15th National Cave and Karst Management Symposium

Proceedings

October 16-19, 2001

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Welcome

Welcome to Arizona, to Tucson, and to the 2001 National Cave and Karst Management Symposium. This, being the first symposium of the 21st Century, will perhaps be the gateway to a new and renewed interest in the study, exploration, and protection of the varied resources existing within caves and karst, with an emphasis on education as a means of insuring that we preserve for all generations to come, what so many of us have come to realize the importance of and to appreciate.

The cave and karst regions of Arizona are found from lowland elevations of 1,000 feet to soaring snow-capped peaks over 12,000 feet, with cave temperatures ranging from 110° to 38° Fahrenheit. These diverse environments consist of solutional limestone caves, lava tubes, earth cracks, and ice caves. As the surface is no static, arid wasteland, neither are the caves that are still being formed and modified by active karst processes and where diverse and incredibly delicate minerals are being deposited. In a deceptively arid region we find caves and karst being developed, destroyed, decorated, dissolved, and quiescent.

We hope you will have time, either before or after the symposium, to further explore the magnificent "Sky Islands" areas of southeastern Arizona. Most of the staff are very familiar with this area and would be happy to recommend activities while you are here. Please also consult the pages in your program regarding half-day and day trips in the Tucson area.

We hope your experience with the symposium and your stay here is rewarding and pleasant, and that you will come back often to further enjoy this unique part of the United States and the friendly and laid-back atmosphere. If we, the staff, can in any way make your visit more memorable, please let us know.

Jerry Trout, Chairman
Jerry Orcutt, Co-Chairman
Sandy Trout, Co-Chairman

Greetings

On behalf of the Coronado National Forest, it is with great pleasure that we welcome you to Tucson and to southeastern Arizona. We are indeed honored that you have chosen our beautiful state and our city as the site for the 15th National Cave and Karst Management Symposium. The Forest Service is equally honored to be your host for the first Symposium of the 21st Century.

Coronado National Forest is very diverse, both geographically and demographically. The Coronado includes 12 mountain ranges known as the "Sky Islands" because of their pronounced setting, rising to elevations of 10,000 feet above the desert floors. These mountains contain many caves, and most are listed as federal significant caves.

It is my hope that during your stay you will have time to visit some of our "world class" cave resources and discover that they are just as diverse in their beauty and design as the above-ground landforms that draw so many people to visit and live in Arizona.

It is my wish that you have a successful and rewarding convention. It is my pleasure to do anything I can to ensure your visit to southern Arizona and the Coronado National Forest is both informative and enjoyable.

John M. McGee
Forest Supervisor
Coronado National Forest

Preface

The 2001 National Cave and Karst Management Symposium had the largest attendance of any symposium to date with 181 participating. This was in part due to a large number of Forest Service; Arizona State Parks; S.W.C.A. Inc., Environmental Consultants; and Environmental Planning Group, Inc. employees who were able to attend as a result of large donations by these agencies of both cash and in-kind contributions. Special thanks goes to these organizations and their members for taking such an interest in, and enthusiastically supporting the Symposium.

Several new features were initiated at the 2001 Symposium, and all verbal and written comments received suggest that, if possible, these should be included in future sessions. These new features included:

- A pre-symposium workshop presented and taught by Project Underground.
- A post-symposium workshop presented and taught by Bat Conservation International.
- Evening "cracker barrel" sessions in which timely topics, as suggested by the attendees, were discussed at length and in which a wealth of information was shared between the participants.

Notable was the large amount of time and effort by Arizona State Parks employees at Kartchner Caverns scheduling the field trip to the Park, which included an extended caverns tour, a viewing of the video in the auditorium, and a rare and special treat of a tour through several undeveloped areas of the cave. The State Parks offered this field trip at no cost to the symposium.

Also notable was the support of the Coronado National Forest by providing employees time and expertise, printing, equipment, and all necessary materials and supplies to insure an enjoyable and successful orchestration of the symposium.

It is our hope that all who attended the 2001 Symposium had an enjoyable and rewarding experience and perhaps might consider returning to Arizona for another session some time in the future.

Jerry L. Trout
Chairman
2001 NCKMS

National Cave and Karst Research Institute—Initial Activities

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Abstract

The National Cave and Karst Research Institute Act of 1998 mandated the National Park Service to establish the Institute. The Act stipulated that the Institute will be located in the vicinity of Carlsbad Caverns National Park in New Mexico and that the Institute cannot spend federal funds without a match of non-federal funds. The Interim Director for the Institute reported in July 2000 for a two-year period to define the purview and scope of operation, design an organizational structure, form partnerships, find funding sources, find a physical facility, and define research needs. The mission provides a framework for the Institute to achieve its congressionally defined goals and to guide development of an appropriate scope of activities in the national interest. The National Cave and Karst Research Institute furthers the science of speleology by facilitating research, enhancing public education, and promoting environmentally sound cave and karst management. The Institute will pass through several phases to reach full development. The Interim Phase of establishing the organizational structure and operating mode is anticipated to take until late 2002. The Gearing Up Phase, requiring an additional year (2003), will consist of staff recruitment and getting established in Carlsbad. The Basic Institute Phase, another one to two years (2004-2005), will see a gradual increase in the capacity of the Institute and accumulation of financial resources. The Fully Operational Phase, when the Institute becomes a significant resource in cave and karst research, education, and support of cave and karst management, should be attained by 2006.

Introduction

The National Cave and Karst Research Institute (the Institute) was mandated by act of Congress in 1998 (Public Law 105-325) under the organizational structure of the National Park Service. The 1998 Act was the culmination of many years of effort by the caving community, private and federal, to have legislation enacted that facilitated gaining a scientific basis for cave and karst management. Primary stipulations of the 1998 Act are that the Institute will be located in the vicinity of Carlsbad Caverns National Park in New Mexico (but not inside the Park boundaries), that the Institute may form a wide base of partnerships, and that the Institute cannot spend federal funds without a match of non-federal funds.

The Interim Director for the Institute reported in July 2000 for a two-year period to move forward with National Park Service efforts to establish the Institute by defining the purview and scope of operation, designing an organizational structure, forming partnerships, finding funding sources and a physical facility, and defining research needs.

Mission and Goals

The mission provides a framework for the Institute to achieve its congressionally defined goals and to guide development of an appropriate scope of activities in the National interest: The National Cave and Karst Research Institute furthers the science of speleology by facilitating research, enhances public education, and promotes environmentally sound cave and karst management. The goals (purposes) of the Institute are enumerated in the text of the 1998 Act. These expanded statements of goals provide a broader view of the operational intent of the Institute:

- Further the science of speleology through coordination and facilitation of research.
- Provide a point-of-contact for dealing with cave and karst issues by providing analysis and synthesis of speleological information and serving as a repository of information.
- Foster partnerships and cooperation in cave and karst research, education, and management programs.
- Promote and conduct cave and karst educational programs.
- Promote national and international cooperation in protecting the environment for the benefit of caves and karst landforms and systems.
- Develop and promote environmentally sound and sustainable cave and karst management practices and provide information for applying these practices.

Time Line for Full Implementation

The Institute will pass through several phases before it becomes a recognized force in the research community with the ability to sponsor a wide range of activities. The *Interim Phase* is anticipated to span about three years (August 1999 to August 2002). This phase began when a Steering Committee was convened to articulate expectations for the Institute and to draft specifications for recruitment of an Interim Director and will end when the Interim Director completes the initializing tasks.

The *Gearing Up Phase* is likely to take one additional year (2003). It would consist of staff recruitment, the move into a building (possibly a temporary facility), initial operational setup, and the transition from the Interim Director to the Director. If funding is available, research grants could be distributed during this phase and the real work of the Institute can begin.

The *Basic Institute Phase* would take another one to two years (2004 an2005) while the experience of the staff and the capacity of the Institute gradually increase and financial resources for full operation are accumulated. A grant process would be operational and results of research supported by the earliest grants may become available.

The *Fully Operational Phase* should be attained by 2006, when the Institute becomes a significant and recognized resource in cave and karst research, education, and support of cave and karst management.

Activities During the Interim Phase

Define the purview and scope of operation

Discussions have been held with a variety of interested individuals and organizations to help determine the most appropriate activities for the Institute to undertake. The relation of the Institute to other organizations is being defined in conjunction with those groups. Partnerships with all types of cave and karst interest groups, agencies, and organizations are critical to the success and utility of the Institute and to creating a national and international focus on research, education, and information dissemination for better understanding and management of cave and karst resources. The Institute, at least in its initial form, will not conduct research internally but rather will guide, focus, and encourage research through grants and partnerships. An important function of the Institute will be to accumulate and organize data and information to make it accessible to investigators and for the Institute staff to use for synthesis of information on regional and national scales.

Design an organizational structure

Staffing would be based on the scope of operation determined for the Institute. An important factor in the size and scope is the level of funding available to support the operation. Business models of other research institutions are being studied for ideas and to determine the most appropriate model for this Institute to adopt. It is envisioned that the initial Institute would have a staff of about 12 people that, in addition to the Director, might include a Science Coordinator and Science Assistant, an Information Coordinator (or Librarian), Computer/Database Specialist, Geographic Information Specialist, an Education Coordinator and Education Assistant, and administrative and clerical staff. Voluntary advisory boards are likely to be part of the organization to advise on science, education, and management issues and programs.

Form partnerships

The Interim Director has met (and continues to meet) with a wide variety of agencies, universities, and other organizations working in or interested in cave and karst issues, and is making international contacts in order to lay a foundation for international collaboration in cave and karst research and information exchange. These meetings are the basis for forming formal and informal partnerships and collaborations. An agreement has been signed between the Institute and New Mexico State University, which has a campus in Carlsbad, for a small amount of office space and administrative support during the interim and gearing up phases. New Mexico Tech and the City of Carlsbad also are important partners in getting the Institute operational in New Mexico. Several National Park Service agreements with other agencies and groups, although not specific to the Institute, are available for use by the Institute if needs arise.

