered the cave.

The first artificial opening was created just to the left of the spring entrance to ease access for development. Just inside visitors would enter on boats to traverse 300 feet of water passage to get to the main part of the cave. Later a motel, cooled by the cave air, was added at this location. This artificial entrance had been abandoned and the motel torn down by the time the Missouri Department of Natural Resources began managing the cave.

The next artificial opening, the Missouri Caverns Entrance, was created in the 1930's. The cave was discovered to run under a property line and the other owner dug into the cave and began his own tours. Lawsuits and World War II put this operation out of business, and the area has been vandalized.

The commercial entrance that is still in use was also created in the 1930's to speed tour movement through the cave. Many of the associated buildings were constructed in the 1940's. These included the restaurant, gift shop, and cave entrance. Many changes occurred as the system grew organically.

The "Cemetery Entrance" was later begun near the same location. The idea was to lessen the slope down which visitors had to descend. However, the area was unstable and was abandoned.

Another entrance, the Submarine Entrance, is located near the last two openings. It was used primarily for maintenance access and running power cables into the cave.

Additional openings were created as new trails and lights were put in. These were essentially well holes drilled into the cave through which construction materials were dumped and power cables were run.

Almost all of these remained open after their use was completed.

All of these openings have had various negative effects on the cave. Being less than secure, they permitted access to the caves by vandals who have smashed speleothems and partied.

At the 1984 Symposium, Ron Kerbo reported on the effects of aggressive air redissolving speleothems. Moist surface air entering the cave condenses, picks up carbon dioxide from the cave air and forms carbonic acid, which can attack the speleothems. This same condensation can affect the aesthetics of our tour by filling areas near the artificial entrances with unnatural fogs after summer rains. At other times the unnatural drafts have dried out the cave, affecting speleothem activity.

This alteration of the natural cave environment via unnatural drafts also affects cave animals. Fletcher (1985) cited that a 2 degree Fahrenheit change in a cave's temperature can decimate hibernating bats. Changes in humidity can also adversely affect animals in the cave which require moist conditions. Amphibians such as frogs and salamanders may abandon areas that dry out seasonally or permanently due to these unnatural drafts.

The Cave Management Plan for the Park called for the restoration of the cave environment by sealing these openings -- usually with a removable seal in order that future options for maintenance and development remain flexible.

In looking at openings that offered a potential entrance for cave vandals, we considered how previous gates had failed. Hinges, latches, and corners were weak points and often attacked because they provided a place for vandals to get leverage and pry open the gate. Thus we set out to design our new closures with a minimum of exposed weak points. Each gate offered its own special challenges.

At the Boat Dock Entrance, an old wrought iron gate was just leaning against the opening. Any normal person could easily squeeze past it. Construction of the new barrier began just inside this old gate. Anchor holes were drilled into the ceiling and a footing was dug into the floor. Vertical members were welded into place, and horizontal bars were bolted to them. The bars were 1 1/2 inch galvanized pipe filled with mortar and rebar to resist prying and hacksawing. The concrete footing was poured to anchor the bottom and to prevent vandals from tunneling under the barrier. Concrete forms were built, and all attachments were encased in concrete columns. The horizontal bar spacing of 6 inches permitted bat flight and also allowed air exchange similar to what the cave may have experienced before alteration. To make the barrier more secure, it was permanently installed and no gate or door was included in the design.

Plans to seal the Missouri Caverns Entrance allowed for no air flow because originally there had been no opening at that location. The original design had exposed bolts and corners and we modified it considerably. Looking at the door from the outside, one sees a featureless metal plate recessed in concrete; there are no obvious points for a vandal to attack. Inside, a metal frame has been bolted to the concrete foundation. Other bolts have been welded to the door's interior. These bolts pass through three cross pieces where wing nuts hold the entire assembly tightly against the frame. The upper and lower cross pieces keep the corners tight and resistant to prying. The entire structure has been caulked.

The old cave entrance building has been replaced by our new visitor center. Included in the plans for this center was an airlock to control air flow through this constantly used entrance. This airlock has ample space to contain the maximum allowable tour size.

The Cemetery Entrance was a self-solving problem. Since it had already collapsed, we considered it adequately sealed. No work has been done on the Submarine Entrance, but a structure similar to the one at the Missouri Caverns Entrance is planned, although it will be smaller and horizontal.

The bore holes presented a special problem. While we could have plugged the bottom and filled the holes with grout, we had to take a different approach because of the requirement that the seal be removable. After consulting with a well-driller and some engineers, we came up with a plan. The bottom of the bore hole was sealed using a mechanical sewer pipe plug. Into the top of the hole we poured a 100 pound bag of powdered bentonite clay. Bentonite absorbs water and swells, creating a water-tight seal which is resistant to the pressure of the water now filling the hole. A second plug was placed in the top and covered with rock flush to the surface. Hopefully grass will soon obscure the opening.

Onondaga Cave is not the only cave in the park that required such attention. Cathedral Cave is also toured and had been modified by artificial openings. The visitor building lay in ruins, and access to the cave was through a door in the foundation. This foundation was modified into an airlock by removing some of it and constructing extensions to the walls.

A box, on top of the one bore hole into Cathedral Cave, blocks most of the airflow through this opening. We could not use sewer plugs here as in Onondaga because of cables which descend through the hole. These cables are the power and data link to a seismic station which is located in the cave.

The natural entrance has a barrel gate on it. It was designed to keep people out, but it was not a good design for wildlife. Indeed, it hasn't been keeping people out either. Someone dug a rather long and deep tunnel under it. Recently volunteers from the Missouri Speleological Survey filled the tunnel with rock, rebar, and cement. A new wildlife-friendly gate has been designed to replace the barrel.

One additional change, unrelated to openings, was made at Onondaga. The old parking lot and associated visitor buildings were removed from the hill directly above the cave, and the hill is being restored to a wild state. This removed possible pollution sources and barriers to the natural movement of water.

We have had some indication that our efforts are paying off. Since the new closures we are unable to confirm that unauthorized people have been in the cave. Monitoring shows the radon level in the visitor center is more than one order of magnitude lower than it is in the cave. As one might expect, the radon level in the airlock is intermediate between the two. Formerly dry areas are once again moist and active. Steam plumes which appeared at openings on cold winter days are no longer there.

The money budgeted for these projects was insufficient, and our success was due in great measure to volunteers from the Missouri Speleological Survey, whose free labor really helped us to stretch our budget.

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ANALYSIS OF SURVEY METHODOLOGY IN A HAWAIIAN LAVA TUBE

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ABSTRACT

Darkness, high humidity, geological limitations, archeological evidence, time constraints, cave biology are things to consider in the collection of survey data for a detailed Hawaiian lava tube map. An ongoing project of the Hawaii Caves Conservation Task Force is the preservation of Pahoa Cave, a major lava tube in the Puna District of the island of Hawaii. In 1987, the Hawaii State Departments of Land and Natural Resources and Agriculture requested the survey of a portion of this cave underlying the Keonepoko Iki Farm Lot Subdivision. The problem of cave roof collapse due to heavy equipment had caused safety concerns among farmers leasing land from the State. Three non-electronic survey methods: theodolite, plane-table and tripod-mounted compasses, were used to survey Pahoa Cave. We initially believed that the tripod-compasses method would be unreliable due to the paleomagnetic effect in the lava rock. We neglected triangulation due to time factors and occasional narrow passages. The theodolite, while giving the highest precision for individual readings, had the greatest closure error: 18.7 m. The plane-table also had an unacceptable closure error: 11.4 m. In spite of paleomagnetism, the tripod-mounted compasses gave the least closure error: 1.3 m. in 906 m. total distance. We decided that closure reduction by statistical methods was not acceptable, so we re-shot several stations. This resulted in the correction of some large survey reading errors. During the survey, we also determined that Pahoa Cave contained significant archaeological, biological and geological features worthy of protection. The Hawaii Caves Conservation Task Force has been instrumental in developing a proposal in which the State has agreed in principle to lease 25 acres of land, including 2 miles of Pahoa Cave, to the University of Hawaii at Hilo as a Cave Preserve. Designating the land as a conservation zone would be the first step in the protection of this cave resource, overburden, and surface environment.

The question arises as to whether the tripod-mounted compasses cave survey method is accurate enough for planning conservation buffer zones. Perhaps a combination of methods using tripod-mounted compasses for detailed cave mapping, Ground-Penetrating Radar (GPR) for superimposed surface map application and GPS surveying for cave entrance locating would be a satisfactory combination of methods. Since cave survey accuracy is a function of not only the type of equipment used but also the observational procedure and distance between stations, over a large area errors can accumulate quickly. The GPR may provide a needed horizontal positional accuracy check of cave survey points with the surface. Overburden thickness could possibly be determined by GPR.

We are currently using GPS (Magellan NAV 1000 PRO) for cave entrance location. Success of the GPR method would provide an independent check of station points along the cave traverse. Future and pending lava tube survey projects, under the name of the Hawaii Caves Conservation Task Force, will be affected by the chosen survey method.

The results of the Pahoa Cave survey support the hypothesis that the tripod-mounted compasses survey is the most accurate of the cave survey methods. An optimization method would help to average the closure errors over the traverse. An optimum traverse length for a compass survey, which is based on the standard deviations of angle and distance measurements, should help eliminate survey reading errors but would significantly lengthen survey time. Are all three methods subject to cumulative errors? Reading errors may account for our large closure errors on the theodolite and plane-table. In order to measure the reliability of the survey methods, a statistical analysis would be necessary. However, due to time constraints in redoing this difficult cave traverse, a frequency distribution based on multiple sampling would be prohibitive.

Field work at Pahoa Cave was done by F.D. Stone, with survey assistance from T. Stone, D.T. Tanaka and B. Tashima from 1987 through 1989. The compilation and eventual merging of, (1) surface survey, i.e. State of Hawaii land plats and (2) Pahoa Cave survey data, was accomplished by F.D. Stone and shows the vertical relationship between these two dimensions.

The Hawaiian archipelago, a group of islands, atolls and seamounts, stretches 1600 miles across the northern Pacific Ocean. They are separated from other high islands and continents by more than 2,000 miles of sea water. Few species of terrestrial plants and animals have been able to reach and colonize the islands through natural means.

Due to the youth of the eastern high islands, which assumed a void of life in the young lava tubes, it jolted the scientific community when F.G. Howarth documented a diverse community of obligate cavernicolous endemic arthropods in Hawaiian lava tubes. Subsequent work by Howarth and F.D. Stone has led to the knowledge of troglobitic species from Hawai'i island through Kaua'i in lava tubes, cracks and fissures.

Lava tube ecosystems are defined by geologic processes. Understanding the modes of formation is useful in observing the adaptations of cave animals to their environment. Although controversy still surrounds the process of lava tube formation, I have chosen to follow the work of Peterson and Swanson. During the 1970-71 eruptive episode of Kilauea volcano, they recorded their field observations in lava tube formation.

Shield volcanoes produce two types of lava, pahoehoe and a'a. They differ in gas content, fluidity, and surface texture. A'a is cooler, has had more gas escape from its matrix, and flows sluggishly compared to pahoehoe. Pahoehoe is hotter, has a higher gas content essentially because the velocity of the lava has given the gas less time to percolate out of the matrix, and moves faster than a'a. During times of sustained volume, a pahoehoe channel can form a crust of crystallized rock between the atmosphere above and the molten lava below. This forms the lava tube, a terrific insulator, which allows the 1150-1160 degree C. pahoehoe to travel as far as 10 k.m. with a loss of 10 to 20 degrees C. The ceiling of the lava tube may thicken with splashing lava, overflows within the lava tube, and surface flows advancing over it.

The cave ecosystem can be divided into four distinct units. These are (1) the entrance zone where surface fauna and flora are present and the light source is great; (2) the twilight zone where decreased light is present; (3) the transitional zone where complete darkness is present but some outside environmental effects are present; (4) the deep cave zone where troglobitic cave species are found.

The survey study was conducted at a part of Pahoa Cave located along a predominately agricultural corridor, which is rapidly losing its rural ambiance, between the urban centers of Keeau and Pahoa on Hawaii island. As Pahoa Cave winds through parts of this corridor, under roads and farms, it remains poorly understood and frequently misused, by the human community. The cave entrances, used as a dump in places, epitomize the "out-of sight, out of mind" philosophy that has impacted Pahoa Cave.

By providing a mapping method that will help complete the task of databasing lava tube locations, management will be able to concentrate on conserving the resource. Because lava tubes are difficult to survey, limited mainly by geologic and environmental restraints, deciding on the survey method is the first step towards managing the resource.

Three non-electronic survey methods were chosen for cave mapping, based on the comparative ease of transporting equipment to and within the mapping site. Two people were used for each mapping method and all distances were measured with steel tape.

Perpetual darkness allowed the eye to respond only to the stimulus of portable light. This caused judgement and depth perception difficulties, related to the void of sensory receptors, and led to observation errors such as bad survey station placement.

Atmospheric air saturated with water vapor caused condensation, with concomitant focal problems, on the lens of the survey instruments. This resulted in distance and directional survey errors when we were unable to read to instruments.

Discrepancies in measured quantities due to human mistakes is common with the inexperienced instrument operator. We got more knowledgeable as the survey progressed.

Small passageways presented intense setup requirements for the bulk area required in theodolite and plane-table mapping. This was still a problem for tripod-mounted compasses, in small passages, but to a lesser degree.

Materials and Methods

1) The first method was with a plane-table, wooden tripod, telescopic alidade and English stadia rod. Person 1 levelled the plane-table, operated the alidade and noted angle measurements.

Person 2 set the station points, called out the distance measurements to person 1 and held the stadia rod. At each station Person 2 noted distance measurements to left and right walls, perpendicular to the line between survey stations.

The margin of error for this survey was plus or minus 0.5 degrees.

The plane-table had the advantage, over the other two mapping methods, in having a drawing surface for field recording. The plane-table allowed Person 1 a visual context aid in reconnoitering map problems.

A disadvantage of the plane-table, because of its large size, was the possibility of accidental jarring. It was easy to bump the plane-table in small passageways when you were close to the wall.

Movement of the stadia rod was a problem for plane-table mapping. Person 2 caused angle errors due to inattention. An unstable stadia rod often resulted in a plus or minus 5 degree horizontal error reading.

2) The second mapping method used tripod-mounted compasses utilizing forward and back shots. Angles were noted as the survey progressed in a non leap frog method. Person 1 read only forward shots and Person 2 read only back shots. Person 2 marked all stations with flagging tape. Sketches of cave passage were done from station points and included cave profiles. The scale of the sketches and profiles lacked the consistency of magnitude found in the plane-table survey.

The margin of error for this survey was plus or minus 1.0 degree.

The advantage of this survey method was that (1) independent readings were taken from each station; (2) relative light weight of survey equipment compared to the heavier plane-table and theodolite.

The disadvantages of the survey method, which resulted in directional and closure errors were (1) sighting was done without the benefit of telescopic sights found in the theodolite and alidade and resulted in increasing errors;
(2) leveling the instrument was neglected for this method. The compasses lacked any leveling device built into the equipment. Angle accuracy was affected and vertical angle measurements were unreliable; (3) the variation in magnetic attraction, of terrestrial magnetism versus paleomagnetism of a lava cave, is a source of potential survey error.

3) The third method of mapping used a theodolite and metal tripod. The first person operated the theodolite. The second person set the survey stations with a flashlight. The lightbulb of the flashlight was placed at the point in space of the survey station which was focused upon by the first person. Cave passage sketches, which included cave profiles, were done from station points. The scale of the sketches and profiles, as with the tripod-mounted compasses, lacked the consistency of magnitude found in plane-table survey.

The margin of error for this survey is plus or minus 1 minute.

Advantages of the survey method were (1) very accurate centering over station points was possible using the bull's eye of the optical plumb bob; (2) the theodolite provided the convenience of swivelling 360 degrees to map points; (3) the large, lighted (outside light source) vernier display provided optical ease in measuring readings; (4) direction was obtained without the presence of magnetic anomalies found in compass surveying; (5) a telescopic lens, built into the assemblage, both enhanced faint objects and allowed greater optical clarity.

Disadvantages of the survey method which can lead to errors in direction and result in significant closure errors were (1) the absence of a visual product, i.e. the field map drawn in plane-table survey, results in the lack of a mental construct to which the operator can be reminded of certain fallacies in the field situation. This was also true for the tripod-mounted compasses; (2) the equipment is very bulky, heavy and requires a substantial tripod. This was also true for the plane-table; (3) waves of radiant energy from the sun is transmitted to the metal legs of the tripod, due to solar energy transfer into a sink of the lower temperature tripod, and results in expansion by excitation. Near cave entrances, when the operator is concerned about vertical angles, transit levelling may be overlooked. this problem becomes moot within the cave.

Results

The mapping of a portion of Pahoa Cave was completed as the statement of: cave traverse + surface traverse = closure. The following errors were noted. Over a distance of 906 m., we had an error of 11.4 m. in the map closure for the plane-table survey. An error of 18.7 m. was recorded, in map closure, for the theodolite survey. An error of 1.3 m. was recorded, in map closure, for the tripod mounted compasses survey. A standard 1/500 ration is acceptable to most surveying operations (Stone, 1986).

Based on the above results, it seems reasonable to believe that the tripod-mounted compasses method is the most accurate non-electronic method of survey in lava tubes.

Cave Management

A cave map increases in value when detail is entered in a cartographically pleasing manner. The information gathered in a cave survey can delineate the extent of the resource. The cave map as a historical tool can be used as an indicator of change since the map was drawn.

Parts of Pahoa Cave lie under State of Hawaii agricultural plots. When a farmer clearing land broke the overburden of Pahoa Cave, he began the practice of using the twilight zone to ripen his banana crop. Foreign matter can now enter the cave ecosystem at this manmade entrance.

Leaking fuel tanks which belong to a trucking company, were situated on top of Pahoa Cave. This resulted in the odor of fuel in the lava tube. The fuel may impair organism survival abilities and result in organism occupation decreases in that geographical area of the cave. Unless action is taken to correct the problem, pollution of the ecological unit, the unfortunate "out of sight, out of mind philosophy" prevails (Howarth, 1981). It can also blow up the neighborhood.

Since the anthurium grower needs a place to dump garbage, Pahoa Cave has become a natural rubbish container. Empty cans of herbicide (brand name Roundup) and insecticide, flower cuttings, broken farm implements, irrigation tubing, and scrap metal have been shoved into a cave entrance. Future study should assess the capability of cave organisms to withstand this hostile man-made environment, assuming diminished organism survivability at the point of pollution, with survivability increasing with increased distance from the pollution point.

The horse (Equus caballus), used extensively in plantation work, was dumped in large numbers in a Pahoa Cave entrance.

Sewage disposal, where local drillers try to please the homeowner by tapping into a lava tube, can impact the cave.

The community needs to be educated on the consequences of dumping things into the ground. Our role as educators would be to provide a source of reliable information to the community on how they would benefit by adopting conservation measures.

The cave management plan that employs an informational network from various sectors in the community, in concurring on the greatest and best use of the resource, will become a tool during land management decisions. The geographical position of caves will provide land-use classification and the end result of land-use maps of the area.

The presence of a viable mapping program can insure, on further surveys of lava tube ecosystems, a methodology for land managers to collect and access information.

A location plan, showing a proposed cave management area, will indicate the geographical relationship of the cave to the existing surface features. Cave mapping would be incomplete without the examination of surface topography, which may reveal such features as lines of skylights, the disposition of which may be related to the lava tube ecosystem below.

Definitions

Arthropoda - The largest related group or phylum in the animal kingdom. Adults generally have a hardened outer covering (sclerotized), segmented body and many-jointed segmented limbs.

Azimuth - Horizontal direction measured on a 360 degree one-dimensional plane.

Breakdown - Material from the walls and/or ceiling of a passage which has formed a pile on the floor of the cave.

Cave Profile - Sketch of the cross-section of a cave taken at a point along a traverse. Used as an aid to visualize the vertical two-dimensional aspect of a cave passage.

Closed Traverse - A traverse that returns to a previous station point and in so doing forms a survey loop.

Closure - The measurement of a series of map stations linked together by measured distances and ending upon a starting point.

Lava Tube - A meandering insulated corridor, which moves lava through the attraction of gravity, towards the earth.

Level - To portray the surface of the earth on a horizontal plane. This is a critical aspect in measuring survey angles because the angular measurement, other than the horizontal, will give a different azimuth reading.

Location Plan - Used to show the position of underground features in relation to existing surface features.

Margin of Error - A value which delineates the boundaries of the acceptable range.

Open traverse - A line of station points that ends in a portion of the cave without returning to a station point.

Overburden - The interstitial ground between the air of the atmosphere above and the air of the lava tube below.

Paleomagnetism - The direction and intensity of the earth's magnetic field in geologic time.

Positional Accuracy - The geographical location of a place in relation to the surface of the earth.

Sensory Receptors - Stimulus provided to sensory organs by a collection of focal points in the area.

Survey Loop - A series of survey points that connects together when the end of one survey point returns to a previous survey station.

Survey Station - Points in space to which a survey is connected by direction and distance (Thomson, K. and Taylor, R. 1981).

Taxonomic Category - Hierarchy of levels in the biological classification of organisms. Categories are kingdom, phylum, class, order, family, genus, species.

Telescopic Alidade - An alidade used with a plane-table, that has a telescopic sight which enables the user to see a survey station marker at a distance, that is mounted to a straightedge. A bubble level is attached, which ensures that the plane-table is on a vertical plane, and a vernier is used to measure vertical angles.

Temporary Survey Station - Removable station markers which do not permanently mar the caves natural state after a survey.

Terminal Breakdown - The ending of a cave passage by the physical barrier of rubble.

Traverse - Connecting a series of lines of measured length, made along a set of survey stations, that intersect at measured angles on the ends of those lines.

Welded Breakdown - Breakdown that has fallen into the liquid lava and solidified upon cooling.

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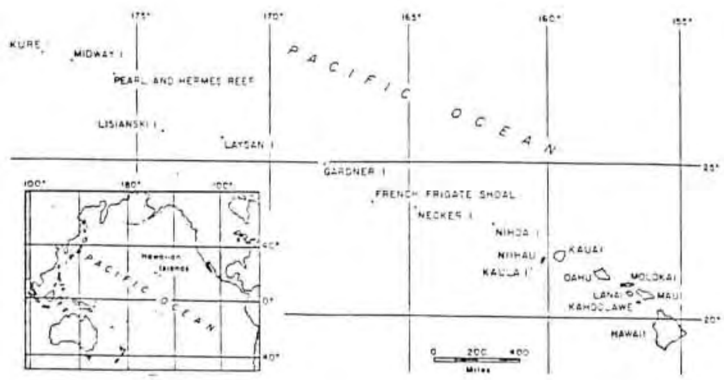

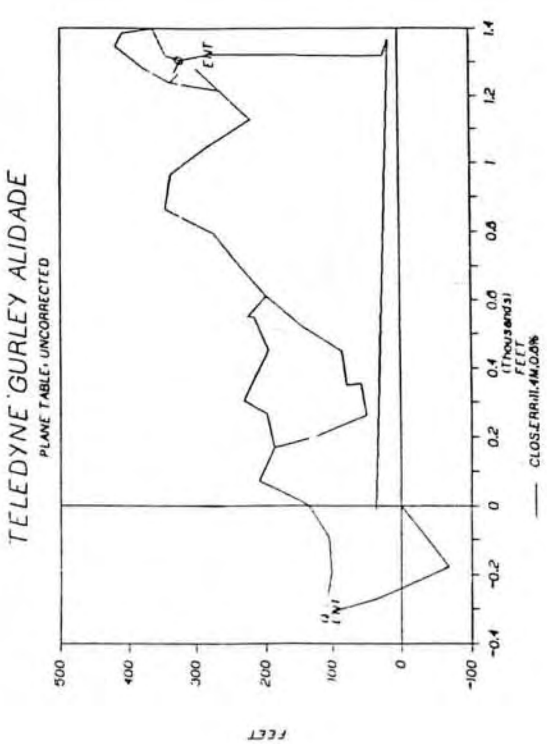
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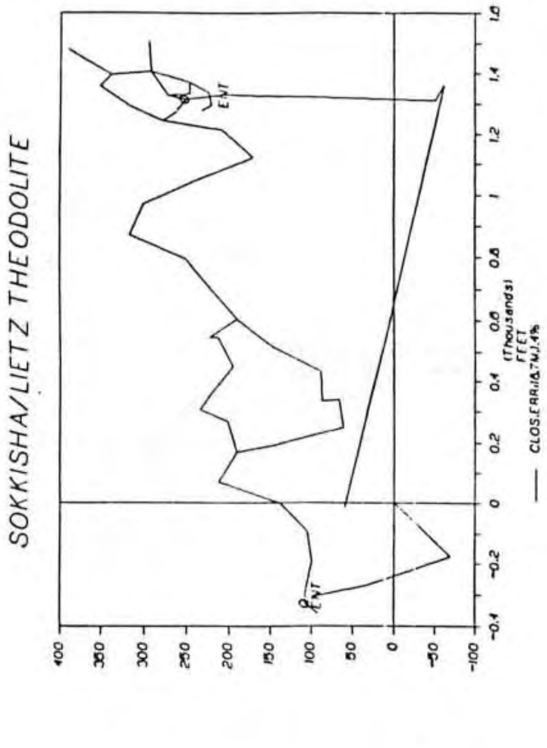
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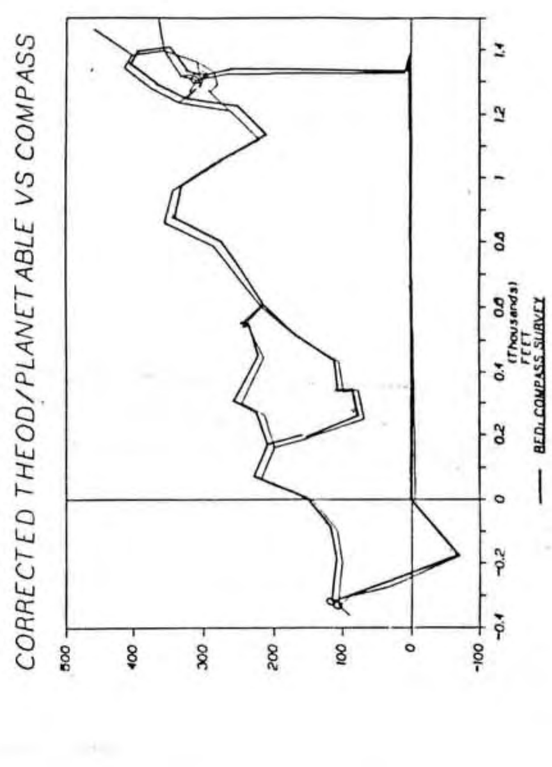
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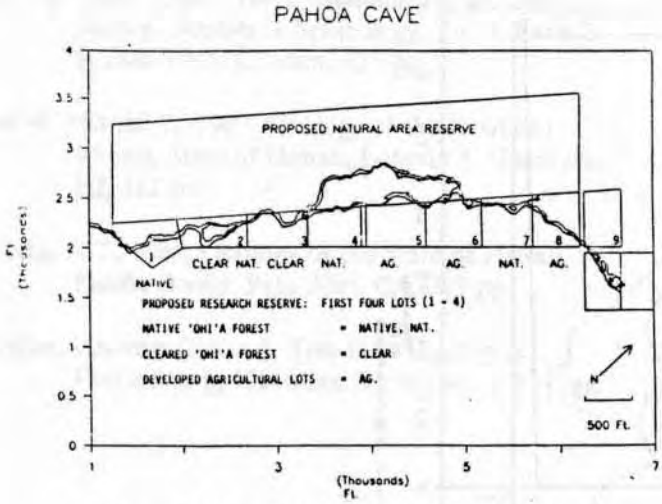
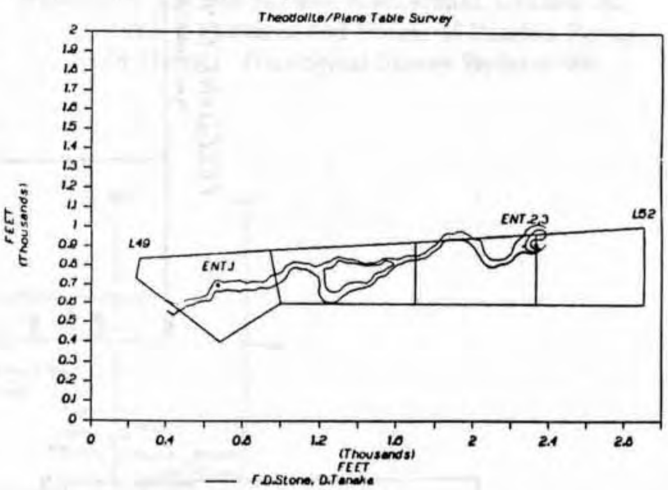
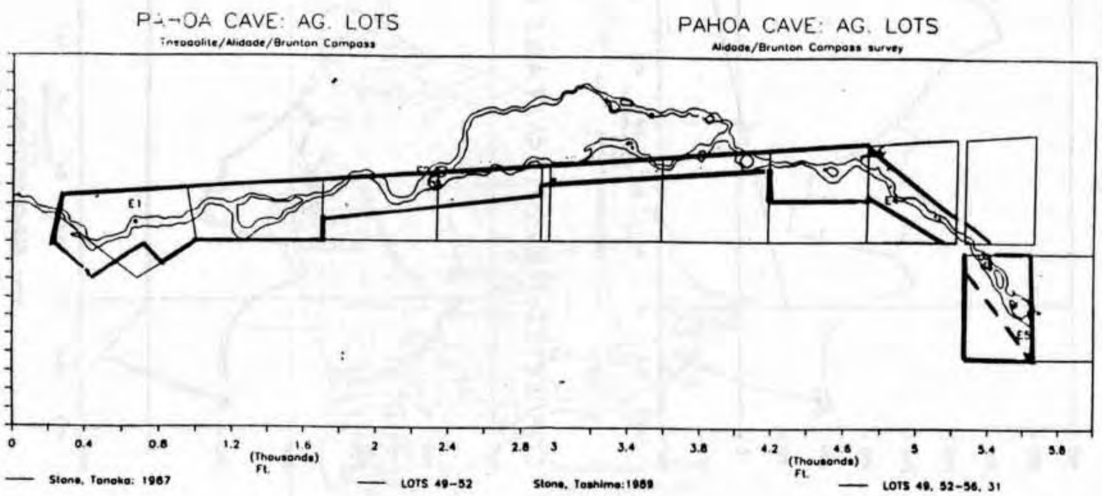


Figure . State of Hawaii Agricultural lots (numbered) and proposed reserves.





Cave Preserve located within dark border

MANAGEMENT CONSIDERATIONS FOR CLAY VERMICULATIONS

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ABSTRACT

Vermiculations are fragile stringers, spots, or patches of fine sediment, usually clay. They display distinctive morphologies, including hieroglyphic and dendritic forms. Vermiculations are most prominent on white bedrock or speleothems, against which their typical dark brown, black, or red colors strongly contrast. Easily smeared or dislodged by touching, vermiculations and associated deposits are too often colonized by plants when near commercial lights. In many cases, vermiculations are degraded by the addition of foreign substances. Vermiculations can be hard to restore; restoration strategies include doing nothing, removing part of the smeared or foreign material, adding material scraped from elsewhere, and cleaning the affected surfaces completely. Vermiculations are an integral component of caves, provide an unstudied biological habitat, and deserve greater recognition, protection, and study.

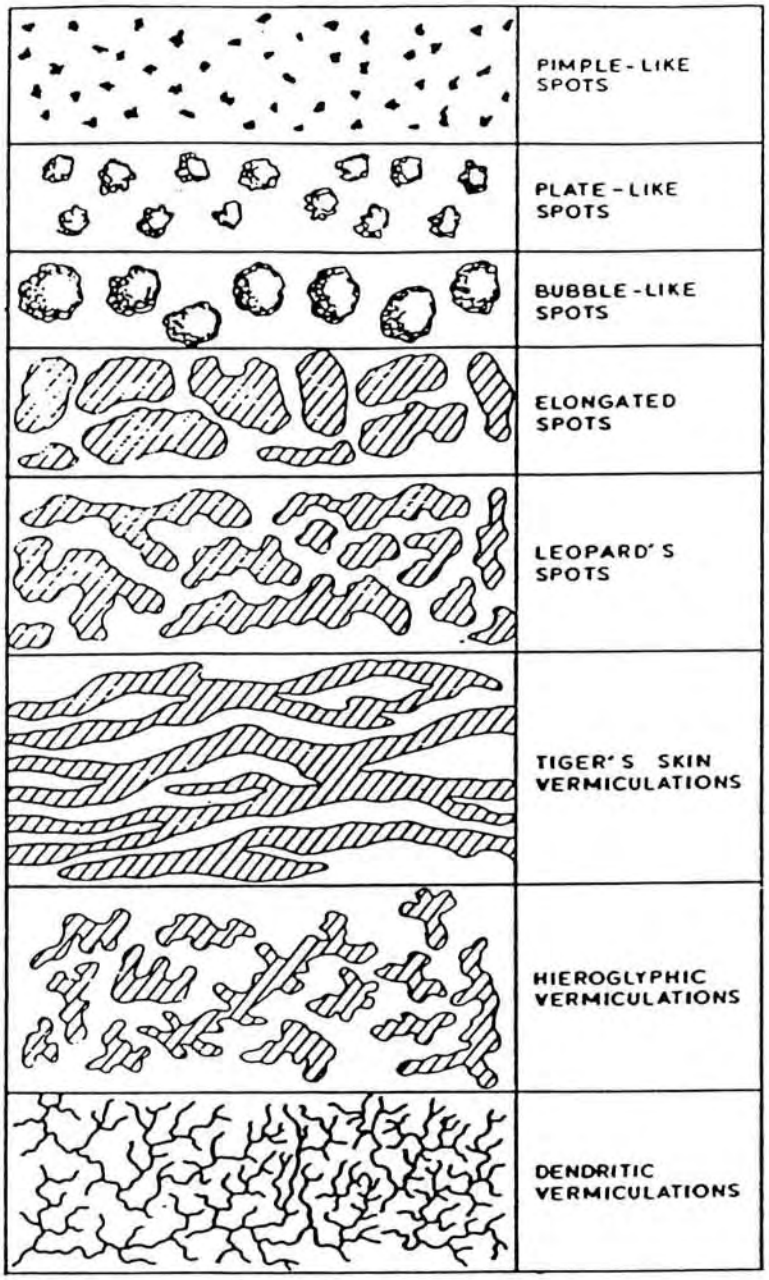
Introduction

Vermiculations are stringers, spots, or patches of fine-grained material, usually clay, with varying amounts of water and organic matter. In caves, they form thin coatings on bedrock surfaces, breakdown, or speleothems. Vermiculations display distinctive patterns as shown in Fig. 1. In simple terms, the intricate patterns of vermiculations result from the wetting and drying of fine sediments. The sediments are first deposited as dusts or aerosols, typically on moist surfaces wetted by seepage or condensation drops and films. The sediments can also originate as uniform coatings left by floodwaters. Wetting and drying cycles result in shrinking of the sediment, which pull together as agglomerations under the influence of surface tensions and electrostatic interactions (Bini et al., 1978).

Most of the work on vermiculations is from Europe; that work is generally inaccessible to Americans, being published in Italian, French, and Spanish journals. However, vermiculations are common in caves of the eastern and midwestern U.S., even if they rarely appear in our cave descriptions or speleological literature. The author has observed vermiculations in caves in Minnesota, New York, West Virginia, Virginia, and Kentucky, including several locations along the Historical Tour route in Mammoth Cave. Hedges (1974) noted their occurrence in Rainy Day Cave of Iowa, and published a photograph of dendritic vermiculations. Hedges (1986) also reported clay vermiculations from Iowa, Pennsylvania, and West Virginia caves, and discussed factors controlling their occurrence. Hill and Forti (1986), in a book devoted almost entirely to speleothems (Cave Minerals of the World), provide the most accessible English-language review of vermiculations to date, and publish photographs of hieroglyphic and tiger-skin vermiculations. Their review is largely based on a paper by Bini et al. (1978), which describes non-karst as well as karst occurrences and critically discusses theories for the origin of vermiculations. Jameson and Alexander (in prep.) describe the occurrence, composition, and distribution of vermiculations and associated deposits from Snedegar's and other caves of the Greenbrier karst in West Virginia.

The present paper reviews some issues in the management of vermiculations. Because vermiculations

Morphology of Vermiculations



after Parenzan (1961)

are rarely noted in this country, and their significance as a cave resource is rarely recognized, vermiculations are increasingly being subjected to degradation.

Recognition of Vermiculations

Vermiculations are too easily missed by visitors, whether cavers, tourists, or cave managers and staff. Vermiculations often blend into their surroundings and may be difficult to see. Many are composed of brown or black muds and cover dark bedrock in generally muddy geologic settings. Yet vermiculations can be highly prominent. The prominence of vermiculations is largely a function of color contrasts between them and their substrate, but also depends on moisture content. Textural contrasts, including the regularity of forms and grain-size variations in the sediment, can play a role. A few examples may help clarify these remarks.

In canyons of the Saltpetre Maze of Snedegar's Cave (West Virginia) vermiculations are abundant, prominent, and distinctive. Their colors are usually yellow-brown, red-brown, brown, or black. The vermiculations contrast strongly with lighter-hued bedrock substrates which have tan or white weathering rinds. A variety of patterns appear, including spots, hieroglyphic forms, and dendritic forms. The vermiculations are particularly prominent when wet. The passages are wet during the summer and early fall as a result of condensation; some areas are perennially wet. Wetting intensifies the colors if the clays have absorbed the water. In some areas, the clays do not absorb the water very well, or are so saturated that additional condensation can appear on surfaces only as tiny (< 1-2 mm) drops. The drops hang as nearly spherical protuberances from the clay particles on walls and ceilings. When illuminated, the drops reflect light in complicated ways and impart an erie glistening character to the cave. Locally, the reflections have a yellowish cast; the cast derives, apparently, from a yellow fungus that grows on moist vermiculations.

In Upper Martha's Cave (West Virginia), vermiculations consist of bright red and red-brown clays deposited by floodwaters on ceilings. The bright colors contrast strongly with the tan and white bedrock substrate. Spots and hieroglyphic forms predominate. In Howe Caverns (New York) and to a lesser extent in Snedegar's Cave, vermiculations cover speleothems, including white stalactites, stalagmites, columns, and flowstone. The vermiculations vary in color and pattern, but all are prominently visible against the lighter substrates. Even the most unobservant of visitors are likely to notice such vermiculations, if for no other reason than that they occur on speleothems.

Significance of Vermiculations as a Resource

Even if vermiculations are seen, it is all to easy to ignore them. Few cavers worry much about touching, walking, crawling, or climbing on dark muddy surfaces while exploring. The degradation of the appearance of mud by smears, footprints, and the like is commonly considered a necessary and justifiable degradation of the cave, if the cave is to be explored at all. Consequently, it is easy to see why some people might consider many vermiculations to be insignificant: after all, vermiculations are "just mud". Worse, some might even consider vermiculations to be detrimental: where they cover speleothems, vermiculations could be considered a blemish on the beauty of the cave.

Nonetheless, vermiculations are an integral part of caves that constitute a valuable, if little recognized and studied resource in this country. Vermiculations are important for at least four reasons.

First, they really are an integral part of caves, part of the richly-textured milieu that constitutes the stimulus for our experiences while exploring, studying, photographing, or, in general, enjoying caves. To say that vermiculations are an integral component of caves is to claim that they are more than isolated features. Bini et al. (1978, p. 14) state that vermiculations "can be found in nearly any cave if looked for very carefully". The claim may be hyperbole, but vermiculations are found to be surprisingly common once they are sought.

Second, vermiculations are clearly features with an aesthetic value. Those who have seen unmarred, intricately-patterned, and often brightly-colored vermiculations, have no difficulty agreeing that removal of vermiculations would constitute an aesthetic degradation of the subsurface environment.

Third, vermiculations may preserve valuable information about the sedimentary and hydrologic history of their host passages. Some vermiculations are composed of wind-borne dust and possibly pollen; these could provide information about past climatic conditions as well.

Fourth, vermiculations support a biotic community that remains unstudied. That community includes the previously mentioned fungus, bacteria, transparent roundworms, and possibly beetles and cave crickets. Observations of clay vermiculations and associated sediments in Snedegar's Cave clearly show evidence of biological activity, for muds are often pelletized, suggesting bioturbation.

Forms of Degradation

Vermiculations are fragile and are subject to several forms of degradation. Degradation is most commonly a result of direct contact, but can result from undesirable fungal, algal, or other plant growths. Contact by touching, climbing, walking, crawling, or dragging of equipment can be detrimental. Smearing is possible if vermiculations are relatively moist; this form of degradation need not result in a loss of material, but does entail a destruction of the distinctive patterns. Part of the surface that was not covered may become covered by the smear. Such degradation disrupts the appearance of vermiculations and can be aesthetically displeasing.

When dry, friable disintegration or flaking may be a problem. Contact loosens clusters of grains or flakes, which detach and accumulate downslope on ledges, in surface irregularities, on speleothems, on breakdown, or on the cave floor. Of course, friable disintegration and flaking can be natural processes. In Snedegar's Cave, ledges and undercuts on canyon walls often have accumulations of clay from overlying vermiculations. Such deposits are readily deformed or smeared by contact and loose their natural appearance. At some locations, however, condensation rates are high, and human degradations are partly mitigated by the influence of descending films of water, which redistribute the clay, restoring a natural appearance.

Another form of degradation results when vermiculations are covered by foreign substances. The biggest problem is that muds from elsewhere (often of different colors and texture) are transported by caver's clothes, gloves, and equipment: the muds come off by contact or flaking and can be smeared or plastered onto vermiculations. Survey marks from carbide lamp black, torch black from saltpetre mining, and muds or other debris from digging projects, are also known to cover vermiculations.

Restoration

Degraded vermiculations can be hard to restore. The choice of a restoration strategy depends on (1) the type of degradation, (2) its extent, (3) its location and visibility, (4) the aesthetic or other impact of the degradation on the experience of visitors, (5) the accessibility of the vermiculations, and (6) possible impacts of the actual restoration activities on the cave.

Five main restoration strategies can be identified. In some cases, the best option is to <u>do nothing</u>. For example, the degradation may be prominently visible yet relatively inaccessible on a canyon wall or a passage ceiling. Merely getting to the degradation may create further degradations that are unwarranted.

A second option is to <u>remove part of the material</u>. This option applies where vermiculations are smeared or covered by foreign substances. Care must be taken in removal; too much removal of vermiculations may impart an unnatural appearance of bare spots uncharacteristic of the setting. Putty knives, knife blades, and toothbrushes may be needed. Gentle spraying of the vermiculations with a spray bottle may be helpful, and the overall goal is to restor as natural an appearance as possible. The details of the procedure will depend on the type of vermiculations and the character of the clays or foreign substances. Some smearings of clay may be very cohesive and difficult to remove without disturbing surrounding vermiculations and adjacent clay coatings, especially where the coatings are relatively continuous. In such cases, removal of the smeared or foreign materials will expose bare bedrock in patterns that look very unlike natural bare spots in the vermiculation patterns.

A third option is to add material scraped from elsewhere. This option may help fill in minor gaps in vermiculations, but care must be taken to obtain clay of the proper color and texture. The clay must be carefully added in the appropriate pattern. This strategy should be rarely used; it is best not to add such artificial "deposits" unless the degradations are prominent and often seen.

The fourth option is to clean clear to the surface, thus removing the vermiculations. Such cleaning may be necessary where vermiculations have been irretrievably smeared, or where fungal or other growths have taken over. The problem is most acute in commercial caves, where lights promote plant growths. In Howe Caverns, vermiculations and other clay deposits often support growth of bacteria, fungi, and even ferns where lights shine too closely.

Prevention of Degradation

Prevention of the degradation of vermiculations must proceed on several fronts. We need to better educate cavers as to the value of vermiculations, and discourage the touching of them. As with other fragile features, it may be necessary to flag vermiculation-covered surfaces so as to warn cavers of their presence and discourage contact. In tourist caves, we need to encourage the movement of lights to prevent unwanted growths; it may also be necessary to re-orient tourist rails to keep vermiculations out of reach of visitors.

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PRE-DEVELOPMENT STUDIES AT KARTCHNER CAVERNS

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ABSTRACT

Kartchner Caverns is a beautiful limestone cave in pristine condition, considered by experts to be the premier cavern in Arizona. It will be protected and displayed to the public as the 25th Arizona State Park. The cavern was discovered in 1974 by two Tucsonans, Gary Tenen and Randy Tufts. They kept the cave secret for fourteen years to protect it from vandalism and to maintain it in its original condition. It is located approximately 8 miles southwest of the town of Benson on the west side of State Highway 90. The park site is 550 acres in size and is situated at an average elevation of 4700 feet.

The cavern is over two miles long with spacious rooms, one of which is as long as a football field, (Figure 1). It is a wet, 'live' cave into which water still percolates from the surface and whose calcium carbonate features are still growing. It contains an unusually wide variety of multicolored cave formations – stalactites, stalagmites, flowstone, shields, helictites and soda straws - some of which are among the best examples in the U.S . It is also a summer home to a colony of approximately 1200 bats. The contrast between the moist interior of the cave (over 99% relative humidity) and the dry desert above makes Kartchner Caverns particularly vulnerable to damaging changes. Changes in airflow, temperature, or humidity caused by improper development could quickly dry out the cave, halt speleothem growth, and diminish the cave's beauty.

To prepare for the public opening of Kartchner Caverns in an environmentally sensitive manner, Arizona State Parks has contracted for a two year pre-development study of the cave with Arizona Conservation Projects (ACPI). This report presents the preliminary results of that 24 month study. The studies focus on four main aspects of the cave environment: (1) cave microclimate and meteorology, (2) hydrology, (3) geology, and (4) biology.

CAVE MICROCLIMATE AND METEOROLOGY

Maintaining the moist conditions within the cave has been identified as the most important consideration in developing the cave. Drying of the cave can result in permanent damage to many of the features which make the cave so attractive. There is a marked contrast between the surface conditions and the interior of the Kartchner Caverns. The surface is a semi-arid desert while the cave is a moist stable environment. On the surface, temperatures fluctuate by 85°F over the course of the year. Deep inside the cave the annual temperature change is less than 1°F. The difference between evaporation on the surface and in the cave is even more dramatic. Outside, the yearly evaporation can exceed 65 inches, inside the cave it is less than 0.08 inches. The rate of evaporation outside is 800 times greater than inside the cave. If outside air were allowed to freely enter the cave it would deplete the entire annual supply of moisture to the cave in only three days.

The cave receives moisture from percolating rain water and infiltration from surface washes. Significant infiltration from washes is sporadic and occurs only during years with above average precipitation. It is, however, the largest source of water for the cave when it does occur. The influx of water from the washes is very important in maintaining the microclimate of the cave. Precipitation and the subsequent percolation of water into the cave is highly variable from year to year. It is still the most reliable source of moisture for the cave. Water is lost from the cave by a system of natural drains and by direct percolation through the floor of the cave. Evaporation from cavern surfaces and the removal of the moist air from the cave by air exchange with surface air is presently responsible for only a small fraction of the moisture loss. However, development of the cave will unavoidably increase the air circulation within the cave resulting in increased evaporation. Surface climate measurements indicate that because of the desert environment, the exchange of outside air with cave air will always have a drying effect on the cave.

An analysis of the moisture balance of the cave indicates that air exchange is the only parameter which can be effectively managed. Increased airflow from development will unavoidably remove additional moisture from the cave. Minimizing the potential for increased air exchange should be a primary consideration of the cave development in order to maintain the moist microclimate of the cave.

Environmental Monitoring Program

The environmental monitoring system is designed to provide data necessary for determining the nature and magnitude of microclimate changes which will likely result from the development of the cave and the construction of one or more man-made entrances. The program of environmental monitoring was initially outlined by the Ozark Underground Laboratory (OUL) with instrument installation, maintenance and data collection performed by ACPI. Approaches suggested by OUL have been modified by ACPI as necessary in order to obtain useable data

The microclimate studies at Kartchner Caverns have measured the following parameters:

- Air Temperature
- Soil Temperature
- Relative Humidity
- Evaporation Rates
- Air Trace Gasses
- Airflow

ACPI has installed a total of 22 environmental monitoring stations (EMS) distributed throughout the cave. The locations were decided on after consultation with Tom Aley of Ozark Underground Laboratory (OUL). The majority of these stations are placed in pairs. One is located as close as is practically possible to the location of a potential entrance. The second station is located one hundred or more feet into the cave and acts as a reference station. The distribution of the monitoring stations is not uniform nor was the original intent of the system to provide uniform coverage of the interior portions of the cave. These stations have been placed so that the existing and future impact of an entrance or proposed entrance on the microclimate of the cave could be assessed.

At each EMS, the following equipment was placed: a 9" diameter water evaporation pan, a PVC pipe stand to hold thermometers, an air temperature sensor and a soil temperature sensor. In the back portions of the cave, temperatures are also taken with a digital thermometer which stores the high and low temperatures. In the front of the cave, each EMS is wired into a computer data logger which records a wet bulb, dry bulb and soil temperature each hour.

Approximately once a month, each station is visited and additional independent air, soil and water temperatures are taken with a portable thermometer. The volume of water lost by evaporation is also measured at this time. Other measurements of relative humidity, alpha radiation levels and carbon dioxide are usually taken at the same time.

In addition to the manual temperature measurements taken at each station on a monthly basis, two computer systems record temperatures on an hourly basis. Gathering temperature data by computerized data loggers has several advantages:

- More measurements can be taken.
- Simultaneous measurements can be taken at different locations.
- Probes have come to equilibrium.
- There is no interference from the presence of the observer.
- Readings can be taken without disturbing the bats.

Two separate systems have been installed in Kartchner Caverns. In March 1989 a data logger and seven probes were installed in the entrance passages. Two of the probes measure unventilated wet bulb temperatures. These allow an estimate of relative humidity to be made.

A second, more elaborate computer data logger system was installed in the Big Room in May 1989. Initially this system had 30 temperature probes. Three temperature probes were connected to each of the ten environmental monitoring stations around the Big Room. At each station, a probe measures air temperature, wet bulb temperature and soil temperature . The initial system measured temperatures with a resolution of 0.5°F. In October and December 1989, the system was expanded to 40 probes and the temperature resolution increased to 0.1°F. See Figure 2 for a graph of the average daily temperature and monthly evaporation rate for one of the stations in the Big Room.

Temperature

The temperatures of large caves are generally considered to be at the same temperature as the mean surface temperature. At Kartchner Caverns State Park the surface weather station has a mean surface temperature of 62.5°F. This agrees well with temperatures based on correlations of the Kartchner temperatures with nearby weather stations.

Inside the cave temperatures vary from 69.7°F to 65.5°F with a mean temperature of 67.7°F for the whole cave. The discrepancy between the range of temperatures inside the cave and the mean surface temperature is the result of three processes.

1) Temperatures in Kartchner Caverns are elevated primarily because of regional geothermal heat flow. The above average heat flow over much of Arizona is responsible for an increase in cave temperatures of 2.4°F to 6.5°F above the mean surface temperature. This indicates that the temperature of Kartchner Caverns should be in the range of 64.9°F to 69.0°F.

2) Flooding of the cave during the winter is the cause of the cold temperatures in the Back Section. While flooding does not occur every year there is insufficient time for the Back Sections to completely return to equilibrium temperature.

3) Stratification of air in the Big Room during the winter causes this part of the cave to become the warmest area in the cave. Cool, dry air from the surface flows along the floor through parts of the Big Room and into the River Passage. At the interface between the cool air on the floor and warmer air above, a condensation fog forms. Condensation releases heat which warms the overlying air.

Evaporation

The moisture content of the air within the cave can become a critical management issue. At the present time, evaporation from cave surfaces is the major source of moisture in the air. The rate at which water evaporates within the cave is expected to be very low. On the surface the energy required to evaporate water comes from the sun, differences in air and soil temperatures and the relative humidity of the air. Inside the cave, temperatures are relatively constant, there is little or no wind and the relative humidity is almost 100%. The rate of evaporation within the cave is largely determined by the relative humidity of the air. It is important to understand that evaporation is proportional to the difference in relative humidity from 100%. If the relative humidity changes from 99.5% to 99.0%, the evaporation rate will double! This means that very small changes in the relative humidity could have major impacts on the moist conditions in the cave.

Precise relative humidity (RH) has been measured with a dewpoint microvoltmeter at each of the monitoring locations. This instrument is capable of measuring the relative humidity and dewpoint temperature with an accuracy of 0.05%. The relative humidity ranges from 96.32% to 100.00% RH. The average relative humidity for all measurements is 99.42% but is highly skewed toward the higher values.

Evaporation rates have been measured at each of the 22 environmental monitoring stations on a monthly basis and at a number of other locations adjacent to the natural entrance. At each location a 9" diameter aluminum pan (surface area 59.2 square inches) is filled with a volume of 750 ml of distilled water. The volume of water can be carefully measured and the evaporation rate determined with an accuracy of 0.05 ml per day. The average evaporation rate for all stations is 0.36 ml per day (0.14"/year).

Because a large proportion of the evaporation occurs near the natural entrance evaporation rates have been divided into two categories. 1) Those stations which are located near the natural entrance and have higher evaporation rates (0.91 ml per day (0.34"/year)) due to cool dry air entering the cave. 2) Stations distant from the natural entrance and which have lower (0.22 ml per day (0.08"/year)), more consistent evaporation rates.

The relationship between evaporation rates and relative humidity has been approached in two ways. Correlating precise relative humidities with pan evaporation for those stations with the most data gives the relationship of 1.0 ml/day per %RH below 100%. A larger sample of evaporation and relative humidity measurements was evaluated by a purely distributional comparison. This yields an estimate of evaporation to be 0.65 ml/day per %RH below 100%. A value of 1.0 ml/day per % RH below 100% is considered to best fit to the data.

Under present conditions evaporation plays a minor role in removing moisture from the cave. This is because the present entrance is quite small and there is relatively little air exchange with the surface. Development of the cave for public viewing can greatly increase the amount of evaporation. Poorly located or constructed entrances can induce a strong airflow pattern which in turn will greatly increase the evaporation. This has been observed in many other developed caves. These problems can be lessened by care in locating or enlarging entrances and connecting tunnels. Steps can also be taken to control the airflow entering the cave. Entryway doors can be constructed to act as airlocks and prevent the entry of outside air. Developing the cave so as to prevent increased airflow and evaporation is the most easily controllable part of the moisture balance.

DRIP WATER MEASUREMENT

Water which percolates into the cave directly from precipitation falling on the limestone surface of the hill is an important source of moisture for the cave. Understanding the moisture balance of the cave requires that we make a reasonable estimate of the quantity of water which enters the cave in this manner. Additionally we need to understand how various patterns of precipitation affect the amount and rate of water percolating into the cave. In order to understand these processes, a program of collecting and analyzing drip water was established.

A series of 8 drip water monitoring locations were established by ACPI throughout the cave. Once a month drip water was collected, with additional samples frequently taken during other trips into the cave. A total of 292 samples were taken during the study. For each sample the rate of flow was determined by measuring the volume of water collected in a known length of time. Samples were taken from the cave and later measured to determine the specific conductivity of the water. The conductivity of the water is related to the total dissolved solids.

When the measured conductivity of drip water samples is plotted by date, a consistent pattern emerges. Conductivity is slightly higher during the summer and early fall than at other times of the year. During the winter the conductivity is at its lowest values. The most obvious interpretation for this seasonal variation is that it is a reflection of the level of biologic activity in the soil. Carbon dioxide is produced by this biologic activity. Higher concentrations of carbon dioxide in the soil allow rain water to dissolve greater amounts of limestone which increases the conductivity of the drip water.

Levels of carbon dioxide in cave air have been periodically measured. When drip water conductivity is plotted against carbon dioxide levels it is apparent that the two are related. For each of four drip water stations in areas where CO_2 has been measured, drip water conductivity increases at a rate proportional to the increase in CO_2. From a nomograph in Palmer's "Origin and morphology of limestone caves" it is possible to estimate the change in conductivity due to a change in CO_2. This works out to be 18 uMHOS per 1000 ppm CO_2, only slightly higher than the observed. This may also indicate that most of the variation in conductivity observed in the other drips is due to changes in CO_2 concentrations within the cave rather than changes in CO_2 production in the soil. While the concentration in CO_2 within the soil undoubtedly increases during the summer, the amount of water percolating through the soil also increases. The increased flow appears to maintain a relatively uniform concentration of CO_2 while it is moving within the limestone. The increase in CO_2 observed within the cave during summer months is due more to increased drip water flow than to changes in CO_2 concentrations in the drip water.

Water which enters the cave from the surface drips from the ceilings creating the numerous formations in the cave. A significant amount of water enters the cave in this way. Unfortunately the amount of water entering the cave as drips is difficult to estimate. Drips are randomly spaced throughout the cave and many are inaccessible. The flow rate is also highly variable and dependent upon surface precipitation. Several approaches have been devised to estimate the quantity of water entering the cave as drips.

The source of drip water is precipitation which falls on the surface of the limestone hill above the cave. Water which is not lost to evapotranspiration and direct runoff percolates down into the limestone. The quantity of water which does reach the cave can be estimated by determining the excess moisture available after accounting for evapotranspiration. A general approach for determining the excess soil moisture is the Thornthwaite Method. In this method excess soil moisture is determined from the mean daily temperature, precipitation, time of year, geographic location and soil moisture capacity.

We can estimate what the long term excess soil moisture is by assuming that Sierra Vista is similar to Kartchner Caverns State Park. Both sites have the same elevation, mean temperature and average yearly precipitation. Based on an analysis of weather records for Sierra Vista from 1955 to 1990, the average excess soil moisture is 1.70" per year. The excess moisture is partitioned between direct surface runoff and water which percolates into the limestone bedrock. A rough guess is that only one third will percolate into the cave, or approximately 0.60" per year.

The amount of water which actually reaches the cave has been estimated by three methods.

1) By counting the number of drips. Frequently when drip water samples were collected, the rate of dripping was also recorded. From this data a general correlation has been found between the number of drips per minute and the flow rate for stalactites in Kartchner Caverns. The flow rate in ml per hour is found to be 4.75 times the number of drips per minute. Therefore, by counting the number of drips per minute in a given area, it is possible to estimate the quantity of water entering that area of cave. This method estimates that 0.17" of water that enters the cave each year.

2) By drip water collection in randomly placed pans. A set of 10 empty, 9" evaporation pans were placed randomly about the Big Room. During this period (145 days) the volume of water, if any, was measured and the pan emptied. After each measurement the pan was moved to a new location. This experiment yielded estimates of the amount of water reaching the cave that range from 0.07 to 0.13 inches per year. This rate must be corrected for the amount of evaporation which occurred. Adding the estimated evaporation to the amounts collected in the pans gives an estimated 0.24" to 0.30" of water reaching the floor of the cave.

3) By evaporation rates in dry areas. There are very few areas that can be found in the cave where the floor and walls are actually dry. Only portions of the entrance passages up to Main Corridor and the Tarantula Room have a dry floor during winter months. The evaporation rate at these areas must exceed the moisture supply. By comparing the evaporation records of monitoring stations in this area we can determine the evaporation rate that will just balance the drying of the cave.

Data from stations near the natural entrance were examined to determine average evaporation rates during those months when drying is known to occur. Based on these measurements it was estimated that 1.3 ml per day of evaporation an area of cave would dry it out within a few months. This corresponds to 0.49 inches of evaporation per year. Since these areas do dry out the moisture supplied must be supplied at a rate less than 0.49" per year. This sets an upper boundary on the moisture influx into the cave by percolating surface water of 0.49" per year.

The three estimates of the annual drip water influx are:

> Drip count estimates 0.17" per year.
> Random collection pans 0.24" to 0.30" per year
> Dry areas 0.49" per year.

The average of these estimates is 0.3" of water per year entering the cave in the form of drips (60,000 gallons per year).

Hydrology

Two off-site drainage areas, Guindani Wash and Saddle Wash have been shown to be the source of the water which sporadically floods the back portions of the cave. Two flooding events occurred during the course of our study. In August, 1990 the back section of the cave was flooded. This was our first indication that combinations of intense, localized summer thunderstorms could produce enough surface runoff to cause flooding. The flooding was not observed but was determined to be rather slow, taking a week or more to flood the cave. The cave was also found to respond slowly to runoff on the surface. The adjacent washes must flow for several weeks before water begins to enter the cave. This indicates that rapid flooding of the cave is highly unlikely. By observing the rate at which flood water left the cave we were able to determine that the drains are very small and inefficient. It took over two months for the flood water to completely disappear. Because the flooding was not discovered until after the peak had passed, it was difficult to determine the points at which water entered the cave. A small flowing stream was found entering the cave at Sue's Room. The source of this stream was determined to be Saddle Wash by dye tracing.

The second flooding event occurred in the winter of 1991. Once again the back sections of the cave flooded. This time the whole sequence of flooding was closely observed. We were able to measure the amount of water being lost from the surface stream and identify the areas where infiltration is taking place. Water was found to be entering the cave at Granite Dells. This confirmed that only a small amount of water enters the cave at Sue's Room. By measuring the rate at which the interior water level changes, the quantity of water reaching the cave was determined. Approximately $^{2}/_{3}$ of the water which disappears from the surface stream reappears in the cave. Positive proof of the connection was made by dye traces from the surface stream into the cave at Granite Dells.

These two surface streams appear to be one of the most significant sources of water for the cave. Changes in land use within these drainage areas can directly affect the quantity and quality of water entering the cave. These watersheds are located on Coronado National Forest lands. Arizona State Parks will be taking steps to see that the cave is adequately protected from detrimental changes in these watersheds.

An analysis of weather records at nearby surface stations has allowed us to develop a correlation between flooding of the cave and precipitation patterns. This indicates that while flooding of the cave has been rare in recent years, historically it is a common occurrence. Flooding of portions of the back areas of the cave has a 67% chance of occurring in any given year. A majority of the flooding events will occur during the winter months. Because the winter runoff which floods the cave is cold water, it has a lasting impact on the microclimate of the cave. The areas of the cave which are flooded have temperatures which are several degrees below that of the adjacent areas of the cave. This creates a zone of cold, dense air which has a controlling influence on air flow patterns in the cave.

Understanding the response of the cave to the heating and cooling from flooding has been useful in predicting the post-development temperatures in the cave. Flooding of the back portions of the cave can have two different effects on the rate of evaporation in the cave. If the flood waters are warmer that the cave temperature, as they were in August, 1990, then the water acts as a moisture source and decreases the rate of evaporation in the cave. Warm moist air rises from the water, when this air comes into contact with the walls and other cave surfaces which are cooler, water condenses onto the surfaces. A decrease in evaporation was observed at several of the monitoring stations in August, 1990. If the floodwater is colder than the cave temperature, then the water will act as a sink for moisture in the cave, increasing the rate of evaporation in adjacent areas of the cave. Air which is in contact with the water is cooled sufficiently to cause condensation on the surface of the water. The net effect is to produce a gradient of relative humidity. Near the cool water, the relative humidity will be 100%. Further away, moisture will move toward the cooler water and thus increase the rate of evaporation in areas adjacent to the water. Increased evaporation was noted at several monitoring stations during and after the winter, 1991 flood.

Carbon Dioxide and Ventilation Rates.

The quantity of carbon dioxide (CO_2) gas contained in the cave air has been used to approximate the rate of air exchange between the cave and the surface. The outside air contains approximately 300 ppm CO_2. The chief advantage of CO_2 as a tracer is that it is predominantly removed from the cave by ventilation. The primary source of the carbon dioxide is thought to be the CO_2 produced in the overlying soil and brought into the cave dissolved in drip water and by air exchange through small cracks in the ceiling. A small amount of CO_2 may be produced by the decomposition of bat guano, bat respiration and tree roots which enter the cave. Most, if not all, of the CO_2 is removed from the cave by the naturally occurring ventilation of the cave with surface air.

Carbon dioxide concentrations have been measured in the cave at two locations on a monthly basis. The upper Throne Room location has an annual average of 3125 ppm $\pm$1200 and a range of 1660 to 5400 ppm CO_2. At Sharon's Saddle, the annual average is 2095 ppm $\pm$1320 and ranges from 852 to 4680 ppm. CO_2 concentrations vary seasonally from a minimum in late winter to a maximum in late summer. The amount and rate of CO_2 entering the cave follows an annual cycle, being dependent on the rate of drip water entering the cave and the biologic activity in the surface soils.

A relatively simple model of CO_2 concentrations in the cave can be constructed from a knowledge of the cave volume, the rate at which CO_2 enters the cave and the ventilation rate. The volume of the cave is reasonably well known from the survey data. The airflow rate has been measured primarily during the winter at the natural entrance. The rate at which CO_2 enters the cave is not known.but we can make a few educated guesses based on the rate of rise and decline of the CO_2 measurements. For the model, the rate at which CO_2 enters the cave is considered to be proportional to two other parameters, the rate at which drip water enters the cave and the biologic activity in the soil. These two parameters are used to index the rate at which CO_2 enters the cave.

The proper values for the ventilation rate and rate of CO_2 introduction which most closely fits the observations has been determined by trial and error. The measured ventilation rate and inferred CO_2 influx were used as starting points. The final model is based on an influx rate of CO_2 that varies from 20 ppm/day in winter to 80 ppm/day in summer. The measured CO_2 concentrations reasonably fit a ventilation rate of 170,000 to 36,000 ft^3/day. The good overall fit indicates that the range of ventilation rates is reasonably well known.

Air Exchange

Air exchange between the cave and the surface has been identified as one of the major routes by which moisture is lost from the cave. For this reason controlling the rate of air exchange is one of the most important tasks in developing the cave. Airflow is also strongly related to other processes within the cave such as the concentration of carbon dioxide and radon gas. Unfortunately the concentrations of these trace gases is also an important management issue. Increasing rates of air exchange would lower the concentrations of these gases but would also result in increased evaporation, drying of the cave and potentially irreparably damage the beauty of the cave. A knowledge of how these three parameters, evaporation, carbon dioxide and radon, are related to airflow is necessary in order to predict the likely effect of development. The maximum concentrations of both of these gases is determined by the air exchange rate. Estimates of the rate at which air is exchanged have been made by several different approaches. These range from direct measurement of airflow to estimates based on concentrations of trace gases, and models of air exchange. No one method has given a clear cut picture but together they give a consistent overall estimate of the air exchange rate.

The pattern of airflow through the cave can be deduced by several different methods. First, the airflow direction can be sensed in constricted passages if there is sufficient air movement. In larger passages and rooms the air velocity is too slow to be observed directly.

A second method is to observe the growth patterns of the cave formations. Sustained patterns of airflow for long periods of time can influence the growth, orientation and type of speleothems.

A third method involves the measurement of the properties of the air. The amount of alpha radiation particles, relative humidity and CO_2 in the air are all indications of how long the air has been in the cave and how frequently it is exchanged with outside air. A final method is by examining the rate at which soil temperatures change throughout the cave. Areas near existing connections to the surface will have large horizontal temperature gradients. The size of the area influenced by an entrance is dependent on the size of the opening and predominant direction of air movement.

The volume of air entering the cave has been measured by ACPI at the Blow Hole and start of the River Passage for a total of 6.07 days. The average volume of air measured entering the cave is 140,000 ft^3/day. Airflow is also thought to be entering the cave through other small openings in the entrance passages than those measured. Based on the estimated areas of these passages, the total volume of outside air entering the cave is estimated to not exceed three times the observed airflow, or 420,000 ft^3/day.

During all periods of measurement, the direction of airflow was overwhelmingly into the cave (97%). The simplest explanation for this would be the existence of another opening(s) at an elevation above the natural entrance. No evidence of such an opening has been found within the cave. It is thought that the upper opening(s) is either very small or partially blocked by rubble. It appears that the size of this upper opening is what controls the volume of air entering the natural entrance.

The annual pattern of air exchange can be qualitatively understood by computing the density of the surface air and the cave air during winter and summer. Assuming that a higher opening exists, the cave will then act as chimney. During the winter, surface air is denser than air in the cave and flows into the cave. During the summer, surface air is less dense and air flows out the natural entrance. This simple relationship is complicated by two other effects. First, the cave is several degrees warmer than the average surface temperature. This increases the density difference during the winter and decreases it during the summer. As a result, winter air exchange is twice as great as summer and summer air flow out of the cave lasts for only 4 months. This asymmetric reversal of airflow creates the second effect. Because more winter air, which is cooler, enters the cave, the entrance passages become quite chilled. This in turn creates a pocket of cool dense air which partially blocks the summer airflow out of the natural entrance.

ALPHA RADIATION

Alpha radiation levels in all caves are elevated and Kartchner Caverns is no exception. While the level is higher in Kartchner Caverns than in most developed caves, it must be emphasized that it is not a hazard for the public visiting the cave. The levels are high enough to be of concern for employees who may work in the cave for many years.

ACPI has researched the available literature regarding guidelines for permissible exposure levels for the general public. The following statement is taken from "Air Exchange and ^{222}Rn Concentrations in the

Carlsbad Caverns", M.H. Wilkening and D.E. Watkins, Health Physics, Vol 31, pp 139-145.

> "Although there are no explicit guidelines for exposure of the general public to radon and its daughters, both the International Commission on Radiation Protection and the National Committee on Radiation Protection have recommended that individuals in the general public be limited to exposures at levels one-tenth as high as those for occupational exposure. Also for a suitably large sample of the general population, the general guideline is another factor of three smaller."

The average radon daughter level in Kartchner Caverns is approximately one Working Level. Applying the above guidelines would allow the general public to spend up to 22 hours and 40 minutes within the cave based on a permissible standard of 4 working level months for employees. A tour of the cave is anticipated to take less than 2 hours. It would appear that the visitors to the cave would experience less than one-tenth of the guideline exposure.

The radon levels within Kartchner Caverns average approximately 100 pCi/l and vary by a factor of two on a seasonal basis. Radon daughters resulting from the radioactive decay of radon average approximately 0.8 Working Level. These concentrations are high enough to be of concern to those who will work within the cave. Prolonged exposure to radon daughters for many years has been linked to increased rates of lung cancer. Radiation exposure to human lung tissue results from inhalation of radioactive radon-decay products that adhere to lung tissue or to airborne particles that become trapped in the lungs. Due to inhalation of these products, the lungs of most people receive more radiation than any other body organ.

Health consequences of radon exposure to underground miners are the primary basis for determining health risk to people exposed to lower, more common radon levels in houses and other buildings. Most estimates of lung-cancer risk due to low-level radon daughter exposure in homes and buildings use a linear extrapolation from high exposure rates experienced by some groups of underground miners. In a linear extrapolation, exposure and risk are proportionally related; for example, half the exposure would constitute half the risk.

There is some question about whether the exposure rates determined for miners are applicable to the much lower exposures encountered in homes and most caves. Mines typically contain large amounts of dust and exhaust from equipment and miners are not a representative sample of the general population. Despite these differences most risk assessments are based on studies of uranium miners.

The Environmental Protection Agency (EPA) has used the risk coefficients determined for uranium miners to project lung cancer rates at lower exposure levels. EPA has determined lifetime risk coefficients that range from 2.4 to 9.4 X 10^{-4} per WLM. Other studies have generally recommend somewhat lower risk estimates. A comparison of risk estimates from 7 studies compiled by Nazaroff gives an average lifetime risk coefficient of 2.1 X 10^{-4} per WLM. The lowest risk coefficient cited in any study was approximately 1 X 10^{-4} per WLM.

If we use the NPS proposed guidelines of 3.5 WLM per year and a lifetime maximum of 105 WLM as reasonable maximum exposure estimates we can calculate the lifetime lung cancer risk. This is between 2.5% and 9.9% based on EPA risk coefficients and 2.2% based on the average of other studies.

We can compare these estimates with other risks commonly faced by workers in other industries. The rate of fatal accidents in American industry is about 1.1 per 10,000 workers per year. Based on 30 years of work, the risk is about 0.33%. The riskiest industry is mining with a fatal accident rate of 6 per 10,000 workers per year. Based on 30 years of work, the risk is 2.0%. The estimated range of risk associated with radon daughter exposure can be the same as or greater than that of jobs that are commonly perceived of as being risky.

For comparison, the low end of the estimate (2.2%) is slightly greater than the risk of dying in an auto accident. The high end of the estimate (9.9%) is comparable to the risk associated with cigarette smoking. These comparisons indicate that exposure to the levels of radon daughters expected to be found in the cave can be a significant risk for those working in the cave for many years. Exposure and risk to the general public is very much smaller because they will be in the cave for a very short period of time. Based on a one and a half hour tour length, the risk to the public is approximately the same as that associated with a 60 mile automobile trip.

The nature of the radioactive decay sequence provides three approaches to mitigating the problem. First, it is necessary to understand that radon gas and radon daughters have very dissimilar properties. While radon daughters are the actual health risk, radon gas is the direct source of radon daughters. Radon gas has a much longer half life than radon daughters (by a factor of over 100.). If radon gas is eliminated or reduced, then the radon daughters will also be eliminated or reduced. The three approaches can be categorized as follows:

- Control of Radon Gas
  - Removal of radon source
  - Removal of radon gas from the air
  - Ventilation to remove radon gas
- Control of Radon Daughters
  - Ventilation to remove radon daughters
  - Air circulation to increase radon daughter plateout
  - Filtering air to remove radon daughters
  - Passive filtration of air to remove radon daughters
- Protection of the individual employee
  - Personal protection methods
  - Manage the length of employee exposure

Many of the processes that allow high levels of radon and carbon dioxide to accumulate in the cave are also those which maintain the moist cave environment. Valuable insight into the operation of the cave's microclimate can be gained by modeling the behavior of radon within the cave. An additional benefit is the ability to make generalized predictions of the consequences of developing the cave for public viewing. Two models of radon and radon daughter concentrations have been considered. One considers those factors which create the individual radon daughters and effect the removal processes. The other model considers the rate at which radon enters the cave and is removed by decay and ventilation.

In 1972, Jacobi published a mathematical model for predicting the concentrations of airborne radon daughters under the influence of various sources and removal processes. The initial model was formulated for use in uranium mines, but the same processes are active inside caves. The model is generally referred to as the Jacobi Model.

Application of the model is dependent on knowing the rates at which the various radon daughters are created by radioactive decay and removed by various processes. The rates at which the individual daughters are created by radioactive decay are well known physical constants. The rates at which the daughters are removed by ventilation, deposition and attachment is quite variable but has been studied extensively in recent years. Five additional parameters are needed to describe the deposition and removal processes.

1) Ventilation rate
2) Aerosol attachment rate.
3) Unattached plateout rate.
4) Attached plateout rate.
5) Probability of recoil detachment.

Once the model has been calibrated on the undeveloped cave, the effect of development of the cave on alpha radiation levels can be estimated. Several important parameters of the model will change after development. The principal change will be an increase in air circulation caused by convective heating from lights and visitors. This will result in a more uniform mixing of cave air and bring the air into more frequent contact with cave surfaces. This will increase the rate at which radon daughters will plate out. The number of condensation nuclei will also increase. These will be produced by visitors and condensation of water vapor near cooler surfaces.

The Jacobi model results predicts that alpha radiation measured in Working Levels will decrease by approximately 15% as a result of development. Application of the Jacobi Model indicates that development of the cave will tend to decrease alpha radiation levels.

Radon enters the cave from the walls of the cave and from cave sediments. As radon is an inert gas there are only two ways in which it is removed from the cave. The primary mechanism is by radioactive decay into the daughter products. The half-life of radon is 3.82 days and if it were not constantly entering the cave, 99% would have decayed within 25 days. The second process which removes radon from the cave is air exchange with the surface. A simple model of radon levels within the cave can be constructed based on these two processes. The only parameters are the rate of radon entry and the ventilation rate. The model must also be consistent with the following general conditions which have been observed inside the cave.

- Average Radon gas concentration is 100 pCi/l.
- Peak radon gas concentrations of 400 pCi/l.
- Radon daughter concentrations and presumably radon gas concentrations vary by a factor of two on an annual cycle, being lowest in the winter and highest in the summer.
- Air exchange rates are at least 140,000 cubic feet per day but are less than 1,000,000 cubic feet per day.

The model has been set up as a steady state system with the influx of radon and ventilation rate being constant for a period that is long compared to the removal rates. The cave is also treated as a lumped system which assumes that radon levels are uniform throughout the cave and surface air is well mixed with cave air. Neither of these assumptions is likely to be correct and so we can only expect the model to predict the gross behavior of the cave.

The influx of radon is first estimated to be 0.45 pCi per square meter per second. This is a general average for most materials. Based on the surveyed volume and estimated surface area, this corresponds to 0.92 pCi/l per hour inside the cave. The decay constant for radon can be determined from the half-life and is precisely known.

We can first solve the model to determine the ventilation rate which would allow radon to build up to the observed average level of 100 pCi/l and determine the likely annual variations caused by changes in the ventilation rate throughout the year. The results of the model run are contained in Figure 3.

The fact that radon levels are significantly different in various areas of the cave indicates that radon influx rate is also variable throughout the cave. The model shows that variations in the influx rate are directly proportional to the maximum radon concentration.

The impact of various ventilation rates can also be examined with the aid of the model. The air on the surface has a very low radon content compared to the air in the cave. Surface air brought into the cave will dilute and transport radon out of the cave, resulting in lower radon concentrations. The model can be used to assess the importance of ventilation in determining the radon concentration and also to investigate the effect of artificially increasing the ventilation to control radon.

The model indicates that ventilation has little effect on the radon levels within the cave until the ventilation rate is less than 30 days. It would be necessary to completely change all of the air within the cave every 5.5 days in order to reduce the radon level by 50%. Such a high ventilation rate would certainly destroy the existing moist conditions within the cave.

SURVEY OF THE INVERTEBRATE CAVE FAUNA

Invertebrates, especially arthropods, make up the majority of all known cave organisms. If development of the cave is to minimize disturbance to all cave organisms and their habitat, the invertebrate species present and their significance must be assessed. With this information the Arizona State Parks Department can prevent the extinction, and/or reduction of species during and after development of Kartchner Caverns. After development, the information gathered on the invertebrate fauna can be used as a baseline for monitoring cave species and for interpretive programs.

Preliminary work indicates there are several new species of cave adapted invertebrates, including at least one new species of cave isopod and a new mite species. The study of Kartchner Caverns is a unique opportunity for an extensive baseline study of the invertebrate cave fauna before development that will allow future follow up studies to determine the effect of development on the cave fauna.

Thirty three invertebrate species were found in Kartchner Caverns during this study. Of the 33 species, 5 (15%) are considered to be obligate cave dwellers (troglobites) and 16 (48%) are facultative cave dwellers (troglophiles). The camel cricket, Ceuthophilus pima, is a trogloxene because they leave the cave to feed. The remaining 11 (33%) species are either accidentals (10) or obligate parasites (1).

All of the troglobites and troglophiles in Kartchner Caverns are dependent on organic material from the surface. Most of this organic material is deposited as Myotis velifer bat guano every summer. Small amounts of organic matter carried into the cave by periodic flooding of the Back Section provide a limited food supply in that area. The camel crickets are the only cave arthropod that is not dependent on organic material carried into the cave.

Few invertebrates were found in the Back Section (Pyramid Room, Rotunda Room, Mushroom Passage, Throne Room, Subway Tunnel, Pirate's Den, and Sue's Room) of Kartchner Caverns. The Throne Room, Sue's Room and the upper portion of the Rotunda Room are without invertebrates.

The Granite Dells area is biologically interesting. The presence of C. pima, a surface spider, and a lepidopteran indicates a direct connection to the surface. Even with a connection to the surface there were few individuals and species in this area due to lack of available organic material at the Granite Dells level.

The area between the Pyramid Room and Big Room (River Passage, Bathtub Room, Grand Canyon, Thunder Room) is a transition zone between the two parts of the cave. No invertebrates were regularly found in this area.

The Front Section (Big Room, Cul-de-Sac Passage, Echo Passage, Red River Passage, Grand Central Station, Main Corridor, Tarantula Room, Scorpion Room, LEM Room and entrance area) is the biological center of the cave with more than 13 invertebrate species in some areas.

In the Big Room and Cul-de-Sac there are a number of Myotis velifer guano piles of different sizes and ages that serve as the primary food source for most of the invertebrate cave fauna. The bats currently roost in two main areas, near the Lunch Spot and on the west side of Sharon's Saddle.

The area from the Pop-up Junction to the entrance is very different from the rest of the cave. There is a significant seasonal fluctuation in temperature and humidity and organic input is primarily limited to scattered guano pellets and occasional surface material carried in by rodents. The dominant cave arthropod is the camel cricket, C. pima. The other fauna in this area varies seasonally with moisture, but includes many of the accidental species found in the cave.

The invertebrate cave fauna and cave community of Kartchner Caverns is unique. Although the cave fauna of Arizona is not well known, some comparisons can be made. There are significant differences in the cave fauna of Kartchner Caverns and other caves in the Huachuca, Santa Rita, Catalina and Whetstone Mountains . Most notable is the absence in Kartchner Caverns of several relatively common arthropods (a troglophilic opilionid, a carabid beetle, and a dipluran) found in other southern Arizona caves .

There are two possible explanations for the absence of these cave forms. One is that they were present at one time, but for an unknown reason they became extinct in Kartchner. Another possibility is that Kartchner Caverns was only available for colonization when the climatic conditions were such that these cave forms were not able to colonize the cave. Additional information on the climatic history of the area and more detailed study of fauna in other caves may help to understand the differences in the cave fauna.

Based on work with the cave fauna there are currently only two openings from Kartchner Caverns to the surface. One is the current entrance used by the bats, humans and arthropods, while the other is in Granite Dells. The Granite Dells entrance is too small for anything other than arthropods and small rodents. The presence of more than an occasional camel cricket has been found to be a reliable indicator of a direct connection to the surface.

The invertebrate fauna of Kartchner Caverns is unique with several new species that may be endemic to Kartchner Caverns. Every effort should be made to keep disturbance of the cave soil to a minimum.

Development of Kartchner Caverns must be scheduled in a way to preserve the bat population in the Big Room. The loss of the bats from the Big Room in Kartchner Caverns would result in the extinction of most of the arthropod fauna in the cave. Development in the Back Section, especially the Throne and Rotunda Rooms would have the least impact on the cave fauna.

Care must be taken during construction and subsequent tours to insure the cave environment remains unchanged and exotic species are not introduced into the cave. A change of the environment and/or the introduction of surface species could result in the disruption of the cave community and eventually the loss of cave species.

BATS

Bat studies at Kartchner Caverns have been performed under the direction of Ronnie Sidner of the University of Arizona. The purpose of this study was to obtain a biological inventory of bats at baseline level prior to the development of Kartchner Caverns. The acquisition of such data before the population has been impacted by much major disturbance provides a vehicle to study the effects of future activities on the population. This purpose has been paramount in the activities carried out thus far concerning bats at Kartchner Caverns State Park.

Among its many other values, Kartchner Caverns is important because it is a natural refuge for a large colony of bats. From May to mid-September of each year, the cave is home to 1000 to 2000 Myotis velifer, a species of insectivorous bat. These bats, primarily pregnant females , return each year to Kartchner Caverns to rear their young. These bats provide an important link between the ecosystem of the cave and the surface. The bat guano introduces a rich food source for Kartchner's cave limited organisms. During the summer, bats are usually found roosting together in a small cluster on the ceiling of the Big Room. Accumulations of bat guano in other parts of the Big Room indicate that they may occasionally use different parts of the room. There is no indication that bats presently use any other part of the cave.

The importance of the bats to Kartchner Caverns State Park is three-fold. For the Arizona State Parks, they are an exciting educational experience for the park visitor. The public has become increasingly aware of the many benefits provided by this often misunderstood animal. Cave parks such as Carlsbad Caverns fill an amphitheater on summer evenings for a natural history talk about bats during the bats' nightly emergence. The bats also act as a natural insecticide for the park property. A conservative estimate indicates that the bats roosting in Kartchner devour approximately one-half ton of insects every summer. The third benefit of a healthy bat roost within Kartchner Caverns is its introduction of excrement (guano) below the roost. This bat guano is the primary source of food for the permanent organisms of the cave.

At this point, we have garnered much information about the bats with minimal disturbance to the population and only little disturbance to some individuals. For species of bat which are readily identifiable at a distance, low-disturbance techniques achieve identification with high confidence. This has been the case with our observations of Plecotus townsendii and Choeronycteris mexicana which occur in small numbers in outer areas of the cavern. On the other hand, a species of Myotis is not so easily identified, and other measures must be employed. We have not netted the bat population in residence in the cavern, however, because of the potential risks that disturbance within a roost can cause. Fortunately, it has been possible to patiently gather much evidence with other low-disturbance techniques to identify the bats in residence. During the study, trips into the cave during the summer were greatly reduced or taken during the night while the bats were out of the cave feeding. Head lamps, with red filters, were used whenever work was performed near the bat roost.

Additional low-disturbance techniques have included examination of bone material and carcasses inside the cavern for species identification; handling only a couple of isolated bats within the cavern for species identification; noting changes in the guano after bats have exited at night to determine which areas are utilized by bats; observing the presence of non-volant juveniles after adults have exited at night to determine maternity use; banding animals outside and away from the roost to confirm cavern use by these individuals when the reflective tags were observed while bats flew from the entrance during the evening exit ; and netting bats outside and away from the roost in order to determine events in the reproductive cycle of the population. Using these techniques a number of bat species have been identified from the interior of Kartchner Caverns. These identifications are based upon observations of live bats and collection of preserved material.

From observations of live animals:

- Myotis velifer
- Plecotus townsendii
- Choeronycteris mexicana
- "small bat" species (small Myotis spp. or Pipistrellus)

Bone specimens:

- Myotis spp.
- Myotis velifer
- Myotis occultus
- Leptonycteris sanborni
- vespertilionid bat bones

The number of bats using the cave has been estimated by careful counts of individuals during the exit flight. Due to the constricted passages near the entrance, bats are forced to leave in small groups which are easily counted. The results of numerous counts made in past three years is shown in Figure 4. The increase in estimated population size from April through August is partially due to the summer birth rate and to recruitment of volant juveniles or adults from other roosts. However, other roosts are not known in the area.

From both public-interest and scientific viewpoints, Kartchner Caverns is even more exciting as a bat roost because it houses a maternity colony. This means also that continued responsible and knowledgeable management is necessary for the bats. From our observations in the cavern and at the cattle tank, we know the period from mid-June to early August is the time when females are in late stages of pregnancy, parturition, or lactation, and juveniles are developing and fledging. This is the critical period of time when the bats require non-disturbance to assure healthy behavior, and in turn, successful reproduction and continued population growth.

In 1990 a BCI bat house was installed on a pole below the main roost site to see if it would be used if available. A temperature probe was also installed and hooked up to the data logger. This allowed us to determine if the bat house was being used from the temperature record. Apparently the bats never used the bat house. We felt that the reason bats did not use the house was that it was much lower than the ceiling and also was attached to a pole which might interfere with flying. In the spring of 1991 the original bat house was removed and two new ones were installed on the ceiling near the roost site. One of these was a new BCI wooden bat house similar to the one previously installed. The second bat house was constructed from two large plastic flower pots, nested together and hung upside down. A temperature probe was installed in the BCI bat house. Both bat houses were washed with a mixture of water and bat guano from the cave to provide a familiar "lived in odor". Preliminary results indicate that neither of these bat houses were occupied during the summer of 1991. This indicates that it is unlikely that attempts to relocate the bats to other areas of the cave would be successful.

The presence of a healthy bat population in Kartchner Caverns provides much potential for scientific interest. For a state park, however, what is perhaps more important is that the bat population provides opportunity for public eduction about these increasingly popular animals and about the exciting and interesting ecology of a subterranean ecosystem. This will require that development of the cave not disturb the bats or drive them from the cave. Options for maintaining the bat population after development are:

- Limit visitor use of the Big Room while bats are present.
- Attempt to entice the bats to use another portion of the cave.
- Mitigate the impacts of development on the bats by trail alignment, low level lights and providing a bat house on the ceiling.

The first option is clear but would limit visitation to the Big Room from May to mid-September. The second and third options have never been successfully implemented in any other cave. The preliminary results from the bat houses placed in Kartchner indicate that there is little reason to expect that the bats could be successfully relocated.

GEOLOGIC STUDIES

The geologic study was conducted to provide a detailed understanding of the geologic setting of Kartchner Caverns and the surrounding area. The objectives of the surface and subsurface geological investigations are twofold: (1) to provide geological engineering information critical to the evaluation of potential visitor access points and (2) to provide a detailed understanding of the geological setting and speleogenesis of the cave.

The geological studies include investigations of the surface geology, subsurface geology, speleothems (cave decorations), mineralogy, sediments, speleogenesis and geophysical explorations to identify unknown extensions to the cave.

The detailed geologic database referenced above provides geological engineering information critical to the evaluation of potential visitor access points. It also provides geological interpretations essential for the understanding of how meteoric water enters the cave--along faults, fractures, and as perched aquifers on top of impermeable marker beds. This understanding should ultimately allow better management of the delicate cave resources.