Funding sources

Non-federal funds must match any federal funds spent to support the Institute's operations. An initial goal for base funding of the Institute is to accumulate enough recurring, non-federal matching funds to allow an adequate matching appropriation from Congress each federal fiscal year (which begins on October 1) to sustain a staff and operational expenses. Once adequate base funding is secure, the Institute can focus on funding to support research and educational activities. Significant progress was made when New Mexico Tech petitioned the New Mexico legislature for an annual appropriation to the school in support of the Institute. Because that petition was successful, Congress appropriated matching federal funds for the Institute for fiscal year 2002. Additional non-federal funding must be pursued, including private or corporate contributions that could support research and educational grants.

Find a physical facility

The City of Carlsbad and New Mexico Tech are collaborating to request building funds from the New Mexico legislature. The building would house offices, library, a basic laboratory, storage, and classroom/meeting facilities. In addition to offices for the resident staff, several offices will be available for visiting scientists who wish to conduct work in the Carlsbad area. If constructed, the value of annual rent and maintenance for the Institute building will constitute an in-kind match for federal funds.

Assess research needs

The Institute can provide a national scope and overarching goals to cave and karst research. A list of research needs is being compiled through informal and formal discussions with a wide variety of interest groups, scientists, and resource managers. This list is accessible on the Institute web site (http://www2.nature.nps.gov/nckri/needs.htm) for comment and additions. As a list grows, groupings of research areas are emerging, which will form the basis for articulating national research needs.

Projects

The Institute currently is sponsoring and participating in a few initial projects that will provide useful products and will help publicize the existence of the Institute. These projects require a small amount of funding, but primarily are being conducted with voluntary contributions of time and expertise by participants. Some of the 2002 appropriation likely will be used to expand the Institute's involvement in projects.

The Institute and the Karst Waters Institute are sponsoring a collaborative project to produce a booklet entitled *Guidelines for Cave and Karst Management for America's Protected Lands.* Associates of Karst Waters Institute and staff of the National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service, and USDA-Forest Service are contributing written sections. The Institute and U.S. Fish and Wildlife Service provided funding for Karst Waters Institute to edit, publish, and distribute the booklet. The booklet, anticipated to be completed in late 2002, can be used as a handbook for resource managers to comply with the requirements of the Cave Resources Protection Act, as a source of information for interpreters, and as a training resource.

The Institute and the U.S. Geological Survey Ground Water Resources Program are collaborating to produce a U.S. Geological Survey Circular (a magazine-style publication) on the topic of cave and karst science and management in the United States. The focus will be on what is being done within federal agencies in order to narrow the scope of the report and to avoid replication of what other groups already have written. In addition to the Institute and the U.S. Geological Survey; Bureau of Land Management, U.S. Fish and Wildlife Service, USDA-Forest Service, and the Environmental Protection Agency will contribute sections to the report. Authors will contribute their writing time, the Interim Director will edit and compile the publication, and the Geological Survey will cover the cost of preparation, printing, and some distribution, which should occur in mid 2002.

The Institute and the National Park Service Cave Resources Management Program are supporting, with some funding, the ongoing karst mapping activities of the U.S. Geological Survey. Scientists and land use planners need better maps for a variety of applications. A karst area map of the United States was published by Geological Survey in 1984, but considerable refinements still are needed. Maps also are needed on regional and local scales. The Institute is facilitating collaboration among USGS and private, state, and University scientists who have been working independently on karst area maps.

Author

Zelda Chapman Bailey is currently the Interim Director of the National Cave and Karst Research Institute in the National Park Service. After graduation from Indiana University in 1977, she began her career as a hydrologeologist with U.S. Geological Survey in Indiana and later moved to Tennessee. Her area of specialization is ground water flow modeling applied to ground-water availability and contamination. Zelda was Assistant District Chief for Operations in the Caribbean District, and moved to Colorado as Associate District Chief for Hydrologic Studies. While in Colorado she also served extended assignments as Acting District Chief for Colorado and for Wyoming. Zelda is a Certified Ground Water Professional, Certified Professional Geologist in Indiana, and a Registered Professional Geologist in Tennessee. She serves on Boards of Directors for the American Water Resources Association Colorado Section and the Greater Denver Area Gem and Mineral Council.

Cave Management Plans: Targeting Your Audience

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Abstract

One of the critical facets of cave management includes putting a management plan in writing, thereby providing a framework for all future activities. However, too often we fail to give adequate consideration to who will be using the resulting document. This presentation will briefly recap the process for developing cave management plans, then will focus on how to most effectively present the information to those who need it. We will discuss how confidentiality concerns, manpower availability, management infrastructure, and target audience considerations all affect the style of the plan. Contrasting case studies from the Hoosier National Forest and the Indiana Karst Conservancy will be used to highlight the key points.

The West Virginia Cave Conservancy: Growing Through Acquisition Problems and Their Solutions

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Abstract

The West Virginia Cave Conservancy has encountered a number of problems since its start in 1997. Many of the problems that are encountered have to do with situations that are beyond the control of the board of directors or others involved with any particular project. They are instead common problems that any young conservancy may encounter as well. These range from land acquisitions taking much longer than expected for various reasons, landowners not finding the urgency to have their resource protected, multiple heirs in estates, and the constant struggle between saving money and getting work done quickly. There are also a number of perceived thoughts that the general public has about conservancies as a whole that should be addressed. This paper will discuss these issues and present the solutions that the Conservancy has conceived in disposing of these problems.

Summary

Through the initial years of its existence, the West Virginia Cave Conservancy has encountered many issues that have proven to be obstacles along a variety of fronts. They range from issues that are encountered primarily in the acquisition phases of hopeful land transfers to those involved in public opinion among cavers and landowners alike. The purpose of this paper is to briefly outline the different types of issues that have proven to be obstacles to the Conservancy's cause. Some of these obstacles have definite solutions. Some of those solutions may or may not work in every situation. There are also some issues that do not have solutions yet, but hopefully recognition of the existence of the problem may help other conservancies in a similar situation find a way to deal with these issues before they become too great of a problem.

A conservancy may encounter quite a wide range of problems. First and most obvious are problems with acquisition, which include the possibility of there being multiple heirs to a property, of the property being offered only at auction, and of there being an issue of easements under neighboring property (underground easements). When there are at least two parties involved, transfers can often take longer than anticipated. Many times, when dealing with land transfers, there are more than two parties involved. There is the buyer, the seller, the lawyer for each side, and maybe a realtor, just to name a few. Each of these may have good intentions to address the issue quickly, but the fact of the matter is that other items do come up and distract each party, especially the parties that may be "hired" by the conservancy. A conservancy is not only in the business of preserving caves and karst, it is also trying to preserve money used in the acquisition of these properties. So it is not uncommon for a conservancy to have a "friend in the business" who will do work for very little or for free. This often slows things down as well, since work done for little or no payment will be put at the bottom of the to-do list. A good solution to this problem is to just go ahead and pay regular price for work done. This may seem like a great deal of money, but if your fundraising tactics are well-tuned, then it should not be a major problem raising the additional money to make up for that which was spent on a lawyer who works swiftly.

Many times the conservancy does not have a choice in how much property is available with the cave that is desired. This means that there is a good chance that there will be too much property offered with the sale, thus running the price up. There are many ways that this can be dealt with. Sometimes it is possible to put the unneeded portion of the property back on the market. This could make back some of the money that was spent to acquire the cave. There could also be a caver who has similar interests as the conservancy and who would be interested in the remainder of the property. This could be a positive situation to explore. Of course, this would all be negotiated only after attempts with the seller to subdivide initially fail.

Public perception can be subdivided into two topics: caver public opinion and non-caver public opinion. Caver public opinion is important since this is where most of the funding for the acquisition will come from. If the cavers do not trust or like what you are doing, then it is very difficult to get their money to help the cause. The best way to deal with this is to just be honest and open. Have regular newsletters that go out to your membership. Write articles to be included in other publications that cavers read so they can see you are active. Invite your membership to act as committee members and seek their input. This helps keep the cavers comfortable with your activities.

Non-caver public opinion can be more difficult to work with. There are many ways in which one can work on this, but the most important things to remember are skills acquired by most cavers who deal with landowners. Treat them with respect, knowing that you (the conservancy or caver) are not the owner of a particular cave at the moment. Do not be too pushy, but do not be a pushover as well. Act professionally when representing your conservancy, but keep in mind that some landowners may feel more comfortable with a less professional approach. Be able to adapt quickly and sufficiently. Finally, offer to be interviewed by your local newspaper, allowing the message to infiltrate the public so they can better understand your purpose. This may also create some unexpected opportunities for your conservancy.

Possibly one of the most overlooked yet influential problems is competition. This also has two categories. The most obvious and most difficult to deal with is the concept of running up the price of caves or land with caves. If the public begins to think that caves can be sold at a premium price, this will make future acquisitions more difficult. Unfortunately, this problem has no good solution. A conservancy can always attempt to get the lowest price, but many landowners always want the most money for their property. The hope is that you can keep the fact that the property has a cave as minor a detail as possible.

Competition as conservancy against conservancy or conservancy against caver has been discussed in a few publications recently, and is becoming a more prevalent issue. The best way to deal with this is to have very clear, open, and effective communication among the cavers in your region and among other conservancies. Even though you may belong to the Mid-Atlantic Cave Conservancy, the West Virginia Cave Conservancy may be a better manager for the cave in the long run, and vice-versa. Proximity to the property usually plays a major role in this and can sometimes be very obvious. The larger problem occurs when an individual caver has interest in a property and a conservancy does not realize it. This is very difficult to catch ahead of time. If it is known ahead of time, it is generally a good idea to support the individual in his quest. In the case of an auction, if the property's price begins to turn more costly, then maybe the two can work together, making spur-of-the-moment agreements. Usually, though, the two parties may not know each other ahead of time. There is probably no good solution for this issue at this time.