The surface geology of the entire Kartchner Caverns State Park was mapped by Dr. Kenneth C. Thomson as part of the initial geologic study. The geologic mapping of the Kartchner Caverns State Park revealed a highly faulted and fractured block of Paleozoic limestones. These limestones, consisting of Pennsylvanian Horquilla Limestone, Pennsylvanian Black Prince Limestone, Mississippian Escabrosa Limestone, Devonian Martin Formation, and Cambrian Abrigo Limestone, have a general dip to the west ranging from 10 to 45 degrees. The fractures or joints have been solutionally enlarged near and at the surface. These minor fractures were probably formed in conjunction with the major normal faults which cut through the limestone with displacements up to several hundred feet. The rock units have been covered in many places by unconsolidated sediments of varying ages from very recent back to Late Tertiary/Quaternary time. This outlying block of limestone has both an east bounding fault (revealed by geophysics) and a west bounding fault.

A more detailed map of the geology of the cave and surface geology of the area overlying the cave was performed by David H. Jagnow. His study focused in greater detail on the structural geology and subdivisions within the Escabrosa Limestone block that contain Kartchner Caverns.Kartchner Caverns is contained entirely within a highly faulted and fractured block of Escabrosa Limestone. The detailed mapping focused on the key marker beds within the Escabrosa Formation, and the associated structures. Identification of key marker beds allowed the surface and interior geology to be closely correlated by projecting surface features into the cave.

The majority of faults cutting Kartchner Caverns are high-angle normal faults that trend northeast from 20° to 60°. Most of these faults are either vertical or dip steeply to the southeast from 90° to 75°. The displacement on these faults is usually less than 10 feet, being down-thrown on the southeast side--a typical normal fault. There are occasional reverse faults, where the fault plane is dipping to the southeast, yet the southeast side is upthrown.

The present study has identified no less than 60 faults that cut or bound the Kartchner Block. The vast majority of these faults are high-angle normal faults that trend NE. Where the displacement and dip of the fault plane is known, there are only 5 known high-angle reverse faults. There are three low-angle faults (dipping 40° to 45°), of which two are normal, and the third shows reverse displacement. There do not appear to be any true thrust faults cutting the Kartchner Block.

The most complexly faulted portion of the Kartchner Block is directly over the Big Room. The high concentration of faults in this area is probably responsible for the increased solubility that formed the Big Room. The majority of faults cutting Kartchner Caverns are high-angle normal faults that trend northeast from 20° to 60°. Most of these faults are either vertical or dip steeply to the southeast from 90° to 75°. The displacement on these faults is usually less than 10 ft., being down-thrown on the southeast side--a typical normal fault. There are two reverse faults, where the fault plane is dipping to the southeast, yet the southeast side is upthrown.

During the course of this study, particular attention was paid to the unstable or potentially dangerous areas throughout the cave. A separate map was prepared locating geologic hazards. These were classified into three categories:

A) Structurally Hazardous Areas
B) Hazardous Ceiling Blocks
C) Incompetent Beds

Geophysics Studies were performed by Arthur L. Lange and Phillip A. Walen of The Geophysics Group. More complete results of their investigations are included in a separate paper in these proceedings.

Geophysical investigations have been performed to map the sub-surface and to detect the presence of auxiliary caverns. Electromagnetics were employed to map near-surface groundwater levels, while a natural-potential survey over the entire Park identified zones of infiltration in the valley alluvium and likely cavern targets in the carbonate outcrop. A gravity survey delineated range-front faults and resulted in a map of depth-to-bedrock beneath the valley alluvium. Although the gravity survey could not resolve the carbonate/schist boundary, it portrayed the regions of shallow bedrock that control ground-water flow and storage. The gravity survey also produced significant anomalous lows over two of the three main cavern sections and identified sites likely underlain by cave galleries not yet discovered.

MINERALOGY

An assessment and inventory of the cave minerals and sediments of Kartchner caverns was performed by Carol Hill. The mineralogy of Kartchner Caverns is both diverse and significant. It is diverse in that six different chemical classes are represented by the cave mineralogy: the carbonates, nitrates, oxides, phosphates, silicates and sulfates. It is significant for a number of reasons:

1. World's longest soda straw 21'-2".
2. Largest and most massive column in Arizona - 58 foot high Kubla Khan.
3. First reported occurrence of nontronite and rectorite as cave minerals.
4. First cave occurrence of "birdsnest" needle quartz. This type of quartz is known only from Jeffrey Quarry, Arkansas.
5. Rare occurrence of nitrocalcite as a cave mineral. First modern description of this mineral.
6. One of the most extensive occurrences of brushite moonmilk in the world.
7. First reported occurrence of "turnip" shields."

The diverse and interesting mineralogy of Kartchner is due to an unusual set of circumstances. Unlike most limestone caves, Kartchner Caverns is located near igneous terrain. Alaskite granite borders the Escabrosa Limestone along fault zones to the west, and the Pinal Schist underlies the cave. The dry Arizona desert supplies another condition: the low relative humidity causes the efflorescence of nitrocalcite in the entrance zone of the cave. Bats add the third ingredient, phosphates and nitrates. In setting and mineralogy, Kartchner Caverns most nearly resembles the caves of the Transvaal, South Africa, where a hot and dry climate combined with an igneous rock-bat guano source of cations and anions has produced an unusual cave environment in which a number of minerals can form (Hill and Forti, 1986).

The carbonate mineralogy of Kartchner Caverns is relatively simple, consisting almost entirely of calcite, $CaCO_3$. While mineralogy is simple, the number of carbonate speleothem types and subtypes is extensive.

Kartchner Caverns is distinguished in that it has the longest known soda straw in the world - "The Soda Straw" in the Throne Room measured at 6.45m (21.16 ft) long. This length beats the previous world of 6.24 m (20.47 ft) in a western Australian cave (Hill and Forti, 1986).

Columns form where a stalactite and stalagmite grow together. Kartchner Caverns has the tallest, and probably most massive, column in Arizona - the 58 foot tall Kubla Khan in the Throne Room.

Nitrocalcite. $(Ca(NO_3)2{\cdot}4H_2O)$ is a deliquescent mineral, efflorescent only under very low humidity conditions (around 50% or so for a normal range of cave temperatures (Hill and Forti, 1986). In Kartchner Caverns, nitrocalcite occurs as cave cotton growing from sediment in scattered areas along the Entrance Passage (e.g. Babbitt Hole, LEM Room) where cold, dry winter air flows into the Entrance Passage from the surface. The growth of nitrocalcite in the Entrance Passage correlates with episodes of low relative humidity in the winter months.

Two phosphate minerals have been identified in Kartchner Caverns: Brushite, $CaHPO_{4{\cdot}2H2}O$, and hydroxylapatite, $Ca_5(PO_4)_3(OH)$. Both are common cave minerals which derive from bat guano (Hill and Forti, 1986).

Four silicate minerals have been found in Kartchner Caverns: illite, nontronite, rectorite and quartz. The last of these, quartz, occurs as vein deposits within fault zones or as needle crystals in or near fault zones. The first three are all phyllosilicate $[(Si, Al)_4O_{10}]$ clay minerals which are found as floor sediment or as clay material filling fault zones.

Potential Entrances

At the present time there is only one entrance into Kartchner Caverns, the original discovery entrance. To reach the main rooms of the cave, one must crawl for several hundred feet through small passages. To develop the cave, a new entrance will need to be constructed. The preferred access point must lead conveniently to the part of the cave people will see, dovetail into a planned traffic pattern, accommodate the number of people that the cave can carry, be amenable to microclimate controls, structurally stable, able to be excavated, and accessible to security supervision. A total of 10 different locations for constructing a new entrance into the cave were investigated. For each location, three schematic designs were considered: a wheelchair-accessible ramp, a flight of stairs and an elevator. For each of these 30 combinations, an assessment was made of the potential for disrupting the microclimate of the cave. Preliminary results from the microclimate study indicate that the potential for increasing airflow and subsequent moisture loss is the most important issue to be considered. Other factors included in the assessment were impacts on the supply of moisture to the cave and impacts on the biota. The biota is not only an important feature of the cave but also provides a sensitive indicator of the conditions within the cave. In the analysis of the potential entrances, a number of severe impacts to the cave were found. These are impacts associated with a particular entrance configuration which would jeopardize the integrity of the cave if that entrance were to be constructed. Three types of severe impacts were identified.

- Entrance tunnels which would disrupt the infiltration of water from the adjacent washes.
- Identification of portions of the cave which are subject to frequent flooding. Such flooding would prevent visitors from entering the cave for several months.
- Entrances which impact a known active bat roosting site or which would result in visitors conflicting with the bats' flight out of the cave.

Potential entrances were also evaluated in regard to development considerations. These include distances to major cave features, length and slope of access tunnels and distance from potential visitor center locations.

Based on a weighted point system, the following three potential entrance locations were judged to be the most favorable.

- Tarantula Room
- Echo Passage
- Throne Room

Future detailed studies will focus on the geology of these locations. Additional studies should be performed to determine a suitable trail system for the interior of the cave based on these entrances.

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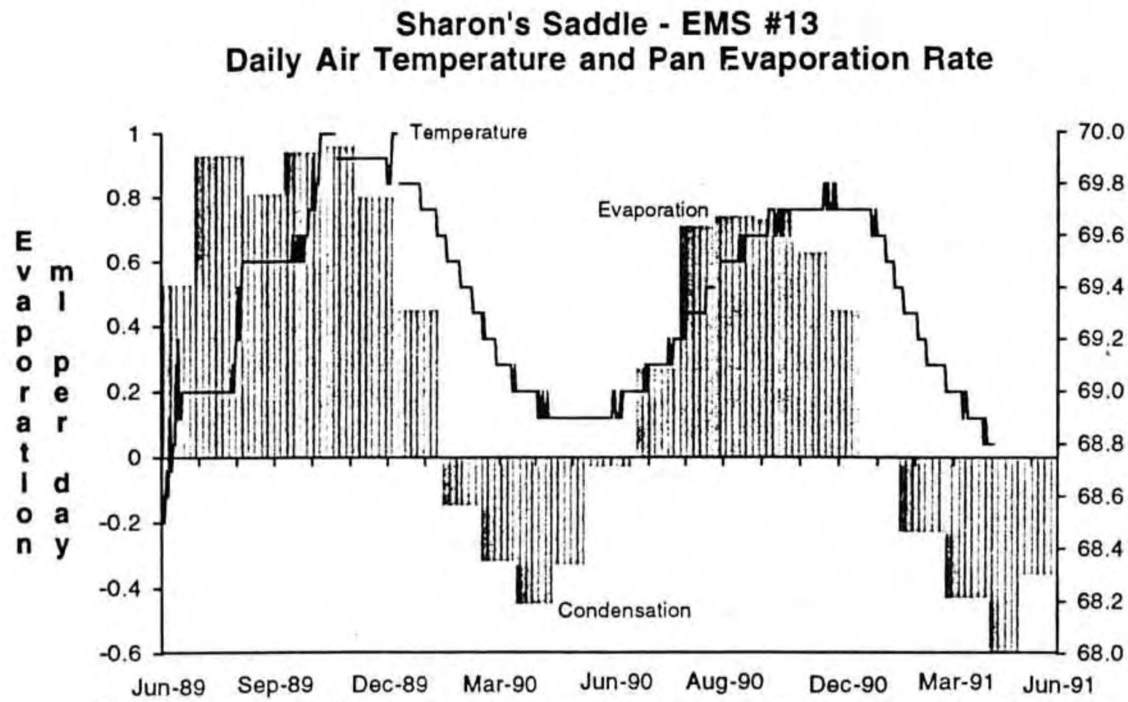

Figure 2. 24 month record of temperature and evaporation from one of the 22 monitoring stations. One ml per day of evaporation is equal to 0.38 inches per year.

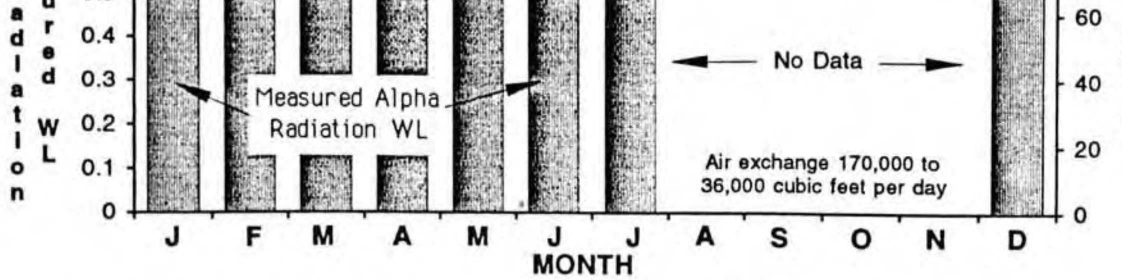

Figure 3. Annual variation in radon gas concentration modeled by ventilation. Note that no conversion factor is implied between radon gas and Working Level.

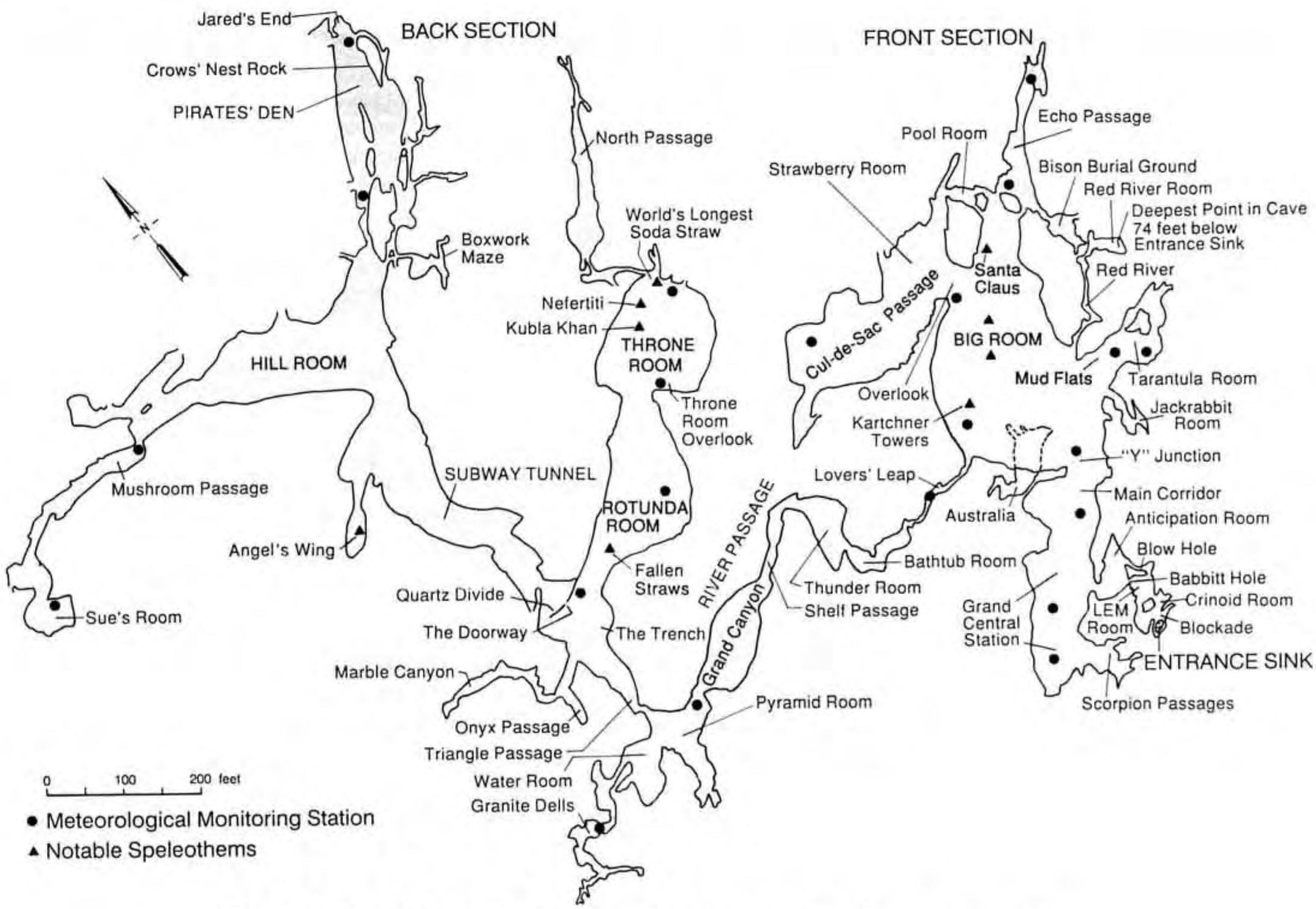

Figure 1. Outline map of Kartchner Caverns. Reprinted from Graf, 1990

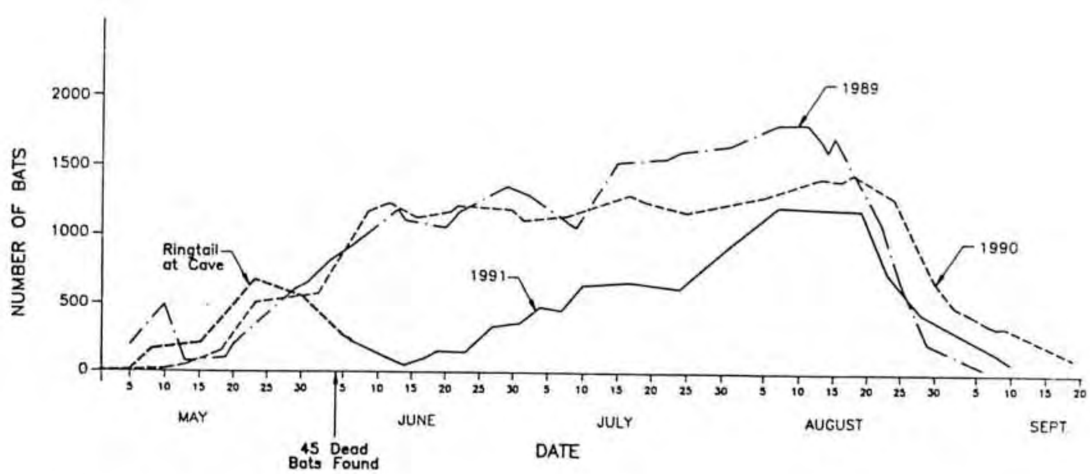

Figure 4. Number of bats utilizing Kartchner Caverns from 1989 to 1991 as determined by exit flight counts.

PRELIMINARY INVESTIGATION OF THE HYDROGEOLOGY AND HYDROGEOCHEMISTRY AT TIMPANOGOS CAVE NATIONAL MONUMENT, UTAH, AND ITS IMPLICATIONS FOR CAVE MANAGEMENT

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ABSTRACT

The Timpanogos Cave system is situated in an area of high relief in the central Wasatch Range, Utah and has formed along minor faults. The fault-fracture system initially provided conduits for acid laden waters, enabling dissolution of several caves in the Paleozoic carbonate rocks. Many of the caves are decorated and decoration is an active process.

Each of the caves has a distinct groundwater flow regime which has affected the types of decorations present. Drip rates in Hansen and Middle Caves respond rapidly to high intensity storms and snowmelt due to conduit flow along fractures. Both of these caves are close to the surface. Timpanogos Cave is much deeper below land surface and has smaller drip rates and greater delays between surface recharge events and increased drip rates.

Analysis of solute data suggests that mineral deposition does not occur uniformly throughout the year, and that during periods of high groundwater flow rates there is a thermodynamic tendency for dissolution to occur. The δ2H and δ18O data suggest that evaporation is a significant factor in the formation of cave decorations.

Past management of the Timpanogos Cave system has been based on incomplete information and to a certain extent trial and error. New findings about cave hydrogeology and hydrogeochemistry should figure prominently in future management decisions on protecting the cave watershed, setting visitation levels, expanding or reducing visitor use facilities, and protecting speleothem appearance and condition.

INTRODUCTION

This report contains the preliminary results of an ongoing hydrogeologic investigation of the Timpanogos Cave National Monument, Utah. The investigation is designed to help provide a scientific basis for cave management by the National Park Service and was initiated in response to the recently approved Cave Management Plan which calls for scientific cave management (Tranel, 1990). Recent management and research efforts include:

1) the restoration of the natural cave climate,

2) an ongoing program of removal of algae growth which is promoted by electric lights in the cave,

3) the installation of a comprehensive atmospheric and hydrologic monitoring system,

4) the initiation of a cave hydrology study.

The goals of the preliminary cave hydrology study are:

1) To determine how management practices, such as pumping cave lakes for visitor drinking water supplies and the use of an open, developed trail network, affect the cave system.

2) To compile baseline watershed and cave hydrogeologic data to help guide future management decisions.

3) To provide an opportunity for the micro study of groundwater recharge mechanisms and shallow sub-surface flow in carbonate terrains in the central Wasatch Range.

4) To develop interpretive information suitable for presentation to cave system visitors.

Timpanogos Cave is situated high in a steep wall of the rugged American Fork Canyon in the central Wasatch Range, Utah (Figure 1). Geological development of the cave system accompanied uplift of the Wasatch Range and the deep erosional incision of the American Fork River (Bullock, 1962). The three caves of the monument, Hansen, Middle, and Timpanogos, are "live" caves in that groundwater seeps and flows from cave ceilings and walls and dripstone formations are actively forming. Each of the caves developed along separate fracture systems.

The Timpanogos Cave system includes just over a mile of passageways, one-third of which have been developed as a tour route (Figure 2). The three caves were discovered separately and were connected by tunnels drilled in the late 1930s (Iorio, 1967). Outstanding features of the caves include a variety of delicate formations such as helictites and aragonite crystal.

Previous research includes studies in geology and cave origin (Bullock, 1942, 1954, 1962; Green, 1975) and mineralogy (White and Van Gundy, 1974). More recent work has emphasized the variety of processes that may have originally formed the cave system (Palmer and Palmer, 1990). Although some water-quality data had been previously collected and both temperature and relative humidity data are available for the past several years, the hydrogeology of the cave is poorly understood.

METHODS

The hydrogeology sampling plan included weekly measurement of cave lake levels and speleothem drip rates, monthly sampling of solute chemistry, and quarterly sampling of isotopic chemistry. Isotope samples are collected for δ2H, δ18O, δ34S, and 3H. More frequent drip-rate measurements were taken in Hansen and Middle Caves to assess peak recharge after major precipitation events and during times of rapid snowmelt. Data collected from December 1989 through September 1991 are discussed here.

Sampling sites for measuring speleothem drip rates were chosen to represent a variety of groundwater flow paths and mechanisms, and to assess hydrologic conditions in all sections of the three caves. Lake levels were measured with staff gauges. Flow meters were installed at pumping locations to measure volumes of water removed from each lake. Lake levels were monitored before, during and after pumping events to develop a stage-volume calibration curve for each lake.

Drip rates were measured with both pyrex flasks and graduated cylinders which were placed beneath dripping stalactites. Most drip rates were measured for 3 minute intervals using 10 to 500 ml graduated cylinders. Where drip rates were slower than 0.5 ml per 3 minutes, drips were collected in pyrex flasks and volumes were measured weekly. Known volumes of oil were used in the flasks to prevent evaporation.

Solute analyses were performed on samples from each drip rate sampling site and from each of the cave lakes. Ph, HCO3^H-, and temperature were determined in the field, and other solute analyses were performed at Brigham Young University using IC and AA methods. Isotopic samples were sealed and sent to Geochron Laboratories in Massachusetts for analysis. δ2H and δ18O, δ13C and 3H are reported relative to SMOW, PDB, and in Tritium Units (TU), respectively.

A weather station was installed above the cave system in the likely recharge area. Both temperature and precipitation data were collected. Snow samples were collected from the likely recharge area, melted under controlled laboratory conditions to prevent evaporation, and analyzed for solutes and isotopes. Water samples from a spring in the cave watershed were also collected and analyzed.

RESULTS

Solute and isotopic data are presented in Table 1. Mean monthly precipitation data are graphically displayed on Figures 2 and 3. Drip rate data are not presented; however drip rates for Hansen Cave and Chimes Chamber are illustrated on Figures 2 and 3, respectively. Saturation indices (SI) were calculated using the computer code WATEQF (Plummer and others, 1976) and the temporal variation in selected SIs for Hansen Cave drip are illustrated on Figure 5.

Results to date demonstrate the general spatial and temporal variations in drip rates and hydrochemistry in the cave system. Both Hansen and Middle Caves exhibit considerable conduit flow, responding rapidly to major precipitation and snowmelt events (Figure 3). Both snow depth and moisture equivalent were greater in the winter of 1990-1991 than the previous year, resulting in greater recharge to the cave system. Significant rainfall events, especially the 100-year event of September 1991, resulted in an immediate response inside Hansen Cave (Figure 3). The September 1991 drip rate measured was essentially conduit flow on the exterior of a large stalactite.

By contrast, most sampling locations in Timpanogos Cave showed a larger component of bedding plane flow, with maximum drip rates occurring two to six months later than in Hansen Cave. Drip rates for a small stalactite in the Chimes Chamber section of Timpanogos Cave were quite different (Figure 4). Peak recharge was observed at least two months later than that in Hansen Cave, indicating more diffuse flow along bedding planes.

As expected, total dissolved solids and pH changed significantly with flow rates at each of the sampling locations. Values for both parameters were much lower during and immediately after peak recharge into the cave system. Ostensibly the low values occurred when recharge water moved quickly through the system and did not have time to reach equilibrium with the surrounding rock.

Analysis of solute chemistry in each of the three caves showed relatively high levels of bicarbonate, calcite, and magnesium (Table 1), indicating dissolution of the aquifer dolomite, which has the misleading name of "Deseret Limestone." Sulfate levels were the next highest at each sampling site, indicating that some gypsum is being dissolved by recharge water as well.

Magnesium-rich waters occurred at the highly decorated Cavern of Sleep and Hidden Lake areas of Timpanogos Cave. Both areas contain shallow lakes with relatively large surface areas. Lake levels exhibit little response to precipitation and snowmelt events. Speleothems in these areas include abundant helictites, beaded helictites, and aragonite crystals. Drip rates are the slowest in the Timpanogos Cave system (i.e. many are <20 ml per week).

Plots of log SI vs. time show considerable temporal variation, especially at sampling sites with high flow rates in Hansen and Middle Caves (Figure 5). During periods when the log SI is negative there is a thermodynamic tendency to dissolve rather than precipitate minerals, and this accompanies peak drip rates in both Hansen and Middle Caves. By comparison, saturation indices for most minerals remained positive throughout the year in the Chimes Chamber of Timpanogos Cave, which is one of the most highly decorated areas in the cave system. This finding also supports the idea of a greater percentage of bedding plane flow as opposed to conduit flow into Timpanogos Cave.

Most stable isotopic values of δ2H and δ18O from both drip and lake samples plot along an evaporation line relative to the meteoric water line (MWL; Figure 6), represented by δ2H = 8 δ18O + 10 o/oo (Craig, 1961). Snow samples from two separate years and the water from an ephemeral spring (Table 1; Figure 6) plot on the MWL. Not surprisingly, the lake waters exhibit the greatest evaporation. The relatively deep Hansen Cave Lake is least affected by evaporation. By contrast, relatively shallow lakes in Timpanogos Cave (Cavern of Sleep Lake and Hidden Lake) and Middle Cave (Middle Cave Lake) exhibit the greatest evaporation. Although Middle Cave Lake receives substantial recharge during spring snowmelt events, the lake level slowly subsides throughout the summer and fall. Water levels in Hidden Lake and Cavern of Sleep Lake remained nearly constant throughout the sampling period.

The δ13C data also support the idea of evaporation in the three shallow lakes. The more positive values of the δ13C data from these shallow lakes relative to the δ13C data from both drips and Hansen Cave Lake (Table 1) suggest isotopic fractionation accompanying carbonate mineral precipitation due to evaporation.

The temporal variations in δ2H and δ18O drip compositions also provide insight into groundwater flow system mechanisms. During the fall and winter, when recharge is negligible and drip rates decline, the isotopic compositions of drip waters tend to exhibit greater evaporation than do the isotopic compositions of spring and early summer drip waters (Table 1; Figure 6). The isotopic compositions of Chimes Chamber drip waters have the least seasonal variation, whereas the isotopic compositions of Hansen Cave drip waters have the greatest seasonal variation. The high variability of the Hansen Cave drip reflects the change from predominantly conduit flow during major recharge events to predominantly bedding plane controlled diffuse flow during the fall and winter months.

There is considerable variation in the δ34S data from samples collected in the cave system (Table 1). The significance of this variation is not yet fully understood and additional data collection is planned. In general, many of the data suggest that water reaching the cave through bedding plane flow often reaches isotopic equilibrium with the gypsum or anhydrite in the surrounding rock and that shallow lakes in the cave system may be subject to significant evaporation. A comparison of values for precipitation (snow samples), a spring in the cave watershed, and water samples from speleothem drips and cave lakes revealed no indication of degradation from acidic precipitation.

DISCUSSION

The preliminary findings outlined above raise several questions for both future research and cave management. For cave hydrology, results to date indicate that most groundwater reaching the cave system is fault controlled, and that both Hansen and Middle Cave are subject to a high percentage of conduit flow. Sampling sites in Timpanogos Cave, by contrast, show that there is a higher degree of bedding plane flow or at least mixing flow paths.

The Timpanogos Cave system is subject to considerable spatial and temporal variation in both recharge rates and water chemistry. Hansen and Middle Caves respond rapidly to precipitation events and especially to spring snowmelt, whereas sampling sites in Timpanogos Cave respond much more slowly to spring snowmelt. However, there are some locations within Middle Cave where bedding plane flow plays a more important role, and likewise points in Timpanogos Cave that respond quickly to surface recharge.

Solute chemistry indicates that limestone, dolomite and gypsum are dissolved in the geologic layers above the caves. Groundwaters which reach the caves are rich in HCO3^H-, SO4+, Ca2+, Mg2+ (Table 1). Both pH and total dissolved solids vary considerably throughout the year at most sampling sites, demonstrating the relationship between flow rates and solute compositions. Analysis of SI is particularly revealing in that it suggests that there is a thermodynamic tendency for precipitation of cave formations during times of low surface recharge and corresponding low drip rates and for dissolution of cave formations during periods of rapid surface recharge and elevated drip rates. It is significant to note that those areas where the drip rates are consistently low have the longest periods of positive carbonate mineral SIs and tend to be the most decorated areas of the cave system. Common helictites, beaded helictites, and aragonite crystal are abundant in these locations.

Several management considerations stem from hydrology research in the cave system. Most important is the overall documentation of cave hydrochemistry; baseline values have been established which will guide future monitoring of the cave system. The approximate location of the cave system watershed has been determined, and as is common in many National Park System areas, it extends beyond the park boundaries. The adjacent area for the Timpanogos Cave system is the Uinta National Forest where the cave watershed has been protected due to its general inaccessibility. However, the long term management of the watershed remains problematic.

Because Hansen and Middle Caves are subject to significant conduit flow, any perturbations to the watershed would likely affect the cave system immediately and profoundly. Although no effects of acid precipitation are apparent thus far in the study, a baseline has been established to which future analyses may be compared. Current threats to the cave system correspond to heavy visitor use and related development, including artificially removing water from cave lakes. Although the effects of pumping have been quantified, impacts upon speleothem development and overall cave conditions such as relative humidity must still be investigated.

Determining the specific effects of hydrochemistry on speleothems is beyond the scope of the present study, but some general trends are indicated and some important questions raised. Preliminary results point to a thermodynamic tendency to dissolve speleothems during periods of high recharge and a tendency to precipitate minerals during the drier fall and winter. However, National park Service management mandates preservation of the system; simply enhancing speleothem development is not a separate management goal.

The importance of evaporation in the cave system is somewhat surprising given the consistent 98-99% humidity in many parts of Timpanogos Cave. Preliminary results indicate that there may be a delicate balance of pH, carbonate mineral saturation levels, recharge rates, relative humidity, and evaporation in the most decorated areas of Timpanogos Cave, such as the Cavern of Sleep, Hidden Lake, and Chimes Chamber. This supports management efforts to monitor visitor effects on temperature and relative humidity and recent restoration of original cave climate.

Finally, new information on the cave system enhances not only cave management, but interpretation for visitors as well. The outdated "fairylanding" approach has been supplanted by new information that is interesting to cave managers and cave visitors alike. Research in cave hydrology has stimulated new approaches to cave interpretive programs, and the combination of research and interpretation have aroused the interest of volunteer groups such as the National Speleological Society (NSS). Local grottos of the NSS have made significant contributions to cave management since hydrology research started in late 1989, including restoration of original cave climate and a complete re-survey of the cave system. Considerable efforts in both research and cave management will continue during the next few years as the new Cave Management Plan is fully implemented.

ACKNOWLEDGMENTS

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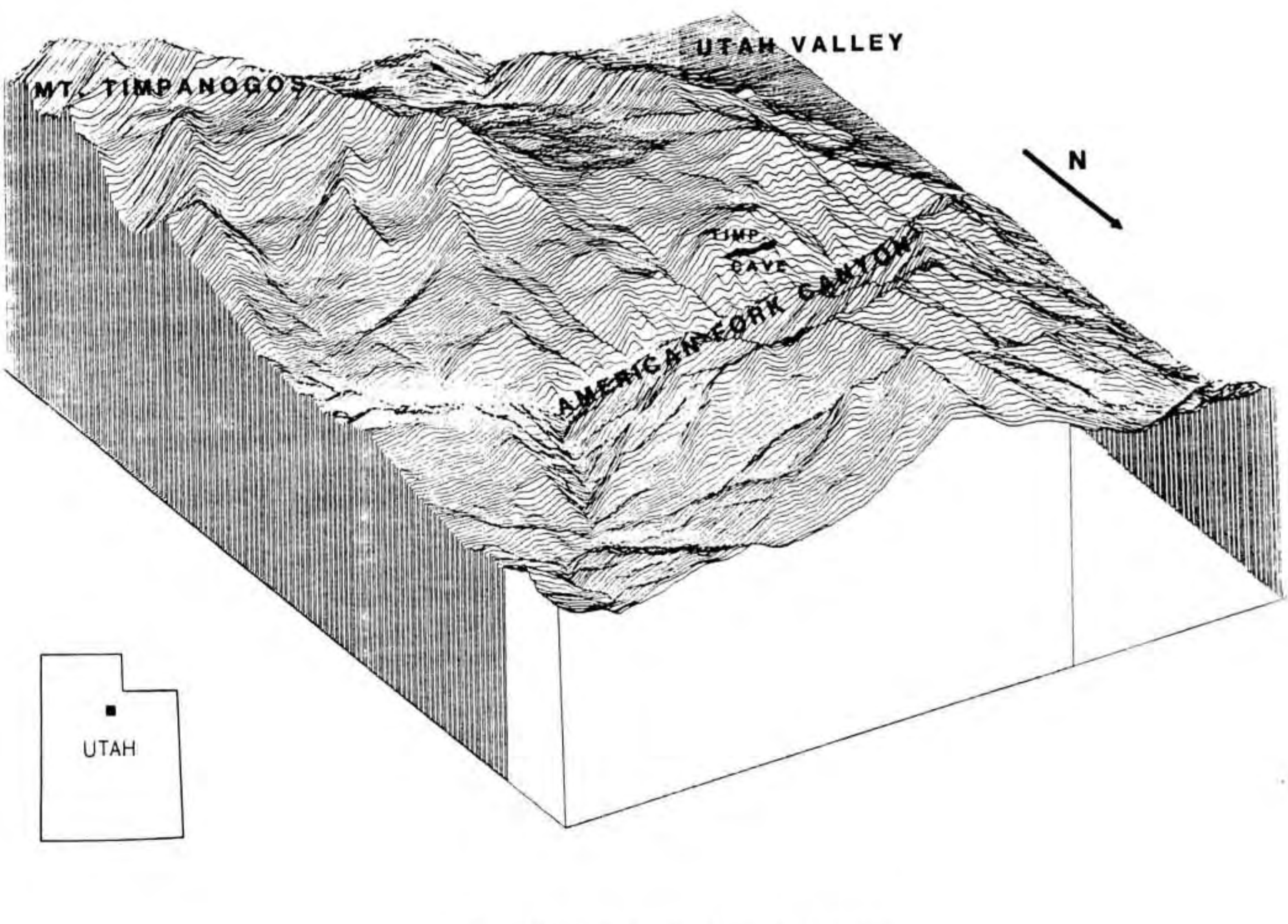


Figure 1 Location and topographic map.

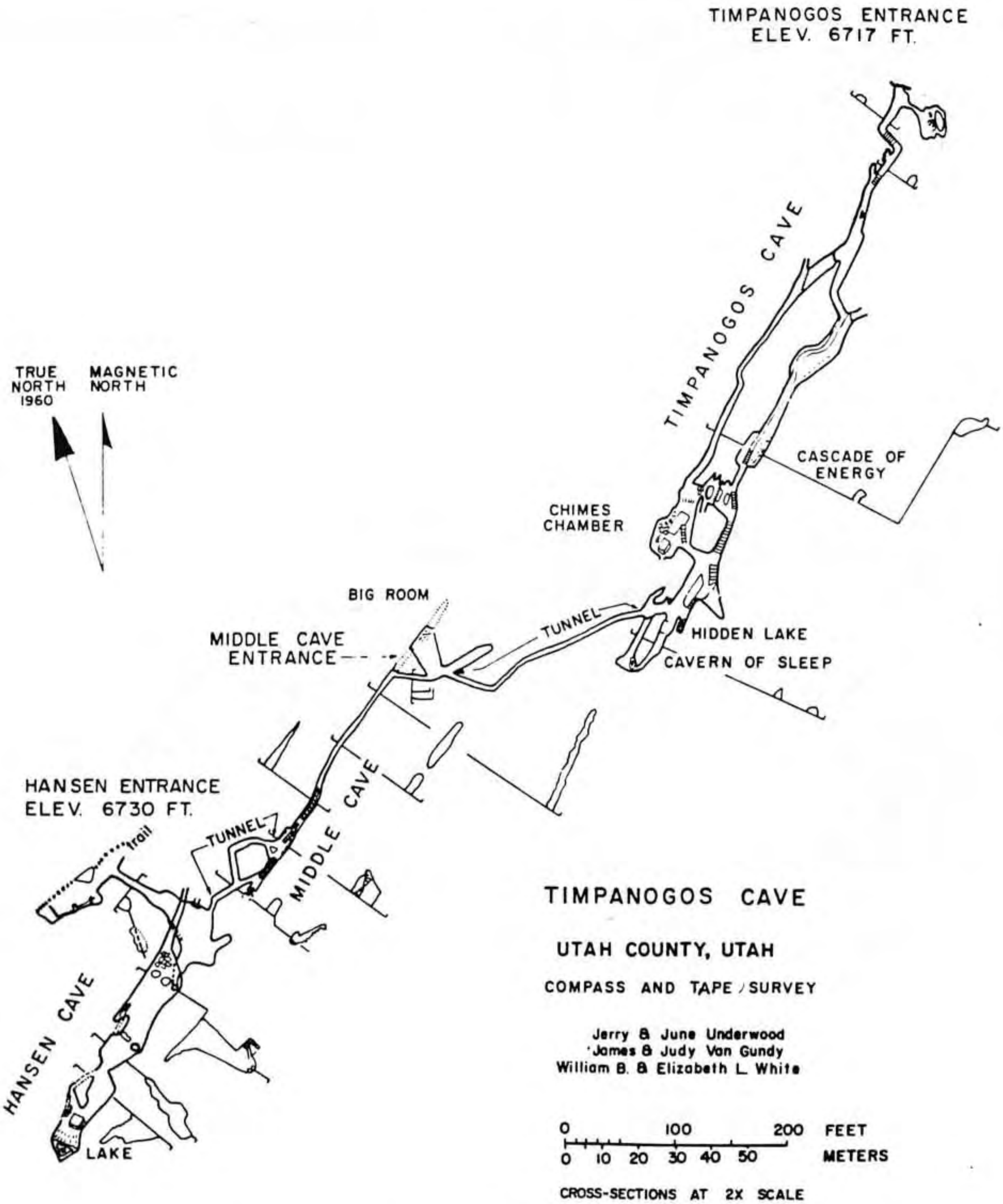


Figure 2 Map of the Timpanogos Cave system showing the location of various caves and lakes (modified after White and Van Gundy, 1974).

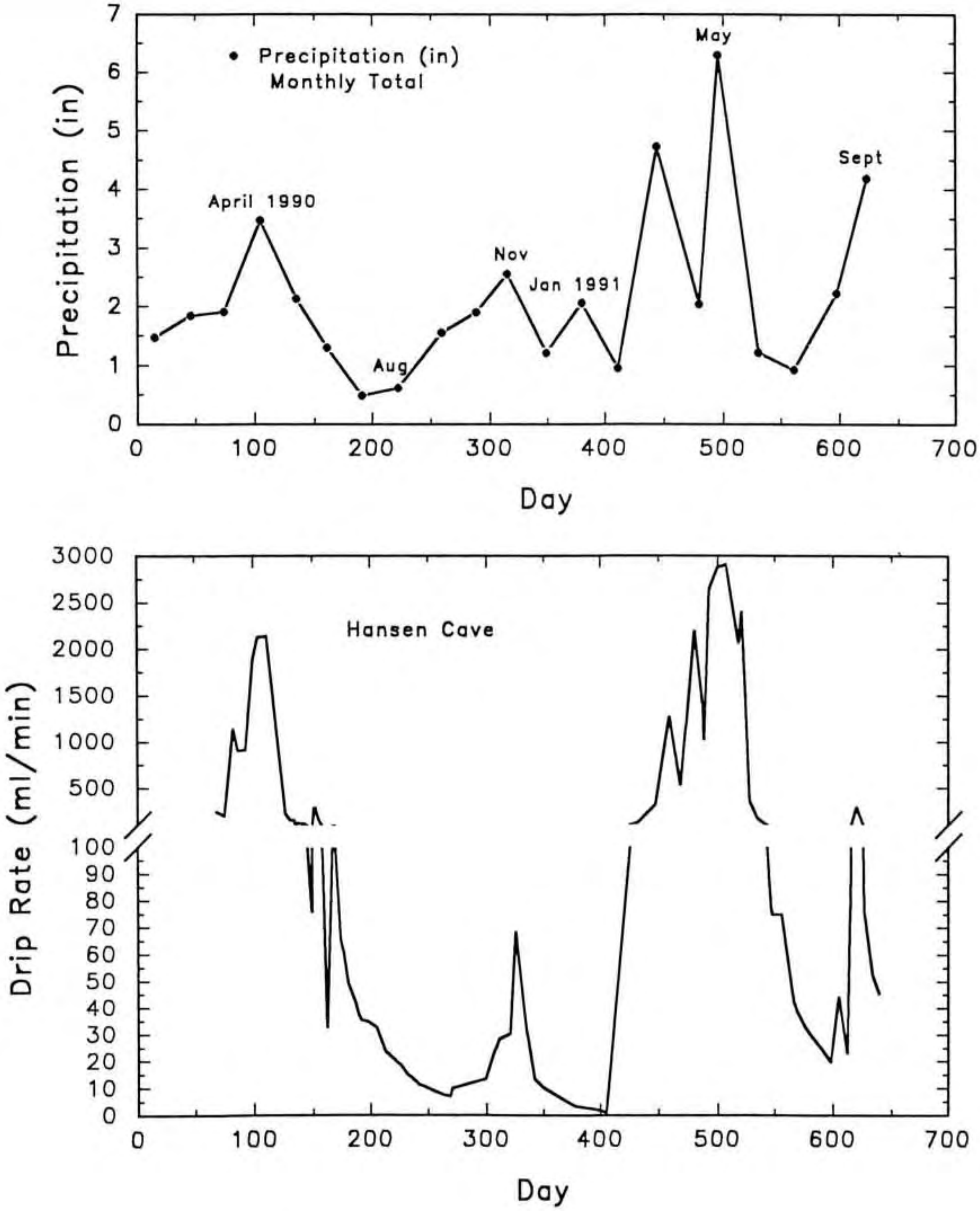
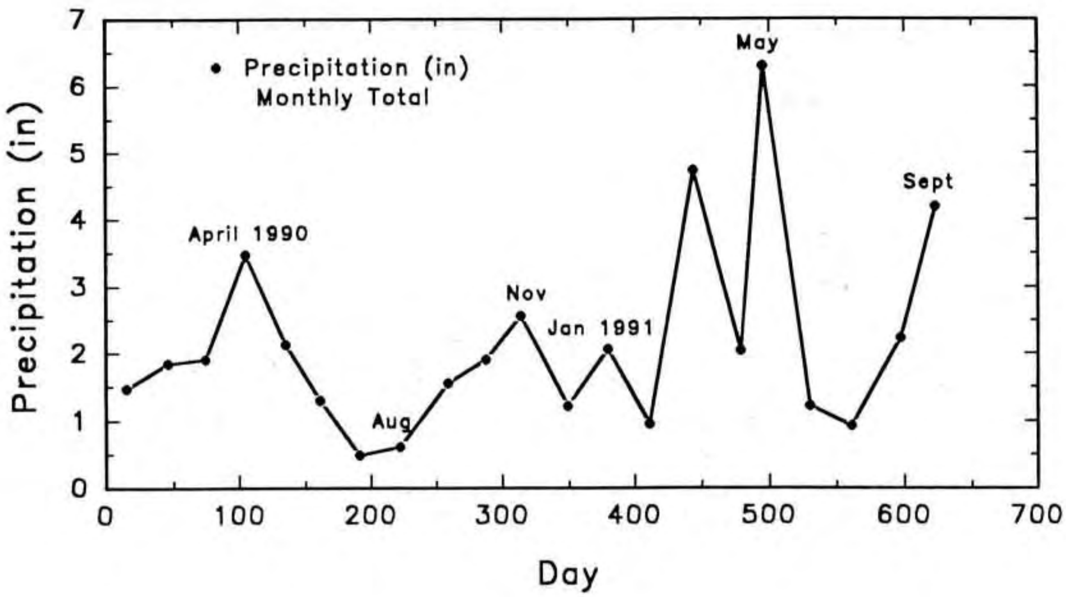


Figure 3 Scatter plots of drip rates vs. day for a major drip in Hansen Cave and mean monthly precipitation vs. day at the weather station in the recharge area. Day zero is January 1, 1990.



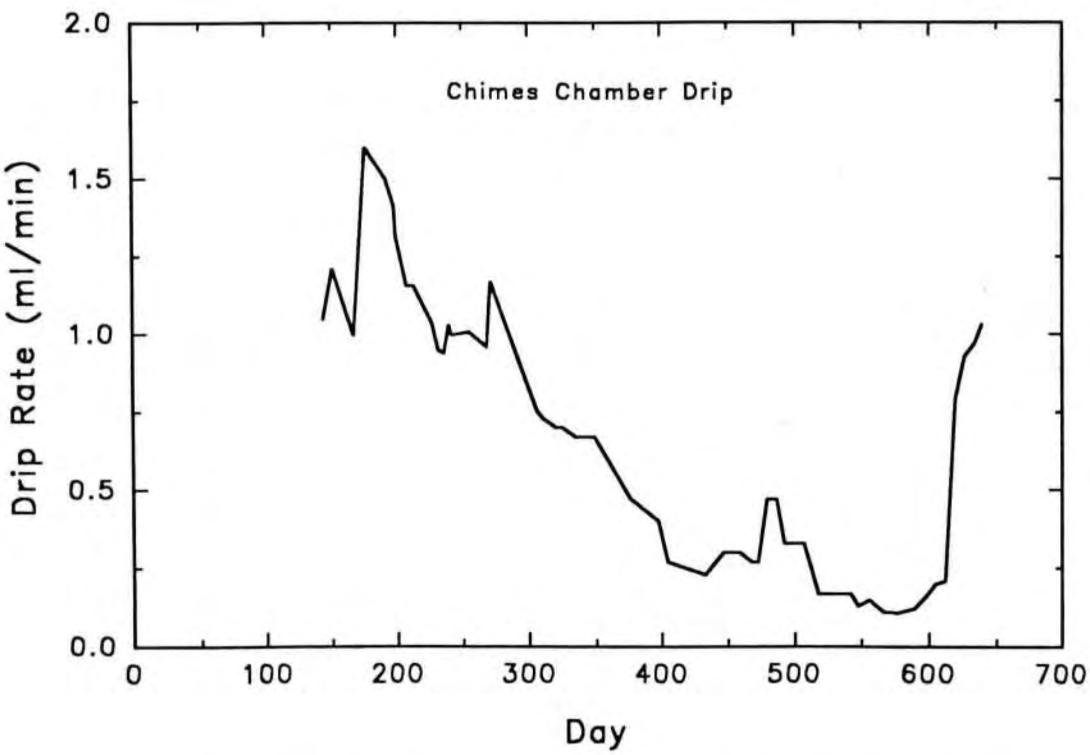


Figure 4 Scatter plots of drip rates vs. day for a typical drip in Chimes Chamber (Timpanogos Cave) and mean monthly precipitation vs. day at the weather station in the recharge area. Day zero is January 1, 1990.

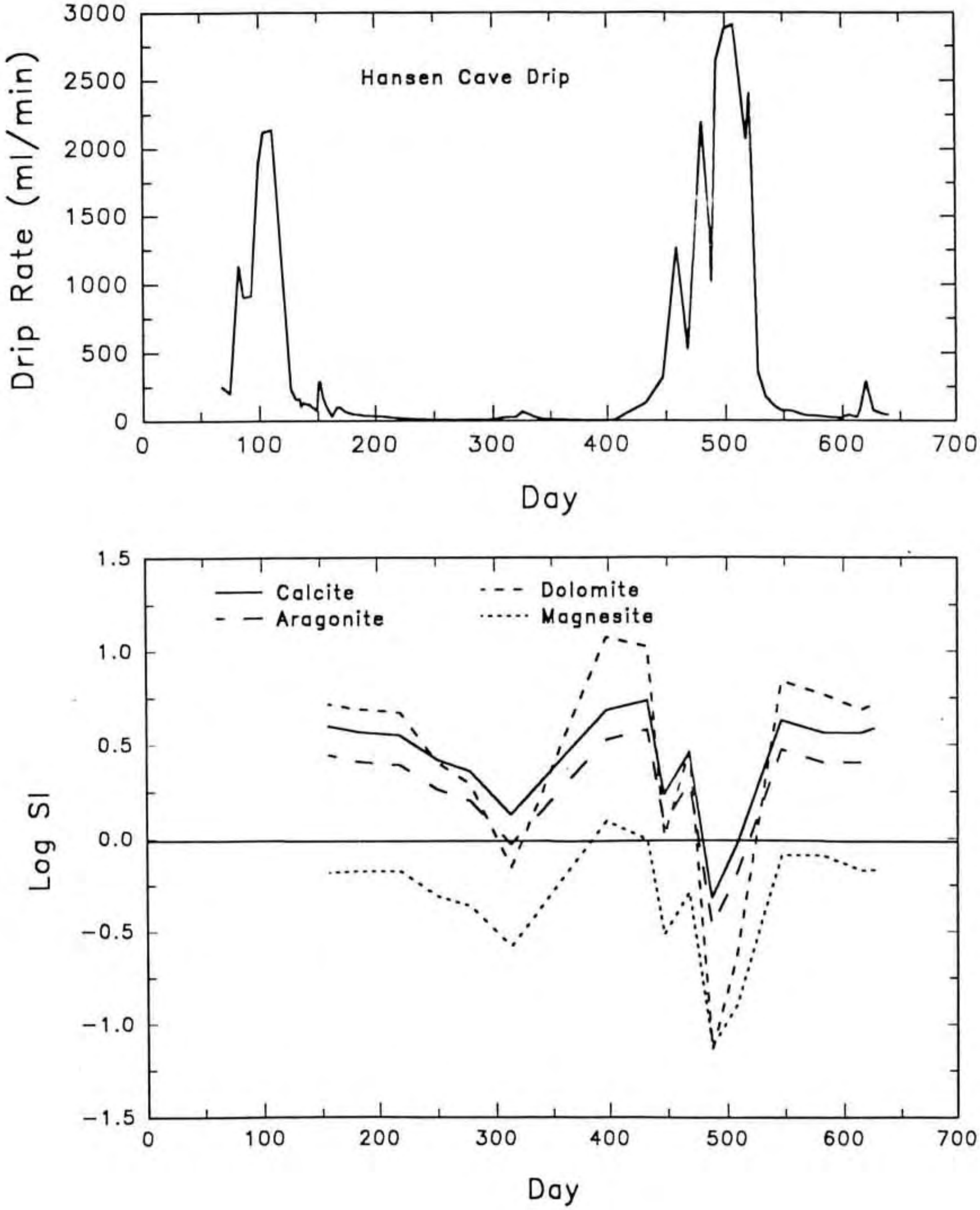


Figure 5 Scatter plots of drip rates vs. day for a major drip in Hansen Cave and corresponding saturation indices for selected carbonate minerals vs. day. Day zero is January 1, 1990.

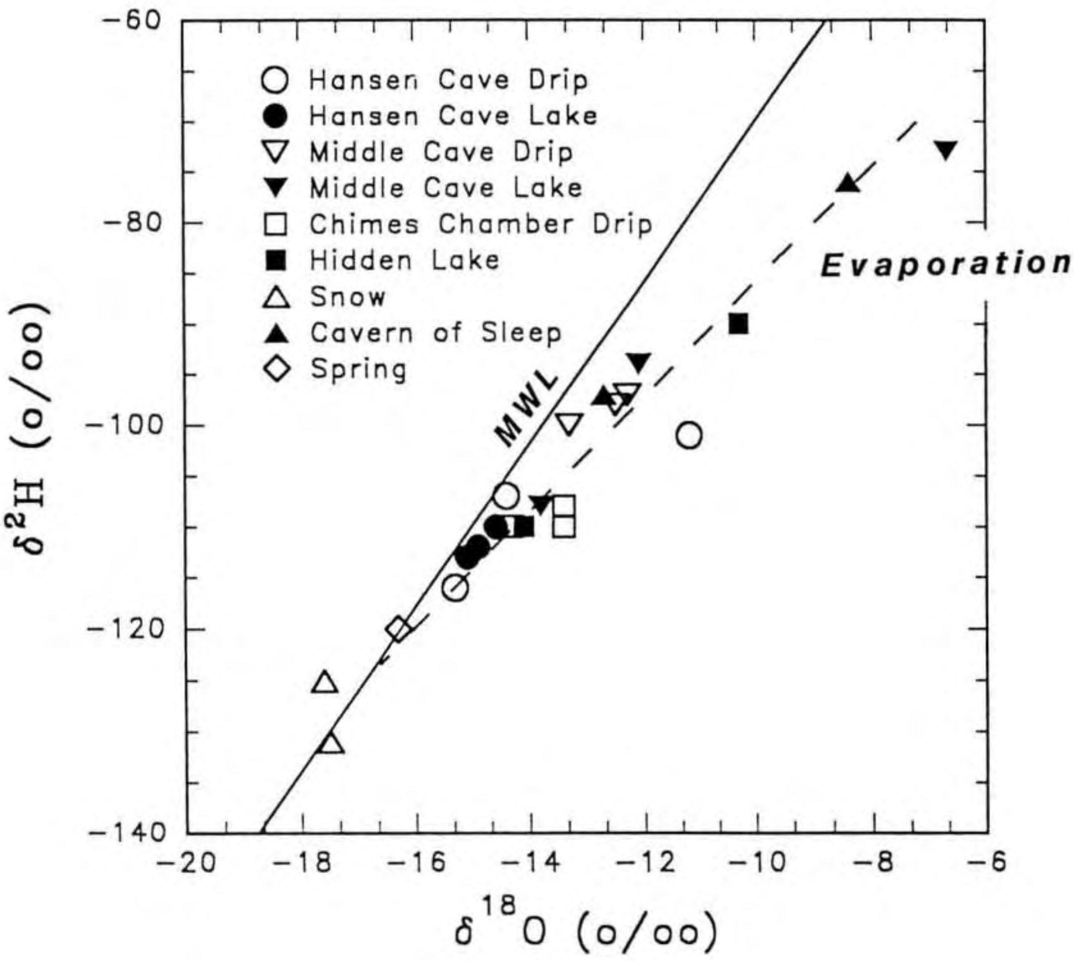


Figure 6 Scatter plot of δ2H and δ18O relative to the meteoric water line (MWL). The dashed line is an evaporation trajectory.

Date	Day	TDS meq/l	Ph	Temp (C)	Ca	Mg	Na	K	HCO3 meq/l	SO4	Cl	F	SiO2 ppm	Isotopes δ18O o/oo	δ2H o/oo	δ13C o/oo	δ34S o/oo	3H TU
									Timpanogos Cave									
Chimes Chamber drip																		
6/06/90	155	14.71	8.05	8.5	4.40	2.86	0.205	0.018	5.72	1.33	0.141	0.037	16.55					
6/30/90	181	15.50	7.90	9.5	4.44	2.98	0.179	0.017	6.28	1.39	0.172	0.037	15.44					
8/07/90	219	15.70	7.65	9.3	4.51	3.01	0.195	0.018	6.31	1.46	0.175	0.034	15.10					
9/07/90	250	15.72	7.87	9.0	4.56	3.06	0.193	0.007	6.29	1.42	0.155	0.035	16.40					
10/06/90	279	15.63	7.82	8.8	4.42	3.01	0.312	0.023	6.40	1.31	0.126	0.026	16.55	−13.4	−110	−9.7	−8.9	
11/09/90	313	14.95	7.65	8.4	4.22	3.09	0.202	0.011	5.94	1.33	0.130	0.027	16.37					
2/02/91	398	15.54	7.95	8.3	4.49	2.98	0.182	0.015	6.34	1.38	0.129	0.031		−13.4	−108			
3/23/91	447	14.78	8.00	8.4	3.91	3.27	0.178	0.016	5.83	1.41	0.133	0.036						
4/13/91	468	14.87	8.00	8.4	4.15	3.18	0.155	0.015	5.88	1.34	0.128	0.028						
5/02/91	487	14.65			4.01	3.08	0.202	0.016	5.85	1.28	0.194	0.025		−13.4	−110			33.2
5/23/91	508	11.68			2.62	3.05	0.188	0.015	4.34	1.27	0.170	0.024						
7/01/91	547	12.53	8.12	9.2	3.04	3.13	0.188	0.015	4.64	1.29	0.178	0.049						
9/07/91	615	15.26	8.10	9.3	4.35	3.03	0.190	0.027	6.20	1.30	0.140	0.030						
9/18/91	626	15.06	7.90	9.2	4.23	3.03	0.190	0.020	6.14	1.29	0.130	0.028						
mean		14.76	7.92	8.9	4.10	3.05	0.197	0.017	5.87	1.34	0.150	0.032	16.07					
st dev		1.15	0.15	0.4	0.55	0.09	0.034	0.005	0.60	0.06	0.022	0.006	0.58					
Cavern of Sleep lake																		
6/04/90	155	12.48	8.00	8.2	1.77	4.05	0.402	0.036	3.85	2.04	0.276	0.053	25.27					
6/28/90	179	12.16	8.05	8.3	1.73	3.77	0.362	0.038	3.93	1.96	0.305	0.052	23.46					
8/10/90	222	12.81	8.23	8.8	1.85	4.08	0.383	0.033	4.15	1.98	0.282	0.055	25.05					
9/05/90	248	13.41	8.15	8.4	2.02	4.18	0.492	0.046	4.20	2.06	0.367	0.053	26.49					
10/05/90	278	13.00	7.95	8.6	1.92	4.05	0.467	0.040	4.24	1.89	0.358	0.040	25.20	−8.4	−76	−6.5	−15.5	
11/09/90	313	12.95	8.30	8.4	1.93	4.11	0.464	0.040	4.13	1.89	0.344	0.042	25.91					
3/13/91	468	11.76	8.04	8.3	1.70	4.12	0.430	0.036	3.16	1.96	0.307	0.043						
5/02/91	487	12.11	7.60	8.3	1.63	4.10	0.423	0.034	3.62	1.96	0.301	0.045		−8.4	−97	−3.8	−12.3	
5/23/91	508	12.02			1.65	3.94	0.413	0.034	3.68	1.96	0.310	0.045						
7/01/91	547	12.49	7.71	8.3	1.71	4.17	0.500	0.036	3.77	1.95	0.316	0.046						
8/05/91	582	13.07	7.75	8.8	2.52	3.09	0.866	0.072	4.00	2.03	0.445	0.046						
9/07/91	615	13.36	8.00	8.5	1.84	4.21	0.613	0.068	4.13	1.96	0.499	0.050						
mean		12.63	7.98	8.4	1.86	3.99	0.485	0.043	3.90	1.97	0.342	0.048	25.23					
st dev		0.52	0.21	0.2	0.23	0.29	0.131	0.013	0.30	0.05	0.065	0.005	0.93					
Cavern of Sleep Drip																		
9/07/91	615		8.30	8.9	1.76	4.21	0.249	0.021	4.22	1.75	0.199	0.045						
Hidden Lake																		
6/28/90	179	12.85	7.75	8.8	2.47	3.08	0.750	0.029	4.36	1.50	0.620	0.038	19.27					
8/10/90	222	13.61	7.95	8.9	2.90	3.09	0.633	0.032	4.75	1.56	0.600	0.040	16.65					

Table 1 Solute and isotopic data. Day zero is January 1, 1990.

Date	Day	TDS meq/l	Ph	Temp (C)	Ca	Mg	Na	K	HCO3 meq/l	SO4	Cl	F	SiO2 ppm	δ18O o/oo (Isotopes)	δ2H o/oo	δ13C o/oo	δ34S o/oo	3H TU
9/05/90	248	13.65	7.87	8.9	2.92	3.29	0.580	0.025	4.84	1.37	0.590	0.042	18.55					
10/05/90	278	13.51	7.43	8.8	3.04	3.04	0.570	0.031	4.84	1.47	0.499	0.029	19.60	−10.3	−90	−8.5	−9.9	
11/09/90	313	13.94	7.70	8.7	3.37	3.16	0.486	0.021	4.98	1.48	0.413	0.029	18.38					
4/13/91	468	14.43	7.28	8.7	3.90	3.10	0.214	0.156	5.36	1.48	0.192	0.028						
5/02/91	487	14.01	7.37	8.7	3.62	3.11	0.286	0.019	5.15	1.53	0.275	0.028		−14.1	−110	−10.3	−14.0	
5/23/91	508	13.51			3.24	3.27	0.291	0.023	4.86	1.53	0.267	0.029						
7/01/91	547	13.96	7.40	8.7	3.48	3.23	0.302	0.019	5.14	1.44	0.318	0.028						
8/05/91	582	14.12	7.50	8.9	3.71	3.16	0.313	0.024	5.13	1.47	0.278	0.032						
9/07/91	615	13.61	7.40	9.0	3.35	3.16	0.364	0.021	4.90	1.45	0.327	0.034						
mean		13.75	7.57	8.8	3.27	3.15	0.435	0.036	4.94	1.48	0.398	0.032	18.49					
st dev		0.40	0.22	0.1	0.40	0.08	0.168	0.038	0.25	0.05	0.147	0.005	1.02					
									Hansen Cave									
Hansen Cave drip																		
6/06/90	155	11.83	8.00	7.2	3.88	1.78	0.135	0.013	4.79	1.07	0.140	0.022	14.12					
6/30/90	181	11.76	7.98	7.4	3.71	1.85	0.130	0.010	4.83	1.07	0.140	0.022	14.48					
8/07/90	219	11.99	7.95	7.2	3.72	1.95	0.140	0.016	4.98	1.02	0.144	0.022	15.01					
9/07/90	250	12.30	7.80	7.2	3.87	2.00	0.144	0.010	5.03	1.08	0.144	0.022	15.58					
10/06/90	279	12.73	7.71	7.1	4.08	2.16	0.144	0.006	5.12	1.10	0.102	0.017	16.41	−11.2	−110	−9.8	−13.6	
11/09/90	313	11.95	7.53	7.5	3.80	2.06	0.148	0.009	4.74	1.09	0.095	0.016	15.70					
2/02/91	398	10.20	8.30	7.4	2.86	2.01	0.150	0.011	3.90	1.15	0.100	0.017		−14.4	−107			
3/09/91	433	12.52	8.10	7.5	4.17	2.04	0.126	0.009	4.92	1.15	0.097	0.014						
3/23/91	447	12.06	7.60	7.6	4.01	1.93	0.117	0.009	4.88	1.02	0.086	0.013						
4/13/91	468	10.77	7.90	7.9	3.57	1.73	0.103	0.008	4.41	0.85	0.082	0.015						
5/02/91	487	9.84	7.20	8.3	3.39	1.46	0.099	0.007	3.75	1.04	0.085	0.013		−15.3	−116	−10.2	−5.3	−21.3
5/23/91	508	10.65	7.45	8.3	3.83	1.40	0.109	0.006	3.71	1.49	0.090	0.013						
7/01/91	547	11.68	8.03	8.6	3.76	1.90	0.128	0.008	4.67	1.09	0.100	0.016						
8/05/91	582	11.72	8.00	7.9	3.48	2.09	0.165	0.019	4.75	1.08	0.118	0.023						
9/07/91	615	12.24	7.95	7.3	3.99	2.04	0.167	0.009	4.79	1.12	0.100	0.020						
9/18/91	626	11.60	8.00	7.4	3.83	1.84	0.130	0.009	4.65	1.03	0.094	0.017						
mean		11.61	7.84	7.6	3.75	1.89	0.133	0.010	4.62	1.09	0.107	0.018	15.22					
st dev		0.80	0.27	0.4	0.30	0.21	0.019	0.003	0.43	0.12	0.022	0.004	0.77					
Hansen Cave lake																		
6/04/90	151	10.62	7.95	7.2	3.61	1.56	0.117	0.009	3.90	1.29	0.113	0.019	14.55					
6/30/90	181	10.94	8.00	7.2	3.51	1.68	0.140	0.011	4.13	1.29	0.155	0.021	14.27					
8/08/90	220	11.07	8.10	7.4	3.37	1.88	0.145	0.018	4.28	1.19	0.172	0.022	13.63					
9/07/90	250	11.69	7.68	7.7	3.72	1.95	0.133	0.010	4.49	1.23	0.140	0.019	15.18					
10/06/90	279	11.79	7.65	7.9	3.67	1.87	0.130	0.012	4.88	1.12	0.096	0.013	15.31	−14.6	−110		−9.7	
11/09/90	313	11.72	7.42	7.6	3.72	1.92	0.135	0.029	4.71	1.10	0.095	0.013	15.47					
2/02/91	398	10.21	7.90	7.2	2.82	2.13	0.161	0.012	3.84	1.14	0.098	0.015		−14.9	−107			

Date	Day	TDS meq/l	Ph	Temp (C)	Ca	Mg	Na	K	HCO3 meq/l	SO4	Cl	F	SiO2 ppm	δ18O o/oo	δ2H o/oo	δ13C o/oo	δ34S o/oo	3H TU
														Isotopes				
3/09/91	433	10.38	8.15	7.3	3.03	2.01	0.147	0.011	3.96	1.10	0.108	0.017						
3/23/91	447	10.45	8.00	7.3	3.15	1.91	0.129	0.008	4.11	1.03	0.093	0.016						
4/13/91	468	9.97	8.05	7.3	3.23	1.61	0.088	0.007	4.17	0.77	0.081	0.013						
5/02/91	487	9.64	7.68	7.3	3.18	1.46	0.088	0.007	3.88	0.93	0.083	0.013		−15.1	−116	−10.2	−5.3	21.3
5/23/91	508	10.20	7.70	7.3	3.45	1.43	0.102	0.007	3.83	1.27	0.093	0.013						
7/01/91	547	10.39	7.95	7.4	3.47	1.49	0.106	0.008	3.96	1.25	0.097	0.014						
8/05/91	582	10.75	8.05	7.3	3.67	1.65	0.135	0.011	3.99	1.19	0.094	0.014						
9/07/91	615	11.02	7.80	7.4	3.63	1.71	0.146	0.009	4.24	1.17	0.100	0.017						
9/18/91	626	10.55	8.00	7.4	3.55	1.58	0.124	0.009	4.29	0.90	0.088	0.015						
mean		10.71	7.88	7.4	3.42	1.74	0.127	0.011	4.17	1.12	0.107	0.016	14.74					
st dev		0.61	0.20	0.2	0.26	0.21	0.021	0.005	0.30	0.15	0.025	0.003	0.65					
									Middle Cave									
Middle Cave drip																		
6/06/90	157	13.61	8.05	7.7	3.63	2.91	0.207	0.023	4.92	1.73	0.158	0.033	16.02					
6/30/90	181	12.87	8.10	8.9	3.44	2.87	0.223	0.032	4.41	1.69	0.187	0.028	16.96					
8/08/90	220	13.64	8.10	8.3	3.62	2.93	0.214	0.018	4.93	1.71	0.183	0.028	15.81					
9/07/90	250	13.66	7.79	8.3	3.62	2.91	0.207	0.023	5.00	1.69	0.183	0.029	16.21					
10/06/90	279	13.60	8.06	7.8	3.60	2.88	0.193	0.018	4.99	1.76	0.138	0.020	16.02	−14.6	−110		−9.7	
11/09/90	313	11.70	8.32	6.4	3.03	2.50	0.193	0.012	4.33	1.49	0.128	0.021	15.02					
2/02/91	398	11.00	8.40	6.8	2.67	2.34	0.171	0.017	4.15	1.49	0.140	0.020	14.86	−12.3	−97			
3/09/91	433	11.40	7.65	6.8	2.73	2.27	0.236	0.125	4.27	1.56	0.190	0.023						
3/23/91	447	10.92	8.10	6.9	2.65	2.25	0.153	0.017	4.28	1.43	0.121	0.020						
4/13/91	468	10.87	7.95	6.9	2.70	2.20	0.148	0.018	4.20	1.45	0.131	0.020						
5/02/91	487	11.37	7.32	6.9	2.82	2.33	0.153	0.018	4.40	1.49	0.140	0.020		−15.1	−113	−8.2	−13.7	
5/23/91	508	12.61	7.55	6.9	3.23	2.68	0.208	0.017	4.70	1.61	0.140	0.021						
7/01/91	547	12.52	7.89	8.7	3.27	2.75	0.181	0.018	4.55	1.64	0.092	0.020						
8/05/91	582	12.63	7.90	9.0	3.19	2.90	0.208	0.023	4.61	1.53	0.148	0.026						
9/07/91	615	12.55	7.80	8.5	3.31	2.70	0.204	0.019	4.62	1.53	0.148	0.022						
9/18/91	626	12.11	7.95	8.5	3.07	2.63	0.200	0.021	4.50	1.51	0.148	0.023						
mean		12.32	7.93	7.7	3.16	2.63	0.194	0.026	4.55	1.58	0.148	0.023	15.84					
st dev		0.98	0.27	0.9	0.35	0.26	0.025	0.026	0.28	0.10	0.026	0.004	0.66					
Middle Cave lake																		
6/06/90	157	8.89	8.07	6.7	2.37	1.84	0.178	0.029	3.34	0.96	0.150	0.024	15.30					
6/28/90	179	9.76	7.95	7.4	2.48	2.06	0.239	0.027	3.57	1.08	0.284	0.023	18.16					
8/08/980	220	10.22	8.15	8.3	2.49	2.29	0.244	0.019	3.69	1.21	0.259	0.024	22.24					
9/05/90	248	10.68	8.11	8.0	2.63	2.44	0.285	0.024	3.70	1.31	0.262	0.025	29.04					
10/05/90	278	10.41	7.75	7.9	2.53	2.42	0.262	0.022	3.58	1.37	0.197	0.021	29.98	−6.7	−73	−4.9	−16.0	
11/09/90	313	9.42	8.19	6.6	2.27	2.23	0.231	0.028	3.29	1.18	0.183	0.020	26.10					
2/02/91	398	10.16	8.30	6.7	2.63	2.33	0.223	0.026	3.47	1.29	0.170	0.021		−12.1	−94			

Date	Day	TDS meq/l	Ph	Temp (C)	Ca	Mg	Na	K	HCO3 meq/l	SO4	Cl	F	SiO2 ppm	δ18O o/oo (Isotopes)	δ2H o/oo	δ13C o/oo	δ34S o/oo	3H TU
3/09/91	433	5.75	8.00	6.8	1.65	1.21	0.084	0.015	2.21	0.50	0.080	0.012						
3/23/91	447	5.75	8.00	6.9	1.63	1.22	0.084	0.015	2.21	0.50	0.079	0.015						
4/13/91	468	7.80	8.01	6.9	2.16	1.72	0.116	0.017	2.91	0.76	0.108	0.015						
5/02/91	487	8.47	7.85	7.0	2.27	1.87	0.126	0.019	3.23	0.83	0.113	0.016		−13.8	−98	−7.3	−7.8	
5/23/91	508	9.64	8.21	7.2	2.53	2.11	0.149	0.024	3.66	1.03	0.125	0.018						
7/01/91	547	9.17	8.01	7.4	2.48	1.96	0.149	0.030	3.49	0.92	0.120	0.016						
8/05/91	582	9.70	7.90	7.8	2.54	2.07	0.204	0.034	3.65	1.03	0.149	0.022						
9/07/91	615	9.83	7.95	7.9	2.60	2.11	0.278	0.039	3.58	1.05	0.168	0.018						
9/18/91	626	6.97	7.90	7.9	1.88	1.45	0.148	0.028	2.76	0.59	0.102	0.017						
mean		8.91	8.02	7.3	2.32	1.96	0.188	0.025	3.27	0.98	0.159	0.019	23.47					
st dev		1.52	0.14	0.5	0.32	0.38	0.065	0.007	0.48	0.27	0.062	0.004	5.43					
Surface Water																		
Cattle Creek headwaters																		
6/29/91	545		7.75	7.0	3.57	0.38	0.110	0.005	3.82	0.21	0.047	0.003						
Cattle Creek spring																		
6/29/91	545		7.72	6.0	4.37	0.41	0.135	0.008	4.43	0.38	0.122	0.005		−16.3	−120	−15.5	−10.4	
Storm runoff−Middle Cave surface drainage																		
9/13/91	621				1.12	0.66	0.071	0.008	1.46	0.24	0.041	0.008						
Snow Pack																		
3/09/90	68													−17.1	−125	−25.6	+8.3	
2/24/91	420													−17.5	−131	−28.0		11.7

A PROFILE OF THE BUTLER CAVE CONSERVATION SOCIETY, INC.

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ABSTRACT

The Butler Cave Conservation Society (BCCS), Inc. is a non-profit scientific, education, and conservation organization incorporated in Virginia. Formed in 1968, the BCCS is the oldest such organization to employ ownership of wilderness resources as a major element of its conservation strategy. Originally formed to manage and conserve the Butler Cave-Sinking Creek System, neither the BCCS constitution nor its bylaws geographically limit its activities. Most BCCS activities, however, have been concentrated in an area of west-central Virginia called Burnsville Cove.

The goals of the BCCS are: to perform scientific studies of caves, to conserve caves for future study, and to educate the public on the value of these unique wilderness resources. The scientific, educational, and conservation projects of the BCCS are discussed. A key element of the BCCS conservation strategy is access control via the techniques of ownership, leasing, gating, and secrecy.

The thirty-seven member BCCS is operated by a seven member Board of Directors (BOD) that includes the three officers of the society (President, Vice President, and Secretary/Treasurer). The main responsibilities of the BOD are to run the society between annual membership meetings and to manage its membership policies. New members are elected by the BOD in compliance with a strictly controlled membership limit. Historical membership trends and characteristics of the current BCCS membership are presented. Current assets of the BCCS include both the longest cave and the deepest cave in Virginia and more than thirty surveyed miles of passages. Major events in the history of the BCCS are discussed.

1. INTRODUCTION

The Butler Cave Conservation Society, Inc. is a non-profit scientific, education, and conservation organization incorporated in Virginia. It was formed in November of 1968 and is the oldest such organization to employ ownership of wilderness resources as a major element of its conservation strategy.

The BCCS was originally formed to manage and conserve the Butler Cave-Sinking Creek System commonly known as Butler Cave. Butler Cave was discovered in May of 1958 (see Nicholson and Wefer, 1983), so that by the time the BCCS was formed, the cave had been known for ten years. Although access during that period had been generally limited to exploration and survey trips, unauthorized "tourist" and "orientation" trips were beginning to have an effect on the cave in the forms of spent carbide, litter, graffiti, and breakage.

Several related events contributed to the formation of the BCCS. For example, because of an earlier involvement in the exploration, survey, and mapping of nearby Breathing Cave, members of the Nittany Grotto of the National Speleological Society (NSS) were in 1968 leading these same activities in Butler Cave. The Nittany Grotto cavers not only had considerable skills in the surveying and mapping of large caves, they also possessed some unique experience in the managing of wild caves.

Hosterman's Pit Cave (located in Centre County, PA) had been discovered in 1961 (Davis, 1963). Concerned about liability, the owners had requested that the Nittany Grotto gate the cave and limit access to qualified cavers, a process begun in 1963. By 1968 Nittany Grotto members had five years of experience at managing a gated wild cave, experience that clearly demonstrated that gating and strict access control were viable (if unpopular) conservation techniques. The Hosterman's experience gave us confidence that the same techniques would work in Virginia. What was to us the obvious need for conservation via access control was the main reason that the BCCS was formed, and the reason that many of its early supporters were cavers from Pennsylvania.

While most BCCS activities have been concentrated in an area of west-central Virginia called Burnsville Cove, it should be noted that neither the BCCS constitution nor its bylaws geographically limit its activities. In recent years the BCCS has expanded its horizons by sponsoring an international expedition to Mexico and several to the Dominican Republic.

2. SCIENTIFIC ACTIVITIES OF THE BCCS

Scientific activities of the BCCS include: geography, cartography, geology, hydrology, biology, meteorology, and related subjects. Each of these is touched upon very briefly below. The intent here is to mention the existence of the activity and to provide a reference to more detailed information. The referenced works describe activities officially sponsored by the BCCS, scientific works which have drawn upon the resources of the BCCS, and activities stimulated by interaction with the BCCS.

2.1 GEOGRAPHY

The primary activities of geography include exploring, surveying, and mapping. Exploration activities of the BCCS have been extensively discussed in the literature. They include exploring the caves in Burnsville Cove as well as caves in other areas of the world.

2.1.1 EXPLORING

In Burnsville Cove the exploration of Breathing Cave, Butler Cave, Better Forgotten Cave, and Aqua Cave have been documented by Wefer and Nicholson (1982). Some statistical characteristics of Butler Cave revealed as a result of its exploration were presented by Wefer (1986a). The more recent exploration of Lockridge Aqua Cave has been covered by Rosenfeld (1986). The exploration of Bobcat Cave has been partially covered by Clemmer (1988), only partially because the process is far from complete. The beginnings of the exploration of the Cathedral System have been discussed by Simmons (1990).

In other areas of the world the exploration of Cueva Diamante in San Louis Potosi, Mexico has been discussed by Rosenfeld (1987), Shifflett (1987), and Wefer (1988a). The exploration of caves in the Dominican Republic (an on-going BCCS project) has been described by Wheeland and Frank (1987), Veni (1987), Wheeland (1987), Veni and Wheeland (1987), Frank (1987a and 1987b), and Veni, Frank and Wheeland (1987).

Aspects of the expedition activity itself as it relates to Butler Cave have been discussed by O'Holleran (1979) and Maxwell (1986) in attempts to better understand how expeditions should be organized and run. Current BCCS practices for expeditions both within and outside of Burnsville Cove are discussed below.

2.1.2 SURVEYING

The BCCS has an active program of surveying the caves it explores. The survey and exploration of Butler Cave and Breathing Cave have involved the use of radio location equipment for finding surface points above key locations in the caves. A detailed study of the radio location technique, especially as it relates to the radio frequencies most useful, was published by Davis (1970).

The computer processing of cave survey data was discussed by Wefer (1971). The computer correction of errors in survey loops was studied by Wefer (1974a and 1974b) using data from BCCS surveys. Techniques used in surveying the caves of the Sinking Creek System were discussed by Igoe (1982) and by Wefer (1982). Studies of the origin, detection, and correction of blunders in survey data have been extensively documented by Wefer (1987, 1988b and 1988c).

2.1.3 MAPPING

The BCCS has an active program of producing maps from the data gathered during the surveying process. Maps have long been available (see, e.g., David and Wefer, 1976) for several of the smaller caves in Burnsville Cove including: Armstrong Cave, Chestnut Ridge Blowing Cave, Boundless Cave, and Better Forgotten Cave. A foldout version of the map of Breathing Cave was provided in Wefer and Nicholson (1982) whose paper also presented several maps of Butler Cave. More detailed maps of Butler Cave are available in eleven large sectional maps currently in the process of being field checked.

In addition to maps of the caves themselves, maps of the surface showing the locations of the cave entrances and maps showing the relationships of passages to surface features have been generated. Detailed large scale maps of Burnsville Cove of the latter type are closely held; however, less detailed versions have been published, for example in Wefer and Nicholason (1982).

2.2 CARTOGRAPHY

In the area of cartography, i.e., the science of making of maps, new ideas and techniques in the computerized generation and display of three-dimensional maps have been explored. Results have been presented in a number of forums: at the 1983 NSS Convention by Wefer, Igoe, and Gillen (1983), at technical conferences by Wefer (1985a and 1986b), in a series of articles in Compass & Tape by Wefer (1989a, 1989b, 1989c, 1990a, and 1990b), and at the 1991 NSS Convention by Wefer (1991a).

2.3 GEOLOGY

White and Hess (1982) documented the study of the geomorphology of Burnsville Cove and the geology of the Butler Cave-Sinking Creek System. The mineralogy of the Butler Cave-Sinking Creek System was discussed by White (1982). Chess (1982) presented preliminary results of a study of the sediments in Butler Cave. White (1984) described the beginnings of a study of paleomagnetism in the clastic sediments in Butler Cave. A preliminary value for the age of these sediments is greater than 730,000 years. White and White (1991) used Burnsville Cove as an example in their study of karst erosion surfaces in the Appalachian Highlands.

2.4 HYDROLOGY

A study of the hydrogeology of Burnsville Cove was presented by Hess, Davis, and Wefer (1971) at the 1970 NSS Convention. Davis and Hess (1982) presented the results of a six-year study of the drainage areas of Burnsville Cove, delineating the recharge areas of four major springs in the Bullpasture Gorge. Harmon and Hess (1982) studied the geochemistry of Burnsville Cove. Chess (1983) described a research project in environmental pollution in the Burnsville karst. He then carried out the project (see Chess (1987)) performing chemical analyses of water from surface and subsurface streams in Burnsville Cove and also performing analyses of total plate bacteria and total coliform.

2.5 BIOLOGY

A preliminary report on the cave fauna of Burnsville Cove prepared by Holsinger (1982) listed nineteen species of cave animals. In the area of paleontology, a small section of passage in Bobcat Cave contains hundreds of mud footprints identified as those of an extinct fisher (martes pennanti) (Clemmer, 1989). Robbins and Haas (1989) discovered filamentous bacteria on the surfaces of red stalactites in Butler Cave, bacteria thought to be responsible for the red color of these formations.

2.6 METEOROLOGY

The variations of the temperature, partial pressure of water vapor, and relative humidity in Butler Cave are being studied as functions of time (season) and position (within the cave). More than 600 pairs of temperature measurements (wet-bulb and dry-bulb) have been made since the study began in April 1984. Preliminary results of the study and related information have been presented in a number of forums: at the 1989 NSS Convention by Wefer (1989d), at the 1991 Appalachian Karst Symposium by Wefer (1991b), and in a series of newsletter articles by Wefer (1984a, 1985b, 1988d, 1989e, 1989f, and 1990c). An annotated bibliography of cave meteorology has also been published by Wefer (1991c) for use by other researchers in the field.

3. EDUCATIONAL ACTIVITIES OF THE BCCS

Educational activities of the BCCS include publishing articles on the scientific activities of the society (in NSS grotto newsletters, the BCCS Newsletter, the NSS Bulletin, etc.) and giving papers at NSS conventions and scientific and management symposia, as discussed above. In addition, in Butler Cave the BCCS has held hands-on training sessions on cave surveying techniques and rescue techniques (see Jones (1982), Maxwell (1982a and 1982b), and Williams (1982a and 1982b).

A very important aspect of education is land owner relations. Efforts at maintaining good land owner relations have included: frequent contact with other land owners of Burnsville Cove, slide presentations to them introducing the BCCS and explaining its activities, and BCCS members individually becoming land owners (eight members now own property in the immediate area).

4. CONSERVATION ACTIVITIES OF THE BCCS

The conservation strategy of the BCCS derives from an attempt to balance two conflicting desires, to understand the caves and to conserve the caves. The conflict arises because the process of understanding the caves (the scientific study of the caves) almost always requires human visitation, and it is recognized that any human visitation has effects, often adverse, on the cave environment. The strategy is to decrease the quantity of human visitation while simultaneously increasing the quality of that visitation, in an effort to ensure that whatever effects the visitation has are cost-effective in terms of balancing the two desires.

In a study of American cavers and their caves Wilson (1978) estimated that the human visitation in Butler Cave is approximately one tenth of what it would be if the cave were open. Allowing entry only for specific purposes and requiring the presence on the trip of a BCCS member (or other responsible person) are measures used to increase the quality of the visitation. A favorable assessment of the conservation techniques and effectiveness of the BCCS was made by Wilson (1981a) who compared five groups which manage wild caves in Virginia and West Virginia.

4.1 ACCESS CONTROL

The BCCS employs a number of techniques to control access to the caves it manages in Burnsville Cove, including: ownership, leasing, gating, secrecy, benign disinformation, and local expeditions. Leasing and ownership of the land surrounding the entrances have both been employed. Once control of the land has been achieved, the entrances can be gated to prevent entry by people who will not respect notices and signs. The BCCS has gated only two of the caves it manages. Wilson (1981b) has discussed some important considerations associated with cave gates and the gating of wild caves for conservation purposes.

Ownership is preferred over leasing because it gives some immunity to problems that can arise with the change in ownership resulting from the death of the owner. Sons and daughters may not share the values of their fathers and mothers, and this can cause real problems for cavers leasing the land.

Burnsville Cove is a relatively large area containing many caves not controlled by the BCCS. The simplest (and perhaps the most effective) way to conserve these caves (to decrease visitation while increasing the value of the visitation) is to not publicize their existence. In some cases, this means keeping the existence of a cave secret from the caving community at large. The BCCS tries to avoid situations where the existence of a cave must also be kept from the landowner.

In at least one case, benign disinformation has been used to forestall interest in a cave being explored and mapped by the BCCS. Bobcat Cave had been "discovered" during the autumn of 1983 (see Clemmer

(1988)) by pushing very difficult passages in a previously known cave. The cave was renamed Bobcat Cave to make it possible to refer to it without giving away its true identity. By 1984 word of the exploration of a new, large, and beautiful cave in Burnsville Cove was beginning to leak out. The cave's name was beginning to be known, but management control of the entrance had not yet been achieved. That year the BCCS Newsletter contained an article called "The Secret of Bobcat Cave" (see Wefer 1984b)). The title of an already written article as well as the name of the cave in this work of fiction were changed in order to create confusion in the caving community. The honest mention of the article by Dyas (1985) in the NSS News only added to the effect. In the end the BCCS was able to achieve access control by gating the cave (with the owners' permission), and in May of 1988 the BCCS purchased the tract of land containing the entrance.

Local expeditions not only serve to provide manpower for BCCS scientific projects, they also provide an important safety valve. If the caves were simply closed, leaving cavers with no hope of getting in, frustration would likely build until serious and probably illegal actions would be taken to gain entry. The fact that nearby Breathing Cave has been open to the public almost continuously during the entire history of the BCCS has also acted as a safety valve. This is the major reason the BCCS has not attempted to gain management control of Breathing Cave.

4.2 MANAGEMENT PLANS

Management plans (see Wefer (1989g)) have been developed for the two major caves owned by the BCCS (Butler and Bobcat). These plans take into account both the similarities of the two caves (comparable size, location, ownership, and access control methods) and their differences (difficulty of travel, length of travel, need for camping in the cave, and team size limitations).

Both of these caves originally had very small entrances and some digging was required to gain initial entry. Access to both caves is now controlled via cave gates that control access by humans without restricting the movement of the indigenous fauna. Visitation is restricted primarily to expeditions held in furtherance of the scientific study of the caves.

4.3 EXPEDITIONS

The BCCS currently holds five or six expeditions per year at Butler Cave. At these expeditions cavers (members and non-members) meet at the Butler Homestead (the field house on the Butler Homestead Property) and are assigned to work details based on matching their talents and skills to the list of ongoing projects. Butler Cave Expeditions are essentially open to all qualified cavers willing to help further the aims of the BCCS. It is common practice to make adjustments in expedition plans based on the skills and equipment of the people who actually show up at the expedition. The actual work is usually performed within Butler Cave, but may, on occasion, take place in other caves in Burnsville Cove.

Bobcat Cave Expeditions are restricted to those people who, in the judgment of the Bobcat Expeditions Leader, are physically and mentally able to withstand the rigors of the cave, have the necessary equipment for camping and caving for extended periods underground, and have skills specifically required for the particular expedition. As a conservation measure, expeditions involving camping in the cave are restricted to a total team underground of nine people.

International expeditions, sponsored on an ad hoc basis by the BCCS, are approved by the Board of Directors (see below). Normally no financial backing is provided with BCCS sponsorship. A report of the scientific findings of the expedition is required to be provided for publication in the BCCS Newsletter.

5. THE ORGANIZATION

As stated above, the BCCS is a non-profit scientific, education, and conservation organization. It is recognized by the IRS as a tax exempt organization under section 501(c)(3) of the Internal Revenue Code. Details of the structure of the BCCS are contained in its articles of incorporation (see Stellmack, Davis, and Nicholson (1970)) and in its bylaws (Sproul (1972)). The existence of the BCCS was brought to the attention of the general caving community by Stellmack (1971). Hess (1976) discussed the BCCS at the 1976 National Cave Management Symposium. His paper also included a copy of the articles of incorporation.

The three recognized elements of the organization are: the BCCS Board of Directors, the BCCS Members, and BCCS Friends, each of which is discussed below.

5.1 BCCS BOARD OF DIRECTORS

A seven member Board of Directors (BOD) runs the BCCS between regular annual membership meetings. The BOD consists of the three society officers (President, Vice President, and Secretary/Treasurer) plus four directors at large. All seven members of the BOD are elected by the members each year at the regular annual membership meeting. The only formal requirement is that members of the BOD must already be members of the BCCS.

The BOD has the major responsibility of managing membership policies. New members of the BCCS are elected by the BOD, not by the existing membership. A strict limit is provided in the bylaws on the total number of members, a limit that can be changed only by a unanimous vote of the seven members of the BOD. This bylaw was specifically designed to empower the minority, as described in some detail by Wefer (1980).

5.2 BCCS MEMBERS

There are no formal membership procedures. By design, anyone is eligible for membership in the BCCS. In contrast to the NSS, there is only one class of membership in the BCCS. Annual dues are currently $45, life membership is $1500. Readers interested in additional information on membership in the BCCS are referred to Wefer (1978a and 1978b) and Williams (1978).

Membership in the BCCS is viewed as a long-term commitment. New members typically have demonstrated this commitment by: past support, agreement with society goals, compatibility with the existing membership, acceptance of possible financial obligations, possession of superior caving skills, and considerable patience. Membership in the BCCS is not touted; there are few benefits, participation is possible without being a member, and membership only means responsibilities.

BCCS members are responsible for helping to define the goals of the society, helping to develop policies that support the goals, providing guidance to the BOD in making major decisions, and providing the necessary resources for achieving the society goals, namely: ideas, labor and money.

The following statistical information on the BCCS membership is based upon data available in October 1991. The number of BCCS members was 37 (the membership limit was 38). It may be interesting to note that while membership in the NSS is not a requirement for membership in the BCCS, 33 BCCS members (89%) were also NSS members. In fact, 9 of the BCCS members (24%) were life members of the NSS and 14 (38%) were fellows of the NSS (including six of the BOD members). Included in the 1991 BCCS membership were: two members of the NSS Board of Governors, two Certificate of Merit winners, two Honorary Members, one Outstanding Service Award winner, and one Lew Bicking Award winner.

The total number of people who had ever been members of the BCCS was 47, hence there were 10 ex-members in the 23 year history of the BCCS. Of these 10 ex-members, 9 were no longer members of the NSS, indicating that they had simply lost interest in caving vice lost interest in the BCCS per se. The membership turnover rate was very low, less than 1% per year. In the BCCS the member/ex-member ratio was 3.7 (there were 3.7 times as many members as ex-members). By comparison, in the NSS this ratio was 0.36, i.e., ex-members vastly outnumbered members.

Table 1 below shows the distribution by state of BCCS members for the three decade years spanned by the history of the society. As can be seen, initially the majority of the members were from Pennsylvania. In the early days of the society this fact was a major point of contention between the BCCS and more local cavers (from Maryland and Virginia). As time went on and it became clear that the BCCS was a successful enterprise, local cavers began to support BCCS efforts and gradually became members. The membership is now more evenly split between Pennsylvania and Virginia, with a smattering of members from states across the country.

STATE	1970	1980	1990
PENNSYLVANIA	16 (67%)	10 (33%)	13 (36%)
VIRGINIA	5 (21%)	9 (30%)	10 (28%)
MARYLAND	1 (4%)	3 (10%)	4 (11%)
N. CAROLINA		1 (3%)	3 (8%)
IDAHO		1 (3%)	1 (3%)
NEVADA		1 (3%)	1 (3%)
COLORADO		1 (3%)	1 (3%)
TEXAS			1 (3%)
WASHINGTON			1 (3%)
FLORIDA			1 (3%)
OHIO		1 (3%)	
CALIFORNIA		1 (3%)	
ALASKA	1 (4%)	1 (3%)	
MICHIGAN		1 (3%)	
INDIANA	1 (4%)		
TOTAL	24	30	36

Table 1. BCCS Membership Distribution. This table shows the distribution of BCCS members by state in three decade years. Representation from Pennsylvania and Virginia have been comparable for the last decade.

5.3 BCCS FRIENDS

Friends of the BCCS are non-members who participate in the activities of the BCCS. This participation may be in local expeditions (Butler Cave, Bobcat Cave, or others) or non-local expeditions (Mexico, the Dominican Republic, or others). It may also be in such activities as helping to maintain the road to the field house or helping to maintain the field house itself. Friends may also attend BCCS meetings and participate in discussions, but have no vote.

BCCS Friends receive free of charge the annual BCCS Newsletter that chronicles the year's activities. Included among the BCCS Friends are those people who make financial contributions to the society, which are, of course, tax deductible. BCCS Friends number between one and two hundred, the number varying from year to year.

5.4 RELATIONSHIP TO THE NSS

The BCCS is not an Internal Organization of the NSS. The BCCS was founded during a period when the NSS was still in the process of deciding the appropriateness of cave ownership as a conservation strategy. In addition, no clear consensus had yet developed on the controversial topic of gating wild caves. Had the BCCS been limited by the then current thinking of the NSS, it would likely never have been formed. Independence from the NSS is felt to be essential to the operation of the society. Accordingly, the BCCS is not bound by NSS policies and/or guidelines on items such as: membership availability, neophyte training, caving practices, or conservation strategies.

The BCCS has been termed a "supergrotto," i.e., an organization that draws its membership from a much wider geographic area than traditional NSS Grottos (see Dyas (1980)). Other attributes of supergrottos include a veteran constituency with less emphasis on novice training, entertaining programs, etc., and only a loose association with the NSS.

The BCCS recently became a conservancy of the NSS. As such, the BCCS serves on the NSS Cave Ownership and Management Committee of the Department of the Secretary/Treasurer. This committee is charged with developing a consistent and workable long-term program for the ownership and management of caves. The committee endeavors to answer any questions on cave management and encourages groups or individuals to ask for assistance relating to cave management.

6. CURRENT ASSETS

The BCCS currently owns two properties in Burnsville Cove. The Butler Homestead Property was purchased in January of 1975 and paid for in November of 1983. It contains the single entrance to the Butler Cave-Sinking Creek System. Butler Cave is the largest cave in the state of Virginia with an approximate length of 17.2 miles and a depth of 624 feet. The property also contains the Butler Homestead, a field house that sleeps fifteen and serves as headquarters for local expeditions. There are some other minor assets on the property, e.g., a log barn and some very small caves/pits.

The Chestnut Ridge Property was purchased in May of 1988 and is not yet paid for. It contains the single entrance to Bobcat Cave. Bobcat Cave is the deepest cave in the state of Virginia with an approximate length of 9.3 miles and a depth of 722 feet. The property also contains the entrance to infamous Better Forgotten Cave with an approximate length of 0.8 miles and a depth of 420 feet, plus the entrances to several other minor caves and pits.

7. SUMMARY

The BCCS is a Virginia based non-profit scientific, education, and conservation organization. Formed in 1968, its goals are: to perform scientific studies of caves, to conserve caves for future study, and to educate the public on the value of these unique wilderness resources. The BCCS is the oldest such organization to employ ownership of wilderness resources as a major element of its conservation strategy.

The thirty-seven member BCCS is operated by a seven member Board of Directors whose main responsibilities are to run the society between annual membership meetings and to manage its membership policies. New members are elected by the BOD in compliance with a strictly controlled membership limit. Current assets of the BCCS include both the longest cave and the deepest cave in Virginia and more than thirty surveyed miles of passages. Further information about the BCCS and its activities may be obtained by writing the author.

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"PETER PIPER MAPPED A CAVE IN PICKLE PARK"

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ABSTRACT

Meramec State Park has long been a Pied Piper to Missouri's prolific mappers and speleologists. Maps of Fisher Cave record successive improvements in cartographic techniques as each new generation became obsessed with accurately representing this cave. A state of the art map is in the process, but the map perfecting process will never end.

For centuries now, man has been attempting to find new ways in which to accurately depict and interpret the surface features on the planet Earth. If we were to examine some of the early methods and compare them to today's informational gathering and production techniques, we too would be able to see how the maps and the information contained therein are more valuable tools. Speleologists, on the other hand, became intrigued with the features contained under the surface and began the process of accurately depicting the subsurface environment. Essentially, this is a process which continues to challenge the speleologists of the Missouri Speleological Survey.

The Missouri Speleological Survey, Inc. developed as an inspiration of three of Missouri's most honored speleologists--Jerry D. Vineyard, Dr. Oscar Hawksley and Frank Dahlgren. In 1956, these men saw a need for an organization that would be dedicated to locate, record, explore, study and conserve Missouri's cave resources. Many cavers throughout the U.S. and abroad have probably read of Luella Owens speleological endeavors in the 1800's and early 1900's, or of J Harlan Bretz's speleological studies in the 1950's in Missouri. In his book, "Caves of Missouri" published in 1956, Dr. Bretz located, explored and reported on 133 of the 437 caves that were known within the state. Perry County, Mo. alone had 650+ caves in 1991, however, Dr. Bretz recorded only three caves in 1956. Presently, Perry County contains the four longest caves in the State.

After thirty five years, the M.S.S. has developed the following information base through the cooperative efforts of the Geologic Survey and the cavers.

a. a huge database which contains Cave Reports, Maps and Photo files.

b. numerous scientific projects and studies have been completed and published in its scientific journal--Missouri Speleology.

c. cavers throughout the state have located 5,000+ caves.

d. M.S.S. cartographers have taken cartographic techniques from their infancy stages to a highly technological state of the art modality.

The cave maps, being produced today, are used by many State and Local agencies to provide relevant information regarding the planning and implementation stages of projects. One such example is the stormwater project within the City of Perryville. Perryville is located on a karst plain very similar to Bowling Green Kentucky and shares many of the same problems. The mapping techniques employed were so accurate that the information was used in planning a stormwater drainage system utilizing the cave systems. We accurately determined the trend of the Streiler City Cave and how a tunnel and moat system could be utilized to prevent the widespread flooding which occurred in this low lying area while minimizing impact on the subsurface drainage patterns. For drilling purposes, the Metropolitan St. Louis Sewer District used an electronic "water witching" device to determine the drill site; the cavers stated that if the city would drill in another area, they would intersect the cavern passage. The first hole was drilled and missed the open passage below by inches. When the caver's suggestion was taken, the drill intersected the middle of the cave passage.

ORIGINS OF MERAMEC STATE PARK

Fisher Cave has been probably know to the local resident of the Franklin County since Philipp Renault began investigating caves in the area for saltpetre and lead in 1720. The park terrain was described as "wild, hilly country." At the time of purchase only nine caves were known to exist on the consolidated acreage.

However our story begins in the early 1900's with the members of the Thomas Benton Dill family. The land on which Fisher Cave is located has had many owners but at this time actually belonged to the Leo and Henry Fisher families. Lester Dill first visited Fisher Cave with his father when he was six and it was love at first sight, the cave provided a fascination that would continue throughout his lifetime. Leo Fisher allowed Les to use the cave to make small change which was and still is a very popular tourist attraction. People would come out from St. Louis during the summer and stop at the Dill farm and ask Thomas Dill to take them on tours in Fisher.

A year prior to the dedication of the park a "Name the Park" contest was sponsored by the St. Louis newspapers. Three of the former landowners cast one vote each for "Dill-Pickle State Park". Legend has stated the Mrs. Maggie L. "Dill" wrote that her husband John Dill was raised and played with the "Pickle" family youngsters on the land which was later dedicated as Missouri's second largest state park. It was largely through the efforts of Joseph H. Bennett that the area became a state park. It was dedicated on September 8, 1928 and Thomas Dill became the park's first superintendent. Therefore the meaning of "Pickle Park". Now to explain the first portion of "Peter Piper Mapped a Cave".

With over thirty caves, Meramec State Park near Sullivan, Missouri has long been a "Pied Piper" to Missouri's prolific mappers and speleologists. Maps of its Fisher Cave record successive improvements in cartographic techniques as each new generation became obsessed with accurately depicting this very intriguing cave. Newly discovered passages or obvious errors in the existing maps have provided the impetus for remapping this cave. A state of the art map is in the process but the cave learning process and map perfecting process will never end.

DEVELOPMENTS IN THE MAPPING PROCESS

During the early mapping process, the techniques employed were generally completed in a haphazard and inaccurate manner. The people giving the tours were primarily interested in the commercialization aspects of the enterprise; little attention was paid to the Geological, Hydrological or Biological significance of these karst features. Les Dill once stated that the tourists provided the information which governed how he presented the cave during his tours. However, today's speleologist asks the questions--How, Why, Where. They wish to know and study the interrelationships between the geologic, hydrologic and speleogenesis factors and depict this information in their maps. If you examine figure 1. you will see some of the results of this research. It shows the relationship between the some of the springs and caves located within the central portion of the park.

The first map drawn of Fisher Cave was completed in 1931, shown in it are essentially only the major features and the walls. The cartographer was challenged to develop what she thought were appropriate symbols for the features, at that time. (Figure 2)

Even when the cave was remapped in 1958, symbols for depicting features in the caves were still in a very rudimentary stage. This map showed more detail however, it too had several problems. (Figure 3)

The cave is approximately 5,000 feet in length and in order to complete the map in an efficient manner, the members of the Middle Mississippi Valley Grotto developed several mapping teams to complete this task and appointed a "Chief Cartographer". Also during this time period, since these were "large" caves, surveyors attempted to complete entire maps in a weekend's time frame. They usually met on Friday evenings and mapped for a while then slept and continued the surveying process on Saturday and Sunday.

In 1981, Eugene Vale, a seasonal naturalist at Meramec State Park, determined that the entrance passage contained an error of forty five (45) degrees. Since the 1931 map, several man-made changes had occurred within the cave--an iron entrance gate at the mouth of the entrance had been installed; the CCC had built concrete walkways, stairs, bridges and trails complete with iron handrailing throughout the cave. Therefore establishing the first opportunity for several errors in the 1958 map, compass bearings were taken too near to the "iron" railings or gate. Since there were several mapping teams, another error can be attributed to the lack of consistent sketching and data collection methods. Were these mapping teams going for distance or accuracy? Another inconsistency is that most of the instruments used were hand held and depended on the reader to determine the bearing; backsights were a technique of the future. Changes in elevation, as we now know, will have an effect on the distance of the shot and the placement of significant features within a given area. As the stages of cave surveying have advanced so have our techniques and instruments. The age old debate of distance versus accuracy continues and it is a decision each cartographer must make himself.

The third remapping of Fisher Cave began in 1980 (Figure 4), after the discovery of the 45 degree error, by the same gentleman who was responsible for the second map of Fisher, Gregory "Tex" Yokum. Since his maps in the early 60's, Tex had produced many maps and strived to advance his cartographic styles and accuracy. The 80's map is more artistic in style and had the assistance of a "significantly" developed M.S.S. symbols table. He was again the "chief cartographer" however he was employing more consistent techniques in his surveying efforts this time. The role of the "chief cartographer" can be compared to that of an orchestra leader, he or she orchestrates and coordinates the activities of the other members of the mapping team. Neither did Tex employ several mapping teams nor attempt to complete the map in a weekend.

A tripod mounted Brunton compass was used to obtain the bearings and was positioned a sufficient distance from the iron railings or gates; every bearing was checked with a backsight reading of + or - 1 degree difference. The Sunto clinometer had placed the water tube, for elevation differences; again with front and back sights being taken to assure accuracy. The Park personnel purchased a telescoping measuring pole for accuracy with ceiling heights which we could borrow during the project. Some of the rooms and/or features are dimensionally very large and the use of radiating angle shots or "Star shots" with station-to-wall measurements were developed at this point. This process aided the correction of misplaced features that have been found in the early maps. One hundred foot Fiberglass Kesson reel tapes were used replacing the metal tapes for distance readings, however the Stanley 25' measuring tapes are used for obtaining the station-to-wall distances information.

This map also includes a completely new feature--the longitudinal profile of the cave, in addition to the traditional cross sections to illustrate significant cavern features and changes in elevation. The longitudinal profile also allows the cartographer to illustrate geologic, hydrological and man-made features throughout the cave. So it is within this longitudinal profile that Tex was able to illustrate these significant features, so that the "average" tourist is able to relate their tour of the cave to the map which is located just outside the cave's entrance following the completion of their tour. During this surveying process, photodocumentation of significant historical artifacts took place which assists the park personnel in developing the history of the cave, its early visitors or uses. Another benefit of photodocumentation is that cave slide presentations can be developed and related to features on the map, so that vandalism or changes in the cave are recorded. The changes that the CCC made to the cave are accurately portrayed. As we measured these features, we found that the stairs and walkways are consistent in width and depth throughout the cave tour. As a tribute to the highly developed state of the art techniques employed in completing the commercial section of this cave map, it received and honorable mention in the N.S.S. cartographic salon.

This process of cave surveying will continue to develop and grow within the boundaries of Missouri's speleologists and who knows what techniques will develop during the next century. Already GIS systems and other technological advances in land surveying are being introduced into the cave surveying process. I have illustrated this progression in just one commercially developed cave. Dr. Ken Thomson and Robert Taylor have just rewritten and published the most up-to-date and complete book dealing with the art of cave surveying; it available through the M.S.S.

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Bretz, J. Harlan. **CAVES OF MISSOURI.** Missouri Geological Survey and Water Resources: Jefferson City, MO, Vol. XXXIX, Second Series. 1956

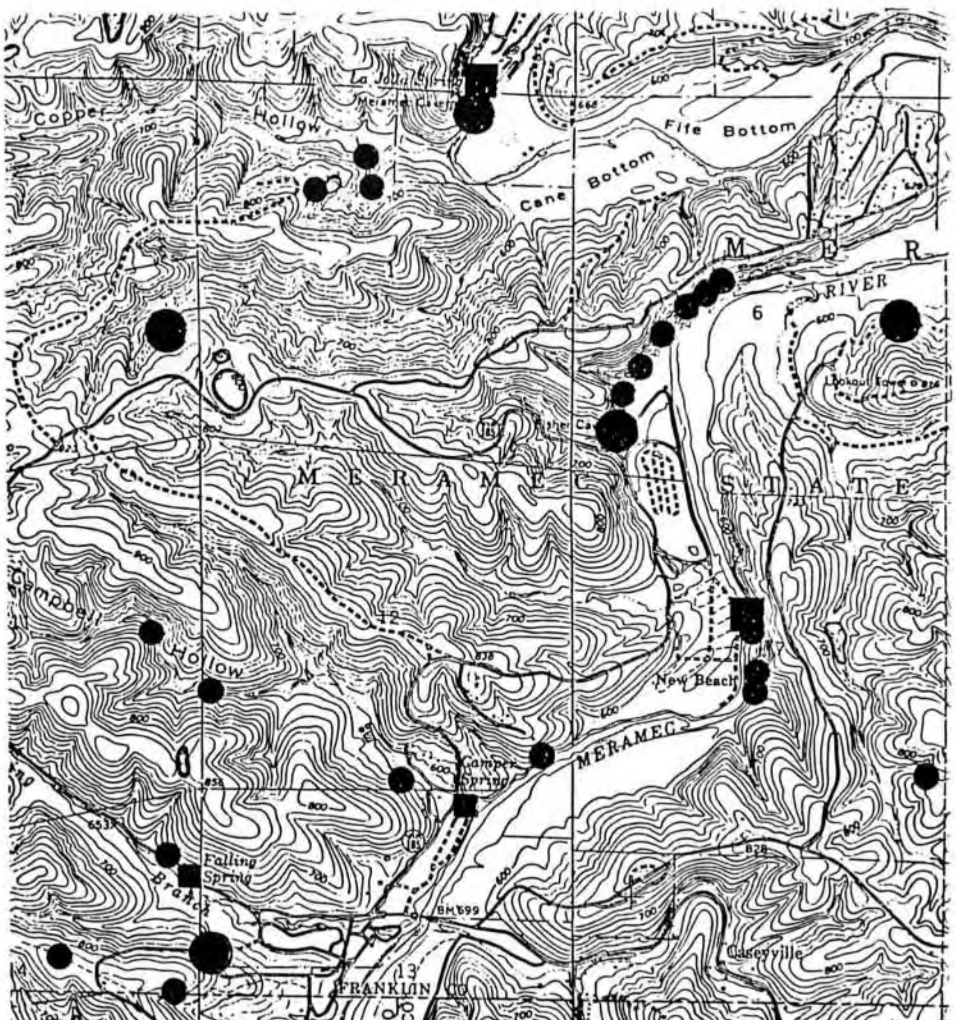


FIGURE 1: Map of Karst Features in central portion of Meramec State Park Franklin Co., Missouri

FIGURE 2

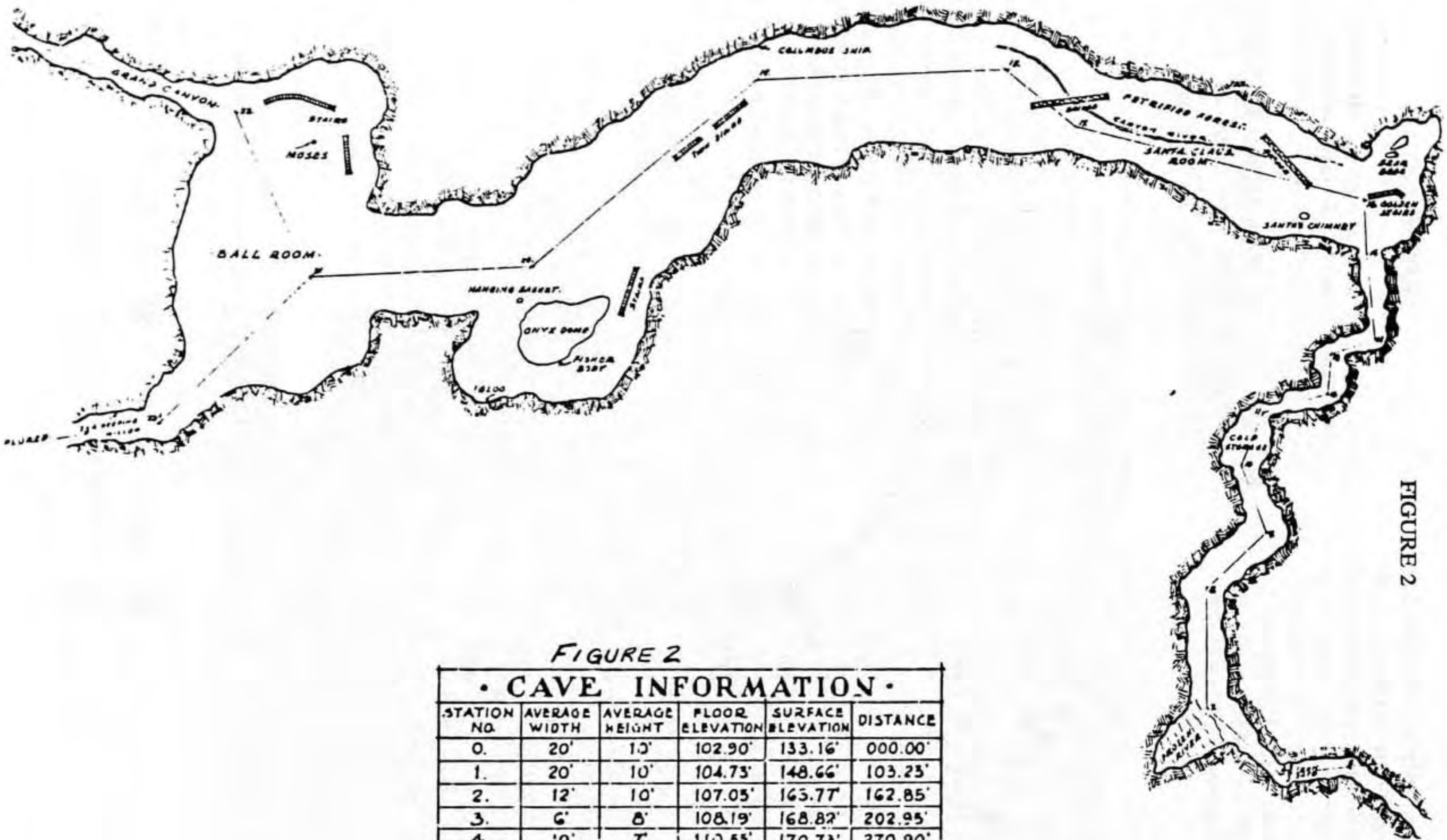
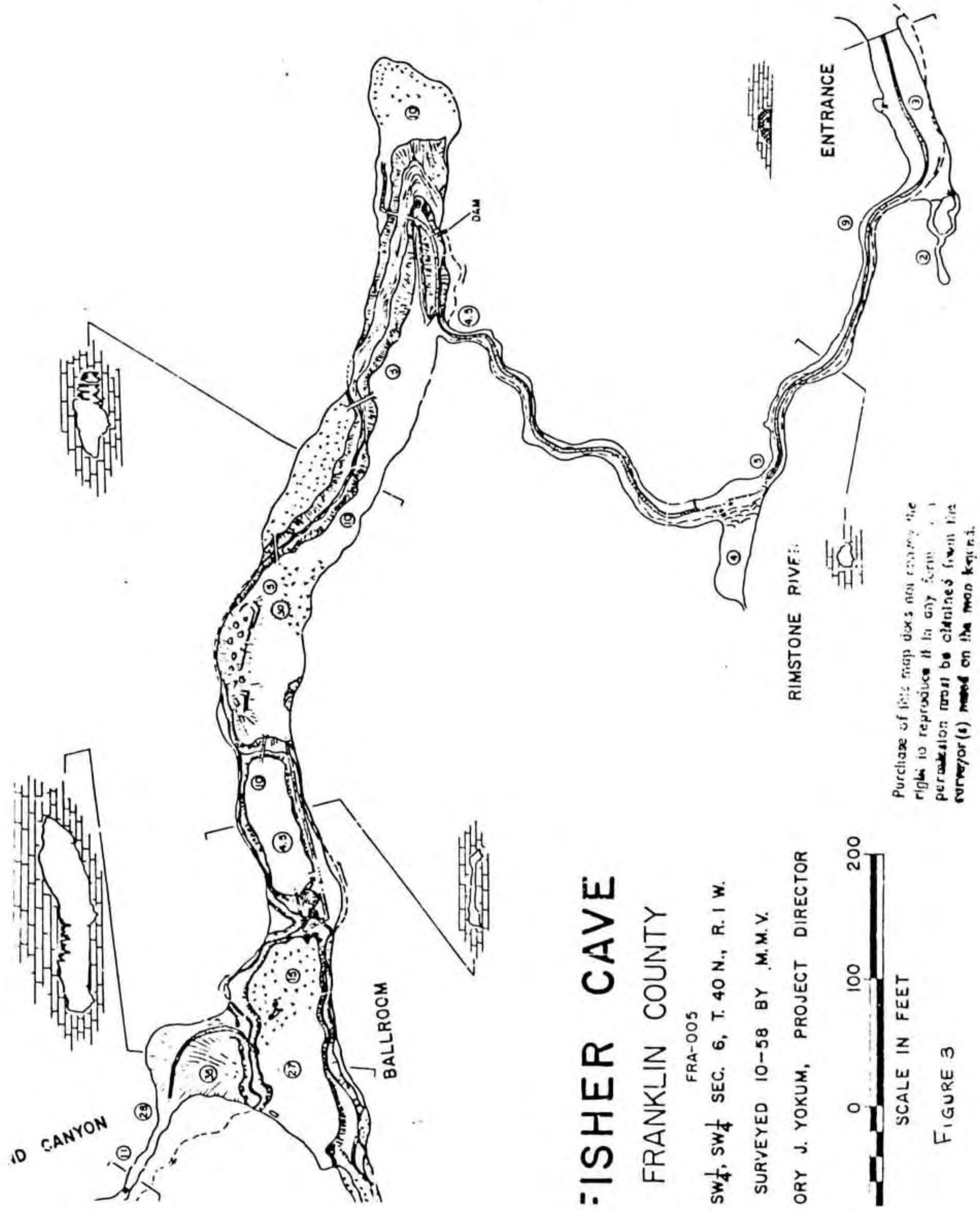


FIGURE 2

• CAVE INFORMATION •

STATION NO.	AVERAGE WIDTH	AVERAGE HEIGHT	FLOOR ELEVATION	SURFACE ELEVATION	DISTANCE
0.	20'	10'	102.90'	133.16'	000.00'
1.	20'	10'	104.73'	148.66'	103.23'
2.	12'	10'	107.05'	163.77'	162.85'
3.	6'	8'	108.19'	168.82'	202.95'
4.	10'	7'	110.55'	170.73'	270.90'
5.	5'	7'	114.28'	180.86'	352.15'
6.	5'	7'	115.43'	172.01'	390.55'
7.	30'	8'	119.32'	182.51'	445.26'
8.	18'	8'	119.75'	205.56'	513.26'
9.	20'	9'	124.25'	215.93'	558.26'
10.	20'	10'	126.12'	229.51'	599.71'
11.	12'	6'	125.68'	239.57'	631.71'
12.	10'	5'	126.90'	241.02'	669.71'
13	15'	4.5'	126.99'	248.40'	692.61'
14.	12'	4'	127.35'	257.55	728.76'
15.	10'	5'	128.18'	270.05'	777.06'

FIGURE 3


ISHER CAVE
FRANKLIN COUNTY
FRA-005
SW¼ SW¼ SEC. 6, T. 40 N., R. I W.
SURVEYED 10-58 BY M.M.V.
ORY J. YOKUM, PROJECT DIRECTOR
0
100
200
SCALE IN FEET
FIGURE 3
ENTRANCE
DAM
RIMSTONE RIVE
BALLROOM
D CANYON

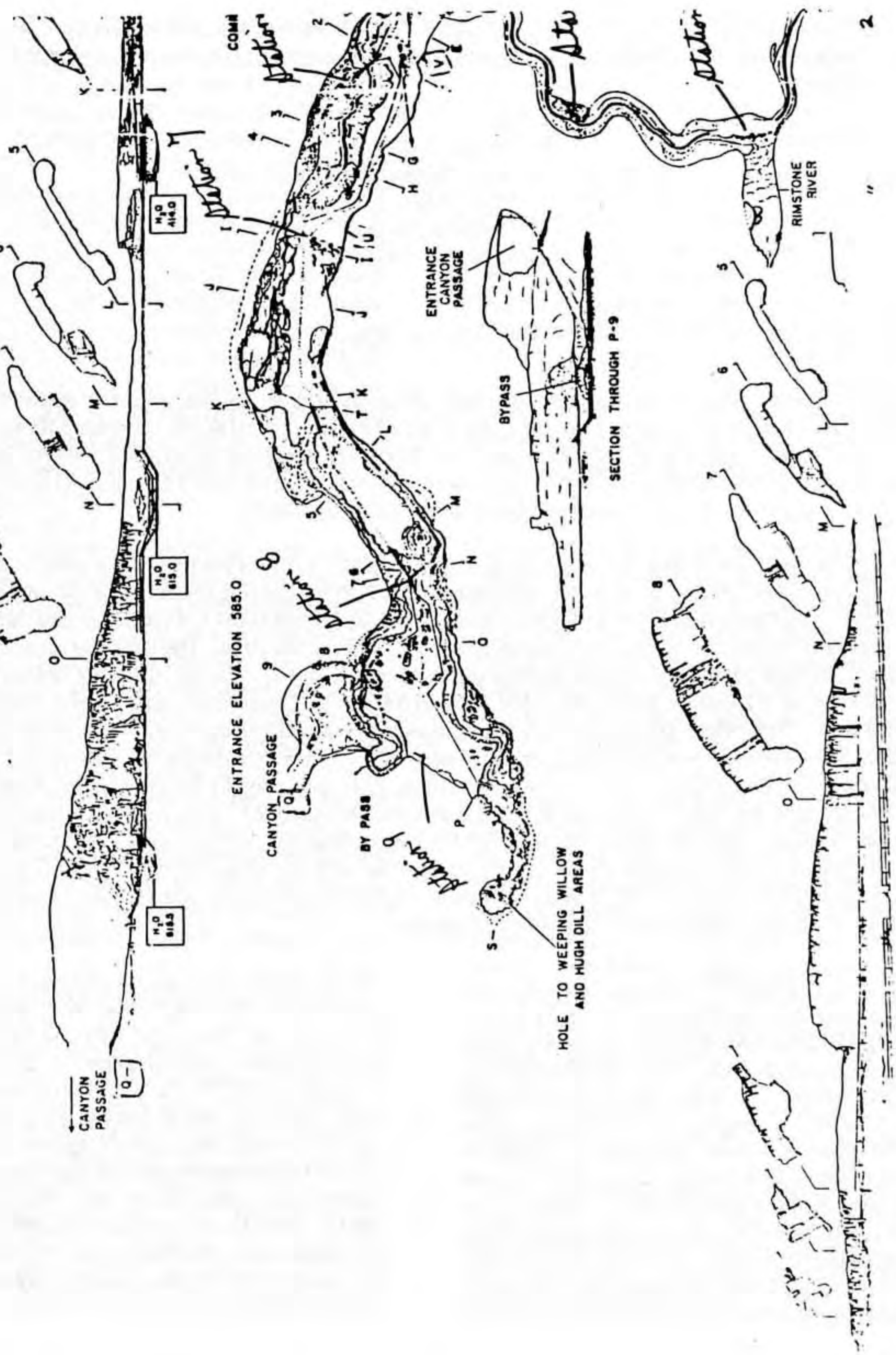
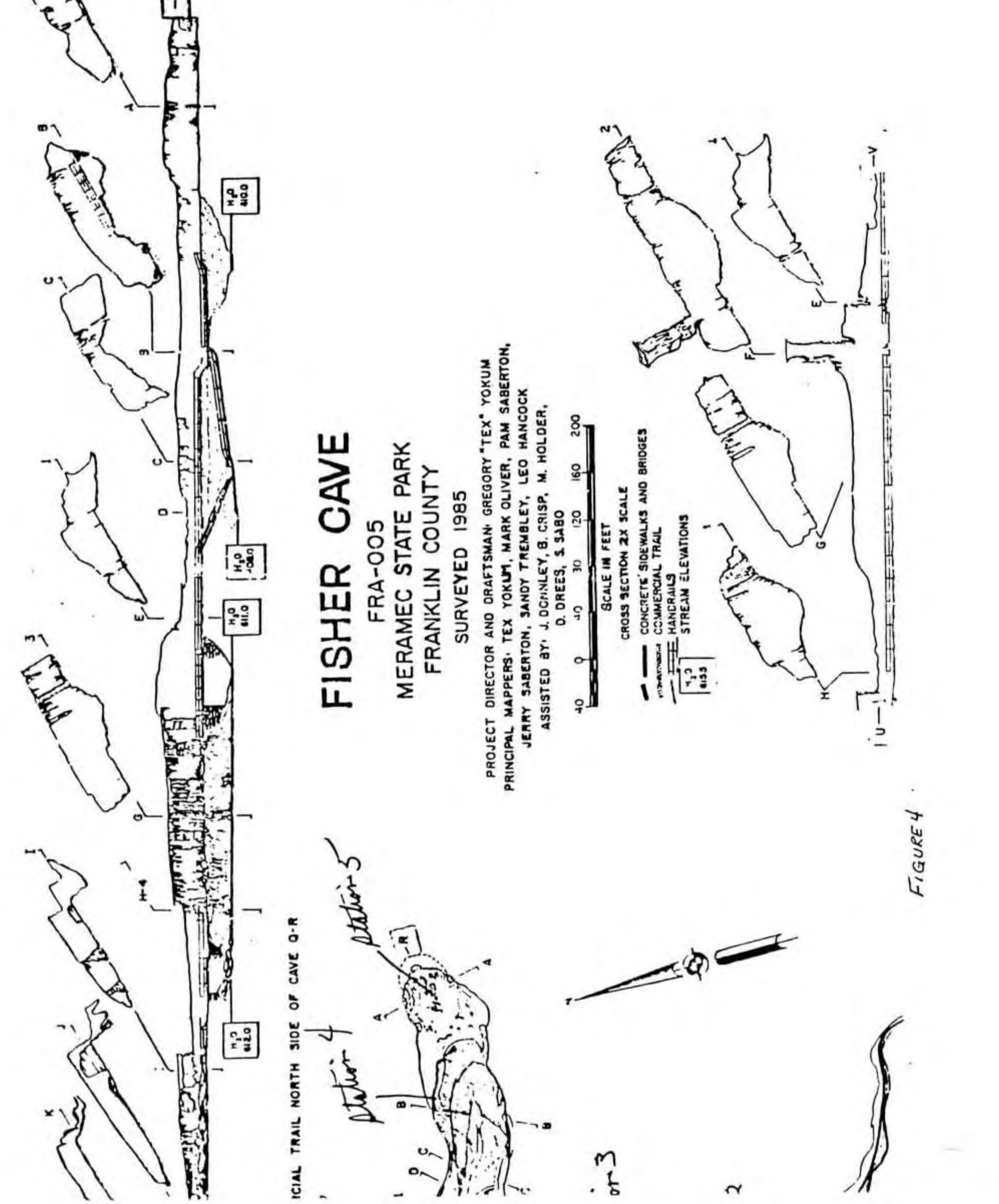

CANYON PASSAGE
ENTRANCE ELEVATION 585.0
CANYON PASSAGE
BY PASS
HOLE TO WEEPING WILLOW AND HUGH DILL AREAS
ENTRANCE CANYON PASSAGE
BYPASS
SECTION THROUGH P-9
RIMSTONE RIVER

FIGURE 4


FISHER CAVE
FRA-005
MERAMEC STATE PARK
FRANKLIN COUNTY
SURVEYED 1985
PROJECT DIRECTOR AND DRAFTSMAN: GREGORY "TEX" YOKUM
PRINCIPAL MAPPERS: TEX YOKUM, MARK OLIVER, PAM SABERTON,
JERRY SABERTON, SANDY TREMBLEY, LEO HANCOCK
ASSISTED BY: J. DONNLEY, B. CRISP, M. HOLDER,
D. DREES, S. SABO
SCALE IN FEET
CROSS SECTION 2X SCALE
CONCRETE SIDEWALKS AND BRIDGES
COMMERCIAL TRAIL
HANDRAILS
STREAM ELEVATIONS
ICIAL TRAIL NORTH SIDE OF CAVE Q-R
Station 4
Station 5
FIGURE 4

MANAGEMENT OF THE KARST AREAS WITHIN THE KETCHIKAN AREA OF THE TONGASS NATIONAL FOREST, SOUTHEASTERN ALASKA

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ABSTRACT

The Ketchikan Area of the Tongass National Forest is located in the southern extreme of the panhandle of Alaska. Over 925 square miles of the Area are underlain by carbonate rocks, mainly Silurian, massive limestones and minor marble. Karst topography is known to have developed on approximately 700 square miles of the Area, the majority being on Prince of Wales and Dall Islands. Thirty square miles of alpine and sub-alpine karst is known to exist.

The Forest is in the beginning stages of understanding the significance of the resource, developing standards and guidelines for resource management, and understanding the scope of the inventorying process. The dense vegetation of the region makes exploring for caves both difficult and dangerous. Preliminary inventories suggest that hundreds of caves exist in the Area. The surveyed areas on north Prince of Wales Island have already yielded several record features. "El Cap Pit" is the deepest known natural pit in the United States, an initial drop of 598.3 feet, "Snowhole" ranks third in the U.S. at 448.8 feet. The seven deepest known caves in Alaska and the five longest have been recorded. Biological studies of the caves have begun. Large numbers of mammal bones are present in the caves. Salmon swim through some caves to spawn upstream, some may actually spawn in caves. Historically, timber harvest has been highest on these well drained areas, where the nutrient rich soil grows the largest timber. These areas still are targeted for timber removal. It is no small task to insure that surface management activities are designed to protect the cave resources. Only recently has protection of the cave resources on the Area been a concern. The challenge is to educate the land managers and public as to the significance of this unseen resource.

Introduction

The intent of this paper is two-fold; to bring to light the tremendous extent of karst development in southern Southeastern Alaska, specifically on the Ketchikan Area of the Tongass National Forest, and to describe the Cave Resource Management Program which is being developed on the Area. The Tongass National Forest is the largest National Forest in the National Forest System, encompassing about 17 million acres. Because of the immense size of the Tongass, the Forest has been divided into three administrative areas. The Ketchikan Area covers about 5.5 million acres, or the southern third of the Tongass National Forest. Throughout this paper, the Ketchikan Area will be referred to as "the Area". Timber harvest is now, and historically has been, highest on the lower elevation karst areas which yield the greatest timber volume per acre. In 1951 the Ketchikan Pulp Company (KPC) signed a long-term timber harvest contract with the U.S. Forest Service. The contract entitles the operator to harvest approximately 8.25 billion board feet of timber over the 50 year life of the sale. Driven by the requirements of the Long-term Timber Sale Contract, the Area must prepare a certain volume of timber to be harvested.

Until recently only a few local residents have known about some of the caves and significant karst features. As a result of the passing of the Federal Cave Resources Protection Act (FCRPA) in 1988, the Ketchikan Area entered into a partnership with the Glacier Grotto, the local National Speleological Society (NSS) grotto, to help evaluate the cave resources. In 1990 the Area began a widespread inventory process to gain a better understanding of the extent and significance of the karst resources. Emphasis was also placed on identifying cave resources within proposed timber sale units where surface management activities could result in damage of karst resources. When significant karst resources are discovered, mitigation to insure protection of the feature are applied. This mitigation is based on observations of the effect of timber harvest on karst features within old harvest units.

The Ketchikan Area is planning to step up its inventory process and strengthen the partnership with local and national caving organizations, research units, and universities. The Area is actively involved in education of its employees and the local communities on the values of the resource, caving safety, and caving ethics. Though the majority of the public and resource managers are excited about the karst resource, there are those who view the resource as "just another resource" which further limits the acreage available for harvest. Herein lies the management challenge -- identifying the significant karst features on the ground so that mitigation to protect the resource can be enacted, and education of land managers and the public as to the resource values of the karst system.

Description of Area and Geologic Setting

Southeast Alaska consists of both a narrow strip of mainland coast averaging 25 miles wide from tidewater to the mountain crests which mark the U.S.-Canada boundary, and the hundreds of islands of the Alexander Archipelago. The topography is generally rugged with the lands rising quickly from the sea. The modern topography of the area reflects the region's glacial history. Several of the straits of the Alexander Archipelago are the result of glacial scouring of pre-existing fault zones. The rounded summits of the mountains of lower elevation are the result of Pleistocene glaciation. The area is heavily forested and is characterized as a temperate rain forest comprised primarily of hemlock and spruce interspersed with poorly-drained muskegs and forested muskegs.

A cool, moist, maritime climate characterizes Southeast Alaska. Average Fahrenheit temperatures range from the 40s to mid-60s in the summer and from the high teens and low 20s to the 30s and low 40s in the winter. Due to the moderating influence of the ocean, summer temperatures are cooler and winter temperatures are warmer along the outer coasts than farther inland. Precipitation is high, about 80 to 160 inches annually, though certain areas receive considerably more or less due to the interaction of weather circulation patterns and local topography (Arndt, et. al., 1987).

The geology of Southeast Alaska is very complex. The bedrock includes lithologies which range in age from Proterozoic(?)-Cambrian to Quaternary (Berg, 1988; Brew, 1984; Eberlein, 1983; Gehrels, 1991). Portions of five tectonostratigraphic terranes are found in the Area (Berg, et. al., 1988). Karst development is limited mainly to outcrops of uppermost Lower to Upper Silurian aged Heceta Limestone and the Middle to Upper Devonian Wadleligh Limestone. Locally these have been metamorphosed to marble. Some 950 square miles of carbonate rocks underlie the Area. All but 25 square miles of carbonate are found on Prince of Wales Island and the surrounding islands. Two thin bands of Permian marble are exposed on Revillagigedo Island (Berg, et. al., 1987) (See figure 1). On Heceta Island, the Heceta Limestone has a maximum stratigraphic thickness of 9,900 feet but the total thickness of the formation probably exceeds 12,000 feet. The limestones are massive or thick-bedded, fine grained, locally fossiliferous, commonly fractured, and light- to medium-dark gray (Berg, 1988; Brew, 1984; Eberlein, 1983; Gehrels, 1991).

Structurally the area is dominated by large, northwest-southeast trending, high angle faults. Many of these are deeply eroded and very visible from the air. These faults break the area into blocks of carbonate and non-carbonate bedrock.

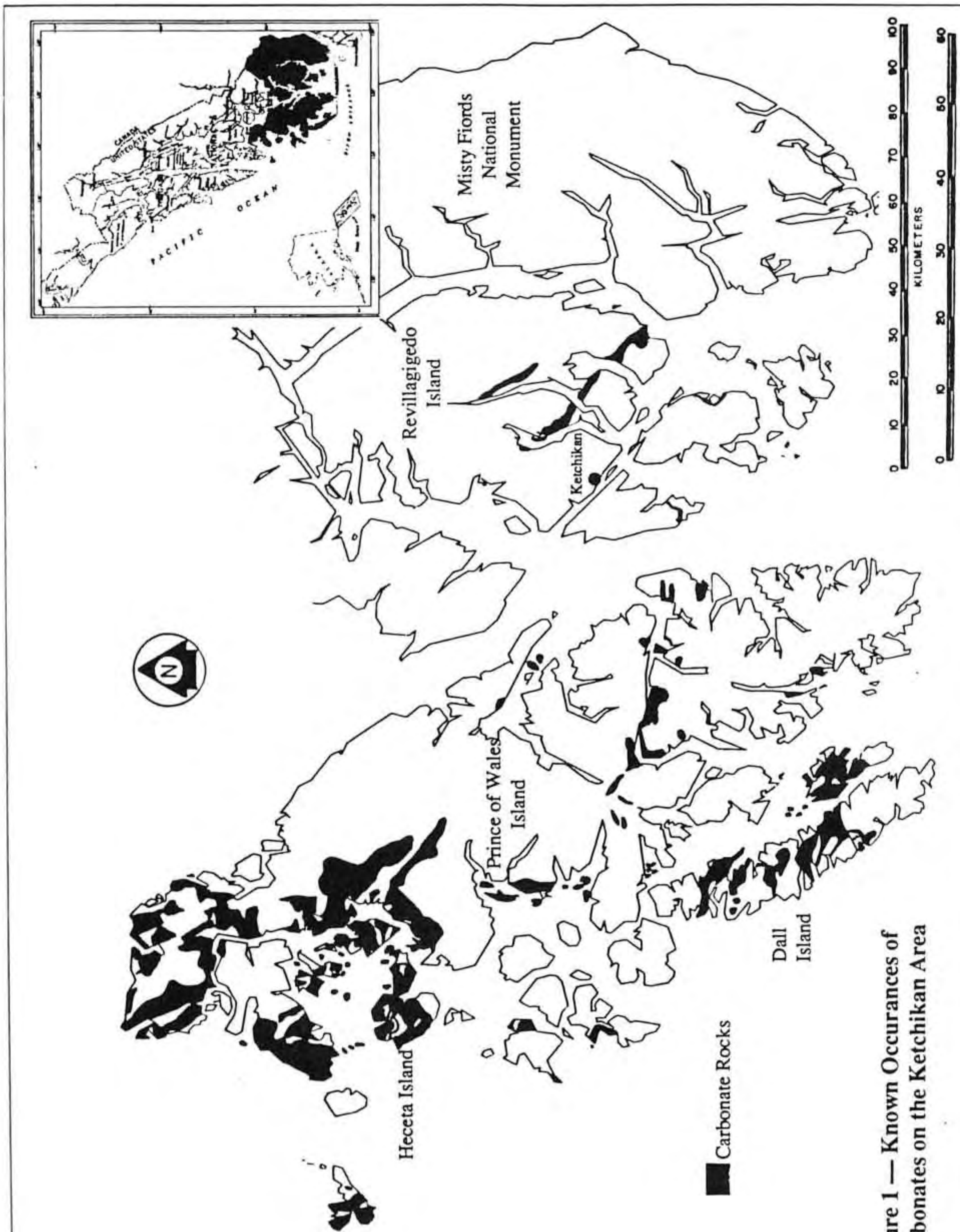

Figure 1 — Known Occurances of Carbonates on the Ketchikan Area

Factors Influencing Karst Formation

As mentioned above, it is estimated that 950 square miles of carbonate rocks occur within the boundaries of the Ketchikan Area of the Tongass National Forest. Karst topography has developed on approximately 700 square miles of the carbonates. There are some 30 square miles of alpine and sub-alpine karst found on the Area. Significant karst is found from sea level to the top of the highest limestone peaks, 3,400 feet in elevation. The characteristics of the karst basically divide it into somewhat distinct types: low-level karst which generally occurs below 1,100 feet elevation, and the sub-alpine and alpine karsts which are found above 1,800 feet. The following generalizations can be made about the physical nature of the karst:

1. Development of the low-level karsts is both a function of geologic structure and the presence of muskegs. The majority of a solution features occur along faults, joints, dikes and sills, and changes in lithology which are generally fault bounded. Muskegs form atop poorly drained non-carbonate rocks and glacial hardpans which overlie carbonates. Surface waters which originate from these poorly drained areas seldom flow more than a few yards onto carbonate substrate before diving subsurface down vertical shafts or into cave entrances. The highly acidic waters from the muskegs seem to accelerate cave development.

2. The cave passages which occur within the low-level karsts are characterized by one or more phreatic tubes atop a vadose canyon. The canyons generally widen towards the floor of the cave. Commonly the caves have a vertical entrance down a shaft greater than 30 feet deep. Evidence suggests that the caves predate the last glacial period. The caves are emerging from the glacial sediments that filled much of the systems.

3. The carbonate bedrock beneath the forest floor has been sculpted by the high rainfall and the organic acids of the forest floor. Roots following soil filled fractures and structural features have guided surface waters downward. This karst surface is characterized by highly dissected, smoothed bedrock with many small pits, arches, and passages. Grikes are common in these areas.

4. Annual rainfall exceeds 180 inches per year in some of the areas where karst has developed. Evidence of the force of the tremendous volume of groundwater responsible for formation of the passages is everywhere in the cave passages. Scalloped walls, spiraling passages, ceiling pendants, deep plunge pools, frequent and dramatic water level fluctuations, flooded passages, and sumps are common. Such pressure tubes or conduits play an important role in cave formation. With large seasonal storms and frequent rain-on-snow events large volumes of water are forced through these passages. Boulders in excess of 2 feet in diameter seasonally batter the walls of some passages. Walls, ceilings, and clasts on the floor bear collision marks from battering during high flow periods. The rapid water level fluctuations in these caves is one of the most dangerous aspects of caving in this region.

5. Groundwater temperatures range from 36 to 40 degrees F. in most caves. Air temperature fluctuates around 40 degrees F. With few exceptions, caves in the Area are wet. Hypothermia is a constant threat when exploring these caves.

6. Above 1,800 feet elevation sub-alpine and alpine karst is well developed. There are areas where thousands of solution features per square mile are present. These features form generally along structural weaknesses, sills, and dikes in the bedrock. Collapse and solution dolines are common where low gradient slopes are found at the higher elevations. Where massive carbonates are exposed, lines of pits and vertical shafts, and deep grikes form along structural features. Between 1,800 and 2,400 feel elevation the slopes support stunted alpine vegetation. Above 2,400 feet little or no vegetation is found. Karst formation is driven by the high amounts of precipitation which fall on these areas. The most recent glaciation has modified existing karst features, leaving a thin mantle of glacial deposits in solution dolines, and choking some features with glacial sediments. Frost wedging within some of the shafts and pits have choked the features with recent rockfall.

Surface Features and Cave Systems

Hundreds, if not thousands, of yet unexplored caves exist within the boundaries of the Ketchikan Area of the Tongass National Forest. In the previous four years of cave inventory and exploration (1987-1990) some 57 caves had been inventoried (Metzler and Allred, 1990). During the 1991 field season the inventory process was greatly accelerated with the increased emphasis on timber harvest for the KPC Long-term Sale Contract. In a six month period some 96 new caves were discovered. Many of these were located, within or adjacent to, proposed timber harvest units.

Karsted surfaces found within the Ketchikan Area display many kinds of features. The features found on the low-level karst differ from those developed on the higher elevations and are best discussed separately.

The low-level karsts, those that are forming below 1,100 feet elevation, are characterized by large closed depressions, uvala, solution channels, collapse and solution dolines, doline fields, vertical shafts, solution runnels, grikes, and caves. All these features are surrounded and/or covered by dense vegetation. Many features are at least partially covered by a vegetative mat which makes cave resource exploration dangerous in these areas. The karst features found in the lower karst zone show similar characteristics to those described from tropical regions. Closed depressions are common, many encompassing several square miles of terrain. There are vast areas where no surface drainage exists in this region where rainfall exceeds 180 inches per year. Cockpit/cone karst (Jennings, 1987) have been described from the northwestern corner of Prince of Wales Island (Allred, C., 1989). Understanding the complex geology of the area is the key to location of the significant karst features. Timber type, vegetation patterns, slope, and proximity to muskeg soils all play a role in cave location. Though some caves and significant karst features are found far from lithologic boundaries and the fringe of muskegs, the majority are discovered proximal to these boundaries. The dispersion of significant karst features is controlled by the drainage patterns developed off the muskegs and non-carbonate lithologies and structural weaknesses in the limestone and marble. Many caves sump or choke within the first 100 feet. Vertical shafts, 30-80 feet deep, are commonly found adjacent to muskegs or lithologic boundaries. The majority of these are choked with glacial sediments and forest debris. Two large vertical shafts have been located this year: Bear's Plungs at 142 feet deep and over 30 feet in diameter, and Yukon's Pit at 150 feet deep and greater than 65 feet in diameter. "El Capitan Cave" is the longest cave discovered so far with 10,190 feet of surveyed passages and a total depth of 256.3 feet (Allred, 1991). Eight caves have been mapped beyond 1,000 feet in length with three of those nearing 3,000 feet. Because of the large number of "virgin" caves and the need to identify the resources within the timber sale units, little or no digging to extend the length of these caves has occurred. Dolines are the most common karst feature encountered. Solution, collapse, and alluvial streamsink dolines have been found. The dolines often occur in large numbers close together forming doline fields. Dolines over 200 feet in diameter and 100 feet in depth have been found. A typical cave within the low-level karsts has an entrance at the base of a 30-80 foot deep vertical shaft or collapse doline. These caves are characterized by a vadose canyon which meanders along structural weaknesses in the limestone or marble.

The sub-alpine and alpine karsts which are found above 1,800 feet elevation, are characterized by a wide variety of solution features. Besides countless dolines, rillenkarren, wallkarren, rundkarren, solution ripples, grikes, and pinnacle karst are found (Jennings, 1987). Joints and fractures have deeply eroded to form steep-sided narrow canyons a few feet wide and often tens of feet deep. It has been estimated that on three selected sub-alpine and alpine areas of northern Prince of Wales Island the doline density per square mile averages 3,200 (approx. 2000/sq. km.) (Allred, K., 1989). Deep vertical pits are aligned along structural weaknesses in the bedrock. Many of these pits are choked with glacial debris and material from frost wedging. Others access yet unexplored cave systems. Many of the solution features are controlled by the numerous dikes and sills which criss-cross these alpine regions. The intrusions act either as impervious barriers to groundwater or as conduits which rapidly carry groundwaters subsurface within open joints. On the north end of Prince of Wales Island, the high-elevation karst occurs atop some 3,400 feet of limestone and marble. "El Capitan Pit", the deepest known natural pit in the United States, with an initial drop of 598.3 feet, is located here (Rockwell, 1989).

The alpine karst areas on Dall Island have formed on some 700 feet of limestone thrust atop granodiorite. Mid-winter reconnaissance flights over these areas have revealed hundreds of melted openings where air exchange in the caves is adequate to keep the entrance free of the deep winter snows. Caves in these areas are characterized by steep, near vertical passages. Resurgences for these systems are generally found between the 800 and 1,100 foot elevations. Exploration of these areas is hampered by their remoteness. These areas are best accessed by helicopter. Weather systems coming off the Gulf of Alaska shroud these areas in fog and clouds most of the year. During the short field season there are only a few days when the weather allows people and supplies to be flown into these areas.

Karst Management

The Forest Service is in the beginning stages of identifying the significance of the karst resources on the Area. With the help of the local NSS Grotto, the inventory process has begun. The focus of the inventory process has been on the north end of Prince of Wales Island where timber harvest threatens the karst resources. Next year the Area plans to expand its inventory process to other karst areas. Programs have been developed to educate resource and land managers of the importance and significance of the karst resources on the Area. Several lectures on the karst resources have been offered to the public through the local museum and schools. Public response to these lectures has been overwhelming. The Area has entered into a cost-share agreement with the National Speleological Society/Glacier Grotto to help the Forest Service inventory and evaluate the cave resources. Last year the Area dedicated over $40,000 to house, feed, and transport cavers who participated in the Prince of Wales Island Expedition V (POWIE V). Eight to twelve individuals worked with the Forest Service for one month during the summer mapping and exploring the caves. Last year during POWIE V, over 50 caves were mapped and more than 18,000 feet of underground survey completed. The Area is also looking to enter into partnerships with universities and colleges to promote research on the karst resource.

The area has proposed that some 14,000 acres of alpine and sub-alpine karst be set aside for its geologic significance. These Karst Special Areas consist of twelve areas ranging in size from 350 to 4,300 acres. These Special Areas have been proposed in the latest revision of the Tongass Land Management Plan. The Plan contains direction and standards and guidelines for management of the cave resources on the Tongass National Forest. These guidelines outline how the Forest will manage the cave resources for the future. The Area has proposed an Amendment to the Long-term Timber Sale Contract which would place in effect these proposed standards and guidelines for karst management.

Past surface management activities have greatly impacted the cave resources. Prior to 1988, and the passing of the FCRPA, no measures were taken to preserve and protect the karst resources. Surface management activities have in-filled many features with sediment and debris. It is estimated that over 50% of the significant karst features found on unharvested land have atmospheric and hydrologic connection to the surface. Most of these features can be physically entered. In existing harvest units, less than 5% of the significant karst features still have atmospheric connection. Logging slash and debris have accumulated within dolines because of past logging practices. The slopes of the dolines are naturally over-steepened and unstable. When logs are yarded through and across these features a furrow is plowed into these unstable slopes. In some old harvest units approaching 20 years in age, these furrows have not revegetated. For years sediments have bled down these slopes and into the karst systems. Many of the caves begin as narrow canyons. In some instances, woody debris from logging have bridged these openings and captured sediment. When this has occurred, cave entrances and lower portions of the dolines have quickly filled with sediment and debris. Many dolines have been in-filled for forest road construction. The dolines are historically a convenient place to focus excess surface waters off roadways. Oversized materials and overburden from road and quarry development have been wasted in large dolines. Dolines adjacent to landings are used not only for slash disposal, but for garbage disposal as well. The lands in Southeastern Alaska regenerate and heal quickly, but the karst resources have been forever altered. The Standards and Guidelines for Cave Resource Management

IV. Standards & Guidelines

A. Prior to determination of significance under the 1988 Cave Act, or Forest-wide comprehensive cave management analysis, the following direction is applicable:

1. During the cave inventory process, map the subsurface extent and position of the caves. Care shall be taken to note subsurface drainage patterns, resurgence areas, surface drainage, and drainage basin characteristics. This information is necessary to determine the cave's ecological relation to the surface.

2. Design of timber harvest, road construction, and other related management activities above or in the vicinity of a cave, or the course of such a cave, will be designed in a way to insure protection of the cave resources.

3. Require retention of vegetation in the vicinity of a cave or cave course to protect the cave's microenvironment. The extent and limits of no harvest buffer surrounding major karst features shall be determined on a case by case basis. Topographic breaks and vegetation patterns should be utilized during buffer design and layout. The intent of the buffer is to insure stability of the cave ecosystem, the integrity of the slopes surrounding cave, and adequate sediment filtration between management activities and the cave resources. There will be no ground disturbing activities on slopes steeper than 30 degrees adjacent to cave entrances. An example of this would be protection of a steep sided, closed basin in which surface drainage flows into a cave system or on steep slopes immediately adjacent and up hill of a cave opening.

4. Similar buffers will be maintained around all direct drainages into caves. This includes sinkholes, cave collapse areas known to open into a cave's drainage system, and perennial, intermittent or ephemeral streams flowing into caves. The immediate area surrounding resurgence springs shall be protected to insure stability of the cave system's ecosystem. The intent of this direction is to insure that additional sediment is not introduced into the cave system, surface flows are not interrupted, and logging slash and debris is not transported into the cave system nor plug the cave entrance.

5. Avoid alteration of cave entrances, or their use as disposal sites for slash, spoils, or other refuse.

6. Avoid diversion of surface drainage into caves.

7. Design roads and related construction to avoid altering surface drainage into karst features or focusing sediment from road surface and/or drainage into karst features.

8. Design quarry and material sources to insure that location and excavation in no way threaten cave resources.

9. Where timber harvest is occurring in the vicinity of a cave, fall trees directionally away from the cave and its course. Yarding should in no way drag timber across and/or through cave openings. Full suspension yarding or other mitigation measures which will insure the stability of the karst slopes is required in these areas.

10. Limit public access if required to prevent damage to the cave resources or if there are safety hazards.

11. Information concerning the specific location of any significant cave may not be made available to the public unless disclosure of such information would further the purposes of the Act and would not create a risk of harm, theft, or destruction of the cave.

12. Scientific or educational use of caves will be authorized by the Forest Supervisor, where appropriate.

13. Communication and cooperation between the Forest Service, caving organizations, and recreationists will be fostered. Exchanged information will not be made public if it could lead to the degradation of sensitive caves.

14. Emphasize enforcement of laws protecting caves from relic collectors and vandalism.

Figure 2 - Proposed Standards and Guidelines for Tongass Land Management Plan Revision for Cave Resources.

proposed in the Tongass Land Management Plan Revision have been formulated from these field observations (See figure 2). Though the Federal Cave Resources Protection Act only charges the Forest Service with protection of significant caves, the Tongass National Forest is working to protect all significant karst resources. Until resource values are determined, the Area is considering all caves significant.

Great emphasis has been put on identifying the significant karst features and caves within the proposed timber sale units. The Area is slowly getting ahead of the timber sale unit identification and offering process in identifying and inventorying significant features. The intent is to mitigate the effects of surface management activities on the karst and cave resources. New and creative methods of timber harvest are being proposed to protect these unseen features. The Area is using the mitigation applied to and surrounding the karst resources as an example for implementation of the Forest Service's New Perspectives Program.

If it is determined that particular cave's resource values are such that management or protection is required, the cave will be placed in one of the three following classes:

1. Class 1: Sensitive Caves: these caves are considered unsuitable for exploration by the general public because of their pristine condition, unique resources, or extreme safety hazards.

2. Class 2: Undeveloped Caves: caves that are undeveloped or contain minimal developments that are suited for persons who are properly prepared.

3. Class 3: Directed Access Caves: caves with direct public access and developed for public use and enjoyment.

In addition, each cave placed within one of the above classes will be given a rating from 1 to 5. A rating of "1" will mean that no caving experience is needed and access and exploration is not physically demanding. A rating of "5" will signify that only the most experienced and physically capable cavers should explore the cave. The Area is in the process of identifying several caves that can be opened to the public within the next two years. The Area is working closely with the Glacier Grotto to examine the resource values of various caves to select candidate caves appropriate for the general public to explore. Sadly, vandalism and speleothem collection by the general public is a real problem. Through public education programs, the Area hopes to stop the degradation of the resource. Regrettably, some gating of the most significant caves is needed to insure that their pristine nature is preserved.

The Area now hopes to put some emphasis on studying the cave formation processes, cave ecosystems, and monitoring the effects of timber harvest on the karst resources. The following is a summary of some of the significant resource values that have been found within the inventoried karst features:

- The karst features give us a unique look into the sub-surface geology of the region. Most of the caves have formed along faults and shear zones. Many caves are closely related to dikes and sills or along lithologic contacts. Silurian and Devonian marine invertebrate fossils can be seen in the walls of many passages.

- Strong evidence that the caves pre-date the last glacial period is found in nearly all caves. The recesses of most caves contain bedded glacial sediments, varved glacial clay, and layered organic debris and silts. It appears that the cave passages are emerging after being nearly choked with glacial deposits. During more recent years, more sediment has been added to the deposits in the caves. Two samples from logs which have been exposed within the floor of one cave have yielded Carbon-14 dates of 6,500 and 4,120+/-60 years before present.

- The caves found within the low-level karst display a wide variety of speleothems. Stalactites, stalagmites, draperies, fans, flowstone sheets, helictites, popcorn, cave coral, etc. are found decorating the passages. Soda straws are common in the drier passages. Some soda straws approach three feet in length. Moonmilk covers many of the walls. Large columnar crystals of moonmilk reach a thickness greater than 16 inches in some caves.

One recently discovered pool is lined by botryoidal crystal forms resembling what is best described as underwater moonmilk. They depress to the touch and rebound quickly, resembling radiating crystals of cotton. Some passages are lined with calcite crystals five to eight inches in length. Caves found in higher elevations contain few speleothems.

- Anadromous fish species are known to spawn through some caves and may spawn within a few cave passages. Resident trout and anadromous fish fry seek shelter in cave openings from bird predation. Many insect forms use the photic zone of the caves to deposit their eggs. This also supplies fish with an abundant food source.

- Bats are known to inhabit many of the caves. Thousands of hours have been logged while exploring the caves during the summers and no bats have been seen, although their fecal deposits and remains have been found. It is possible that bats from the interior of Alaska migrate to these caves to winter (Cook and West, 1991). It is also possible that the Keen's bat, a sensitive species, may inhabit the caves. Working with the University of Alaska this winter, a bat trapping and tagging program is planned.

- Almost without exception, the caves and vertical shafts contain the remains of various mammal which have fallen in. The bones of black bear and Sitka blacktail deer are common. The remains of birds, beaver, and other small furbearers have been reported. Some animals have survived the fall, to walk through the cave and find a place to lie where their articulated remains were found. Fish bones from the stomach content of some bears can be found. Most recently, the remains of what is thought to be a giant short-faced bear (*Arctodus simus*) have been discovered (Heaton and Grady, 1991). The remains of what is possibly a Pleistocene wolverine have also been located (Allred, 1991). Next year the Area is hoping to excavate the remains of the bear and other mammals to gain further understanding of the natural history of the area. If proposed grants are approved, the excavation will be under the direction of the Smithsonian, National Geographic, National Speleological Society, and the Forest Service.

- There are many littoral caves along the western shorelines of the outer islands. Many of these caves are now well above mean high-tide due to isostatic rebound of the earth's crust after glacial retreat and/or sea level fluctuations. These caves range in size from those only a few feet deep to those well over 300 feet in depth and over 150 feet in width. Beach logs, deposited in the caves centuries ago, lie stacked on the floors. One such log sampled has yielded a Carbon-14 date of 4,200+/- 70 years before present. Scattered on the floors of these caves are mammal bones and bones of sea birds. Deer utilize several littoral caves for shelter and one cave is home to a pack of wolves. Some of the less accessible caves act as rookeries for a wide variety of sea birds. Early natives also sought shelter in these littoral caves (Autrey, 1991). The walls of one cave are decorated by magnificent paintings which incorporate the structural folding of the limestone and speleothems into the art. Another littoral cave shows possible human habitation dating back some 2,250 years (Reger, et al., 1986). Smaller solution features were utilized as burial sites along the shore (Autrey, 1991).

- A wide variety of insects utilize the recesses of the caves. No detailed analysis of the species have been carried out, but collections have been made. Several insects, unfamiliar to the cavers working during the summers, have been collected (Allred, 1991). Collections have been forwarded to the Burke Museum of Natural History on the University of Washington campus for analysis, and a few species have been identified (Crawford, 1989).

Conclusions

The karst resources found within the Ketchikan area of the Tongass National Forest are as unique as they are vast. Karst is well developed from sea level to alpine mountain tops. The karsted surfaces display many kinds of features. Caves are numerous, but often obscured by the dense vegetation and glacial deposits.

The karst found within the Area may be one of the best examples of temperate rain forest karsts in the world. Though past surface management activities have affected some karst systems, the Forest has the opportunity to learn from the negative effects of past surface management practices. The Area is working hard to mitigate impacts of surface management activities on the karst resource. An accelerated inventory process will work to put the Area ahead of the timber sale unit design and offering process. This will allow more time to be devoted to understanding the karst systems and not solely to protection. The Area hopes to enter into partnerships with universities, colleges, state and private organizations, and caving organizations to begin research in the following areas:

- Gain an understanding of the role the organic acids from the soils and muskegs play in karst development.

- Through dye tracing and close monitoring of atmospheric conditions and rainfall, gain a better understanding of the relation between the surface and subsurface hydrologic systems of selected karst areas.

- Monitor the long-term effects of surface management activities on the cave systems.

- Study the effects of water infiltration and saturation rates as the result of removal of the forest canopy over cave systems.

- Study the importance of karst waters for anadromous fisheries.

- Begin an intensive insect and small mammal inventory program. This would include determination of the relationship between bats and the cave systems.

- Begin studies which would look into the passage formation rates, aging of speleothems, and long-term climatic studies utilizing oxygen isotope ratios and palynology.

- Continue paleontological and cultural resource evaluation when discoveries are made.

The extensive karst resources of the Ketchikan Area are unique. They are truly "Tongass Treasures".

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OREGON CAVE TOUR STANDARDS, 1989-1991

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ABSTRACT

In 1989, the National Park Service (NPS) wrote an audit form to evaluate concession tours. The standards were to 1) be fairly short, 2) be easily understood by park and concession staff, 3) be a training document, 4) be measurable, 5) enhance conservation, and 6) result in consistent scores when used by different auditors.

The 1990 average scores for each element were higher than 1989 scores. Improvement since 1990 has slowed overall. The averaged scores of only two elements (Content and Presents Whole) increased over the 1990 scores. 1991 tours are more educational than 1989 tours but often don't show good interpretation.

Scores by ten NPS interpreters of the same guides at similar times show an average spread of seven percentage points, indicating that most elements are consistently measurable. However, the most variable scores were also those showing the least improvement between 1990 and 1991. Improvement of these more complex, subjective elements must continue.

Cave or surface tours by first-time NPS seasonals at Oregon Caves and Crater Lake, Mammoth Cave and Redwoods National Parks scored an average of 81, consistent with the goal of bringing concession guides up to NPS standards. However, park and concession returnees averaged four points higher than first-time seasonals, indicating that increasing turnover decreases interpretive quality in both park and concession staff.

Introduction

Requests from most commercial caves in the US and a review of over 60 audit forms from National Park Service (NPS) areas showed that no single audit form came close to meeting the eight goals. So a new form was built on elements taken from most of the forms. Critiques on a draft sent to most commercial caves were merged into the certification standards.

Results

The abstract summarizes the most important results.

Discussion

The more concrete, factual elements (either you have a correct theme or not, either your facts agree with the manual or not) have been improved upon. The Speech element had the lowest average score, perhaps because speech problems are difficult to correct within a single season. Guides with substantial speech deficiencies need to be screened out during the selection process. However, better selection of potential guides in 1991 has probably made tours more educational. Initial overall scores were higher than in 1990.

There needs to be more in-cave audits and continued training and evaluation by the Head Guide and Park Ranger after initial certification.

The following are those important performance elements with the lowest average final certification scores and those with the most improvement. Extended comments follow for all elements.

1991	Elements	Suggestions for Improvement
69%	Speech	Reduce meaningless and/or distracting sounds/words. 78% in 1990, 76% in 1989.
73%	Combines Many Arts	Use more stories, metaphors, role playing, anecdotes, word pictures, sensory involvement, analogies, and demonstrations. Use more creative and spontaneous humor. 88% in 1990, 66% in 1989.
78%	Non-verbal	1990 score was 91. Be less flippant and use silence and more visual body movements.
81%	Relates to Visitors	Seek out visitor interests & use questions. 91% in 1990, 75% in 1989
83%	Aim is Provocation	Challenge expectations. 89% in 1990, 61% in 1989
88%	Presents Whole	Tie in questions to theme. 75%-1991, 73%-1989
93%	Content	Stick to current manuals and check extrapolations with Head Guide or NPS. 85% in 1991, 64% in 1989

	Written Test Score	Provisional Audit	Final
1989 Average	77	71	82
1900 Average	85	78	86
1991 Average	87	72	87

SUMMER 1991 STANDARDS FOR OREGON CAVE TOUR GUIDES

INTRODUCTION

Reasons for Standards: Performance standards and training to meet these standards are needed because the National Park Service (NPS) is mandated to conserve park resources, provide for a meaningful, enjoyable, value-for-money experience for visitors, and find uses compatible with such mandates. The NPS requires that Oregon Cave guides have enough communication skills to accomplish these mandates. Even after some understanding occurs, more training is needed to make use of new information and to give dynamic and exciting interpretive tours in a seemingly unchanging Cave.

HOW THE SYSTEM WORKS

The Operating Plan (CC-ORCA001-87) states that "the NPS naturalist determines if the guide-in-training is sufficiently knowledgeable before he/she is certified to conduct cave tours." To allow the guide to become familiar with the cave and the performance standards and to conduct tours at the beginning of the season, certification is divided into provisional certification and full certification.

Provisional certification means a concession employee can give cave tours up to 14 days before he/she is or isn't fully certified. A person is provisionally certified if he or she:

1) correctly answers 80% or more items on a written test;
2) attains a final score of at least 65% on the first audit;
3) gives all required beginning messages;
4) has a visitor restate the tour's theme at the tour's end.
5) gives a theme-oriented interpretive tour that doesn't imitate tours prepared by other people, and;
6) meets at least two of three measurable, written objectives.

Provisional certification is withdrawn after 14 days or if there is less than an 80% score on the second audit. A noncertified guide who gives a public tour while not accompanied by a certified guide cannot be certified for one year from the date of the tour.

Written Test: The Operating Plan (CC-ORCA001-87) requires cave guides to take a written test. All test questions derive from material in this document, including all appendices. Questions are multiple choice, true-or-false, fill-in-the-blank or essay. If the guide scores below 80%, he or she may take another test after two days. Failure to pass both tests results in the guide not being certified. A guide must pass a test within ten days of his/her first day of training.

Audits: Each guide has at least one audit. The Head Guide has each guide read and sign the audit form (Appendix A). Then the Head Guide tapes and scores the 1st audit. Based on analysis of the audit, the park ranger gives a final score, either agreeing with the score given by the Head Guide or changing it. If the final score is less than 80%, a subsequent audit is done by the park ranger within seven days of the first audit. The 100 total possible points are spread among three sections: MECHANICS (20 points), COMMUNICATION (40 points), and TILDEN'S INTERPRETATION (40 points). Each section in turn is divided into four elements. A high score can be reached without using most of the methods listed in these standards; quality is more important than quantity. Guides who develop clear themes, are accurate, inspire, provoke, share their excitement and love for the Cave, relate well with visitors, and follow procedures usually score above 80%. Improving how themes, humor, questions, etc. are presented often will raise scores in several elements. Although observing audience reactions is vital in scoring an audit, allowance will be made for an unusually unresponsive group as long as the guide strives to provoke, build rapport, etc.

Full Certification: A guide who scores at least 80% on both an audit and the written test is recommended for full certification by the Area Manager. Full certification remains valid unless the guide scores less than 80% on a future audit. Guides are re-certified within at least one year of their last certification. To be re-certified, a guide must improve based on at least half of all suggestions from the last audit.

AUDIT STANDARDS

Note: See Appendix A for the score sheet.

MECHANICS (20 of the 100 total possible points)

Appearance (5 points): Follows written standards.

Control (5 points): Encourages participation in resource-protection by example and theme. Head counts occur at the 110 Exit and the Ghost Room. Closes and/or locks cave doors. Has a firm, tactful, and effective direction and arrangement of the group. The reasons for the rules are explained clearly. The lowest control level needed to insure compliance is used. Keeps within sight of the lead visitor.

Observed federal or state law violations are reported to the ORCA ranger office when the first phone is reached. A call is made if there is a doubt as to whether an offense has occurred. The exception is touching of formations. However, the ORCA ranger office is called if a visitor continues to touch formations after being asked several times not to do so.

Safety (5 points): Alerts all visitors to hazards. Diplomatic, tactful, and sensitive to potential embarrassments. All life-threatening emergencies are reported as soon as the nearest phone is reached. The report includes location of the subject, extent of the injury, type of illness, state of consciousness, breathing or pulse condition, and any condition that could have contributed to the incident. Less serious incidents in which swelling, bleeding, limping, or illness occurs are reported to the ORCA ranger office as soon as the tour is ended.

If a person is injured or becomes ill on a tour, the guide calmly gets him or her comfortable. The person is not moved if a spinal injury is suspected. Gives first aid only up to one's level of training. If the ill person does not begin to recover after a few minutes of rest and observation, the tour guide reaches the nearest phone and calls the ORCA ranger office.

Nobody is placed in charge of the group while the guide obtains help. The group is told to remain where they are and is assured the guide will return shortly. Upon return, the guide stays with the group and is available to assist until relieved by a ranger. The tour continues when directed to by NPS staff.

When lights go out in the Cave, the guide uses his/her light, gives spare light to the last person on the tour and tells all to stay where they are. He/she stays puts and does not proceed until the lighting system is on or until told to by park staff. Paradise Lost is bypassed. Extra safety warnings are given.

Timing (5 points): Tour is on time. Chats with visitors before tour. The introduction begins at the scheduled time. Gives a required introduction that includes: 1) a welcome, 2) a statement that the guide works for a private concession, the Oregon Caves Company, 3) NPS objectives that include the rule about touching and stresses the Cave's fragility; 4) the strenuous nature of the tour and it not being recommended for anyone with walking problems, 5) distance and time to be covered; and 6) the tour's theme. The theme also must be restated or touched upon at the end of the tour and two of the three measurable objectives must be met in order for the guide to be fully certified.

COMMUNICATION (40 of the 100 total possible points)

Content (16 points): Information agrees with this document and the current ORCA Training Manual. Uses information mostly for theme support. Teachable times such as unexpected events relate to the theme. Doesn't imitate other tours. Stops and talks vary. Explains new concepts in ways one can understand. Doesn't state the obvious.

Para-verbal Communication (16 points): Enthusiastic, confident, courteous, warm, sincere, and relaxed. Is not bored or "burnt out." Shares excitement about and love of the Cave, first-time-in-caves experiences, and other feelings. Does not lecture.

Body movements add to effectiveness. Has potential eye contact with all visitors most of the time. Number and extent of stops and silent periods are appropriate. Makes visitors feel safe. Talks with visitors, not at them. Is not flippant.

Speech (8 points): Language is well-enunciated, readily grasped, relates to an actual, specific thing or instance and is often tangible. Words are colorful, not off-color. Sentences are complete. Verbs are active. Uses proper grammar. Style isn't stilted or tape-recorded. Avoids unneeded sounds.

When talking, usually faces the group and avoids walking. Insures all can understand. Rate and change of delivery and pitch are adequate and conversational. Speech is slow enough to be understood and fast enough to maintain interest. Uses transitions. Hints as to what to look for ahead.

TILDEN'S INTERPRETATION (40 of the 100 total possible points)

Successful interpretation increases understanding, appreciation and protection of park resources.

<u>Relates to Personality or Experience of Visitor</u> (8 points): Alters content and style as appropriate. Uses themes, tour stops, and/or interpretive methods not used during the 1st audit. New terms and concepts are few.

Questions are encouraged, repeated, one-at-a-time, relevant to visitor interests and experiences, and directed to the entire audience. Rarely answers his or her own questions. Is patient, allowing time for visitors to answer questions. Guide corrects answers in a supportive manner and draws out discussion. Does or says the kindest or most fitting thing without compromising NPS policies, and shows respect for others' points-of-view.

<u>Combines Many Arts</u> (10 points): Gives content life and imagination. Humor is appropriate and builds rapport or depicts an important point. Much humor is spontaneous and not "built" into a certain part of the tour. Familiar things are seen in a new light. Different points of view are offered.

<u>Chief Aim Is not Instruction but Provocation</u> (8 points): Visitors are inspired to widen their understanding and alter behavior. Reveals/connects meanings, processes, and relationships instead of stating facts such as names of rooms or formations. Visitors are provoked but not offended; they still have a good time. Challenges expectations, what the visitor believes has or will happen. Maintains anticipation, attention, and curiosity. Tour pace, surprises, suspense, ironies, and initial "grabbers" engage/provoke interest. Equally attentive to all visitors.

<u>Presents Whole rather than a Part</u> (14 points): A theme is a concept stated in one sentence and which ties together what is talked about. A theme provides continuity and organization and leads visitors in the direction the guide wishes them to follow. Acceptable themes are those found in Appendix B or those approved by the Area Manager or his/her appointee. <u>To be both provisionally and fully certified, all guides must 1) present a central acceptable theme and 2) have at least one visitor restate that theme near the end of the tour.</u>

Guide infers or deducts new information from the tour's theme and encourages visitors to do the same. Some answers are tied back to the main theme.

Appendix A CAVE TOUR AUDIT FORM ___ Provisional ___ Full

I, ________________________ (print name) have studied the 1990 STANDARDS FOR OREGON CAVE TOUR GUIDES and am ready to be audited using this form. My theme #_______ of the 5 themes* found in the standards. Listed at the bottom of the page are my 3 measurable objectives. Auditor scores on each blank underline before the maximum number of points for each category. Maximum score is 100. Passing for full certification is 80 or above. Circled items are those in need of improvement.

MECHANICS (20 points) COMMENTS

Appearance (__ of 5) ____
(Conforms to dress, uniform, grooming, and posture standards)

Control (__ of 6) ____
(Firm; appropriate; model; credible; explains rules; monitors all persons on tour; positions self and audience; teaches preservation by example, explanation, theme, and appreciation)

Safety (__ of 5) ____
(Gives warnings, follows emergency procedures; monitors group; uses tact; has appropriate concern; adjusts suitably)

Timing (__ of 4) ____
(Says required elements at start of tour. Allows for warm-up time; tours are well spaced and on time)

COMMUNICATION (40 Points) COMMENTS

Attitude (__ of 8) ____
(Enthusiastic; confident; shares feelings; courteous; friendly; relaxed; curious, not flippant, "burned out" or boring)

Content (__ of 16) ____
(Uses up-to-date information; separates opinion from fact; purposive; appropriate for theme; uses surprises; creative; gives his/her own tour, doesn't imitate other tours; uses and rearranges new data and techniques)

Non-verbal (__ of 8) ____
(Gestures, pauses, silence, and stops appropriate and purposive and instill credibility; distractions few; personable; congenial, sympathetic, accepting; involves multiple senses)

Speech (__ of 8) ____
(Articulate; conversational; concrete; clear; colorful; avoids meaningless sounds, jargon, trite sayings, and breathiness; transitions are smooth, linked, varied, and more than two)

(To be certified, must state their theme at the beginning and end of a tour, have visitors state it, and give a theme-oriented tour; consistent; linked; illustrated; supported; approved; goal oriented; structured; unified; deductive)

NPS Total Score is _______ points. GENERAL COMMENTS

Objective #1 ______________________________

____

Objective #2 ______________________________

____

Objective #3 ______________________________

____

*List theme if not in #1-#6 - ______________________________

____

HEAD GUIDE INITIALS ___ PARK RANGER CONCURS ___ DATE ___

MANAGEMENT OF LECHUGUILLA CAVE, NEW MEXICO

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ABSTRACT

The recent exploration of more than 50 miles of new cave passages in Lechuguilla Cave have focused national attention on this New Mexico discovery. The large amount of publicity accompanying these discoveries has brought increasing numbers of cavers interested in exploring the cave; interest from the community in commercializing the cave; and a renewed interest in the concept of "underground wilderness". This session will discuss the management implications of the Lechuguilla discovery.

No Paper Received - Please contact the author for further information.

CAVE MANAGEMENT IN HAWAII

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ABSTRACT

As in other states, caving and speleological study are increasing rapidly in Hawaii. Cave management here must consider special factors rarely if ever relevant in other states. Geographic, demographic, and political isolation has hindered development of broad-based cave management plans, with small, single-purpose factions the norm. With the recent chartering of a Hawaii Grotto of the National Speleological Society (N.S.S.), it is proposed that it is time to coordinate the cave conservation and management activities of all constituencies based on minimum-impact, tread-softly concepts.

Cave management is in its infancy in Hawaii. Yet, as in other states, caving and speleology are increasing rapidly here, with caves increasingly in the public eye. In Hawaii Volcanoes National Park, Thurston Lava Tube is perhaps the world's most widely advertised lava tube cave, visited by thousands monthly. Even more pay to visit Fern Grotto on the island of Kauai, and some continue north to the roadside attractions of Maninoholo Dry Cave and Waikapalae and Waikanaloa Wet Caves. Wainapanapa Wet and Dry Caves are similar attractions of a state park on the island of Maui, and Long Cave in Maui's Haleakala National Park is partially developed for visitors. On the outskirts of Honolulu, Makua Cave appears in innumerable tourist items. Located alongside a main highway, urbanization has turned it into a horrible example; though historic, no one seems interested in protecting it. A recent article in Maui, Inc. told all about a sensitive burial cave on the grounds of a famous Waikoloa hotel. Several tour operators conduct well-advertised boat trips into large littoral caves on the spectacular Na Pali coast of Kauai. A picturesque cave entrance on Moku Manu Islet adorns the flyer of an Oahu boating company. Cave and cavern dives are advertised by several dive shops on various islands. In the suburbs of the city of Hilo, the county even has provided steps for local beginners down into a notable cave and named the site Kaumana Cave County Park. Many local spelunkers get their start here.

The staff of Hawaii Volcanoes National Park commonly encounters ill-informed local cavers hunting for caves to visit in that park, not knowing that a permit is needed to enter any cave there except Thurston Lava Tube. And indeed, in talking to local people living in burgeoning nearby subdivisions containing important caves, I have found much the same spectrum of attitudes to caves and to their preservation and to caving as on the mainland.

Progress of urbanization of these poorly planned subdivisions is a special and ever-growing threat to the caves within them. Another is the state's willingness to abolish cave-containing Natural Area Reserves without even a public hearing (recently opening one such wilderness to destructive commercial use). With land prices recently soaring in much of the cave country near Hilo, few cavers can afford to buy lots containing cave entrances to protect them, and after a decade, the proposed Hawaii Caves Conservancy still does not exist.

Some owners of large tracts of land do enforce notably stringent exclusion of trespassers, including cavers, speleologists, environmentalists, and just about everyone else. But from the standpoint of cave conservation, these exclusions are fringe benefits of traditional oligarchy. And in some cases, current development of these oligarchal lands is threatening vital habitat caves with little or no knowledge by conservationists.

The Native Hawaiian community is splintered in its attitudes, but a highly respected segment properly views at least some caves as inviolate "kapu" burial vaults sacred to certain families.

One controversial law of uncertain constitutionality seems to have vested title to all Hawaiian caves in the state, without recompense to owners. Yet I cannot find any state agency that considers that it has title to the caves of Hawaii, and no state agency known to me has promulgated a Cave Management Plan. As for federal cave managers, geographic, demographic, and political isolation from the mainstream of American cave management has hindered development of rational cave management plans. Perhaps worse, some local representatives of at least one highly respected national conservation organization seem to have placed other factors above preservation of threatened cave habitats, and the few speleologists who were aware of this problem kept the information within a very small, tightly knit local network.

Each constituency concerned with protection of caves in Hawaii has its own data base, jealously guarded against every other constituency, as well as against the public and agencies. The files of the Hawaii Speleological Survey (H.S.S.) are guarded no less closely than those of cave biologists, consulting archaeologists, state agencies, and the national parks. Data in files of Hawaiian Burial Councils perhaps is the most guarded of all (other than family burial information not written down anywhere). Often it is even difficult to find out what caves are "kapu" to one group or another and should be avoided by some or by all. Bad-mouthing of other constituencies is so common as to be almost the norm.

An N.S.S. Hawaii Caves Conservation Task Force has existed for almost a decade, but most of its work was secretive, and until very recently there was no perceptible N.S.S. presence in the state. Now there is an N.S.S. Hawaii Speleological Survey and a Hawaii Grotto, with another grotto being formed. All are committed to tread-softly, minimum-impact caving.