Land acquisitions can be a difficult task that can mean a great deal of time and effort for all involved. This paper does not cover all the problems a conservancy may encounter when acquiring land, but it certainly addresses some of the more common. Again, all the problems do not have definite answers, and the ones listed here are not the only solutions. They are just the ones that the West Virginia Cave Conservancy has found to be helpful when trying to acquire caves. The ultimate goal is that all cavers work together on this common goal and show support when possible. Communication tends to be the initial step in doing this, so hopefully this communication will help others in the future realize that there is a great deal involved and a great deal to learn.

Dying To Go Caving, 50 Years of Fatal Accidents In North America

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Abstract

Fatal accidents in North America from 1948 to 2000 were examined. These accidents are an un-biased indication of caving activity. Starting with an initial compilation of fatal accidents by Richard Breisch (1977) the number of fatalities was brought up to date with information from the annual *American Caving Accidents*. Fatal accidents were then divided into "fatal incidents" which was defined to be a mistake that led to one or more fatalities. Incidents were further broken down into two categories, general fatalities and vertical fatalities. It was found that both general and vertical fatal incidents correlated well with the growth of the National Speleological Society. A comparison of the first and last 25-year periods shows that the rate of fatalities has decreased by about 25%. The largest gain has been a 40% decrease in the rate of vertical fatalities. The decreased fatality rate is tentatively attributed to the introduction of better equipment.

Karst Management in Urban Areas

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Abstract

In the eastern United States there are many urban areas located upon karst terrain. Karst management in these urban areas is considerably different from in the western states where much of the karst is located on federal lands. In the eastern states, most local karst related statutes are designed to protect people and property from the hazards of living upon a karst landscape. This paper discusses the karst hazards of sinkhole flooding, sinkhole collapses, and groundwater contamination and the methods used in some urban areas to mitigate these problems. Local statutes in most areas deal primarily with prevention of sinkhole flooding, often by directing storm water runoff into cave streams at sinkholes, sinking streams, and storm water injection wells. Cave streams in these areas naturally drain storm water runoff and thus serve the same function as surface streams in that they receive and transport storm water runoff from the surrounding landscape. The water quality of these cave streams will reflect the land use in the area just as surface streams do. Unfortunately, there are contaminants associated with urban storm water runoff, just as there are contaminates associated with agricultural land use. It is unrealistic to believe that water flowing through cave streams or resurging from cave springs in these karst areas can ever be sufficiently pure for home consumption without treatment. However, there are ways to greatly improve the water quality of urban storm water runoff before it sinks into cave streams and this paper concludes with a discussion of several techniques.

Caves and Karst of the National Park Service

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Abstract

With such famous caves as Wind, Jewel, Carlsbad, and Mammoth, the public has long associated caves with the National Park Service. However, the diversity of "lesser-known" caves within the National Park Service is also quite high. Of the 281 National Park Service sites that contain significant natural resources, 76 contain caves and an additional 24 contain karst. This makes caves and karst one of the more dominant ecosystem/habitat/resource types within the entire National Park System. Seven of the eight cave types are represented, including several that may be considered the "type specimen." Managers, when evaluating potential impacts to caves, should evaluate both the individual resources within the particular cave and the cave's relationship to the regional and national environment. Karst and cave processes are not always easily recognizable. For instance, although no soluble rocks are exposed, karst processes are likely to play a significant role in one of the primary resource threats affecting Oklahoma's Chickasaw National Recreation Area. For many years, researchers have investigated the park's springs to determine their characteristics and to explain their slow disappearance. These researchers employed traditional groundwater investigative techniques, only to find conflicting and inconclusive results. However, many traditional groundwater techniques do not work well in karst terrains. Karst research at Chickasaw National Recreation Area may lead to a better understanding of the springs and the cause of the impacts to these significant park resources. This is but one example highlighting the importance of an inventory of cave and karst resources within the National Park Service.

Introduction

There are 384 units of the National Park Service as of March 2001. There is at least one unit located in every state within the United States except Delaware. Of these, 281 (73 percent) are considered to contain significant natural resources. Additionally, there are National Park Service sites in Guam, Puerto Rico, the Virgin Islands, and American Samoa. This represents a diverse array of parks and associated ecosystems.

There are also diverse caves within the National Park Service. With such famous caves as Wind, Jewel, Carlsbad, and Mammoth, the public has long associated caves with the National Park Service. However, the diversity of "lesser-known" caves within the National Park Service is also quite high. Of the 281 sites that contain significant natural resources, 81 contain caves and an additional 39 contain karst. Therefore, a total of 43 percent of all National Park Service sites containing significant natural resources contain caves and/or karst This makes caves and karst one of the more dominant ecosystem/habitat/resource types within the entire National Park System.

Definitions

Cave- the Federal Cave Resources Protection Act defines a cave as "any naturally occurring void, cavity, recess, or system of interconnected passages beneath the surface of the earth or within a cliff or ledge, including any cave resource therein, and which is large enough to permit a person to enter, whether the entrance is excavated or naturally formed." For the purpose of this paper, the term "cave" is less inclusive. Caves are reserved for only those features meeting the above definition and having a sufficient length-to-entrance width ratio whereas the cave's environment is noticeably altered or modified. This ecological component was included to eliminate the many rockshelters, overhangs and other small recesses that have no real "cave climate" or "cave ecology." With this more restricted definition, caves must have sufficient length so that the humidity, temperature, ambient light, and other environmental factors differentiate it from surface environments. This is of course subjective, however two generalizations can often be made: the cave must reach a point of near or total darkness, and if a suspected "cave" contains organisms that are known to be cave-adapted, or partially cave-adapted organisms, it probably is a "cave." With such a definition, this list does not include parks, such as Canyon de Chelly National Monument or Chattahoochee River National Recreation Area, that contain features called "caves," but do not fit the definition of caves used in this paper. Although many of these cave-like features would fit under the broader definition of a cave as defined by the Federal Cave Resources Protection Act, these features do not serve the ecological role that a "true" cave does. These features may be more properly called "rockshelters." Additionally, since the broader definition has no clear minimum bounds or standard, the reporting of the number of caves within any park would be nearly impossible. If one were to include rockshelters, the number of parks containing caves and the total number of caves within National Park System would dramatically increase.

Karst- for the purposes of this paper, surface morphological features such as sinkholes, sinking streams, and the like are not used as a definitions of karst, aspects that are more functional are utilized. Quinlan *et al*. (1991) defines a karst aquifer as "an aquifer in which flow of water is or can be appreciable through one or more of the following: joints, faults, bedding planes, and cavities—any or all of which have been enlarged by dissolution of bedrock." In his investigation, Quinlan found that dye injected into nearly any carbonate rock experienced non-Darcian flow typical of karst aquifers, even those carbonate rocks that did not contain any outward appearances of being karst. Due to these findings, karst is defined as any carbonate, sulfate, or other rock capable of relatively rapid dissolution by water under naturally occurring pH ranges. No attempt was made to define the minimum thickness of rock necessary to be considered karst. However, minor in-fillings and veins were not included.

Discussion

In the discussion of which parks contain karst, one must also consider the vertical location of the karst. For instance, some definitions would only include rocks exposed on the surface. However, for the purposes of this paper a broader interpretation is used. A park is included if the karst rock unit is shallow enough to enable it to interact with surface or groundwater. The inclusion of buried rock units where there are no surface exposures was due to four reasons:

(1) land management within the National Park Service is inclusive of a vertical column extending from the atmosphere above the surface portion of the park down through towards the center of the earth;

(2) just because a rock unit is not exposed does not mean that these rocks are not having an effect upon surface and subsurface processes. For instance, non-soluble rocks overlie a significant portion of Mammoth Cave, the longest known cave in the world. However, undeniably, the underlying cave is having an effect upon surface and subsurface water.

(3) if there are surface or subsurface processes occurring that are affected by covered karst, then there is a possibility that land managers could unknowingly alter, modify, or interrupt these processes out of ignorance.

(4) it is a natural process within a National Park Service unit, and the National Park Service has been directed to manage natural processes.

The following list summarizes the parks that contain caves or karst. This is a dynamic list due to at least eight reasons:

(1) many National Park Service areas have not been adequately inventoried for cave and karst resources;

(2) some National Park Service managers consider caves as a relatively minor resource within the National Park Service; therefore, adequate attention may not have been placed upon caves or karst;

(3) many people knowledgeable about the presence of caves closely guard these secrets;

(4) historically, caves were viewed more as recreational resources and less so as natural laboratories for scientific research; therefore, the quantity of published references and research within National Park Service caves is often sparse;

(5) cave and karst processes are often not as well understood by National Park Service managers compared with many other park resources and processes; so therefore, park management's ability to recognize cave and karst processes is hampered;

(6) caves are still being discovered;

(7) since some cave types are formed by rapid processes, new caves have formed since parks have been established;

(8) people's definition of a cave varies, so that the number of caves within an area varies depending upon the source.

The references included in the following list are not intended to be a complete list, quite the contrary. The listed references were included to provide examples of some of the sources that author used to confirm the presence of caves or karst on National Park Service lands. The many references used to confirm which parks do not contain caves or karst have not been listed. The author attempted not to rely on only one source of information but rather obtain published material that collaborated other information, such as personal interviews. Occasionally, sources conflicted. In these situations, the author evaluated and judged the validity of data.

The author has been maintaining an inventory of National Park Service areas containing caves and karst for a number of years. Such an inventory is never "complete." Therefore, the author would appreciate any additions or corrections.