Under these circumstances, strategies aimed at protection and management of caves and their resources and values cannot be based successfully on the ostrich principle, nor on the related principle that only scientists and administrators are properly concerned with cave protection and management.

But cave management in Hawaii must consider certain factors rarely if ever relevant in other states. As in the Galapagos and other isolated oceanic islands, the remote location of Hawaii has produced a specialized biota above and below ground. Hawaii has notable and vulnerable cave and interstitial habitats for specially adapted creatures like the no-eyed big-eyed hunting spider. Cave burials and other cultural features are at least as needful of protection, as well as the fragile geological and paleontologic features. Wilderness, recreational, and other resources and values must be meshed into this unique nexus.

In late 1990 at least two bitter controversies erupted out of this nexus. The person charged with preparation of a Cave Management Plan for a large Hawaii national park had never been in a wild cave, nor had any member of his staff. While his intentions were good, he clearly had a distorted concept of cavers and speleological organizations, and in a private conversation he revealed himself as hostile to organized caving. While he made good use of scientific input, initially he also was hostile to input from a very experienced speleologist of equal rank in that park. After a considerable brouhaha he promulgated a final Cave Management Plan which was considerably improved but still included personal interpretations that distorted the intent and language of the Federal Cave Resources Protection Act.

Then in December 1990 a frustrated local spelunker went to the newspapers about damage and threats to culturally important caves in what had been the Wao Kele O Puna Natural Area Reserve--now a site for geothermal exploration and development. Normally, information on culturally important caves is closely guarded, and going to the press was an unheard-of last resort. The situation was especially complicated because he had promised certain families that he would not show their "kapu" family caves to anyone else. From what he considered bitter experience, he had lost all confidence in the state agencies which he thought should protect these cultural values. Although he knew one member of the N.S.S. Hawaii Caves

Conservation Task Force, he had never heard of the N.S.S. nor the American Cave Conservation Association (A.C.C.A.) until the H.S.S. contacted him. Thus he had no way to know that help was available from these organizations.

The N.S.S. Conservation Committee immediately investigated, and its Board of Governors quickly passed a strong resolution of concern and support, calling for an Environmental Impact Study as demanded by the Sierra Club Legal Defense Fund. This subsequently was adjudged in federal court, with the N.S.S. resolution cited in the judge's favorable decision. The Hawaii Speleological Survey subsequently has volunteered to undertake the necessary field work for the Environmental Impact Study at no expense to the government.

This curious situation remains curious. Despite withdrawal of federal funding pending completion of the Environmental Impact Study, the state of Hawaii has continued to fund the geothermal exploration. At the moment, the work is in abeyance because of numerous technical problems and public outcry. And only in the hassle did it come to light that one state agency was in the process of protecting one of the caves in the Wao Kele O Puna area and a wide strip around it, as a result of input from a Hawaii Caves Conservation Task Force member. In addition, this agency had developed an especially curious plan to protect some other caves in the area which might be reported by bulldozing or drilling teams. The principal requirement for protection is that they be 8 feet or more in height. Since most cave burials encountered by the Hawaii Speleological Survey are in caves less than 4 feet high, this is highly controversial, and the reason for selection of the figure of 8 feet remains obscure. A report on this protection plan promised by January 1991 still has not been released, supposedly as a result of opposition by the branch of the state government promoting geothermal development. Despite two face-to-face meetings and promises of cooperation with the H.S.S., as of this date this state agency has never communicated in writing with the Hawaii Speleological Survey or the Hawaii Grotto.

In such a milieu, local recreational cavers are careful not to tell anyone but their friends where they go caving. Most are completely unaware of the importance of local conservation essentials such as avoiding pendant root habitats and other fragile cave features, much less tread-softly, minimum-impact concepts and the existence of the N.S.S. and A.C.C.A. Caves are suffering as a result. This has spawned outreach by the H.S.S. and the Hawaii Grotto. Plans are underway for an educational sign at the entrance of Kaumana Cave, for example.

But factionalism continues to be harmful to the caves of Hawaii. In nearly every state, there are valid reasons for cave management consensuses that certain caves, or parts of caves, should be accepted as closed seasonally, temporarily, or permanently, to some or to all. Similarly, reasons exist for similar consensuses on the relative values of cave resources and values, thus permitting pro-active management and preservation strategies (the semiquantitative Nieland system of rating cave resources and values is one such method). At present, factionalism in Hawaii is preventing development of such consensuses, with unfortunate results. For example, in the Puna District near Hilo, I know two important burial caves where spray paint has appeared on the cave walls, and the burials have been disturbed recently. Three separate trails lead to the entrance of one of these caves, and the other is alongside a paved road. Nothing has come of Hawaii Speleological Survey's efforts to bridge the gaps between constituencies concerned with such matters. I have not been able to find any group or agency willing to give more than lip service to protecting either cave.

Essential to the success of the consensus approach is mutual accountability of all concerned. At present, each constituency in Hawaii seems to see itself as accountable only to itself and woefully uninformed about at least some of the others. Noncavers' perceptions of caving practices lags 20 or 30 years. Recognition of tread-softly, minimum-impact caving and of the conservation ethic and action bases of the N.S.S. and the A.C.C.A. is badly needed.

I do not contend that all of the factions should mesh their data bases. There are some Hawaiian caves for which this is inappropriate, and data should remain restricted. But consensuses on which caves should remain restricted imply that restricted caves will remain at risk when the risk to others is reduced through broad consensual agreement.

Fortunately, I think I perceive the first beginnings of cooperative cave management in Hawaii, albeit at a very informal level. Developers of a new golf course of Kauai have posted a sign proclaiming their protection of a cave containing a population of the no-eyed big-eyed hunting spider (albeit the cave still is being used as a dump for trash and grass clippings). On the recent oral recommendation of a Hawaiian activist in state government, the H.S.S. is planning an ethnologic approach to older Hawaiians, some of whom do not speak English, to determine what caves are kapu family burial vaults. Both the Hawaii Caves Conservation Task Force and the Hawaii Speleological Survey have begun educational campaigns for caver visitors to the islands, and the members of the former took part in the recent 6th International Symposium on Volcano-speleology held in Hilo in September 1991. But much remains to be accomplished.

I propose that, as a step toward better management and protection of Hawaii's caves, all constituencies examine their postures toward and knowledge of other factions. Hopefully, each will conclude that accountability toward the others will provide better protection for Hawaiian caves.

And beyond Hawaii lie other isolated islands where hard-learned lessons of Hawaii speleology may yield even greater biological, cultural, and other speleological dividends.

BLASTING FOR CONSERVATION: THE ETHICS OF BLASTING AND DIGGING IN CAVES

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ABSTRACT

The justification for modifying a cave using objective comparison (consequencialist) methods requires that all of the consequences of blasting and digging be weighed against not blasting and digging. The results are then compared in terms of which course of action contributes to attaining one's highest value. A case history using Perkins Cave as an example will be presented.

Please contact the author for further information on this paper.

AN INVENTORY SYSTEM FOR LARGE CAVE SYSTEMS

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Wind Cave National Park

ABSTRACT

With the advent of Geographic Information System (GIS) software designed specifically for caves, complete resource inventories of cave systems have become more important than ever. After several years of experimentation, Wind Cave National Park has devised an inventory system which allows data to be collected in a form easily used by a cave GIS. The system consists of a series of forms used in the cave for recording information, and a data entry program which minimizes the amount of time spent entering the information into a dBASE III Plus database for use by the GIS. The system was designed to be used in both previously explored passages, and in newly discovered passages during the survey process. Designed for use in a large cave, the system allows detailed inventory information to be collected and entered in a minimal amount of time.

Introduction

The exploration of Wind Cave has taken place sporadically over a one hundred year period of history. The earliest explorers recorded nothing more than vague written descriptions of their adventures. In only a few instances is it possible to determine the rooms or passages being described.

After the 1890's few additional discoveries were made until the mid 1960's, when explorers discovered the Spillway. Beyond this crawl, the cave seemed to open up significantly, with passages leading off in virtually every direction. By this time, the standards of cave exploration required a survey of the passages being discovered. Although these surveys were performed, very little information concerning the contents of the newly discovered passages was recorded.

Exploration accelerated in the early 1970's with the involvement of the Windy City Grotto. The discoveries were once again numerous and dramatic, but the explorers neglected to record much information beyond the usual measurements taken during a survey. The prevailing survey standards of the day did not require many detailed observations.

During the mid 1980's, the National Park Service (NPS) grew concerned about this lack of information. In effect, the NPS was charged with managing a cave which it knew almost nothing about. Basic cave management decisions, such as setting limits on group sizes in off trail areas, were being made without the benefit of knowing what resources could be impacted. At that time, roughly 42 miles of the cave had been explored. The only information regarding the contents of most of these passages was in the form of memories locked in the heads of explorers who were dispersed throughout the entire country.

It seemed obvious that if its responsibilities to the cave were to be met, the NPS would need to initiate some kind of an inventory program which would address this lack of information. Exactly how this would be done was not obvious, however.

Early Attempts

The first attempts at inventorying individual passages in Wind Cave were performed in the spring of 1985. Since we knew of no other large cave system which had performed a passage by passage inventory, the initial work crews were given complete freedom to record the information in any way they saw fit. The variety of inventory methods was as large as the number of groups inventorying in the cave. The results ranged from a few illegible scribblings to detailed, meticulously recorded observations.

Three important lessons were learned as a result of this experience. First, if the NPS wished to have information of consistent quality, it would have to establish specific instructions for inventory. Second, in order for the information to be of use, it had to be tied to cave maps in some fashion. Unless an inventory party had recorded their observations on a cave map, it was difficult to determine with certainty which passages contained the features being described. This relationship between inventory data and cave maps would change over time, but it would remain one of the fundamental issues of the project.

The third important lesson learned as a result of these early attempts was that this project would be generating a huge amount of data. Some system would have to be designed to make this information both accessible and useable.

Strike One!

During the summer of 1985, the first cave inventory procedures were written. The inventory procedures contained instructions on recording data in the cave, and also outlined how the data would be used on the surface.

Inventory crews were asked to enter the cave armed with pencils, paper, and a copy of the 1:600 master map of the cave. A single notetaker was responsible for recording all observations. Upon reaching the area to be inventoried, the crew would spread out and begin to look for items of interest. When something worthy of noting was found, its discoverer would stand near it until the notetaker arrived.

A method for recording the information was suggested. The area to be inventoried would be divided into sections roughly 100 feet in length. For each section, a general description such as "classic upper level cave, walking sized, with smooth, sandy floors" was recorded. Descriptions of individual items in the inventory were recorded either directly on the map itself, or on another piece of paper if insufficient space was available. To ensure that a location in the cave was tied to each item, a letter reference was noted on the map, with a corresponding letter reference and description on the other piece of paper.

The procedures also outlined what would be done with the data once it was out of the cave. A series of overlays were to be developed which could be aligned with the master map of the cave. There were to be overlays corresponding to speleothems, cave levels, biological items, historical items, and hazards. Each transparency would have a color code for each of the items it highlighted. For example, on the speleothem overlay orange represented flowstone, brown represented boxwork, blue corresponded to popcorn, and so on. Since each inventory crew recorded locations of the inventory items on copies of the master map they brought into the cave, it was a simple matter to transfer this information to the overlays. This arrangement allowed any interested person to recognize at a glance what each inventoried passage contained.

The system worked, but in a short time some of its failings became apparent. As before, the most serious shortcoming of this system was a lack of consistency. Although inventory crews were now recording all of their information in a consistent manner, consistent quantities of information were not being recorded. This was largely due to vague instructions in the procedures. Inventory crews were asked to record all "notable resources", yet no definition of what constituted a notable resource was offered. What was notable to one person often was not notable to another.

Also at this time, the park began to acquire increasingly powerful personal computers which were capable of storing and retrieving the raw information in a much more efficient manner. The present system of recording information in the cave provided nearly exact locations of individual features in the cave, but did not tie that information to anything which could be easily referenced by a computer. Due to all of these shortcomings, a new set of procedures was developed early in 1987.

Strike Two!

The new procedures were designed to retrieve data as detailed as that obtained by the older system. All items mentioned in the inventory were to be referenced to the closest survey station. Detailed computer databases, with each record of the database corresponding to a survey station in the cave, could then be constructed.

A special checklist was brought into the cave to remind crews of the resources they should be looking for. The checklist contained lines next to the name of each resource which were used to list the survey stations which contained the resource. The notetaker would move throughout the cave, recording the name of the closest survey station on the lines for each resource being seen. Additional details were recorded in special sections of the checklist devoted to notes. Exact locations for each feature being inventoried were recorded either on a copy of the master map or, if the master map was not accurate, on a new sketch of the passage.

This new system resolved the problems associated with earlier inventory systems. The checklist assured the park that all inventory crews would be looking for the same cave features, thus providing more consistency. Referencing each feature to the closest survey station simplified the switch to computer databases for data storage and retrieval.

Once again armed with pencils, maps, and forms, inventory crews entered the cave to test the new procedures. The system worked well, but after many trips it became obvious that it had one remaining flaw. It was too slow. By the end of 1989, less than two miles of the cave had been satisfactorily inventoried. The cave, which had grown to 53 miles in length, would require decades to inventory at the current rate.

The Present System

In early 1990, inventory procedures were again reviewed, this time to improve efficiency. It had been obvious from the beginning that the notetaker had been the bottleneck of the process. One person was responsible for recording all of the information obtained by the inventory crew. To eliminate this bottleneck, the inventory checklist/form was divided into three different forms. Instead of one notetaker, there would now be three. Each notetaker would be looking for, and recording information about, a subset of the original checklist. One would be providing information regarding the physical characteristics of the passage, another would look for only speleothems, and the third would search for items of historical, biological, and general geological interest. See Figures 1, 2, and 3 for examples of these forms.

It was also decided to eliminate the requirement of providing exact locations of items on maps or sketches of the passage being inventoried. The average distance between survey stations in Wind Cave is roughly 25 feet, so on average, simply referencing the nearest survey station locates a resource to within 10 to 15 feet of its true location. This was decided to be accurate enough for most purposes.

Eliminating these two bottlenecks from the old inventory system drastically increased the efficiency of the process. A well trained crew can now inventory in an hour what used to take an entire day. In addition, efficiency was improved to the point where it was suddenly possible to perform an inventory during the survey of new passage. Although it adds an additional duty to the survey process, it does not slow the survey down in any way. One person, usually the person assigned to the tape, is responsible for all inventory work. Even though this person is filling out all three forms, he or she is still able to stay ahead of the sketcher, who remains the bottleneck of the survey process.

Marking the main routes out to the areas requiring inventory in this exceptionally mazy cave has enabled a larger number of volunteers to assist with the project. During 20 months in 1990 and 1991, over 17 miles of passages were inventoried in Wind Cave, largely due to the efforts of a dedicated group of volunteer cavers from Colorado. Roughly half of this total was performed in previously surveyed cave, while the remainder was performed in passages surveyed during this time period.

Entering the Data

Soon after the decision was made to reference all inventory data to the nearest survey station, work began on designing the databases which would hold the enormous amount of information the inventory project would generate. With more than 12,000 survey stations in the cave at the time, it was desirable to automate data entry as much as possible. A program was written which created a record in the database for each existing survey station in the cave. The fields corresponding to features in the cave were left blank, but the fields representing the station name, its x,y,z coordinates, and survey date were automatically filled in.

This left us with databases representing all of the cave, but the databases were largely empty. Filling in the blanks for inventoried stations could be done in two ways. The first method would involve entering the data a station at a time. The data entry person would scan the inventory forms for items occurring at a particular station, fill in the appropriate fields, then move on to the next station in the inventory. Alternatively, a program could be written to enter the data from an entire inventory all at once. Both methods have advantages and disadvantages, so a program was written to handle data entry both ways.

The standard database management software for the National Park Service is dBASE III Plus. Therefore, it made sense to use dBASE to produce the data entry program. This program, called INVENT.PRG, was written in the dBASE language. It allows the user to choose the mode in which data entry takes place. The initial screen for this program is shown in Figure 4.

If mode B (data entry by individual station) is chosen, the user is first asked for the name of the station for which data entry is to take place. After first checking to be sure the station exists in the database, the program displays the first of several data entry screens. The names of all features listed on the inventory forms, in the same order as they appear on the inventory forms, appear in these screens. If a particular feature was noted in the inventory at the given station, some kind of a code, often just an "X", is placed in the space provided next to that feature. A memo field is available to enter miscellaneous observations, or to elaborate on any item noted in the inventory. One of the data entry screens for mode B is shown in Figure 5.

Mode A (data entry by group of stations) is the method most often used to enter the data from an entire inventory trip. After being asked for the range of stations in the inventory, and ensuring that those stations exist in the database, the user is presented with a number of screens which strongly resemble the original inventory forms. If a particular feature is noted at least once sometime during the inventory, a code is placed in the space in front of the feature name, and the station numbers where that feature was noted are listed in the space after the name. The program is quite flexible in the way stations are listed in this space, so data entry is usually just a matter of typing exactly what is found on the line for each feature in the inventory forms. After all lines are filled in, the program automatically updates all of the records in the range of stations provided to contain the proper information. Figure 6 shows an example of a data entry screen for mode A.

Since data entry for a group of stations is often just a matter of copying exactly what is on the original forms, the data for an entire inventory can be entered in a matter of minutes. This may take a bit longer if many detailed comments and observations were recorded, since all memo field text must be entered a station at a time.

Using the Data

Once the inventory information is in the database it is immediately useful. Mode D of INVENT.PRG allows the user to produce a printed report which summarizes what is found at a station or group of stations. Querying the database from within dBASE can provide quick answers to complex questions such as "what percentage of upper level passages contain aragonite?". But when the ability to query the database is combined with computer generated maps of the cave, the real power of the data becomes apparent.

Computer generated line plots of caves have been around for decades. They are useful for illustrating the extent of a cave, or for providing quick profiles, but by themselves they provide little to no information regarding what is in the cave. Another program was written at Wind Cave to interact between the inventory databases and line plots of the cave produced by AutoCAD, a popular computer aided design program. This program allows the user to query the database for any given set of conditions. The program then checks the database for the conditions specified, and highlights the stations in the line plot which satisfy the conditions. Thus it is possible to quickly and easily look for *spacial* relationships in the data. Sometime in 1992, the NPS will receive copies of an expanded version of SMAPS, Doug Dotson's cave survey data management program, which provides these and other GIS capabilities.

The first illustration of how this information could be used came in the summer of 1991. Donald Davis, as a part of some ongoing research regarding the origins of Wind Cave's unusual helictite bushes, requested line plots (both plan and profile) showing the location of all helictite bushes in the cave. Davis felt that the helictites had some kind of a subaqueous origin. He believed that rising water entered the cave from below, mixed with cave waters of a different chemistry, and formed the helictites. Wanting more evidence to substantiate his theory, he forwarded his request for the line plots, along with a map he had found which showed a magnetic anomaly in the vicinity of the cave.

As Figure 7 illustrates, helictite bushes in Wind Cave, with only a single exception, align themselves along the cave's major northwest/southeast axis. Figure 8, which consists of a profile of the major axis area, shows that the bushes are always, with no known exceptions, located in the very lowest passage in the area where they are found. In other words, they are located precisely where mixing would have taken place had water entered the cave from below. While this certainly does not prove Davis' theory, it does provide compelling circumstantial evidence. Further evidence was provided by digitizing the magnetic contour map Davis had located, and geographically referencing it with a map of the cave. As Figure 9 shows, the western flank of the magnetic anomaly runs directly along the helictite bush area of the cave. Could this have provided the source of the rising water?

The fact that we are now able to look for such relationships so easily and so quickly is exciting. Hundreds of cavers had viewed the helictite bushes in Wind Cave, but because they lacked the "big picture" that inventory data provides, none had ever noted these simple spacial relationships. In the future, the inventory data will probably serve as a starting point for many research projects in the cave.

The inventory project at Wind Cave is now finally proceeding at full pace. During an average month, a half mile of previously surveyed passage is inventoried, along with roughly a half mile of passages surveyed during the same time period. This results in more than a mile of inventory data being gathered per month. Even when the backlog of previously surveyed cave is inventoried, the inventory project will not end. Since it is now a part of the survey process, the inventory of Wind Cave will not be complete until the cave has been fully explored. All indications are that this will not be for quite some time.

AREA NAME OR SURVEY: ____________________
DATE INVENTORIED: ____________________
PARTICIPANTS: ____________________
YOUR NAME: ____________________

PHYSICAL DESCRIPTION

MINIMUM SIZE
squeeze ____________________
crawl ____________________
stoop ____________________
walk ____________________

LEVEL
upper ____________________
u. middle ____________________
middle ____________________
l. middle ____________________
lower ____________________

FLOOR
bedrock ____________________
s. brkdown ____________________
l. brkdown ____________________
mud ____________________
loose soils ____________________
false floor ____________________
mud cracks ____________________
other ____________________

WATER
seeping ____________________
dripping ____________________
pooled ____________________
none ____________________
other ____________________

NOTES

FIGURE 1 The physical description form for Wind Cave. Each station number along the inventory appears once, and only once, in the "Minimum Size" and "Level" sections. Station Numbers must appear at least once in the "Floor" and "Water" sections

AREA NAME OR SURVEY: ____
DATE INVENTORIED: ____
PARTICIPANTS: ____
YOUR NAME: ____

SPELEOTHEMS

CALCITE
boxwork ____
popcorn ____
spar ____
calcite coating ____
flowstone ____
stalactites ____
stalagmites ____
columns ____
draperies ____
helictites ____
rafts ____
"gonads" ____
zebra rock ____
other ____

ARAGONITE
needlelike ____
bush type ____
X-mas tree ____
other ____

GYPSUM
needles ____
luster ____
cotton ____
flowers ____
starbursts ____
spiders ____
other ____

HYDROMAGNESITE
on floor/wall ____
on frostwork ____
other ____

NOTES

FIGURE 2 The speleothem form for Wind Cave. Station numbers appear in each section only when a particular speleothem is seen. Like the other forms, a "Notes" section is included for detailed descriptions and observations.

AREA NAME OR SURVEY: ____
DATE INVENTORIED: ____
PARTICIPANTS: ____
YOUR NAME: ____

GEOLOGICAL
quartz____
chert____
fossils____
manganese____
paleo-fill____
other____
____

AIRFLOW
direction at entrance____
Indicate all stations where air-flow is noted, together with direction and intensity.
____
____
____

BIOLOGICAL

VERTEBRATES
bat____
bat scratches____
scat____
nest____
bones____
other____
____
____

INVERTEBRATES
springtails____
crickets____
spiders____
other____

ORGANIC MATERIAL
mold____
wood____
needles____
roots____
other____

RECENT	CULTURAL	HISTORIC
____	signatures	____
____	graffiti	____
____	dates	____
____	paper	____
____	wood	____
____	candles	____
____	glass	____
____	metal	____
____	string	____
____	other	____

HAZARDS
chimneys____
pits____
slippery____
unstable____
loose rocks____
tight crawls____
other____
____

NOTES

FIGURE 3 The miscellaneous form for Wind Cave. As with the speleothems forms, station numbers are recorded only when a particular feature is noted. For cultural items, station numbers are recorded under the "Recent" heading if they are less than 50 years old.

```
                         CAVE  INVENTORY
                           DATA  ENTRY

  INSTRUCTIONS:

  - to abort a record, hit <esc>           - to move cursor up, down, or
                                             to the side, use cursor keys
  - to save a record, hit <ctrl> <end>
    or hit <Page Down> several times       - to enter 'ALL', hit <F8>

Select File By Number: █    1. Historic             5. Half Mile Hall
                            2. Colorado Grotto      6. North
                            3. Club Room            7. Silent Expressway
                            4. Lakes                8. Southern Comfort

Select Mode by Letter: █    A. Group of stations
                            B. Individual station
                            C. Individual station with single page view
                            D. Print data from a group of stations
```

FIGURE 4 The main menu screen for INVENT.PRG. Wind Cave is divided into eight "Zones" for a number of management purposes.

```
                 INVENTORY BY INDIVIDUAL STATION

              Survey: AT
             Station: 58
   Date of Inventory: 07/16/88
 Status of Inventory: 1 ==> 1-solid   2-incomplete   3-from survey notes
     Travel Corridor: █ ==> D-developed trail   T-travel corridor

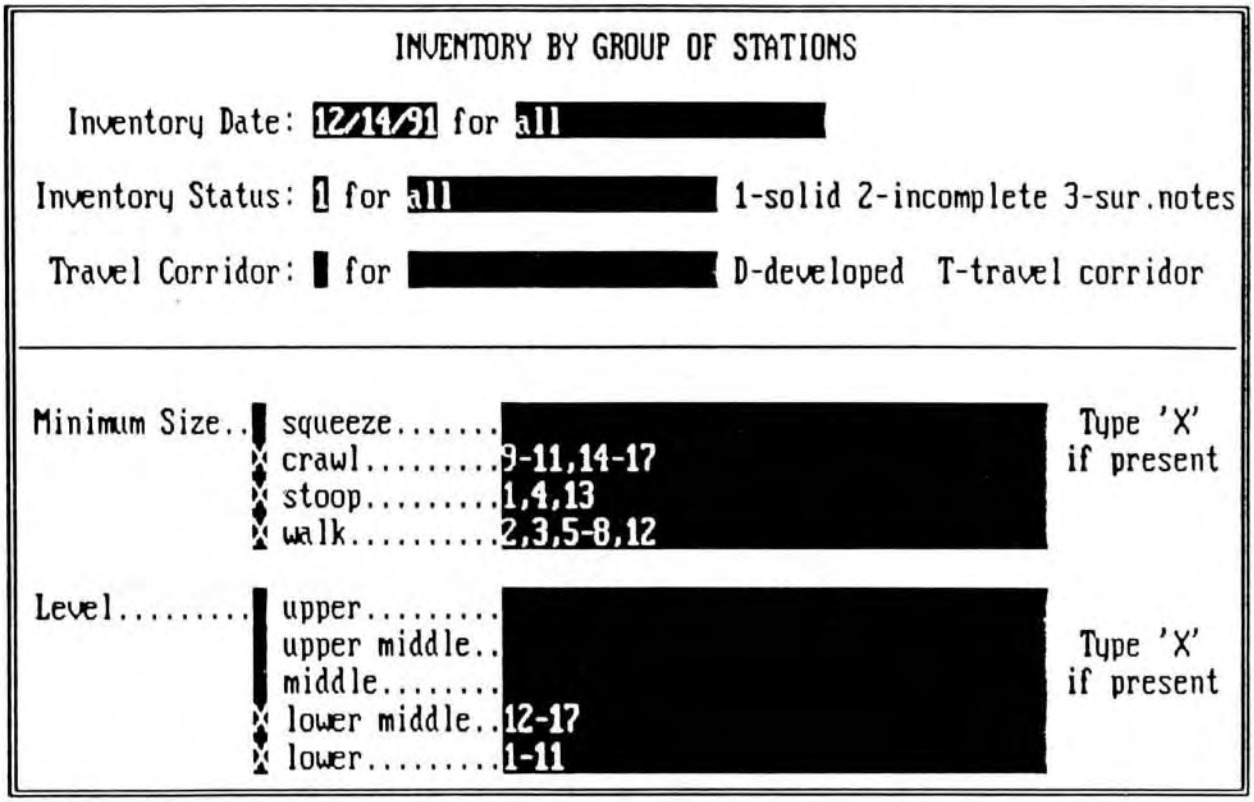
   Minimum Size.......█ squeeze
                      █ crawl              Type 'X' for appropriate line
                      █ stoop
                      X walk

   Level..............4 1-upper  2-u. middle  3-middle  4-l. middle  5-lower

              Memo: memo  hit <Ctrl> <Page Down> to enter memo text

Page One:  General Information
```

FIGURE 5 Screen one from "Individual Station" mode (Mode B) of INVENT.PRG. As this screen illustrates, station AT58 is a walking size passage in the lower middle level of Wind Cave. All memo field information must be entered using this mode.


INVENTORY BY GROUP OF STATIONS

Inventory Date: 12/14/91 for all

Inventory Status: 1 for all 1-solid 2-incomplete 3-sur.notes

Travel Corridor: for D-developed T-travel corridor

Minimum Size.. squeeze....... Type 'X' if present
X crawl......... 9-11,14-17
X stoop......... 1,4,13
X walk.......... 2,3,5-8,12

Level......... upper......... Type 'X' if present
upper middle..
middle........
X lower middle.. 12-17
X lower......... 1-11

Page One: Physical Description

FIGURE 6 Screen one from "Group of Stations" mode (Mode A) of INVENT.PRG. In this mode, information is entered almost exactly as it appears on the original forms. This makes it possible to enter entire inventories at once. Like the forms themselves, INVENT.PRG can be customized to suit any cave.

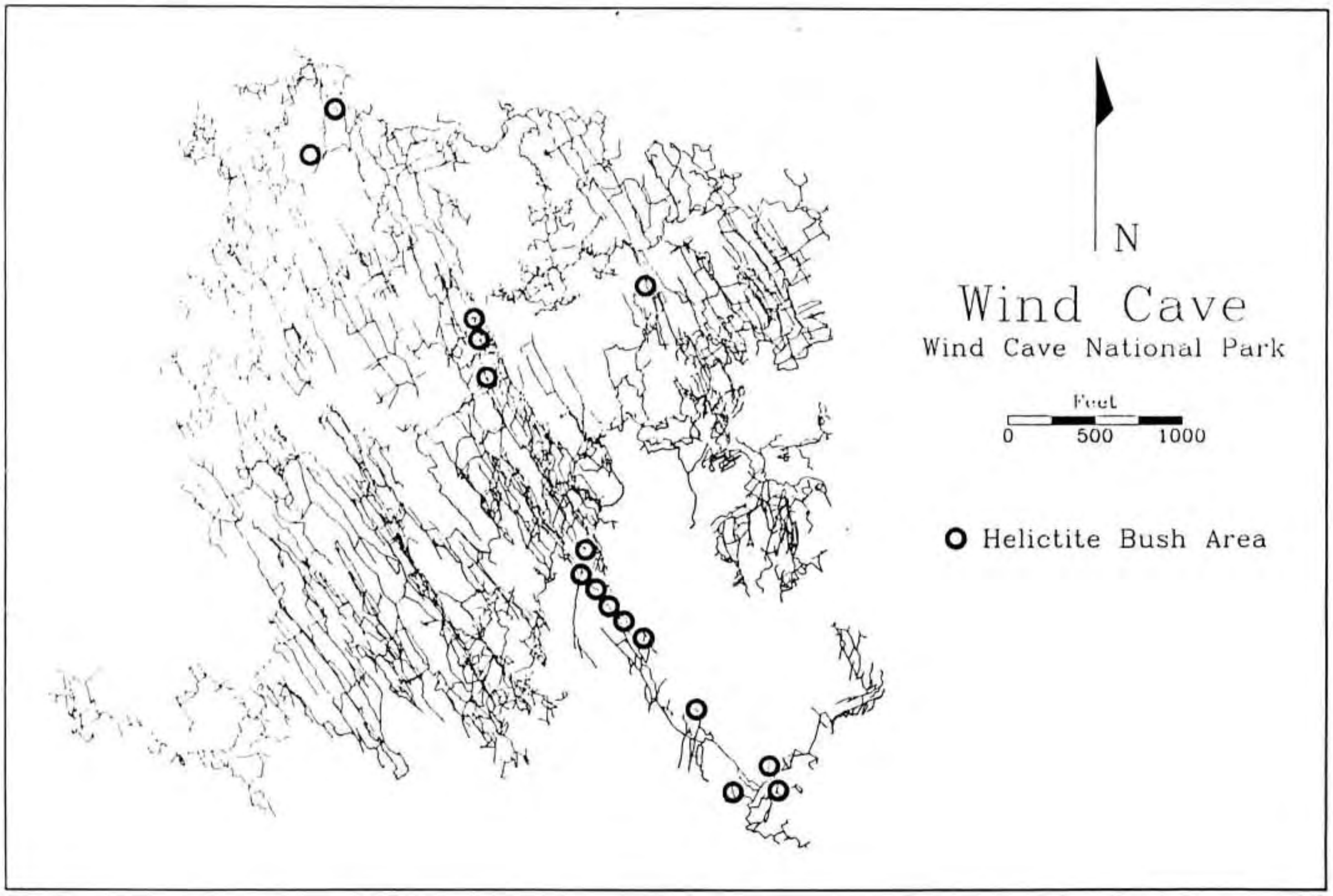


FIGURE 7 A map highlighting helictite bush locations in Wind Cave. By interfacing inventory data with computer generated maps of the cave, a nearly infinite number of new maps can be generated.

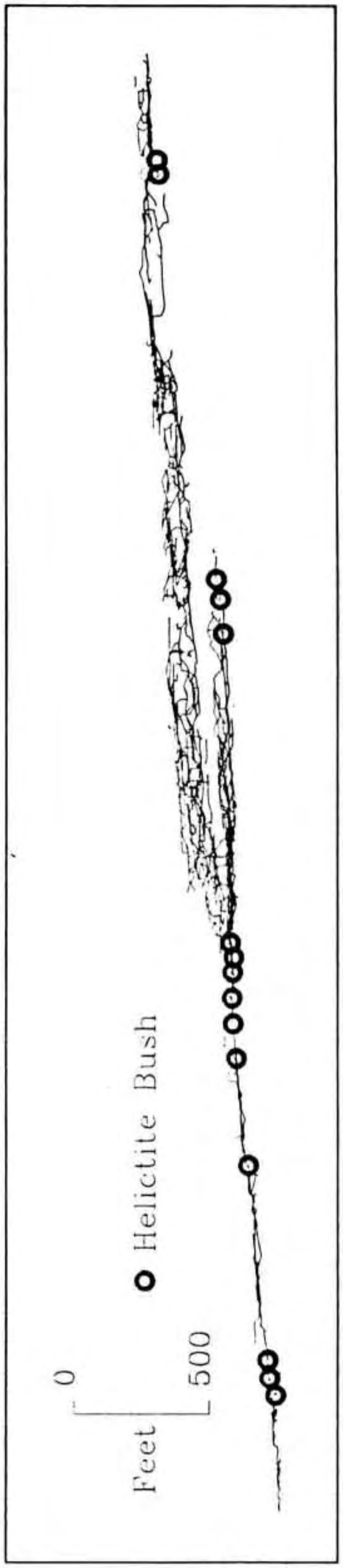


FIGURE 8 A profile of the narrow band of Wind Cave which contains the helictite bushes, viewed from the northeast. Maps such as this can reveal spacial relationships in the inventory data.

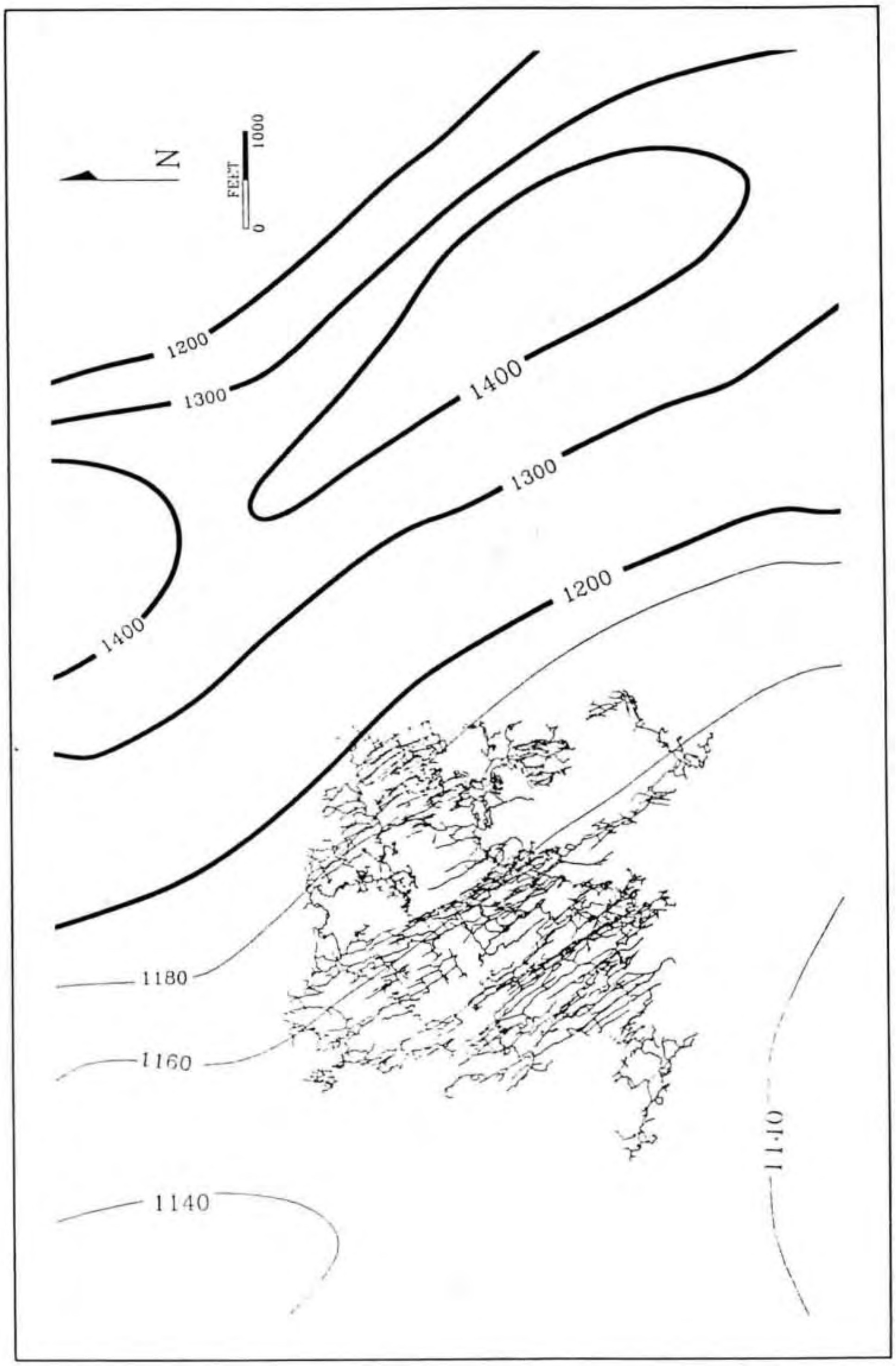


FIGURE 9 A magnetic contour map, together with a map of Wind Cave. The western edge of the anomaly, the 1160 gamma contour, runs along the helictite bush areas of the cave.

APPLICATIONS OF A GEOGRAPHIC INFORMATION SYSTEM TO THE MANAGEMENT OF GREAT SALTPETRE CAVE, ROCKCASTLE COUNTY, KENTUCKY

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ABSTRACT

The writer has begun a project to incorporate spatial and descriptive data concerning Great Saltpetre Cave and the surrounding property into a Geographic Information System database. The project is expected to provide an invaluable management resource needed to make inventories and assessments, and to allow planning to be based on the most complete information available.

Geographic information systems (GIS's) are a relatively new computer technology that have found increasing acceptance in facilities and resource planning and management, and promise to be used increasingly in new applications. Among these new applications is to the field of speleology, where computer technology has the potential to revolutionize the analysis and portrayal of cavern systems and their relationship to the surrounding karst landscape. Very early in the "computer revolution" of recent decades, the data generated by metes and bounds cavern surveys lent itself readily to data processing. Beginning in the 1960's, many computer programs were written by various individuals in languages such as Fortan and Basic. Initially, these fairly simple programs were limited to tabular output of processed data that were then drafted by traditional hand methods to produce a visual rendition of cave passages. With the advent of CADD technology, visual translation of cave survey data files as line plots to monitor screens and output to printers and plotters could be accomplished. One fairly sophisticated software package of this type, SMAPS, is popular with many of today's cave mappers. Software of this sort may be considered as a limited geographic information system.

However, more sophisticated applications are available that allow integration of a far broader range of spatial data, including not only passage surveys but also surface topography and subsurface geology as well as numerous other characteristics, and allow manipulation and analysis of such data. GIS technology is presently being used to build a spatial database for the Great Saltpetre Cave Historic Preserve in Rockcastle County Kentucky. With this analytical toolbox, best management practices may be developed and implemented for the cave and surrounding tract, consistent with budgetary constraints and conservation ideals.

HISTORY AND SIGNIFICANCE OF THE CAVE PROPERTY

Potassium nitrate, known also as saltpeter or niter, as the major constituent of gunpowder has been an important item of world commerce for centuries. During the period just prior to American independence, the major source of supply for this commodity was the Bengal region of India, controlled by the British. Though smuggling of munitions and artificial methods of saltpeter production allowed the colonies to successfully wage war against the British during the revolution, by the advent of the second war with England thirty years later, large naturally-occurring deposits of saltpeter had been discovered in caves on the American frontier. Lexington, Kentucky, became the central marketplace for wholesale trade in saltpeter, and received shipments from the numerous caves in the surrounding belt of Mississippian limestone. Speculators and brokers established themselves in that community, and a flourishing local powdermill industry sprang up seemingly overnight in the Bluegrass region. However, most of the niter supply was shipped to large Eastern manufacturers, primarily the DuPont company in Delaware. With war impending, saltpeter mining became an important and lucrative source of employment for many Kentuckians, who exploited the caves in their vicinity as, most commonly, small-scale, rural cottage industries, but also occasionally as large mining and refining operations utilizing dozens of workmen. The two largest known saltpeter mines in Kentucky were Mammoth Cave in the west-central part of the state, and Great Saltpetre Cave, fifty miles south of Lexington. **1**

Great Saltpeter Cave began production shortly after its reported discovery in 1798 by John Baker. Within four years, a small operation for extracting saltpeter from the cavern soils had been established. George Montgomery and James Kincaid used slave labor to mine approximately 1000 pounds of refined saltpeter per week. In 1804, Kincaid defaulted on a mortgage taken on the cave property and through a complex series of transactions the cave passed into the hands of the partnership of Dr. Samuel M. Brown and Thomas Hart, Jr., both of Lexington. Dr. Brown was a scientist as well as physician, and devoted considerable energy to research into the occurrence and production of saltpeter. Under Brown's management, following the re-engineering of the production facilities by John James DuFour, niter production zoomed to over three tons per week in 1805. DuFour had invented two types of rectangular leaching hoppers, a pumping system to bring water up to the cave from Crooked Creek, and made a compass and chain survey of the cave to produce the second oldest known cave map in the United States. **2**

Unfortunately there are few records to indicate where the saltpeter manufactured at the cave was destined. It seems likely that a greater part of this may have been shipped to the Lexington market. At South Elkhorn in Fayette County, an entire community of powdermakers arose about 1806, representing a cluster of powdermill facilities, and the present writer believes that Great Saltpetre Cave constituted a major source of saltpeter for these mills. At about this same time, Charles Wilkins of Lexington began operating as a large-scale saltpeter broker. Wilkins purchased Mammoth Cave in 1810, and it is of interest to note that niter-manufacturing facilities subsequently constructed at Mammoth duplicated the earlier engineering at Great Saltpetre. **3**

The saltpeter and gunpowder manufacturing industries collapsed in Kentucky following the end of the War of 1812, and there is little to indicate that saltpeter refining continued at Great Saltpetre Cave in any important quantity following that time. Although niter manufacture in the southern states during the Civil War far exceeded that of the 1812 war, Kentucky was a border state not firmly committed to the southern cause and apparently little of this manufacture was carried on in the state. Some minor production occurred Great Saltpetre Cave under supervision of Federal officers. **4**

Following the Civil War, little activity of any kind was seen at the cave, save for occasional local social functions. An attempt to commercialize the cave began about 1941, when the property was purchased by John Lair. Lair had recently established the Renfro Valley Barn Dance, a country music enterprise, and held occasional concerts in the cave that were enhanced by the splendid acoustics of Echo Auditorium. On opening night, CBS broadcast the Barn Dance from the cave. The commercialization of the cave was short-lived, however, and by 1943 public tours were halted. Over the next two decades, only a few paid tours were conducted through the cave. In 1966, a new period of commercial activity began, with some facility improvements made and tours held on most weekends. Regular tours could not be sustained, however, and by 1976 visitation became solely self guided. In 1985 the cave and property were sold and the cave was closed to the public. In 1986 the cave was again placed on the real estate market. **5**

Great Saltpetre Cave was one of the most important niter mines on the continent during the War of 1812, and as such contributed to the production of munitions by the United States in an effort to hold their newly-established independence. It has been established that gunpowder manufacture in Lexington was used in several important engagements of the war, including the battle of Thames River in Canada and the battle of New Orleans. Although never a successful commercial tourist operation, due in large part to the lack of capital on part of the owners and the remoteness of the location, the cave became tied to the local country music industry. The cave is identified on numerous published maps of the state and region, and a state historical marker noting the significance of the cave has been placed in Rockcastle County at the intersection of I-75 and U.S. 25, several miles from the cave. In addition, the 309 acres of the cave tract constitute a significant block of relatively undisturbed wilderness: the Crooked Creek drainage basin, an important area of major karst development. There are several internationally significant caves near the property, and a number of small caves and promising new cave leads on the tract in addition to Great Saltpetre Cave. **6**

ESTABLISHMENT OF THE GREAT SALTPETRE CAVE HISTORIC PRESERVE

During the summer of 1989, a group of casual cave explorers from Kentucky and Ohio found themselves suddenly and unexpectedly charged with the management of this former commercial cave and significant historical site. These cavers were representatives of the Cincinnati and Bluegrass local chapters of the National Speleological Society (NSS). The tract had been purchased by a private historic preservation foundation, which subsequently arranged with the NSS for local volunteers of that organization to manage the cave tract as a historic preserve. This was accomplished amid some debate and minor controversy, resulting in the formation of an ad hoc management committee comprised of four members from each of the two local chapters ("grottos"), and the chartering under Kentucky law of a non-profit scientific and educational organization -- the Great Saltpetre Cave Historic Preserve.

The eight-member committee possessed enthusiasm for the project but little or no experience in site management; in fact, the two grottos had, in the past, only occasional and casual contact with one another although individuals from each group had shared an interest in explorations and research in the cave-rich region of Kentucky's Cumberland Region. The management committee was and is handicapped by a lack of necessary funds for maintenance and development of the property and operates primarily on small donations from interested individuals and organizations, and with labor donated by members of the associated grottos.

An initial management plan was developed by the committee, with stated goals being to manage the property as an "educational, scientific, and nature oriented preserve." However, it was soon discovered in the formulation of the plan that very little was known concerning the assets of the property. In order to provide best management for the Great Saltpetre Cave property, preserving historic artifacts and wisely using the available resources of nearly one-half square mile of land, accurate maps would be required along with detailed inventories of the surface and subterranean features and assets. **7**

BUILDING THE GEOGRAPHIC INFORMATION SYSTEM

As a member of the management committee, the writer set about to build a GIS database that would incorporate spatial and attribute data concerning the property. Advanced computer facilities were provided by the Department of Geography at the University of Kentucky in Lexington, as part of a graduate research project conducted by the writer.

In a limited sense, a GIS is a tool for computerized cartography, but in a larger sense a Geographic Information System can realize the potential inherent in its name, as a spatial database in which geographic data for a specific area is captured, stored, retrieved, analyzed and displayed to emphasize particular characteristics and allow best management practices based on informed decisions. Visual data from many sources may be integrated with alphanumeric attributes contained within traditional database formats.

The geographic information system software chosen to develop the database was a commercial package known as ARC/INFO, marketed and supported by Environmental Systems Research Institute (ESRI). Although a number of comparable alternate GIS packages exist, ARC/INFO was chosen for a number of reasons. Primary among these was ease of access to this package, as ARC/INFO is the instrument of choice for the Department of Geography in instruction and applications, and also for the Kentucky Natural Resources and Environmental Protection Cabinet (KNREPC). As the writer is employed by the Groundwater Branch within the Division of Water, opportunity was provided to learn the software both on the job as well as part of a graduate education. Additionally, the PRIME minicomputer facilities available to the Department used the INFO language for database programming, and thus the writer had gained familiarity with the foundations of ARC/INFO prior to learning GIS applications. As the geographic information system for KNREPC (Kentucky Natural Resources Information System, or KNRIS) was still in the process of development and not yet readily available by network in the Division of Water, the facilities of the University of Kentucky were chosen upon which to build the database. The actual software used, PC ARC/INFO, version 3.3, was run on microcomputers and had slightly less capability than ARC/INFO designed for minicomputers and mainframes but still provided sufficient ability. The first step in building the database was to acquire basic geographic information concerning the cave and property. A color aerial photograph of the vicinity was obtained from the Kentucky Transportation Cabinet, Phototechnic Services, enlarged to a scale of approximately 1:4800. The actual distance between large visual objects on the ground was measured and compared to the aerial photo, so that the actual scale of the photo was determined to be 1:4938. The aerial photo, taken from a 1985 overflight, has served as the major data source for the project. Other important sources of cartographic data have been the land survey of the property from the recent sale, obtained from courthouse records, and the original underground survey of the cavern passages, made in 1982 by members of the Cincinnati and Louisville Grottos. To a lesser extent, U.S.G.S. 7 1/2-minute topographic quadrangles have also been used, although reliability was considered to be much less than the aerial photography.

APPLICATIONS OF THE GREAT SALTPETRE CAVE GIS

At the present time, the full potential of a GIS system has only been partially tapped, as the project is still in initial stages. Spatial data thus far incorporated allows portrayal of the surveyed property lines, major surface features of the property such as streams and roads, and the survey plot and passage outlines of Great Saltpetre Cave (Fig. 1). Distinction can be made among various feature types of the same class, for example roads, which are displayed as paved, gravel, and dirt by means of differing line symbols. Additional differentiation is made among features by the use of color, so that line symbols may be graphically identical for a secondary road as for a secondary stream but are easily separated visually. Features may be viewed at any desired scale, from an overview of the entire property to extreme magnifications revealing considerable detail. Maps may be displayed on-screen for manipulation or modification, or output to an attached color pen plotter. In addition, automatic calculations are built into the database that determine area or boundary measurements, and other calculations may be specified.

ARC/INFO is a vector-based GIS; information is captured and manipulated by representing spatial features as points, lines, or polygons. For example, a karst spring or a utility pole location would represent point data; roads, streams, and cave survey plots are line data; and property boundaries or areas of differing vegetation are polygon data. A line or polygon is built from a number of connected points, with locational and other reference data attached. Each data item, point, line segment, or polygon, may have additional attribute data. Examples of attribute data would be station field ID numbers or passage heights for points on the cave survey, or lithologic unit names for polygons representing underlying bedrock formations.

At this stage in the creation of the Great Saltpetre Cave GIS, digitizing of the cave map has provided sufficient accuracy for current needs. However, digitizing the survey line first places the points and subsequently calculates locational coordinates. However, it is possible to input numeric information directly, building a table of actual survey data that creates the plot with greater accuracy. Data generated by a conventional cave map program such as SMAPS, when converted to an ASCII file, can be accepted and used to create an ARC/INFO data file. This will be accomplished during 1992 to replace the digitized survey, allowing additional passage surveys to be more readily incorporated. Other spatial data that will be added in the near future include surface geology (lithologic units), topography (contour lines), vegetation types (e.g., mixed deciduous hardwood, coniferous, pasture, wetlands), and structures such as sanitary facilities, campground pavilion, and RV hookups.

Features that will require more effort to add to the database include the external plumbing and wiring systems that serve the campground, karst features such as springs and sinkholes that are too small to be discernable on topographic maps or even on enlarged airphotos, and locations and surveys of other caves on the property. One of the most challenging of the surface tasks will be the creation of a network of hiking trails that link the most aesthetic portions of this rugged woodland karst environment. It is expected that the GIS will be important in evaluating alternate routes that connect points of interest. When trails are finally constructed, following the evaluation process, they will be surveyed and the survey data incorporated into the database.

Within Great Saltpetre Cave itself, there are numerous assets and features that need to be inventoried and built into the GIS for detailed displays. These include the various historic artifacts within the cave, particularly the remnants of the 1812 saltpeter works. Some of the subterranean features to be built into the database are counterparts of features existing on the surface. The wiring and lighting system within the cave has deteriorated considerably and much needs replacement and upgrading. Here, too, the GIS will be able to help plan the most economical and efficient rewiring of the most heavily traveled routes, and to aid in maintenance through constantly updated displays of junction boxes, lighting fixtures, and similar hardware that may need periodic servicing. In addition, the GIS will be able to display the various trails in the cave, showing different routes that may be available.

Great Saltpetre Cave is not a large system, and so building these various features into a database is not the overwhelming, years-long task that might be faced for some other caves that are measured in miles or tens of miles. The significant advantage of the Great Saltpetre Cave geographic information system is that it is able to incorporate not only the cave survey data that produces a conventional cave map, but to quickly allow the portrayal of any number of relationships between the cave and various features of the surface and subterranean environments.

NOTES

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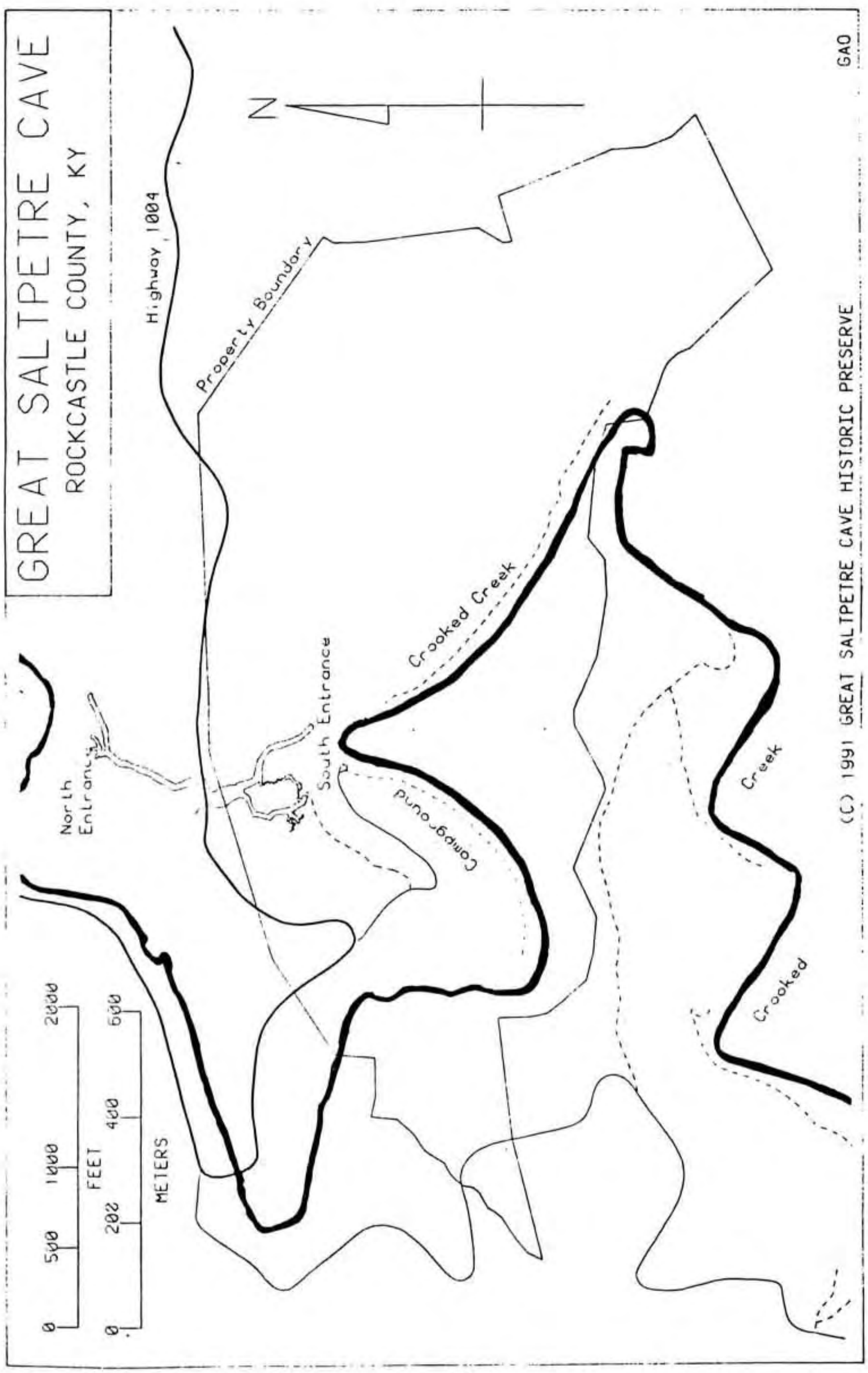

FIGURE 1 Pen plotter map of Great Saltpeter Cave and vicinity, composed of various physical and political feature layers. Original in color.

IMAGE DATABASE
A RESOURCE AND INFORMATION MANAGEMENT TOOL FOR TOMORROWS TECHNOLOGY

W. Gerry Estes
Image Database Software

ABSTRACT

Advancements in computer software design led to the development of a visually oriented, hypertext, data management system. This system links many dissimilar types of specific information to high-resolution, scanned images of more general figures. The use of Windows, multimedia, and hypertext has led to a system which is intuitive, user friendly, easy to operate, and powerful.

The complexion of the Personal Computer Industry has changed significantly over the past two years. The raw computing horsepower available in today's PC rivals that of many past generation mainframe systems, many of which are still in use. We have entered an era of PC price wars. Prices on comparable, fast, powerful systems has dropped from over $8,000 in 1988 to under $1,700 in 1991. You can get more hardware for the dollar then ever before. Where is the industry heading? What is the direction of the next step in innovation? Perhaps we shouldn't look at price-driven hardware; perhaps we should look at evolutionary steps being made in software development.

Windows, the Future of PC Computing

When Microsoft introduced Windows 3.0 in May of 1990, it was a tremendous hit. In one year, over 4 million copies of Windows 3.0 were sold. It is projected that the number of unit shipments of various Window applications will increase from 3.8 million in 1991 to 7.7 million in 1992. Dataquest, a leading market analysis company, estimates that the sales of Windows will equal sales of Macintoshes in 1991 and exceed them thereafter. The Gartner Group, another leading market analysis company, predicts that Windows will pace the entire microcomputer operating systems market, grabbing a 41% share of new installations by 1995, and sales of DOS systems running Windows will outnumber sales of non-Windows DOS systems by 1993. Where is this leading? Why should we design software for Windows? Why is Windows becoming so popular? Perhaps the answer is threefold. First of all, Apple had the right idea when they designed the graphical user interface for Macintosh. People do indeed think visually and it makes sense to design systems that make it easy for people to use computers. Second, the IBM world was slow out of the gate with a graphical user interface, but the popularity of Windows proves that they are not only picking up momentum, but that they may soon surpass Apple in the implementation of new design technologies. Finally, the computer industry is changing so quickly that application software needs to be designed so that it utilizes the rapid evolutionary changes in technology.

Image Database Technology

The first step in taking advantage of these technology changes was to design a visually oriented information management system called Image Database. Image Database is a software tool for Windows 3.0 (and beyond) which utilizes leading edge technology to manage many different kinds of information visually. No matter whether the application is a Resource Management System, a Geographical Information System (GIS), a multimedia educational program, or a medical reference system, Image Database links text, photographs, scanned images, and various elements of the computer system together in a easy, intuitive, and user-friendly way. All information, no matter how complex it may seem, is immediately available and no farther away than a click of the mouse. You can look at a map of recreational sites, well locations, photographs of core samples, schematics of a electrical system, and immediately have available all information concerning that item. The prototype design application was a Cave Inventory GIS System for the more than 200 small caves in Mammoth Cave National Park, presented at this meeting for the first time.

Scanned Images as the Focal Point for Information Retrieval

The premise of this information system and what sets it apart from other GIS or information management systems is its use of scanned images and visual information as the focal point of the system rather than the conventional text viewpoint. The presumption made is that the visual information such as maps, photographs, illustrations, etc., are works of art and as such, already have been produced by someone. Why not scan that information and, as part of the program, link other sources of information to those images by using hypertext, hypermedia, and object orientated, event driven programming techniques? *Hypertext* is a system in which a word or graphic in a document links to information located elsewhere. *Hypermedia*, seen most frequently in museum kiosks, on-line databases or encyclopedias with keyword search, and interactive educational systems, is a collection of information you can navigate through in many different ways. The information can appear as text, hypertext, graphics, sound, animation, or video. *Object oriented programming* is a technique in which each object seen on the screen has program code associated as part of that object. The program code defines not only the action that object may take, but also action other related objects may take in response to action taken by the original object. This technique can make the program not only appear to have a certain level of artificial intelligence, but also to have a one-on-one interaction with the user. This one-on-one interaction, or event driven programming, makes the computer respond directly to user actions.

Locator System

The prototype system for Mammoth Cave uses a key map called the Locator. This locator is a scanned image of the shaded relief map of Mammoth Cave National Park, computer enhanced to 256 shades of gray. The map can be scrolled on the screen and when a region of interest is seen, clicking the mouse on that point will zoom in to a topographic map showing the area selected. Then, by clicking the mouse on the magnified topographic map, the map zooms in again to still a higher magnification. At this highest level of magnification, objects of interest can be seen. In this case each small cave entrance.

Information Box

By clicking the mouse on a cave entrance, an information box will appear with a text description of that cave entrance. This text description, which can be scrolled through the information box, includes but is not limited to such items as: what the entrance looks like, any special gear needed for exploration, whether the entrance has a gate or not, a brief summary of the significance of the cave, or any other pertinent information. The Information Box also has four buttons which may be pressed with the mouse. The four buttons are: Notes, History, Map, and Photo. The Notes button displays text describing any additional notes concerning the cave such as a biological or geological summary. The History button displays information concerning the history of exploration and in some cases, past trip reports. The Map button displays a survey map of the cave at several magnifications. In some cases, photographs are linked to cross-sections of the cave passage, showing an actual photograph of the cross section. The Photo button displays a photograph of the entrance. Any of this information, including maps and photos, can be printed out.

Drop Down Menus

There is a drop-down menu system associated with the Locator map and with each topographic map section. The drop-down menus for the topographic section have a 1) Find Cave section (you can find the location of a particular cave or locate all caves in a particular region), 2) a Geographical Information section (passages can be overlaid on the topographic map and geological maps of the area can be displayed showing the relationship of the entrance to the geology), 3) a on-line training tutorial, and 4) exit the program. The Locator drop-down menu system has such features as: 1) Type of Resource (Archeology, Biology, Cultural and Historical, Geology, Hydrogeology, Mammoth

Cave Tour System, Small Cave inventory, and SurfaceTrails), 2) Maintenance (both Surface Maintenance and Subsurface Maintenance), 3) an on-line training tutorial, and 4) quit the program.

Information Exchange

Image Database has extensive data exchange capabilities and, as such, can operate as a front end to other applications. Data can be exchanged with any other Windows program through the use of DDE (Dynamic Data Exchange), or through the use of OLE (Object Linking and Embedding). Data can be exchanged with DOS-based programs such as dBase, dBase3, and SQL through the use of DLL (Dynamic Link Library). In addition, ASCII information (both fixed length fields and ASCII delimited fields) can be imported into the program. Visual file formats such as BMP, PCX, TIF, WMF, CGM, DIB, DRW, and EPS can be imported directly into the program. Other visual file formats such as GEM, PICT, HPGL, DXF, and PIC can be imported through a conversion process.

Why is Image Database Different

Many popular GIS systems today require a digitizer tablet to hand-input the x-y coordinates from a map, use some sort of text and numeric database for storage of the data, and frequently use a separate vector graphics Computer Aided Design (CAD) program such as Autocad for on-screen output. This type of system is labor-intensive in data input and demands heavy requirements in terms of computer resources. For many applications, this heavy computer resource demand requires the purchase of a expensive workstation, RISC Processor, or minicomputer with many megabytes of storage. Conversely, Image Database uses scanned images of pre-existing maps, drawings, and illustrations, and is designed for present generation PC's. The data linked to the visual images can reside either within Image Database or elsewhere and be brought into the program with data exchange, as mentioned previously. Vector graphics are available with a resolution of 1440 dots per inch, however, the power resides in its ability to manipulate graphic images, especially scanned images. The graphics resolution is dependent upon the graphics adapter installed on the system. It can range anywhere from VGA at 640 x 480 pixels with 16 colors to 32 bit Truecolor at 1024 x 768 pixels with 16.8 million colors. Similar to Autocad, Image Database has a different layer for each object or group of objects, with a total of 65,535 layers available. To use an analogy, Image Database is a encyclopedia and each volume is a different graphics view. Similarly, the Locator is the reference volume for the encyclopedia, a particular topographic region is a book, and each magnification of the topographic region is a page. The Information boxes reside on a page but are hidden from view except when selected. Image Database has the capability of running other programs from within itself, so it quite easily lends itself to a modular design. In essence, when you change views from the locator to a topographic map, you are running another program. Because this modularity allows us to keep adding different modules without altering the main program, we can create templates for many different types of applications.

Image Database for Productivity Enhancement

Image Database is designed not to replace conventional GIS systems, but to enhance their productivity. It is time consuming to redraw all vector images in a CAD system every time you want to see a drawing. The use of Scanned images allows us to display a drawing in just a few milliseconds. While GIS systems frequently have pages of questions for data input encompassing every possible descriptive scenario, perhaps a system which allows access to the most frequently used information is more feasible for everyday use. That is the purpose of Image Database - to access the most frequently needed information easily and quickly.

What are the Computer Requirements for Image Database

Image Database will operate on any PC compatible computer with a 80286, 80386, or 80486 processor, 2Mb of memory, a hard disk, and a color VGA (or better) graphics card. Just about any present generation PC will do, however, the optimum system would have 4-8Mb of memory 100-200 Mb hard disk, and a super VGA graphics card. The entire prototype Image Database for Mammoth Cave Small Caves is slightly less than 2.5Mb. Each module is less than 300K.

How Much Does it Cost and Where Can I Get it

As you can imagine, Image Database is a custom designed tool and is meant to provide easy access to your specific resource data. Since it is custom designed, it is hard to put a price tag on it. An accurate price can only be determined by your specific resource needs. We can, however put together three possible scenarios for pricing:

1) **A generic Tool Shell** which allows you to scan your own images and construct a program around them. This shell would consist of a series of programs which write their own program code based on a fixed set of parameters. Perhaps a ball park figure for a shell would be $10,000.

2) **A custom program** would be designed especially for your needs. In this case, we would scan the images and provide the finished working program for you. We could even supply the computer hardware at cost. Of course, the cost would depend on the complexity of your resource needs, but lets say a ballpark figure of $7,000 for the finished program.

3) **A generic Tool Shell** with Training. This would consist of a generic Tool Shell as mentioned in number 1, but we would teach your staff how to make custom programs. In this case, we would provide training at the start of the project and could provide additional training on a cost basis. A ballpark figure for this scenario would be $13,500.

Other pricing methods could be time and materials. In addition to the Image Database program, we also could not only provide continuing training on a cost basis, but also program maintenance in which we update your custom program for you on a fixed schedule. You can obtain additional information about Image Database from Gerry Estes, Image Database Software, 13509 Oakland Drive, Burnsville, MN 55337 (612-898-3426).

What Other Applications Are There for This Technology?

In addition to the Image Database as a resource management tool, many other products can be designed using the features of this type of programming. By utilizing the interactive aspects of this technology, we could design, for example, full multimedia kiosk systems for visitors centers and museums. By featuring such items as animation, full motion video, sound (music and voice), hypertext, and graphics, a visitor center display could be a complete sight and sound experience. In the case of Mammoth Cave, after taking a tour, let's say the Historic Tour, the visitor could explore the tour route with a computer in the visitors center and find out additional information about places they saw along the route. If they wanted additional information out about a place, lets say River Hall, they could access any information available describing that landmark including history, photos, exploration, etc. You could also access information about science in the cave. In this case, you could show photos of cave life, habitat, ecology, etc. With this application, Image Database becomes an interpretive tool. Other applications for this type of technology could include a computerized card file system for museums which not only show each item's description and location, but also photographs of each object on display - from paintings to artifacts. Also, computer-based educational training programs which include information testing and evaluation modes could be designed.

What Other Projects are in the Works

In addition to developing a generic program shell, we are in the process of designing a cave survey/database/drawing tool. This program shows a picture of a cave survey book on the screen. You can enter data by typing in the book just as you would during the survey. You can edit the data by just dragging the mouse over the old data and typing in the replacement data. You could have the program draw the passage on the screen as you type in the data - in real time. Data could be stored in the program, stored separately as ASCII data, stored in dBase, or stored in a spreadsheet like Excel or Lotus for Windows. The advantage of using a spreadsheet is the ability to do calculations based upon the data. Many different features of the program would be available through drop-down menus. Since you would be working in Windows, all of Windows virtual memory would be available for the program. For example, a 4Mb computer system would have as much as 15Mb of virtual memory available. This not only breaks the old DOS 640K barrier, it greatly expands the system resources available. Plans are in the works to continue development onto the next generation of operating system, the 32 bit Windows NT. With this system we hope to be able to cross platforms into a hardware independent world.

Thanks

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USING CAVE REGISTERS TO FURTHER THE UNDERSTANDING OF THE HUMAN EFFECT ON CAVES

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ABSTRACT

CCUS versions 5 and 6 cave registers have been in use for more than three years. Some results have been returned to the study group, and preliminary results show the average caver is older now than in the earlier phase of the study. The revised format cave register is intended to provide more information of value to cave managers, conservationists, and cave organization leadership. Results indicate that it will be more beneficial than the old format cave registers. The CCUS software is facilitating the processing of cave register data. A "how to" outline on operating a register program explains operation and maintenance of register books, container and data processing.

Understanding caves requires an understanding of the impact people have on the cave environment. This impact is often more significant than any other factor. Thus, good data on the effect people have on caves is essential in the same way that the traditional cave map survey helps to understand caves. Caving is a significant part of Man's impact on caves, and cave registers provide the most cost effective means of getting information on caving. Therefore, the Contemporary Cave Use Study (CCUS) of the NSS has chosen to use cave registers as one of its major means of investigation of contemporary human cave use.

Cave registers are often misunderstood by cavers as something to be used by someone other than themselves. For the study to be most effective in building models to describe caving, it has to gather data from a significant sample of all types of cavers, including all NSS members. As the degree of participation increases, the conclusions drawn from the data will increase in reliability, and the procedures necessary to insure generalize-ability will be less costly. The present cave register program is in use throughout North America as part of the 25 year CCUS project.

This research is designed to establish a standardized national data base of the people who enter caves in order to:

1. Accurately describe the sample caver population and achieve greater ability to generalize to the entire cave population in terms of:
   a. caver demographics
   b. cave use
   c. caver impact on the cave environment
   d. speleological knowledge
   e. skill in the use of environmental ethics systems.

2. Facilitate comparison and correlation research. The basic register program may be classified as descriptive research. Later supplemental studies may use experimental, quasi experimental, comparison, and ex post facto research designs. For example, a researcher may undertake a study of values and want to know if his results may be generalized to another population. Much greater reliability

may be achieved, provided that the researcher gathers the same basic data as is asked in the register. Using analysis of covariance, the two samples can be compared and initial differences adjusted to allow for generalization.

WIDE SPREAD COOPERATION IS SOUGHT AND TIME SAVERS ARE AVAILABLE

Version 6.0 of the register questionnaire is now being used. This format has the most important questions marked with an "*", so that cavers who make repeated visits to the same cave may save time by responding to only those questions. Version 6.0 has a new layout, making it easier to read and answer quickly. Non-affiliated cavers will have the convenience of return post cards that may be mailed to the NSS for membership information. The cards are self mailers, printed 3 to a sheet, perforated, with an address on the other side and a place for postage. Several of these sheets will be bound into the cave register book.

Cave registers serve many different purposes. Besides facilitating scientific research, they provide a conservation message, a means of communication, historical documentation, and a way of encouraging unaffiliated cavers to join the NSS.

The research interests do not require that the caver give his name and address. Actually, the research component does not require identification of individuals at all. However, some variables like length of time a person has been an NSS member can best be measured by NSS number. The reason that name and address are asked is to provide the option to NSS chapters and others interested in promoting NSS or grotto membership to contact people who have recorded in registers and who might be potential members.

In short, cave registers serve not only the goals of the cave researcher, but the cave manager, the cave organization supporter, the historian, the conservationist and many others. The format is intended to provide for the needs of many different interests in a cooperative effort to build widespread support for the program.

A new version 7 is being developed that will have two questionnaires per page and larger type to make it easier to read. Other changes that will be included in this version are to:

1. Put the word "optional" beside address to down play its importance in order to get more people to record into the register, reduce the time it takes to complete it, reduce the time to enter the data in the computer, respond to concerns by some cavers who do not want their address in a public place like a cave, and rely on the NSS information return card for membership promotion. It is generally agreed that the delay in retrieving and processing the cave registers reduces the effectiveness of gathering the address data to use for NSS membership promotion.

2. Include a section in the questionnaire to provide for time in and out of the cave and area of the cave visited. This data would be useful for search and rescue and cave management.

3. Have more white space in the questionnaire for improved readability.

USED UP, DAMAGED, OR WET BEYOND USE?

If you find a cave register in which all of the questionnaires in the register book are filled out, or if it is wet or damaged beyond use, please mail the register(s) to: John M. Wilson, Contemporary Cave Use Study, c/o NSS, Cave Avenue, Huntsville, AL 35810. If the manager of the particular cave has included his address in the register book you may wish send it to him. The study group very much appreciates the help of anyone who returns an unusable cave register, since registers will not dry out in most caves. Unusable registers serve no purpose when left in the cave, NSS members can help by getting them out and getting them back to the appropriate person.

CAVE REGISTER SUPPLIES MAY BE ORDERED

Any NSS member may order these register supplies by filling out the CCUS order form and agreeing to the principles of participation listed on the form. The form is available from John M. Wilson, 9504 Lakewater Ct., Richmond, VA 23229.

Register Books Available

Cave register books are available in six sizes:
NSS standard (144 questionnaires), large (216 questionnaires), extra-large (288 questionnaires), colossal (360 questionnaires), small (96 questionnaires), and custom made. Register containers should be placed in the cave, with two to five register books per container.

Register Containers Available

There are three types of containers available from CCUS.

1. The standard 4 inch diameter register container with or without [addition] built in pencil sharpener. This register is constructed with 4 inch diameter, white PVC drain pipe. It is intended for use with inexpensive mechanical pencils or conventional pencils.

2. The lightweight 4 inch diameter register container is for use in controlled access or managed caves in which the cave user is not likely to abuse the container. It is a simple, inexpensive to manufacture container with a slip-on cap and it is the easiest to use of all containers.

3. The extra large 6 inch diameter register container is for use in caves with extensive traffic. This register is constructed of heavy duty aluminum with wing nuts used to seal the lid.

Software Available

The widespread use of personal computers has made this project possible. New software, Version 1.0, designed by Tim Kilby is available from CCUS for cave register data entry, editing, reporting, and statistical analysis. This software will run on IBM or compatible PC, XT, and AT computers. 384K RAM is required. 640K RAM is recommended, as is 1 hard disk and 1 floppy. However, the program will run on a system with two floppy drives. It is a compiled software program that is very easy to learn. The user does not need any previous training or knowledge to use it. The program provides basic statistical reports on cave use and mailing lists which may be limited by user defined conditions. This program provides the preferred method for people or groups who maintain cave registers and wish to meet their contractual agreement of sharing data with the Contemporary Cave Use Study Group of the NSS. It includes a 24 page user's manual.

Most cave register project participants process the data that they get from cave registers, then forward the data on floppy disk to CCUS for centralized data analysis and interpretation and research by CCUS and other researchers. More advanced statistical reports can be easily generated from the data base, since it is in the Dbase format and can be imported directly into many other software applications.

Version 5.0 of the cave register questionnaire represented a major change from the past register programs. Analysis of data collected from earlier formats was limited by the lack convenient access to computers. Thus, the number and type of questions were limited and data entry was centralized and expensive. The cost of conducting this program is now feasible to volunteer organizations, and cave clubs can conduct the entire program including statistical reports and mailing lists without any capital investment, provided someone in the group has an IBM compatible computer.

PARTICIPATION

Sixty-one individuals have requested and placed cave registers in the past three years, most of these represent active cave register programs. CCUS has shipped 530 register books and 130 register containers as of January 1992. Some of the groups using the registers built their own containers.

This research proposal is envisioned to be a cooperative venture, with design and implementation coming from many different sources. Ideally, there will be multiple authors, researchers, analysts, and others, all of whom will be recognized as part of the study. The officers are: John M. Wilson, Chairman; Evelyn Bradshaw, Treasurer; Tim Kilby, Data Management Designer. The Regional Coordinators are: Mid Appalachian Region, John Chenger; Mississippi Valley - Ozark Region, Bob Springston; Northeastern Region, Emily Davis Mobley; Northwest Caving Association, David M. Klinger; Southeastern Region, Jeff Harris; Southwestern Region, Bill Heath; Texas Speleological Association, Mike Walsh; Virginia Region, Robert M. Frostick; Western Region, David R. Squire.

FIELD INTERVIEWS, DIRECT OBSERVATION, OTHER STUDIES, AND WRITTEN RECORDS

CCUS will use cave registers, plus many other tools, to gather data and improve the understanding of human interaction with caves. One method that will be used to gather data is direct observation and interview. This method can be used to compare cavers who do and do not complete the cave register. Thus, some cave researchers may observe cavers entering and recording in a register cave over a sufficient time period to get a representative sample and interview them after their cave trip at the cave entrance. The interview should include questions that are in the cave register and others, in order to assess the accuracy of their responses. Comparisons can be made using measures of central tendency, correlation, and analysis of covariance. CCUS may be able to reconstruct data from caves where complete records have been kept for projects that had control over access.

STATISTICAL VALIDATION

The following validly procedures are considered. Do the respondents give the correct information? Does the questionnaire measure what it is intended to?

Validity can be measured by the following survey design. The reliability of the questionnaire can be determined. External reliability can be described as the degree that the results can accurately be generalized to a larger population. Internal reliability is achieved if the questionnaire and validating test show equivalence and stability. This form of reliability verification should be done over an extended period of time in a representative sample of caves located in different parts of the country. Minimally, it requires that register questions be asked in an interview at the register cave. The results are compared using analysis of covariance.

RESULTS

From 1976 to 1978 the study group had access to a computer and information from versions 2, 3, and 4 was entered into a punch card data base. The study was less active when access to the computer was lost in 1979 until 1988 when economical personal computers became widely available to members of the study. Although most recently produced cave registers are still in caves or information has not been entered into the data base, some preliminary results are presented in the table on page (?). The table depicts the dramatic increase in the average age of cavers and several other variables. More detailed analysis will be published as data becomes available and is analyzed.

SUMMARY

The goal of CCUS is to provide the NSS leadership and cave managers with information that improves their ability to make good decisions, and a data base for other cave related research.

PROCEDURES FOR CONDUCTING A CAVE USE STUDY

I. DETERMINE THE PURPOSE FOR THE PLACEMENT OF A CAVE REGISTER (SAMPLE PURPOSES)

A. Discovering information about cave use for learning's sake
B. Getting information to assist in the management of the cave
C. Learning more about cavers
D. Learning more about cave use
E. Using the register as an educational tool
F. Using the register as a conservation tool
G. Using the register to promote NSS or other group membership
H. Using the register to promote grotto membership
I. Collecting humorous or interesting statements from cavers

II. MANAGEMENT

A. Establish the appropriate organizational structure
B. Appoint a person in charge
C. If not an organization, any individual may take responsibility and conduct his own register program
D. Communicate the results of these decisions to the Contemporary Cave Use Study Group

III. CAVE MANAGEMENT

A. Establish criteria for selecting the cave or caves from which to gather data
B. Select the specific cave or caves to use

IV. CAVE OWNER PERMISSION

A. The owner of the cave or his agent should grant permission to place the register. It is usually best to confirm his granting of permission in writing, or at least write a letter stating your intent to place the register and again acknowledge his permission.
B. The Contemporary Cave Use Study is structured to accept two types of limitations placed on the use of data by the owner or managing group. See the code at the bottom of the register.
   1. That no membership or other appeal be made of the people recording from the registers
   2. That the owner or managing group retain the right to control the release of specific data

V. ORDER SUPPLIES FROM THE CONTEMPORARY CAVE USE STUDY GROUP

A. Type of register books available. All books with one or more sheets of NSS information request return cards.
   1. NSS standard register book
   2. Large register book
   3. Extra-large register book
   4. Colossal register book
   5. Small register book
   6. Custom made register book

B. Type of register container
   1. Standard 4 inch diameter register containers <u>with built-in</u> pencil sharpener. This register is constructed with 4 inch diameter, white PVC drain pipe and incorporates changes that have reduced the cost of materials and the amount of labor required in assembly.

2. Standard 4 inch diameter register containers <u>without</u> pencil sharpener. This register is constructed with 4 inch diameter, white PVC drain pipe and incorporates changes that have reduced the cost of materials and the amount of labor required in assembly.
3. Extra large 6 inch diameter register containers for use in caves with extensive traffic. This register is constructed of heavy duty aluminum with wing nuts used to seal the lid.
4. Lightweight 4 inch diameter register containers. It is designed for use in controlled access or managed caves in which cave user is not likely to abuse the container. It is a simple, inexpensive to manufacture, container with a slip-on cap and it is the easiest to use of all containers.
5. Other cave registers that may be in use at some locations:
   a. Old 4" PVC Style recycled, no longer in production
   b. Sub standard 3" diameter PVC or S & D, used by some register maintenance groups under severe financial constraints
   c. Off the shelf containers, such as jars, cans, buckets, and boxes
6. All cave registers, regardless of type, should be labeled with the "Please Complete" sign.

C. Rationale for container design
1. Sewer and drain pipe register construction as opposed to PVC is used to:
   a. Reduce cost
   b. Reduce its value and thus, the likelihood of theft
   c. Reduce shipping weight
2. The Standard NSS register is used, in most cases, instead of recycled containers because:
   a. No other container has worked as well over all
   b. It is not used as a carbide dump or trash receptacle as are some jars
   c. It tends to appear more important and is taken more seriously than some recycled containers
   d. Truly adequate recycled containers (jars, cans, buckets, and boxes) are difficult to find and to maintain as a regular resupply source
3. Register containers of less than 4" diameter tend to:
   a. Contribute to more rapid deterioration of the register book
   b. Cause more curl in the paper, making them more difficult to use
   c. Limit the use of multi-book and extra large books
4. Attachment of register to the cave
   a. Discourages theft
   b. Discourages "helpful relocation" of the register
5. Cap attachment
   a. The cap to the register is attached by cable to discourage theft or misplacement
6. Holes in the register
   a. Are used to attach the wire cables
   b. Destroy some of the value of the register parts to discourage theft for other uses
7. Register signs
   a. Let the cavers know the purpose of the device
   b. Provides basic instructions for register use
   c. Conveys an additional degree of importance
8. Pencil sharpener
   a. Some cavers may not have writing implements or a pencil sharpener with them and all the pencils in the register may be defective

VI. DETERMINE THE PROCEDURES FOR MAINTENANCE

A. Determine location for register

1. For most purposes, it should be near the entrance on the most heavily traveled path into the cave at a convenient place to stop. Usually, it is placed beyond daylight so as not to measure casual visitors without their own light source.
2. To measure the amount of vertical caving, the register is placed at the bottom of the drop, in the area of the cave one is studying.
3. More than one register may be used when doing comparison studies. For example, the percentage of cavers using a part of the cave versus the total number of caves as measured by an entrance register may be studied.

B. Type of container

The NSS standard register 4" diameter should be used in all situations except the following:

1. The register is in a cave where there is a very high chance that the register will be stolen or vandalized, in which case there are two options:
   a. Use a very cheap container and be prepared to replace it frequently as the containers are stolen or vandalized.
   b. Use the large container and secure it to the cave with extra ordinary means.
2. Where the recording rate is high enough to justify the larger register.
   A high recording rate is defined as one that requires more than 75 sheets or 900 questionnaires in the register at one time.
3. Where there is a need for an aluminum register.
4. Where expedience and availability of off the shelf containers dictate the use of mass produced cans, jars, boxes, or buckets.

C. Type of register book

Generally, the more heavily traveled caves require the use of larger register books. The typical size of the caving group is also a factor in that larger groups need more books for simultaneous recording. It is usually better to place more registers than larger ones.

D. Number of register books

1. If a cave is visited by some groups of more than five people, use at least two books to allow simultaneous recording.
2. If a cave is visited by some groups of more than 10 people, use at least three register books.

E. Frequency of maintenance

1. At least annually.
2. The greater the cave use, the more frequent the register maintenance.
3. The wetter the cave, the more frequent the maintenance should be.
4. Popular caves, those with more than 200 recordings a month, should not have maintenance schedules longer than 4 months.

F. Number and type of pencils

1. Use #2 type pencils in most situations, #1 or 1.5 lead pencils may be helpful in wet caves where the paper tends to become damp.
2. Place at least three pencils in each register.
3. Add an additional pencil for each additional 20 sheets of registers placed in the container.
4. Mechanical pencils may be used instead of conventional pencils.

G. Equipment to take with you when maintaining registers
1. Spare register container
2. Extra cable, plastic coated
3. Appropriate number of register books
4. Vice grips
5. Screw driver
6. Pencils, sufficient in number to replace all that the register would normally have
7. Container for pencil shavings and other trash

H. Items to check on register maintenance trip
1. Replace all register books that are damaged or wet.
2. Replace books that are more than three fourths full.
3. Sharpen or replace pencils as needed.
4. Clean out pencil sharpener shavings.
5. Check cable and reattach container if necessary.
6. Check cap for ease of operation.
7. Check sign on register container, replace register if necessary.
8. Clean trash from register area.
9. Observe any damage to the cave and biota resulting from impact of cavers stopping at the register. If excessive, select new register location.

VII. DATA PROCESSING

A. Limitations that may be placed on the distribution of the data collected with the cave register by the cave owner or by the group maintaining the register. See previous section on permission.
1. No member solicitation
2. No release of specific data

B. Data analysis
1. Determine the type of data analysis that would be most helpful to your project
2. Communicate these needs with the Study Group
3. Assist in the development of data processing

C. Requirements
1. The Contemporary Cave Use Study of the NSS has developed this program over approximately 18 years. The supplies and concept were developed by the Contemporary Cave Use Committee of the NSS.
2. The ideas of register development represent a major investment of research time, and all participants in the program are expected to share the findings with the NSS through the Contemporary Cave Use Study Group.
3. As part of the study, each participant should do three things:
   a. Let the study group know the names and general locations of the caves where the registers were placed and maintained.
   b. Evaluate or provide feedback of your register program.
   c. Share the data collected with the Study Group of the NSS.
4. This sharing of data can be done in any of the following ways:
   a. Send the Study Group the processed data on a floppy disk. A software program is available for this purpose. This is the preferred method.
   b. Copy the completed pages and send them to the Study Group.

c. Send the Study Group the completed registers. Data can be returned to the person or group maintaining the register, depending on the specific arrangements that are negotiated.

d. Share data in some other mutually agreed manner.

5. Regardless of the method of sharing data, the register data should be sent to:

John M. Wilson, Chairman
Contemporary Cave Use Study Group
National Speleological Society
9504 Lakewater Court
Richmond VA 23229.

VIII. PUBLISHING

A. Assist in the distribution of cave management information

B. Publish in cooperation with the Study Group

1. Joint author arrangements are encouraged.
2. Joint research efforts are encouraged.

C. Publish specific results independently

IX. METHODS SUMMARY

There are many constraints upon cave research of this type. The most significant is financial. With only minimal funding available, the data system is dependent upon cavers willing to place and maintain cave registers. Usually, this means that register maintenance is incidental to other cave projects. The voluntary nature of the data collection also imposes constraints on the register program. The result of the constraints has been to design brief, easy to answer questions, limit the number of questions per page, and attempt to build more durable registers. The more questionnaires per page, the more responses before a new register book is needed. A four inch diameter or larger container allows several registers to be placed in each container, resulting in less frequent maintenance and simultaneous entry. When one considers the cost of servicing registers in terms of travel and man hours, the economics of register programs require designs that minimize maintenance.

COMPARISON OF CAVER DATA
From Cave Registers

Variable	1975 - 1977		1989 - 1991	
	Number Respondents	Average or Percentage	Number *** Respondents	Average or percentage
Age				
Mean	2127	21	1147	28
Mode	2127	18	1147	21
Sex				
Male	1755	80%	919	80%
Female	452	20%	223	20%
Number of Cave Trips				
Mean	1778	36		791
Mode	368	1		1
NSS Member	464	21%	457	39%
Experience		5 Years		10 Years
Light source*	1935			
Carbide	1403	72%	294	25% .
Helmet Electric	381	7%	616	53%
Flashlight	142	20%	442	38%
Candle	3	0		
Other	6	0	146	12%
Group Size **				6 People
Hours in Cave **				5 Hours
Purpose of Cave Trip **				
Exploration			316	27%
Education			146	12%
Conservation			58	5%
Mapping			39	3%
Photography			125	10%
Recreation			765	66%
Science			19	1%
Other			76	6%

* These questions were not asked in the same format in the different versions of the questionnaire; thus, comparisons must be made with caution.