Table 1. **National Park Service Caves/Karst: Cave Sites**

Park	Cave Type	**# of Caves**	**References**
Abraham Lincoln Birthplace National Historic Site	(Ls)	001	42
Acadia National Park	(Er)	012	101,112
Amistad National Recreation Area	(Ls)	030	83,92,203
Aniakchak National Monument or Preserve	(La)	001	PV
Apostle Islands National Lakeshore	(Er)	075	136
Badlands National Park§	(Er)	050	25,29,71
Bandelier National Monument	(La)	002	42,46,47,181
Bering Land Bridge National Preserve	(La,Er)	113	64,113
Big Bend National Park	(Ls)	007	34,117
Big South Fork National River and Recreation Area	(Ls)	001	36
Bighorn Canyon National Recreation Area[I]	(Ls)	001	19,69,93
Bryce Canyon National Park	(Ls)	001	35,57,148,193
Buffalo National River	(Ls)	275	11,72,135
Carlsbad Caverns National Park	(Ls)	095	9,42,67,68,74,75,76,144
Catoctin Mountain National Park	(Te)	002	50
Cedar Breaks National Monument	(Ls)	001	103
Channel Islands National Park	(Er)	369	PV
Chesapeake and Ohio Canal National Historical Park	(Ls)	011	50,73,124
Chickamauga & Chattanooga National Military Park	(Ls)	013	42,89
Coronado National Memorial	(Ls)	009	2,133
Crater Lake National Park	(Er)	051	4,90
Craters of the Moon National Monument	(La)	130	23,29,173
Cumberland Gap National Historical Park	(Ls)	015	94
Death Valley National Park	(Ls)	002	21,24,187
Denali National Park	(Ls,Gl)	003	53
Dinosaur National Monument	(Ls,Er)	005	29,100,146,191
El Malpais National Monument	(La)	240	42,131,139,167
Fort Donelson National Battlefield	(Ls)	001	PV
Gates of the Arctic National Park	(Ls)	007	178
Glacier National Park	(Ls)	006	19,20,29,105
Glacier Bay National Park or Preserve	(Gl)	001	198
Golden Gate National Recreational Area	(Er)	119	154

Golden Spike National Historic Site[£]	(Ls)	004	71,202
Grand Canyon National Park	(Ls)	400	82,121,152
Grand Teton National Park	(Ls)	017	29,69,103
Great Basin National Park	(Ls)	014	71
Great Smoky Mountains National Park	(Ls)	010	3,42,54,110,126,137,138,162,201
Guadalupe Mountains National Park	(Ls)	025	42,67,68,74,75,76,130
Haleakala National Park	(La)	024	111
Harpers Ferry National Historical Park[I]	(Ls)	001	32,42,66,79
Hawaii Volcanoes National Park	(La)	155	18,38,55,56,80,127,147
Jewel Cave National Monument	(Ls)	012	29,43,49,142,200
Kalaupapa National Historical Park	(La)	016	61,165
Kaloko-Honokohau National Historical Park	(La)	004	18
Kenai Fjords National Park	(Er)	012	185
Kings Canyon National Park	(Ls)	012	37
Lava Beds National Monument	(La)	399	5,51,60,91,104,132,158,170,195
Mammoth Cave National Park	(Ls)	350	42,143
Mojave National Park	(Ls,La)	010	1,96,196
Montezuma Castle National Monument	(Ls)	001	129
Mount Rainier National Park	(Gl)	005	6,28,40,42,62,102,168
Natchez Trace Parkway	(Ls)	005	122,177
Noatak National Preserve	(Ls)	004	163
Obed Wild and Scenic River	(Er)	001	184
Olympic National Park	(Er)	003	26,42,62,102,182
Oregon Caves National Monument	(Ls)	012	85,118,119,157
Ozark National Scenic Riverways	(Ls)	320	14,141
Pea Ridge National Military Park	(Ls)	001	11,175
Pinnacles National Monument	(Te)	006	42,45,123,134
Point Reyes National Seashore	(Er)	139	154
Pu'uhonua o Honaunau National Historical Park	(La)	006	18
Redwood National and State Parks	(Er)	002	172
Rocky Mountain National Park	(Gl)	001	29,42,140
Russell Cave National Monument	(Ls)	010	58,77
Saint Croix National Scenic Riverway	(Er)	012	44
San Juan Island National Historic Site	(Ls)	001	31,42,62,102
Sequoia National Park	(Ls)	188	37
Shenandoah National Park	(Ls)	001	12
Stones River National Battlefield	(Ls)	001	120
Sunset Crater Volcano National Monument	(La)	001	10,169
Theodore Roosevelt National Park[§]	(Er)	006	29,42,159
Timpanogas Cave National Monument	(Ls)	006	29,71
Valley Forge National Historical Park	(Ls)	005	88,128,176,204
War in the Pacific National Historical Park	(La)	012	39
Wilsons Creek National Battlefield	(Ls)	002	11
Wind Cave National Park	(Ls)	015	29,43,49,71,108,142
Wrangell-St. Elias National Park	(Ls,Gl)	008	7,52,99,106,155,161
Wupatki National Monument	(Er)	012	145,160

Yellowstone National Park	(Ls,La)	006	69,107
Yosemite National Park	(Te/Ls)	014	154
Yukon-Charley Rivers National Preserve	(Ls)	006	156,178
TOTAL 81 Parks and 3,926 Caves			+

Table 2. **National Park Service Caves/Karst: Karst Areas With No Known Caves**

Park	References
Agate Fossil Beds National Monument	29
Alibates Flint Quarries National Monument	13,116,150,194
Antietam National Battlefield	197
Big Cypress National Preserve	81,95,114
Biscayne National Park	30,86,97
Bluestone National Scenic River	174
Buck Island Reef National Monument	115
Canaveral National Seashore#	48,179,180
Castillo De San Marcos National Monument#	171
Chickasaw National Recreation Area	22,63,183,189,199
Colonial National Historical Park	151
Cumberland Island National Seashore#	59
De Soto National Memorial#	8,186
Delaware Water Gap National Recreation Area	166
Denali National Preserve	53
Devils Tower National Monument¥	29,42
Dry Tortugas National Park	115,164
Everglades National Park	15,27,78,98,190,192
Fort Caroline National Memorial#	17,171
Fort Frederica National Monument#	PV
Fort Matanzas National Monument#	171
Fort Pulaski National Monument#	PV
Fort Sumter National Monument#	PV
Fossil Butte National Monument	29
Gates of the Arctic National Preserve	178
Lake Mead National Recreation Area	16,153,188
Lake Meredith National Recreation Area	13,116,150,194
Lyndon B. Johnson National Historical Park#	87
National Park of American Somoa	115
New River Gorge National River	174
Ross Lake National Recreation Area¥	42,65,102
Saguaro National Park	84
Salt River Bay National Historic Park & Ecological Preserve	115
Timucuan Ecological and Historic Preserve#	17,125
Tonto National Monument	70
Tuzigoot National Monument	129
Virgin Islands National Park	42,115
Wrangell-St. Elias National Preserve	52,99,106,155,161
Zion National Park	41
TOTAL 39 parks containing karst, however with no known caves	

THERE ARE 120 NATIONAL PARK SERVICE UNITS CONTAINING CAVES OR KARST

KEY:
Ls- Solution Caves
La- Lava Tubes/Lava Caves
Gl- Ices Cave (caves in summit ice caps or glaciers)
Ta- Talus Caves
Te- Tectonic Caves
Er- Erosion Caves

† = Carbonate rocks consists of active or recent coral reefs
# = Buried karst - no karst feature visible on surface
¥ = Very minor or very thin lens of soluble rocks
i = Cave is within the park but the entrance is located outside park boundaries
$ = Contains cave-like karst features but unknown how long, may not be an actual cave
? = Small cave like erosion features, may be too small to be called a "cave," however contains bats.
Œ = May no longer be present due to glacial melting.
PV = Partially verified at time of press due to misplaced or incomplete reference.

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The Hoffman Institute/Cave Research Foundation China Karst Scientific Program

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Abstract

Among the world's finest karst regions is that of Guanxi Province in southern China. The province's capital, the 2,200-year-old city of Guilin lies along the Li River, whose route through a deep gorge just downstream from the city is one of the world's most spectacular river trips. The region has been the subject of intense study by scientists interested in karst landscape development as far back as the legendary Chinese geographer Xu Xiake in the 1630s. Today Guilin is home to the Institute of Karst Geology of the Chinese Academy of Geological Sciences, the premier karst research center of the nation. A cooperative scientific program between Western Kentucky Uuniversity's Hoffman Institute, the Cave Research Foundation, and the Karst Institute is in its sixth year. This paper summarizes recent activities, which in 2000 and 2001 include four trips by Western Kentucky University/Cave Research Foundation scientists to China, and two visits of Chinese scientists to Kentucky. Two trips by Western Kentucky University/Cave Research Foundation scientists and students in 2000 focussed on (1) presenting a three-day, karst related GIS course to Chinese scientists and graduate students, (2) continuing study of CO_2 landscape/atmosphere interactions, (3) new isotopic methods for karst landscape evolution studies, and (4) comparative studies between south central Kentucky and south China karst-related economic development. Western Kentucky University/Cave Research Foundation scientists and students will travel to Guanxi and Guizhou Provinces of China in September and December of 2001. Two trips were also made to the U.S. during 2000 and 2001 by Chinese scientists and karst tourism officials, which resulted in significant technology transfer in both tourism-based economic development and solutions to common karst environmental problems.

A World Perspective on Cave and Karst Protection: Paradox and Problems

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Abstract

In the last ten years there has been a growing movement for consideration of the special features of karst areas and the establishment of protected areas to protect these. This has been driven in part by a growing recognition of both the values and fragility of karst ecosystems. Although there has been considerable progress in awareness, protection, and quality of management, a number of paradoxes and problems have come more to notice. These demand consideration and discussion and this paper will raise some of the issues in the hope that delegates will make a contribution to that thinking process. So, at least the following will be discussed: National parks—Yellowstone and other models. Values of different environments for example, forests compared with deserts. Role of so-called experts in other cultures. The general failure to recognize much earlier protected areas. The place of indigenous people and their rights in parks. Collaborative management—what does it mean?