** This information was not asked in the earlier versions of the questionnaire.

*** Many more cave registers have been returned but the information on them has not been entered into the data base due to a shortage of volunteers to enter the data and/or money to pay for data entry.

This information was obtained using the standard statistical printout available from CUSS. Much more extensive analysis can be made by any interested researcher as the data is stored on floppy disk.

USING THE NSS REWARD TO DETER CAVE VANDALISM

John M. Wilson. Chairman
Cave Vandalism Committee
of the National Speleological Society

ABSTRACT

The NSS has changed the Cave Vandalism Deterrence Reward to a flexible reward with a minimum of $250 and a maximum of $1000. The reward will be given to the person or persons providing information leading to a conviction for cave vandalism. This reward replaced the $500 reward that has been in effect since 1982. The changeover date was 1 June 1990. The Commission is recalling all of its previous posters, replacing them with the new version. Sponsors are being sought and encouraged by listing their names on the poster. A one-time contribution of $250 will list you or your organization on the vandalism deterrence poster for as long as the NSS offers the reward. These notices will be posted at show caves, managed caves, and other places in cave areas.

I. DETERMINE THE PURPOSE FOR PARTICIPATION IN THE CAVE VANDALISM DETERRENCE PROGRAM

The reward is intended to be used as an educational, conservation, and a cave management tool. It can also be used as a tool for restitution and as a deterrent to cave vandalism. It is not intended to be used for retribution.

II. THE NEW REWARD PROCEDURES AND THE PURPOSES

A. The reward has a minimum of $250 for all qualifying recipients, this lowers liability.

B. The reward maximum has been increased to $1000. It now has greater impact as an educational tool. There is a greater incentive for the recipient to do specific things.

C. The reward is now more flexible. Larger awards are paid to people whose efforts have contributed to deterring cave vandalism.

D. The determination that a reward applicant has met the reward criteria and the amount to be paid are to be at the sole discretion of the Commission, are now clearly stated on the reward poster. This reduces liability and improves management efficiency.

E. The new procedures require that the applicant provide information that the conviction occurred. It recommends that other information helpful to the Commission be provided by the reward applicant. All reward applicants will be sent a questionnaire on the conviction and related matters. These procedures:

1. Reduce liability
2. Reduce chance of fraud
3. Reduce work for the Commission members
4. Help create more usable results to improve the effectiveness of the Commission in carrying out it's mission
5. Require a publication date on the poster
6. Reduce liability in the event the offer is withdrawn.

F. The reward poster states that the poster remains the property of the National Speleological Society. This reduces liability and eases recovery if the reward is withdrawn.

G. The new poster has an invalidation statement about the previous poster. All previous rewards offered by the National Speleological Society and the conditions for compliance are hereby revoked. This policy reduces liability and reduces administrative costs.

H. The new procedures require that the reward request be made within three months of the conviction. This is not a change in policy but was not stated on the old poster. This policy reduces liability and administrative and verification costs.

III. THE NEW PROCEDURES ALLOW MORE FLEXIBILITY IN DISTRIBUTION

The requirement that the location of all posters or notices be recorded has been deleted. This change has resulted in a substantial increase in the use of the reward notice. The Commission can now encourage unlimited distribution of the reward notice.

IV. MANAGEMENT OF THE REWARD BY NSS CHAPTERS AND OTHER GROUPS

A. Any group that is planning to establish a reward program in cooperation with the Commission should establish the appropriate organizational structure to distribute the reward notices and other cave vandalism activities. This activity could be assigned to committees already established.

B. The group should appoint a person in charge, if this has not already been done.

C. If not an organization, any individual may take responsibility and post reward notices on his own.

D. The individual or group should communicate the results of these decisions to the Commission.

V. GENERAL REWARD ACTIVITIES OTHER THAN POSTING THE NOTICE

A. Print advertisements in newspapers or other publications, as was done by several NSS chapters in California, specifically intended for the protection of caves in Tuolumne and Calaveras Counties.

B. Suggest inclusion of the reward concept in cave related feature articles in print and broadcast media.

C. Use word of mouth to inform others of the reward at meetings, informal gatherings, and one to one exchanges.

D. Make the reward concept an integral part of the cave conservation and management program of each cave organization.

E. Use the reward as an example of a responsible environmental activity in talks, speeches, papers, and news releases.

VI. REWARD NOTICE WHEN LOCATED IN WILD CAVES

A. Establish criteria for selecting the cave or caves from which to post the reward notice.

B. Select the specific cave or caves in which to post the notice.

VII. REWARD NOTICE WHEN LOCATED IN SHOW CAVES, BUILDINGS, AND UNDEVELOPED PROPERTY

A. Select other locations for reward notices. Locations could be any place in which some of the people who would see the sign might:

1. Enter a cave
2. Influence someone who might enter a cave
3. Provide information about someone who could potentially vandalize a cave.

B. Example locations are: show caves, public institutions, schools, parks, and other buildings.

C. The agent or owner of the cave, show cave, undeveloped property, or building should grant permission to place the sign. It is usually best to confirm his granting of permission in writing, or at least write a letter stating the intent to place the register and again acknowledge his permission.

VIII. ORDER POSTERS FROM THE CAVE VANDALISM DETERRENCE REWARD COMMISSION

There are two sizes of posters available from the Commission. There are 8.5" x 11" and 11" x 17" that are printed on paper. The Commission recommends that the user laminate and/or encase the reward notice in acrylic.

IX. DETERMINE THE PROCEDURES FOR MAINTENANCE

A. Determine location for reward notice in the cave. For most purposes, it should be near the entrance on the most heavily traveled path into the cave at a convenient place to stop. More than one notice may be used in some caves.

B. Determine the location of the reward notice in a building, show cave, or undeveloped property.

C. If the notices are placed in caves where there is a very high chance that the registers will be stolen or vandalized, there are two options:

   1. Use very cheap signs such as treated card-stock and be prepared to replace them frequently as they are stolen or vandalized. Placing them out of normal reach may help some.
   2. Use strong frames and secure them to the cave with extra ordinary means. Also place them in locations that are difficult to reach.
   3. The cave environment may require that the notices be laminated as a minimal standard. In this event, a brief analysis of maintenance versus replacement costs should be done to determine the best compromise.

D. Frequency of maintenance

   1. One should check the condition of the notice occasionally, at least annually.

X. SUMMARY OF THE REWARD AND IT'S SIGNIFICANCE

The conviction of a few offenders by itself is of relatively small importance compared to the need for a change in values throughout society. The reward is a tool to help change the values and get cavers and others to take a more positive role in promoting and enforcing needed values. The need for the reward was not seen and should not be seen as a system of vengeance but as a tool for the improvement of society's values toward the environment, specifically the cave environment.

Since 1981, approximately 47 people have been charged with cave offenses based on information supplied to the Commission. Almost all have had their cases resolved in a way that has contributed to cave conservation. It is likely that the establishment of the reward contributed to this dramatic change in challenging and confronting cave vandals. It may not be the fact that the $250 to $1000 reward is offered so much as that the value of taking positive action was sanctioned not only by the NSS Board of Governors but by many other cavers. This concept has been accepted by cavers who disagree on other cave conservation strategies but generally agree that active measures should be taken to stop cave vandals, and at the very least, vandals should be forced to reconsider their actions.

The tables on pages 260-262 provide a summary of the cases of cave vandalism known to the commission. Much of the information has been provided by the reward recipients. The offenders are typically young people with no or little caving experience. Most are teenagers, few are older than 25. The offenders are mostly white, 41 males and six females. Flashlights are the exclusive light sources, if they have a light at all. None of the offenders have backup light sources. The purpose of their trips are usually recreational, and included two trips for the purpose of alcohol consumption. Trip sizes vary from 2 to 15 members. None of the offenders are or were affiliated with any organized caving group, and three offenders, at the most, have developed any interest in caving or speleology. Some of the peripheral offenders may have retained some caving activity.

The offenders have a relatively low understanding of cave conservation, caving, and caves in general. The recipients report that prior to conviction, the offenders do not have even a layman's understanding of the value of caves as a biological habitat, their aesthetic value, or scientific value. Most believe that it is acceptable to write on cave walls, collect formations, and kill bats, although most did not do these acts.

Many offenders are high school students, and a few may have graduated from high school. It appears that the offenders had not done much thinking about caves and the appropriateness of their behavior. The offenders apparently had very limited knowledge of the law. All of the recipients report that the offenders, prior to their arrest, were not aware of the laws against trespassing or vandalizing a cave. None knew that there was a reward of up to $1000 offered for information leading to conviction for cave vandalism.

The offenders are perceived by the recipients as generally helped by the experience and are much better informed about the importance of caves than before. There is one reported exception of being helped by the experience. One of the Missouri offenders has been previously arrested and is generally unresponsive to the criminal justice process. Of the 47 offenders, five have had other convictions that are known to the reporting sources available to the author.

It is remarkable that the offenders have so little knowledge of caves, even less than the average non-caver. It is speculation but plausible that part of the reason these people were caught was that they had so little knowledge about where and how to cave. It does not necessarily follow that as a person gains more cave experience, he will be a more responsible caver. However, experience does seem to reduce one's chances of getting caught for cave offenses. By the time a person starts using a hardhat while caving, he probable knows enough about how and where to go caving or spelunking without getting caught for trespassing or cave vandalism.

The goal of the Cave Vandalism Deterrence Commission is to reduce cave vandalism, primarily through improved education and promotion of a greater understanding of the value and role of caves in the environment among the public, the cave vandal, and the potential cave vandal. The Commission has no mandate to punish, inflict pain, or in any other way harm or recommend harm to anyone for their wrong or inappropriate behavior in a cave. The Commission has had no direct input in any court decisions to date. The Commission's role is to decide on the merits of paying the reward to the person who provides information that leads to conviction, court mandated restitution, or restitution in kind, and to determine the amount of that reward between $250 and $1000. So far, on the five cases in which rewards have been paid, the information that we have is that the judgments have been legally sound, appropriate, and fair. This information comes from prosecutors, judges, victims, and concerned cavers.

3/30/92

Summary of Awards Paid by the Cave Vandalism Deterrence Commission of the NSS

Cave: A BLM administered Cave State: NM Reportor: Noble Stidha
Offerders: Unknown
Number of Offenders: 4 Type of Conviction: Administrative
No. of Male Offenders: 4 Race of Offenders: W
No. of Female Ofenders: Age Range of Offenders: 17-24
Amount of Reward: 250.00
Date of Offense: 10/01/90
Date of Conviction:
Date of Reward: 12/03/90
NSS Reward: Y
Other Organization Reward:
Fines and Fees: $100 Citation ea
Total amount of Fines: 400.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashlight

Cave: Berome Moore Cave State: MO Reportor: L. R. Brisco
Offerders: Jeff Niccum, Doug Koenig, Roger Brewer, Bobby Comte, Kathy Weekley
Number of Offenders: 5 Type of Conviction: Misdemeanor
No. of Male Offenders: 4 Race of Offenders: W
No. of Female Ofenders: 1 Age Range of Offenders: 16-19
Amount of Reward: 500.00
Date of Offense: 1/18/86
Date of Conviction: 5/21/86
Date of Reward: 10/07/86
NSS Reward: Y
Other Organization Reward:
Fines and Fees: 1 year suspended sentance
Total amount of Fines: 0.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashight

Cave: Con and Bear Caves State: PA Reportor: Kim Opatka
Offerders: Keith David McDowell
Number of Offenders: 1 Type of Conviction: Misdemeanor
No. of Male Offenders: 1 Race of Offenders: W
No. of Female Ofenders: Age Range of Offenders: 19
Amount of Reward: 400.00
Date of Offense: 3/09/91
Date of Conviction: 10/03/90
Date of Reward: 3/05/92
NSS Reward: Y
Other Organization Reward:
Fines and Fees: Fine of $279
Total amount of Fines: 279.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse:

Cave: Fort Stanton Cave State: NM Reportor: Steve Peerma
Offerders: Unknown
Number of Offenders: 3 Type of Conviction: Administrative
No. of Male-Offenders: 3 Race of Offenders: H
No. of Female Ofenders: Age Range of Offenders: 15-25
Amount of Reward: 350.00
Date of Offense: 12/13/90
Date of Conviction: 12/19/90
Date of Reward: 5/13/91
NSS Reward: Y
Other Organization Reward:
Fines and Fees: $50 each one $100
Total amount of Fines: 200.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashlight

Cave: Goodwins Cave State: VA Reportor: Mary Sue Soc
Offerders: Kenneth Fisher, Scott Sisson
Number of Offenders: 2 Type of Conviction: Misdemeanor
No. of Male Offenders: 2 Race of Offenders: W
No. of Female Ofenders: Age Range of Offenders: 18-19
Amount of Reward: 500.00
Date of Offense: 4/23/89
Date of Conviction: 5/18/89
Date of Reward: 1/17/90
NSS Reward: Y
Other Organization Reward:
Fines and Fees: $140 each
Total amount of Fines: 280.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashlight

Cave: Kingston Saltpeter Cave State: GA Reportor: Jerry Amos,
Offerders: Fred Bearden, James Guidetti
Number of Offenders: 3 Type of Conviction: Misdemeanor
No. of Male Offenders: 3 Race of Offenders: W
No. of Female Ofenders: Age Range of Offenders: 15-22
Amount of Reward: 500.00
Date of Offense: 4/07/84
Date of Conviction: 9/14/84
Date of Reward: 10/01/84
NSS Reward: Y
Other Organization Reward:
Fines and Fees: $385 fine, $19.80 Restitution
Total amount of Fines: 809.60
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashlight

Cave: Kingston Saltpeter Cave State: GA Reportor: Lisa Amos, J
Offerders: Tabb, Shatto, Robertson, Lyons, Pierotti, Guber, Garrison, Partington, Turner
Number of Offenders: 12 Type of Conviction: Out of Court
No. of Male Offenders: 9 Race of Offenders: W
No. of Female Ofenders: 3 Age Range of Offenders: 17-25
Amount of Reward: 500.00
Date of Offense: 11/17/84
Date of Conviction: 12/21/84
Date of Reward: 5/07/87
NSS Reward: Y
Other Organization Reward:
Fines and Fees: Fine and resitution
Total amount of Fines: 960.00
Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y
Light Sourse: Flashlight

3/30/92 Summary of Awards Paid by the Cave Vandalism Deterance Commission of the NSS.

Cave: Kingston Saltpeter Cave — State: GA — Reportor: Betty Amos
Offenders: Scott Hudgins, Cliff Woods
Number of Offenders: 2 — Type of Conviction: Misdemeanor
No. of Male Offenders: 2 — Race of Offenders: W
No. of Female Ofenders: — Age Range of Offenders: 25
Amount of Reward: 500.00 — Date of Offense: 9/07/88 — Date of Conviction: 10/31/88 — Date of Reward: 1/09/89
NSS Reward: Y — Other Organization Reward: — Fines and Fees: $200 fine probatation fee $120 — Total amount of Fines: 640.00 — Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y — Light Sourse: Flashlight

Cave: Perkins Cave — State: VA — Reportor: Charles Rice
Offenders: Mullins
Number of Offenders: 1 — Type of Conviction: Misdemeanor
No. of Male Offenders: 1 — Race of Offenders: W
No. of Female Ofenders: — Age Range of Offenders: 20
Amount of Reward: 500.00 — Date of Offense: 6/01/83 — Date of Conviction: — Date of Reward:
NSS Reward: Y — Other Organization Reward: — Fines and Fees: — Total amount of Fines: 0.00 — Apparent Purpose of Trip: Recreational
NSS Reward Applied for: Y — Light Sourse: Flachlight

Summary of Offenses with NSS Awards

Total Amount of All NSS Rewards: 4,000.00
Total Number of NSS Rewards Paid: 9
Average Size of NSS Rewards Paid: 444.44
Total Number of Offenders: 33
Total number of Male Offenders: 29
Total Number of Females Offenders: 4
Total Fines For All Offenses: 3,568.60

Total of Other Organization Rewards: 0.00
Average Date of All offenses: 9/20/87
Number of Applications for NSS Reward: 9
Number of NSS Rewards Pending: 0
Total Number Cave Offenses with Judicial Proceedings Reported to the Commission: 9

Summary of All Cave Offenses

Total Amount of All NSS Rewards: 4,000.00
Total Number of NSS Rewards Paid: 9
Average Size of NSS Rewards Paid: 444.44
Total Number of Offenders: 47
Total number of Male Offenders: 41
Total Number of Females Offenders: 6
Total Fines For All Offenses: 21,818.60

Total of Other Organization Rewards: 1,000.00
Average Date of All offenses: 4/16/87
Number of Applications for NSS Reward: 9
Number of NSS Rewards Pending: 0
Total Number Cave Offenses with Judicial Proceedings Reported to the Commission: 13

3/30/92

Summary of Other Cave Related Offenses with No NSS Reward Request

Cave: Fort Stanton Cave State: NM Reporter: Joe Hummel Amount of Reward: NSS Reward: NSS Reward Applied for:
Offenders: Bob Pierce, Betsy Pierce, Bruce Holthouse Date of Offense: 4/20/85 Other Organization Reward: 500.00
Number of Offenders: 3 Type of Conviction: Admin Violation Date of Conviction: 7/11/85 Fines and Fees: $150
No. of Male Offenders: 2 Race of Offenders: W Date of Reward: 9/10/85 Total amount of Fines: 150.00
No. of Female Ofenders: 1 Age Range of Offenders: Apparent Purpose of Trip: Recreational Light Sourse: Flashlight

Cave: Fountain Cave State: VA Reporter: John Wilson Amount of Reward: NSS Reward: NSS Reward Applied for:
Offenders: Date of Offense: 10/10/82 Other Organization Reward: 0.00
Number of Offenders: 4 Type of Conviction: Judical Administ Date of Conviction: Fines and Fees: No conviction after paper writ
No. of Male Offenders: 4 Race of Offenders: W Date of Reward: Total amount of Fines: 0.00
No. of Female Ofenders: Age Range of Offenders: 18-20 Apparent Purpose of Trip: Recreational Light Sourse: Flashlight

Cave: Lewis and Clark Cave State: MT Reporter: Lee Flath Amount of Reward: NSS Reward: NSS Reward Applied for:
Offenders: E Lemke, D. Mills, Kathy Welch Date of Offense: 3/10/90 Other Organization Reward: 0.00
Number of Offenders: 3 Type of Conviction: Felony/ Misdemea Date of Conviction: 6/15/91 Fines and Fees: $5500 fines & re 6 yr sup jail
No. of Male Offenders: 2 Race of Offenders: W Date of Reward: Total amount of Fines: **********
No. of Female Ofenders: 1 Age Range of Offenders: 21-41 Apparent Purpose of Trip: Recreational Light Sourse: Flashlight

Cave: Thornhill Cave State: KY Reporter: Unknown Amount of Reward: NSS Reward: NSS Reward Applied for:
Offenders: Ronnie Brown, Jimmy Brown, Kenny Smith, Timmy Harper Date of Offense: 1/10/87 Other Organization Reward: 500.00
Number of Offenders: 4 Type of Conviction: Misdemeanor Date of Conviction: 8/20/87 Fines and Fees: $400 fine each 40 hours restit
No. of Male Offenders: 4 Race of Offenders: W Date of Reward: 9/21/87 Total amount of Fines: 1,600.00
No. of Female Ofenders: Age Range of Offenders: Apparent Purpose of Trip: Bat killing Light Sourse:

SUMMARY
Total Amount of All NSS Rewards: 0.00
Total Number of NSS Rewards Paid: 0
Average Size of NSS Rewards Paid: Total of Other Organization Rewards: 1,000.00
Total Number of Offenders: 14 Average Date of All offenses: 4/28/86
Total number of Male Offenders: 12 Number of Applications for NSS Reward: 0
Total Number of Females Offenders: 2 Number of NSS Rewards Pending: 0
Total Fines For All Offenses: 18,250.00 Total Number Cave Offenses with Judicial Proceedings Reported to the Commission: 4

UNDERGROUND WILDERNESS: THE TIME IS RIGHT

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ABSTRACT

The Wilderness Act (P. L. 88-577, 78 Stat. 890) has been in force for twenty-seven years. Efforts to create a legal cave wilderness have been pursued for as many years. Yet, to date, no cave has been designated as a wilderness on its own merits even though many federally managed caves are acceptable under the constraints of the law. It should be noted that some significant caves do occur in designated surface wilderness areas. Most of these caves are managed as wilderness. Unfortunately, many are ignored.

A number of factors have hindered the designation of cave wilderness. These factors include federal agency inaction and reluctance to set precedent, opposition by local business interests, a diversity of opinion among cave scientists and recreational cavers, and a lack of motivation by mainline conservation groups. Perhaps, most significantly, is public apathy, due to the lack of awareness, of the many values of caves.

Many caves on federal land qualify as legal wilderness, some of them are already within designated surface wilderness areas, some are already being managed as wilderness, and some have few competing interests. The time is right, especially during this 50th anniversary of Mammoth Cave National Park and the 75th anniversary of the National Park Service to recognize the significance of caves by establishing the nation's first cave wilderness.

INTRODUCTION

Since the passage of the Wilderness Act in 1964 nearly 500 separate wilderness areas have been established by Congress and remanded to the control of four different government agencies. The size of these areas are from two acres up to 9 million acres. The hundreds of environments represented range from alpine tundra to tropical marine. While numerous caves have been incorporated within the boundaries of wilderness areas, not a single wilderness area has been designated for the preservation of spelean resources. A number of federal employees have worked hard to establish such a wilderness, however their pleas have been largely ignored to date. The cave ecosystem, with all of its uniqueness, deserves the recognition with the mantle of our government's highest environmental protection.

FORCES OPERATING AGAINST CAVE WILDERNESS

One can find a number of articles relating to the value and significance of wilderness. Holmes Rolston (1985) has done a thorough job in presenting these values in an article in Environmental Ethics. Huppert and Wheeler (1986) relate these values to the cave environment. This article will take a brief look at reasons that a cave has not been designated as a wilderness area on its own merit. The author admits that some of the information in this paper is anecdotal in nature as the literature on cave wilderness is quite limited. A bibliography of cave wilderness literature is only now being compiled. The forces working counter to the establishment of cave wilderness are as follows:

First, as may be expected, the primary force working against cave wilderness is usually the local business community. Wilderness is generally perceived as a threat to the economic interests of these establishments. In the case of the proposed Mammoth Cave Wilderness, there would have been little change in the visitation levels in the commercialized portion of the cave system from what it was when first proposed in the 1960s. Indeed growth would have continued until a conflict with wilderness values finally occurred. Although visitor levels with wilderness designation may have been capped below current levels, the tourist oriented claptrap that surrounds the park would still exist. In the case of Lechuguilla Cave, little can be said about the proposed Lechuguilla Cave Wilderness as it did not really get far enough for serious review. However, the same greed raised its ugly head there as well. This was another fine example of a community resisting a sound environmental action so as to avoid the possible loss of future gain. In this case local business leaders hope that the U. S. taxpayers will fully subsidize a gift worth millions of dollars to develop a show cave at Lechuguilla. This is in an area where the value of the existing show cave, Carlsbad Caverns, had not been fully capitalized on by that same community. Fortunately, Lechuguilla Cave still remains under an existing wilderness area. In order to develop a show tour at Lechuguilla Cave, it would require significant boundary changes and the redesignation of portions of that wilderness area. This is an action that would probably stir much resistance from mainline conservation groups. This issue is covered in greater detail by Kerbo and Roth (1989) and Rhinehart (1989).

Second, another source of resistance to a cave wilderness has come from within the various land managing federal agencies themselves. This resistance has had several facets. Early on in the process of consideration of a cave wilderness a significant number of agency personnel have felt that caves were not environmentally significant enough to deserve such legal standing. This argument has largely been subdued through an extensive education program, the National Cave Management Training Seminars, arranged by the American Cave Conservation Association and often sponsored by the National Speleological Society and the various federal and state agencies involved. In addition, the efforts made through the mid-1980s to get the Federal Cave Resources Protection Act of 1988 (P. L. 100-691, 102 Stat. 4546) played an immense educational role in changing the minds of many people.

A third problem frequently presented to the author can be stated as followed, 'If you have a cave wilderness, you will have to be gated in order to be protected and a gate, being an artificial structure, cannot be allowed in a wilderness area.' This argument is false on a number of accounts. First, not all wilderness caves may require a gate. Remoteness, size of entrance, or perhaps a number of other factors may reduce or preclude the necessity of gating. Other protective measures may be more effective and less costly. Second, if keeping the wilderness 'pure' is a great concern the wilderness area boundary can be drawn to exclude the entrance area so a gate can be constructed without compromising the 'pure' wilderness. However, this alternative is not ideal and could lead to other management problems. Third, in legal terms this debate is unnecessary as the law does allow for a number of artificial structures in wilderness areas. Section 4. (c) of the Wilderness Act (1964) states:

> c) Except as specifically provided for in this Act, and subject to existing private rights, there shall be no commercial enterprise and no permanent road within any wilderness area designated by this Act and, except as necessary to meet minimum requirements for the administration of the area for the purpose of this Act (including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any such area.

It would seem that the above clause would allow the construction of a gate for 'the purpose of this Act' (protecting the cave ecosystem) or for safety of persons within the area. The gate in place at Lechuguilla Cave in Carlsbad Caverns Wilderness Area shows the legality of such a gate and renders the argument moot. The problem lies in the fact that many individuals, including agency personnel, have difficulty separating their idealized perception of wilderness from that allowed by the Act. (The Carlsbad Caverns Wilderness Area is an interesting name as none of the known passages of Carlsbad Caverns is enclosed by the wilderness.)

Fourth, many individuals have stated that wilderness designation is not necessary as there are other, more efficient ways to protect caves. This approach has been stressed in the literature by Hummel (1982). This viewpoint asserts that caves can be protected by various agency withdrawals of land from potentially damaging uses. This can be done on the local level by the unit land manager quicker and for much less cost than wilderness designation by Congress. Where this has been done there has been mixed success. It must be realized that these protective withdrawals can be reversed as easily as enacted. (It is particularly important that in some agencies, for example the National Park Service, there is a standard practice to shift superintendents and other personnel every 3 or 4 years.) Wilderness designation can only be removed by an Act of Congress. While such withdrawals may be useful as a temporary action to protect a cave, it should not be considered as a long term solution.

A fifth argument against designating a cave wilderness is that most of the caves which might be considered for such designation are actively being explored. Because of that fact the wilderness boundaries would have to be flexible in order to take into consideration any new discoveries outside of existing wilderness boundaries. Here is one example of where the often rigid mind-set of many federal agencies clash with innovative ideas. The concept of an expanding wilderness can work in many circumstances if carefully written into the enabling legislation.

If a cave of wilderness quality is located well within an existing wilderness area there should be no problem if there is no real chance of the cave's passages crossing the boundaries of the surface wilderness. Of course, existing conflicting land use rights (mineral, etc.) must be considered and resolved. There are many suitable caves on federal lands that fall into this category. If the cave extends onto other federal lands, often land exchanges and other compromises can be negotiated. Real problems can occur when a proposed wilderness cave encroaches onto state or private land (or federal land under private lease). Proper selection of the cave for wilderness can avoid this and if encountered it may still be possible to effect a compromise. An extreme move would be to exclude the portion of the cave off federal land from wilderness designation. It has also been argued in the case of Lechuguilla Cave that the cave passages may someday intercept those of the nearby tour cave Carlsbad Caverns. It is contended that all of Carlsbad Caverns would then become wilderness and tours would have to cease. It should be noted that the non-tour part of Carlsbad Caverns are now treated as wilderness. Also the enabling legislation could specifically be written to keep this from happening if the connection did indeed occur.

Cave wilderness can be and ideally should be more than a wild cave that contains wilderness qualities. The best situation would be to have wilderness quality land above the cave and all watersheds feeding into it. This would allow for maximum protection of the cave but is not entirely necessary. Land overlying a cave that is not up to wilderness standards but where significant recovery has occurred and is expected to continue should be seriously considered. Many miles of the Mammoth Cave System would fall into this category.

A sixth concern expressed to the author comes from a small number of scientists and cavers. They fear being cut off from their research areas or exploration activities if their favorite cave becomes a wilderness. This seems unlikely in the case of areas where groups or individuals have already established a record of having a responsible program of research or exploration. Indeed some level of restriction is placed on most federally managed caves. This varies from simple verbal permission or a permit to control access to almost complete closure in rare cases. The large federally managed systems (Jewel Cave, Wind Cave, Mammoth/Flint Ridge System, Carlsbad Caverns, Lechuguilla Cave, etc.) are open to both exploration and research through a variety of agreements between the concerned federal agency and the group of cavers and/or scientists. While somewhat restrictive, these agreements provide a filtering system with the ultimate purpose of protecting the resource. These agreements generally remove the direct responsibility of deciding who goes into the cave from already overworked on-site agency personnel. Although there may certainly have been abuses of this type of access control they have worked more often than not. Refer to Estes and Alexander (in press) for a fascinating history of research at Mammoth Cave National Park and the profound lack of understanding and hinderance of research by some, but not all, park personnel. However, it seems that most competent cavers and scientists who will submit to the permit or agreement requirements will be allowed to pursue their projects.

A last problem with having a cave designated as a wilderness area is that of public apathy as the result of a general ignorance and perhaps fear of caves. Caves do not have a pristine, wilderness-like or romanticized image in the minds of most of the public. This is reflected in the lack of real motivation by most of the mainline conservation associations to put cave wilderness as a significant priority. One notable exception has been The Nature Conservancy which has long recognized the importance of caves (especially as habitat for unique biota) and has acted on this conviction by purchasing many caves for preservation.

This public ignorance is slowly, perhaps too slowly, being changed as more visitors are being educated by better, more conservation-oriented programs at federal, state, and some privately owned show caves. One good example of the latter is Fantastic Caverns in Missouri. In addition, through the efforts of the American Cave Conservation Association, the National Speleological Society, Bat Conservation International, and many individuals, caves are getting better and much more positive coverage in the media through the past few years. An example of this was the rescue at Lechuguilla Cave in April 1991. While various reporters presented some bizarre ideas about caves (and cavers), the park personnel and cavers interviewed generally expressed much concern about protecting the cave resource during the rescue. The message to the public that came across was that the cave was worth preserving as well as the victim.

This short paper summarizes a number of the most frequently heard arguments against the designation of cave wilderness. All of the arguments can be countered from a legal standpoint. The barrier is built of ignorance, greed, politics, and lack of motivation by Congress. There is a cave wilderness out there (in fact, many caves; see Huppert, 1986) waiting for designation. The time is now before it is too late.

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CAVE MANAGEMENT BY PRESCRIPTION AN ALTERNATIVE TO CLASSIFICATION SYSTEMS

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ABSTRACT

The Federal Cave Resources Protection Act of 1988 is a mandate for cave management in cooperation with "those who utilize caves." Historically the USDA Forest Service has tended to view caves as recreational curiosities except when responding to legal requirements for the protection of "threatened and endangered species," or "cultural resources." Consequently, the focus has been on protecting cave resources from cave visitors, rather than protecting caves from potential impacts resulting from other resource activities.

This paper presents a procedure that integrates cave resource management into land management planning at the same level of consideration as other resources. Classification systems have been avoided in deference to a case-by-case analysis of each cave in relation to its karst environment.

Under the Hoosier National Forest Land and Resource Management Plan, approved in April 1991, each cave and karst area will be fully inventoried to identify values to be protected or managed. Based upon analysis of the data, a management plan is written for each cave. Resource values are identified and examined in detail to determine potential impacts. Prescriptions are written to protect those values. Criteria and monitoring procedures (Limits of Acceptable Change) are developed to assure the protection of identified values. Several unique cave management principles are employed to guide this process, including the provision for caver volunteers to participate as partners in the inventory, planning and monitoring of caves.

HOOSIER NATIONAL FOREST CAVE MANAGEMENT PRINCIPLES

There are a number of principles that are basic to cave management on the Hoosier National Forest:

* Locate and protect karst and cave resources while minimizing impacts on other Forest uses
* Assume minimum dollars available
* Work with cavers and establish trust
* Meet the intent of the Federal Cave Resources Protection Act of 1988
* Provide information for project planning regarding caves and karst resources, and in particular to identify critical habitat for Federally listed Threatened and Endangered species
* Since HNF caves are not well known, use is light so the focus of preservation is on avoiding impacts resulting from management activities
* We manage the entire karst environment including caves
* All caves will be managed as significant

* The confidentiality of cave locations is the first line of defense for protection of sensitive cave resources. Maintaining this confidentiality serves to distribute use and will allow for more caves to remain open.

* All caves are open to the public for recreation use, provided sensitive cave resources are not seriously threatened. The thrill of discovery is protected by not giving out cave locations.

* As in wilderness, risk is part of the challenge of exploration. Caves will be treated as part of the general Forest environment, as are streams, cliffs, and other unique features. Caves will not be closed for the purpose of shielding cavers from risk.

* The water, sediment, nutrient and temperature regimes of caves and karst features are sensitive to the activities of man. These features will be protected so that these environments can function naturally.

* There will be no "sacrifice" caves on the Forest, all caves will be protected to established Limits of Acceptable Change.

* Cave and karst resource management will be given consideration equivalent to that received by other Forest sensitive resource values.

THE CAVE INVENTORY AND MANAGEMENT PROCESS

This process assumes several that basic steps have been completed on a Forest-wide scale, they are as follows:

* Identify specific Forest-wide general issues and concerns from, "Those who utilize caves" (see Federal Cave Resources Protection Act of 1988); contacts should include local Grottos and cave clubs, as well as researchers from local colleges and universities. These issues and concerns will evolve into basic cave management principles that will form the foundation for the cave management program.

* Develop partnerships formalized through Memorandums of Understanding with local grottos and cavers. Cavers and speleologists will form the core of the inventory and management program and should participate at every stage of the process.

* Using your identified Issues and Concerns, write Forest-wide Standards and Guidelines and a Cave Management Implementation Plan to be included in your Forest Plan by amendment. This is done in full cooperation with your cave management "partners" after a long series of caver and Forest planning team meetings and consultations.

* Develop support for the Forest cave management program both within your Forest staff and among local caver users groups through joint training sessions and field trips.

The following cave inventory and management process is a common sense approach that conforms to many existing Forest planning processes already in use in the Forest Service. Contrastingly, it is unique in its simplicity and holistic approach; it includes caver partners while at same time protecting cave location confidentiality. It is site (cave) specific and cave resource specific. It avoids the use of a classification system. It is designed to be functional, simple and comprehensive.

STEP 1 EXISTING DATA COLLECTION

This objective is to collect all existing information about the specific caves and karst areas to be managed, including cave locations. In most areas, cavers have been systematically exploring and documenting information about local caves for 40 years or more. In addition, other sources, such as land surveys, can provide valuable documentation.

* Develop agreements with local grottos and cave surveys to provide cave location data bases, and research grotto libraries.

* Check local college libraries.

* Area experts, land surveys, etc.

* Published cave surveys

* Acquire relevant NSS Bulletins, and Newsletters.

STEP 2 CAVE LITERATURE LIBRARY AND LITERATURE SEARCH

In order to identify inventory needs and support proposed cave and karst resource conservation measures a good library of cave resource literature must be accumulated.

* Contact NSS, Grotto, CRF and other organizations for research literature on the cave resource.

* Science Journals provide useful research documentation.

* Local college and university libraries.

STEP 3 CAVE AND KARST INVENTORY (FIELD DATA ACCUMULATION)

Cave springs, swallow holes, rises, sinkholes, karst windows, blind karst valleys, and cave entrance locations are all part of the total cave environment. It is important to locate as many caves and karst features as possible, and determine their spatial and hydrologic relationships to approach a full understanding of these unique ecosystems. The mysteries of the subterranean world are elusive. A total picture is not practical, but as much information as possible should be accumulated for each enterable cave.

* Ridgewalk and map all karst features, including caves.

* Map each cave to a standard suitable for cave studies.

* Inventory each cave for resource values, i.e.: Biologic, Cultural, Geologic/mineralogic/paleontologic, Hydrologic, Recreation, and education/scientific.

* Identify research questions.

STEP 4 ANSWER RESEARCH QUESTIONS

It is just as important to identify "questions to be answered" as it is to identify obvious resource values. The inventory will identify questions that can only be answered by an expert, or may require a dedicated research project to resolve. This is where, with further scrutiny, a hidden cave resource value might become identified as significant. For example, the field inventory in Zillion Cave (see chart) located an unusually large number of bear wallows. A follow up study by a well known Paleontologist established that there is a substantial collection of bear wallows, a significant cave resource.

* Enlist researchers, agency specialists, and speleologists in resolving these questions.

STEP 5 INDIVIDUAL CAVE MANAGEMENT PLANS

Each cave will have a site specific management plan written that includes a description of cave resource values, prescription for management, and a monitoring plan (with identified limits of acceptable change). The plan should be written by a team that includes cave inventory volunteers and other knowledgeable specialists with personal knowledge of the cave's resources.

These documents are not formal NEPA (National Environmental Policy Act) documents, but are management agreements that support later NEPA documentation as needed. They are signed jointly by the respective Ranger, the Forest Supervisor, and a representative of the Indiana Karst Conservancy. Since the NEPA process is a public involvement process, this step is necessary to protect cave location confidentiality. Any management project that could modify the cave, including gating, will require a NEPA document.

The plan development process and resulting document is divided into the following segments or stages; each stage is derived from analysis information developed at the preceding level(s):

A. CAVE RESOURCE VALUES

For each of the Federal Cave Resource Protection Act significance criteria categories (Biologic, Cultural,Geologic/Mineralogic/ Paleontologic, Hydrologic, Recreation, Education/Scientific), describe all that is known about each resource value contained within the cave. This segment later becomes the supporting document for nomination for significance.

B. LIST OF ISSUES, CONCERNS, AND CONSTRAINTS BY RESOURCE VALUE ELEMENT

In this stage, list the environmental attributes that must be preserved to protect each resource value element identified.

For example, water quality, temperature, and a source of food is critical for blind cave fish. These three items should be identified as being important constraints to maintain a healthy blind fish population.

C. LIMITS OF ACCEPTABLE CHANGE

Identify indicators of response for selected cave resource environmental elements (cave temperature for example), and specify standards, or limits of acceptable change. If the limit is already exceeded in its current state, prescribe management actions (see "D" below), if not, prescribe actions to be taken if the standard is exceeded. It is important at this stage to have interested cavers involved so if management action does become necessary you have the support of the affected public.

D. MANAGEMENT PRESCRIPTION

Describe standards of management actions to protect identified resource values. There should be a supportable need which requires no more or less restriction than necessary to provide protection to the target cave resource value. For example, a map might clearly define the surface drainage area where use of pesticides would not be allowed to avoid hazard to the blind fish population.

Each ICC would be addressed by one or more prescriptive standards or management actions. These site specific stipulations must be respected or mitigated in order to assure no harm to cave resources would occur. Any projects planned within the karst area in which the cave is located should respect the standards developed, and avoid harm to the cave resources.

Management actions involving the cave itself, such as a requirement to obtain a permit for entry, are also developed and should relate to specific threat to an identified resource.

E. MONITORING

Monitoring is essential to follow-up on Limits of Acceptable Change standards and implementation of prescription guidelines. As much as possible, the caver volunteers involved in the inventory of the cave will be utilized to conduct periodic monitoring inspections, according to the monitoring plan which is an integral part of the cave's management plan.

The entire management plan for each cave should not require more than a few pages for the average cave. For very small and simple caves with like resources, these could be combined under one plan to reduce paperwork, but only after site specific individual analysis for each cave. New discoveries could result in the modification and amendment of individual cave management plans, or monitoring could trigger changes. Generally however, the cave environment is quite static and the plan should be good for many years without change.

STEP 6 NOMINATION PROCESS UNDER FCRP

The description of the cave's resource values contained in the management plan along with the cave map can now be combined to serve as the nomination documentation for cave significance determination under Federal Cave Resource Protection Act Regulations.

STEP 7 PROJECT IMPLEMENTATION

The cave management plan for each cave is contained in a folder along with supporting documentation ready for use as needed. The karst area location maps are made freely available to local unit managers. When a project or area analysis is proposed within or adjacent to a karst area, the file the that area and the files for each of the potentially affected caves are pulled and provided to the planning team along with cave resource specialist input about the potential conflict of other resource activities on cave resources. The cave management prescriptions are reviewed for cave protection provisions relevant to the proposed project. Project plans should be adjusted accordingly.

Management procedures for subterranean use of cave will normally be to maintain confidentiality of locations. Visitation impacts are minimal for most caves on the Forest and location secrecy is sufficient protection. Individual cave management plans that call for management actions such as a gate (only as a last resort), a permit system, or other protective measure within the cave are put on the District action plan and are treated like a project. Monitoring of the cave is the joint responsibility of the Forest cave resource specialist and the District Ranger, depending on the type of monitoring action required.

WHY A CAVE CLASSIFICATION SYSTEM WAS NOT USED

The decision not to use a cave classification system on the Hoosier National Forest was intentional. Classification systems are designed to simplify by lumping similar items into groupings so that individual distinctions, and consequently details, are reduced. This is fine for management efficiency, but the concept requires that either, (1) a complete knowledge of the items being classed is available or, (2) many details can be ignored, or safely set aside for later consideration or, (3) the details not being considered are not important. We are not comfortable with this concept when applied to the caves on the Hoosier National Forest because:

(1) All caves on the Forest are either significant or potentially significant (pending further discoveries).

(2) Cave management and protection of cave and karst values is (should be) site specific. We protect and manage values; we must identify what, and where, those values are to be able to design site specific protective measures. This also assumes we will not take land away from other resource uses for cave protection if there is no justification.

(3) In our review of some of the cave classification schemes now in use, we observed that they tend to focus on subterranean impacts (cave visitation) exclusively. This does not account for impacts from the surface. We feel a holistic analysis, with all the values and potential impacts considered together at one time is the best way to develop a total picture of the management needs for a particular cave system. Not to do this overall approach runs the risk of overlooking a critical interrelated factor.

(4) Existing classification schemes for caves tend to focus on dangerous generalizations using a black box approach where a number of ratings shake out to an oversimplified management category at the bottom. Ratings on such things as risk and safety (this alone can increase potential for suit) can be very arbitrary and result in caves being closed unnecessarily. (On the Hoosier National Forest we treat caves as part of the general Forest environment, and recognize that risk is a legitimate element in the pursuit of this sport). Management access categories such as, "Directed Access Caves" (if not managed properly these are also known as "Sacrifice Caves"), and "Scientific Study only" (who says scientists don't damage caves) are very general and run the risk of not meeting the true management needs of the cave.

(5) Just like a kid with a set of cans and some marbles there is a natural tendency to want to put some caves in each category. Under a correct management scheme possibly all the caves in an area belong in one category; or better yet, why not manage each cave on a site specific basis, with specific values identified

and appropriate management measures fitted to the need.

(6) Since classification schemes lend themselves to quick decisions based on potentially incomplete information, there is a danger of placing a cave into a marginally inappropriate slot. Caves do not tend to fit in neat little categories easily, but as with most things in nature are a part of a continuum, so there is the danger of trying to force a square peg into a round hole just because the mathematical ranking system, or an arbitrary decision made by a team of people somewhat familiar with the caves at hand, allocated it to a particular category. Once done, such a thing is often difficult to change and biases future decisions involving management of the cave when additional data is acquired. In other words, I believe, the classification systems tend to set up self-fulfilling prophecies.

(7) There is no assurance that a classification system results in better protection of the cave, and may likely result in unnecessary cave closures and arbitrary decisions. This is an apparently easy to use administrative tool; however, if the cave is inventoried and managed properly, it simply results in extra work because the cave inventory and management process as I have described above must be done anyway in one form or another. It is just extra work, or a quick, and arbitrary fix depending on the level of emphasis the Forest is willing to place on its particular cave and karst resources.

We believe that thoughtful analysis, with all the facts that can be reasonably discovered at hand, is superior to any classification or ranking system for cave management planning; "Classification systems are really a cookbook solution that relieves managers of the responsibility for critical thinking and creative problem solving" (ROS--Boon or Boondoggle By Alan Jubville).

We have determined on the Hoosier National Forest that the Forest cave and karst features are unique and special resources and deserve the same quality of analysis and treatment as the other significant resources on the Forest; for these reasons, and those listed above, we have rejected the use of a cave classification system.

CAVE MANAGEMENT BY PRESCRIPTION A SUMMARY

Cave management by prescription provides for a holistic picture of the entire cave and karst environment. The entire ecosystem is considered. It enables managers to integrate cave management into the Forest Service management program in a way that involves the cavers who are the primary special interest group, recreational users, and subject matter experts on this segment of the Forest. It is sometimes difficult for those of us who went to Forestry School, Wildlife Management School, or other land management specialties to admit to ourselves that there is one area of the environment over which we are charged to manage that we know very little about. In fact, it has been my experience that most land managers would only go into a cave in their worst nightmare. Most of us were simply not trained in the cave ecosystem. Management by prescription combines the things that we have a comfortable knowledge about, with the expertise of the people who do know and love the cave environment. It is this working together to a common synergistic end that is the biggest pay-off with this system.

Cave management by prescription is site specific, it generally does not take much land away from other resources, yet provides for adequate and informed decisions about land use practices required for protecting cave resources.

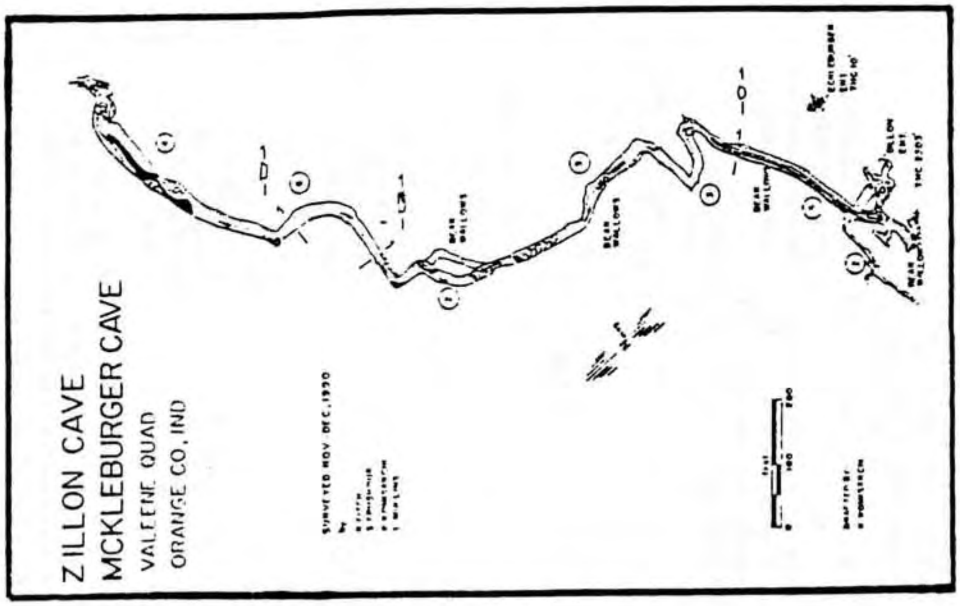
Since cave management by prescription is site specific and identified cave resource value specific, cave resources are protected, regardless of significance designations. It avoids the generalization pitfalls of many classification systems.

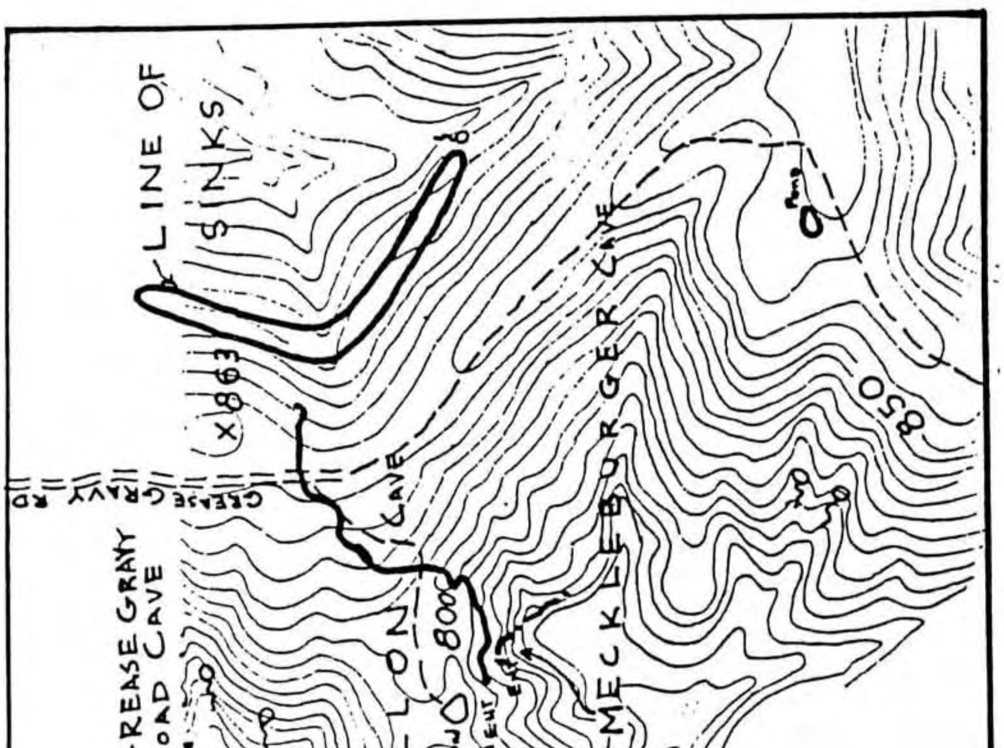
Cave management by prescription, combined with the total ecologic consideration provided by including karst as well as caves (provided a fairly complete inventory is conducted), will provide the best vehicle to insure that we do not inadvertently damage sensitive cave resources.

EXAMPLE CAVE MANAGEMENT PLAN FOR ZILLION CAVE

Identified Resource Values	Issues, Concerns, & Constraints	Limits of Change	Management Prescription	Monitoring and Action Plan
BIOLOGIC: A balanced ecosystem includes some 50 little brown bats, cave flies, isopods, blind crayfish, leopard frogs (few), and cave beetles (2 species)	Maintain current air temp, water temp, air humidity, sediment load minimal, existing level of detritius	Hold population of bats to 45 min, Maintain crawfish population at 25 min.	Allow no vegetative manipulation in the recharge area or visual seen area as shown on the attached map	ACTION PLAN: Install signs and Forest Order prior to June 1, 1992
GEOLOGIC/ MINERALOGIC/ PALEONTOLOGIC: Dillion is in a thick bed of Beech Creek Limestone. It is an exceptionally large cave for this rock layer, with considerable walking passage along its one half mile length. Paleontologically it has more bear wallows (32) than in any other cave in Indiana. Well over 100 years old, the wallows are well preserved and still exhibit claw marks in the clay.	Protect bear wallows from vandalism	* Tolerate no more than 10% damage to bear wallows	Allow no trails, roads, or earth disturbing activities within the recharge area illustrated on the attached map.	Remove graffiti and mark trails using caver volunteers prior to May 1, 1992. MONITORING: Forest Speleobiologist to do bat count and crawfish count annually
HYDROLOGIC: This cave is unusual since the stream stays about the same size and does not flood. It has been dye traced on an "L" shaped line from a sinkhole with a spring not far away. Apparently the spring serves as an overflow thereby holding the water level constant and providing good habitat for the bears. This feature is key to the popularity of this cave for bear use.	See Biological. Protect overflow spring	Hold stream flow, fluctuation, and quality to current levels.		Forest Hydrologist to sample water annually. District Para -Archaeologist to inspect bear wallows twice annually.
CULTURAL: Smoke on the ceiling dates back to 1836 which means the cave has been visited for over 150 years.	Remove all graffiti except the 1836 date at the end of the cave.	Remove all graffiti except the 1936 date at the end of the cave.		Caver Volunteer to inspect annually: Remove register forms
RECREATIONAL: Cave is not heavily used but is very interesting. Recreational value is very high.	Retain visual qualities at entrance. Clean up old graffiti. Try to retain free access.	* New graffiti to a max 3 occassions/yr.	Mark a travel trail within the cave to avoid the bear wallows. Install three lexan signs in cave explaining why travel is limited.	Log Graffiti (remove immediately) Remove trash Reset trail markers
EDUCATION/SCIENTIFIC: Dr. Richards is conducting a study of the bear wallows.	Preserve bear wallows.	Establish Forest Subpart B order to stay within marked trail.		

*If exceeded, close cave; go to permit system.


ZILLON CAVE
MCKLEBURGER CAVE
VALEENE QUAD
ORANGE CO, IND


GREASE GRAVY ROAD CAVE
GREASE GRAVY RD
LINE OF SINKS
X 863
ZILLON CAVE
800
MECKLEBURGER CAVE
850

Legal Brief

Law and Sound Policy Require the National Park Service and the Secretary of the Interior to Review the Underground Portions of Mammoth Cave National Park as to their Suitability for Wilderness under the Wilderness Act of 1964.

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Conservation Chairman[1]
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1417 Ninth Ave. W., Seattle, WA 98119

(on advice of counsel)
June 25, 1974[2]

SUMMARY

I. Land, as defined in the Wilderness Act, includes the surface and subsurface portions of the earth. Just as land can be divided into various divisions in a horizontal plane, there is also ample legal precedent to establish that land may be divided by boundaries between various layers of the earth's crust.

II. Congress recognized the existence of caves and the applicability of the Wilderness Act to cave protection.

III. Mammoth Cave National Park was established to protect caves. The caves, along with other features of the park lands, must be reviewed for their wilderness suitability.

IV. Substantial portions of the cave systems in Mammoth Cave National Park meet requirements of the Wilderness Act and are eligible for immediate recommendation for inclusion in the National Wilderness Preservation System.

V. The designation of underground wilderness is acceptable upon scientific and environmental grounds.

VI. Failure to conduct a proper review, accompanied by a legally acceptable Environmental Impact Statement, of all of the roadless Park lands is a violation of the Wilderness Act and the National Environmental Policy Act.

The Wilderness Act of 1964, 78 Stat. 890 (1964), 16 U.S.C. 1131 et seq. (1965), in Section 1131 (c), [references below to the Wilderness Act are to the U.S. Code sections] defines wilderness as follows:

> A wilderness...is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation,...and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude of a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other

> features of scientific, educational scenic, or historical value.

Conservationists, scientists, and speleologists have advocated for many years that the caves and other speleological features of Mammoth Cave National Park should be afforded the protection of the Wilderness Act. The National Park Service, on the other hand, has consistently taken the position that these features are not eligible for inclusion in the National Wilderness Preservation System because the Wilderness Act does not specifically mention "caves." Their most recent statement in this regard is found on p. 48 of the **"Draft Environmental Statement for the Master Plan and Wilderness Study for Mammoth Cave National Park,"** released on 24 April 1974:

> Much of the discussion about "underground wilderness" has focused on the Flint Ridge Cave System which has been studied and mapped by scientists since 1947. The proponents of underground wilderness feel that the language of the Wilderness Act is broad enough to cover this concept except for the "semantic problems of subsurface acreage." Surely, caves are places where "man himself is a visitor who does not remain," and they provide truly "outstanding opportunities for solitude." On the other hand, the words "landscape," "area," and "land" all appear in the definition of wilderness in the Act and each refers specifically to the surface of the earth, according to the dictionary. Clearly, when considering passage of the Wilderness Act, Congress did not extend the concept of wilderness to caves or cave systems. In view of the fact that underground wilderness was not identified in the Wilderness Act, nor have underground wildernesses been established subsequently, the National Park Service neither endorses nor proposes underground wilderness for Mammoth Cave National Park.

We contend, on the contrary, that the language of the Wilderness Act specifically includes the subsurface as well as the surface of the earth, and that the National Park Service is required by law to review those areas as to their wilderness suitability.

I. **Land, as defined in the Wilderness Act, includes the surface and subsurface portions of the earth. Just as land can be divided into various divisions in a horizontal plane, there is also ample legal precedent to establish that land may be divided by boundaries between various layers of the earth's crust.**

Examination of the legislative history of the Wilderness Act reveals no evidence to suggest that Congress intended that any but the usual definition of the word "land" apply to the use of that word in the Act.

Black's Law Dictionary defines land as follows:

> LAND, in the most general sense, comprehends any ground, soil, or earth whatsoever..."Land" includes not only the soil or earth, but also things of a permanent nature affixed thereto or found therein, whether by nature,...as mineral under the surface, or by the hand of man... It embraces not only the surface of the earth, but everything under or over it... It has in its legal signification an indefinite extent upward and downward... Land is or includes the solid material of the earth, whatever may be the ingredients of which it is composed, whether soil, rock, or other substance (p. 1019).

There are numerous cases in the United States supporting this definition, which is based upon the common law. In **Higgins Oil and Fuel Oil Co. v. Snow**, 113 F.433, 438, 51 C.C.A. 267 (1902), the Fifth Circuit Court of Appeals in pointing out that "it is elementary that "land" itself, in legal contemplation, extends from the sky to the depths," quotes extensively from prior legal authorities, including Coke, Blackstone, and Washburn. In **Edwards v. Sims**,232Ky.791, 24 S.W. 2nd 619, 620 (1929), specifically involving cave ownership in Kentucky (actually within what later became part of Mammoth Cave National Park) the Court of Appeals of Kentucky reiterated this ancient doctrine. See also **Marengo Cave Co. v. Ross**, 212 Ind. 624, 10 N.E. 2nd 917, 7 N.E. 2nd 56 (1937) and **Wyatt v. Mammoth Cave Development Co.**, 26 F. 2nd 332 (1928).

Thus it is quite clear that in the United States as a whole and in Kentucky in particular, land, in a legal sense, comprises the subsurface as well as the surface of the earth. In **Bidart Bros. v. U.S.**, 157 F. Supp. 373, (1957), the U.S. District Court for the S.D. California found that "in the absence of a definition of a word...resort may be had to the definition contained in the law of the State in which the problem arises for the purpose of ascertaining the meaning of such word," and quoted Black's definition for "land." See also **U.S. v. Pollman**, 364F. Supp. 995 (1973), which again applies the Black's definition of "land" to interpret the U.S. Code.

A recent legal opinion of the Interior Department concurs in this definition of land:

> With respect to lands and minerals under the jurisdiction of the United States, and in connection with the use of the term "lands" in the unit segregation provision of section 17 (j) of the Mineral Leasing Act, as amended, the fact that a lesser estate, e.g., the surface, has been carved out of the land and disposed of does not make that which is left, the mineral estate, any the less "lands," and, it follows that if the mineral estate is further divided horizontally into two or more parts, each part is nevertheless "lands." **The Segregative Effect Upon a Federal Oil and Gas Lease of a Partial Unitization Embracing Less than All Formations, Horizons, or Strata, or Limited to a Particular Depth, Interval, or Zone within the Exterior Boundaries of the Lease**, Interior Department Legal Opinion M-36776 (May 7, 1969).

There is additional evidence in the Wilderness Act itself to indicate that Congress intended the usual meaning of the word "land" to apply. The comprehensive definition of the land to include the subsurface as well as the surface is supported by the wording of section 1133 (d) (3) of the Wilderness Act, which extends existing mining laws to "national forest lands" until 1983, but requires "restoration as near as practicable of the surface of the land disturbed,..." and reserves to the United States "all title in or to the surface of all lands..." (emphasis supplied). Obviously, if land did not include the subsurface as well as the surface, such distinction would not only be unnecessary, but superfluous.

An examination of other statues referring to Mammoth Cave National Park makes it clear that the caves are included as part of the land. The legislation establishing Mammoth Cave National Park on both the federal and state level refers only to the lands or interests in lands to be acquired or ceded. Thus the Act of May 25, 1926 (44 Stat.635) authorizing the establishment of the park refers to "titles to lands" that are to be secured. The Kentucky legislature in 1930 (Acts of 1930, ch. 132, p. 405, **Carroll's Kentucky Statutes**, sec. 3766e-17) ceded to the United States "exclusive jurisdiction... over, within, and under all the territory" of the park. Congress accepted that cession on June 5, 1942 (56 Stat. 317, 16 U.S.C. sec. 404c-1) using the same language.

The United States, by its management and administration of the park, has clearly demonstrated that it has jurisdiction and authority over the subsurface as well as the surface portions of the park lands. In procuring lands for park purposes, "cave rights" as well as surface rights were obtained. The law is enforced below the surface of the land, within the caves, just as it is above the surface. The Master Plan and its Environmental Impact Statement refer to activities and actions proposed for institution below the surface of the earth as well as above the surface and on the surface. Park Service management activities regulate the subsurface as well as surface environments.

Clearly, Congress intended that the term "lands" should include both the surface and subsurface of the park, just as it intended that "lands" in the Wilderness Act should include the subsurface as well as the surface. Such intent, when considered together with the precedent set by the Park Service administration of both the subsurface and surface lands, dictates that future management activities, including review for wilderness suitability, should include all of the land.

There is also ample legal precedent to establish that just as land can be divided by boundaries in a horizontal plane, it may also be divided by boundaries between various layers of the earth's crust. "For purposes of separate ownership, land may be divided horizontally as well as superficially and vertically" 62

Am. Jur. 2nd 301. "It has been said that while formerly a man who owned the "surface" owned it to the center of the earth, now the "surface" of the land may be separated from the strata beneath it, and there may be as many separate owners as there are strata" 31 A.L.R. 1533. "We have felt constrained to recognize the susceptibility of land to division into as many estates fee simple as there are strata that make up the earth's "crust" **Lewey v. H.C. Frick Coke Co.**, 66 Pa. St. 536, 31 A. 263 (1895). "That an estate in lands may be divided by the owner, and separate estates carved out of different elements which go to make up the lands, there is no doubt. One may be the owner of the surface of the land, another the trees standing upon it, and another the minerals under the surface, and all of them be the owners of lands" **Gabbard v. Sheffield**, 179 Ky. 412, 200 S.W. 943 (1918).

In **Cox v. Colossal Caverns Co.**, 219 Ky 612, 276 S.W. 540 (1925), the principle of land division by vertical boundaries was extended to caves. The Kentucky Court of Appeals cited **Ball v. Clark**, 150 Ky. 383, 150 S.W. 359 (1912); **Kincaid v. McGowan**, 8 Ky. 91, 4 S.W. 629 (1909) in support of its decision that the surface could be owned by one person while the caves, together with "so much of the material above, about, and below the cavity as is necessary to preserve and maintain the cave" could be owned by another.

The separation of the "cave rights" from the "surface rights" has become quite common in cave areas, and in fact the United States owns only the "cave rights" on at least one tract of land near Mammoth Cave National Park. "The United States owns the cave rights only beneath a 2.99 acre tract along the park boundary southeast of Little Hope Church" (Master Plan, p. 64).

There is ample precedent to establish that land may be divided by vertical as well as horizontal boundaries. Thus it is legally permissible to establish an "underground wilderness area" which includes only that portion of land below the surface. It would also be permissible to designate as wilderness a particular stratum of land, such as the Girkin limestone and the Ste. Genevieve limestone.

It makes no difference that the United States is the owner of all of the land, surface and subsurface. Wilderness areas are usually designated adjacent to other non-wilderness lands owned by the Federal Government. Roadless areas in the National Parks are usually next to roads or developed areas, yet this does not preclude their designation as wilderness. The only difference in this case is that the boundaries between wilderness and non-wilderness areas are in a vertical instead of a horizontal plane.

Land, then, comprises both the subsurface and surface areas of the park, and may for management purposes be divided horizontally and vertically.

II. Congress recognized the existence of caves and the applicability of the Wilderness Act to cave protection.

In 1957 Congress established the Outdoor Recreation Resources Review Commission (ORRRC), which studied outdoor recreation resources. Throughout the hearings on the Wilderness Act held from 1958 onwards, there was continued reference by witnesses to that study commission, and final action on a wilderness bill was delayed pending the receipt of its reports. The final report, as well as Study Report No. 3 of the ORRRC, entitled **Wilderness And Recreation–A Report on Resources, Values, and Problems**, were mentioned in both the House and Senate reports on the Wilderness Act as having guided the final preparation of the Act, and were quoted extensively in the Reports. In the "Summary of the Major Findings and Recommendations" of the Study Report No. 3, section 1, entitled " What is Wilderness?" part c, reads as follows:

> c. Wilderness Rivers and Caves. Rivers and caves are considered in the report as important potential wilderness resources, and we have attempted a limited inventory of wilderness rivers and discussion of cave preservation in appendixes to the full report. It is apparent that special study is needed to develop suitable definition of these recreation resources, which can be applied in survey and management efforts at the hearings before the House Interior and Insular Affairs committee on H.R. 9070, held in May 1963, Victor A. Schmidt, conservation Chairman of the National Speleological Society, testified as to the value of wilderness designation for cave protection, and presented a resolution

supporting the Wilderness Bill passed by the Board of Governors of the National Speleological Society. Upon questioning by Congressman Aspinall, Dr. Schmidt agreed to provide additional information on wilderness cave resources to the Committee, and that information was printed in the hearing record following his testimony.

Other speleologists, including Dr. William R. Halliday, also testified at hearings on the wilderness bills. Thus it is obvious that Congress was certainly aware of the need and suitability for protection of caves by the Wilderness Act. No special provision was placed in the Act to exclude the cave resources. Therefore Congress must have assumed that such resources were covered by the Act as passed.

The special studies referred to in the ORRRC report have been done in the intervening ten years since the passage of the Wilderness Act. The first of these was the National Speleological Society study which culminated in **A Wilderness Proposal for Mammoth Cave National Park**, a report published in 1967. Because the surface of Flint Ridge in the park is not presently eligible for wilderness designation, this report concludes that "it is feasible to have an area declared as underground wilderness where surface wilderness status is not possible or desirable....Surface uses such as roads and other visitor facilities that exist or are planned in these areas need not be affected by such a designation, so long as they do not interfere with the cave ecosystems below. The advantage of such a designation of underground wilderness status without a corresponding surface wilderness over the same area is that it establishes a priority of administrative importance in favor of caves and underground features" (p. 7).

The most comprehensive study yet completed is that by the Cave Research Foundation, entitled **Wilderness Resources in Mammoth Cave National Park: A Regional Approach.** This report pointed out that "a significant feature of Mammoth Cave National Park is the large area of underground wilderness that it contains. This is an underground land of substantial acreage in its own right, and although it is geologically and biologically linked to the surface, its wilderness characteristics are largely independent of surface conditions....Mammoth Cave National Park simply contains the largest area of underground wilderness in the world. Thus it is both necessary and useful to employ the concept of the underground wilderness when evaluating the natural environment of park caves" (p. 23). The report goes on to extensively define the wilderness resources of Mammoth Cave National Park, and discusses underground wilderness management and administration.

A third study, **Underground Wilderness in the Guadalupe Escarpment: A Concept Applied**, by Stitt and Bishop, although primarily dealing with the underground wilderness resources in Carlsbad Caverns National Park, also contains extensive discussion of underground wilderness concepts and their definition. This study points out that "the management for a karst area...would provide "multi-level" management guidelines to assure that the surface and underground environments were managed in total harmony with one another. Just as the concept of surface wilderness is an important management tool for surface resources, so emphatically is the concept of underground wilderness important for management of the underground resources" (p. 79).

All of these studies have recommended the establishment of underground wilderness areas as part of the National Wilderness Preservation System, and have concluded that such designation is acceptable within the scope of the current legislation. Copies of these studies are attached to this statement for inclusion in the hearing record.

Section 1132 (c) of the Wilderness Act states that "within ten years after the effective date of this Act the Secretary of the Interior shall review every roadless area of five thousand contiguous acres or more in the national parks...and shall report to the President his recommendations as the suitability or nonsuitability of each such area for preservation as wilderness."

The wilderness regulations of the Department of the Interior define a "roadless area" as a "reasonably compact area of undeveloped Federal land which possesses the general characteristics of a wilderness and within which there is no improved road that is suitable for public travel by means of four-wheeled, motorized vehicles intended primarily for highway use" 43 C.F.R. Sec. 19.2 (e).2

By this definition, it is clear that the entire underground section of Mammoth Cave National Park with the exception of the electrically lighted tourist trails in Mammoth Cave Ridge, is a "roadless area" and thus must be reviewed.

In conducting a review of a "roadless area," the Secretary of the Interior is directed to determine the "suitability or nonsuitability" of the area for "preservation as wilderness." It is not the place of the Secretary to arbitrarily limit the applicability of the Act to certain lands on any grounds other than that of whether or not they constitute a "roadless area."[3]

In **Parker V. United States**, D.C. Colorado, 309 F. Supp. 993 (1970), the court noted that "one of the major purposes of the Wilderness Act was to remove a great deal [of] discretion from the [agencies] by placing the ultimate responsibility for wilderness classification in Congress." The court quoted the House Report on the Wilderness Act:

> A statutory framework for the preservation of wilderness would permit long range planning and assure that no future administrator could arbitrarily or capriciously either abolish wilderness areas that should be retained or make wholesale designation of additional areas in which use would be limited.
>
> The committee accordingly endorses the concept of a legislatively authorized wilderness preservation system. Furthermore, by establishing explicit legislative authority for wilderness preservation, Congress is fulfilling its responsibility under the U.S. Constitution to exercise jurisdiction over the public lands, H.R. Rep. No. 1538 on the Wilderness Act, 2 U.S. Code Cong. & Adm. News at, pp. 3616-17 (1964).

The court held that "the Act quite clearly reserves the decision to classify as wilderness to the President and ultimately Congress. The duty of [the Secretary] is to study and recommend, and this duty is mandatory" 309 F. Supp. 598. The court further pointed out that the agency "does not have uncontrolled discretion where [the mandatory review requirements of the Act apply and the area] is shown to be primitive in character; that the determination must be preserved for the President and Congress; that it is not to be preempted" 309 F. Supp. 600.

On the basis of this decision, which was affirmed upon appeal, 448 F. 2nd 793 (1971), cert. den., 405 U.S. 989, the Park Service and the Secretary must review the park lands solely on the basis of whether they meet the definitive criteria and the Wilderness Act and must make recommendations to the President and ultimately Congress upon these grounds. The agency review should not be based upon arbitrary decision that such lands are not subject to review. Since the ultimate decision as to the designation of the wilderness is up to Congress, that body should be provided with such information necessary to its making the decision.

There are no exceptions, restrictions, or other provisions in the Wilderness Act which might allow the interpretation that either the surface or subsurface of Mammoth Cave National Park were to be excluded from the review process required by Section 1132 (c).

The only clause in the Act which might possibly modify the review requirement is Section 1133 (a) (3): "Nothing in this chapter shall modify the statutory authority under which units of the national park system are created...." A review of that statutory authority for Mammoth Cave National Park reveals nothing which might exclude the subsurface lands of the park from the review process.

A word is necessary at this point regarding the applicability of the review process to the subsurface areas of all national parks--indeed, all federal lands. Clearly it was not Congress' intent to require such a review for those lands where the subsurface is not accessible by natural means. Thus mandatory review of subsurface areas only applies to those parks which contain known or suspected cave resources of outstanding wilderness quality. Mammoth is of course the most important of these parks; this list includes Carlsbad Caverns National Park, Wind Cave National Park, Jewel Cave National Monument, Craters of the Moon National Park, and Lava Beds National Monument, among others. The National Spelelogical Society has participated in the wilderness review process for many of these parks, and, where applicable, has asked for underground wilderness protection for the cave systems included in them. In some cases the wilderness recommendations made by the Park Service provide satisfactory protection for the wilderness cave resources; in others Congress may have to exercise its ultimate authority and modify the agency recommendations if adequate protection is to be provided. In those parks where the subsurface resources were not reviewed, further review by the agency might be appropriate.

The Park Service has argued that there is no precedent for the establishment of underground wilderness under the Wilderness Act. Such lack of precedent is, of course, no excuse for failing to review the cave resources. But it is perhaps explained by pointing out that lack of precedent is entirely the responsibility of the Park Service, which has failed not only in its responsibility to recommend cave resources to the Congress for inclusion in the National Wilderness Preservation System, but has failed to review them for their suitability in the first place.

We find, then, that Congress was certainly aware of the applicability of the Wilderness Act to the protection of cave resources when it passed the Wilderness Act, and that since cave resources were not specifically excluded, they are eligible for protection. Since 1964 management concepts for wilderness cave resources have evolved to the point where it is clearly possible to provide protection within the framework of existing legislation, the Wilderness Act of 1964. The mandatory review process requires the review of cave resources of Mammoth Cave National Park, and a recommendation to Congress by the President as to their suitability or nonsuitability for inclusion in the National Wilderness Preservation System.

III. **Mammoth Cave National Park was established to protect the caves. The caves, along with other features of the park lands, must be reviewed for their wilderness suitability.**

A study of the legislation establishing Mammoth Cave National Park reveals that the park was established upon the recommendation of the Southern Appalachian National Park Commission. It was from the very beginning quite clear that the park was to be established primarily for the preservation of the caverns and other karst phenomena of the area. In its report of April 18, 1926, the commission recommended national park status for the Mammoth Cave Region of Kentucky because of "the limestone caverns which contain 'beautiful and wonderful formations,' the 'great underground labyrinth' of passageways 'of remarkable geological and recreational interest perhaps unparalleled elsewhere,' and the "thousand of curious sinkholes of varying sizes through which much of the drainage is carried to underground streams, there being few surface brooks or creeks"(Master Plan, p. 612). The caves are the major and prime features of the park, and are so recognized by most of the visitors who penetrate the parks' interior. The name of the park is "Mammoth Cave National Park," further recognizing the importance of the cave system as the major attraction of the park.

References to the cave and their contents are made at several places in the legislation. In the Act of June 5, 1942 (56 Stat. 317) the Secretary of the Interior is empowered to make and publish rules for the "preservation from injury or spoilation of all ... mineral deposits, natural curiosities, or wonderful objects." The Act of May 14,1934 (38 Stat. 775) amending the original Act establishing the park precludes development of the area until "all of the caves thereof..." have been accepted by the Secretary.

Viewed in light of their importance as prime features of the park, failure to review the cave systems for their wilderness suitability is a blatant disregard of the intent of Congress "to secure for the American people of present and future generations the benefits of an enduring resource of wilderness," the main purpose of the Wilderness Act expressed in Section 1131. Obviously wilderness protection would not be desirable for all the caves of the park, as that would deny much of the public the opportunity to visit any of the caves. Furthermore, the already developed portions of the cave systems are clearly not eligible at present for wilderness. But all of the cave resources of the park should be reviewed, and those which are not presently developed, and that are of obvious wilderness quality, should be recommended for inclusion in the National Wilderness Preservation System.

IV. **Substantial portions of the cave systems in Mammoth Cave National Park meet the requirements of the Wilderness Act and are**

eligible for immediate recommendation for inclusion in the National Preservation System.

This point has been discussed extensively in other documents, all of which have been submitted to the Park Service in the past, and many of which have been referenced in the Master Plan, the Wilderness Study, and the Draft Environmental Impact Statement. Two of them are attached to this brief.[4] In addition to its own staff, the Park Service has available the expertise of the Cave Research Foundation and other scientists working within the park whose knowledge of the cave systems is quite adequate for carrying out a complete study of cave systems. It would not be appropriate to include here a passage by passage analysis of the cave systems, for that is the job of the Park Service Wilderness Study Team and its hired consultants. In this discussion we will analyze the definition of wilderness found in the Wilderness Act and apply it generally to cave systems in the park.

"A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain."--Certainly a cave system, apart from those area where human artifacts may intrude upon the natural scene, is a prime and outstanding example of an area where the works of man are dwarfed by the massive presence of nature upon all sides. With the exception of the TB Huts (and even there the inhabitants did not remain long), the saltpetre mining relics, and the electric lighting systems installed in Mammoth Cave Ridge, there are no permanent habitations or developments in the cave system. In those parts of the cave systems which have not yet been discovered by humans, there is no better example on this planet of an "area where the earth and its community are untrammeled by man." Even the bottoms of the oceans are more affected by pollution that are the utmost reaches of the Flint-Mammoth Cave System.

"An area of wilderness is further defined to mean in this chapter an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural condition."--There could be no better description than the above of much of the Flint-Mammoth Cave System. The System is clearly undeveloped federal land. It retains its primeval character and influence. There are no human habitations. The only permanent improvements are on Mammoth Cave Ridge, where trails have been developed and lighting installed to allow large numbers of visitors to view the natural wonders without damaging them. Even the present management of the system is aimed at preserving its natural condition, although there have been some notable failures in this regard in the past, probably because a lack of statutory wilderness designation allowed a lapse of normally high management standards.

"And which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable."-- Except in the developed sections of this cave, the presence of Nature is overwhelmingly evident. Even in those portions where developments existed before the park was established, these developments which are no longer in use are "substantially unnoticeable" in many cases, and in others could easily be made so by the removal of civil defense supplies and lighting equipment and the natural deterioration of trails.

"(2) Has outstanding opportunities for solitude or a primitive and unconfined type of recreation."--Certainly there exists no other place on earth where one may be so cut off from other humans than in the depths of a cave, where even the sounds of airplanes passing overhead or automobiles on a nearby road are absorbed by the overlying rock layers. Cut off from his or her fellow humans, the underground wilderness visitor relies upon primitive senses in travelling through a labyrinth of passages exceeding 165 miles in length.[5] There are sections of the Flint-Mammoth Systems where no one has ever set foot, and in most places the number of visitors is limited to a few score. Even the well travelled sections have been viewed at most by only a few hundred persons. Only a few feet off the tourist trails in Mammoth Cave Ridge, one may be truly alone. The opportunity for solitude is indeed outstanding.

"(3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition."--Clearly, if the boundaries of an underground wilderness area are defined by establishing boundaries upon the surface and projecting them underground, there is no question but that the underground areas of the park exceed 5,000 acres, and thus qualify. However, Congress specifically included the word **or** to differentiate the second category of qualification as being equal in acceptability to the first. (This point was discussed in length in the Conference Report on the Wilderness Act). A cave system has the inherent property of being naturally protected, if gates are installed and maintained at entrances and visitation is regulated to within environmentally acceptable limits. (Methods of controlling and distributing visitor impact are discussed in Outdoor Recreation--A Legacy for America, Bureau of Outdoor Recreation, 1973, p. 49).

"And (4) may also contain ecological, geological or other features of scientific, educational, scenic, or historical value."--There is no question but that this section applies to Mammoth Park Caves. They have for the past one and one-half centuries been famous throughout the world for their features of scientific, educational, scenic, and historical value, and that is in fact the reason why the area was designated a national park.[6]

There is, then, no question but what much of the park's cave systems are wilderness by the above definitions, and qualify for inclusion in the National Wilderness Preservation System. The only question remaining is one of specifics. Certain sections of the caves show substantial human influences, and thus might not be eligible for wilderness protection. The purpose of a wilderness review is to determine which, if any, portions of an area of federal land do qualify by the above definition, and which do not. Therefore such a review should be carried out, and recommendations made, based upon the definition of wilderness provided by the Wilderness Act.

V. The designation of underground wilderness is acceptable upon scientific and environmental grounds.

Ample discussion of this point exists in the publications already submitted to the Park Service, and mentioned above. Obviously there would be some restraints necessary upon surface uses overlying and surrounding an underground wilderness area to assure that the wilderness was not polluted or destroyed through careless acts. Normally these precautions are included within the management procedures necessary to meet the statutory requirements established by the National Parks Act (16 U.S.C. 1) and other legislation affecting the national parks. If the proposed Master Plan is carried out, the surface will be managed in such a way compatible with the maintenance of underground wilderness.

The major effect that underground wilderness designation would have is to assure that surface management was carried out in ways compatible with preservation of the underground wilderness environment. When surface developments are installed over an underground wilderness area, it may be necessary to take extra precautions to assure that pollution or other adverse environmental effects do not occur. If these precautions are taken, there would be no objection to the designation of underground wilderness below surface developments.

VI. Failure to conduct a proper review, accompanied by a legally acceptable Environmental Impact Statement, of all of the roadless Park lands is a violation of the Wilderness Act and the National Environmental Policy Act.

The Wilderness Act of 1964 clearly requires the review by the Secretary of the Interior of all "roadless areas" of more than five thousand acres within the National Parks and a report to the President as to the suitability or nonsuitability of each area for preservation as wilderness. We have shown that "land" within the meaning of the Wilderness Act includes both the subsurface and surface, and that land may be divided by vertical as well as horizontal boundaries. Since the Congress recognized the existence of caves and the applicability of the Wilderness Act to their protection they are indeed included under the Act. Mammoth Cave National Park was established to protect cave systems, and since substantial portions of those cave systems are eligible for inclusion in the National

Wilderness Preservation System, the Secretary should review them and so recommend them.

The crux of the matter is whether or not a proper review of the underground portions of the park land has been made. The evidence suggests that it has not. The "Wilderness Study" presented to the public hearings in May 1974 made no mention of the underground portions of the park. The Park Service indicated in its Draft Environmental Statement that it had chosen not to recommend inclusion of the caves in an underground wilderness. However, that recommendation was clearly based not upon a review, but upon an arbitrary interpretation by the Park Service of departmental regulations and the intent of the Wilderness Act.

Section 102 (2) (C) of the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et. seq., 83 Stat. 852, Pub. L. 91-190) requires that "a detailed statement by the responsible official" on the environmental impacts of "every recommendation or report on proposals of legislation" "shall accompany the proposal through the existing agency review processes." With respect to the wilderness recommendations presented at the hearings in May 1974 the Environmental Impact Statement presented was hopelessly inadequate, since it did not include a discussion of several of the points required by Section 102 (2) (C), specifically the sections on adverse environmental impacts which cannot be avoided, the relationship between short term uses and the long-term productivity, and irreversible and irretrievable commitments of resources. It contains an arbitrary analysis of the data and a misrepresentation of the legal definition of wilderness; it completely ignores departmental wilderness guidelines; it proposes overdevelopment of wilderness without justification; it contains a completely inadequate discussion of wilderness and non-wilderness impacts; and its discussion of alternatives consistently misinterprets the conservationist's wilderness proposals and argues against "straw men."

Because citizen wilderness proposals have all included recommendations for underground wilderness in the park, a discussion of the various wilderness alternatives in the Draft Environmental Impact Statement includes a cursory analysis of the environmental impacts of underground wilderness. However, as we pointed out in our comments on that Draft Environmental Impact Statement (a copy of which has been submitted for inclusion in the Wilderness Hearing Record), the entire discussion of wilderness fails woefully short of meeting even the minimum requirements of NEPA., and the discussion of underground wilderness is for all practical purposes non-existent since it fails to present a balanced and fair assessment of the impacts. Instead it seems to be aimed at justifying the Park Services' choice to recommend no underground wilderness.

Thus we find that the Park Service and the Department of the Interior have clearly complied with neither the Wilderness Act nor the National Environmental Policy Act. They have failed to adequately review all of the wilderness resources of the roadless areas of Mammoth Cave National Park, and the Draft Environmental Impact Statement presented at the Wilderness Hearings in May 1974 was not adequate to meet the requirements of the law. Therefore, we recommend that the National Park Service, and the Department of the Interior, should "go back to the drawing boards" and perform an adequate review of the park lands and present the results of that review, together with an adequate Environmental Impact Statement, to the President for recommendation to Congress.

We realize that the time remaining before the September 3, 1974 deadline set by Section 1132 (c) of the Wilderness Act is short; but the Department has been aware of that deadline, and could have proceeded more rapidly through the review process. Conservationists have been asking for a review of the underground wilderness resources since 1967, and the agencies should be well aware of their responsibilities under the law. The failure to act can only be ascribed to an overt intent to thwart the will of Congress.

The interests of the Park, the wilderness cave resources and the people of the United States would best be served by immediate review of the subsurface resources of Mammoth Cave National Park, and a recommendation by the Secretary of the Interior and the President to Congress for designation of substantial portions of the underground areas of Mammoth Cave National Park as underground wilderness.

References Cited

(1) National Speleological Society. **A Wilderness Proposal for Mammoth Cave National Park, Kentucky.** Vienna, Va.: National Spelelogical Society, 1967.

(2) Davidson, Joseph K. and William P. Bishop. **Wilderness Resources in Mammoth Cave National Park: A Regional Approach.** Columbus, Ohio: Cave Research Foundation, 1971.

(3) Stitt, Robert R. and William P. Bishop. "Underground Wilderness in the Guadalupe Escarpment: A Concept Applied." **Bulletin of the National Speleological Society,** 34(3):77-88, 1972.

Author's Note: The following pieces demonstrate the response to the above legal brief from the Interior Department and the President:

United States Department of the Interior
Office of the Secretary
Washington, D.C. 20240

May 12, 1975

Mr. Robert R. Stitt
Conservation Chairman
National Speleological Society
Conservation Committee

Dear Mr. Stitt:

This responds to your letter of March 6, 1975, concerning the Department's wilderness review of Mammoth Cave National Park.[7]

Let me commend you and your organization for your interest in and efforts on behalf of wilderness in Mammoth Cave National Park. In our letter to the President dated August 23, 1974 (enclosed), we stated: "There is no legal barrier to the designation of subterranean lands as wilderness." Moreover, in that letter the Department committed itself to carrying out explorations of the subterranean lands in Mammoth Cave National Park and making additional recommendations to the Congress. This, of course, constitutes a change from the earlier position of the National Park Service that underground wilderness areas were not within the scope of the Wilderness Act. This change was occasioned in no small measure by the cogent analysis of the issue in your organization's legal brief submitted June 25, 1974. Certain points raised in your letter center on issues as to which reasonable men may differ. For example, you are apparently convinced that much of the park's surface land has been restored to a natural state, whereas it is our judgment that virtually all of the surface land in the park still displays marked signs of man's presence. I stand by the Department's recommendation and see little to be gained by a lengthy discussion of the issue. The Congress, of course, will ultimately decide the matter. Similarly, your contentions that the Hearing Officer's conclusions are not supported by the record is a subject which we could debate at length to little purpose: I believe that the Hearing Examiner acted properly. Again, your assertion that, contrary to the statement in the Department's recommendation to the President, more is known about the park's cave than its surface lands can be left to Congress for further consideration. (I would point out, however, that it does not matter whether, as you state, more has been written about the caves than about the surface; our point is that many of the caves contain large unexplored segments, whereas the surface lands have been thoroughly assessed.)

Many of your arguments concern legal issues and the interpretation of the Department's recommendation to the President. These I would like to discuss in some detail.

[Paragraph responding to allegation that the recommendation for no wilderness lacked an adequate environmental statement as required by NEPA.]

Your letter also contends that "there was no review of the underground wilderness resources of the park." I cannot agree. I can assure you that the subject of wilderness designation for subterranean lands in Mammoth Cave National Park was discussed at length in the Department prior to the final recommendation to the President. Evidently your view that there was no review is predicated upon the fact that the Department did not conduct exhaustive explorations of the subterranean lands prior to making its recommendation.[8] The Wilderness Act does not specify the kind of review called for in section 3 (c). I am convinced that a serious consideration of all known facets of an area suffices a review within the meaning of that section. The subterranean lands of Mammoth Cave National Park were given such a consideration, and it was the Department's determination that the imminent 10-year deadline of the Wilderness Act and the enormous expense involved rendered a crash program to explore the subterranean lands infeasible. Using the best available data, we concluded that too large a portion of the subterranean lands in the park was terra incognita for us to be able to recommend them as wilderness at that time.[9]

[Paragraph discussing the Green River impoundment and its status under the Wilderness Act.]

Finally, I cannot accede to your request that an "immediate wilderness reevaluation be conducted" in Mammoth Cave National Park. Certainly there is no intention to procrastinate in making the reassessment promised in our recommendation letter. On the other hand, there is no threat to the underground resources of the park; our commitment to reassess these lands entails that we take no action in the meantime which would be incompatible with their designation as wilderness. Accordingly, we shall adhere to an exploration and reassessment schedule that is in keeping with fiscal and manpower restraints as well as overall requirements for proper administration of the park.[10] We do not contemplate any material difference in the criteria used to evaluate the wilderness potential of subterranean lands in Mammoth Cave National Park from those criteria employed elsewhere in the National Park System.

Sincerely yours,

/s/ Nathaniel Reed

Assistant Secretary of the Interior

United States Department of the Interior
Office of the Secretary
Washington, D.C. 20240

August 23,1974

The President
The White House
Washington, D.C. 20500

Dear Mr.President:

The Wilderness Act (78 Stat. 890) directs the Secretary of the Interior to recommend to the President areas within its jurisdiction which are suitable for designation as wilderness. Having reviewed Mammoth Cave National Park, we conclude that none of the park area should be designated wilderness at this time.

Mammoth Cave National Park, a 51,354 acre area in south-central Kentucky, was established by an Act of Congress in 1926. Its focus is the world's most extensive lineal cave system, which is toured by more than 600,000 persons per year. The park also offers some of the finest riverscapes in the state, along the Green and Nolin rivers. The park harbors abundant wildlife, particularly Virginia white-tailed deer. Prior to the establishment of the park, the surface lands of the Mammoth Cave area were settled and farmed. At present virtually all of the surface lands of the park still display marked signs of man's presence there. We believe that several more decades will be required before these lands can return to their natural condition. The subterranean portions of the park contain extensive undeveloped caverns. There is no legal barrier to the designation of subterranean lands as wilderness. However, many of the caverns are unexplored and largely unknown. New knowledge gleaned from exploration may entail changes in management and use of the caves as a whole. To recommend any of these areas for wilderness designation prior to their exploration and prior to an assessment as to how they fit into the park as a whole, we believe, subordinate the values for which the park was established to wilderness concerns.[11] For these reasons we recommend that no part of Mammoth Cave National Park be designated wilderness at this time. We shall reassess the situation as exploration progresses and report back to Congress at a later date.

In accordance with the terms of the Wilderness Act, a public hearing on the recommendation was held at Bowling Green, Kentucky, on May 29, 1974. A summary of the hearing record and written expressions received concerning it is contained in the enclosed brochure. Complete records have been compiled and are available for inspection by the public.

Sincerely yours,

/s/ ??Wheeler

Acting Secretary of the Interior

Presidential Wilderness Message

Excerpt from the CONGRESSIONAL RECORD-SENATE. December 4, 1974. p. S20450ff.

To the Congress of the United States:

[Proposes 37 new additions to the National Wilderness Preservation System]

Three other areas...contain surface lands suitable for wilderness designation...

After [review] the Secretary of the Interior has concluded that four areas are not suitable for preservation as part of the National Wilderness Preservation System. These [include]:...Mammoth Cave National Park, Kentucky...As to [this park], however, I am directing that a wilderness reevaluation be conducted at such time as management perogatives and other prospective uses of the areas are better defined...

Gerald R. Ford

The White House, December 4, 1974

Notes:

1. As of 1974. The author is currently (1991) Chairman of the Cave Conservation and Management Section of the NSS, and has variously served as Director, Executive Vice President, and President of the NSS since 1974.

2. This paper was originally prepared in 1975 to be presented as part of the Master Plan and Wilderness Hearings for the Mammoth Cave National Park in 1974. It was responsible for the acceptance of the legality of underground wilderness by the Department of the Interior. However, to date there have been no designations of underground wilderness; agencies seem reluctant to set a precedent. Note that the original paper was not footnoted. Footnotes that appear here have been added to present some historical perspective looking back from 1991, without distracting from the original paper. To experience the paper as it was originally presented, the reader should ignore the footnotes.

3. The "RARE" roadless area reviews performed in the late 1970's and early 1980's by Federal agencies in general neglected underground wilderness. The U.S. Forest Service did study one area, the Cave Creek area in Kentucky, but in the end decided that it was not suitable for wilderness recommendation.

4. These referenced materials, of course, are not included here. They are listed at the end of the paper.

5. By 1991 it is over 300 miles in length and still growing.

6. And why the Cave System was designated a "World Heritage Site" in the 1980's by the United Nations.

7. The letter to which this letter responds was written to feel out the Department's positions on these issues in preparation for a lawsuit to force the issue. The issue was not pursued due to changing priorities in the conservation movement and a general feeling that there was little further to be gained by pressing the issue at that time. In hindsight, that may have been a mistake. However, it was clear that the Department would toss the ball to Congress, and at that time we did not feel we had the political clout to succeed.

8. That wasn't exactly it. My conclusion was reached because they did not publicly discuss the subject of underground wilderness in any of the documentation presented. I would argue to the contrary of their point of view that exploration of the underground is not a prerequisite to wilderness designation. In fact, there would be no finer wilderness than that which is being explored for the very first time. And underground wilderness is probably the sole remaining opportunity for this type of wilderness experience on earth.

9. Consider the irony of this. We can't designate it as wilderness because it is too wild (i.e., unknown).

10. Insiders in the Interior Department suggested that five years would be the normal reevaluation interval. However, to the best of my knowledge, no reevaluation has taken place--at least not publicly.

11. Well, this makes a little more sense than Reed's comments about not designating wilderness until it is known. But not much. Certainly any designation of wilderness subordinates other values. The real question is, what is the best management of the total resource to preserve all the values?

CAVE WILDERNESS DESIGNATION IN AMERICA: A NEW ACTION PROPOSAL

William R. Halliday, M.D., Chairman
Wilderness Subcommittee of the Conservation Committee of the
National Speleological Society

ABSTRACT

Despite 25 years' efforts, not a single designated cave wilderness exists in the United States. Promulgation of new USDI-USDA joint regulations implementing the Federal Cave Resources Protection Act offers a new opportunity to obtain statutory protection for all major federally owned wild caves in a single package, at least for caves protected by the FCRPA. This would avoid piecemeal approaches to individual wild caves which might threaten protection of similar cave wilderness resources and values elsewhere.

As in the case of wilderness proponents in general, at least two major schools of though exist among proponents of cave wilderness. One of these recently was expressed admirably in a letter to me by a well-known cave conservationist:

> We have set aside the "best" of our natural areas as wilderness. The NSS should propose only the "best" of our caves as wilderness...I would...say that <u>most</u> significant caves do not deserve that status....

Some wilderness proponents with this mindset have told of undergoing a transcendental, almost orgasmic experience from wilderness, above or below ground, and see little importance in wilderness resources and values of lower caliber. I have had such an experience, when two of us topped up over the col from the Columbia Ice Field and first looked into the awesome Castleguard Basin. Yet my own mindset is in the other school of thought, expressed well in 1972 by Red Watson and Phil Smith. At that time they defined cave wilderness as:

> ...cave (areas) that generally appear to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable.

Acceptance of this 1972 definition would include major parts or all of the majority of caves in lands managed by the National Park Service, the U.S. Forest Service, and the Bureau of Land Management. It is fully in accord with the wording of the Wilderness Act and all subsequent modifications thereof and is also fully in accord with the intent of that milestone Act. I assert this as one who worked side by side with Howard Zahniser in the final days of enactment of the Wilderness Act, and I am prepared to support this assertion at any time. Further, maintenance of the wilderness resources and values of the caves covered by this definition would have the effect of keeping wild today's wild caves protected by the FCRPA, a goal which is overwhelmingly supported by today's organized American cavers and speleologists.

I do not quarrel with other supporters of cave wilderness with higher standards. In the best of all worlds, our best and most threatened caves would receive the best protection, soonest. But 30-odd years of exhausting effort toward designation of individual cave wildernesses have left us with no designated cave wildernesses at all. Nor even an N.S.S. policy on cave wilderness. It seems to me that a new approach is needed. And it also seems to me that enactment of the Federal Cave Resources Protection Act and the forthcoming implementation regulations offer a new, timely vehicle for a new approach.

After reviewing the files of the last resurrection of the N.S.S. Wilderness Subcommittee, I bounced some ideas off N.S.S. Conservation Chairman Mark Laing, then asked some noted cave conservationists to serve with me on the subcommittee--Dave Foster, George Huppert, Ron Kerbo, Rob Stitt, Red Watson, and Sarah Bishop. And I asked each of them to write down their initial thoughts on the content of a cave wilderness policy for the N.S.S. This itself was a new approach. In the past this has traditionally been a one-person subcommittee, acting with no policy guidance. Sarah has not yet said whether she will accept or merely advise from outside the subcommittee. The others all accepted, and most have sent useful input on the proposed N.S.S. policy.

Further, in response to a note in the N.S.S. News, looking toward additional new blood for the subcommittee, Mike Katz and Dr. Jerry Lewis expressed interest and have been appointed.

At the 1991 N.S.S. convention, I further bounced some ideas off a group of more than a dozen "old heads" and interested newcomers. Discussion was vigorous and forthright and modified some of my own personal ideas. But basically I am continuing to propose formal designation of cave wilderness for all "federal" caves or parts of caves that would qualify under the 1972 definition I quoted above. For this I propose to utilize a mechanism arising out of the implementation of FCRPA, whether or not specifically addressed in the implementing regulations we continue to await.

Regardless of the regulations, to implement the FCRPA properly, cave managers of the National Park Service, U.S. Forest Service, and Bureau of Land Management must prepare Cave Management Plans for areas containing one or more "significant" caves. I suspect that we will be arguing over the definition of "significant cave" for some time to come. But I expect this to be only a peripheral issue in the struggle for designation of cave wilderness. Much more relevant will be the identification of cave wilderness resources and values of each "federal" cave, and their quantification. Such identification and quantification will be required by Cave Management Plans wherever duly promulgated.

In many, perhaps most, cases, this identification and quantification of cave wilderness resources and values will be an entirely new concept. The process already is beginning. For example, Hawaii Volcanoes National Park is using a modification of the Nieland semiquantitative system, categorizing cave wilderness resources and values as follows:

(1) A cave within which it is difficult or impossible to avoid intrusive works of modern humans, and whose entrance is located in a developed area and accessed by paved roads and trails.

(2) A cave within which, at ordinary rates of travel, less than 30 minutes can be spent without encountering intrusive works of modern humans, regardless of where the entrance is located.

(3) A cave within which, at ordinary rates of travel, less than 60 minutes can be spent without encountering intrusive works of modern humans, and whose entrance is located at least ¼ mile from any developed area.

(4) A cave within which, at ordinary rates of travel, less than 4 hours can be spent without encountering intrusive works of modern humans, and whose entrance is located more than ¼ mile from any developed area.

(5) A cave within which, at ordinary rates of travel, more than 4 hours can be spent without encountering intrusive works of modern humans, and whose entrance is located within a designated Wilderness Area.

Whether we agree with the specific criteria for each category and for each area, throughout America responsible cavers and speleologists need to be alert to ensure that other "federal" cave managers use some kind of relevant system to similarly identify and quantify cave wilderness resources and values.

Such a process inevitably will bring the existence of important cave wilderness resources and values to the attention of many cave managers who previously have been unaware of them. Further, each Cave Management Plan will have to deal specifically with preservation of these resources and values. Even for those units of the National Park Service, U.S. Forest Service, and Bureau of Land Management, which have not written policy on cave wilderness, such Cave

Management Plans will be at least the administrative equivalent of an unwritten policy, and carry more weight. I suspect that the process will lead to the development of many written policies without much prodding.

But, as a government administrator with almost 17 years' experience, I have seen so many policies changed overnight, and so many written and unwritten "exceptions to policy" that I have little faith in agency policies over the long run. I believe that congressional action is necessary to protect "federal" cave wilderness resources and values beyond the near future. And I believe that the forthcoming assemblage of quantified data can speak compellingly to congressional supporters of cave conservation.

An enormous effort will be needed to enact such legislation, either as an amendment to present law or as a new bill. But much of this effort will consist of caver education, and the Wilderness Subcommittee expects to undertake this anyway, whether we ever go to Congress. One of the first steps will be a proposal for a source book on cave wilderness, compiled and published by the subcommittee.

My greatest fear in this campaign is not the necessary effort. Instead, it is the specter of a bitter schism in the ranks of the strongest supporters of cave wilderness. I hope, but have no assurance, that those who fear dilution of wilderness quality can come to believe that it is better to save too much rather than too little. To avoid schism, perhaps we can make constructive use of the term wild cave in place of cave wilderness, as was proposed at the 1991 N.S.S. convention for other reasons. And certainly we can count on enormous caver support for keeping wild caves wild. Further, there are other strong wilderness proponents who feared past single-purpose cave wilderness efforts as threats to broader protection of cave wilderness and thus are more likely to favor a broader proposal.

Neither I nor the Wilderness Subcommittee have a fixed position at this time. The subcommittee and I personally welcome your suggestions and assistance. Probably I will appoint two or three more members in the near future. As we develop an educational program for the N.S.S. membership and work toward an N.S.S. policy on cave wilderness and whatever lies beyond, let us hear from you.

CAVE RADIATION

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Discussion Leader: Bill Austin

(The following is the transcript of a tape recorded discussion session based on an initial concept paper by Tom Aley.)

Bill Austin: When you all join in this panel discussion speak up and maybe we can get it on this recorder. This is a poor substitute for the real thing, but maybe you can hear it. My name is Bill Austin and I have on this suit and tie so maybe you won't confuse me with Tom Aley. And to further differentiate it I'm going to tell you one of Tom Aley's jokes. You've heard this story, haven't you, that if you play rock music backwards you get Satanic messages? You all heard Tom's joke? You know what happens when you play country music backwards? You get out of jail, you get your car back, you get your job back, you get your wife back.

Incidentally, I saw a thing on educational television last night on the Nova program. If it ever comes around again I recommend that you watch it very closely. This is dead serious. This is one of the most incredible caving experiences I have ever seen, and it was done in the foundation works and sub-basements of the Chernobyl nuclear reactor and it was done by a team of Soviet scientists trying to assess the damage, and more importantly, trying to find out where was the fuel. They didn't know, and I won't spoil the story, but I will tell you that they did some incredible caving under some highly radioactive conditions and they found the fuel. If it ever comes up on Nova be sure and watch it.

Well to start out again and talk about radon, there really has to be something to this radon thing because it is obvious that monkeys went into caves and mutated and they came out and they were resource managers and cave operators, so ... (laughter). Rangers have now become resource managers I understand. The next thing on my notes here is Tom thought I might remind you that government can profit from radon and radon monitoring. For instance, very soon after it became an "in" thing down at Mammoth, they put five people on the staff including the daughter of an ex-superintendent and they have a lot of people employed throughout the National Park Service utilizing these random numbers so it is a very big program and it makes your desk a little larger because you've got more people to supervise. And I'm sorry that Ron left because I wanted to address something else about National Parks. He was worried about this boundary thing. It has been my experience that National Park boundaries keep leaping out where ever they think there's a cave. And that's not a problem because if you find a cave pretty soon you will find the boundary not far behind. So, that is the worry about it. It isn't the boundary that is going to cause you the problem, it is the management that comes with it.

And that brings me to the history of the discovery of radon and the early management of the program. There was an academic type. They let one into Carlsbad by mistake in about 1976 or 1977 and he discovered radon gas in Carlsbad and the managers jumped on this problem and they did one thing that was remarkably good. They got in the folks from the Denver Technical Support Center which was an organization set up under the Bureau of Mines that provided technical support and advice to the uranium mining industry. And this was a really good organization. They did research, worked on equipment, ventilation techniques, ways of getting radon out of the air, and were available to the uranium mining industry as a technical support service and you could call these people in if you had a problem at your uranium mine you could call these people in and they would help you reconfigure your ventilation or do whatever you needed to do to get your mine back into compliance. And by the genesis of their act they were not allowed to report you to the Bureau of Mines enforcement people.

enforcement people. So there was no way that you could get in trouble by calling them in. They were a very good group, very professional, and if I had a radon problem they are the people I would call on. However, they found out the radon levels weren't very high in Carlsbad and the managers said well we'll solve this we'll just accept for Carlsbad the standards that are set up for the mining industry and they actually published those standards in the Federal Register as the standards that would apply for Carlsbad.

Now there are several things that are wrong with this. They hadn't checked any of the other caves and they had a few caves that were hot enough that if they were a uranium mine they would close them. Mammoth was one of the caves. And in fact, not only did they have that problem at Mammoth, but they put a ventilation shaft in for their administrative buildings over there and were using the cave air to air condition the buildings and the secretaries were getting more exposure than the guides.

Anyway, the National Caves Association became interested in this problem. They hired Tom Aley as a consultant and I worked with Tom. We bought radiation equipment and went around and measured quite a few of the show caves in the East and took radiation measurements to sort of get an idea of the magnitude of the problem in these various caves. Working with this information and trying to work with the National Park Service we came up with some overall industry standards. We found it necessary to adopt a set of precautionary standards that apply only to the National Caves Association. The National Park Service said they would abide by those standards, however, to this date we haven't seen much progress on their part. They have kept on with the random number programs monitoring their people very closely, not informing the public about radon, and so on and so on. In the course of all these negotiations we suggested several things that they might do to alter the tours through National Park caves that would make the problem less. In other words, decrease the exposure of people, rather than as with the monitoring program where you are putting more people into monitoring and you are actually increasing total exposure. They didn't like some of these suggestions. We suggested that perhaps they should shorten cave tours, that they should not have souvenir shops in caves, or they should not have dining rooms in caves because all of those things unnecessarily prolong people's stay times in caves and they have certain other undesirable effects. Anyway, in all this negotiating back and forth we finally wound up with the National Caves Association standards and the National Park Service doing their own thing.

More recent, and I am just about to shut up and we can get into the discussion stage, our contention from the very first was that conditions in caves were quite different from conditions in mines. There are a lot of carcinogens that you find in mines that you don't have in caves. A lot of dust, some with metals in it, some with asbestos fibers in it. We have diesel fumes, particulate matter in a lot of mines, and in essence you are carrying on an industrial, heavy industrial type process in there where you are dealing with rocks, and beating them up. One of the unfortunate things we think that has happened is that caves were early on connected with mines and now the EPA has connected, extrapolated, this uranium miner data to cover households. There is some hope in recent years. There has been a lot of research carried out that seems to indicate that radon is not going to be much of a health hazard at normal cave or household levels. Now I'll cite from a recent paper written by Blot, William J. et al. All the other names are Chinese. The title of it is "Indoor Radiation and Lung Cancer in China". It was published in the Journal of the National Cancer Institute, Volume 82, Number 12, June 20, 1990, pages 1025 through 1030. This was a study that was done in a Chinese city that had fairly high radiation levels in the houses. In this study they split it between two groups. One group of women, 308 of whom were diagnosed as having lung cancer. 356 women in the other group were just random samples. The houses they had lived in were measured by one year alpha track recording so it was accurate. The median time of residence in these houses by these women was 24 years, so they had a long term study. The median levels of radiation they found in the houses was 2.3 picoCuries per liter. 20% of the houses had levels greater than 4 picoCuries per liter. Now to put this into perspective, the average household would give you the exposure you would get on a normal 1 hour cave tour. This would be a daily one hour cave tour as against one day in the house. So you can see we are talking about fairly good relationship with cave levels. The results they found were very interesting. The lung cancer levels were not higher in homes that developed lung cancers than in control homes. They found no correlation. They found that lung cancer risk did not increase with increasing radon levels. This is in a household situation. Remember many of these people smoked and they had open fireplaces. There was no association between radon and lung cancer observed regardless of cigarette smoking status of the people in the study except for a non-significant trend among heavy smokers. And there was no positive association of lung cancer cell type with radon levels observed except again for a non-significant risk of small cell cancer among the most heavily exposed. The conclusions includes this statement: "Our data suggest that projections from miners exposed to high radon levels may have over-estimated the overall risk of lung cancer associated with levels typically seen associated with homes in this Chinese city.

I was very pleased to see that another public agency, the State of Arizona, recently bought a cave in an area of potentially high radiation levels. Obviously they made a decision to develop this property into a show cave even though it has high levels. I think this is a very important step by this agency because Kartchner is the first cave development I know of that has come along, significant cave development, that has come along and been undertaken since radon became an issue. Obviously they think it is not a very big issue. That's all folks. Anybody want to speak up.

Unknown Person: What is the overall rate of lung cancer in China verses the United States? Have there been any studies of radon affecting miners in their own uranium mines? I assume they must have some.

Bill Austin: I don't know, I had a copy of this paper, but I couldn't find it so I had to call Tom and get this reference. But, you can look it up.

Same Unknown Person: I was curious if the overall rate of lung cancer in China verses the United States might overwhelm the effect of radon.

Bill Austin: I don't know.

Dr. William R. Halliday: Having been in China I don't think you can rely upon that type of statistic at all. It sounds like they were doing good science in this paper. I'd like to say a little bit on this general topic. I've been quite concerned about this whole approach by the EPA and other agencies for some time. A group of us were talking to Nick Crawford at the mouth of Lost River Cave the other day on the field trip and he was talking about their radiation monitoring, and he said rather plaintively, "Where are all the bodies from all these radon daughters or whatever term you use for that"?

Bill Austin: Where are all the dead bats?

Dr. William R. Halliday: And this struck a note with me, for as some of you know, my field of specialization in medicine originally was chest surgery, and one of the reasons that I changed my specialization in medicine was that I became so depressed from working with people who were dying of lung cancer. I sought a happier branch of medicine. And I got to know these folks real well. I took good histories from them. And every one of my patients, without exceptions, had their 40 pack years of cigarettes. One of them by the age of 29, and his cancer was too far gone for me to even take it out. Later on I worked in administrative positions where for a very small group the impact of overwhelming exposure to asbestos and the asbestos trade the epidemiology was very clear. The effect of asbestos was the causation of lung cancer. But I never saw any evidence whatever, and talking to other lung surgeons at meetings around the country, none of us ever talked in terms of any cause of lung cancer except asbestos and cigarettes. That doesn't mean we weren't thinking properly along those lines, but 100% of my patients with lung cancer were cigarette victims. There are various epidemiological studies of the effect of pitchblende mining in central Europe and the rate of cancer among pitchblende miners. Excellent epidemiological studies; that's what started all of this. But I haven't done a computer search of the literature and I've lost track of it a bit in the last few years, but I have been unable to find any citation of any epidemiological study verifying that we do in fact have a large number of people dying of causes of lung cancer other than cigarettes and asbestos. If there were this, there should be an easy epidemiological study of these people who pay good money to go and sit in uranium mines supposedly to improve their health.

Bill Austin: I had a call several years ago from a young lady down at the CDC [Center for Disease Control] and they wanted to initiate a study and they were having a lot of trouble finding a base. They thought perhaps there could be a base among the private cave operators, and I explained the transient nature of most of our employees and sent them over to talk to the folks at Mammoth Cave where they tend to have long term employees and keep these random numbers. I'm afraid they would have found that even there the statistical base was too small; the numbers were too small for an accurate statistical base.

Dr. William R. Halliday: All that I have found in the literature that I have looked at and all that I have heard cited are estimates that go clear back to the pitchblende miners a hundred years ago. A totally different situation. Have you got something to the contrary?

Unknown person: Having no knowledge of this all, I gather what you are really saying is that the threshold is probably much higher than what was originally set. It would seem to me that you could get enough radiation at some level to cause you some harm.

Dr. William R. Halliday: That's what happens to the pitchblende miners. But beyond that what we have is extrapolations and estimates from that to very low doses compared to the pitchblende miners that should serve as an excellent working hypothesis that there is a need, to my way of thinking, in scientific medicine of a detailed epidemiological studies to prove the hypothesis. I can't find that this has ever been done.

Unknown person: My understanding is that there are some things that if they don't reach a threshold, sort of like a light value that doesn't mess with your film at all, and if you don't get above that light value you don't get anything at all. So it may be that there is a threshold and below that point it is irrelevant. It seems to me that this may be what is happening. I don't know, but I gather this is sort of what you are saying?

Dr. William R. Halliday: I'm asking if anybody has any data to the contrary.

Bill Austin: Well there is some data that was put out by the folks at Denver Center and others that indicates that low levels of exposure are beneficial.

Bob Buecher: I'm Bob Buecher, I've been working at Kartchner Caverns, and despite what Bill has been saying, radon and its effect on the management of Kartchner Caverns is a very real problem. The state is very concerned about it, and it could radically alter the way that the cave is developed. I wish that wasn't the case.

As a result I have done a considerable amount of research into radon, some of the more current studies on radon. I think we all have to realize that there is no doubt that radon is a health problem. It is a question of how much of a health problem is it at the levels to be encountered in a cave. And also ...

Dr. William R. Halliday: On what basis is it a health problem?

Bob Buecher: Well, you know, you just heard the results of one study saying that it isn't. For every one study that says it isn't, there are nine studies that say it is. The overwhelming scientific conclusion is that this is, you know, this is a definite effect. I'll also point out that I can supply some of the references. A number of animal models of radon exposure. So it is very valid to say that what happens in a uranium mine-- there are so many other confounding factors that it is probably not as valid. But there have been animal studies looking at those effects. What happens if we expose animals to radon, and then what happens if we expose the animals to radon plus diesel fumes or high dust concentrations. This is fairly well worked out, and I think that we are vastly on the wrong track to sit here and bury our heads in the sand and say: "this isn't a health problem, this is not a health problem," when everything else points out that it is a health problem. There are agencies setting policies on that basis. And we are just trying to deny the basic fact that what we should really be facing is radiation of any form is something that the public is very scared of and whether or not you know it, the greatest source of radiation exposure that any of us has, any of the population, is from radon. It is a problem in any radiation exposure regulation that the naturally occurring radon that we are all exposed to is the greatest source.

Dr. William R. Halliday: At what altitude?

Bob Buecher: At any altitude.

Dr. William R. Halliday: Cosmic radiation?

Bob Buecher: It is vastly more greater. Alpha radiation we are exposed to is something like 30 to 40% of the total exposure.

Comments by unidentified people: Hard to make it out on the tape. Much of the discussion deals with the absence of studies from situations other than mines. One person notes that it is not just the radon that is involved, like Bob Buecher suggested, but is also cigarette smoke, etc. Bob Buecher: There are these correlations, and some of them do project down to fairly low levels. It is just that if you get the lower levels you need larger and larger numbers [of persons in the samples]. On the uranium miners, if you get a couple of hundred uranium miners who are getting exposures...What they use is working levels, say, basically 100 picoCuries might be equivalent to a working level. If you work in that for say 170 hours you have a working level month. Uranium miner are exposed to levels of thousands to ten thousands of working level months. If those exposures, a hundred to two hundred miners, you can get very conclusive results. When you are down around a household level, a couple of picoCuries, to do a definitive study you need something like a hundred thousand people.

Unknown person: But those studies exist? You say?

Bob Buecher: No. Those studies have never been done. You have little studies like this Chinese study, and it sort of says no we didn't see a result, but that's not really a big enough sample. What you end up doing is having 20 studies like that, you start seeing that yes, some of them show something, and some don't.

More discussion follows.

PETROGLYPHS AND PICTOGRAPHS IN CAVES AND ROCK SHELTERS: A MISSOURI PERSPECTIVE

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ABSTRACT

Approximately 30 percent of the petroglyph and pictograph sites in Missouri occur in caves and rock shelters. With over 5,000 caves reported in Missouri, more rock art sites are expected to be discovered in archaeological surveys, and by cavers who have been alerted to these cultural resources endangered by weathering, biological encroachment, and increasing vandalism. Information gathered during the fieldwork of this NSF research project has magnified the need for awareness, management, and preservation of these fragile and irreplaceable records of the past.

The importance of caves as an endangered natural resource was not recognized until fairly recently. Thus it is understandable that the endangered cultural resources they contain have also been neglected. Because of the fragile nature of these cultural resources and their informational potential for studies in the prehistory of Native American groups, I decided to make the inventory and analysis of the state's rock art my doctoral dissertation project. In 1989, I received a 2-year National Science Foundation grant and this summer (1991) completed the fieldwork. I was impressed with the percentage of ancient rock carvings and paintings that occur in caves and rock shelters.

Humans began making images and keeping symbolic records more than 25,000 years before the invention of writing. The oldest such records now known date to not long after Homo sapiens appeared in Europe. While no one knows the precise time for the first appearance of petroglyphs and pictographs, commonly referred to as "rock art," on the North American continent, we can be fairly certain that by A.D. 900 graphic communications painted on or carved into rock were in wide use with the highest densities appearing in parts of Canada, the Southwest, and the Eastern Woodlands.

According to Campbell Grant (1981), the Southwest is heavily dotted with rock art sites but the only large concentration in the Eastern Woodlands is in Missouri near the confluence of the Mississippi and Missouri Rivers. There are between 50 and 60 in this area and more than 100 in the entire state. Approximately 30 percent of these are in caves and rock shelters. About 20 percent of the total have been completely destroyed through construction and wanton destruction, and the remainder are in serious danger of obliteration through weathering, biological encroachment, and vandalism.

Missouri is "The Cave State" with over 5,000 caves recorded. Hence it is likely that many more caves, often used in prehistoric times for shelter or ceremonies, with rock art are awaiting discovery. I have spoken on a few occasions at the meetings of the Missouri Speleological Survey about this situation. Although I received one or two leads, the majority of cavers honestly told me that they had little interest in that aspect of caving. While some were wiling to note artifacts on a cave floor, very few had even thought to inspect the walls for graphics. Most prefer to explore and map the caves, and of course, to discover new ones. In fact, Missouri cavers report an average of 140 new caves yearly and have been doing so since 1956 when the MSS was established. In any case, one of my goals is to persuade as many cavers as possible to check the walls of caves carefully, particularly near the entrances, for prehistoric rock art. This is the first step in preservation: identifying and recording these cultural features.

Missouri rock art is very special in that most sites contain distinct motifs. In 1913, David Bushnell investigated the ancient rock carvings of Ceremonial Cave in Ste. Genevieve County (fig. 1). Not until the late 30s and 40s did an interest in rock art surface again. At that time, amateur and avocational archaeologists began to record and photograph the prehistoric rock art of Missouri, primarily in the area surrounding the confluence of the Mississippi and Missouri Rivers. If it were not for these early records, information about many of the sites would have been lost forever.

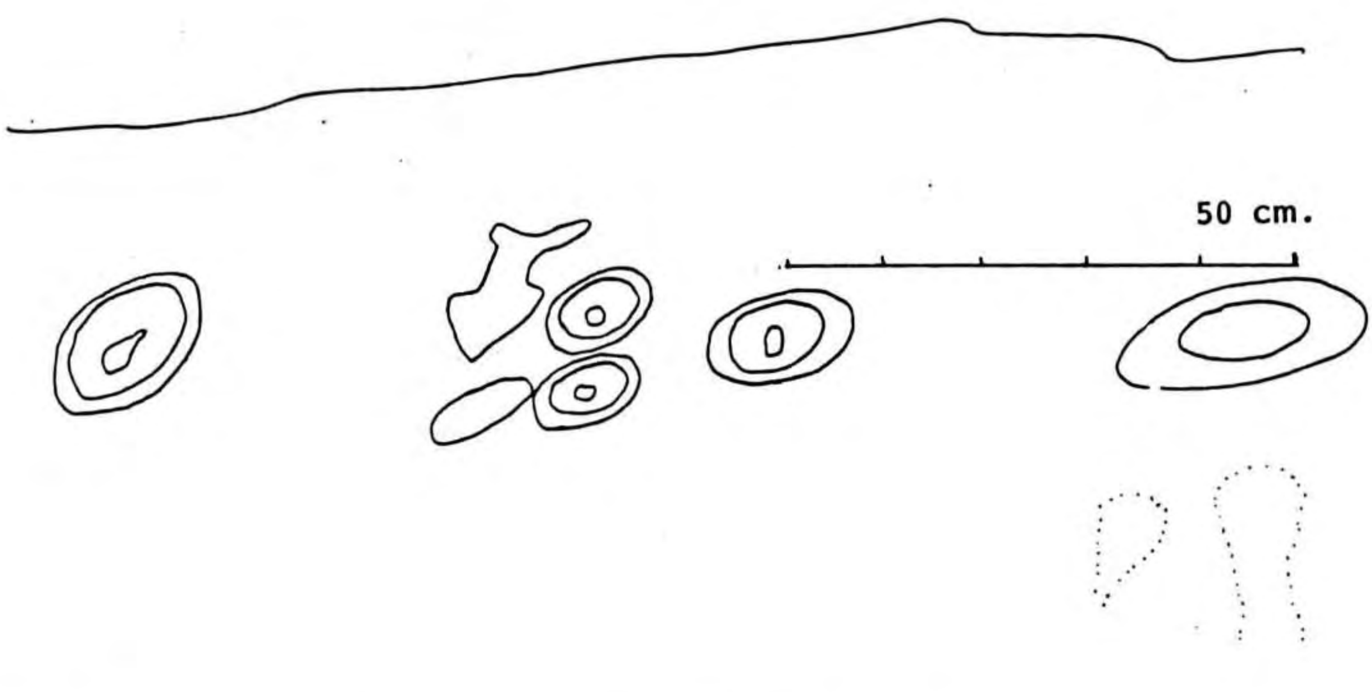

Fig. 1. Petroglyphs inside entrance of Bushnell's Ceremonial Cave in Ste. Genevieve County

As opposed to petroglyphs (rock carvings), pictographs (rock paintings) occur more frequently in caves, although the two are equally present in rock shelters. In fact, it is not unusual to see both on the same wall, or to find petroglyphs that have been painted with red, black or white pigment. However, it is only in the cave environment, and in some shelters, that we find these prehistoric paintings well-preserved. While the enclosed environment is ordinarily beneficial for preservation, sometimes the most profound deterioration occurs in these areas not exposed to air and sunlight, that is, where moisture is retained. The undersides of shelter overhangs, where rock art frequently appears, are most severely affected by this problem (fig. 2).

It was the consensus of the stone conservationists whom I consulted at the Smithsonian, Columbia University in New York, and at the Canadian Conservation Institute, that the one natural agent most responsible for deterioration of rock art is water. It is important to note the climate factor here as the exfoliation of the sandstone shelters is believed to be caused by thermal expansion and contraction after moisture enters minute fissures parallel to the rock surface. I do not believe that this process affects caves where a constant temperature is maintained.

Another problem at these sites, somewhat related to the heavy moisture retention problem, is biological encroachment, primarily in the form of lichens. A lichen needs water to grow, and absorbs it rapidly. It is this water retention behavior of the lichen that is much to blame for the escalating deterioration of the stone, and Missouri has a very high yearly rainfall. In addition, it is reported that rock from which lichens have been removed is often pitted as a result of rhizome penetration. One of the benefits of lichens in the ecological picture is that some of them produce acids that breach down rocks in simple soils in which other plants can take root. Of course, when the acids are breaking down 1,000 year old rock carvings, it is a matter of concern for archaeologists and conservationists alike.

The third cause for concern, vandalism, is extremely diverse in its effects on rock art. At one end of the spectrum is the wanton destruction of sites through scratching, chipping, initial carving, and the removal of entire carved boulders. At the other end of the spectrum are the well-meaning but damaging rubbings, castings, and repeated chalkings. At the Washington State Park Petroglyphs, Missouri's largest rock art site, park conservationists in the 60s felt it imperative to scrub the prehistoric carvings with a wire brush to "clean" them and in the fall would frequently be seen sweeping leaves from these vertical outcrops of friable sandstone. Both actions have rendered these rock carvings very faint and most assuredly destroyed all delicate details.

RECOGNIZING AND RECORDING

Because the continued existence of rock art whether in caves, rock shelters, on outcrops or on bluff facades is dependent on weather, plants and people, it is the consensus of most conservationists that the highest priority in preserving these sites is to record them thoroughly. Of course, one must be oriented to recognizing rock art and it is difficult to transmit that knowledge on paper. Nevertheless, I encourage all cavers to become familiar with the motifs and execution styles in their area through documents or by consulting the local experts, be they academic or avocational.

Recording can be done by a number of effective methods which, when used in conjunction with each other, capture all the visual details of three-dimensional rock art. These include: mapping, drawing, photography, and photogrammetry. Color photography, preferably slides, is ideal for pictographs. However, because rock carvings are a three-dimensional phenomenon, two-dimensional photography in color or black and white cannot totally or accurately record the texture or surfaces nor the depth of the carvings. For this further step, one might look to the method of depth photography called photogrammetry.

Photogrammetry is a method of recording that has been used extensively in aerial reconnaissance mapping. The process employs two cameras (stereometric cameras) on a rigid bar with parallel axes. These cameras are triggered simultaneously and the result, when viewed with a photogrammetrical plotting machine, is a three-dimensional image. Measurements taken from this "stereo model" can be used to

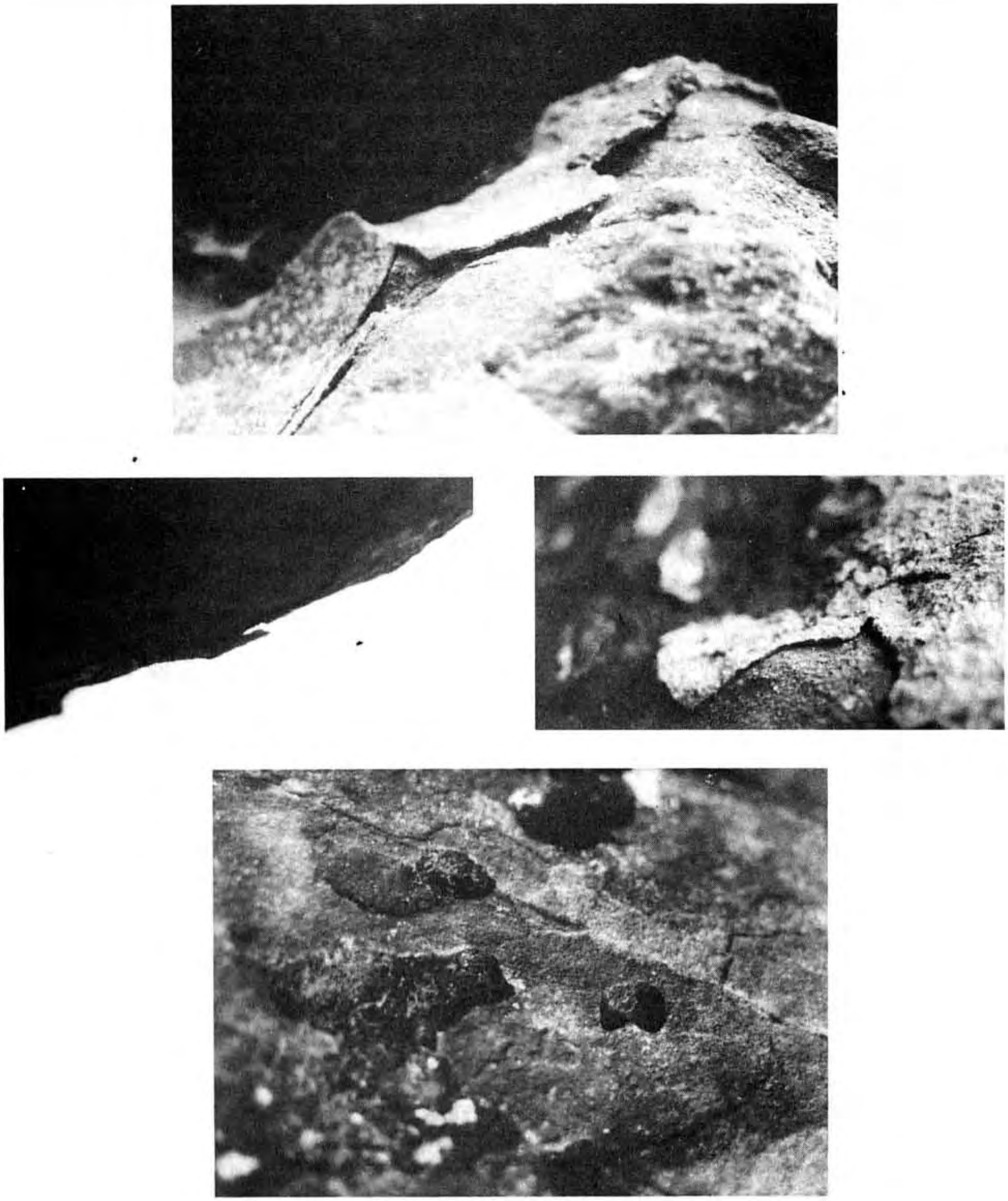

Fig. 2. Exfoliating sandstone from inside and underside of shelter at Rocky Hollow Site

reconstruct any numerical data or graphic reproduction of the original.

A set of such photographs would insure an accurate data base for future reconstructions should anything happen to the original petroglyphs. Unfortunately, the scarcity of equipment coupled with the added expense usually leaves this ideal method of recording to research institutes. For most situations, cavers should at least photograph the designs in the context of their surroundings and with a scale.

PRESERVATION AND SITE MANAGEMENT

While photography remains the most reliable method of long-term preservation of rock art, preservation of the actual sites is still a concern as natural forces are controllable to some extent. In regard to natural weathering and biological encroachment, a number of methods have been tried. It has been determined through observation that the exfoliation form of weathering is a direct result of water run-off, which is extremely difficult, if not impossible, to control. One solution is to divert the water away from the rock art. This can often be done with carefully engineered shelters, gutters, and/or drip flashings. The effect of such a structure detracts from the natural setting to a certain extent, but in the name of preservation this could be tolerated.

Some research regarding the protection of rock art from the damaging effects of water run-off focuses upon the coating of the rock surface with a synthetic high polymer substance. This procedure, however, has often proven to accelerate deterioration and exfoliation by preventing natural evaporation of subsurface moisture. Research continues on the potential of coating rock for protection. One method is to try to improve the structural integrity of sandstone by promoting the polymerization of low molecular weight monomers within the stone structure itself. This process leads to a degree of preservation with little or no change in outward appearance.

Effective biocides for lichens, algae, moss, and other micro-organisms have been extensively investigated in connection with historic buildings and monuments although not much research has been applied to petroglyph sites. The Canadian Conservation Institute reports that a solution of ortho-phenylphenol in dehydrated ethanol is an effective biocide for both crustose and foliose lichens. Other algicides under study include chelates of copper citrate and copper gluconate, quaternary ammonium compounds, and combinations of substituted phenyl ureas and triazine derivatives.

Although natural weathering forces are controllable to some extent, vandalism poses a more serious problem. Aside from closing a site, as is sometimes done with caves by gating, it is felt by conservationists that the only possible deterrent to vandals at rock art sites is to build a fence or appropriate protective enclosure. One consideration when planning an enclosure is the degree to which it will interfere with the integrity of the site in its natural setting. This is a difficult decision to make, especially if management wishes the rock art to continue to be visible. But when the cost of the natural setting means the loss of the rock art, conservationists agree that protection comes first. The determination of the size and extent of such protection is the task of the cultural resource manager, if the site has one. If the site is privately owned, then the landowner should be encouraged to protect it.

When sites are located in Federal or state parks, an effective addition to enclosures has been the "interpretive center." Explaining the possible origins of the rock art, its informational potential, and the protection laws, is felt to be a management tactic that deters at least some would-be vandals. Interpretive messages may be in the form of singular or multi-paneled boards with photos and/or drawings covered by a protective plexiglas front. Such interpretive boards cannot usually be used, however, when sites are on private land or in remote wilderness areas.

CONCLUSION

The prognosis for rock art sites in Missouri as well as other states in the Eastern Woodlands is unfortunately negative. Conditions for survival are far from favorable in view of the long-term effects of weathering, acid rain, biological encroachment, and the various forms of vandalism. There is increasing awareness and interest on the part of conservationists, however, and some slow progress is being made towards preservation, at least for the visual information contained within the remaining sites.

None of the methods listed above as possible avenues of preservation is adequate individually, but in combination they can serve to help save what is left of this irreplaceable cultural resource. The products resulting from these recording methods have the additional advantage of outlasting the original. The cultural resource manager for the site, the caver, or researcher should discuss with the landowner, management bureau, and/or local professional archaeologist, further steps to preserve each cave and shelter's prehistoric rock art resources.

At present a double-edged sword is destroying these irreplaceable treasures of the past through both human and natural forces. It is important that all who work with caves -- cavers, geologists, biologists, hydrologists, archaeologists, engineers -- be alerted to cultural remains not just on the floors of caves but on the walls of caves and shelters, and at least report them to their state's historic preservation officer or to the anthropology department of the nearest university. The first and most important step toward preservation of cave and rock shelter petroglyphs and pictographs is to find them. Then they can be recorded, and plans can be formulated to protect them for future generations to enjoy and to study.

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THE LOOTING OF A CHEROKEE BURIAL CAVE: THE LAKE HOLE ARPA CASE

CHEROKEE NATIONAL FOREST

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ABSTRACT

The Lake Hole ARPA case began on March 26, 1990 when the Forest Archaeologist was informed by forest personnel on the Wataiga R.D. of the Cherokee National Forest that an unrecorded cave containing human remains, and apparently in the process of being looted, had been discovered by Roby Phillippi, a Forest Service technician in that district. Quentin Bass and Norman Jefferson met Forest Service Special Agent Jerry Wilson and other Forest Service law enforcement officers at the cave that afternoon. Preliminary investigation indicated that the cave was a burial tomb for multiple Indian burials, that it was in the process of being looted by graverobbers, and that the perpetrators would be back to continue their activities. It was decided to place the cave under 24-hour surveillance in an effort to apprehend those responsible for the vandalism.

On the evening of March 29 Forest Service LEO's and Special Agents arrested three individuals inside the cave with digging equipment. They were: Robert Mains, 36, of Mountain City, Tennessee; Allen Lee Huddler, 27, of Abingdon, Virginia; and Freddie Caudill, 36, of Abingdon, Virginia. All individuals subsequently gave the Forest Service permission to search their houses for evidence. This resulted in the seizure of extensive collections of Native American burial artifacts, numerous parts of protected and threatened and endangered species (American Bald Eagle, Great Horned Owl, Red-Shouldered Hawk, Bengal Tiger/African Lion parts) and parts of numerous Black Bears, as well as drug (marijuana) paraphernalia. Additionally, a bag containing approximately 1/4 pound of marijuana was retrieved from the cave. Mains, Huddler and Caudill were arraigned at Federal District Court in Greeneville, Tennessee on March 30 and released on $5000 bond. It took the Forest Archaeologists in excess of two weeks to number, catalogue and photograph the exhibits seized from their houses. During the interim, Mains, Huddler and Caudill plea bargained with Guy Blackwell and Sara Shults, Assistant United States Attorneys for the Eastern District of Tennessee who were handling the case. Mains plead guilty to felony violation of ARPA (Archaeological Resource Protection Act) and Huddler and Caudill plead guilty to misdemeanor violation of ARPA. Both their pleas and sentences were to be contingent on their future help in apprehending other perpetrators, for it was becoming evident at that point, with further investigations by Special Agents Wilson and Jowers, that other individuals were involved in looting the cave.

Simultaneous with this, further investigations were carried out at the cave to gather additional evidence, determine the cultural affiliation of the burials, and formulate a damage assessment estimate for purposes of prosecution and resource management/restoration. First, a steel gate was installed over the mouth of the cave to secure it. The cave was then formally mapped in detail and a final damage assessment was made. A final minimal damage assessment of $91,000 was submitted to the United States Attorneys.

Further investigation of the cave resulted in the recovery of parts of a minimum of 13 individuals, primarily adult males, but also including at least one child and probably one female. Recovered artifact remains indicated at least one child and probably one female. Recovered artifact remains indicated the individuals were adorned with elaborate grave paraphernalia which included: marine shell ornaments, pottery, stone tools and copper and iron trade artifacts. These artifacts allowed the Forest Service to determine with confidence that the burials were Cherokee of the protohistoric period (A.D. 1550-1650). This Cherokee affiliation made the cave a cultural resource of extraordinary significance because, up to this point, there has been no evidence, either archaeological or in the written literature, that the Cherokee ever buried their dead in caves; burial in and around the village being the common known form of inhumation. The cave therefore preserved an aspect of Cherokee lifeways about which we were heretofore totally ignorant. As a consequence, its destruction was not simply a case of graverobbing and an offense to all human sensibilities, which it indeed was, but also a clear-cut case of the destruction and theft of part of the cultural heritage of the people of the United States; a part of our cultural heritage which is, as is the case with all archaeological sites, not only non-renewable, but one for the loss of which, and the crime committed, was even greater since this type of site had been previously unrecorded.

Concomitant with these investigations at the cave, Forest Service Special Agent Jerry Wilson continued to follow leads and interview concerned parties. During this period, Robert Mains was contacted by a Newall Charlton of Elizabethton, TN, who wanted to sell Indian artifacts to Mains. Mains contacted Jerry Wilson about this and Wilson convinced Mains to wear a hidden recording device in order to tape any artifact purchase and any other conversation relevant to the Lake Hole ARPA case. Although no artifacts were purchased, tape recordings were made on two occasions. These not only provided evidence which implicated Charlton, but also a number of other individuals in the vandalism of the cave.

Concurrent with this, Special Agents Wilson and Malcolm Jowers, following information supplied by informants, interviewed Eddy Ray Perry, 41, of Butler, TN, about his participation in the looting of the cave. After intense questioning by Wilson and Jowers, Perry confessed that he and his two cousins, Montie Pierce, 42, and Johnny Pierce, 38, also of Butler, had participated in looting the cave along with Newall Charlton, 62, Mike Honeycutt, 47, Hampton, TN and Ralph Potter, 43, Roan Mtn., TN.

This combined evidence was given to Guy Blackwell and Sarah Shults who took it before the Federal Grand Jury in Greeneville. The Grand Jury returned a sealed true bill of indictment charging all six individuals with felony violation of ARPA, felony theft of Federal property and felony depredation of Federal property. On 6 June, 1990, all six individuals were arrested and arraigned before Federal Judge Thomas Hull at Federal Court in Greeneville, Tennessee and released on $5,000 bond. Soon after this, Eddy Perry and the Pierce brothers plea bargained and plead guilty to felony ARPA. As with Mains, Huddler and Caudill, the severity of their sentences was contingent upon their cooperation in the prosecution of Honeycutt, Potter and Charlton.

At the time of his arrest, Forest Service Special Agents and LEO's requested permission from Potter to search his house for Indian artifacts which could be related to the case. Potter gave his permission for the search, but no artifacts of consequence were recovered. However, a total of 18 firearms were recovered from the residence. Since Potter had prior felony convictions (attempted murder, felony assault and battery on two Carter County, Tennessee deputies, etc.) it was a felony for him to possess firearms. Consequently, Potter was also charged on the weapons violation.

The ensuing period before trial was taken up with management of the cave site and the case with other agencies and institutions. This included a series of meetings, communications and reports within the Forest Service, especially with the Regional Office in Atlanta which supplied funding to support the handling of the case on the forest level, regional level law enforcement and cultural resource personnel support, and even support from the geometronics section of the Regional Office whose personnel produced detailed 3-D mapping of the cave. Additionally, the Tennessee State Historic Preservation Officer was apprised of the progress of the case, as required by Federal laws and regulations. As is the policy of Region 8 (Southeastern U.S.), every forest has an Advisory Committee for the

Treatment of Human Remains. The committee was consulted to determine the disposition of the human remains and future management of the site. In line with Federal regulations, the committee recommended the damaged areas of the site should be scientifically excavated, the recovered materials analyzed and the human remains reinterred; the mode of reinterment to be decided upon the by the Tennessee Commission of Indian Affairs and the Tribal Council of the Eastern Band of Cherokee, Cherokee, North Carolina. Since the burials were determined to be Cherokee, Harley Grant of the Tennessee Commission of Indian Affairs deferred to the wishes of the Cherokee. So, future disposition of the human remains from the cave will be determined by the Cherokee in conjunction with the Forest Service.

Between June and September trial was postponed twice. During this period, considerable further effort was spent in preparation of the case for the government. This included the additional compilation of evidence, further investigation of informants, additional investigation of the cave, finalization of the damage assessment and evidence charts and maps and a continuous, close coordination with the Assistant United States Attorney and the Eastern Band of Cherokee Indians.

Finally, Guy Blackwell severed for trial Charlton, Honeycutt and Potter for separate trials, starting with Charlton on October 9, 1990. The entire case became even more complex at the outset of the Charlton trial. First, as soon as the jury was seated, Mike Honeycutt's father, Paul Honeycutt, 67, of Elizabethton, Tennessee, approached one of the jurors and attempted to persuade him not to find Charlton guilty; his reasoning being that if Charlton was found innocent then his son stood less of a chance of being convicted when he went to trial the following week. The juror, frightened by Paul Honeycutt's action, reported the contact to Judge Hull. As a consequence, both Mike Honeycutt and Paul Honeycutt were arraigned before Judge Hull who ordered both detained until after the conclusion of the Charlton trial. Paul Honeycutt was subsequently charged with felony jury tampering and felony obstruction of justice.

Simultaneous with all of this, Ralph Potter failed to appear for a hearing on the felony weapons charge. A warrant was issued for his arrest, but he could not be located. In subsequent contacts with reliable sources, Forest Service Special Agents learned Potter had threatened Perry and one or more of the Pierce brothers. Potter then appeared at the courthouse the following morning in the company of Perry and the Pierces who were going to testify for the prosecution. His supposed intent was to intimidate all three witnesses from the gallery. Potter was immediately arrested and detained by U.S. Marshals. In a detention hearing the following morning, testimony of Potter's putative threats and coercive behavior were submitted to Judge Tilson. Other supporting evidence was also submitted, including: testimony from a Tennessee Drug Enforcement Task Force agent who stated that Potter had publicly said he intended to kill him (the agent); Potter's previous convictions for violent felonies; and Potter's position as a primary suspect in at least one unsolved murder. After reviewing this evidence, Judge Tilson ordered Potter detained in jail until after the conclusion of the Charlton trial.

The Charlton trial continued well into the next week, being postponed from the previous week due to the lack of preparation on the part of the defense attorney. When the trial did resume, testimony against Charlton included reading of the two damaging secret tape recordings; the testimony of Robert Mains, Eddy Perry and Montie Pierce; and the testimony of many of the Forest Service employees involved in the case. Testimony for the defense was limited to Dr. William Bass, Forensic Anthropologist and Head of the Anthropology Department at the University of Tennessee, who was employed in an unsuccessful effort by the defense to diminish both the archaeological significance of the site and government's damage assessment. Charlton did not take the stand in his defense. The trial was concluded on the afternoon of October 18 and the jury returned a verdict within two hours. Charlton was found guilty on all three felony counts. Sentencing was set for December 18.

Over the following weekend, Guy Blackwell corresponded with the Justice Department and obtained immunity from prosecution for Charlton from any other charges in the case and associated crimes from which he had not yet been tried (it being known that he had a long history of vandalizing archaeological sites and looting graves, especially on U.S. TVA property). The grant of immunity, coupled with his recent convictions, which lost Charlton his 5th Amendment right not to testify in the future trials, made Charlton a potentially powerful witness for the prosecution for the upcoming Honeycutt and Potter trials. In effect, he was now required to testify as to the involvement of Honeycutt and Potter, for any reluctance to cooperate would result in contempt of court charges, while any prevarications could result in perjury charges.

The following week, preliminary to the Honeycutt trial, Charltons condition of immunity was filed in court before Judge Hull. The lawyers for Honeycutt and Potter were present, and minutes after Charlton's immunity status was registered with the court, they requested a plea bargain - Honeycutt wishing to plead guilty to misdemeanor violation of ARPA and Potter wishing to plead guilty to misdemeanor violation of ARPA and the felony weapons charge. Guy Blackwell and Sarah Shults discussed the offer with us (Special Agents Malcolm Jowers and Jerry Wilson and myself) and suggested we accept the pleas. Although we all knew Honeycutt could be convicted on at least two felony counts (felony violation of ARPA and felony destruction of government property) we all agreed the pleas should be accepted. This was because subsequent to the Charlton conviction, investigation by Special Agent Wilson had unearthed hard evidence that Perry and the Pierce brothers had lied to the government as to their involvement in looting the cave - their actual involvement being much more than they were willing to admit. We had known this all along, but now that we had hard evidence of their deceit we had to transmit this evidence to the defense attorneys. Perry and the Pierces lying in no way reduced the culpability of Charlton or the remaining defendants, but proof that they were liars damaged the credibility as witnesses and the government's case against Honeycutt and Potter. As a consequence of this, the defendants' pleas were accepted and sentencing was set for December 18 along with that of Charlton.

On November 1 I went before the Tribal Council of the Eastern Band of Cherokee Indians in Cherokee, North Carolina. I apprised the Council of the history and course of the Lake Hoe ARPA case, and asked for their input in management of the site and reburial of the remains. Additionally, I requested their presence and input at the upcoming sentencing hearings. The Council expressed their appreciation for the government's efforts and agreed to attend the sentencings and testify if called upon. The Council also passed a resolution which expressed the Cherokee feelings regarding the Lake Hole ARPA case.

On November 7 Mains, Caudill and Huddler were sentenced. Mains (felony ARPA) was put on supervised probation for two years and banned from the forest for the same period. He was also fined $795.62 (the average cost of scientifically excavating and analyzing a cubic yard of fill in an archaeological site. Huddler and Caudill (misdemeanor ARPA) were given three and two years probation, respectively, also banned from the forest during this period and fined $499. No restitution costs were placed on any of the three.

On November 28 Perry and the two Pierce brothers were sentenced (all felony ARPA). All were given six months imprisonment, three years supervised probation, banned from the forest for that period, required to perform 300 hours of community service and required to pay $3000 each in restitution. No fines were levied since all defendants declared themselves <u>in pauperis</u>.

On December 18 Charlton, Honeycutt and Potter were sentenced. All were ordered to pay a fine of $499 and restitution of $2500. Honeycutt was placed on supervised probation for five years and banned from the forest for that period. Potter was given 6 months imprisonment for the misdemeanor ARPA violation and 16 months imprisonment for the felony weapons violation, both sentences to run concurrently. His probationary period will be determined after his release from prison. Charlton was given 22 months imprisonment and a probationary period to be determined upon his release.

In February 1991 Paul Honeycutt was sentenced to two years supervised probation and fined $5319.84 for jury tampering and felony obstruction of justice. Since he is in ill health, the U.S. Attorneys asked for a downward departure in his sentencing.

The Lake Hole ARPA case is remarkable for several reasons. It is important because it is the first trial felony conviction for an ARPA violation outside the Southwest U.S. It is also noteworthy because of the number of convictions and the number of defendants - 10 felony and 4 misdemeanor criminal convictions and all ten defendants were found guilty. The case was an education for all parties concerned and clear evidence that the Forest Service, the Justice Department, the Cherokee and the greater American public wish to preserve and protect their cultural resources. The entire process also made it abundantly clear to all of us that an ARPA case cannot be successfully prosecuted without the close cooperation of the United States Attorney and Forest Service personnel.

Excavation of the damaged areas of the cave are planned for the Spring/Summer of 1991. After analysis, the human remains will be reburied in the cave by a traditional Cherokee medicine man. I asked the Cherokee Tribal Council if I could attend the ceremony and they have given their permission.

THE PROBLEMS OF OWNING AN ARCHEOLOGICAL SITE: AN EXAMPLE FROM SAVAGE CAVE

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ABSTRACT

In the early 1980s, Murray State University obtained the Genevieve Savage Cave from the Archeological Conservancy. The cave, located in Logan county, Kentucky, had been known by cavers and archaeologists for several decades. Murray State's purposes for acquiring the cave were primarily preservation and study. This paper reviews the history of Savage Cave, its scientific significance, and what has happened to the site since becoming a part of Murray State University.

INTRODUCTION

Savage Cave, 15Loll, formerly called Cook's Cave, is located in Logan county, Kentucky, about 1 1/2 miles east of Adairville. Total mapped cave passage measures approximately 3 and 1/2 miles in length. Murray State University acquired Savage Cave from the Archeological Conservancy of Sante Fe, New Mexico in 1982. The Conservancy had previously purchased five acres of land containing the cave from the late Mrs. Genevieve Savage. Murray State University's purpose for obtaining the cave from the Conservancy was three fold: Murray State University's newly formed archeological program was looking for a long-term archeological project. Savage Cave was a nationally-significant and somewhat controversial archeological site that seemed to fit the bill nicely and held promise for quickly developing the archeological program at MSU. Secondly, the MSU administration was interested in acquiring Savage Cave because of its location. The site was in the backyard of our sister institution, Western Kentucky University, and a recruiting war existed between the two schools. An active archeological program at Savage Cave could prove very beneficial to Murray State University's recruiting future, or so felt Dr. Constantine Curris, then President of Murray State University. Lastly, Murray State University wished to partially maintain the site as an archeological preserve. Mrs. Savage was of ill-health, and it was conceivable that the site might fall into unscrupulous hands after Mrs. Savage's death. MSU, wishing to acquire the site but not wishing to spend any money in doing so, contacted the Archeological Conservancy, a newly formed organization that purchased nationally-significant archeological sites and turned them over to universities for curation and preservation. Such was the case with Savage Cave. Upon approval of Murray State University's Savage Cave Management Plan by the Conservancy, and the transfer of $2,000 from MSU's Foundation to the Conservancy--(the money had been donated by the Russellville, Kentucky, Rockwell International plant)--, the Archeological Conservancy deeded five acres of land including the cave entrance to Murray State University in 1982. The Savage Cave site was the first prehistoric site to be purposefully purchased by a university in Kentucky. It was also the first and only archeological cave site to be purchased by the conservancy. Because of the apparent scientific significance of Savage Cave's archeological deposits (felt by some to be the oldest and most complete in the New World), it was believed that the Savage Cave site should serve as a model for site preservation and management. Showing all the promise of best laid plans, Murray State University embarked on its program of research and preservation.

MSU'S HISTORY WITH SAVAGE CAVE

The initial thrust of Murray State University's archeological activity at Savage Cave, beginning in 1982, included obtaining copies of all published and unpublished reports pertaining to the site, obtaining a surface study collection from the site, reexamining the stratigraphic wall profiles in James Cambron's excavation units from the late 1960s (Cambron 1974), collecting an oral history of the site from Mrs. Savage, enacting the Savage Cave Management Plan which included pulling together a board of directors for the Savage Cave Management committee, and obtaining a series of radiocarbon assays from materials excavated during the mid-1960s by Don Dragoo of the Carnegie Institute.

This work was both preliminary and necessary. The administration of owning an archeological site and administering who could or could not make use of this research resource were instrumental to the success of a long term study program. Selecting just the right members for the Savage Cave Management board of directors included individuals who were believed to be both influential and interested, including a local manufacturing president, Mrs. Savage, a university vice president and dean, a state archeologist, and an archeologist from Murray State. These individuals would guide and direct the use of Savage Cave in accordance with the Savage Cave Management Plan approved by the Archeological Conservancy. Chairman of the Savage Cave Management Board of Directors was the dean of the College of Humanistic Studies at Murray State University.

In accordance with the Savage Cave Management Plan, no new archeological field work could be conducted at the site until the immensely large backlog of unpublished Carnegie field notes and artifacts had been studied and published (Carstens 1982). After all, the Savage Cave archeological site was considered to be one of the most significant sites in North America. It was deemed better to 'clean the closets' in order to understand that which had already been done, before adding to the accumulation of unpublished data. Furthermore, understanding what had been previously accomplished would further guide future work at this extremely important site. Therefore, the amount of actual archeological work that could be accomplished during the initial years at the site would be limited to studying wall profiles--which was done in the fall of 1981 (Carstens 1981), submitting a series six radiocarbon samples from contexts excavated by the Carnegie Museum (Lawrence 1985:3135), collecting a representative artifact collection from the site's surface, and mapping the sink/Vestibule area of the site. Lastly, the initial study also called for obtaining an oral history of the site from Mrs. Savage based upon her knowledge of past archeological projects at the site (Carstens 1980: 25). Unfortunately, Mrs. Savage died in March of 1983 before the oral history part of the project could be completed.

Following Mrs. Savage's death, Murray State University attempted to secure funds to purchase Mrs. Savage's house, which would be used as a housing-research facility similar to the Austin House at Flint Ridge in Mammoth Cave National Park. Unfortunately, funds were not secured with which to buy the house, and Murray State would be faced with an unforeseeable problem: who would watch the site in Murray State's absence now that Genevieve Savage was no longer living. For a short period of time, the problem was solved by Mrs. Savage's daughter who moved into Genevieve's house. Following a small fire in the home's miniature museum, Genevieve's daughter moved back to Russellville, Kentucky, leaving the house vacant and again for sale. Eventually, Jim Wilkerson from Odum Sausage in Adairville stepped forward and purchased the house. Wilkerson, who sat on the Savage Cave Management board of directors, allowed Murray State University to find a tenant who would take care of the property and also watch the cave. Unfortunately, the tenant did neither. Indeed, for more than a year, the university had great difficulty collecting monthly rent, and it was also at this time that the first of many break-ins at Savage Cave began to occur. Eventually, the tenant family would be evicted, but it would be another seven years before someone would move into Genevieve's log cabin home. Unforseen changes were beginning to occur and the one-time rosy outlook for Savage Cave was beginning to fade.

All was not well at Murray State University either. The president of the university, Constantine Curris, had been fired and the new administration did not maintain the same enthusiasm for the Savage Cave property as had Curris. Indeed, their was a general movement afoot to divorce one's self from anything which had taken place during the previous administration. To make matters worse, the chairman of the Savage Cave Management board of directors was not pleased with his new role as rent collector. All of a sudden, it seemed as though the positive thrust that initially pushed the Savage Cave project to the forefront was now changing gears and priorities. To the new administration (and to those that survived the ousting of the old), Savage Cave was no longer an important project, and promises of monetary support for long distance research projects were no longer made available.

Meanwhile, sheltered in the corners of the archeology lab, the Savage Cave archeological project pushed forward as planned. Joining the small program was Pam Schenian, an ABD-level archeologist from Northwestern University looking for a Ph.D. dissertation topic. Savage Cave, she felt, was ideally suited for her work and research interests. Schenian embarked on an impressive campaign to locate and obtain all prehistoric cultural materials previously excavated at Savage Cave, as well as all published and unpublished field notes, reports and photographic records from the site (Schenian 1984, 1985a, b, 1986). Schenian's research soon revealed that people from California to Pennsylvania and from New York to Florida had worked at Savage Cave, but few had left written documentation of their work. Through her efforts, however, Schenian was able to piece together a rather thorough site history that had not been previously known. Her work with the site collections, now numbering well past 25,000 artifacts, also began to take meaningful shape, and it appeared that the Savage Cave project was about to be reborn. Unfortunately, Schenian's thesis advisor advised against using the Savage Cave data base for her dissertation as it was becoming evident that the context for many of the artifacts was questionable and problematic.

Site vandalism was also increasing. Concerned reports about site looting from caving friends, Preston and Sherry Forsythe, prompted Murray State to design an environmentally-sound cave gate that would permit cave animals to enter and exit the cave system freely, allow the cave to breath, and attempt to keep vandals out of Murray State's cave entrance. The gate was constructed, and a large sign detailing pertinent laws was posted immediately above the cave gate entrance.

To no avail, however. Vandalism at the site seemed to increase. Each biannual visit to the site demonstrated that some other approach for protecting the site had to be found. During the summer of 1987, Carstens gave a series of public lectures to the Russellville and Adairville communities, and several articles were run in local newspapers as an attempt to educate the public and to invoke the public's assistance at helping preserve the site. Daytime and night-time watchmen from Odum Sausage were supposed to check Savage Cave on their daily rounds. Unfortunately, no looters were ever caught, and it is doubtful that the watchman ever made the mile trip to the cave site. Carstens also met with several detectives from the Bowling Green State Police post, the Logan County sheriff's office, and the local county coroner in an attempt to educate the law enforcement agencies about antiquity laws, and to invoke their powers to control vandalism occurring at the site. None of the law enforcement agencies were familiar with the antiquity or coroner,s laws, so copies of each were provided to the state police, sheriff, and coroner. Again, however, to no avail. Site looting and vandalism continued to occur. And little to no assistance came from the law enforcement agencies.

On January 22, 1988, Pam Schenian and I met at the site with Philip Di Blasi, then president of the Kentucky Organization of Professional Archaeologists, Dr. R. Berle Clay, the State Archeologist of Kentucky, two Kentucky State Police Officers, and the Logan County Coroner to again assess the amount of recent vandalism at the site, collect physical evidence from the vandalism, re-educate the law enforcement officers about various antiquity and coroner laws, and devise a plan of protection for the site.

As we will hear in Jan Hemberger's paper, there are many different laws that protect archeological sites, and laws that also prohibit vandalizing caves and graves. But, laws are only as good as are the enforcement systems. Both the Bowling Green State Police Post and the Logan County Sheriff's office know that Murray State University will prosecute any vandal caught looting the Savage Cave site. Unfortunately, at any given time, there are only two state troopers assigned to Logan County. The State Police have flatly stated that they can not protect the site. The Logan County Sheriff's office has similar logistical concerns. As a result, the two chief offices capable of catching site vandals are simply, too busy, and Savage Cave is not a high priority to them. It is understandable that there is an obvious logistical problem. But also at work is an unwilling effort by the law enforcement agencies in Kentucky to make a commitment to catching antiquity and cave violators. Breaking antiquity and cave laws are simply not considered to be serious crimes in Kentucky, despite the passage of new antiquity and cave laws that carry felony and misdemeanor charges, respectively (K.R.S. 164.990, 1988; K.R.S. 433.885, 1988). And, unfortunately, the courts in Kentucky have agreed with that sentiment. As an example, note the vandalism at Sinking Springs Cave in Simpson County where the judge simply made the vandal promise not to dig in that county, or the more famous Slack Farm case in Union county, Kentucky, where 10 men paid $10,000 to a farmer to mine a prehistoric site on the farmer's property; the vandals were caught and charged, but the case was dismissed despite public outcries and extensive press and media coverage.

This past summer, I received a phone call from a concerned citizen who had heard that Savage Cave was about to be visited by vandals again. Permission was sought from the Office of the President at MSU to proceed with a plan to catch the looters. Following the newly prescribed echelon of command at MSU, I informed the director of campus security with respect to the situation, the university's willingness to prosecute, and which laws might possibly be violated (including felony charges now associated with the new State antiquity laws). The director thanked me, and promised he would contact the State Police post at Bowling Green so that the vandals would be apprehended in the act of the felony. Unfortunately, the relay between the desk sergeant and the new rookie trooper in Bowling Green left much to be desired. Instead of waiting at the cave for the vandals to arrive, the trooper drove to Genevieve's house and informed the new home owners to call the police if they saw anyone in the cave that weekend (I might add, you can not see the cave entrance from Genevieve's house). As a result, and not surprisingly, no vandals were reported and none were caught. This was the first time a tip foreshadowing site vandalism was made known, but nothing came to fruition because the case was not handled seriously or professionally.

In a subsequent conversation with the citizen who reported the intended vandalism, I was informed that the vandals were probably coming from Tennessee, and that they parked their cars in back of an old church about one-half mile from the site (he had observed their cars parked there previously). If the vandals were indeed coming from Tennessee, then the Federal ARPA laws (Archeological Resource Protection Act), would apply. Until recently, ARPA laws had much greater strength than did various state laws; more importantly, the federal courts have upheld ARPA convictions and have levied prison time, fines, and loss of equipment judgements against convicted vandals. As a result, an FBI agent from the Bowling Green post was contacted and federal investigations are currently underway at Savage Cave.

CONCLUSION

It would appear that the best solution to catching the Savage Cave vandals, and therefore protecting the significant archeological deposits at the site, will include some form of neighborhood watch program, in conjunction with both federal and state law enforcement officers. Also important will be increased visibility at the site by Murray State and other university research teams.

It has been said that archeology exists for the public good. If, however, that prehistory is going to be studied by the professional archeologist for the good of the public, then the public must be involved to help protect these very fragile, and non-renewable cultural resources. Site protection programs, similar to neighborhood watches, must be utilized to help protect sites that are in out-of-the-way locations, like Savage Cave.

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PREHISTORIC GRAFFITI AND SELF-EXPRESSION: EXAMPLES FROM THE CENTRAL KENTUCKY KARST

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ABSTRACT

Several examples of supposed aboriginal art found deep within caves are discussed. These include newly discovered examples of drawings in mud as well as drawings made with cane torches. A drawing discovered in the mid-1970s is reexamined in light of the recent discoveries. Arguments are presented in support of the aboriginal source of this art.

INTRODUCTION

In 1979 a recreational caver exploring a cave in east Tennessee found a series of drawings which were immediately recognized as prehistoric mud art. This discovery eventually led to the site's examination by a team of investigators from the University of Tennessee at Knoxville and to the description of a previously unknown Mississippian body of art (Faulkner, Deane, and Earnest 1984:350-361). Eight radiocarbon determinations from inside the passage date from 465 A.D. until 1605 A.D. However, "it is believed that the intensive utilization of Mud Glyph Cave occurred during the Mississippian Period, especially around the thirteenth to fourteenth centuries A.D." (Faulkner, Deane, and Earnest 1984:358). Several other caves and rockshelters containing petroglyphs have been described by Faulkner and others which have been ascribed to the Mississippian period (Faulkner 1986).

A tradition of Mississippian art and motifs has been identified. However, it has been known that the prehistoric use of caves in Tennessee and Kentucky dates to the Terminal Archaic/Early Woodland period. Until recently, there has been no art found within caves which clearly date to this early use of caves. Two discoveries have located both mud and cane torch drawings which appear to date to this earlier period.

The first discovery occurred in May 1986, while University of Louisville students were participating in a recreational caving event known as Speleofest in central Kentucky. During one of the cave trips they happened upon an upper-level passage measuring approximately 150 m long and 4 m wide, with a mud-covered floor. They reported the floor as covered with incised geometric drawings. In 1987, as a Western Kentucky University class was being shown Salts Cave in Mammoth Cave National Park, another set of drawings was discovered. This example was drawn with cane torches on a large slab of ceiling breakdown. Examination of these two examples of prehistoric art shows that they have several motifs in common, yet they differ significantly from the Mississippian motifs described by Faulkner and others. This paper argues for an earlier tradition of art in caves, dating to the Terminal Archaic/Early Woodland use of caves.

THE MISSISSIPPIAN MOTIFS

Mud Glyph Cave in Tennessee presents a situation in which numerous Mississippian motifs can be identified. These motifs include anthropomorphic, herptomorphic, geometric, "Southern Cult," and animals (primarily birds) (Muller 1986:36-80). Anthropomorphic examples include representations of the human form which range from complete individuals to recognizable body parts. Most frequently, the body part represented is the face and head. Many of the faces include the Eastern Woodlands "Weeping Eye" motif. One individual appears to represent a "bird man" (Muller 1984:51-56). The herptomorphic representations cover several meters and have circles or diamonds for eyes. Several of the serpents have possible wings and apparent bird heads (Muller 1984:56-59). One of the drawings consists of a "horned serpent" which is represented by a zig-zag line, with a circle for a head and upturned horns (Muller 1986:50, Plate VII b). Yet another represents a turtle drawn by altering a bare human footprint. The posterior portion of the footprint (depression formed by the heel) was altered by adding several incised lines--one encircling the depression (forming the carapace) and others which make up the extremities, tail, and head. The anterior portion of the footprint (ball of the foot and toes) was altered by the addition of incised lines to form an anthropomorphic face or "human mask" (Faulkner 1984:354, 355, Figure 4). Geometric motifs include circle, inverted "V," diamond or rhomboid, and ogee. Also noted are simple arcs of curved lines and cross-circles. The "Southern Cult" motifs present include the weeping eye, the bilobed arrow, and maces (Muller 1984:60-62). The animal motifs include the owl, hawk, woodpecker, and a possible opossum (Muller 1984:62-64). Several herptomorphic motifs appear in Mud Glyph Cave.

Abstract designs were also found in Mud Glyph Cave in Tennessee. One such design consisted of "meanders and macaroni drawn with the fingers" (Faulkner, Deane, and Earnest 1984:353). Cross-hatching and latticework designs found were usually components of larger units such as animal or human figures (Faulkner, Deane, and Earnest 1984:353).

B. Bart Henson (Henson 1986:81-108) describes three sites in the Eastern United States where herptomorphic glyphs are associated with Mississippian motifs. Site 11, Jackson County, Alabama, has a horned snake as well as a spiral and rectangle (Henson 1986:98). Site 16, Franklin County, Alabama, has a turtle, anthropomorphic, and other zoomorphic designs "painted in black" (Henson 1986:101). Site 30, Washington County, Missouri, has a snake, other zoomorphic designs, as well as spirals, a mace, and bilobed arrows (Henson 1986:106). All of these sites are either rock outcrops or rockshelters, and there are no radiometric determinations.

Officer Cave and Devil Step Hollow Cave, both in Tennessee, contain anthropomorphic petroglyphs which are similar to the glyphs of Mud Glyph Cave in Tennessee (Willey, Crothers, and Faulkner 1988:55). Notable details are the weeping-eye motif and the "toothed mask" (Willey, Crothers, and Faulkner 1988:55). Radiometric determinations for Devil Step Hollow Cave of 920 and 1330 A.D. support the contention that these petroglyphs are Mississippian.

One of the most distinguishing characteristics of the Mississippian Period art described by Faulkner and others is the naturalistic and realistically drawn figures, particularly when compared to the glyphs found in central Kentucky. Additionally, many of the motifs can be found on Mississippian ceramic, copper, and shell art.

THE TERMINAL ARCHAIC/EARLY WOODLAND MOTIFS

Presently, three caves are known in the central Kentucky karst which contain glyphs--Adair Glyph Cave, Mammoth Cave, and Salts Cave. The latter two contain glyphs drawn in charcoal from burnt cane torches, and the former glyphs are incised on the mud floor of a passage. As in the glyphs described by Faulkner, there are distinct stylistic similarities among the three sets of drawings; however, these differ from those described from Tennessee.

The glyphs found in Adair Glyph Cave consist of geometric patterns, primarily zig-zags, chevrons, and cross-hatching, and are over 1 km from the entrance. These drawings are incised, at a large scale, in the damp mud of the floor. Preliminary examination of the passage indicates that the drawings do not overlap. Close visual examination indicates that the incising was carried out with a pointed or sharp-edged object, such as a stick, small fragment of breakdown, or the edge of a freshwater mussel. In fact, a freshwater mussel was found near the entrance to the passage. The beak of this mussel appears worn, as though it had been used to draw in the stiff mud. The glyphs appear to be executed with some care, they do not overlap, and the individual elements are fairly symmetrical.

Since only two trips have been made into the passage, to examine the photograph and glyphs as well as gather charcoal for radiometric determinations, it is unclear if there is an overall pattern to the drawings. Plans are presently being made for complete photodocumentation of the floor and the production of a cave map.

The zig-zags appear to be one of the more common motifs present. Each zig-zag is composed of parallel lines, which are usually spaced 2 or 3 cm apart. The zig-zags occur in single and paired examples. The paired examples are very symmetrical, appearing as mirror images. Another form of zig-zag appears as a series of single lines which overlap each other, forming a series of diamonds. Several of the zig-zags are connected at the top, forming a pattern very similar to a simple "Christmas tree-like" design. The sizes range from approximately ½ m to well over 1 m in length and 20 to 30 cm in width. Frequently, the zig-zags are found in rows paralleling one another.

The second most common motif is cross-hatching. The cross-hatching or grids are typically large and usually square, or nearly so, in the area they cover. These grids do not appear to be as carefully drawn as the zig-zags. The spacing of the individual lines is somewhat uniform, but the lines end in a rather ragged fashion. Areas of cross-hatching observed range from circa 50 cm to over 1 m^2.

Two chevrons were observed. These are in close association to one another and are approximately 1.5 m long and 50 to 70 cm wide. They taper abruptly from one end to the other.

All of the glyphs incised in the mud of the floor of Adair Glyph Cave are patinated. The modern traffic through the passage has broken the patination and can be readily differentiated from the drawings. A single charcoal sample has been dated from the passage. The sample was collected from a small area and is composed of ash from the cane torches used to illuminate the passage aboriginally. The extended count date obtained on 0.45 gm of carbon was 3560 B.P. ± 110 years (Beta--16932) or 1610 B.C. ± 110 years. A second sample has been collected but has not been analyzed.

Several sets of glyphs have been identified in Salts Cave, Kentucky. The first is a series of cross-hatching situated near survey station P63, 485 m from the entrance. The second is 841 m from the entrance, situated approximately half way between stations P50 and P53 (Watson 1969:Figure 3).

In the area of P63 on the side of a ledge is a carbide sooted "f-s" or "x-s" with an arrow pointing downslope. To the left of the modern notation is an area of cross-hatching drawn with a cane torch. The cross-hatching covers an area 20 cm high and 70 cm wide. It appears to represent three different events, due to the different styles and sizes of cross-hatching.

The glyphs halfway between P50 and P53 are drawn with charcoal from torches and are situated on the edge of a slab which is approximately 50 cm thick and 3 m wide. There are three central zoomorphic figures. In addition to the central figures, there are numerous charcoaled "random lines" and stoke marks present. There are also several incised random lines and cross-hatched areas.

The upper figure represents a turtle, approximately 10 cm tall and 10 cm wide. The carapace is round, and all four legs are extended, as are the tail and head. The upper left portion of this figure is smudged. The upper extremities are poorly executed, being irregular in size and disproportionately large, especially the right. The lower extremities are better executed, being well proportioned and including the detail of three digits or claws on the right foot and four on the left foot. The tail is represented by an elongated triangle.

The figure on the lower left is the most distinct of the three. It is uncertain if it is actually zoomorphic or possibly anthropomorphic. It is approximately 10 cm tall and 4 cm wide. The body is short and stocky, with what appears to be a "head" situated at the top. Four short (less than 1.5 cm long) stocky (ca. 1 cm wide) appendages extend from the body. The upper left extremity has three digits or claws. A short (1 cm long) stocky (less than 1 cm wide) "tail" can be observed at the bottom of the body. Several incised curved random lines transect the "torso" of this figure, and several incised straight random lines transect the lower body, extremities, and tail. A curved charcoal line transects the head of this figure. It cannot be determined if this is a random line or an intentional part of the figure. If part of the figure, it could represent downward-curved "horns."

The lower right figure is herptomorphic, possibly representing a salamander or lizard with a set of "horns." The body is long and thin (ca. 10 cm long, including the "tail," and 1 cm wide). The thoracic region appears broader than the abdominal area. The four extremities are proportionally drawn (ca. 1 cm long and 0.5 cm wide) with no detail such as digits or claws. The head is drawn as a round shape just above the upper extremities. From the head, in a crescent shape, are two disproportionately large "horns." An incised area of cross-hatching covers this figure and extends approximately 10 cm downward and to the right. This cross-hatching has removed the charcoal, indicating it was drawn after the salamander.

There are additional "drawings" found on the face of the slab. Approximately 25 to 30 cm left of the three central figures is an area of incised cross-hatching. This cross-hatching covers an area ca. 15 cm on a side. This cross-hatching is not horizontal in orientation. Rather, the lines are at approximate 45° angles to horizontal and vertical. As with the cross-hatching, which occludes portions of the lower right figure, the margins of the cross-hatching appear "frayed." In other words, the cross-hatching is not contained within a boundary; rather, the cross lines end at different distances past the last intersection. Additionally, the lines making up cross-hatching are not quite parallel. The surface contours of the rock or the angle of the "artist's" stroke may account for these irregularities. This incised cross-hatching has been drawn over several large, roughly horizontal, charcoal lines.

Between the lower left figure and the incised cross-hatching is an area covered with broad, widely separated, charcoal lines. There are four lines from upper left to lower right and three lines from upper right to lower left. These lines are ca. 20 cm long and are irregularly spaced from ca. 1.5 to 2.0 cm apart.

Above and to the right of the lower right figure is a fourth cross-hatched area which is incised. This cross-hatched area is 10 cm by 10 cm and oriented more or less vertically.

Twenty centimeters to the right of the lower right figure is a fifth cross-hatched area. It is incised and is the most irregular of the cross-hatched areas. It is possible that it is actually a series of overlapping zig-zags. It is 15 cm tall by 15 to 20 cm wide.

To the left of the central figures is a cluster of "random lines." In this cluster of random lines, three are oriented from upper left to lower right. Additionally, there are five or six lines which originate from upper right and extend to lower left.

Recently, several cross-hatched areas have been discovered in Salts Cave, and several others have been noted by cave surveyors in the past. All have been found in areas of extensive Late Archaic/Early Woodland traffic. These cross-hatched areas appear to be near intersections of cave passages.

Materials dated in Salts Cave demonstrate that the majority of prehistoric activity occurred during the Terminal Archaic and Early Woodland periods (Benington et al. 1962, Watson 1969, Watson 1971:25, Watson 1972:50, and Watson 1972). A single date from 15Ad70 suggests a similar temporal association (DiBlasi 1986a, DiBlasi 1986b).

Pat Watson (Watson, personal communication) indicates cross-hatching has been found in association with bare human footprints in Fisher Ridge Cave. Radiocarbon determinations reveal that prehistoric peoples were in this cave circa 800 B.C. ± 85 and 1225 B.C. ± 80 (Kennedy et al. 1983:22).

In Mammoth Cave, again in areas known to have been visited during the Late Archaic/Early Woodland period, several charcoal drawings have been noted. An area of cross-hatching near the "Consumptive Huts" is unusual in the sense that a historic signature was written on the wall and was spaced in such a way as to avoid it. Two other charcoal drawings are known in historic Mammoth Cave. One, known since the 1830s, has been referred to as "The Devil's Looking Glass" (Lee 1835). Unfortunately, none of the descriptions specifically describes this feature, and it is extensively damaged by historic signatures. The only recognizable element present appears to be a broad zig-zag in the lower right corner. Due to the extensive historic damage, it is virtually impossible to discern any other detail, and it is unclear from the descriptions if the feature known as the Devil's Looking Glass refers to the charcoal drawings or the unusual vertical slab of ceiling breakdown. Within 50 m f this feature is a drawing discovered by Carstens and Watson during their examination of historic Mammoth Cave.

The drawing located by Carstens and Watson is dissimilar from the other drawings described above. It appears to have two principle elements present. The first is a rectilinear drawing composed of three uprights which are transversely sectioned by lines. The other is spiral-like, with several circles at the ends. Several people have suggested the spiral could represent a cave map, with the terminal circles representing deep pits. However, comparing modern maps with the area has yet to resolve this question.

CONCLUSIONS

A number of motifs have been described that have been found deep within caves which were known to have been used during the Terminal Archaic/Early Woodland period, particularly Salts and historic Mammoth Caves, Kentucky. In Adair County, Kentucky, there is a single contemporary date from the passage covered with drawings.

Similar motifs are found carved on Late Archaic bone objects. However, a survey of incised bone objects has yet to be accomplished. If such an examination should indicate that these items are ornamental rather than functional, it is possible that these motifs may be symbols of authority or for protection.

Adair Glyph Cave could be a place where members of society were taught those symbols of where the act of drawing the symbols was performed in secret. Those locations in Mammoth, Salts, and other deep caves where drawings are found could represent localities where protection was sought from the darkness.

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MANAGING KENTUCKY'S CAVES: A CULTURAL RESOURCE PERSPECTIVE

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ABSTRACT

Three caves are discussed which exemplify different cave types and management problems. Each was an "accidental discovery" in the sense that they were brought to the attention of archaeologists by recreational cavers. Archaeologists generally have to rely on cavers as sources of information. These accidental discoveries demonstrate the need to be better prepared to record these unique sources of data. Knowledge of specialized recovery techniques and protection options are necessary management tools. Quick action can mean the difference between protecting a site for the future and scavenging through looter's backdirt.

INTRODUCTION

Caves have long been an object of man's curiosity, drawing him inexplicably into their dark recesses. There, man has found shelter (for both the living and the dead), important natural resources, satisfaction for an innate need to explore, secluded and mystical places of ritual, and literary settings. In pursuit of the first four, man has left behind numerous and varied evidence of his presence, and through the last, has fostered man's fascination with caves.

Evidence left in caves by man provides information about man's adaptation to his environment. Through environmental factors of constant temperature and humidity, caves are capable of preserving mummies, woven materials, and paleofeces not found at open sites. Cultural information available is not restricted to items brought in by man but includes activities such as mining.

Caves, while capable of preserving fragile resources, are themselves fragile resources. Irreparable damage can easily be caused to caves and the cultural resources they contain. It is the purpose of this paper to discuss the importance of caves as a cultural resource repository and to suggest ideas for their conservation.

Three prehistoric cave sites, representing three different cave types and management problems, are presented. The three sites are: Adair Glyph Cave, 15Ad70, a rather typical multilevel cave containing mud glyphs drawn on the floor of a passage; Pit of the Skulls, 15Bn51, a pit cave containing human remains; and Sinking Creek Cave, 15Si9, a section of trunk passage containing stratified cultural deposits. Management approaches, either proposed or attempted, are presented.

ADAIR GLYPH CAVE

Adair Glyph Cave, a multilevel cave situated in Adair County, Kentucky, has been noted in caving literature since 1965 (Wainscott 1965:7-8, Nantz 1972:53-54, George 1986:14). The first mapping survey was completed in 1975, resulting in 1,623 m of mapped passage and an additional 914 m of explored passage. No evidence of prehistoric activity was noted during the mapping and exploration.

In 1986, what appeared to be prehistoric mud drawings were discovered by a group of recreational cavers on the floor of an upper level passage which had not been surveyed and mapped. Realizing the importance of the find, the cavers retraced their steps to avoid further damage and report the find.

Fortunately, two of the party members on this trip had been involved in an archaeological survey of small caves and were able to provide valuable preliminary information. The drawings were described as being incised in mud and covered with manganese deposits and fungi. Motifs described included chevrons, zig-zags, cross-hatching, snakes, sunbursts, and trailing lines.

A trip was made to assess the drawings, photograph them, collect radiocarbon samples, and look for other evidence of aboriginal activity. To access the glyph passage on the third level of the cave required traversing several areas which present logistical problems. The entrance level contained a 30-m-long stoop, a plunge pool, and 1,000 m of stream passage. Reaching the second level required climbing a steep muddy bank. Once there, 1 60-by-60-cm crawl had to be negotiated, and a pit with rapidly flowing water in the bottom had to be traversed. Reaching the third level required scaling a 2.5- to 3-m wall. Once there, the researchers had to traverse a soft mud floor where they found and flagged two aboriginal footprints. They also had to negotiate a 30-cm-high crawl just before the glyphs.

Once in the glyph passage, the party immediately determined that almost the entire floor was covered with drawings and that some had already been destroyed by "modern traffic." An observable "path" made by recent cavers was followed to the end of the passage, which measured 100 m long by 4 m wide.

A technique for recording the drawings was established. Two people recorded descriptions of the glyphs as the party moved forward. Two photographers worked on the task of photodocumentation. All of this had to be accomplished from a narrow path. Upon completion of the examination and while exiting the passage, ash was collected from the floor for radiometric determination.