The National / Local Level

Protection is essentially based in national or more local—for example, state or provincia—legislation. Any of the levels of world recognition do not, in themselves, confer legal protection, but simply recognize and support the actions of national governments. So, for instance, world heritage status can only be granted once a country has made and undertaken its own protective commitment.

Confusion often arises because each country has its own terminology to describe protected areas and the meaning of any one title may well vary a great deal from one country to another. As the most obvious example, there is little in common between the use of the term national park in the United States on one hand and most European countries on the other. Most European countries use the term to refer to areas of scenic and/or historic value and these have at least medium population densities with a high level of land use for agricultural or other industrial purposes. Some other countries may designate as national parks what are no more than national monuments or habitat management areas.

In order to provide for comparability, UNESCO has approved a hierarchical classification of protected areas. It will be seen that these are ranked in a general order according to the intended rigor of protective control, although as we all know, there may well be a gap between intention and reality in any governmental actions.

- Strict Nature Reserves (limited or no visitor access)
- National Park (providing a high level of nature protection, but also visitor access for appreciation and enjoyment, compare with Yellowstone)
- National Monument (generally small areas to protect a specific feature)
- Habitat/species Management Area (to protect only a specific environmental association or species)
- Protected landscape/seascape (to protect a feature of exceptional beauty or scientific interest, for example, the protected coastlines of Great Britain)
- Managed resource protected area (often areas which combine and integrate conservation and development)

The summary descriptions in brackets are in my own words—for a full understanding of the classification, the manual on protected area classification, published by IUCN and also available on the Web, should be consulted.

Dilemmas and Debates About the "Yellowstone Model"

For many years, the "Yellowstone model" has been seen as the benchmark and standard for national park management. It has been presented to other countries as establishing the correct pattern for national parks. I am sorry to be critical, but I can only say that this is really no longer a valid position.

Firstly, even in the United States, the underlying assumptions have been very seriously challenged (see, for instance, Alston Chase's *Playing God in Yellowstone*). Similarly, the resulting organizational and staffing arrangements are sadly outdated, based as they still are in the traditions inherited from the many years of the parks being managed by the U.S. Army.

Much more seriously, the model is often totally inappropriate in other countries. The imposition of one somewhat abnormal form of United States culture upon other totally different cultures may well have tragic results, particularly for the ethnic minorities whose land has been placed within a so-called national park. Fortunately, some of the great parks of the world are still managed according to their own cultural traditions. One has only to visit some of the major parks in those countries that have inherited the cultural and philosophical traditions of the Austro-Hungarian to see a quality of management that puts the U.S. National Park Service to shame.

So, we have to rethink issues like the place of indigenous peoples in parks, the possibility of expertise transfer between cultures, and the patterns of management and visitor relations that we might build. There is, of course, no question that expertise can be transferred between cultures. One of my U.S. colleagues tells me that he learned more in a six-month advisory mission to Bulgaria than in the previous 25 years of his professional career. Personally, I have certainly learned much of my current thinking from Eastern European and Asian or Pacific countries.

There is also the myth that Yellowstone was the world's first-ever national park. It may well be the first to use the English language words but nothing more. Let me just note two of what could be hundreds of other examples. When the first humans arrived on Niue, they decided that the Havalu Forest was so beautiful that they would maintain it in its pristine state and never use it for housing, food, or timber gathering. It remains in place to this day. But that is relatively young, having been established somewhere between one and two thousand years ago. For what is probably the world's longest standing park, we should look to the Buskett Gardens of Malta, where there is good evidence that this has been a continuing and important park, possibly since the Neolithic, and certainly since the Bronze Age.

Problems About Specific Features in Conservation

In general, the places and organisms that attract most attention from the conservation movement have fur, feathers, or leaves. And even when one is concerned about animals, that usually means creatures with a spine, and largely ignores the existence of invertebrates, or even the bacteria and nanobia that are the most vital life forms.

So karst conservation has to convince the conservation movement that rocks are also important. With the current passion for protection of biodiversity, we can at least argue that the basis of most biodiversity comes from the underlying geodiversity. In fact, the current passion for biodiversity serves karst protection reasonably well. Most karst areas have a great variety of micro-habitats, each with its own micro-climatic conditions and hence some of the most remarkable demonstrations of biodiversity in the world.

The International Support Systems

There are three major systems for international recognition and support of conservation through protected areas.

The first is the Man and Biosphere program, with its recognition of Biosphere Reserves. Essentially the biosphere reserve brings together a range of lands from protected areas through to highly developed and utilised lands, and a nomination currently under consideration even includes a major urban sector. The central concept of the biosphere reserve is to foster conjoint sustainability of use and protection of natural values across the range of lands represented in the reserve. It demands a broad-ranging commitment to the principles from all land owners and managers within the reserve.

I believe this concept has a very important role in karst is often under pressure from wine growers and others, yet they can truly play an important part in maintaining the integrity of the karst and its groundwater systems. Some of the very excellent work being done in the U.S. by the karst conservancy movement is based upon very similar principles. It is even possible that some such areas might gain international recognition under the Man and Biosphere program.

Interestingly, a related and important new direction in conservation through protected areas is the Integrated Conservation and Development Projects, where two or more partners work together to achieve safeguarding of a protected area in close association with an adjacent development program. A successful Integrated Conservation and Development Project demands a shared vision, genuine partnership between the major stakeholders, and appropriate co-operation and joint policies within governmental authorities. At least several of the major examples on karst lands are based in partnership between protected area authorities or NGOs and cement companies. In fact, one of the first projects of this kind, established at Bamburi in Kenya over 20 years ago (long before the idea had a name of its own) grew out of partnerships initiated by a cement company operating in a karst area.

The best-known mechanism for international recognition is the World Heritage Convention, providing for recognition of both natural and cultural sites. Here there are two inter-related central concepts of protection and maintenance of integrity on one hand, and accessibility for the peoples of the world on the other. As this is more widely recognized, and currently covers some 42 karst areas, I will discuss the special issues involved below. Finally, the RAMSAR convention on the protection of wetlands is now becoming a significant opportunity for recognition of important karst aquifers. Although originally established to provide for international recognition of the need for multi-national co-operation in the protection of migratory water birds, it rapidly developed a wide-ranging concern for major water bodies. A resolution several years ago provided for the recognition of "subterranean wetlands," at least in part because of concerns about the protection of the remarkable biota of karst wetlands, but in effect expressing recognition of the great importance of karst waters as mega-reservoirs of very considerable practical importance in water supply. A small group in Europe has developed policies and procedures for its implementation, and nominations are now welcome.

The IUCN / WCPA Cave and Karst Task Force, with its responsibilities for assessment and monitoring of karst world heritage sites, is now working together with the subterranean wetlands committee of RAMSAR. We trust this will enable more effective and appropriate recognition than might be achieved by either one alone.

Some World Heritage Issues

There are various common misunderstandings that demand clarification. The World Heritage Convention is administered by its own Council and Executive Committee, comprising elected delegates from signatory nations. It receives administrative and logistic support from the UNESCO World Heritage Bureau, with scientific and technical support from IUCN (natural heritage) and ICOMOS (cultural heritage).

Any nominated site is assessed against a rigorous set of criteria to confirm that the site is genuinely of "outstanding universal value" and is managed in such a way that its integrity will be maintained. There is also both opportunistic and systematic monitoring of existing sites to ensure that proper standards of management are maintained, and regular state of environment reports are submitted to the Council.

One might well ask what purpose does World Heritage recognition serve. My personal experience suggests that the recognition of a site in itself provides a powerful incentive for better management; that the recognition also carries an international obligation for support in the continuing protection of a threatened site and this has proved invaluable in assisting countries in crisis; and where the standards of management in any one country or at any one site fall short of what is desirable, it provides an invaluable avenue for dialogue and negotiation to resolve problems.

Thus one question that is sometimes raised concerns the extent to which World Heritage recognition may be claimed by a country to indicate international approval of their management practices. Alternatively, it may be seen by others as an improper support of management practices which might, for instance, be inherently and improperly racist or discriminatory. This is a common issue in any international agency—and, in the case of World Heritage, it may be important to recognize the importance of a site while still continuing dialogue with the host state about its management standards. In other words, recognition may provide the opportunity for dialogue which otherwise might not occur.

Another concern is the extent to which the tourism industry clearly benefits from World Heritage recognition.This may well result in considerable pressure to recognize a site for the sake of the economic benefits that are anticipated, rather than for its continuing protection and integrity. Certainly this is one of the issues sometimes raised in reviews of the state of environment and most countries fully accept the importance of controlling any adverse impacts from excessive tourism. But the issue of tourism impacts certainly demands more thorough attention and research. A extremely valuable international workshop on monitoring of karst sites has been held in Slovenia since this symposium and the report will shortly be available.

Then we also face a gaggle of special problems to do with the dispossession of ethnic minority peoples, despite the very real efforts by a special group within IUCN aiming to achieve more inclusive and collaborative management in such situations. There are some major problems of law enforcement including poaching of rare fauna or of swiftlet nests ("white gold") and stealing of major timber trees for the specialist furniture market. Finally, corruption serves to divert a remarkable amount of funding to other purposes.

So, the World Heritage Convention provides an important and valuable tool, but its fully effective implementation is sometimes difficult and demands both vigilance and skilled negotiation to achieve the necessary action by the host states.

Speleologists, particularly in their own local activism either through karst conservancies or in other ways, may find it valuable to invoke international support for their efforts. Even more importantly, it is often expedition speleologists who discover and provide the evidence of the karst values which identify potential, and a number of actual World Heritage Sites. Their role is of fundamental importance in protection of the world's great karst areas.

The Ozark National Scenic "Karstways"

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Ozark National Scenic Riverways

Abstract

The Ozark National Scenic Riverways (National Park Service) was created in 1964 ostensibly to preserve 134 miles of the free-flowing Current and Jacks Fork Rivers. But the stated purpose of the enabling legislation included the preservation of springs and caves. Today some of the largest springs in the National Park System and over 300 caves lie within the Ozark National Scenic Riverways. Due to the priority of managing the river resources, management of the cave and karst resources has not always been consistent or funded. Nonetheless, standards for management have evolved over the years. A cave management plan (and subsequent cave management team) in cooperation with donated services have created a management system that seems to be working (although much room for improvement exists). An overview of the resources and the history of management will be discussed.

A Prerequisite to Managing Karst Systems: A Model for Evaluating the Basic Elements of Karst Development

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Abstract

An understanding of karst systems and how they form and function is important for developing strategies to preserve, protect, and manage these systems and their associated resources. Karst systems form in a variety of geologic settings and hydrologic regimes. As the geologic and hydrologic cycles progress and change over time, the karst systems associated with them also evolve and change. The variety of conditions under which karst systems form, coupled with the continuing evolution of geologic conditions, make it impossible to assign one mechanism of speleogenesis and descriptive mode to address all existing karst systems. Despite the differences in form and development of karst types, all share several fundamental elements. These elements include lithology, solvent, porosity/fractures/fissures, gradient, and evolution through time. All karst systems can be related and compared based on these fundamental elements. To develop the basic principles of this approach, several different karst types (the Caribbean Isla de Mona and the Florida Suannee River Karst) were comparatively evaluated to determine how these fundamental elements can be applied to each. It was determined that this approach is useful both in a descriptive and comparative sense in highlighting not just the differences between karst types but also in emphasizing their inherent similarities. In face of significant differences between these systems, the similarities teach us something about the fundamental nature of just what karst is about.

Protecting Karst Resources Requires an Understanding of Karst Resources

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Abstract

The authors, along with many of our colleagues, propose that we cannot protect that which we do not understand. An evolving, cooperative graduate education program between Western Kentucky University and the National Park Service continues to develop. This program is providing training to a variety of National Park Service scientists with responsibilities for karst resource management. The program has a long history with the Western Kentucky University Center for Cave and Karst Studies' Mammoth Cave "Summer in the Park" Program, founded by Nick Crawford in 1980 and which continues as an important component of the program today. Simultaneously, since 1990 numerous Western Kentucky University graduate thesis research projects in water quality, air quality, and karst landscape evolution have been completed at Mammoth Cave National Park. More recently, the intensive, yet flexible, graduate programs of David Ek (Fort Clatsop and Chattahoochee River), Joel Despain (Sequoia/Kings Canyon), and Katie Seadler (Mammoth Cave) are serving as models for an evolving program that in the future should expand into other resource management areas as well as serving the needs of resource managers from other government agencies.

Performing Monitoring and Air Studies with In-cave Weather Stations

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HDS Systems
Tucson, Arizona

Abstract

Understanding the cave environment entails gaining an understanding of air flows within the cave environment, including mechanisms that set the air in motion, the transport of heat, the transport of moisture, and the interactions of the cave air with the outside air. To achieve a detailed understanding, it is necessary to accurately measure small changes in temperature, humidity, slow air flows, and changes in pressure. This data needs to be collected in sufficient detail to build an accurate model that can predict. Uses of this data include monitoring cave systems for changes as well as aids to exploration. A network of very accurate data collection systems is discussed that can collect the necessary data over extended periods. These stations are designed to support long term studies that can last for decades.

Human Factors in Resource Management
. . . or . . .
Is it Good to be the King?

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SSP Inc.

Abstract

This paper will examine human tendencies and the problems and benefits they can produce in such areas as: see my badge syndrome; special interest groups and problems; who is our real boss, a reality check; the art of over reaction and alienation; empire building; obtaining broad base support; how others see us and how we see ourselves; the road to hell is paved with good intentions and programs; and the relationship between corn flakes and cave management. These topics will be presented along with case histories and discussions. There will be an opportunity for interaction and role playing scenarios if desired.

Karst Vulnerability Assessment Procedures and their Linkage to Forest Management Guidelines, British Columbia, Canada

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Abstract

British Columbia, on the west coast of Canada, contains significant tracts of forested and mountainous terrain, with forestry being an integral part of the British Columbia economy. Some of the best known karst and cave areas in British Columbia occur on Vancouver Island, where considerable activity in forestry occurs. In 1997, an initiative was put forward by the British Columbia Ministry of Forests to manage karst as a functional ecosystem. Since that time a set of karst inventory standards have been developed, along with a handbook for karst management guidelines. (The latter has yet to be released.) A karst vulnerability rating procedure is used to directly link the karst inventory data/attributes to the karst management guidelines at the site level (1:5,000 or 1:10,000 scales). Karst Field Assessments are required for any proposed forest development (for example, a cutblock or road) on or adjacent to karst areas. The attributes evaluated during the Karst Field Assessment include: (1) the karst unit boundaries and geological characteristics; (2) the surface epikarst; (3) the overlying soil thickness and texture; (4) the location, density, and significance of surface karst features; (5) the roughness of the overall karst surface; (6) karst streams and hydrology; (7) the potential for caves and other subsurface openings; and (8) the occurrence of unique or unusual karst biota and/or habitat. A four-step karst vulnerability procedure is used to stratify the forested karst landscape, resulting in polygons with low, moderate, high, or very high vulnerability ratings. This procedure evaluates a combination of epikarst sensitivity, surface karst feature density, and subsurface karst potential. The procedure also allows for the integration of three modifying factors: fine textured and erodible soils, karst topographic roughness, and unique or unusual karst biota and/or habitats. In karst landscapes with a low vulnerability (for example, poorly developed epikarst, no surface karst features, and thick soil cover) management using existing British Columbia Forest Practice Code guidelines would be acceptable. In karst terrain with a moderate vulnerability (for example, a small number of surface karst features, thin soil cover and moderately developed epikarst) certain modified practices would be required along with the Forest Practice Code guidelines. In karst areas designated as high vulnerability (for example, well developed epikarst, high density of surface karst features and high likelihood for subsurface openings) management would likely involve measures not currently covered by the Forest Practice Code. These measure could include specialized road construction techniques and harvesting practices (for example, partial cutting or heli-logging). In very high vulnerability karst where there is a high level of openness between the surface and subsurface, no harvesting or road construction would normally be carried out. The vulnerability rating procedure as outlined could have applications for other development activities in karst terrain, such as mining, urban construction, and park lands. The vulnerability rating procedure used in these situations would systematically stratify the karst landscape, allowing for management constraints or prescriptions to be applied in an unbiased manner.

Conflict Among User Groups

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Abstract

Conflict among user groups has become one of the most pervasive and perturbing issues facing managers of outdoor recreation settings, particularly in the "West." Public land agencies have had to deal with a steady increase in the number and complexity of situations in which one or more recreation groups has been at odds with each other or with another public land constituency. Perhaps nowhere is there such an increase in the number of users as in caving, which translates to an increase in the number of conflicts. Conflict is typically defined in recreation management as "goal interference attributed to another's behavior" (Jacob and Schreyer, 1980). Because motivations and desired outcomes differ among caving activities, for example NSS cavers may be much more likely than party cavers to seek places where they can escape the sounds of the city, conflict is said to result when the activities of one group restrict another group's ability to achieve it's goal. Amy (1987) describes three general sources of conflict: ***misunderstandings*** **–** when parties are differently informed about an issue; ***interests*** – in which people want to use the same resource for different things; and ***values*** – in which disputants differ in deeply-rooted beliefs about what is "right." The goal interference model refers almost entirely to interest conflicts, yet one can easily imagine conflicts that arise from misunderstandings ("I thought this area was off limits to recreational caving") or values ("cave photographers tend to sacrifice conservation practices to get the perfect Picture").

Summary

If outdoor recreation conflict is indeed on the rise, there is likely to be several reasons for this. Foremost of these in the continued proliferation of "new" activities that can be enjoyed in dispersed recreation settings. Population growth in both urban and rural areas has led to perceived crowding at many recreation settings, which tends to intensify disputes between constituencies that must share those settings. Recreation conflict mirrors the trends in environmental politics overall—as the political environment becomes increasingly contentious, recreationists have learned to organize activity-focused interest groups that have successfully used the same political and legal tactics as commodity and preservation groups.

When we think of outdoor recreation conflicts, we are likely to imagine disagreements between participants in *two different activities* that are wholly or partly incompatible. Recent examples from outdoor recreation research include: hikers versus mountain bike users (Watson *et al*, 1991), power boaters versus river rafters (Cole, 1989), and cave researchers versus recreational cavers (Trout, 1991); however, conflict can also occur between participants in the same activity. Such conflicts may result from differing ways to enjoy the same activity, as when conservation minded cavers perceive conflict with groups who use caves as a party place, or from disagreements about the management emphasis that should be given to commercially outfitted versus non-outfitted users of caves.

There are also conflicts between *recreation users and other natural resource stakeholders*. A classic example involves conflicts between recreation interests and advocates of commodity land uses. For example, mining companies and mining-dependant communities may oppose plans to designate an area as wilderness or a cave as significant because such designation carries restrictions on mining activities. A variant on this theme that is increasingly common involves conflict between recreation interests and environmental organizations. Such conflicts most often involve groups such as outfitter guides that advocate publication of cave locations and government agencies and cave conservation groups that believe that such listings are potentially the greatest threat to cave resources.