It was tentatively decided that the drawings were aboriginal, based upon the motifs, the presence of bare and/or moccasined footprints, and stoke marks found throughout the passage. As the cave was heavily traveled and the landowner was known to allow anyone into the cave, they were informed of the extremely fragile nature of the find. The landowner agreed to limit access and allow continued archaeological investigations. The site was determined eligible for inclusion in the National Register of Historic Places (DiBlasi 1986b), thus affording the site protection under Section 106. It was determined, during the nomination process, that the entire cave was not "owned" by the entrance owner. Actually, two other individuals own portions of the cave. A 1920s decision of the Kentucky Supreme Court considers caves similar to mineral rights.

Since the discovery and preliminary description of Adair Glyph Cave, a new "Cave Protection Law" [Kentucky Revised Statutes (KRS) 433.871-885] has been passed in Kentucky. In effect, the new law makes it a class A or B misdemeanor to "knowingly or willfully deface" archaeological materials. However, just walking in this passage could "deface" the drawings. The only legal way to protect Adair Glyph Cave would be to have the owner of the entrance post the cave as per the cave law and have the owner of the passage post the interior of the cave. This would meet all the legal requirements of the law, but in actual practice it would be virtually impossible to enforce.

At present, the most feasible option for the preservation of the mud glyphs is to accomplish state-of-the-art photodocumentation and possibly casting of the drawings and then pursue enforcement of the cave protection law as rigorously as possible. Additionally, use of various cave-gating techniques, both at the entrance and at the passage, may provide protection.

PIT OF SKULLS

Pit of the Skulls is situated in Barren County, Kentucky. As its name implies, it is a pit cave containing human remains. It was first discovered and explored in June 1981 by members of the Cave Research Foundation. Survey disclosed the pit to have four distinct levels, a depth of 30 m, and a surveyed length of 82 m. Scattered human remains, representing a minimum of five individuals, were recovered, including two exhibiting occipital deformation and one showing evidence of dismemberment of butchering. None of the individuals was complete due to the method of collection, rodent gnawing, and method of disposal. Another trip made to collect animal bones recovered 17 species.

A thorough examination of material from the Pit of the Skulls resulted in two conclusions. First, the animal bones recovered occurred in the pit naturally. No butchering marks were noted, nor was there any evidence of burning, indicating that live animals fell into the pit. The depth of the pit (30 m) prohibited its use as an animal trap by prehistoric hunters. Secondly, the pit served as a specialized disposal area for human remains. It is highly unlikely that so many people fell accidentally into the pit. Evidence for the dismemberment of one individual indicates that some form of processing was taking place prior to final deposition in the pit.

Technical abilities required to gain access make this a "self-protecting" cave. The nature of the cave, while self-protecting, does pose a data recovery dilemma. To safely access the cave takes vertical ropework. "Surface" collections of easily recognizable items were made by the cavers mapping the cave. This was also the technique used on the second trip, specifically made to collect animal bones. These small samples produced valuable information, demonstrating the need for safe and efficient data recovery methods.

SINKING CREEK CAVE

The Sinking Creek Cave System, located in Simpson County, Kentucky, has a section of trunk passage containing stratified cultural deposits. It was being explored and mapped as part of a Master's Thesis on karst hydrology by a Western Kentucky University student, with support of the Green River Grotto. Survey members found a projectile point in a stream situated within the cave but became aware of more significant cultural deposits when vandals started looting a portion of the cave known as the "loft."

The cave system's amphitheater entrance was examined by archaeologists and a vertebrate paleontologist called by members of the Green River Grotto. The investigators determined that significant cultural deposits, both prehistoric and historic, were confined to the main trunk passage (Wilson 1984:27-28). Human remains, collected by the landowners after the looting activity, included elements of two adults and one infant. In addition, the remains of white-tailed deer were identified (Wilson 1984:30).

In 1984, Sinking Creek Cave became the focus of a court case. While archaeologists from the University of Louisville and Washington University were trying to gather scientific information from already disturbed cultural deposits, further extensive damage was done by looters. Criminal charges were eventually pressed against one of the looters.

The Coroners Law (KRS 525:110--Desecration of a venerated object) and the state Antiquities Act (KRS 164.730--Failure to report an archaeological site or object of antiquity) were the only two laws the landowners could use to protect the site. Donation of an archaeological easement had been discussed, but it could not be pursued since the land was in receivership with the Federal Land Bank Association of Elkton, Kentucky. Had this been an actual Federal Land Bank, vandals might have been charged with violation of the Archaeological Resources Protection Act of 1979 (ARPA), since the site would have been temporarily owned by the federal government and thereby afforded protection under ARPA.

Philip DiBlasi, Staff Archaeologist, University of Louisville, had to convince the Simpson County prosecutor to prosecute the vandal for violating the Antiquities Act and "desecrating a sacred place" (i.e., a burial). The county prosecutor wouldn't press charges until a complaint had been signed (Simpson County District Court Case Number 84-M-126).

The outcome of the trial was less than encouraging. The charge of desecration was dropped because the judge felt that the looting of prehistoric burials had not caused a public outraged by KRS 75;525.110). The defendant was found guilty of not reporting a site under the Kentucky Antiquities Act (KRS 164); however, this carried no penalty. He had to sign a bond indicating he would not dig or promote the digging for prehistoric materials in caves within Simpson County, Kentucky, for a period of 1 year.

Recently, prompted by the wholesale looting of prehistoric burials at 15Un28--the Slack Farm Site, penalties for both charges have been upgraded to felonies by an emergency act of the Kentucky Legislature. It is probable that if the Sinking Creek Cave case were tried today, the defendant might be convicted of two felonies. Sinking Creek Cave has been irreparably damaged, but upgrading the violation of the Coroners Law (dealing with human remains and burial objects) and the state Antiquities Act to felonies will serve to protect other sites.

DISCUSSION

As demonstrated by the diverse nature of the cultural material and the cave environments described in the three examples above, it is clear that there should be careful consideration of data recovery, documentation, and protection methods when dealing with cave sites. Methods presented below range from low-impact recording methods to means for site protection using recently passed legislation.

Photodocumentation of archaeological sites and materials is important, and in a cave it can prove to be extremely difficult. Cave photography is a very specialized process due to the total lack of light, and information should be sought from publications such as the NSS News. It is important to be aware of the extreme conditions the photographic equipment will have to pass through to get to the subjects. Special consideration should be given to the possibility that the equipment would have to be totally submerged or dragged through passages containing extremely abrasive gypsum sand. Successful cave photography requires that the equipment (particularly the flash system) be in working order when it is needed.

It is important to consider the recovery and curating of materials from caves. Either working survey station to survey station or dividing a large passage into units can be used as locational control for the recovery of materials. Materials should be well documented before being moved, and all materials should be well packed for transport. As discussed above for photographic equipment, materials may have to be transported through extreme conditions.

Determining sample size must be decided on a case-by-case basis. Should a cave be relatively well protected, either physically or legally, removing only a small sample of materials would be adequate. If the materials are not in imminent danger of vandalism, the best preservation option is to leave them in the cave environment. Often, caves are brought to the attention of archaeologists because of active looting. A large sample of materials should be taken in these cases. Additionally, stringent protection measures should be sought and implemented at such a cave. Materials, if removed from a cave, should be curated in a facility that is capable of replicating these conditions.

Protecting the archaeological, biological, and geological resources of caves is important. Legal and physical means of protecting caves must be actively implemented and enforced.

Kentucky's Cave Protection Act, enacted in 1988, provides caves, including those privately owned, with legal protection. Penalties are class A and B misdemeanors. The landowner lease/easement agreement, an important piece of interim legislation, provides for privately held properties to be leased or for easements to be donated to the state in order that they be provided the same level of protection as sites on state-held lands. The State Antiquities Act (KRS 164) and the Coroners Acts have been upgraded from misdemeanors to felonies.

Clearly, even the best legislation will not protect all archaeological sites. Physical means are also needed to protect sensitive cave resources. Currently, the most commonly protected cave resources are bats, with the most widely used method being the construction of an entrance gate. Gates allow bats and authorized individuals to pass. Several cave-gating methods are described in a publication provided by the National Speleological Society entitled Cave Gating (Hunt and Stitt 1981). The construction of a cave gate must take into account environmental impacts prior to construction.

Another cave protection process is the nature of the cave itself. Caves which are extremely complex or require specialized equipment or knowledge to enter are reasonably "self-protecting." However, pressures from uninformed or untrained individuals grow as the recreational nature of caving grows. Even the most untrained can "accidentally" find their way into an archaeologically sensitive passage and cause damage.

Public education has great potential in the long-term preservation of archaeological materials in caves. If the public is made aware of the natural and scientific value of these materials, then the chances of inadvertent damage will be reduced. It is not the only answer. The answer is in the effective use of both public education and the legal and physical protection of caves. By using every means possible, we can preserve these incredible resources for the future.

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CAVE FAUNA CONSERVATION IN TEXAS

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ABSTRACT

A review is presented of cave fauna conservation in Texas, including controlling biologic, geologic, historic, and economic factors. Texas has many caves and a high species diversity, owing to its geologic complexity and location. New cavernicole species are still being discovered at the same time that caves are being degraded or found. The major threats to cave fauna are land development, ground water overpumping, fire ants, human disturbance, and pollution. The special problems associated with the conservation of bats, salamanders, invertebrates, and ground water are discussed. Cave preserves are being created under the auspices of at least two habitat conservation plans, Texas Parks and Wildlife Department, Texas Nature Conservancy, Texas Cave Management Association, and other organizations.

INTRODUCTION

The aim of this paper is to discuss the numerous threats, past and present, to the cave and ground water fauna of Texas. Few of these threats have been satisfactorily resolved, although a number of partial solutions seem to be at hand.

The Texas Speleological Survey (headed by James R. Reddell and the writer) has recorded data on about 2,500 caves and more than 500 other karst features. Over 1,100 caves have been mapped. In Texas, about 80% of the caves are privately owned, which is both an advantage and a disadvantage for conservation. The advantage is that many caves are isolated on ranches and are protected by most owners. The disadvantage is that some owners feel free to dump trash in a cave or allow anyone to damage a cave or its fauna. Developers in urban areas have almost no incentive to conserve karst features, except avoidance of engineering problems, enforcement of the Endangered Species Act, or vague and poorly enforced state ground water regulations.

Caves continue to be discovered in areas under investigation, especially in the Austin area where consulting speleologists are excavating filled sinks. Although the average Texas cave barely exceeds 100 m in length, there are 33 caves longer than 1 km and 9 caves deeper than 100 m. Significant caves need not be large— most of the rich biological caves in Central Texas are less than 100 m long. A few cave systems, such as Honey Creek Cave and Powell's Cave System, are large, integrated, drainage networks with long geologic histories. Most caves are formed in Cretaceous limestones, such as the Edwards Group (and its equivalents) and Glen Rose formation in the Edwards Plateau and the Balcones Escarpment (fig. 1). Significant karst is also formed in Paleozoic limestones in the Llano Uplift and in Permian gypsum beds in Northwest and Far West Texas. The Capitan Limestone (Permian) contains some significant caves in the Guadalupe Mountains and other mountains of Far West Texas and adjacent New Mexico (Smith, 1971; Fieseler et al., 1978; Kastning, 1978; Elliott, 1987a).

Texas has a high species diversity owing to its complex geology, physiography, and climatic history. The state is a biogeographic crossroads to the tropics, the desert Southwest, the Great Plains, and the eastern forests. The cave fauna of Texas reflects this diversity, with elements originating from many geographic sources.

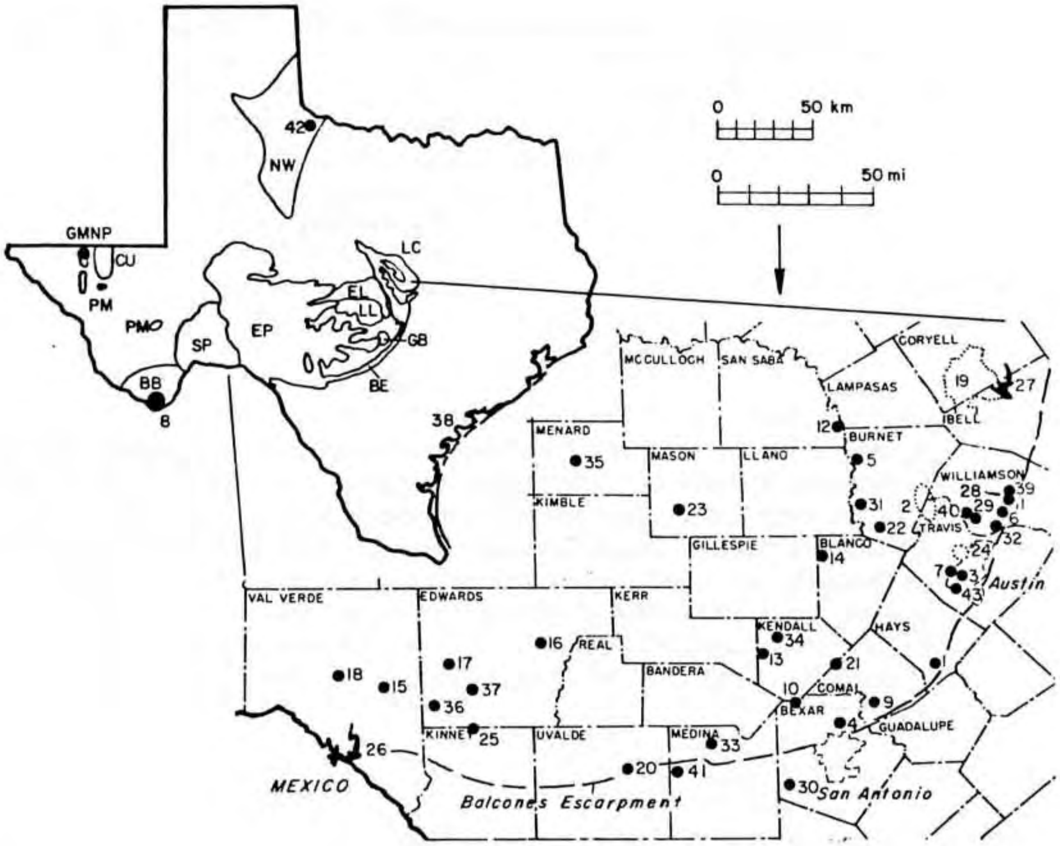

Fig. 1. Texas karst regions, caves, and places discussed in text.

Karst regions:

BE	Balcones Escarpment
BB	Big Bend Area
CU	Culberson County Gypsum Plain
EP	Edwards Plateau
EL	Ellenburger Area
GB	Guadalupe/Blanco Area
LC	Lampasas Cut Plains
LL	Llano Area
NW	NW Texas Gypsum Plain
PM	Permian Mountains
SP	Stockton Plateau

Caves and places:

1	Artesian well, San Marcos
2	Balcones Canyonlands National Wildlife Refuge
3	Barton Springs
4	Bear Cave
5	Beaver Creek Bat Cave
6	Beck Horse Cave
7	Bee Creek Cave
8	Big Bend National Park
9	Bracken Bat Cave
10	Camp Bullis
11	Chinaberry Cave
12	Colorado Bend State Park (Gorman Cave)
13	Comfort bat tower
14	Davis Blowout Cave
15	Devil's River State Park (Fawcett's Cave)
16	Devil's Sinkhole
17	Dunbar Cave
18	Fern Cave
19	Fort Hood
20	Frio Bat Cave
GMNP	Guadalupe Mountains National Park
21	Honey Creek Cave
22	Huber Limestone Mine
23	James River Bat Cave
24	Jollyville Plateau (Tooth & Kretschmarr Caves)
25	Kickapoo Caverns State Park (Kickapoo Caverns and Green Cave)
26	Lake Amistad
27	Lake Belton
28	Lake Georgetown
29	LakeLine Cave
30	Living Waters artesian well
31	Longhorn Cavern
32	Mural Cave
33	Ney Cave
34	Old Tunnel Wildlife Management Area
35	Powell's Cave
36	Punkin Cave
37	Rucker Bat Cave
38	San Antonio Bay
39	Temples of Thor Cave
40	Testudo Tube
41	Valdina Farms Sinkhole
42	Walkup Cave (Beasley Cave)
43	Whirlpool Cave

About 900 animal species are recorded from Texas caves, about 210 of which are troglobites (obligate cave-dwellers). Only about 102 of the troglobitic species have been described (Elliott, 1990).

Taxonomic studies of the Texas cave fauna began in 1896 with Stejneger's description of the Texas blind salamander *Typhlomolge rathbuni*, after a new artesian well at San Marcos, Hays County, disgorged blind salamanders and crustaceans. Some papers describing this ground water fauna were published about 1900. Deep artesian wells near San Antonio produced two species of blind catfish: *Trogloglanis pattersoni*, described by Eigenmann in 1919, and *Satan eurystomus*, described by Hubbs and Bailey in 1947. Neither fish has been found in accessible caves. Little more was done until the 1940s and 1950s, when several articles on bats and their parasites appeared.

True biospeleological studies began in the late 1950s with a visit by Thomas C. Barr, Jr. to Texas, which soon produced a number of taxonomic studies on beetles and millipedes by several workers (Reddell, 1965). In 1962 Reddell and associates of the Texas Speleological Survey began a systematic survey of the Texas cave fauna, which continues to this day. The survey resulted in many taxonomic descriptions by numerous workers.

Ecological and behavioral studies of Texas cavernicoles commenced with Robert W. Mitchell's work on the troglobitic carabid beetle *Rhadine subterranea*, which preys on the eggs of cave crickets (1968a,b,c). Mitchell (1970) also conducted an important study of Fern Cave (1970) and numerous studies of the Mexican cave fauna. Mitchell's students studied temperature and relative humidity responses of troglobitic millipedes (Bull and Mitchell, 1972), temperature responses of crustaceans (Elliott and Mitchell, 1973), and other ecophysiological modalities. Barr's revision of *Rhadine* (1974) and Elliott's morphometric study of *Speodesmus* millipedes (1976) revealed much more endemism in Texas caves than had been assumed.

A series of descriptions of ground water invertebrates appeared in the 1970s and 1980s as a result of the work of Glenn Longley and his associates. The Edwards Aquifer was found to contain an almost incredible array of blind snails and crustaceans— even a blind diving beetle. A forthcoming volume of *Speleological Monographs*, to be published by the Texas Memorial Museum, will contain numerous new species descriptions of invertebrates. Reviews of the Texas cave fauna may be found in Reddell, 1965, 1966, 1967, 1970a, 1970b, 1970c, 1991; Mitchell and Reddell, 1971; several authors in Lundelius and Slaughter, 1971; Elliott, 1978, 1990; and Elliott and Reddell, 1989.

BAT CONSERVATION

Mining in bat caves is an old practice in Texas, probably dating to before the Civil War. Beaver Creek Bat Cave and Longhorn Cavern, Burnet County; Davis Blowout Cave, Blanco County; and Ney Cave, Medina County; were sources of saltpeter for making black powder (Phillips, 1901; Poole, 1980; Elliott, 1987b, 1987c, 1987d). Gunpowder was manufactured in Longhorn Cavern for the Confederate Army (Craun, 1948).

In the early 20th Century several caves were mined for guano, most of which was shipped by rail to South Carolina and the eastern United States, some eventually to Europe, and some to California to be used as fertilizer. Phillips (1901) estimated that up to 10,000 tons of guano had been shipped over three railways during 25 years. The price at the railhead was usually $11 to $13 per ton. Ney Cave was mined almost continuously until the 1970s. The guano also was used on truck farms near Castroville and Hondo. The Marbach family of New Braunfels probably owned Bracken Bat Cave, Comal County, before 1901 and Frio Bat Cave, Uvalde County, since 1909. Before then an English company, the Texas Guano Company, mined Frio and shipped guano to England. The Marbach's guano mining operations probably helped to protect the Mexican freetail bat, *Tadarida brasiliensis mexicana*. Mining generally was limited to the winter, when the bats are largely gone to Mexico. Traditionally guano was sacked by hand and Bracken was completely cleaned of guano each year. In about 1987 a vacuum system with a 4-inch PVC pipe was used to remove the guano from Bracken to a large box outside (Menking, 1990). Because of renewed interest in bat guano for organic gardening, 80 to 85 tons of guano (4 to 6 tractor-trailer loads) reportedly have been mined annually from Bracken Bat Cave in recent years (Peterson, 1990). Other freetail caves that have been mined for guano include Beaver Creek Bat Cave; Davis Blowout Cave; Ney Cave; Devil's Sinkhole, Green Cave, and Rucker Bat Cave, Edwards County; and Fern Cave, Val Verde County. Smaller mining operations occurred in *Myotis velifer* caves such as Dunbar Cave, Edwards County, and many others.

Guano fires have been reported from Beaver Creek Bat Cave, Davis Blowout Cave, Frio Bat Cave, and Punkin Cave. Davis reportedly had a great explosion and then burned for two years after a hunter set a fire to smoke out a bear (Roessler, 1871; Phillips, 1901). Phillips saw piles of ashes 2 to 3 ft deep in the northwestern part of Beaver Creek Bat Cave and reported that the bats had deserted that part of the cave for the eastern part. In 1977 and 1987 most bats still roosted in the more spacious eastern chambers of the cave, but ashes were no longer visible (Elliott, 1987c). Campbell (1925) reported ashes 15 feet deep and guano fires without identifying the exact caves, and he said that ranchers called the caves "smoke holes". Punkin Cave may have had a guano fire lasting for months (Reddell and Smith, 1965). A smoldering guano fire persisted for several months in Frio Bat Cave in about 1977. A bat flight still occurred even though smoke was observed from at least one of several entrances (D. Craig Rudolph, pers. comm.). It is not known how the fires started, but Campbell claimed that the heat of decomposing guano started fires and that it only occurred in bat caves that were not mined. There is little doubt that freetail bat guano can sustain combustion.

Other mining operations probably adversely affected bats. Green Cave probably was affected by too much ventilation caused by an artificial shaft near the end of the cave (Rex Wahl, pers. comm.). Since acquiring the cave in 1986, the Texas Parks and Wildlife Department closed the shaft and the bat population has increased. Bracken Bat Cave also has a shaft at its end, but this seems not to have affected the bat colony, which is still the largest known (20-40 million). Beaver Creek Bat Cave and Davis Blowout Cave were guano mines as recently as the 1940s. They have been protected by ranchers. The removal of guano from some caves may have benefitted the bats by preventing some chambers from filling with deposits. One major freetail cave, Valdina778 Farms Sinkhole, Medina County, was ruined by a recharge dam, constructed by the Edwards Underground Water District. The cave formerly housed up to 4 million bats, but had none after serving as a recharge structure (Veni, 1987). There are only about 16 major Mexican freetail roosts in Texas, 13 of them caverns (Davis et al. 1962; Wahl, 1989.)

In the 1910s and 1920s Dr. Charles A.R. Campbell of San Antonio promoted the construction of numerous bat towers, structures that looked like church belfries on stilts. As the chief public health physician for the City of San Antonio, one of Campbell's jobs was to maintain quarantine camps. He theorized that bats would control mosquitoes, which would reduce malaria, still an important disease in Texas at that time. He also promoted guano as fertilizer; in one year (1917) he recovered 2,996 pounds of guano from a tower at Mitchell's Lake, a sewage lake near San Antonio. Campbell influenced the State Board of Health, and the state legislature (1917) passed a bill, "Protecting bats". Bats were declared to be beneficial to public health, and it was a misdemeanor to kill them, punishable by a $5 to $15 fine. Campbell's theory, which he insisted was a proven fact, interested even the Italian and Austrian governments. In 1919 the state legislature passed a resolution nominating Campbell for the Nobel Prize. In his book, *Bats, Mosquitoes, and Dollars* (1925) Campbell claimed that the bat guano from his towers contained mosquito fragments and he had many people attest in writing to a dramatic reduction in mosquitoes at Mitchell's Lake after installing a bat tower in 1911. He also claimed to have eliminated malaria in that area. The benefit of the towers was questioned after Storer (1926) demonstrated that the Mitchell's Lake tower, which contained Mexican freetails, contained no mosquito fragments in the guano. Freetails generally feed on moths, flying ants, beetles, leafhoppers, and true bugs (Schmidly, 1991). There is no doubt that bats are economically beneficial to humans. Davis et al. (1962) estimated that the summer populations of freetails in Texas caves reach 95.8 to 103.8 million, and that these bats eat from 6,000 to 18,000 metric tons of insects annually in Texas. Only one Texas bat tower remains; it is on private land near Comfort and is marked with a state historical plaque.

The benign attitude toward bats was reversed by a rabies scare in 1956, when George Menzies, a Texas Department of Health rabies researcher, died of rabies.

In 1959 a mining engineer died of rabies; he, like Menzies, insisted he had not been bitten by a bat or any animal and had simply gone into Frio Bat Cave (Constantine, 1967). In the two cases, however, there was a skin lesion or a bleeding scratch that could have been infected. Later studies by Constantine on animals caged in Frio Cave demonstrated that rabies could be contracted by the "aerosol route", that is by inhalation of the virus contained in bat saliva and urine aerosols. The transmission was more effective when ventilation of the cave was the lowest and many bats were present, as shown by carbon dioxide and ammonia measurements. Ever since those studies many public health people have assumed that humans are at a high risk of contracting rabies by merely entering a bat cave.

As a result of the rabies scare, the legislature unanimously rescinded the bat protection law (1957), and the public attitude toward bats hardened. Campbell's bat towers were even torn down. However, at least two considerations seemed to have been overlooked. First, the caged animals probably were exposed to ammonia vapors for up to 30 days. The writer has measured ammonia in Bracken Bat Cave at 53 ppm, which is hazardous to humans, and 195 ppm was detected in Frio by Constantine. Such ammonia concentrations should cause severe lung tissue erosion, transforming the alveoli into open sores. The ammonia exposure also should have severely weakened some of the animals, making them more susceptible to infections. Second, other possible routes of exposure were not eliminated in the case of Menzies. As a bat rabies researcher, he handled rabid animals and virus in the field and in the laboratory. One source of virus was an experimental, live rabies vaccine that was administered to Menzies by his own physician when Menzies reported that he thought he had rabies (Bobby Davis, pers. comm.). Thus, Menzies may have contracted rabies by any of three routes: inhalation in the cave, skin lesion in the field or laboratory, or treatment.

Certainly, many cavers and biologists have visited bat caves over many years, and none has died of rabies, to the writer's knowledge. However, exposure time is brief in most cases. Few of these people had received rabies vaccine until recent years. In actual practice the risk to humans of contracting rabies by the "aerosol route" is low rather than high. However, the risk of ammonia-related illness or histoplasmosis may be rather high in some of the caves. Properly fit-tested air-purifying respirators with ammonia cartridges and perhaps HEPA filters are needed for entering bat caves with large colonies.

Unfortunately, imagined public health concerns overshadowed the ecological benefits of bats, even though scientists like Constantine pointed out the benefits. However, it is fortunate that one of Constantine's recommendations (1967) was not followed: to ventilate freetail bat caves in order to reduce airborne virus concentrations and the incidence of rabies in the bats. It is known that pregnant freetails prefer the warm temperatures of the nursery colonies, created partly by an incubator effect and partly by the structure of the caves they inhabit (Herreid, 1963, 1967). It is now known that bat rabies is but one (or more) strain of rabies, as determined by monoclonal antibody studies, and that it is rarely transmitted to other species (Keith Clark, Texas Department of Health, pers. comm.). Bat rabies has little public health significance.

In 1932 the Texas State Park Board acquired Longhorn Cavern. The Civilian Conservation Corps (CCC) worked for several years to excavate 20,000 cubic yards of clay fill from the cave and develop trails for the public. The scientific and natural values of the cave were not adequately preserved, but it was The Depression and people needed work. A survey party, led by H.M Law of Southern Methodist University, mapped the cave. Law reported, "Bats are so numerous in some parts as to necessitate their removal before the rooms can be opened to the public." (Craun, 1948; R. Burnett, pers. comm.). Bats no longer inhabit the cave, and the cave is nearly biologically sterile except in a few areas.

A new attitude toward cave life was evident in the 1980s when the Texas Parks and Wildlife Department (TPWD) began a program of acquiring ecological preserves, many containing significant caves. In two purchases (1984 and 1987) TPWD acquired Colorado Bend State Park, San Saba County. The park contains numerous caves, one of which, Gorman Cave, is a large and important *Myotis velifer* (cave myotis) cave. In 1985 TPWD purchased the Devil's Sinkhole, Edwards County, a major freetail cave and historic site that also contains significant crustacean species in its lakes. In 1986 TPWD acquired the Seargeant Ranch, Kinney County, now known as Kickapoo Caverns State Park. It also contains Green Cave, an important freetail bat and cave swallow cave, and numerous smaller caves. In 1988 TPWD purchased Devil's River State Park, Val Verde County, which contains Fawcett's Cave, an important *M. velifer* cave. In 1991 TPWD purchased Kendall Tunnel, an abandoned railroad tunnel in Kendall County, now called "Old Tunnel Wildlife Management Area." The tunnel houses thousands of freetail bats (Bigony, 1991). Other properties contain numerous small caves, and TPWD sponsors volunteer projects by the Texas Speleological Association and Texas Cave Management Association to study the caves (Elliott and Reddell, 1987; Fralia, 1989). Scientific studies sometimes are supported through contracts. Altogether, TPWD owns at least 288 caves in 19 parks, about 12% of the state's caves.

The U.S. Government owns about 90 caves, mostly in the following areas: Guadalupe Mountains National Park, Big Bend National Park, Camp Bullis, Fort Hood, Lake Amistad, Lake Georgetown, Lake Belton, and several minor areas. None are important bat caves but some contain interesting invertebrates. Fort Hood is currently supporting a cave faunal study by James Reddell (pers. comm.)

In 1986 the Texas Cave Management Association (TCMA) was founded and began several projects, including a revision of the Texas Caverns Protection Act. The statute originally had been passed in the 1960s at the request of commercial cave owners, but was partly rescinded later when the Texas Penal Code was revised. A section relating to pollution was removed (Carolyn Biegert, pers. comm.). The statute was reauthorized (1977) but retained its original weakness in permitting destruction of caves if the owner gave written permission. A bill drafted by TCMA was sponsored in 1987 to strengthen the statute by adding protections for ground water, bats, and cave fauna and to increase the penalties for vandalism. The bill was rejected in committee even after receiving favorable support from all who testified. The bill's chances may have been damaged by its own sponsor—when questioned by the committee about bat protection, she speculated that bats probably could be written out of the bill since they probably were not natural inhabitants of caves anyway. Subsequent testimony by a biologist correcting several misconceptions about bats did not sufficiently persuade the committee.

To further its conservation goals, TCMA acquired a recharge cave (Whirlpool Cave, Travis County) in 1990 and may acquire or manage other caves. TCMA also manages two caves in West Texas for the University of Texas System. To date none of its caves are especially managed for biological purposes. In 1989 TCMA succeeded in having a bill passed to add cave owners to an existing statute that protects landowners from liability for injuries sustained in outdoor activities, such as hiking and boating (Texas Legislature, 1989). However, many landowners still believe that owning a cave is a legal liability, despite the statutory protection and the fact that no one has yet been sued in Texas, to the writer's knowledge, for a cave-related injury or death.

In 1986 Bat Conservation International's founder, Merlin Tuttle, moved his organization from Milwaukee to Austin. Tuttle's public lectures and publicity about the ecological benefits of bats created high interest in bat conservation. A local chapter of BCI was formed in Austin, which began sponsoring bat census studies and educational trips to Bracken Bat Cave to observe the evening flight. A large colony of Mexican freetail bats living under the Congress Avenue bridge in Austin began to receive positive publicity, whereas previous news reports on the colony were very negative. By 1991 several hotels and restaurants near the bridge claimed that the bridge colony actually attracted tourists to watch the evening flight. Part of BCI's program includes controlling access to Bracken Bat Cave and gathering information on threatened bat caves (Elliott, 1987d).

In 1990 the Texas Nature Conservancy (TNC) bought James River Bat Cave, Mason County, and renamed the new preserve Eckert James River Bat Cave. The cave has been a popular study site for biologists for many years and is now available for groups to view the evening flight of freetails. In 1991 TNC announced its plans for a "Texas Hill Country Bioreserve" system, which will involve purchases of critical habitats and watersheds in the Edwards Plateau and Balcones Escarpment (Collier, 1991a). TNC has stated that it recognizes that private landownership still provides the best means of protection, but that it will raise a large fund over three years to purchase and protect bat caves if they become threatened through property sales (Jim Fries, pers. comm.).

Many significant bat caves and tunnels remain in private ownership. A significant new freetail colony took up residence in an abandoned section of the Huber Limestone Mine near Marble Falls, Burnet County. The population, estimated in 1989 at about 4 million (Wahl, 1989) is protected by the mine owners. The writer videotaped the impressive bat flight in 1989.

Although the large freetail colonies in Texas are few and vulnerable to destruction, the smaller bat caves harboring *Myotis velifer*, *Plecotus townsendii*, and other species, have already suffered from human pressure. Most of the large freetail caves are relatively inaccessible to the public and have such oppressive atmospheres that few people venture inside. *M. velifer* caves are smaller, more numerous, and more inviting. Several examples illustrate the vulnerability of small bat caves: 1) In 1961 an entire colony of *M. velifer* was killed or driven off from Chinaberry Cave (Bat Cave), Williamson County, by an unidentified intruder using a .22 caliber rifle with rat-shot. The dead bats were found by James Pope (pers. comm.) and his father; the latter had visited the cave before and was familiar with the bat colony. 2) In 1973 the San Antonio River Authority built an aquifer recharge dam 60 m downstream from Bear Cave, Bexar County, which was a bat roost (probably for *M. velifer)*. The cave soon was completely flooded and washed out. In 1984 an overweight individual became stuck in the smaller pit entrance and had to be rescued. A local developer then filled the cave with large boulders, sand, and gravel, out of fear of liability. About 20,000-100,000 bats were roosting in the cave when it was filled. In 1985 floodwaters reopened the cave. Since the cave is a planned recharge feature, the situation continues to endanger bats that repopulate it (Veni 1988, pers. comm.; K. Menking, pers. comm.). 3) Numerous bats have been killed in Walkup Cave (Beasley Cave), Hardeman County. Brown (1987) reported that locals have shotgunned the bats. In 1983 he caught a group of a dozen high school students spraying the roosting bats with gasoline and setting them on fire. The bat colony may have moved to a nearby cave, Lady's Descent, because of such harassment (Butch Fralia, pers. comm.) Walkup Cave was an important hibernaculum for *M. velifer*, *Eptesicus fuscus pallidus*, and *Plecotus townsendii pallescens*. 4) In the late 1980s the writer, Merlin Tuttle, and members of the Austin Chapter of Bat Conservation International noted several small caves in the Austin area that probably were formerly inhabited by *M. velifer* but which now lack bats. Ceiling stains and guano deposits often indicated sizeable former colonies. *M. velifer* may be less loyal to its cave roosts than freetails and seems to move from site to site readily. Whether this behavior is caused more by natural ecological factors or by human disturbance is unclear. *M. velifer* can tolerate humans in larger caves where it can flee to alternate roosts. Such is the case in Fawcett's Cave, Gorman Cave, and Powell's Cave.

Sometimes a bat cave can be recolonized. In 1970 *M. velifer* specimens were transplanted from a New Braunfels cave to Ezell's Cave, Hays County, because human disturbances had driven off the Ezell's colony. The transplant failed, but guano was occasionally brought in to try and restore the energy cycle of the cave (Davis, 1971). *M. velifer* returned to two Williamson County caves: Mural Cave in 1987 and Beck Horse Cave in 1991. All that was done was to clear vegetation away from the entrances, which were partially blocked (writer's data and Mike Warton, pers. comm.). Powell's Cave was recolonized by *M. velifer* in 1989 after a mapping project by the Texas Speleological Association excavated the entrance, which had slumped (Veni, 1989). No bats had inhabited the cave before it was opened by cavers in the 1950s (Pete Lindsely, pers. comm.).

CONSERVATION OF OTHER VERTEBRATES

In 1967 the Texas Nature Conservancy acquired Ezell's Cave to protect the Texas blind Salamander *Typhlomolge rathbuni* (Davis, 1971). This was TNC's first preserve in Texas and the first preserve for a Texas cave species. TNC still maintains the cave, although for several years there was a major problem with intruders. Local college students traditionally used the cave for parties or rites, and they repeatedly broke through the gate. Finally, brush was cleared from the entrance area so that trespassers could be seen, and a maximum security gate was built, which has not been penetrated. The students' tradition eventually died away, and no break-ins have been attempted recently (John Cradit, pers. comm.). Studies of the base-level lake are in progress in which water levels, water chemistry, and temperature are recorded electronically. Salamanders have been seen in the lake within the last two years (Cradit, pers. comm.)

Typhlomolge rathbuni was first seen in 1895 when an artesian well was drilled close to the San Marcos River. It is considered one of the most cave-adapted vertebrates in the world. The species was later found in Ezell's Cave. For a long time Ezell's was thought to be the only locality in which the species could still be found, hence the interest in preserving the cave and listing the species. The salamander was the first species listed in 1967 under the Endangered Species Conservation Act and was automatically included under the Endangered Species Act of 1973.

In the early 1970s Glenn Longley of Southwest Texas State University, fitted a net onto the discharge pipe of the artesian well and began to recover the salamander and a host of other ground water fauna, much of it undescribed. About 40 rare species occur in the San Marcos Pool of the Edwards Aquifer. *T. rathbuni* is now known from six localities in San Marcos but is still considered endangered because of various threats to ground water (Longley, 1978, 1981, pers. comm.). Another salamander *Typhlomolge robusta* is known from a single specimen collected from a spring outlet in the bed of the Blanco River. Its status is unknown as it has not been seen since it was collected in 1948 but it is on the state endangered species list.

Eurycea nana, the San Marcos salamander, was placed on the federal endangered species list in 1980. It is an eyed but neotenic form known only from the San Marcos River, which is fed entirely by the large San Marcos Springs. The San Marcos River also contains the endangered Texas wild-rice *Zizania texana* and the endangered fountain darter *Etheostoma fonticola* which is now extinct in Comal Springs, Comal County. Other spring and cave salamanders of the genus *Eurycea* are limited in distribution and may be listed eventually. One undescribed species is the Barton Springs salamander from Austin, Travis County, which is endangered by pollution and loss of recharge to the aquifer. In January, 1992, the U.S. Fish and Wildlife Service (USFWS) received a petition to list the Barton Springs salamander as endangered (Collier, 1992). Another new cave *Eurycea* occurs on the opposite side of the Colorado River to the north (Paul Chippindale, pers. comm.).

CONSERVATION OF INVERTEBRATES

In 1984 land development began to encroach on the rural Jollyville Plateau west of Austin, particularly the Kretschmarr Ranch, which contains some of the state's more important biological caves, such as Tooth Cave. These caves had been protected since about 1970 under an arrangement between the owners and the Texas System of Natural Laboratories (TSNL). Further studies of the caves were conducted to document the rare species and numerous caves in the area (Reddell, 1984). It was hoped at that time that the developers would voluntarily set aside some of the land to preserve the more significant caves. Although the City of Austin had adopted a Comprehensive Watershed Ordinance, it was too weak and too late in coming to protect the caves. The land was considered valuable and was to be developed into "The Parke", a mixed residential-light industrial area. For a while one developer offered to donate cave land to the University of Texas at Austin, but the University turned it down. There was no definite commitment by the developers but The Parke development was scaled back somewhat. Part of the northern half was developed, but the cave areas were mostly left alone.

In 1986 the Travis Audubon Society petitioned USFWS to list six species of cave arthropods, mostly located on the Jollyville Plateau, as endangered under the federal Endangered Species Act (Chambers and Jahrsdoerfer, 1988). The USFWS studied the petition and sought information from cave biologists. A long period passed with no real progress made by the developers or USFWS. Meanwhile, the land development boom in the Austin area was subsiding, and the pressure was off for awhile. While local biologists were concerned, most local cavers remained unfamiliar with or uninterested in the caves at The Parke. Bill Russell and others worked quietly with the City of Austin to help protect many caves and sinkholes in the city's jurisdiction.

Meanwhile, other conservation issues began to heat up in Austin. People became interested in the endangered birds, such as the golden cheek warbler and the black capped vireo, and rare plants, such as the bracted twistflower. The news media frequently mentioned these species and the relentless trend of land development in the hill country west of town. These became popular causes, along with concern about water-quality degradation in the Barton Creek-Barton Springs watershed and the Colorado River, Austin's water supply.

In 1988 some of these issues came to a head. Private negotiations with the developers seemed stalled, so a group called Earth First! began to openly trespass at The Parke to draw attention to the destruction of potential bird habitat. They then occupied some caves as a political stunt and obtained news media coverage. This action got much attention, but Earth First! did not endear itself to the caver community although both wanted the caves protected.

Meanwhile, the USFWS listed five of the six proposed cave species as endangered: *Texella reddelli* Goodnight and Goodnight, the Bee Creek Cave harvestman; *Microcreagris texana* Muchmore, the Tooth Cave pseudoscorpion; *Neoleptoneta myopica* (Gertsch), the Tooth Cave spider; *Rhadine persephone* Barr, the Tooth Cave ground beetle; and *Texamaurops reddelli* Barr and Steeves, the Kretschmarr Cave mold beetle. The five species actually are seven due to a taxonomic split that will occur when two new species are described. In addition, Ubick and Briggs (in press) will soon describe many new species of *Texella* and Chandler (in press) will be describing several new pselaphid beetles, one of which is a new *Batrisodes* from the area. Two of the new species are legally protected because most of their populations are endangered and some were included in the previous definitions of *Texella reddelli* and *Texamaurops reddelli*. However, when the new species are described a legal loophole may open and they may be unprotected. Other taxonomic papers in press will describe spiders (Gertsch), pseudoscorpions (Muchmore), schizomids (Cokendolpher and Reddell), amphipods (Holsinger), and isopods (Bowman).

As a result of the listings, a series of reconnaissance biology studies on the seven species in the Austin area were conducted, supported by USFWS, TPWD, TNC, the City of Georgetown, numerous developers and banks, and Melvin Simon & Associates, Inc. (Elliott and Reddell, 1989; Reddell, 1991; Reddell and Elliott, 1991). Between 1989 and 1991 the number of known localities for the seven endangered cave species was increased from 13 to 64. However, most of the additional caves involve just two of the species, and most of the caves are in urbanizing areas threatened by development anyway. The studies helped increase general understanding of the biology of all the cave fauna in the area.

Veni (1988) and Elliott and Reddell (1989) documented the rate of cave filling and destruction in Central Texas. At least 5% of known Texas caves have been destroyed or filled by humans, mostly during land development. In Bexar County (San Antonio), at least 44 caves were destroyed or filled and another 9 were severely damaged by trash dumping. In Travis County (Austin) at least 32 caves were destroyed or filled. In Williamson County, at least 10 caves were degraded. Most of the damage occurred since 1970. If one projects the destruction rate of 1970-1989 into the future, no caves would be left intact in Travis County by the end of the 21st Century (Elliott and Reddell, 1989), assuming that no new caves were discovered. Because of the protection of endangered species, this historical trend has been significantly slowed since 1989 in Travis and Williamson counties and previously unknown caves are being dug open faster than old ones are being destroyed. A large number of caves are being gated in Travis and Williamson counties, but true cave preserves with long-term ecological management have yet to be created. The destructive trend continues in Bexar County and surrounding areas.

Land development is not the only threat to the Texas cave fauna. The red imported fire ant *Solenopsis invicta* originally from Brazil, invaded the United States in the 1930s through the port of Mobile, Alabama. The ant may have arrived in soil used as ship ballast. The species had moved into Texas by 1956 and is currently expanding westward. Although limited to areas south of the 10°F minimum temperature line, the red fire ant is expected to infest irrigated areas across the southwestern U.S. and eventually invade the West Coast (Vinson and Sorensen, 1986). The species has already infested most areas of the Deep South.

In the late 1980s fire ants began colonizing karst areas in Central Texas, and cavers began reporting infestations in cave entrances (Elliott and Reddell, 1989; Elliott, in press, in litt.). By 1991, at least 24 of the 64 known endangered-species caves in Travis and Williamson Counties had fire ants foraging inside from nearby colonies. The temperature of Texas caves, about 65-75°F, is nearly optimal for fire ants, although they do not actually construct nests in caves except in some entrances where there is sufficient soil. The fire ant is extremely voracious and can severely reduce the species diversity of the native soil fauna and any ground-nesting animals (Porter and Savignano, 1990).

Fire ants have been observed preying on young cave crickets, millipedes, pseudoscorpions, earthworms, and other cave fauna. A fire ant control and ecological study in and around 12 endangered species caves was completed in late 1991 (Elliott, in press, in litt.). The study involved baiting of 1 or 2-acre plots around the caves with either "Logic" (fenoxycarb) or "Amdro" (hydramethylnon). Both are low-impact pesticides formulated on corn grit with soybean oil and are very attractive to the ants. Colonies in and near cave entrances were treated with boiling water, which is more effective and avoids direct contamination of the cave environment but is also more labor-intensive. Treatment schedules were timed so that the ants would retrieve most of the bait before sundown, when cave crickets come out to forage. Logic impairs insect reproduction and is more effective than Amdro, but is not yet permitted by the Environmental Protection Agency for use on agricultural land, including ranches, because of the need for studies proving its safety. It is expected that the Ciba-Geigy Company will eventually receive approval for the use of Logic in agricultural areas.

In 1989 the conjunction of several issues resulted in the formulation of an ambitious regional habitat conservation plan (HCP) at the urging of the USFWS. About 30 such plans have been assembled by local interests in various parts of the country, and such HCPs are encouraged under the Endangered Species Act. As of February, 1992, the Balcones Canyonlands Conservation Plan was nearing completion but needed further economic analysis and approvals from the City of Austin and Travis County before going to the voters and to the USFWS for final approval. About 29,100 acres of land may be purchased for preserves largely through funds generated by "habitat loss fees", authorized under the Endangered Species Act (Collier, 1991a, 1991b). The total cost may be $122 million over 20 years, including land management and scientific studies. About $48.5 million would be for land purchases, of which $20.7 million would be raised through increased local property taxes and water fees, costing the average area home owner a few additional dollars per year. Other costs would be paid out of developer fees, which may range up to $3,000 per acre. About 6,000 acres may go to karst preserves and the rest for two endangered birds, rare plants, and watershed protection. The Resolution Trust Corporation, a federal agency whose job is to resell lands forfeited by failed lending institutions, agreed to sell large areas to the BCCP and TNC at low cost. The plan had already been revised several times because of political objections from Williamson County, which subsequently backed out of the plan. As a consequence, Williamson County may have to assemble its own HCP. Political opposition to the HCP from the Texas Farm Bureau and some landowners is expected to become a major issue in Washington, where Congress will consider reauthorization of the Endangered Species Act in 1992 (Collier, 1991c).

In addition to the local HCP, the USFWS has announced plans to purchase 41,000 acres in the Post Oak Ridge area northwest of Austin, primarily as a bird preserve (caves there have no known endangered species). Many private properties would be purchased at fair market value for a cost up to $30 million, plus operating costs. The area will be named the "Balcones Canyonlands National Wildlife Refuge."

The Melvin Simon Co. developed its own LakeLine Mall Habitat Conservation Plan (H. Co. Simon, 1991) in response to problems encountered with karst on development property it had purchased near Cedar Park, Williamson County. Since two endangered invertebrates were involved, the company sought to obtain a Sec. 10(a) permit from USFWS, which would allow incidental take of *Rhadine persephone* beetles and *Texella* new species harvestmen while building a shopping mall. Construction of the mall was delayed for about two years as the plan was formulated. The plan, approved in February 1992, includes the purchase by the company of three karst preserves in the area to mitigate the take of the two species during construction. These preserves will be turned over to TPWD for long-term management and ecological studies in LakeLine Cave, Testudo Tube, and Temples of Thor Cave. The company will support ecological studies of troglobites and cave crickets and land management for several years. Management will entail surveillance and gating of caves, fire-ant control, and perhaps more subtle management problems, such as control of Ashe juniper ("cedar"), which is a general problem on rangeland in Central Texas.

Actually, many more described and undescribed troglobites from the Balcones Escarpment of Central Texas may have to be considered for listing because they exist in urbanizing areas. The Balcones Escarpment is highly dissected geologically, which has resulted in intense speciation in the cave faunas. About 100 species and subspecies of rare cave and ground water invertebrates may be endangered, including both aquatic and terrestrial forms. Forty-two of these species are known from single localities only, so they are extremely vulnerable to land development and other man-made pressures, such as fire ants. Travis County contains 32 rare troglobites, 20 of which occur only in that county. Based on an analysis by Elliott (1991), the Balcones Canyonlands Conservation Plan may select at least 40 caves that would offer protection for all 32 rare troglobites, including the 6 endangered cave species in Travis. In January 1992 USFWS received a petition from a coalition of 5 conservation groups to list 9 troglobitic invertebrate species in Bexar County. The species include 5 spiders, one harvestman, and 3 beetles, a total of 11 taxa counting 4 included beetle subspecies. The San Antonio area may be the focus of another HCP if some of these species and subspecies are listed.

GROUND WATER ISSUES

A major environmental and political issue is the Edwards Aquifer, a karst aquifer which stretches from Del Rio to north of Austin along the margin of the Edwards Plateau. The aquifer provides drinking water to about 1.5 million people in the San Antonio area. Overpumping of the aquifer not only is threatening several rare species, such as *Stygobromus pecki* (Comal Springs amphipod), but the human economy as well. Water rationing in San Antonio and other cities may soon become commonplace. In addition, the Comal and San Marcos Rivers, which originate from large karst springs, are important in maintaining the Guadalupe River ecosystem, including the important San Antonio Bay estuary on the Texas coast. The bay also contains endangered species.

The State of Texas did not limit the use of ground water by landowners until 1991, when the State Attorney General issued an opinion that Sec. 28.011 of the Texas Water Code, which gives the Texas Water Commission the authority to regulate ground water usage, is constitutional (Lott and Garcia, 1991). Previously, the section had not been enforced because of court rulings. The legal confusion had contributed not only to a lack of effective regional ground water planning but to blatant waste.

The issue boiled over in 1991 when an extremely high-volume water well was drilled for the Living Waters Artesian Springs catfish farm near the Medina River in Bexar County (Swanson, 1991). The record-breaking well, drilled with an oil rig, was 30 inches in diameter, 1600 feet deep, and gushed over 43 million gallons a day, more water than several small cities combined and over 25% of the City of San Antonio's daily pumpage (Lott, 1991a,b). There ensued a series of legal maneuvers by the Texas Water Commission, Edwards Underground Water District, San Antonio River Authority, U.S. Environmental Protection Agency, and the USFWS to regulate the farm's water usage. In April 1991, the USFWS announced that it would assume that Comal Springs would go dry in 1992 and would institute regional controls under the Endangered Species Act if necessary.

Because of a lawsuit by the San Antonio River Authority and the Edwards Underground Water District, the catfish farm shut in its well in late November, 1991. The level of the Edwards Aquifer then rose about two ft. in two weeks. The level had not generally risen in 1991, despite the fact that it was the wettest year on record. Obviously the catfish farm was having a large effect on regional water supplies (Glenn Longley, pers. comm.). At last it appears that Texas is entering a new era of ground water conservation, although much of it may be done through regional committees of local, state, and federal agencies. The public is becoming more aware of the need to preserve karst to maintain good ground water. Concerns about water supplies and endangered species will increasingly influence the extent to which ground water is regulated in Texas.

DISCUSSION

Twenty years ago Gehlbach (1971) proposed that Texas biologists and conservationists begin building a system of cave preserves with a variety of trophic structures. Gehlbach bemoaned the fact that few biologists were taking the time to preserve caves for research. That proposal went unheeded and Ezell's Cave and the Kretschmarr Ranch remained the only Texas cave preserves for many years. In the 1980s the Texas Parks and Wildlife Department began to acquire large areas containing different types of caves. Exactly how to manage these cave areas is still problematical.

Urban karst preserves are being created, but some are only a few acres in area and are covered with juniper and fire ants. We have a tendency to conserve cave entrances and not karst areas. To truly conserve a cave, the cavẽ's ecological and hydrological connections must be taken into account. In many Central Texas caves the major energy inputs are raccoons, bats, cave crickets, harvestmen, and plant detritus, yet few of the preserves have sufficient area and long-term management plans to ensure that these inputs are not degraded.

There are reasons to be hopeful. Support for long-term ecological studies and management of a few areas will develop in 1992 through habitat conservation plans. A need still exists for detailed hydrogeologic studies to scientifically delineate boundaries for karst preserves. Incentives are needed for landowners to conserve significant caves and surface environments, rather than consider them as dumping grounds or economic and legal liabilities. Significant biological caves should not be ruined in the name of water conservation, as were Valdina Farms Sinkhole and Bear Cave.

The history of state legislation in this area is not encouraging. Education of the public on endangered species should be improved but the biologists who are most knowledgeable of the local species have not been adequately utilized to that end. Progress has been made largely because of scientific studies followed by activism, enforcement by the federal government, and land purchases by the state and private conservation groups. Incentives for private landowners exist but are poorly developed. In the 1990s state and private programs, federal enforcement, and habitat conservation plans will be the important vehicles for cave fauna conservation in Texas.

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THE EFFECTS OF CAVE VISITATION ON TERRESTRIAL CAVE ARTHROPODS

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ABSTRACT

The effects of heavy human visitation on arthropods present in the terrestrial cave environment is investigated. Five cave sites (2 heavy traffic and 3 light traffic) in the Organ Cave System were sampled for arthropods using two methods, bait trapping and quadrat sampling by mouth aspiration. Samples were taken from three communities at each cave site; the surface community, the entrance community, and the deep cave community. Jacknifed samples suggest that there is a slight decrease in the species evenness of entrance bait trap and deep cave quadrat aspiration samples in cave sites associated with heavy human visitation. A small decrease in diversity and evenness is also evident in heavy traffic entrance bait trap samples, when viewing troglobitic and troglophilic species. Overall analysis of results indicates that heavy human visitation has a slightly negative effect, if any, on terrestrial cavernicolous arthropod communities.

INTRODUCTION

HISTORY

Indirect Anthropogenic Stress

Historically, most cave stress studies have involved pollution. Organic pollution, sewage, has drawn the most attention, as its appearance is easily detectable in cave systems through standard microbiological methods. Diverse changes have been reported in aquatic cave invertebrate communities existing in organically polluted areas (Holsinger 1966, Iliffe and Jickells 1984). Environmental "poisonings" such as leaking gasoline have also been studied. In one circumstance, observations indicated damage to the whole aquatic cave ecosystem was occurring (Hobbs 1988).

Direct Anthropogenic Stress - Human Visitation

Studies concerning direct anthropogenic impact on cave faunal communities have been directed primarily toward bats. Researchers have documented bat population declines and associated these with winter caving activities and the agitation of hibernating bats (Humphrey 1969, Stebbings 1971). Caving in areas where bats rear their broods has also been determined as dangerous to the juvenile bats (McCracken 1989).

Only a handful of other studies concerning direct human impact in the cave environment have been attempted. Only one of those dealt with terrestrial cave invertebrates (Crawford and Senger, 1988). Crawford and Senger's study revealed that a numeric decrease of an abundant troglobitic species (a dipluran) was correlated to excessive human visitation of the study caves.

The premise of this project is to look at the whole terrestrial invertebrate community in each of three different environmental zones, in caves with differing amounts of human visitation. Analysis of the community enables a robust assessment of direct human impact on terrestrial cave fauna to be obtained.

MATERIALS AND METHODS

Study Location - Organ Cave System

Many historical and geological criteria for an acceptable study location were reviewed before settling on the Organ Cave System. The Organ Cave System is situated in the Organ Cave Plateau, in Greenbrier County, West Virginia (See Figure 1).

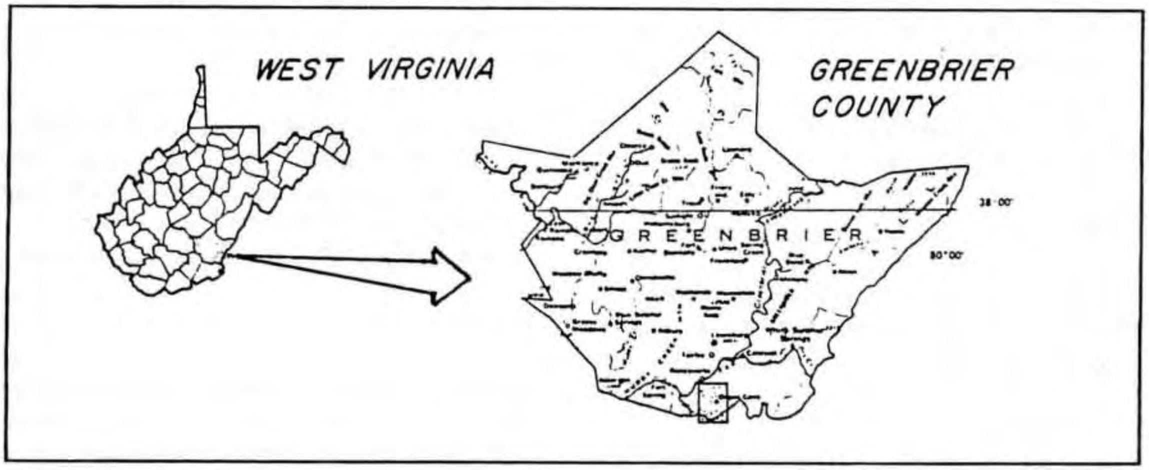

Figure 1. Study Area Location
(Modified from Figure 1.1, Stevens 1988)

Relative levels of human visitation were determined by interviewing persons well experienced with caving patterns in the Organ Cave System. Additional information was obtained from landowners of cave site property. Two cave groups consisting of five cave sites, were chosen for the study (See Table 1).

Table 1. Locations of the Study Caves (Stevens 1988)
Ronceverte quadrangle (N3737.5-W8022.5/7.5)

Cave Entrance	Coordinates	(UTM)	Visitation	Elev.
Deems	N-4174480	E-548410	L	2260
Erwins	N-4174090	E-547890	L	2360
Humphreys	N-4174010	E-547830	L	2360
Lipps	N-4174570	E-548540	H	2260
Organ Main	N-4174490	E-549600	H	2149

L = Little Human Visitation   H = Heavy Human Visitation

Cave Site-Zones

Three zones were determined for each cave site; the surface zone, the entrance zone, and the deep cave zone. Each zone represents a unique invertebrate community (Culver and Poulson 1970). Spatial parameters for the zones were patterned after existing environmental conditions. The surface (light) zone was located 0-20 meters outside the cave. The entrance (twilight) zone was located 0-40 meters inside the cave's entrance. The deep cave (dark) zone was located 60-120 meters inside the cave's entrance.

Zone-Sample Sites

Each zone was sampled five times at random locations within the zone. Five sites seemed most economical when viewing time and effort required for sampling.

Sampling Techniques

Two techniques of sampling were employed at each sample site to estimate the diversity of species present; baiting with rotted meat, and quadrat collection using mouth aspiration. It has been suggested that sampling complementation can resolve more of the extant communities character (Gibert et al. 1981).

Data Collection Procedures

Terrestrial bait traps for cool temperate areas (Newton and Peck 1975) were used as the first method of collection. Bait traps were set in each sample site on 7/14/90. After one week, the bait traps were collected in the same order dispensed, and later emptied and analyzed in the lab.

After each bait trap was removed, a 30 cm. * 30 cm. quadrat centering on the removed bait traps location was inspected for further collection. Invertebrates present were collected using mouth aspirators.

All terrestrial or aerial invertebrates captured in either manner were cataloged by site and method of capture, taxonomically identified, and preserved. Combining all locations and sampling divisions reveals that a total of 150 samples were taken (5 cave locations * 3 zones * 5 sample sites * 2 techniques) for this study.

Analysis

After the taxonomic identification of the arthropods was complete, two groups of data were compiled. The first group of data summed the species in all samples (Group 1). The second group of data (Group 2) was composed only of the troglobites and troglophiles found in the samples. These two groups were then subject to the jacknife estimation technique (Zahl 1977, Magurran 1988) using the ecological indices for richness, abundance, diversity, and evenness.

Richness, the number of species, was examined using S. Abundance, N, was tabulated using total counts of all individuals per species. For diversity, the Reciprocal Simpsons index (N2), was used. Species evenness or equitability, was calculated using the Shannon evenness index (SE).

All four environmental indices were calculated for recombined (jacknifed) samples in each zone. The species richness and abundance indices were averaged after the recombination, while the diversity and evenness indices were converted into jacknife pseudovalues and then averaged. These averages, with their derived standard errors, were used to graphically represent differences between cave sites within each zone. Summary charts were generated from these graphs (See Table 2 and Table 3).

RESULTS

Table 2. Summary of Graphical Representations for Group 1.

Total Data

Zone	Richness (S)	Abundance (N)	Diversity (N2)	Evenness (SE)
Surface Bait Trap	+	-	-	-
Entrance Bait Trap	-	-	-	+
Deep Cave Bait Trap	-	-	-	-
Entrance Aspiration	_	-	-	-
Deep Cave Aspiration	-	-	-	+

+ = All Three Low Traffic Caves > Both High Traffic Caves
- = At Least One High Traffic Cave > One Low Traffic Cave

Table 3. Summary of Graphical Representations for Group 2.

Troglobitic and Troglophilic Data

Zone	Richness (S)	Abundance (N)	Diversity (N2)	Evenness (SE)
Surface Bait Trap	-	-	-	-
Entrance Bait Trap	-	-	+	+
Deep Cave Bait Trap	-	-	-	-
Entrance Aspiration	_	-	-	-
Deep Cave Aspiration	-	-	-	+

+ = All Three Low Traffic Caves > Both High Traffic Caves
- = At Least One High Traffic Cave > One Low Traffic Cave

CONCLUSION

Community Response

Characters for each community (Surface, Entrance, Deep Cave) and for stress were investigated and categorized (See Table 4.). Predictions for the effects of heavy visitation on each community were generated. Predictions for both Group 1 and Group 2 proved to be similar.

Table 4. Community and Stress Characters for Terrestrial Arthropod Communities.

Community Var.	Surface	Entrance	Deep Cave
Life Span	Short	Short/Long	Long
Generation Time	Short	Short/Long	Long
Growth Rate	Fast	Fast/Slow	Slow
Colonizing Ability	Good	Good/Poor	Poor
Trophic Levels	Many	Moderate	Few
Species Number	Many	Moderate	Few
Patchiness	Low	Moderate	High
Stress Var.			
Energy	Low	High	Moderate
Frequency	Low	High	Low
Duration	Moderate	High	Low
Timing	Dependent	Dependent	Any

The "Indicator Community"

The entrance community in Table 4. displays a bimodal grouping of characters. Any type of stress (beneficial or detrimental) will increase the r-selected portion of the population at the expense of the K-selected organisms and foster instability. The entrance community should therefore be expected to exhibit stress's effects most distinctly. The deep cave community displays the next greatest potential for change. Its characters describe a situation in which recovery from stress takes a significant amount of time. The communities' extreme spatial patchiness, however, somewhat limits the usefulness of these characters. The surface community reveals qualities that make determination of stress difficult. Superior short term generation and colonizing ability denote rapid recovery to predisturbance conditions.

Table 4. also demonstrates that direct anthropogenic stress is highest in the entrance zone. It is in this area that human traffic is most concentrated and frequent. Stress is next highest in the deep cave zone. Traffic in the deep cave is diffuse and more infrequent due to alternatives in route choice. Stress affects the surface zone the least. Travel on the surface is not restricted to certain paths, as in caves. This lowers stress's effect by spreading out the impact even further. The speculations provided by both sets of variables complement each other. They predict that stress's effects will be exhibited best in the entrance zone (community). Correspondingly, the deep cave and

surface zones (communities) have less chance for revealing underlying stress effects.

Community Indications

Originally, Group 1 established no pattern in support of the predictions (See Table 2.). All communities had similar numbers of positive incidents (1). A positive case was determined to be an incident in which all three low traffic cave sites had higher values than both heavily visited cave sites.

Subsequent results supported earlier predictions. When Group 2 was examined, two positive cases were found in the entrance community. Only one positive case was found in the deep cave community (See Table 3).

Group 1 and Group 2s' results were then lumped together. The entrance community displayed three positive incidents out of a possible 16 cases (18.75%). In the deep cave community, two incidents out of 16 cases (12.5%) were positive. In the surface community only one incident out of 8 cases (12.5%) was positive.

Results support the conclusion that heavy human visitation detrimentally affects the terrestrial arthropod entrance community more than other communities. The meager amount of positive occurrences suggests that heavy human visitation has only a slight negative effect on any of the communities.

There were no incidents of heavy human visitation having a beneficial effect on the communities.

SPECIES INDEX RESPONSE

Evenness

Evenness reflects the variations in species relative abundances, and is independent of the species count, or richness. Essentially, it is a measure of community organization. Reorganization of species dominance hierarchies usually changes community evenness (Sheldon 1969).
Lumped results for evenness (Group 1 and Group 2) show four incidents out of 10 cases (40%) being positive (See Table 2. and Table 3.). This means that in 40% of the cases, evenness was lower in both high traffic caves. For each group independently, the results were the same. Both groups had two incidents out of five cases (40%) that were positive. Findings indicate that heavy visitation negatively influences organization in terrestrial arthropod communities.

Abundance

In all cases (Group 1 and Group 2), abundance values for the heavily visited caves were similar to those of the lesser visited caves. This suggests that heavy visitation doesn't affect terrestrial arthropod cave site abundances.

Species Diversity and Richness

High diversity is usually associated with high evenness (Kormondy 1976). Sometimes this relationship reverses. According to the intermediate disturbance hypothesis, as disturbance originally increases, so does the diversity. This trend proceeds up to an point upon where the diversity starts reducing in relation to the increasing stressor. Species richness follows in the same manner. Since evenness decreases as disturbance increases, under intermediate stress levels, evenness and diversity (richness) are actually indicating opposite things. A stressful condition in this situation might be desciribed by an increase in diversity (richness) in heavy traffic sites.

Diversities' mode of change arises out of an opening up of niche space. Previously filled climax community niche space is subdivided by perturbation or stress. This open niche space is then saturated by other non-climax species. Community heterogeneity results from this. Original influx of pioneer and mid-successional species temporarily inflates both diversity and species richness. As disturbances effects compound, the amount of species that can coexist with the disturbance decreases. Frequent, high energy stresses, of long duration can erode communities completely (Freedman 1989).

Interpretation of the data on diversity and species richness is not as clearcut as that of evenness or abundance because of the intermediate disturbance effect. In this study, the actual level of disturbance experienced by the communities is not known. An arbitrary construct, the level of human visitation, was used as a replacement. Because of this substitution, results could approximate one of two cases.

The first case encompasses communities in heavy traffic areas that are receiving an intermediate level of disturbance. Results do not support the intermediate disturbance hypothesis in this case. In no situations do both heavily visited cave sites have values greater than the low traffic cave sites. Inferentially, this means that the high traffic caves have not had their diversity and richness values increased by pioneer and mid-successional species influx. Therefore, heavy human visitation (intermediate community disturbance) has no positive effect on terrestrial arthropod communities (Group 1 or Group 2).

The second case involves communities in high traffic areas that are receiving high levels of disturbance. Most of the values in heavily visited sites, resemble those of low traffic sites. This is supported by noting only one positive case out of 5 (20%) under the diversity column (Group 2 - Table 3.), and one positive case out of 5 (20%) under the richness column (Group 1 - Table 2.). Fewer positive cases indicate fewer differences between the cave sites. In this circumstance, one could say that heavy human visitation has no apparent negative effect on either Group 1 or Group 2 communities.

The Final Say?

Overwhelming evidence has not been shown to support the hypothesis that heavy human visitation has no effect on terrestrial arthropod communities. Marginal detrimental effects were seen when observing the community evenness and, to a lesser extent, the entrance. Results suggest that heavy human visitation has a slightly negative effect, if any, on terrestrial cavernicolous arthropod communities.

Further, there is no evidence to support hypotheses promoting the beneficial effects of heavy human visitation. Findings show that there is not an intermediate level of community disturbance occurring in heavily visited areas.

Analysis of both groups of data indicates that there is no difference in the effects of visitation for each group. Troglophiles and troglobites (Group 2), and entire community groupings (Group 1), respond similarly to heavy human visitation.

DISCUSSION

Sensitivity?

In current times, conservation minded cavers are acknowledging that an "un-restricted use" policy for caving may not be the proper strategy for preservation of cave ecosystems. Cave management strategies such as entrance gating are being used in several cases to limit visitation into areas deemed sensitive. In many of these, management studies are implemented before objective studies determine if any faunal damage is occurring. Recognition of anthropogenic injury to terrestrial cave biota should be the first step in a complete cave site management program.

Recognition

There are many methods one can use to recognize if a cave habitat is receiving chronic stress. These methods can be lumped into two distinct groups; caving records, and community censusing.

Caving records describe aspects particular to the trips taken into the cave habitat. These records have such variables as; date in, time in, time out, number of people, which cave explored, and cave conditions. Caving grottos usually use these records for safety purposes. These records can also function as a subjective measure of what cave is receiving more than its fair share of stress. Coupled with faunal listings and particular cave attributes this can be a very powerful management tool.

Community censusing involves direct faunal collecting to determine ecosystem impairment. For biological purposes it is a better informational tool than cave visitation records, but has obvious drawbacks. Faunal censusing in itself is an anthropogenic stress. Most current methods rely on organism death and subsequent identification. Not only does this method alter the cave communities directly, but compiled results are subject to individual interpretation. A standard method for non-invasive live faunal community censusing has not been designed as of yet. This still does not preclude the use of limited censusing as another management tool.

Treatment

If records or studies suggest cave ecosystem impairment, activities shift toward what should be done about it. Decisions have to be made to mitigate or cease the stressor if further treatments are to proceed. If mitigation or cessation is achieved, there are three directions one can choose when dealing with the damaged ecosystem.

1) The first and most economical choice lies in the implementation of a hands-off policy.
2) The second involves restoring select attributes of the community, such as the important abiotic aspects, or particular populations of organisms.
3) The third involves complete restoration of the ecosystem to predisturbance conditions.

Management and Monitoring

After treatments to the ecosystem are finished, the last phase of restoration can be implemented, that of monitoring and manipulative management. Since restoration ecology is not a predictive science, this last phase is essential.

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THE EFFECTS OF CAVE RESTORATION ON SOME AQUATIC CAVE COMMUNITIES IN THE CENTRAL KENTUCKY KARST

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ABSTRACT

During the last decade there has been an increasing interest in the restoration of cave habitats that have been modified to accommodate mans' needs, ranging from tourist trails to sewage disposal. In Hidden River Cave a positive recovery is now occurring due to the rerouting of sewage effluent through a surface pipeline. However, in Mammoth Cave, a significant troglobitic community in Cathedral Domes has declined due to restoration efforts.

The central Kentucky karst contains some of the most heavily exploited caves in the United States. Subsequent to the extensive mining of Mammoth Cave (and other local caves) for saltpeter during the early 19th century, it became a focal point of tourism. Over the course of time many central Kentucky caves, with Mammoth Cave in the lead, were heavily modified with trails, lighting and so forth, to accommodate visitation by tourists. As towns developed, waste disposal for the growing population became a major problem. Domestic waste from outhouses or septic fields could be treated by the age-old process of soil filtration and groundwater dilution without major pollution problems. However, as the population increased and other industry was solicited, the easiest method of sewage and other waste disposal was typically to put it down the nearest sinkhole.

With the environmental awareness of the 1960's, sewage treatment plants were constructed, but still fell back on discharging their effluent to sinkholes. Only during recent years has there been a pronounced interest in cleaning up the subterranean environment. Some of these efforts at cave restoration have been markedly successful, while others give the impression of "throwing out the baby with the bathwater". Herein, the effects of restoration on the South Branch of Hidden River Cave and the Cathedral Domes area of Mammoth Cave will be examined.

One would suppose that the basic tenet of cave restoration would be to bring the habitat back to that resembling its untouched state. In central Kentucky, discerning that which is "normal" is difficult, if not impossible. Most cave streams above base-level in Mammoth Cave National Park appear to contain relatively clean water, which has been verified in some cases by spot checks of their water chemistry. It stands to reason that a shaft drain stream with headwaters on the surface in forested, relatively undisturbed land within the national park will probably be uncontaminated. However, examination of the surface headwater region is definitely in order, even if it is within the boundary of the national park. The pristine appearing Shaler's Brook, in Gratz Avenue near the Historic Entrance of Mammoth Cave, is fed by water flowing from the MCNP post office, gas station and campground complex. Although reasonably clean today, this has not always been the case.

The communities found in streams flowing from upper level shafts and terminal breakdowns are fairly predictable and have been discussed elsewhere in some detail (Lewis, 1981a; 1981b; 1982; 1988a; 1988b; and T.M. Lewis 1980; 1983). Typically there will be an isopod (Caecidotea stygia), an amphipod (Stygobromus vitreus) and a flatworm (Sphalloplana percoeca). In lower level shaft drains (e.g., Mammoth River near Kentucky Avenue) crayfish are added (Orconectes pellucidus) and the isopod and amphipod present are different (Caecidotea bicrenata whitei and Stygobromus exilis, respectively). Either or both of the flatworms known from Mammoth Cave may be present (Sphalloplana percoeca, Sphalloplana buchanani). The common denominator of these communities is that all of the species named above are eyeless, highly specialized cave-adapted organisms.

In base-level cave streams in the Mammoth Cave area it is more difficult to be sure what is "normal" and what is not, since some of the larger cave rivers originate outside of the park on the sinkhole plain. In this case, it becomes of importance to differentiate streams whose headwaters are within the park (e.g., River Styx, Mystic River) versus those which flow in from the sinkhole plain (Echo/Roaring River, Hawkins River). In any case where the headwaters are not within the park a high level of suspicion must be held as to the purity and nutrient content of the water.

Typical inhabitants of the cave rivers appear to be the isopod, amphipod and crayfish also found in lower level streams listed above, along with the cavefish (Typhlicthys subterraneus, Amblyopsis spelaea), snail (Antroselates spiralis), and shrimp (Palaemonias ganteri). Again, all of these animals are troglobites, although numerous trogloxenic/troglophilic fish and other animals are common in the flooded subterranean spring conduits where they may enter from the Green River.

One of the more spectacular areas of Mammoth Cave is Cathedral Domes. At one time it was possible to enter from the surface and wind ones way to the bottom of the 130 foot high dome complex via a massive wooden staircase built to allow tourist access. With the collapse of the entrance the route was no longer used and over the course of time, the staircase fell into the shaft drain stream running across the floor of the dome. Although there is evidence of a modicum of organic debris entering the Cathedral Domes stream (twigs, hickory nuts, etc), the decaying wood from the staircase was (until recently) a nutrient windfall for the stream community. This is the only place in Mammoth Cave where I have seen such a large quantity of wood present for a food source for a stream community, albeit artificially introduced. The small Cathedral Domes stream supports the most diverse community of its type with which I am familiar in Mammoth Cave. Periodic censusing has revealed that the dominant species present are a relatively large, vestigially eyed (but troglobitic amphipod) Crangonyx packardi and the upper level isopod Caecidotea stygia. Other species present are both species of Mammoth Cave amphipods (Stygobromus vitreus, Stygobromus exilis) and both flatworms (Sphalloplana percoeca, Sphalloplana buchanani). It is noteworthy that the crayfish present in almost every stream this deep in the cave (the floor of Cathedral Domes lies beneath the contact of the Ste. Genevieve and St. Louis limestones) is absent in Cathedral Domes. This is presumably due to the 40 foot pit into which the stream plummets, up which even the most adventurous crayfish would have difficulty climbing.

The most unusual animal present in the stream at Cathedral Domes is the amphipod Crangonyx packardi. My observation in caves in the central Kentucky karst has been that this species appears in streams in which mild nutrient enrichment is present. Considering the relatively large size and vestigial eyes of this amphipod species, it appears that it is less highly adapted to subterranean life than the Stygobromus amphipods. It may be that Crangonyx packardi is unable to survive in the food poor environments present in most streams in Mammoth Cave. However, it thrives in clean, but mildly nutrient-enriched streams. Besides Cathedral Domes, this amphipod once occurred in Shaler's Brook at a time that the stream was reportedly being mildly contaminated by waste from the surface. This is no longer the case and Crangonyx packardi is now absent in Shaler's Brook. Crangonyx packardi also occurs in L&N Cave, in Cave City. Although the cave does not appear to be significantly polluted by septic waste, nor have large amounts of detritus washing into it, nitrate levels are somewhat higher than normal. This probably reflects the presence of the cave in the an agricultural area where nitrogen-rich fertilizers are being used.

With the clean-up that had been occurring in other parts of the Historic Section, I addressed in a discussion with Resource Management personnel at Mammoth Cave National Park my desire that the stream in Cathedral Domes not be disturbed by clean-up efforts. The site was not located on any tour route except the low volume "Wild Cave Tour" and it was my opinion that the unique nature of the troglobitic community outweighed the presence of the boards as an eyesore. This was agreeable to the staff of Resource Management and I was requested to place a "Do Not Disturb" sign at the research site and write a letter formalizing the request of non-disturbance of the Cathedral Domes habitat, with which I complied. Perhaps ironically, Barr (1971) pointed out the significant role that the existence of rotting boards had played in the discovery by biologists of Mammoth Cave's extensive troglobitic community.

In the autumn of 1990 I was informed that during that summer attempts were made to "restore" Cathedral domes as part of the continued clean-up and restoration of the Historic Section of Mammoth Cave. Volunteers were enlisted to gather up and carry out all of the boards from the stream passage in Cathedral Domes.

The effects of the restoration were readily apparent during a visit in November. Bootprints were everywhere in the stream and physically damaged cave animals were in evidence during the census. When compared to a November census from another year the numbers of amphipods present were down sharply, presumably due to the fact that most of them had formerly made their homes on boards.....and had been carried off and discarded as rubbish. A more lasting damage may have been the fragmentation of the wooden planks. After having been in the cave stream for several decades, the wood was in various stages of decay. Undisturbed, this made for a plentiful, but slowly released source of nutrients to the animals of the stream community. However, when pried out of the cave floor, much of the wood turned into a sawdust-like material that was found carpeting the stream bottom. This nutrient windfall supplied a microbial "bloom" on the previously clean stream bottom formerly inhabited by the various crustaceans, which were now present in greatly reduced numbers.

It would be suggested that this restoration could have been managed much more effectively with communication from the park. This interesting community could have been at least partly preserved by removing most of the boards, but leaving a couple and attempting transplantation of the fauna from boards to be removed back to the habitat. Alternately, the animals could at the very least have been transplanted back to the habitat, boards or not. As it stands, it is difficult to say what will happen given the methods (or lack thereof) which were used and the mess that was created by the "clean-up".

The other case to be discussed is the infamous Hidden River Cave, in the town of Horse Cave. The total degradation of Hidden River Cave has been documented in some detail (Quinlan and Rowe, 1977; EPA, 1981). The cave was formerly a tourist attraction famous for its large dome rooms and subterranean river. Problems with groundwater pollution became apparent in the 1920's, with the occurrence of typhoid ending the cave's use as a water source. In 1944, a creamery began discharging waste into the cave, necessitating closing Hidden River as a commercial cave. Subsequently, the Cave City and Horse Cave sewage treatment plants began discharging their effluents into the cave. The Cave City treatment plant received primarily domestic waste, while the Horse Cave plant attempted (mostly unsuccessfully) to treat a mixture of domestic sewage, creamery waste and heavy metals from a plating plant.

My biological reconnaissance of Hidden River starting in 1982 revealed that in the South Branch the troglobitic community had been extirpated. Formerly, Hidden River had been well known for its cavefish population (Bailey, 1933). Two other organisms now replaced the troglobites, tubificid "bloodworms" and sewage "fungus" bacteria. A check of the stream's oxygen level revealed only about one part per million oxygen available (i.e., nearly anaerobic conditions). The stench in the cave was over-powering.

The water quality improved below the confluence of the East Branch of the river with the South Branch. Flowing from under the entrance breakdown, the East Branch contributed water coming from both the Cave City Sewage Treatment Plant and L&N Cave (also in Cave City). However, the water travelled several miles underground prior to reaching Hidden River. In this distance some degree of purification occurred and the dissolved oxygen levels of water flowing from the East Branch were good. The combined waters of the South and East branches flowed a short distance (through a now breached dam) and formed a deep, wall-to-wall pool. In this pool the tubificid worms were present in large numbers along the edges, but the sewage bacteria were no longer present in the quantities seen upstream. Large, surface crayfish were abundant. Their presence was presumably allowed by the reasonable oxygenation of the water, and encouraged by the quantities of worms available for food.

These conditions had probably been present for decades. However, on December 16, 1989, new facilities at the Cave City and Horse Cave sewage treatment plants were dedicated. At this time the effluents from both plants were routed directly to the Green River via pipeline. Both plants have been totally rebuilt, including the installation of modern equipment for primary and secondary sewage treatment.

Four visits to examine the stream community after the rerouting of the sewage effluent have been made to date. On March 30, 1990 the sewage community remained in full bloom in the South Branch, with the stream still having the characteristic appearance of sewage graywater. During a trip six months later (October, 1990) the tubificid worms were absent, the sewage bacteria was for the most part gone and the overpowering odor was greatly reduced. No invertebrate life of any sort was present in the South Branch. However, in December, 1990 Tom Poulson and I met at the cave prior to the Mammoth Cave Karst Symposium and found that conditions had again deteriorated and the sewage community was as bad as ever. The most recent visit was on August 31, 1991 and major changes had occurred. It was obvious that oxygen had returned to the water of the South Branch and with it, the troglophilic crayfish had migrated upstream from below the dam. A census of two stream pools revealed 19 (in a 30 foot long pool) and 24 crayfish (in a 55 foot pool). As a search of the stream revealed no isopods or amphipods (the usual food of crayfish), one would assume that they were feeding on the formerly common sewage worms. Virtually all of the crayfish present in the South Branch were subadults, obviously much smaller than the huge individuals found below the dam.

Although the major source of the problems in Hidden River has now been stopped, pollutants are still possibly entering from a variety of industrial, domestic and agricultural sites, not to mention the nutrient load from decades of receiving sewage effluents. Perhaps the best that can be hoped for the recovery of the cave will be the establishment of a community similar to that of L&N Cave, which contributes its water to the East Fork of Hidden River. In L&N Cave the community includes the blind fish Typhlicthys subterraneus, the cave crayfish Orconectes pellucidus, the troglobitic isopod Caecidotea bicrenata and the amphipod Crangonyx packardi. An occasional epigean crayfish is also present.Although L&N Cave has its own problems, this community would certainly be a huge improvement over sewage bacteria and tubificid worms. A search of Hidden River downstream of the dam revealed occasional troglobitic isopods and David Foster (personal communication) has related the presence of a single cave crayfish in a side passage adjacent to the stream passage. The restocking of the cave stream from upstream in the East Branch or downstream (Hick's Cave) has started. How long it will take for troglobites to reappear in the South Branch of Hidden River Cave remains to be seen.

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STATUS OF ENDANGERED BATS IN THE EASTERN UNITED STATES

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ABSTRACT

Three eastern U.S. cave dwelling bat species are listed as endangered by the U.S. Fish and Wildlife Service; three additional species are under review for possible listing. Endangered are: Myotis grisescens, gray bat; Myotis sodalis, Indiana bat; and Plecotus townsendii, Townsend's big-eared bat. Three additional eastern U.S. cave bat species are under review for possible listing as endangered or threatened. These are: Myotis austroriparius, southeastern bat; Myotis leibii, eastern small-footed bat; and Plecotus rafinesquii, Rafinesque's big-eared bat.

Three eastern U.S. cave bat species -- the gray bat (Myotis grisescens), the Indiana bat (Myotis sodalis), and Townsend's big eared bat (Plecotus townsendii) -- are listed as endangered (i.e., in danger of extinction throughout all or a significant portion of their range) by the U.S. Fish and Wildlife Service, as well as by most state wildlife agencies. The gray bat and Indiana bat are considered endangered throughout their entire ranges, while only the two eastern-most subspecies of Townsend's big-eared bat are presently listed as endangered. These are the Virginia big-eared bat (P. t. virginianus) and the Ozark big-eared bat (P. t. ingens).

Three additional eastern U.S. cave bat species are under review for possible listing as endangered or threatened. These are the southeastern bat (Myotis austroriparius), the eastern small-footed bat (Myotis leibii), and Rafinesque's big-eared bat (Plecotus rafinesquii). Although not listed as endangered or threatened by the U.S. Fish and Wildlife Service, the remaining four eastern U.S. cave bat species 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 U.S. 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 2 to 3 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 U.S. Fish and Wildlife Service has had Recovery Plans prepared for the Indiana bat and the gray bat by a Recovery Team comprised of bat experts. A Recovery Plan for the Ozark big-eared bat and the Virginia big-eared bat has also been written. Certain protective management measures have already been taken, as recommended in the Recovery Plans. These include gating or fencing important bat caves and placing of warning/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 of up to $50,000 for each violation.

Several state and federal agencies and organizations are now actively involved in bat conservation. These include state wildlife and conservation agencies, U.S. Fish and Wildlife Service, U.S. Forest Service, National Park Service, U.S. Army Corps of Engineers, Tennessee Valley Authority, state parks, natural heritage commissions, Nature Conservancy, National Speleological Society, Cave Research Foundation, American Cave Conservation Association, and Bat Conservation International. Members of several other organizations and numerous private landowners and other individuals are also involved. All are to be commended for their efforts.

The following accounts contain information on status of endangered eastern U.S. 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 percent 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 ft^2. They choose hibernation sites where temperatures average 42 to 52 degrees 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 degrees 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 percent 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 2 miles, and usually less than 1 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 ft 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 percent decline in Kentucky (Rabinowitz and Tuttle 1980), a 72 to 81 percent decline in Missouri (LaVal and LaVal 1980), a 61 percent decline in Arkansas (Harvey 1986), and a 76 percent decline in Tennessee and Alabama (Tuttle 1979).

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 400,000, with more than 85 percent hibernating at only seven locations -- two caves and a mine in Missouri, two caves in Indiana, and two 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 degrees F and with relative humidities of 66 to 95 percent (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 ft^2, although as many as 480 per ft^2 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 1/2 mile of creek. Foraging habitat was confined to air space from 6 ft to ca. 95 ft 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 percent decline from 1983 to 1989.

VIRGINIA BIG-EARED BAT--Plecotus townsendii virginianus

and

OZARK BIG-EARED BAT-- Plecotus townsendii ingens

The endangered Virginia big-eared bat occurs only in certain sections of Kentucky, Virginia, West Virginia, and North Carolina. The total population of this race is estimated to number approximately 10,000.
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 1700. Approximately 1400 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 and Virginia big-eared bats are so rare, little is known about their respective biologies. However, much is known about the species in other parts of its range, most of which may also apply to Ozark and Virginia 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.

Virginia and Ozark big-eared bats hibernate in caves (sometimes mines) where the temperature is 54 degrees 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.

Virginia and 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).

Virginia and Ozark big-eared bat pups are large at birth, weighing nearly one-fourth as much as their mother. They can fly in 2 1/2 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).

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DESIGN IMPROVEMENTS FOR GATING BAT CAVES

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ABSTRACT

The author will present updates on site selection, and the latest design and construction techniques for bat gates on endangered species bat caves.

Since the introduction of the angle iron gate in the late 1970's and through the mid 1980's, the design underwent many changes. The Low air flow restriction gate was introduced in 1982 and became known as the C.C.I. Bat gate. This design was refined over the next few years, but has changed little since the mid 1980's. Construction techniques have improved greatly in recent years allowing easier and quicker construction.

The basic design criteria for bat gates have been the limiting factors in design development. The spacing of the horizontal bars must be such that bats will freely pass through the gate, but they also must prevent human passage. This requirement severely limits the range of horizontal bar placement. The strength of the material of the horizontal bars determines the spacing of the vertical columns.

The design of the mid 80's required a vertical spacing of 5 1/8 inches, and the maximum distance between columns was not to exceed four feet. This maximum distance has been increased to five feet by increasing the thickness of the horizontal bars from 1/4 inch to 5/16 inch. The use of greater spans also provided the vandal with a sufficiently long lever arm to break the welds at the connection point on the columns. This was the basic design until 1991.