Finally, there are outdoor recreation conflicts between public land managers and their constituents. Managers tend to see themselves as "just doing their jobs" as stewards of the land, or mediators between competing interests, but persons angry over unfavorable solutions to shared-use problems often see managers as being as culpable as those who hold the competing interests. Conflict can also occur entirely within agencies as managers, whose primary responsibility is recreation, disagree with colleagues responsible for commodities or environmental protection.

Jacob and Schreyer (1980) identified four major "factors" which can be used to predict the intensity of perceived conflict and the likelihood conflict will occur. *One such factor* is the personal meanings that people attach to activities; for example, the extent to which an individual's self-concept is linked to the activity. A *second factor* is the significance attached to using a particular setting for a particular activity. Still *another factor* is the mode of experience for a particular activity, since people may be more likely to perceive conflict if their preferred activity involves continued awareness of their entire environment rather than focused attention (a caver rapelling down a 500-foot drop must concentrate fully on the technique). The *fourth factor* is the perceiver's tolerance for life-styles different from his or her own.

Managers have several options for addressing situations of conflicts over shared use of recreation settings. Although we often hear references to "conflict resolution" – it may be more reasonable to refer to these as strategies for "conflict management." The latter term accounts for the fact that recreation use conflicts often cannot go away entirely since they are rooted in fundamental differences over how one should experience the natural environment. It also is consistent with the idea put forth by social theorists that conflict serves a crucial function in the maintenance of societies.

In a sense, all conflicting interests are likely to attempt to "manage" conflicts in ways that can tilt the balance of a dispute in their favor. Lincoln (1990) describes a continuum of these strategies, which vary according to the intensity of the conflict. In order from lowest to highest intensity, these strategies include: inaction, negotiation, facilitation, mediation, arbitration, administrative appeal, judicial appeal, legislative appeal, non-violent civil disobedience, and violence. Public agencies also undertake to manage conflict as part of their legal mandates to balance the needs and interests of multiple constituencies.

Because solutions in this second category are frequently disputed by one or more parties and can be very costly if they prompt administrative or judicial appeals, agencies increasingly promote collaborative decision-making processes that allow the conflicting interests themselves to join in drafting a way to minimize the conflict. Such processes hold promise, but they require managers to have "people skills" that go beyond the traditional leadership skills required of natural resource professionals (Rasmussen and Brunson, 1996), and they must be carefully organized in order to ensure that they are consistent with the Federal Advisory Committee Act (5 U.S.C. Appendix 2).

Definitions

1. Conflict in caving activities or outdoor recreation typically is defined in terms of social-psychological consequences of on-site interaction, following Jacob and Schreyer (1980) who defined conflict as "goal interference attributed to another's behavior" (p 369)

2. A frequently observed phenomenon in recreation conflict situations is "asymmetric antipathy," which is said to occur when one party perceives conflict with another due to goal interference, but the second party experiences little or no goal interference from the first and thus perceives no conflict (for example, Adelman *et al.*, 1982).

3. Recently the Jacob and Schreyer (1980) definition has been criticized for failing to describe the full range of conflicts that center on outdoor recreation.

- There may be occasions when people simply feel that others in a shared setting should not behave as they do, regardless of whether that behavior interferes with their ability to achieve desired outcomes; for example, some people may believe that loud, boisterous behavior in caving activities is inappropriate even if escape is not among their recreation goals (Trout, 1994).
- Jacob and Schreyer's conceptualization focuses on causes and symptoms within the recreation setting itself, yet recreation conflict is often manifested in the policy arena through public debates over appropriate uses of recreation settings or through administrative and judicial actions intended to force or prevent restrictions on one or more user group.
- Much of what is termed "asymmetric antipathy" is in fact two-way conflict in which one group perceives the conflict on-site while the other perceives it off-site as soon as the first group attempts to influence policy to im-

prove its ability to achieve its goals (for example, by imposing restrictions on uses that are seen as interfering with them).

4. Further insight can be found in analyses of non-recreation environmental conflicts. Amy (1987) describes conflict as arising from any of three sources.

- Misunderstanding-based conflicts surface if there is inadequate access to available information or differing interpretations of the information.
- Interest conflicts occur when people want to use the same resources for different things. In the case of caving, visitors may want to use the same cave to pursue activities that are partly or fully incompatible (for example, recreation and research or trail marking and photography).
- Value conflicts are based on differences in the deeply rooted beliefs of user group members regarding proper modes of conduct and/or desirable end-states. Often such activities can be a symptom of higher-order value conflicts, as when "environmentalists" who enjoy cave restoration projects move to communities where party caving is the predominant recreation activity for longtime residents.
- Some experts in the field of conflict resolution (for example Burton, 1990) suggest that only value-based disagreements truly qualify as conflict. Burton refers to the other types as "disputes."

Conflicts Rise to Prominence in Cave and/or Recreation Management

1. As new activities such as speleothem restoration, microbial research, or trail marking have increased in the past decade, so has conflict between groups.

The potential for conflict with other cave users grows exponentially with each new activity at a given site because each user group can have points of negative interaction with participants in all of the other activities.

Exacerbating the situation is the tendency for participants in more traditional pursuits such as cave exploring, photography, mapping, or cave surveying to view those who enjoy newer activities as "interlopers" who do not deserve equal standing in disputes over territory or regulations.

2. Perceived restrictions associated with increased cave usage tends to cause simmering disagreements to intensify into full-blown conflict.

Use of outdoor recreation setting seems to be growing nationwide after a period of stagnation during the 1980s. Nowhere is this more evident than in caves, particularly in fast growing cities in the west and southwest USA.

While sheer numbers of recreationists may be smaller in some rapidly growing rural areas, recreation conflicts in such places can be intractable because new migrants—for whom outdoor recreation often is a chief reason for moving—may pursue different activities than longtime residents who are already distressed by the sudden increase in use of their outdoor backyards and caving areas.

3. Activity-focused interest groups such as the Cave Research Foundation, American Cave Conservation Association, or National Speleological Society use more sophisticated political and legal strategies than the more local or loosely organized caving or recreation groups of the past.

Categories of Outdoor Recreation Conflict

1. The most typical form of recreation conflict is that which occurs between participants in two different activities that are wholly or partly incompatible that must share a cave or recreation setting. There are hundreds of pairs of such activities, but some of the most common ones in caving include:

Participants in scientific activities such as biological, hydrological, or geological research often perceive conflicts with persons who enjoy recreational pursuits. Such conflicts can be extremely contentious. For example, Floyd (1993) developed a model of conflict intensity based on the degree of similarity of competing interest. He later reported (pers. comm.) that his model worked well except in the case of motorized versus non-motorized recreation conflicts.

Inter-activity conflicts often occur if participants in one activity tend to see another activity as promoting reckless or unsafe behavior. Conflicts involving vertical caving often fall into this category, since there are so many different styles, techniques, and types of equipment.

Activities whose participants tend to be especially sensitive to the presence of others (at least in terms of the number of times they appear in scientific or popular articles about recreation conflict) include cave photography, surveying, and many other specialty type activities.

2. Conflicts can also occur *within* activities due to differences in the ways that people prefer to participate in that activity.

Variation in experience levels can lead to conflicts within activities, as more skilled participants may prefer not to share areas with groups they identify as less-experienced (for example, Boy Scouts versus veteran cavers)

Experience levels can be correlated with status hierarchies in some caving activities. Classic examples would be researches vs. sport cavers or especially party cavers. Cavers also have disagreements with people who use caves for "non-caving" reasons such as bolting entrances, partying, or cult type activities. Outfitters and their clients may come into conflict with non-outfitted participants in the same activity. In several western caves where caving use is restricted, there are sometimes concerns over the proportion of permits allocated to outfitters and researchers vs. recreational caving.

3. Conflicts also occur between recreation participants and other natural resource constituencies.

The most typical of these involve conflicts between recreation and scientific interests and commodity uses such as crystal harvesting or mining.

Increasingly there are conflicts between recreation users and some environmental organizations. Although preservation groups sometimes oppose some recreation uses, most often these conflicts involve activities that environmental activists see as detrimental to wildlife and other resources. Fears about erosion of "rights" have led to the formation of several coalition type organizations.

Similar kinds of conflicts have arisen between caving interests and advocates for Native American cultural rights.

4. Participants in recreation activities often perceive conflicts with managers whom they blame for decisions that somehow reduce their ability to participate in a preferred activity at optimum times and places. In such cases managers may not see themselves as part of the conflict (though they typically recognize that others are displeased with them). Within agencies, there also can be conflicts between managers responsible for recreation uses and those who focus on other resources.

Factors that Can Enhance the Likelihood of Recreation Conflict

1. While the concept of a recreation or scientific "activity" implies a more or less standard set of behaviors, people may place different personal meanings on the same behavior. These differences in meanings can make persons more sensitive to conflict under certain situations.

- Some people may view their caving activities as a central life interest—a critical source of rewards outside work. Often such persons choose jobs or places to live because they enhance opportunities to participate in that activity.
- Persons who perceive their mode of activity as having higher status—for example, researchers as opposed to recreational cavers, or free climbers as opposed to "top-ropers." Are more likely to perceive conflict with others.
- More experienced participants tend to be more susceptible to conflict.

2. If a person attaches a special meaning to a particular place for engaging in a particular activity, because of its superior qualities for engaging in the activity or because of an emotional "attachment to place," conflicts with other users may be more likely to occur.

3. A major component of a recreation experience is interaction with the natural environment, but some activities allow more awareness of the environment than others. Researchers vs. "speed cavers" for example.

4. Some outdoor recreation participants may have greater or lesser tolerance for diversity in lifestyles. Conflicts over nude caving for example are often rooted in this phenomenon. Long time cavers may be intolerant of people who use stereos in caves or bring in beer or other substances that can increase the possibilities of accidents.