Drawbacks of the Old Design

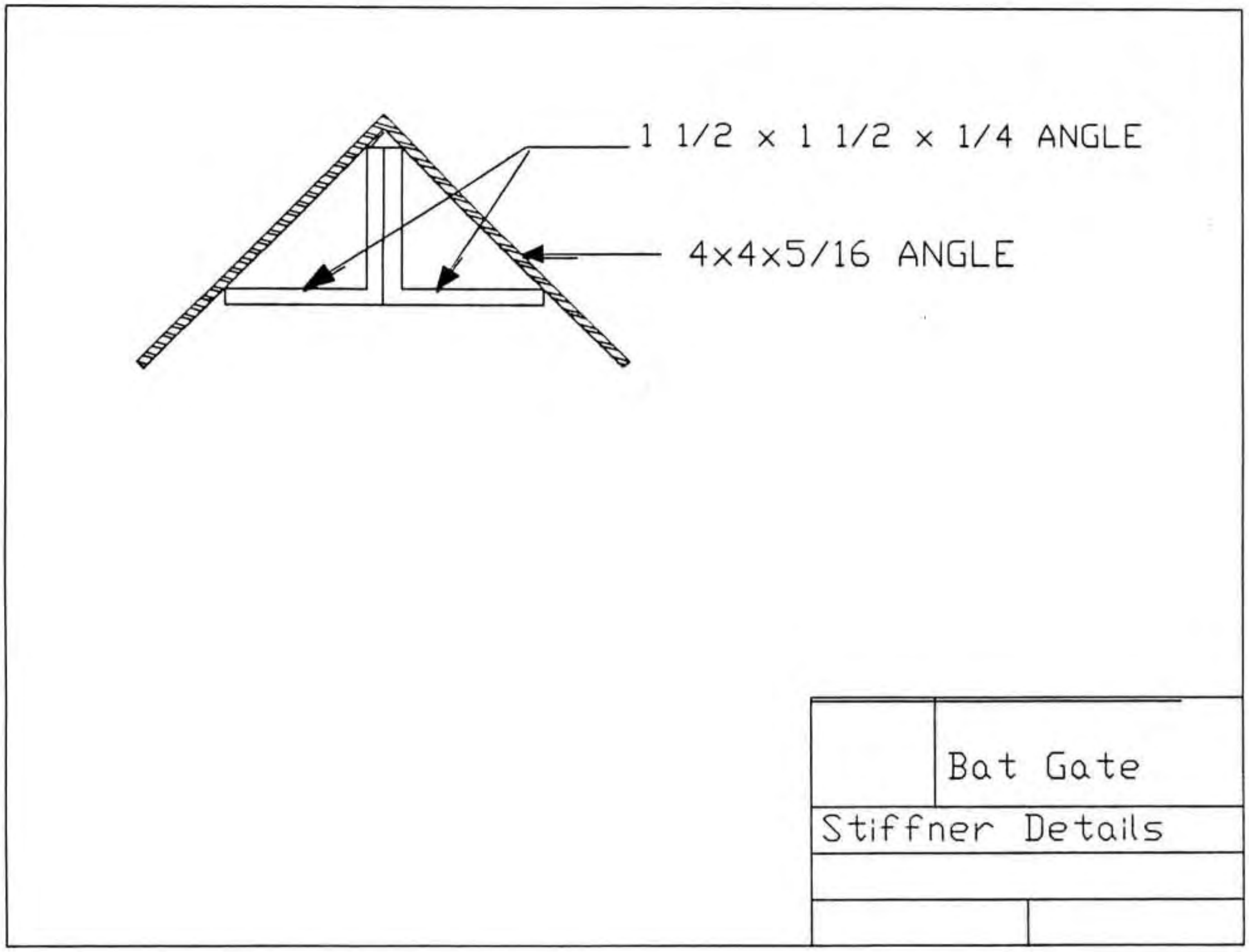
Bats have a greater sensitivity to vertical bars than to horizontal bars. It is desirable to have the vertical columns as far apart as possible. The previous design limits this spacing to a maximum of five feet. The amount of cutting and welding for this type of gate is time consuming. Closure of the distance between the end columns and the irregular walls of the cave is always difficult and time consuming.

Construction of this type of gate required a sill plate set into a concrete foundation. Concrete is a major problem in remote and inaccessible sites, usually requires many hours to construct, and was labor intensive.

The New Design

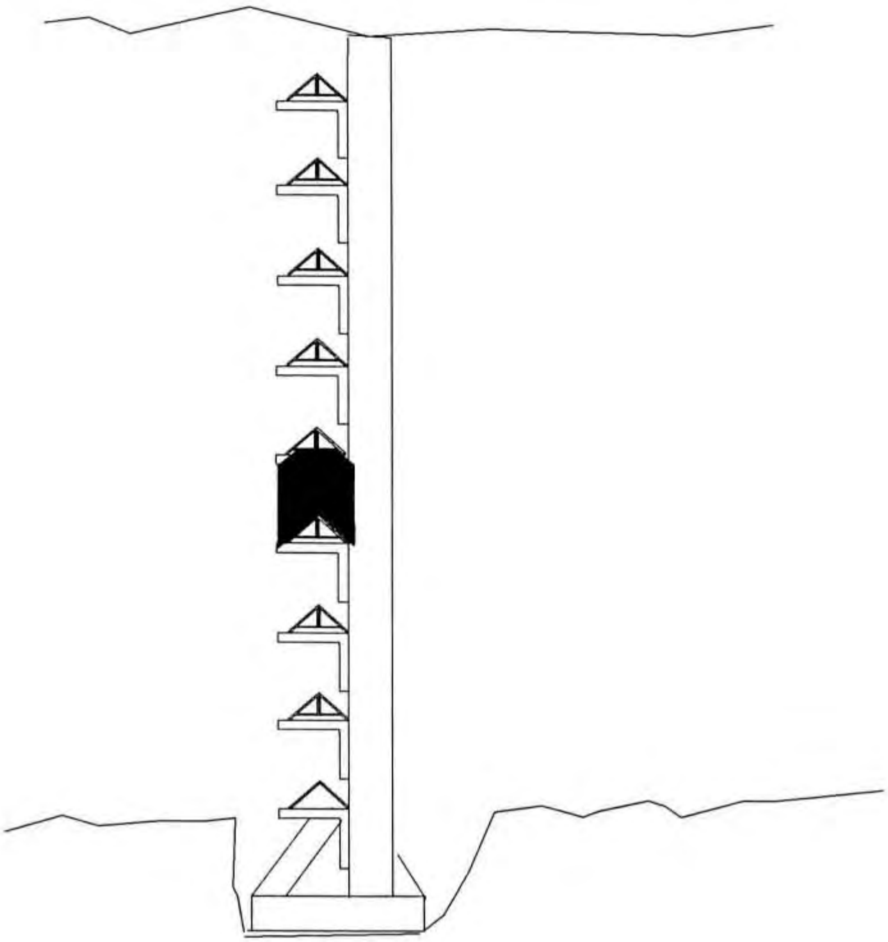
In May of 1991 a new design was used in the construction of a bat cave at Mountain View, Arkansas. This was a very large gate which was only a few square feet shy of being as large as the Hubbard gate in Tennessee. Although not as high as the Hubbard gate, the Arkansas gate was wider. The Hubbard gate required over 10,000 man-hours to construct. Using the new design and new construction techniques, the Arkansas gate only required 405 man-hours to construct.

The Arkansas gate was constructed without concrete. Although this is not the first gate constructed in this manner, it is the largest. The sill plate which was a 6 x 6 x 1/2 inch angle, was leveled with jacks and supported by steel footers attached to bedrock. A steel skirt extended in front of the gate for several feet to prevent tunnelling under the sill. The size of the horizontal bars has not increased from 4 x 4 x 5/16



(Fig. 1)

inches, but 1-1/2 x 1-1/2 x 1/4 inch angles (stiffeners), were placed inside them (Fig. 1). This allowed the distance between vertical supports to be increased to 10 feet. The distance between the horizontal bars was increased to 5-3/4 inches. The horizontal bars extended from one central column to each side, a maximum of thirty feet on the front of the gate and twenty five on the side. On the front section of the gate compression plates were used for each 10 foot span instead of rigid columns. This increases the available area for bat passage and greatly decreases the amount of cutting and welding required. The central column was increased in size from 5 x 5 x 5/16 to 6 x 6 x 1/2 angle. This prevents the horizontal bars from extending past the front and back of the column exposing sharp edges which must be removed. 6 x 6 x 1/2 angle was also used to frame the door. This allowed the entire locking mechanism to be protected inside the frame and greatly reduced the construction time of the door and locking mechanism.



(Fig. 2)

On the side section of the gate two 4 x 4 x 5/16 inch columns were attached every ten feet to the back of the sill plate and the horizontal bars were attached to these posts with hangers. Compression plates were then installed to prevent levering of the bars (Fig. 2).

From this experience in Arkansas it became apparent that the design and methods used was vastly superior to the old design and old construction methods. The amount of effort required to construct a gate now becomes mainly a function of the height instead of the height and the width. The distance between verticals has doubled. The problem of weld sheer has been eliminated. Closure has become automatic. Cutting and welding has been greatly reduced thereby reducing the amount of gasses and weld rods required. The overall strength of the gate has been increased.

In July of 1991 using Indiana Karst Conservancy personnel a second gate of this design was constructed for the Indiana Park Service and Indiana Division of Natural Resources at Wyndotte Cave. This construction took place during the busiest weekend of the year. All tourists had to pass through the gate while it was under construction. Despite this handicap the construction was completed in record time with minimum personnel.

CAVE GATES: DESIGN AND CONSTRUCTION CONSIDERATIONS

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ABSTRACT

When asked to do this paper I had originally hoped to be here to illustrate with pictures, slides,and models what a good gate would look like but unfortunately circumstances make it impossible to be with you today. I seek not recognition by this but rather to reduce..through knowledge...the wanton destruction of some of our finest caves as well as the damage that can be done by people who just don't know any better.

In our world today with so many regulations and litigations we hate to think about making new restrictions and especially on our recreation. Regulations often have the effect of turning people off to a sport or making enemies out of those who's job it is to protect us from our world...granted we should not be restricted from everything in life that is fun but there are times that we need a little slowing down. That is where a well constructed cave gate comes in.

REASONS TO GATE

There are three good reasons for gating caves.

1. PROTECTION FOR CAVE LIFE
A cave gate can be a boon to the life within the cave as it protects bats and other cave life from intrusions during periods of hibernation and nursery. As such it needs to also allow for the passage of these animals during times of forage or other activities outside the environment of a cave. A gate of the proper dimensions can allow for the passage of cave life during these times and still offer protection. Just as it is important to close roads during certain times of the year to insure the migration of elk we also need to protect our friend the bat...mother nature's little debugger and fertilizer.

2. PROTECTION FROM VANDALISM
Caves aren't very pretty when people write their names all over the walls or remove the formations for sale at the road side stand. In the case of limestone caves with enough time and the right conditions the formations may grow back in a hundred years or maybe a thousand. In the case of a lava tube however once destroyed the formations will never be seen again in our lifetime.

3. SAFETY
In many cases the hazards involved in caving are no problem to the well informed and well equipped caver, but when Mom and Dad and the kids wander in just looking for something to do the hazards can be multiple and insurmountable. Knowing for instance that a pit is just around the corner at the bottom of a slide would avoid a nasty accident, or knowing that you need a map to find your way in or out would be helpful. In these cases gates offer the manager an opportunity to make the explorer aware of dangerous or sensitive areas.

TYPES OF GATES

As with any mechanical device there are many different approaches to building and designing cave gates. However it has proven over the years that only one kind really makes sense....those that are tough. Gates that are weak serve little purpose besides to harass the very creatures that they are designed to protect, and in the vandals mind how dangerous can a cave be if the gate can be breached with a few hammer blows or a hack saw. We will discuss some of the lesser designs here and some of their problems.

CHAIN GATES

Chains stretched across the opening of the cave, various locking schemes. Good points - lots of air flow, holes usually allow bats to fly through and if not the reality is that the bats will probably be able to go through unimpeded after the first guy with a hack saw comes through. Bad points - weak and sometimes hard to figure how to rewrap the chains to block the entrance. Easy to breach. Chains heavy enough to deter the vandal are usually too heavy to hang back in place.

FENCES

Usually of the chainlink variety at or near the entrance. Good points - can be built to allow bats access above the fence, good air flow. Bad points - can impede bat flight by restricting them to a smaller area above the gates. These gates usually fall victim to the first group of scouts with wire cutters.

REBAR GATES

Rebar used to form jail like gate and door...Good points - easy to construct, can be made bat safe, looks real neat when done. Bad points - easily breachable, in a notable case in Idaho a rebar gate was breached so often that the only ones that stopped for the key were conscientious cavers as a courtesy to the Parks service.

When the new gate was built, two men and a 10 year old boy removed the entire gate and all traces of its existence with two sledge hammers and a hack saw in thirty minutes. It was 4' x 15'.

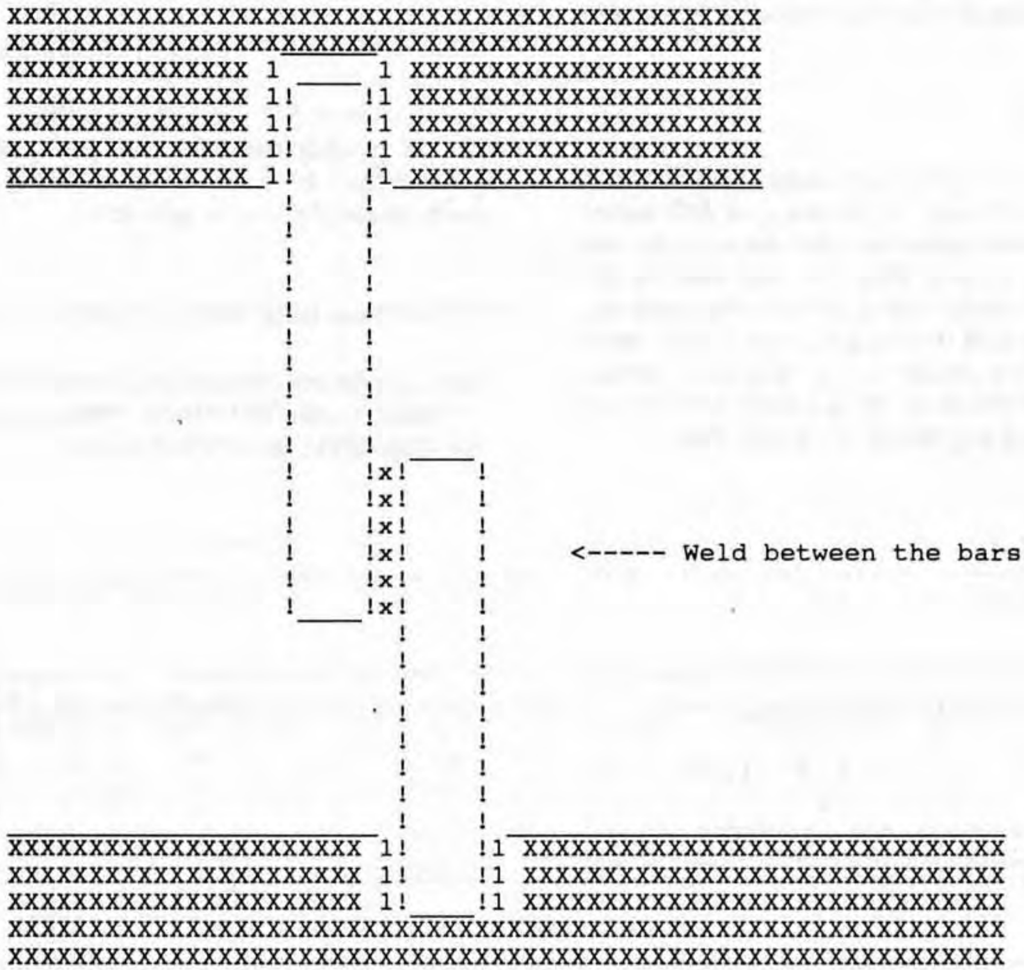
WEAK LINK GATES

In some areas of the country and in the NSS manual on cave gating weak link gates were thought to be a great idea. The idea was to build a gate and build in a portion of the gate that was easily breachable. The idea being when the vandal comes in to the gate he just breaks the weak link and spares the gate. Good points- saves the gate from having to be rebuilt except when visited by really dumb vandals. Bad points - Sort of like leaving your car locked with the window down so the thief won't break your window when he comes in to steal your CD player. No doubt a really determined thief/vandal will get in if they want to but why let everybody have a crack at it. Liability is the biggest worry with this type of gate. Imagine yourself as an attorney for an instant...My client didn't think this cave was dangerous because the gate was meant to be breached that's why we're suing for his injuries when he fell down the pit...or... my client had no idea any one would be coming by to lock the gate since it was open when he came in, he didn't have any tools to break the gate so he waited helplessly for 6 days before someone came by to rescue him. It is quite obvious that gates need to be strong so that when used properly accidents and litigation can be decreased or avoided entirely for the most part. In reality weak link gates have no place in our society. Strong defendable gates are better but no guarantee that the determined individual will not gain access. No gate can withstand the truly dedicated cave vandal but at least we should try to make the job tougher for him. If it takes extra time or special tools for him to break in we have at the very least reduced the number of potential vandals as well as increasing the chance of them being discovered in the act of breaking in to the gate.

HOW TO MAKE IT DIFFICULT

One of the easiest ways to make it difficult for the vandal is to choose a defendable position for the gate..examples of a defendable position include - placing the gate far enough from the entrance that it can't easily be reached with standard length torch hoses, 150 -200 feet will usually cut down on the use of standard size torch tanks because of their weight and difficulty in transporting them over rough terrain....Locating the gate in a smaller portion of the cave will make harder to break too. For the vandal trying to take the tools of destruction into a small crawlway and work in cramped quarters may be just enough to discourage them. Nobody likes having to drag equipment any farther than they have to build a gate but with enough volunteers the job can go amazingly fast and at least in our area has on occasion brought new cavers closer to the old dogs of the sport. In addition to bringing cavers together it also gives everybody the chance to meet you, the land manager and learn that you're really just a person who cares about the resource, not the Ogre that wants to keep them out of the cave. Having played a part in

FIGURE 1. ANCHORING THE GATE



producing a gate often times brings cavers to a better understanding of why the gate needs to be in place and they become more cooperative about playing by the rules. Use a little caution when choosing where to place a gate though, don't create booby traps or place the gate in a situation that the vandal will get injured when trying to break in. Another way may be to build a second gate just beyond the first gate so that after the first one is breached the vandal will have to break another one just beyond, again increasing the time it takes to get through and increasing the chance of being caught in the act.

PSYCHO LOCKS

One of the most effective deterrents that is available to you in building the gate is the psycho lock. Simply put..use two locks, one visible (for the vandal to shoot at) and one that's hidden. A psycho lock is a lock that looks like it opens the gate and could be removed with a little effort,(don't make it too easy). the idea being that after the vandal finally succeeds in removing this lock (hacksaw, bars, bolt cutters, bullets, etc.) the gate still won't open and he may feel that because of his efforts the gate is now jammed for good and he will go away.(In a notable case in Idaho this psycho lock worked extremely well, it was shot off with about three boxes of twenty two shells fired from ten feet away. All this time the hidden lock, well protected, prevented entry.

ANCHORING

Part of making your gate impregnable is to anchor it well. one of the best ways to do this is to drill anchor holes into the rock, anchor the gate every two to four feet all the way around. Drill one inch holes in the ceiling and floor, install one inch rod in the upper and lower holes and weld them together where they meet. This makes a firm anchor that is difficult to defeat, protect this by building an upright box from four inch angle iron welded together at the seams. These protected uprights then become the supports for the crossbars of the gate. The crossbars are anchored to the sides of the cave in a similar fashion.

DISTANCE BETWEEN UPRIGHTS

Leave at least 24" but not more than 48" between vertical uprights, this allows bats plenty of room to fly between them but not so much room that a vandal can easily spread the bars to gain access.

DISTANCE BETWEEN HORIZONTAL BARS

Leaving a distance between horizontal bars of 6"+- 1/4" will allow the bats and critters room to go between but will stop all but the smallest cavers.

```
    [------------------- 48" ----------------------------]
 ! !                                                     ! !
 ! !-----------------------------------------------------! !
 !---------------------------------------------------------!
 ! !          !                                          ! !
 ! !        6 +- 1/4"                                    ! !
 ! !          !             48"                          ! !
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 ! !                                                     ! !
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ORIENTATION OF HORIZONTAL BARS

Horizontal made of four inch angle iron should be oriented so that air will pass by them with the smallest amount of turbulence.

PREFAB GATE SECTIONS

This type of gate also lends itself well to prefabrication, that is building the gate or sections of it prior to installation. Not only does the job of installation go quicker but by prefabricating sections it reduces the chances that a vandal will come by between construction times and figure out any hidden locking mechanisms.

SLIDING BAR LOCKING MECHANISMS

Doors in the gate can be made by building one or more crossbars that slide horizontally creating an opening in the grid. Bars that slide from side to side leave no edges that can be pried on to gain entry.

CROSS SECTION VIEW OF HORIZONTAL BARS

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       / /\ \
     / /    \ \
   / /        \ \
  /_/    ___   \_\
          !
          !        <-----    6" +- 1/4"
          !
         /\
       / /\ \
     / /    \ \
   / /        \ \
  /_/          \_\
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HARDENING OF THE GATE

Gates can be hardened by using a special type of welding rod along the edges of the gate that will reportedly take the teeth off a hacksaw. Check the local welding supply for the best choice of hardening rod.

ADDITIONAL INFORMATION

More detailed drawings and additional information is available at no charge from Jim Hathorn, 1227 Vivian Avenue, Boise, Idaho 83704, (208) 376-7317 or (208) 376-3582.

Your comments positive or negative are also greatly appreciated.

RESPONSES OF WINTER POPULATIONS OF THE FEDERAL ENDANGERED INDIANA BAT (MYOTIS SODALIS) TO CAVE GATING IN KENTUCKY

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ABSTRACT

During the past decade, winter populations of federal endangered Indiana bats (Myotis sodalis) have been monitored intensively at most of the known hibernacula located in Kentucky. This effort has resulted in the documentation of population trends for this species in individual caves throughout most of the state.

Historic information available from past bat censuses at several large hibernacula, coupled with the earliest counts at many sites that have been relatively recently discovered, indicates that Kentucky caves once harbored at least 300,000 Indiana Bats during the winter months. By 1981, numbers had fallen to just under 100,000, and by 1991, only about 84,000 Indiana Bats remained in Kentucky hibernacula (source: census data compiled by the author). The majority of the population losses have occurred at four caves (Bat Cave in Carter County, Coach Cave and Long Cave in Edmonson County, and Line Fork Cave in Letcher County) which, if taken together, once held about 260,000 Indiana Bats (1960's). The composite population of these four caves had dropped to about 68,000 by 1981, when the author began to systematically census Kentucky's Indiana bat hibernacula, and had further declined to about 54,000 by 1991.

At the time that the Indiana bat was first proposed and listed as an endangered species, most bat biologists felt that the major reason for the widespread population declines in the species was human disturbance to hibernacula during the winter months. In an effort to halt such disturbance, cave gates have since been constructed at the entrances to several Kentucky caves specifically to protect hibernating Indiana bats.

For two of these caves (Bat Cave and Ash Cave), the major goal of the gating process was the exclusion of human intruders; the general feeling among those who planned and built the gates was that the bats would be able to maintain themselves indefinitely if winter disturbance and vandalism (direct killing of bats) could be eliminated. At Bat Cave, passable bat flyways were provided above both gate doors but virtually no consideration was given to the possible impacts of the upper and lower gate structures on the cave microclimate. At Ash Cave, the winter cave microclimate was maintained but the gate design necessitated that most bats had to actually land on the gate to enter the cave.

The overall state of our knowledge of winter bat ecology, and of the potential impacts of poorly-designed cave gates on hibernating bat populations, has increased considerably in recent years. Much of the current information that is available, in fact, has come to light as a direct result of cave gating projects that have inadvertently had severe adverse impacts to the very bats that the gates were designed to protect! Both Bat Cave and Ash Cave were regated in the 1980's, and three additional Indiana bat caves in Kentucky have been gated since then, in such a manner as to allow the free flow of air and water and the free flight of bats into and out of the caves.

Eight other Kentucky caves which contain Indiana bats during the winter months have been gated for various reasons not necessarily related to bat protection. Two of these caves (Coach Cave and Long Cave) contain gates and other entrance structures which have had, and continue to have, significant negative impacts on Indiana bat populations. The remaining six gated caves all contain relatively small winter colonies of Indiana bats; the cave gates are reducing human disturbance and maintaining these colonies but the caves themselves offer such marginal winter habitat that there is little hope that bat populations will ever increase here. Hibernating populations of Indiana bats have now been documented at 78 different caves in Kentucky. Thirteen of these have been gated. Thirty-five Kentucky caves have had winter populations of 100 or more Indiana bats; fifteen of these have harbored populations in excess of 1,000. Documented events that have negatively affected Kentucky hibernacula during the past 30 years (in addition to poorly-constructed cave gates) have included flooding at three caves, the building of fires in the entrance areas at four caves, and the direct killing of bats by vandals at five caves. Flooding may not be preventable unless, as in one case in Kentucky, it is caused directly by the mismanagement of the land directly above cave passage. Fire building and the direct killing of bats by vandals, however, are entirely preventable by the use of gates - making cave gating an extremely valuable tool in the management of winter Indiana bat populations.

The purpose of this note is to present the available information on the responses of Indiana bat winter populations to cave gates - both properly and improperly designed - so that individuals, organizations, or agencies that are considering the gating of bat caves might be able to better predict how this species might respond to such conservation efforts in the future.

A. CAVES WITH GATES DESIGNED FOR INDIANA BAT PROTECTION.

As of October, 1992, five caves in Kentucky have been gated with angle iron gates designed by Roy Powers (American Cave Conservation Association) and Robert Currie (U. S. Fish and Wildlife Service). Indiana bat population data are available for three of these caves - Bat Cave in Carter County (original gate constructed about 1970; re-gated summer 1983), Ash Cave in Lee County (original gate built in the mid-1970's; re-gated summer 1989), and Cave Branch Cave in Menifee County (gated summer 1989). A fourth cave - Line Fork Cave in Letcher County - was gated during the summer of 1991 but has not been completely censused since that time. The fifth cave - Well Cave in Menifee County - was gated during the summer of 1992 and also has not as yet been censused for bats with the cave gate in place. Indiana bat population figures for the three caves for which post-gate population figures are available are presented below:

CAVE NAME/COUNTY

1. Bat Cave, Carter County

DATE(S)	INDIANA BAT NUMBERS
15 Jan 1957	100000
15 Jan 1960	100000
15 Jan 1962	100000
Original Cave Gate Constructed (1970?)	
15 Jan 1974	40000
15 Jan 1975	40000
15 Jan 1981	51500
26 Jan 1983	43500
Angle Iron Gate Constructed (1983)	
23 Jan 1985	36450
10 Feb 1987	37600
7 Feb 1989	45280
28 Jan 1991	49575

Bat Cave, located at Carter Caves State Resort Park, is owned and managed by the Kentucky Department of Parks and is also (since about 1980) a Kentucky State Nature Preserve. Bat Cave was originally gated by the Department of Parks sometime around 1970 to protect the large Indiana bat hibernaculum there shortly after vandals had entered the cave and killed about 10,000 bats (Engel et al., 1976). Gates were placed on both the upper and lower entrances; extensive rockwork was used to block most of each entrance and door-sized metal bar gates were installed. The rockwork associated with these gates seriously impeded the flow of cold air through the cave in winter, altering winter microclimate regimes and raising both relative humidity levels and winter temperatures in the sections most heavily used by hibernating Indiana bats.

The precipitous drop in the winter Indiana bat population of Bat Cave - from about 100,000 in the 1960's to about 36,500 in 1985 - can probably be attributed almost entirely to the design of the original cave gates. These gates and their attendant rockwork were torn out during the summer of 1983 and replaced with massive angle iron gates that extended the width of the entrance passages. The new gates allowed the original winter air flow patterns to be restored throughout Bat Cave. The gradual increase (13,000 over 8 years) in the Indiana bat winter population of the cave since that time can probably be attributed directly to this regating project.

It should be noted that bat counts that were made prior to 1983 generally tended to be "eyeball estimates" of the wintering Indiana bat population in Bat Cave. Counts from 1983-1991 were conducted by Indiana Bat/ Gray Bat Recovery Team leader Rick Clawson (Missouri Department of Conservation) and are felt to be both precise and consistent.

2. Ash Cave, Lee County

Original Cave Gate Constructed (1975?)

17 Jan 1984	132
16 Feb 1988	104

Angle Iron Gate Constructed (1989)

19 Jan 1990	78
6 Feb 1992	73

Ash Cave is located on lands owned and managed by the Daniel Boone National Forest. Prior to the construction of the original gate, the cave was regularly visited and vandalized - nearly every rock formation had been broken off and carried away and the cave floor was pitted extensively where visitors had illegally dug for artifacts.

The original cave gate permitted good air flow but was virtually impassable to bats unless they landed on it and crawled through. This gate was also easily and frequently violated by "pot hunters" and local residents. At the time it was gated, this was the only known Indiana Bat hibernaculum in the Daniel Boone National Forest.

A new gate for Ash Cave was planned and constructed during the summer of 1989. The rationale for building it included the slowly decreasing Indiana bat population in the cave, the frequency with which the existing gate was violated, the difficulty provided by the existing gate to the free traffic of bats, and the extensive amounts of faint ceiling stains that were observed in the cave (possibly indicating the former existence of a large winter bat colony there).

The new gate has been effective at keeping humans out of the cave; many broken and damaged cave formations are beginning to recover but the Indiana bats have not increased in numbers. Since rebuilding the Ash Cave gate, we have checked winter temperatures and humidity levels throughout the cave and determined that only a relatively small section of passage is capable of meeting the winter needs of Indiana bats (midwinter temperatures 4-8 degrees C; relative humidity less than 100%). In fact, the only portion of the cave that seems suitable for hibernating Indiana bats is a low section beneath a ledge - well within the reach of a raccoon and thus making the bats that roost there very susceptible to predation.

There are two additional large (1000+) Indiana bat hibernacula nearby (within a mile). Disturbance to both of these has been appreciably reduced in recent years - each has been marked with USFS bat signs and caving groups have been cooperative in leaving the caves alone during the winter months. It may be that bats that had been disturbed at these other caves once moved into Ash Cave in mid-winter and that Ash Cave no longer functions as a refugium for these bats.

3. Cave Branch Cave, Menifee County

30 Dec 1983	176
19 Dec 1985	282
9 Feb 1988	354
1 Dec 1988	366

GATED 1989 SUMMER

19 Jan 1990	418
16 Jan 1992	618

Cave Branch Cave is also owned and managed by the Daniel Boone National Forest. The cave was ungated until after it was acquired by the Forest Service (with assistance from The Nature Conservancy) in 1989. The cave was previously visited fairly frequently by vandals - fresh trash and spray paint graffiti was always observed during bat census visits.

A temperature profile of Cave Branch Cave was made during the winter of 1988, prior to cave gate construction, by the author and Robert Currie. Winter temperature data indicated that the one large room in the cave where Indiana bats were known to hibernate had the potential to harbor several thousand additional bats. There has apparently been a good Indiana bat response to the gating of this cave.

B. CAVES WITH INDIANA BAT POPULATIONS THAT ARE NEGATIVELY IMPACTED BY GATES AND OTHER STRUCTURES

1. Coach (Hundred Dome) Cave, Edmonson County

15 Jan 1960	100000
15 Jan 1975	4500
15 Jan 1982	550
27 Jan 1983	600
21 Jan 1985	424
11 Feb 1987	250
8 Feb 1989	50
29 Jan 1991	48

The privately owned and managed Coach Cave is located at Park Mammoth Resort. The upper entrance to the cave was completely closed when a gift shop was constructed over it in the early 1960's. This structure effectively halted the flow of cold air into the lower entrance during the winter months by preventing the upper entrance from functioning as a chimney in cold weather. Without the warm air rising and escaping through the upper entrance, cold air from outside was not longer being pulled into the lower entrance to maintain the low temperatures required by the bats. In addition to warming the critically important hibernation passages, the presence of the gift shop prevented many of the incoming bats from gaining access to Coach Cave through their preferred entrance route.

The gift shop burned two years after it was constructed. If the debris that was left had been cleared away immediately afterward, or even within a few years after the fire, the Indiana bat population in Coach Cave might have been well on the way to recovery by now. Unfortunately, the upper entrance has remained almost entirely blocked by sheet metal and foundation debris, the Indiana bat section remains too warm in winter for the bats, and the ever dwindling population has probably fallen to such a low level that recovery is virtually inconceivable. The remnant winter Indiana bat population uses a small pit area near the lower entrance as a hibernation site.

2. Long Cave, Edmonson County

15 Jan 1947	50000
15 Jan 1953	22000
15 Jan 1962	2000
15 Jan 1969	6000
15 Jan 1978	5057
16 Feb 1982	7527
21 Jan 1985	3717
12 Feb 1987	2801
7 Jan 1988	2646
12 Jan 1989	2669
1 Feb 1991	1249

Long Cave is owned and managed by the National Park Service and is located within Mammoth Cave National Park. The present cave gate has been in place since some time prior to 1982. The cave entrance lies at the bottom of a steep sinkhole. A thick concrete wall blocks most of the natural opening; a metal gate has been built to fit a 2 x 3 foot opening in the wall. The concrete wall seriously impedes the flow of air into Long Cave, and the gate is difficult for bats to fly through (we have used night vision equipment to observe and videotape bats that are attempting to pass through it in late summer). The gate is due for replacement in early summer of 1993. Bob Currie (USFWS) has obtained maximum and minimum temperatures throughout the year at a number of points in the cave, and some data on Indiana bat cluster sizes and roost locations is also available. This will allow good documentation of the impacts of the rebuilt gate on the recovery of the winter population.

C. OTHER GATED CAVES THAT HARBOR INDIANA BATS

1. Thornhill (Wind) Cave, Breckinridge County

8 Dec 1963	3680
Winter 1977	0
27 Feb 1986	82
13 Jan 1987	71 (66 dead)

Thornhill Cave is privately owned. The winter Indiana bat population in this cave was a large one until most of the bats were killed by flooding in the mid-1960's (DeBlase et al., 1965). Bat populations in Thornhill Cave never really recovered after the flood; there were still fewer than 100 Indiana bats in the cave when it was censused in 1986. Vandals entered Thornhill Cave in midwinter of 1987 and killed most of the bats that were hibernating there, including at least 66 Indiana bats. Only five living Indiana bats were found when the cave was censused during the recovery of the carcasses.

The cave was gated with a round bar gate by members of the Louisville Grotto shortly after the bat kill had taken place. The bat population there has not been censused since that time. The lack of bat recovery here after the flood event of the 1960's (thru 1986) indicated that it may be virtually impossible for Indiana bat populations to recover in some caves after a certain low population point has been reached.

2. Saltpeter Cave, Carter County

28 Jan 1983	13
10 Feb 1987	39

Saltpeter Cave is owned and managed by the Kentucky Department of Parks (Carter Caves State Resort Park). This cave is open for tours throughout the year; there is a small but variable winter Indiana bat population that hibernates in pockets in the ceiling near the entrance. A large room-sized cage gate stands above the entrance, permitting the free flow of cold air into Saltpeter Cave in winter.

3. Bat Cave (MCNP), Edmonson County

19 Dec 1959	present
27 Mar 1960	present
16 Feb 1982	212
20 Mar 1985	66
4 Feb 1987	70
1 Mar 1990	57

Bat Cave is owned and managed by the National Park Service and is located at Mammoth Cave National Park. The round bar gate on this cave permits good air flow and bat access. The cave itself, however, does not appear to offer good conditions for hibernating Indiana bats; much of the passage is too warm and/or humid to support heavy winter use by this species.

Bat Cave contains some extensive deposits of bat bones. These can be seen in layers (interspersed with layers of silt) in crawlways near the entrance. It has been postulated that these are the bones of Indiana bats which have been trapped in the cave and drowned by flooding from the Green River. If this is the case, then Bat Cave probably once had either a radically different upper passage configuration, or else have had at least one additional entrance, that would have allowed the development of suitable Indiana bat temperature and humidity regimes during the winter.

The interspersion of the bat bones with other layers of sediment would seen to indicate that several different flood events had taken place here over time. The dozen or so bat skulls that the author has examined in Bat Cave have included those of big brown bats (Eptesicus fuscus) and Eastern pipistrelles (Pipistrellus subflavus) in addition to those of bats of the genus Myotis.

4. Colossal Cave, Edmonson County

15 Jan 1953	6000
17 Feb 1982	349
20 Jan 1985	445
12 Feb 1987	498
13 Jan 1989	614
1 Feb 1991	556

Colossal Cave is also located at Mammoth Cave National Park. The present cave entrance is artificial; it was constructed after the original entrance collapsed and became filled with rubble some time after 1953. The existing cave gate does not seem to be impacting Indiana bat numbers in Colossal Cave; the entrance takes in a considerable flow of cold air in winter and the section of the cave used by the bats appears to be capable of harboring a much larger population than is presently there. The fate of the fairly large colony of

6,000 Indiana bats that inhabited Colossal Cave prior to the entrance collapse is unknown.

5. Jesse James Cave, Edmonson County

15 Jan 1980	1293
27 Jan 1983	700
21 Jan 1985	230
11 Feb 1987	160
6 Jan 1988	30
8 Feb 1989	75
29 Jan 1991	1

This privately owned and managed cave, like Coach Cave, is located at Park Mammoth Resort. Jesse James Cave serves as a major (USFS Priority I) hibernaculum for about 200,000 gray bats (Myotis grisescens); these overwinter in a deep, cold pit section that also harbors a few Indiana bats. The present gate has been in place for many years; it appears adequate for air flow but the spaces between the bars are oriented vertically and it is difficult for bats to fly through. Many bats land momentarily on the gate while entering and leaving the cave; others must change speed and direction to fly in or out. In either case, the bats which use Jesse James Cave are quite vulnerable to predators when passing the entrance.

In October, 1989, the heads and wings from about 85 gray bats were found beside the gate - apparent victims of a family of feral cats that had taken up residence in a deep crevice at the cave entrance. The declining Indiana bat population here appears to have been caused more by the presence of overwhelming numbers of gray bats, also federally endangered, than by any aspect involving the cave gate.

6. Great Saltpeter Cave, Rockcastle County

15 Jan 1964	10
10 Jan 1978	10
6 Feb 1981	0
4 Mar 1990	0

Great Saltpeter Cave, a long-time tourist attraction that has now been closed to the public for several years, is privately owned. The existing round bar gates have been in place for many years. These gates may slightly restrict bat access, but the flow of cool air throughout the cave tends to be very good. The entire cave is cold and windy except for a few warm, humid side passages. Very few bats of any species hibernate in Great Saltpeter Cave, and very little potential exists here for Indiana bats in winter.

In the overall picture, it has been demonstrated repeatedly that properly designed and constructed cave gates can make it possible for declines at Indiana bat hibernating sites to be halted and/or reversed. It has also been shown that improperly designed cave gates and other structures, even if placed on only one entrance of a multiple-entrance cave, can bring about drastic declines in Indiana bat populations. In fact, virtually the entire historical drop in Indiana bat numbers in Kentucky since the 1950's and 1960's can be directly attributed to the impacts of cave gates and buildings on the flow of cold air through cave systems during the critical winter months.

There may be something to be said for managing Indiana bat populations by keeping cave locations secret, putting closure signs within the entrances so as not to attract attention to the caves from the outside, soliciting the assistance of the organized caving community in circulating information on which caves should not be visited in winter, and visiting the caves only once every second winter for a bat census. Twelve caves located on or adjacent to the Daniel Boone National Forest in Rockcastle and Jackson Counties in Kentucky were managed in this way - these caves collectively showed a decline of only 37 Indiana bats over a ten year period (1981-1991). Fifteen additional caves on or near the Daniel Boone in Lee and Menifee Counties, Kentucky, were managed in a similar manner and showed a net increase of 574 Indiana bats over the same time period.

The problem with this method of management, however, lies in the occasional and unpredictable case of cave vandalism that usually comes about when local residents enter sensitive caves during critical periods of the year and either kill hibernating bats outright or damage populations by making frequent visits to the caves or by building campfires in cave entrances. Over the past 10 years in Kentucky, nine of the 78 known Indiana bat sites (11.5%) have been impacted by the direct killing of bats or by campfires. Numerous other Indiana bat caves show evidence of similar activities having taken place in the past. For this reason, it seems imperative that as many as possible of the most significant remaining Indiana bat caves be equipped with properly designed and maintained cave gates.

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REVISED SYSTEM FOR MANAGEMENT OF CIVIL LIABILITY FOR CAVE RELATED INJURY

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National Speleological Society

ABSTRACT

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

Appended to this paper are several forms, including releases, that can be reproduced and used in attempts to reduce and control potential liability. These forms are strongly worded and make their intent as clear as language will allow. They have been adapted from various forms that have been developed and used in various parts of the United States over the past ten years. Although these forms are designed to afford the maximum protection to the caver and to the landowner who seek to avoid liability, you must remember that no legal document is entirely and universally effective and the use of these forms does not guarantee the avoidance of liability. They may or may not be effective under the law of your particular jurisdiction, and the advice of counsel is advised in regard to the use of any of the appended forms.

Contemporary America is a society that litigates. Our Courts, over the past thirty years, have expanded the scope of civil liability for personal injury, and the awards of Juries have increased at least as sharply as has inflation. Although the scope and the cost of liability has expanded, and despite the fact that there are differences, sometimes substantial differences, among the fifty American jurisdictions, the basic principles upon which liability is imposed have remained the same for generations.

The branch of law that deals with claims for wrongful death or injury to persons or property is called the Law of Tort. The concept of tort is so general that no inclusive definition has ever been successfully fashioned by any Court, but, for the purposes of this discussion, a tort can be defined as: civil wrong, arising from a breach of duty, for which the law will provide a remedy. In the following pages, we will examine the basic rules of tort liability and will discuss how they can be used as guidelines for the reduction or elimination of civil liability in the context of cave exploration and cave ownership.

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

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

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

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

The standard to which each of us is held is simply to act as the Reasonable Man would act under the circumstances as they appear to him at the time. The standard has the flexibility to fit any case which might arise. The conduct of the Reasonable Man will vary with the circumstances with which he is confronted. If the Reasonable Man has superior knowledge or training, he will be required to utilize that superior knowledge or training in conforming his actions to the circumstances. Likewise, if the situation involves increased danger or risk of injury, the Reasonable Man will conform his conduct to that greater risk of danger. If the Reasonable Man is aware of an unguarded elevator shaft he will give warning. If he is involved in blasting operations he will remove people from the area, post lookouts and take other steps to prevent injury or damage. If the Reasonable Man is aware that children are in an area he will increase his lookout, decrease the speed of his automobile or take other steps to compensate for children's known propensity to not take care of themselves.

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

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

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

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

Duty can arise in two ways. It may arise by operation of law, that is, through the enactment of statutes or by the decisions of Courts. Duty can also arise when it is voluntarily assumed. The act of undertaking to fence the edge of a precipice, for example, is the assumption of the duty to provide a reasonably safe and secure fence.

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

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

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

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

Traditionally, in the common law, the ownership, use or management of land gives rise to certain duties that are owed to those who come onto the land. The legal status of the person coming onto the land will therefore define the minimum duty owed by the landowner to that person.

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

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

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

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

Children, whatever their legal classification while on the land, are owed a higher duty than that which is owed to adults. The reasons for this are twofold and obvious. Children cannot be expected to appreciate danger with the same discernment as adults and children are neither physically nor mentally as able to take care of themselves as are adults. Because of the special and peculiar circumstances which children present, the Courts developed the doctrine of attractive nuisance. The doctrine was developed to allow recovery by children who were injured while trespassing on the land of another. The theory conclusively presumes that the child is attracted by something on the land. Originally, this had to be something created by the landowner, the classic examples being quarries, railroad turntables and artificial farm ponds.

Most American jurisdictions have abandoned the doctrine of attractive nuisance in favor of an even broader new rule which is based upon foreseeable consequences. Basically, this rule posits that children can be expected to meddle, to use poor judgment and to explore. The fact that a child is involved in the particular circumstance makes special dangers foreseeable. The standard of the Reasonable Man is then applied and acceptable conduct is determined to be that conduct in which the Reasonable Man would have engaged under similar circumstances involving like children.

The traditional distinctions of trespasser, licensee and invitee are, to some extent, being blurred by the Courts. More and more often, especially in cases where strict application of the traditional approach would lead to a harsh result, Courts are applying the Reasonable Man standard to the acts and omissions of landowners. Undoubtedly this trend will continue and little, if any, reliance should be placed on defenses that depend solely on the status of the injured party especially if the injury was reasonably foreseeable.

As the Courts develop this approach, the distinctions of trespasser, licensee and invitee will tend to become more an element of foreseeability and not the controlling element of the case. The prudent owner or manager can no longer rely solely on traditional distinctions of status.

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

There is no way that a landowner can totally avoid all possible liability. Even if he simply forbids entry into a cave, a trespasser could enter, receive injury and demand compensation. Blasting the entrance shut, or putting a gate on it does not guarantee that entry will not, nevertheless, be made. It is not far fetched to imagine a scenario where rescue efforts could be hampered or injury exacerbated by such modifications. Probably the best solution to the liability enigma from the landowners' point of view is a simple management plan which would include some policy for limiting use of the cave, a means of informing cave users of known dangers, and the requirement of the reading and signing of a strongly worded liability release by all visitors.

A release, sometimes called a waiver, is basically a contract where the caver, in exchange for the right to enter the cave, sells to the landowner the caver's right to sue for injury received in the cave. The most important thing to remember about a release is that it is not always effective although several recent cases have upheld well drafted releases and thereby barred recovery for SCUBA related diving injuries. As indicated, a release is a contract and it must, therefore, be supported by consideration. The consideration should not be money because, in most jurisdictions, that could constitute the caver an invitee and would place the landowner under a higher duty to him. The consideration in exchange for which the permission is given should be the release of the right to sue and nothing more. In some jurisdictions it may still be necessary to recite a nominal consideration, usually one dollar.

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

If a release has any significant chance of being enforced by the Courts, it must be clearly written and it must appear, from the document itself, that the parties agreed and understood their transaction at the time it was made. The document will be construed against the party drafting it, usually the landowner, and it is to that party's benefit to avoid any ambiguity in the language of the release. At all costs "legalese" should be avoided entirely.

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

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

The signature of the minor should also be required on the release. Although the signature is of no contractual effect, it can be used to show that the minor was actually aware of the risks and dangers involved in cave exploration and this can, in many cases, furnish a defense - contributory negligence or assumption of the risk - in the event that a claim is made.

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

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

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

The joint venture theory can, in some situations, increase rather that reduce exposure to liability. For example, if a landowner is included in the joint venture, he may incur liability of some sort to third parties for acts of the other members of the joint venture. Although the inclusion of a joint venture theory may greatly enhance the effectiveness of a release, it should never be utilized without the advice of an attorney familiar with the laws of the jurisdiction in which the release will be used. The risks of unintended consequences are simply too great to attempt to use this device without qualified legal advice.

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

To cause an assumption of a risk the parties must recognize an identifiable risk to be assumed and that risk must specifically be assumed by the party who undertakes it. The assumption of the risk should be supported by consideration. It would, under most circumstances, be sufficient to simply refer to the consideration for the release.

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

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

At Common Law a Tort Claimant was required to be free of fault in order to obtain a recovery. This concept is known as the doctrine of contributory negligence and it bars any recovery as a matter of law if there is any negligence, no matter how slight, on the part of the Claimant. Because of the harsh results that often resulted from application of the doctrine of contributory negligence, it has been abandoned by the overwhelming majority of American jurisdictions. It has been replaced by the concept of comparative negligence in which a claimant's recovery is reduced by the proportion of fault attributable to him. In some jurisdictions the doctrine of Comparative Negligence has been held to have abrogated or modified other defensive doctrines, such as assumption of the risk.

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

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

Likewise, neither the manager nor the trip leader should give an opinion regarding specific caving gear. A specific brand or generic type of gear should not be recommended or required. At the other extreme, the manager cannot allow a caver to enter the cave with obviously inadequate gear, or with gear that is clearly worn to the point of unreliability. This is an area of fine distinctions and the manager must develop not only a real understanding of the Reasonable Man concept, but also a genuine expertise about technical caving and climbing gear. The successful manager will know what types of equipment are generally considered to be unsafe or inadequate. He will then require those whom he allows to enter the cave to use gear which generally falls within the class of gear that is accepted in the caving community. As in the case of caving skills, the manager should never allow himself to certify the adequacy of cave equipment.

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

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

The leader of a caving trip will generally not be in a position to take this approach. He will, in all probability, know the skill level of all members or the party, and if he does not, then he is almost surely in violation of his duty to the party. He will owe a special duty of care to inexperienced members of the caving party. The trip leader must limit his liability by being willing to prohibit participation in a trip by cavers who clearly do not have the required skills, by clearly explaining the nature of the trip and the inherent risks during the early planning stages and by insisting that the Grotto or other organization have a proper training program.

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

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

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

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

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

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

MANAGEMENT OF GOVERNMENT OWNED CAVES WITH AN EMPHASIS ON THE FEDERAL CAVE RESOURCES PROTECTION ACT

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ABSTRACT

Two of the largest land management agencies of the federal government have a responsibility to manage historic, cultural, recreational and natural areas. There are also units that have been designated specifically to protect caves. However, many other units contain cave systems that must be considered as integral segments of overall management schemes. In the past, caves were thought of only in order to protect the public from perceived hazards associated with these caves. Recent positive actions such as the passing of the FCRPA has forced federal agencies to assess the overall significance of their cave resources. This session addresses some of the things currently being done by the National Parks Service and the U.S. Forest Service to consider caves in their proper perspective as an integral part of land management mandates and ethics.

LOOK IT UP SOMETIME, IT IS WRITTEN DOWN or LET'S DON'T RE-INVENT THE WHEEL

In 1986 Ronal Kerbo authored a book entitled "Bat Wings and Spider Eyes" and for his opening statement he writes: "We can only build on those things we have learned, on those things we share in common with others." Ron concludes this first page with saying "Look it up sometime, it is written down". These statements reflect a wisdom many of us overlook.

Too often many of us begin a task without finding out what others have done before and I see this happening to a large extent with cave management. My principal work related frustrations have often been that I see many, many tasks being redone over and over. Cave management plans have been in existence for 20 years and cave symposia and management workshops for 17 years. Quite frankly, many of the long-time individuals concerned with cave preservation and protection are weary with the same material, information, and planning sessions. I often hear these individuals express that they think it is time to "put the plans to work, we have planned and talked long enough". Thus my statement "Let's don't re-invent the wheel" for cave management. This is not to say that we cannot improve on what we have been doing, but let's not start all over.

We seem to live in a society that thinks "new is better" and "surely no one has thought of this before". For example I have observed the "new" women's styles over and over to the point that most observant women know that whatever clothes they have that are out of style need only to be put away for a few years and they will again become "new and better" and absolutely the "in" thing. Some very wise person once said "until you know what that old fogy knows you have a poor starting point".

I was delighted to listen to Roger Brucker's banquet address last night which he entitled Transferring Wisdom in Cave Management". Roger's topic title says a lot. I almost had the feeling that we must have discussed many of his thoughts in our dreams as I heard him saying many things I had felt to be true for some time. For me, confirmation of heading in the right direction is that I find many people are thinking, sharing, and writing the same things without knowledge of one another's work. Most of us find that as we are doing something worthwhile we soon learn that someone across the country is doing it also. Let's learn from each other and build upon that knowledge. It is apparent that too many times we start anew and almost never catch up.

It is timely for us to assemble a "Cave Management Handbook" and to do our best to make it available and its existence know. Information sharing and communication is a must if we are to see on-the-ground results in cave management. A prime example of lack of communication is the number of caves that have been repeatedly inventoried and surveyed which is an activity that usually results in a variety of negative impacts on the cave resources. There are many caves that have been mapped 2, 3, and 4 times with some having the same work repeated up to 10 times and possibly more.

It is possible to overplan. It is also possible to get too technical and put too much emphasis on requiring finite data to make determinations and decisions. It is further possible to ignore that often times we can make good judgments using our God given powers of observation and conclusions.

These thoughts are confirmed to me in that during this symposium Bob Buecher has explained that in many areas of his study of Kartchner Caverns for the State of Arizona he has seen the same results with state-of-the-art data collecting devices compared to simple random studies. Jim Nieland has conveyed his experience of having detailed, time consuming, on-site inventory procedures produce exactly the same resulting evaluation, resource rating, classification, and cave management direction as was achieved in a short meeting with a group of cavers with knowledge of the same caves. Roger Brucker's dialogue of "Love the baby until grown" gave further similar testimony.

Please do not misunderstand what I am saying. No one should leave here thinking that we should take decision making lightly and/or make decisions arbitrarily. The Forest Service must be careful to follow our mandate to use the N.E.P.A. (National Environmental Protection Act) decision making process and involve all known interested individuals and groups. Several government agencies have been taken to task not because they made the wrong decision but because of such problems as poor documentation of the decision process, too little or no input from the interested parties, and lack of alternatives considered.

The National Forest Management Act required each National Forest to prepare a Forest Plan. Forest Plan objectives are to be accomplished by various resource management activities. To assure that those activities are in accordance with Forest Plans and appropriate laws and regulations, several project implementation processes (PIP's) have been developed.

The PIP's were developed to reflect a strong commitment to an "integrated resource management" philosophy. Integrated resource management (IRM) is defined as a land management philosophy which recognizes that all the natural resources are connected through an intricate series of interrelationships.

The PIP's all incorporate a 13-Phase process which incorporates the NFMA, NEPA and public involvement processes. The first Phase in each PIP is review of the Forest Plan, followed immediately by the initial determination of the parameters of the project. Subsequent Phases guide the design process so that NEPA compliance is assured, Forest Plans are maintained, citizen participation is sought and utilized, adequate environmental analysis is accomplished, and successful on-the-ground implementation is achieved.

Other wheels that do not need to be re-invented are the NEPA, IRM, and PIP process documentation items. There has been a great deal of cave management work done on identifying issues, concerns, opportunities, public contacts, items monitored, project alternatives, etc. and these documents are available from the Coronado National Forest, Sierra Vista District, Gifford Pinchot National Forest, Mount Saint Helen's District, the Lincoln National Forest, Guadalupe District, and others. Each person involved with cave management should create a list of others doing similar work. That list should include Ron Kerbo, Jim Goodbar, Jim Nieland, Bob Buecher, Terrie Marceron, Hans Bodenhamer, Larry Mullins, Susan Rosenthal, and I had better stop there because name lists seem to always leave some very important people out and/or offend. These are simply some of the people with whom I have worked closely and been most impressed with.

Still other wheels that do not need to be re-invented are contracts for cave related work such as Challenge Cost Share agreements for cave gate construction, restoration projects, maintenance projects, inventory and mapping, etc. There are models of Memorandums of Understanding, Cooperative Agreements, Environmental Impact Statements, Environmental Assessments, and Biological Evaluations.

Communication, balance, and working together must be the methods of operation for all agencies involved with cave management if we are to stay abreast with managing a resource that has already been severely mishandled and ignored. We must include the caving community in all that we do. The knowledge and expertise available in most caving groups is considerable and we have rarely worked closely enough with them. I do have a 3-page handout concerning the proposed procedure for listing significant caves under the Federal Cave Resources Protection Act of 1988. This handout should be self-explanatory and it is for your future reference.

Again, a great deal of work has already been documented in the area of cave management so let's try to reduce duplication of efforts by sharing this information. I close with my friend Ron Kerbo's statements "We can only build on those things we have learned; on those things we share in common with others", and "Look it up sometime, it is written down".

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PROPOSED PROCEDURE FOR LISTING SIGNIFICANT CAVES UNDER THE FEDERAL CAVE RESOURCES PROTECTION ACT OF 1988

Introduction.

The Federal Caves Resources Protection Act of 1988 (FCRPA) (16 USC 4300-4309) directs the Secretaries of Agriculture and The Interior co prepare and maintain a list of significant caves. The proposed process for listing significant caves involves two separate and distinctly different processes. The first or initial listing will be a special project to capture known cave information quickly on a state by state basis and will be an interagency effort. The second or subsequent listing process will utilize the initial listing as a benchmark and will be done as a part of the regular land management planning processes in use by the various federal agencies.

Both processes will involve interested private individuals, organizations, and governmental agencies.

Each of the processes involves three steps: (1) nomination, (2) evaluation, and (3) determination.

The final procedures will be set forth in a Memorandum of Understanding between the two Departments following analysis of comments received from reviewers.

Initial Listing.

Section 4(1)(b)(A) of the FCRPA states that "the Secretary shall prepare an initial list of significant caves for lands under his jurisdiction not later than one year after the publication of final regulations." The following procedure is proposed for use by the USDA Forest Service and agencies of the U.S. Department of the Interior for developing the initial listing of significant caves.

Reference the following chart illustrating the proposed process.

NOMINATION: A public notice calling for nominations will be made on a national level. Nominations will be accepted for six months. Nominations will be sent to one location within a given state. The list of state locations accepting nominations will be listed in the public notice. Individual cave nominations should provide the following information: Name, address, and telephone number of individual or organization submitting the nomination and/or who can answer questions about the nomination; date of submission; cave name; legal description and/or location shown on a topographical map; cave map or extent of known passages; Federal agency responsible for the cave's management; discussion of the characteristics of the cave as it relates to the criteria in 36 CFR 290.3(b). Nominations may be submitted by any interested party.

EVALUATION:

Nominations will be evaluated by interagency teams appointed by the appropriate officers i.e. Regional Forester, State Director etc. Team membership will include representatives with cave expertise and/or sufficient knowledge of cave resources to evaluate a cave nomination against the criteria in proposed 36 CFR 290.3(b).

Private sector interests will be consulted in the evaluation.

The team will make recommendations to the deciding officer as to which one of the four categories a nomination should be placed. These categories are "Does Not Meet Cave Definition of FCRPA", "Inadequate Information", "List of Significant Caves", and "Caves Not Listed". Cave management will be different depending upon what category the cave is placed in.

Caves listed as significant will be managed under forest plan cave standards and guideline and the FCRPA. Caves not listed will be managed under appropriate forest plan cave standards and guidelines. Cave nominations returned for inadequate information will be managed in a manner to protect them for a reasonable amount of time until sufficient data can be collected. "Caves" that do not meet the definition of FCRPA will be managed under appropriate forest plan direction.

DETERMINATION: For the National Forest system the decision maker will be the Regional Forester.

Caves in the "Inadequate Information" categories will be protected under the confidentiality requirements of proposed 36 CFR 290.4. The list of significant caves from the initial listing process will be appended to the Forest Plan and are exempt from the requirements of the Freedom of Information Act.

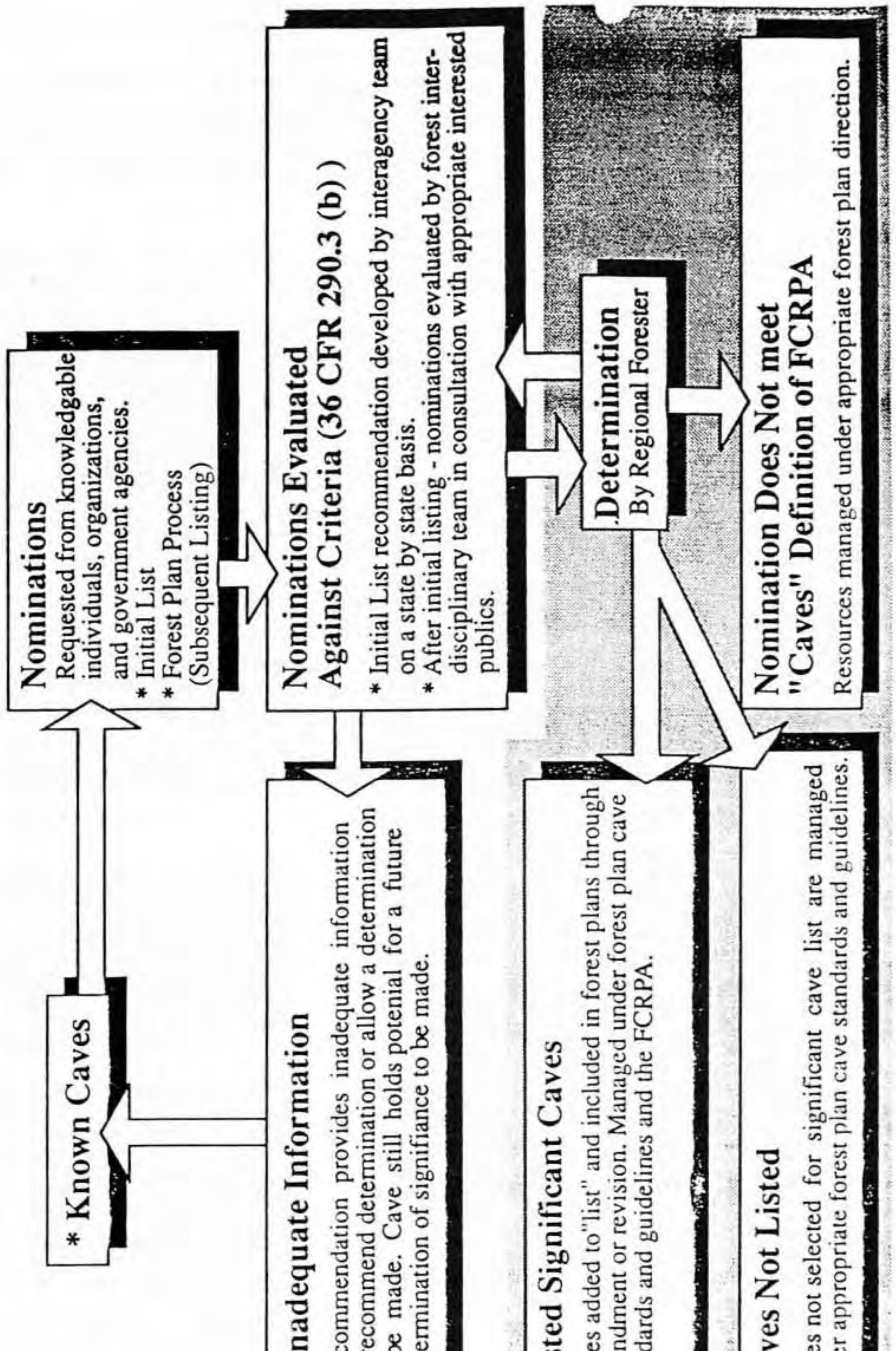
Determining Significant Caves following Initial Listing.

Section 4(b)(1)(B) of FCRPA directs that "The initial list of significant caves shall be updated periodically, after consultation with appropriate private sector interest, including cavers. The Secretary shall prescribe by policy or regulation the requirement and process by which the initial list will be updated, including management and measures to assure that caves under consideration for the list are protected during the period of consideration".

After the initial listing process is completed, future nominations, evaluations and determinations will be made as part of the Forest Planning process (36 CFR Part 219). In general, subsequent listing procedures will follow the process described above except for the following changes:

> Nominations would be accepted on a continuous basis by the authorized officer. The authorized officer will evaluate and decide upon nominations received on an annual basis and in consultation with appropriate private section interests, including speleologists and/or cavers. Caves determined to be significant will be added to the list in the Forest Plan appendix and will be managed accordingly.

Proposed Procedure for Initial and Subsequent Listing of Significiant Caves Found on National Forests



*Caves managed under existing regulation at 36 CFR 261 & 290.4 to protect them during the period of consideration.

THE SIGNIFICANCE OF A CAVE

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ABSTRACT

The concept of cave significance will be increasingly important in cave management since the passage of the Federal Cave Resource Protection Act of 1988, which requires that Federal Cave managers protect "significant" caves. The question of "what is a significant cave?" will be asked frequently in the future. The question is simplified if all caves are treated as "significant" unless they have been shown to be not significant. Thus caves that have not yet been evaluated are "potentially significant" and must be treated as significant. Very few caves are not "potentially significant" (the most PS cave in recent history was Lechuguilla). Strategies and methodologies for evaluating the significance of caves are discussed and a sample evaluation is presented.

Many of the concepts in this paper were developed nearly twenty years ago as a draft manuscript. A review of the literature on this subject reveals that the definitive paper on significance remains to be written. Ideas on significance and how to determine it developed by Richard Powell, Rane Curl, the California Lands Commission, and the Congress of the United States are included. Parameters of significance can include the nature of the resource, the benefits from uses to which it is put, its uniqueness, and contributory values. Methods used to prove significance include the opinions of experts, comparison to other caves, and demonstration of meeting the requirements of laws or regulations defining significance.

The Federal Cave Resource Protection Act of 1988 provides protection to "significant" caves on Federal Lands. The process for determination of significance is to be codified into regulations by the various Federal Agencies. As of the date of this writing (June 14, 1991, October 14, 1991) the regulations have not yet been published in the Federal Register, in spite of a mandate in the law requiring that the regulations be completed within a year of the passage of the Act. The law also mandates that within a year after the adoption of the regulations, that "significant" caves on federal lands shall be identified. Since cavers are the most knowledgeable as to which caves are found on Federal lands, they are also the most likely to be able to evaluate which caves are the most significant and can be listed and protected.

Significance is defined (in my word processor's thesaurus) as the quality or state of being important. What we consider to be important depends on our background, attitudes, and interest. And the measure of significance is value. Value is a measure of those qualities that determine merit, desirability, usefulness, or importance. Strictly speaking, we are considering importance, but merit, desirability, usefulness are also of use in evaluating significance.

One measure of value used in our society is monetary worth, but the concept is not very useful in evaluating caves. The values that we consider here are more abstract and less tangible than money, and they are certainly more subjective. While money is a common denominator that means roughly the same thing to everyone, a cave is certainly more valuable to a caver, for example, than it is to a cosmetologist or a window washer (unless, of course, they also happen to be cavers).

This paper is about how to determine the value of cave. While not directly focused thereupon (and maybe it should have been) it is about merit, desirability, usefulness, or importance. Most of the paper deals with determining what features or characteristics of a cave could be considered to be of value, and suggests criteria that could be used to establish the value.

In spite of the following discussion, which provides some ideas to be used in actually evaluating the significance of a cave, the overall utility of the concept of "significance" is questionable. It is unfortunate that the word "significant" was added to the FCRPA, since it only complicated the administration of the Act, without adding anything useful to managers in managing caves. The fact is that all caves are "potentially significant" since they may contain features that are not currently known, but when discovered may make the cave significant.

In fact, the entire discussion that follows may become unnecessary if we adopt the position that all caves are "potentially significant" and should be treated that way under the Act. This provides us with two classes of caves:

a. **Significant caves** that have been evaluated and determined to be definitely significant.

b. **Potentially significant caves** that have not yet been determined to contain significant features, either because they have not yet been evaluated, or because they were evaluated and found lacking based on the information known at the time.

Prudent management, of course, would treat "potentially significant" caves exactly the same as "significant caves," since a potentially significant cave today might be a significant cave tomorrow. The best known example of this is Lechuguilla Cave in New Mexico. As recently as ten years ago it was a small cave, generally considered to be not significant. Today it is one of the most significant caves in the country if not the world. The difference between then and now is simply knowledge. Another example is Horsethief Cave in Wyoming. Up until 1968 it was considered to be just a small cave, dwarfed by Bighorn Caverns a few hundred feet away. A small crawlway led to a giant system, eventually connected to Bighorn, and possibly to be connected to other newly discovered systems in the future. A simple discovery converted the cave from "potentially significant" to "significant" in a single day.

This concept is likely to drive many managers bonkers. A basic principle of management is that you can't manage what you don't know. As I demonstrated in my paper on Underground Wilderness, Agency cave managers have argued that they can't designate certain caves as wilderness because they are relatively unknown or unexplored. In their mind, an unexplored cave does not exist. Or to put it another way, it has no value--it is insignificant.

However, I believe that the concept of "potential significance" will actually make it easier to administer the Act, and to manage caves. First of all, it allows managers to adopt a single set of rules and methods that apply to all caves within their jurisdiction. Second, it makes the actual management process simpler, since it is no longer necessary to evaluate the significance of a cave "right now" before taking any action. Since the cave will be treated essentially the same whether or not it has current significance, the pressure to "know" the cave so that it can be evaluated will be reduced. Managers will be able to concentrate on management instead of evaluation. Finally, it will actually reduce the short term management effort required to manage caves. Since the determination of significance can be deferred, less personnel will be needed.

This is not to imply that all caves must be treated exactly the same. Clearly, caves with known features that need special care or management can get that care. A cave developed for high density public use (Carlsbad, for example) would obviously be treated differently than a wilderness cave like Lechuguilla. The caves have different needs and must be managed differently. But small caves, that do not have the same significance as Carlsbad or Lechuguilla should be afforded the same care as needed since in five years they might fall into the same class.

The mere process of determining significance could potentially cause harm to the caves, particularly if the compulsion to "know all" is applied. There could be a concerted effort to explore, map, measure, collect from, and otherwise measure the cave. And this process, particularly if forced to take place on many caves over a short period of time, could cause damage that would not occur with a more leisurely approach.

Cavers will be asked to provide inputs to the process of determining significance. The following discussion, originally drafted in the early 1970's, provides information useful in making a determination and recommendation. It was originally written to assist cavers, in demonstrating the significance of a cave to the public or the agencies involved in cave protection.

The process of determining significance could follow these steps:

1. Determine which caves are on Federal lands.

2. Gather together information regarding these caves, as well as other caves in the state.

3. Evaluate the caves in the terms of the criteria listed below. Prepare a summary paragraph for each cave, stating the case in these terms.

4. Prepare a list, including a descriptive paragraph for each cave outlining the factors that contribute to its significance.

This reference list could be submitted to the agencies, published in caver publications, or simply retained for future reference, when questions are asked by agencies. Note that the process outlined here does not rank caves, nor does it make value judgments on its own. That is because the FCRPA regulations will define a process for evaluation of the evidence submitted. The process outlined here is designed to obtain information and to present it to the agency for further evaluation.

The remainder of this paper was originally written in 1974, to have been included in a Cave Conservation Handbook being written by the author during his tenure as NSS Conservation Chair. A variety of intervening projects has delayed the publication of this material until the present. One would wonder if the material is not perhaps outdated. Surprisingly, the direction of the cave management literature[1] over the last twenty years has dealt only slightly with the question of determining significance. The thrust seems to have been on inventorying caves (certainly a prerequisite for determining significance) without worrying about ranking them in terms of significance; and in managing the ones already determined as significant without questioning how they were selected. A few notable exceptions include the study done in the New Melones area in California in 1977 by Mike Grady and Mike McEachern.[2] James Nieland discusses "Evaluation of Surface and Cave Resources" in a 1979 paper,[3] but concentrates on explaining which features of caves should be evaluated without proposing a scheme or methodology for deciding the relative significance of the features. One of the main themes of the 1976 National Cave Management Symposium in Arkansas was "Cave Inventory, Valuation and Assessment," but a review of the papers published reveals little about the question of valuation (determination of significance); a few words in the session summary reveal concern among participants as to how to do this--but subsequent symposia did not either phrase or answer the question.[4]

Richard Weisbrod presented a paper on the methodology of decision making at the 1975 symposium[5] but the discussion did not deal directly with significance.

[1]The bulk of the published literature has been included in the various **Proceedings** of the National and regional Cave Management Symposia that have been held since 1975.

[2]Grady, Mark and Mike McEachern, "The New Melones Cave Evaluation Study: An Example of Management Implementation," in **National Cave Management Symposium Proceedings: Big Sky, Montana, October 3-7, 1977**. Albuquerque: Adobe Press. 1978. pp. 13-18.

[3]Nieland, James. "Evaluation of Surface and Cave Resources," **Far West Cave Management Symposium Proceedings: Redding, California 1979.** Oregon City: Pygmy Dwarf Press. 1980.

[4]"Session II: Cave Inventory, Valuation and Assessment," **National Cave Management Symposium Proceedings: Mountain View, Arkansas, October 26-29, 1976.** Albuquerque: Speleobooks, 1977. pp. 15-27.

[5]Weisbrod, Richard. "Values, Decision Making and Cave Management." **National Cave Management Symposium Proceedings: Albuquerque, NM October 6-10, 1975.** Albuquerque: Speleobooks, 1976. pp. 130-134.

Several cave managing agencies[6] have over the years adopted the inventory and classification system developed in New Mexico and described by Jerry Trout in 1977. Although the system does allow for classification of caves by managers, it is generally applicable only to caves within a limited system and is relatively one-dimensional in its approach, concentrating on aesthetic and scientific values.[7]

The Australians appear to have recognized the need for evaluating significance and attempted to develop methodology. Elery Hamilton-Smith reported on progress in this area in 1987[8] but his thoughts on the matter first appeared in print in 1976.[9]

The Virginia Cave Commission has probably done the most in this area, generating a list of "Significant Caves of the Virginias" and maintaining it over several years.

Criteria for Determining Significance

A concept that is going to be of increasing importance in obtaining the assistance of government agencies and the public in preserving caves is that of their national significance.[10] While it is not an idea that is easy of definition, this discussion will try to clarify what the term means and how we can determine the significance of a cave and prove to others that it is significant. Although this discussion is set at the level of national significance, of course the concepts covered are also applicable to the determination of regional, statewide, or local significance also--they must merely be considered within the framework of the level of significance to be determined.

It is important to remember that national significance is not necessary to make the cave significant--the longest cave in state, for example, is automatically significant, even thought it may be much shorter than a cave in a nearby state. The idea of National Significance is useful when dealing with Federal Agencies--but local or state agencies may be interested primarily in protecting natural features to make exaggerated claims of national significance when the feature is only of local or regional significance.

The points discussed here are not necessarily mentioned in an order of importance that would be applicable to all caves or cave areas. It may be necessary to stress one point more than others, or to reorder the factors to create the strongest argument. This should be done only after considering the particular factors involved, including the actual situation, political problems involved, the sources of support, and/or opposition to your stand.

Richard Powell in his massive 1970 study of selected significant caves of the United States,[11] has considered caves in terms of four groups:

1. Geology and hydrology
2. Paleontology, history and archaeology
3. Biology
4. Science

[6]For example, British Columbia. See Jacques Marc, "British Columbia Ministry of Forests' Cave Management Policy." **Far West Cave Management Symposium Proceedings: Portland, Oregon 1981.** Oregon City: Pigmy Dwarf Press, 1981.

[7]Trout, Jerry. "A Cave Classification System." **National Cave Management Symposium Proceedings, 1977.** pp. 19-23

[8]Hamilton-Smith, Elery. "Cave and Karst Management Down Under." **1977 Cave Management Symposium: Rapid City, South Dakota, October 1987.** Huntsville, National Speleological Society, 1989.

[9]Hamilton-Smith Elery. "Evaluation of Caves and Karst" The National Estate Assessment Study." **Cave Management in Australia II: Proceedings of Second Australian Conference on Cave Tourism and Management, Hobart, May 1977.** Victoria: Australian Speleological Federation. 1977. pp. 87-96

[10]Particularly since the passage of the Federal Cave Resource Protection Act (FCRPA) in 1988. The Act requires that the Federal Government make a determination as to the significance of caves--but does not provide detailed criteria for that determination. As of the time this article is going to press, the deadline for promulgation of regulations and a list of significant caves is long past, with no apparent public action taking place.

[11]Powell, Richard L., **A Guide to the Selection of Limestone Caverns and Springs in the United States as Natural Landmarks,** Indiana Geological Survey, 1970 (restricted distribution). p. 101

Powell classified caves by both their primary and secondary significance.

The California State Lands Commission has suggested the classification of land according to natural, habitat, historical, or cultural values.[12] These and other similar groups represent the traditional features for which land planners value caves. Since these categories tend to be self-explanatory, this discussion will not dwell on them, other than to point out their usefulness as general categories. Three of Powell's areas fall into the category of scientific use, which will be discussed below; one into that of aesthetic/developed recreational use; and one additional category is added in this discussion--that of wilderness type recreation. Powell did not discuss this last because the purposes of his study (to make recommendations for National Landmark Status) were not really conducive to the promotion of this use and proper protection when it is allowed.

Rane Curl[13] has suggested some questions that might be asked in each of six areas as an aid to determining the significance of a cave:

a. **Historical:** Was the cave involved in any important way with the history of the United States? A frontier refuge; a stop on the Underground Railway; a hideout for bandits; a meeting place for any organization of government? All such facts contribute to historical interpretation, and hence are reasons for preservation.

b. **Archeological:** Was the cave used by early cultures, for habitat of ceremony? Does it contain artifacts or remains that would contribute to the understanding of the heritage of the land we inhabit?

c. **Geological:** Is the cave in an unusual geological setting? Is it of unusual length, depth or breadth, or does it contain features of other natures that make it significant? A cave that is one of only a few in a particular geological setting would make that cave of national significance.

d. **Hydrological:** Is the cave now part of an important hydrological system? This is important either as a feature of the present hydrology, or as a type locality for some variety of underground drainage. Would its study further hydrological understanding elsewhere?

e. **Biological:** Is the cave a habitat for any unusual, rare or endangered species? Is the cave an unusual habitat, whose biology has not been studied? Is the cave part of a wider regional ecological system that would be upset by its destruction? Is the cave a hibernaculum or breeding site for bats?

f. **Recreational:** Does the cave provide an important natural experience for visitors? Does it satisfy a local need for cave exploration? Would its destruction cause additional pressure on nearby, more sensitive (biologically or geologically) caves?

Answering the above questions can be important in each of these specific areas. The following discussion deals with more general questions applicable to all type of caves, despite their particular value or usage. It is important to bear in mind that any cave may be significant in more than one area. Obviously the more areas that are significant the more important the cave will be.

We should first consider the cave on its own terms, showing that it has merits of its own, and then put into a larger perspective, showing that it compares favorable with other caves that have already been afforded protection. Thus a discussion of the cave and its contents and features would begin any analysis. The following general points should be considered in developing the significance of a cave:

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[12]State Lands Commission, State of California. **Guidelines for Identifying Lands having Unique Environmental Values.** Sacramento, 1973.

[13]Personal Communication.

Usage of the cave. We ordinarily consider that there are three main uses[14] for caves (that are acceptable to conservationists concerned with assuring the continuance of the cave in a natural state). These are: scientific study, wilderness recreation, and developed recreation.[15] Another acceptable, although less common use, is the use of a cave as a management baseline (in comparison to a nearby developed [or otherwise managed] cave). In this regard, then, we must consider a cave with respect to its potential uses, its value and significance for such uses, and the benefit to be obtained.

Importance to the furtherance of the science. Have knowledgeable persons such as speleologists, biologists, historians, or others considered it to be important? Has the cave been studied in the past? How much previous work has been done? What is the potential of the cave for further contributions? What can be learned from further study? Is it likely that this study will be performed? If so, when? The cave also should be considered in terms of its historical or other value, including the presence of endangered or rare species, unique speleothems, etc.

Recreational benefits. How is the cave presently used for recreation? Is such use beneficial or harmful to the cave? What recreational benefits would be lost if the cave were lost or destroyed, or if improper use were to take place? Consider this in terms of both wilderness and developed type recreation.

Uniqueness. We come then to the telling test. Is this cave a unique feature--that is, does it contain features found nowhere else (or that are rare)? Would the loss or destruction of this feature result in the unavailability of this feature for future use-- i.e., study or recreation? The California Lands Commission has suggested that most definitions of uniqueness can be broken down into five categories: "the only one of its kind; an exceptional example; a 'textbook' example; a popular object; and a contributory element. These definitions, adapted slightly to apply specifically to speleological resources, are included here.

1. **The only one of its kind;** the last one; the first one; the last unit or aggregation of a nonrenewable resource (all caves can be considered nonrenewable resources); a rare species (one with limited range--often typical of cave fauna) or an endangered species (threatened with extinction); the single; only example or remnant of a vanished class, group, period or life style; the sole species of a genus, class, family, or order when in limited or declining number; the only undeveloped portion of a cave in a developed (or developable) cave or cave area.

2. An **exceptional example** of a population of objects or processes; outstanding beauty; singular, unparalleled, unrivaled; unusual or peculiar, nonpareil; as, an extraordinary series of canoeing rapids, (pits, breakdown, soda straws, or . . .) or an unusual display of an otherwise common occurrence; an undisturbed, natural area or ecosystem; a virgin cave; a key, cornerstone or turning point in archaeology or history, or in physical or biological processes; variations in a species at the extremity of its range.

3. A **"Textbook" example** of a population of objects or processes; a paragon; epitome of a principle, a condition or a type; the mythical "average" object or ecosystem embodied. For example, a representative biological community or relationship, geological formation or soil profile, a typical example of, say, a geological province or historical period.

4. A **popular, or well known object** or scene; highly esteemed statewide, regionally, or nationally; one accessible and therefore unique when compared to others that may be inaccessible for study, observation, recreation, or other nonconsumptive uses, such as a cave located near population center, or a publicly owned cave in the midst of privately owned caves.

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[14]There are many unacceptable uses; trash disposal, civil defense shelters, water storage, speleothem mining--to list a few, that are generally considered unacceptable.

[15]Developed recreation includes show caves developed to some degree for public visitation.

5. **A contributory element** in the uniqueness of other land, such as a cave used by bats feeding on surrounding land or the surface land overlying a significant or unique cave or cave system; a protected species of animals, a "buffer parcel", an upwind or up watershed parcel that could threaten a cave resource if it were developed or altered; or in the event that an endangered species might be brought out of danger of extinction, a parcel of land containing habitat that such a species could use to help it achieve a self-sustaining level.[16]

It will be noted that in general the first four classifications are most applicable to individual caves or combinations of caves, whereas the fifth classification can be used to support the uniqueness of areas around caves that contribute to their preservation. Thus all surface areas overlying significant caves are a **contributory element** to the uniqueness of the cave, and are thus unique themselves.

When using these classifications to evaluate caves or cave areas, it is important not only to state the degree to which a cave fits one of these categories, but also the character of the cave in question--i.e., whether it is of historical, geological, biological, archaeological, paleontological, or recreation value; and the scope of the value--whether it is of local, regional, statewide, or national significance.

Values. What are some other values of the cave--wilderness, recreational, etc., depending on the cave and its proposed best usage discussed above? How could these values be best protected? Should they be protected? What is the probability that the proposed action will cause loss of the values?

The question of value, of course, is a difficult one, since cave values are usually intangible and difficult to express in economic terms, whereas the value of a cave destroying project is often easier to express in economic terms--and in fact such projects are commonly justified (by law for Federal projects) in terms of **cost-benefit** rations, e.g., if the benefits outweigh the costs, then the project is justified. Usually, of course, the value of caves, archeological sites, etc., is not considered in figuring the cost-benefit ration.[17] The environmental benefits of a project can often be easily justified in economic terms (additional recreation, boating, irrigation, etc.) while the adverse environmental effects cannot so easily be quantified in economic terms. It is likely that since the quantity of natural phenomena such as cave resources is fixed, and decrease as more caves are destroyed, that their value will become greater as time goes by.[18]

Because of the intangible nature of the cave values, it probably would be best to avoid trying to make an economic justification for cave preservation, since this would mean promoting the increased use of the cave, which might in the long run increase the environmental degradation and thus decrease the value. However, it is possible to calculate recreational benefits that could accrue under different types of management--from wilderness to developed, and to determine approximately the value of scientific research that could be carried on in the cave. The development of the cave, for tourism, a research center, or for educational purposes, would increase the economic value--but in turn might reduce other less tangible values--such as wilderness and completely natural research values. It is probably better to approach the whole question of value from a more abstract point of view. Several authors have demonstrated the value of speleological research, including Bishop and Davidson[19] and Poulson and White.[20]

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[16]Adapted from California Lands Commission, *op. cit.*

[17]This was probably true 20 years ago, when these words were first written. In 1991, greater environmental awareness and the effect of NEPA have forced planners to take recreational and other benefits into account in calculating cost benefit ratios.

[18]Cichetti, et al. **Science** 24 Aug. 73

[19]Davidson, Joe and Bill Bishop, **Wilderness Resources in Mammoth Cave National Park: A Regional Approach.** Columbus, Ohio: Cave Research Foundation, 1971

[20]Poulson and White, "The Cave Environment," **Science,** 165, pp. 171-181, 1969.

The above factors, and others, should be considered in determining the significance of the cave. How they are used, of course, depends upon the situation and the particular approach you are taking.

Method of Determining Significance. There are several methods that can be used to aid in the determination of significance and in arguing this significance before the public or a government agency or landowner. The **opinions of experts,** such as speleologists, biologists, historians, and others who are familiar with the cave can be valuable. These can be expressed in the form of letters, previously published articles, or articles you ask them to write specifically for your particular project. The more expert opinions you have on your side, the better off you are.

A second approach is **comparison** of the cave to other caves of a similar nature. Does the cave compare favorably to other caves of its type--is it of equal or greater importance; does it contain equal or better features; etc. An allied approach would involve contrasting the cave to other areas of a similar or different nature: is it bigger, better, darker, etc.? Uniqueness is again a factor.

> Consideration of how the area meets or could meet some of the legal requirements for the application of different types of protection such as the Wilderness Act, inclusion in the National parks System, or as a Geological area or Special Use Area under Forest Service regulations should be made. These standards are the law of the land, and as such are an official recognition of the value of the protected features. It is reasonable to expect that lawmakers and land planners, in deciding which new lands, areas, or features should be protected, will turn to existing statutes for information about the intent of the legislatures and the people. A more detailed discussion of the types of protection available, and how they can be used, are included in the other chapters. Here I will discuss only two: The Wilderness Act of 1964 and the Presidential Proclamation establishing Carlsbad Caverns National Park (1923). These will provide background for a later discussion of the Federal Cave Resources Protection Act (1988).

Although there is considerable controversy regarding the question of whether caves in themselves can be protected by the Wilderness Act, the principles expressed in it are typical of the standards that must be applied to wilderness caves if their wilderness values are to be retained. Since thousands of words have been written on the subject of underground wilderness,[21] it will not be discussed in depth here. The Wilderness Act is quoted here as an example of one type of legal requirement that has been established to decide whether an area (which implied cave) can and/or should be protected, and one set of legal standards that have been developed to determine significance. Obviously other standards, including the regulations of other Federal Agencies, state agencies, etc. should be consulted for more information.

The Wilderness Act of 1964 (78 Stat 890) defines wilderness as ". . . an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which is . . . affected primarily by the forces of nature, has outstanding opportunities for solitude or a primitive and unconfined type of recreation, is 5000 acres or larger, or is of sufficient size to make practical unimpaired preservation and use, and may also contain ecological, geological or other features of scientific, scenic or historical value."

[21]The body of literature is voluminous, mostly favoring the principle, but with a few isolated voices opposing it. See, for example, Smith and Watson, Davidson and Bishop, Stitt and Bishop, for arguments in favor; and Lorenzo Millers, "The Underground Conflict: Should Caves Be Designated as Wilderness?" **BYU Journal of Public Law,** Vol 4, No. 1, 1990, pp 133-156 for arguments against.

Another type of applicable standard is that established by the proclamation or enabling legislation for a National park or Monument. The Presidential Proclamation for Carlsbad Caverns National Monument issued by Calvin Coolidge in 1923, describes Carlsbad Caverns as ". . . of extraordinary propositions and of unusual beauty and variety of natural decoration; . . . other vast chambers of unknown character and dimensions exist; . . . several chambers contain stalactites, stalagmites, and other formations in such unusual number, size, beauty of form, and variety of figures as to make this a cavern equal, if not superior, in both scientific and popular interest to the better known caves; . . . the public interest would be promoted by reserving this natural wonder as a National Monument . . ." While it is not likely that we will find another Carlsbad,[22] the type of wording typified by this proclamation is that used to describe a cave that is recognized as significant, and it would be valid to compare your cave to one already recognized as significant; such as this.

In **summary**, then, we can establish the following points in demonstrating the significance of a cave or cave area:

a. What significant features does the cave contain?

b. How do these features compare to others of a similar nature within the region, the U.S., or the world.?

c. How prevalent or unique are these features?

d. Are there additional significant values present (less tangible, perhaps)?

e. Has there been precedent set (through laws, prior protection, etc.) for the protection of this type of feature?

The evidence that can be presented to show that a cave is significant includes the following:

a. Expert Opinion

b. Descriptions of the features themselves.

c. Opinion contained in laws.

d. General and public opinion, expressed by letters, personal contact, etc.

e. Published opinion, such as newspapers, magazines, scientific journals, etc.

The following is a sample paragraph put together as an example and combination of the situation described above. When coupled with more specific information about a particular cave or resource, it can serve as a general guideline for a significance description:

> It is the conclusion of this report that this area is a national significance and thus deserves the protection of [applicable laws or regulations]. By national significance we mean that the area contains features of great scientific, cultural, scenic, educational, or historical value that are of such importance and uniqueness that they would be of interest to persons throughout the United States and the world. Although these features may now be somewhat unknown to the public, if they were to become generally known, they would constitute an attraction for many persons from throughout the country. This applies not only to such characteristics as might attract the general public for aesthetic and recreational purposes, but to those that would bear the attention of specialists such as scientists. The area is additionally of national significance because of the possibility that wide public knowledge of such features without proper protection could lead to their destruction through overuse or improper use. Finally, such features are generally acknowledged by informed persons to rank

[22]He so prophetically wrote in the early 70's. And of course by the 90's we did find another Carlsbad -- Lechuguilla

favorably with similar features found elsewhere in the U.S. that have already been given protection, as recognized by their inclusion in the National Park System, the National Wilderness Preservation System, or their declaration as Natural Landmarks, or by their inclusion in a National Recreational Area.

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