Strategies for Conflict Management

1. Conflicts often are more effectively addressed if the focus is on "managing" rather than "resolving" them. Resolution may be an unrealistic goal for two reasons:

- Conflicts often are rooted in basic value differences, that is, fundamental disagreements about the proper way to experience the environment that are not easily "resolved."
- Many sociologists believe that conflict, rather than being a symptom of dysfunction in society, plays a vital role in the evolution and maintenance of social institutions (Bernard 1983).

2. Strategies to "manage" conflict in a particular direction can be adopted by all competing interests, who may use a wide range of approaches ranging from cooperative persuasion to violence against others.

3. Public land agencies have management tools for recreation conflict that can be employed both on- and off-site. Typically agencies try to first use approaches that do not entail changes in the site or its management. These

are favored because they are inexpensive in terms of dollars, time, and personnel and because they are less controversial among recreationists.

- Education/information campaigns are often the first strategy tried when a conflict arises. Often these focus on teaching proper etiquette, as when cavers are told to confine their travel through a cave to a single path.
- Often educational approaches are coupled with efforts at improved enforcement of existing boundaries of segregated use and/or rules against depreciative behaviors.

4. If education and enforcement fail, managers are likely to adopt strategies that change the physical and/or managerial characteristics of the setting.

- The standard way to do this is to segregate uses. This approach ensures that recreationists have a place where they know their experiences won't be diminished by interference from others. In caving this has been accomplished by installing gates and allowing only one group at a time to be in the cave; therefore, insuring the "wilderness" quality of caving without the interference of others. The disadvantage is that the total area available to participants in all or some activities is reduced.
- For this reason, groups such as the National Speleological Society favor solutions that "design out" conflict, for example, making more caves accessible to spread out visitation.

5. Increasingly agencies seek collaborative solutions to problems of shared use.

- Such processes allow the conflicting interests themselves to join in drafting ways to minimize conflict. For example, if researchers and recreational cavers are able to jointly choose locations for segregated use, they may be able to agree on areas they are more willing to "give up" to the competing interest, rather than having managers choose the sites and face acrimony from all sides.
- These approaches build on theories of procedural justice (for example Lind and Tyler, 1989) which suggest that people are more willing to accept unfavorable outcomes if they had a hand in designing the process by which the decision was made and believe that the process was fair.

6. Collaborative processes hold promise, but they remain largely unproven and pose some new challenges to outdoor recreation and cave managers.

- They require skillful management by people with "people skills" that may be rare within agencies because they surpass the traditional leadership skills required of natural resource professionals (Rasmussen and Brunson, 1996).
- There can be enormous time demands for collaborative processes.
- Some interests shy away from participation in collaborative processes, believing either that their interests are more likely to be served by alternatives to a negotiated settlement, or that they cannot allow their values to be compromised by offering concessions to a competing interest.
- Agencies are leery of violating the Federal Advisory Committee Act (5 U.S.C. Appendix 2). The structure of collaborative processes must be carefully designed to ensure consistency with the tenets of Act and the National Environmental Policy Act (42 U.S.C.A. # 4231-61).

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Lincoln National Forest, Guadalupe Ranger District, Cave Permit System

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Abstract

The Lincoln National Forest implemented a closure order in 1972 restricting cave access to those with a permit. Over the years the permitting process has evolved to provide enhanced protection for cave resources while still allowing recreational use of most of the Guadalupe Ranger District caves. Following policy and direction set in the Forest Service Manual, Lincoln National Forest Plan, Federal Cave Resources Protection Act, and Lincoln National Forest Cave Ecosystem Management Direction, Lincoln National Forest caves are managed as nonrenewable resources to maintain their geological, scenic, educational, cultural, biological, hydrological, paleontological, and recreational values. Caves have been assigned management classifications based on potential impact to the cave ecosystem by visitors. Management classifications range from Class 1 to Class 6. Class 1 defines a cave as being highly developed, and Class 2, 3, and 4 being undeveloped. Class 5 and 6 are caves closed to recreational use. Management Class 2 caves may be visited with a guide or approved trip leader. To allow more people to visit Management Cass 2 caves; a Trip Leader program has been developed. Cavers become approved Trip Leaders when they participate in restoration projects within a certain cave, or they complete in cave Trip Leader training. A Cave Steward program is also being initiated. Cave Stewards work under Volunteer Agreements and receive in depth training to protect cave resources while leading visitors on recreational trips.

Summary

To provide protection for the caves, the Lincoln National Forest implemented a closure order in 1972 restricting cave access to only those with a permit. Jerry Trout, who is now the United States Forest Service National Cave Coordinator, was instrumental in implementing this far-sighted managerial action. The Guadalupe Ranger District has been managing a cave permit system for 29 years. Over the years the permitting process has evolved to provide enhanced protection for cave resources while still allowing recreational use of many caves on the Guadalupe Ranger District of the Lincoln National Forest.

Following policy and direction set in the Forest Service Manual; Lincoln National Forest Plan, approved September 1986; the Federal Cave Resources Protection Act of 1988; and Lincoln National Forest Cave Ecosystem Management Direction, approved February 1995, the Lincoln National Forest caves are managed as nonrenewable resources to maintain their geological, scenic, educational, cultural, biological, hydrological, paleontological, and recreational values.

The Lincoln National Forest has taken extensive measures to protect cave resources. These measures range from withdrawing approximately 27,300 acres from oil and gas drilling and mineral exploration to creating and distributing cave conservation pamphlets and videos. Guided interpretive tours are provided in some caves. The educational value of these tours plays a significant role in the conservation of all non-renewable cave resources. Individual caves receive some protection through the permit system, and 23 of the caves are gated.

The Guadalupe Ranger District has developed a dynamic management system to try to meet the demands of a diverse group of users while protecting complex cave ecosystems. Caves have been assigned management classifications based on potential impact by visitors to cave ecosystems. Management classifications range from Class 1 to Class 6. Class 1 defines a cave as being highly developed, and Class 2, 3, and 4 being undeveloped. Class 5 and 6 caves are closed to recreational use.

Currently, there are no Class 1 caves on the Lincoln National Forest. Management Class 2 caves contain sensitive natural and/or cultural resources and require a guide or an approved trip leader to supervise all trips into these caves. Class 3 caves may be visited without a guide because the resources within these caves are less easily impacted than Class 2 caves and they can be enjoyed without incurring significant alteration if groups are conscientious and conservation minded. Class 4 caves are closed pending further evaluation. Class 5 caves are closed to general use because they contain biological, archaeological, paleontological, or other resources of special scientific value that would be easily altered even by careful use of the cave. Class 6 caves are closed to all use (except minimal administrative entries), because they contain extremely hazardous passages, very fragile resources, threatened or endangered species, or they are being preserved for future scientific study. Some of the larger, more complex caves have been divided into areas and assigned more than one management classification. Some caves are assigned seasonal Management Class 6 for threatened or endangered species protection.

Management classification is a dynamic tool. As new information is gained about a particular cave, it may lead to reclassification. For example, a species gaining threatened or endangered status may require that a cave it uses as habitat be moved from a Management Class 3 to Management Class 6. In the last couple of years, volunteers have provided inventory information for several caves and subsequently these caves have been moved from Class 4 to Class 3. When monitoring shows that visitor impacts are so acute that a cave has to be withdrawn from the recreational permit system while restoration is done, the cave management classification is temporarily changed to Class 4. In January of 1996 Wonderland, Black, Hidden, Pink Dragon, Three Fingers, Virgin, and Hell Below Caves were withdrawn from the recreational permit system and reclassified from Management Class 3 to Management Class 4.

On the Guadalupe Ranger District, as of this writing, there are 108 caves listed as significant in accordance with the Federal Cave Resources Protection Act of 1988. Most caves in the Guadalupe Mountains require managed access. These caves contain irreplaceable works of art created hundreds and thousands of years ago.

Currently, there are eight Management Class 2 caves. Two of these, the Second Parallel of Cottonwood and Cave Tree Cave, require a Forest Service guide. To allow more people to visit Management Class 2 caves, a Trip Leader program was initiated in January 1995. The other six Management Class 2 caves may be visited with a Trip Leader who has been approved for that cave.

Cavers become approved Trip Leaders when they complete in-cave Trip Leader training. Restoration work counts as training in Hell Below Cave. Trip Leaders may obtain permits, within the allowable monthly limit, to visit caves they are approved as Trip Leader for.

Twenty-four of the caves on the Guadalupe Ranger District are Management Class 3 caves, and 14 of these are available, via permit, for people requesting caves to visit. Directions in the form of step logs are available to most of these caves. The other Management Class 3 caves are not popular with the majority of permit seekers, because they require extensive hiking over rugged terrain and the cave may appear rather bland and only be a few hundred feet long.

There are 68 Management Class 4 caves. Many of these may become Management Class 3 caves, but it is unlikely they will receive much visitation due to their remote locations, small sizes, and lack of speleothems.

There are seven Management Class 5 caves identified thus far on the Guadalupe Ranger District. These caves contain sensitive biological, archaeological, paleontological, and geological resources of special scientific value. Examples of these resources are pristine microbiological communities, human fossils, and Pleistocene animal skeletons.

In the Management Class 6 category there is only one cave closed yearlong. This is to protect a maternity colony of Townsend's big eared bats (*Corynorhinus townsendii*), and to protect the public from exposure to histoplasmosis. There are five other caves, or areas within a large cave, that have seasonal closures to protect hibernating bats, maternity colonies, or a threatened or endangered species.

The permitting process is managed on a first come first served basis. Reservations are typically taken by telephone in the Guadalupe Ranger District office. Cave permit reservations may also be made via U.S. Mail, e-mail, or in person. Each cave open for recreational use has a limited number of permits available each month, usually three. After these visits have been reserved, no additional reservations are taken for that cave for that month. Reservations are taken anywhere from the day of the requested visit to three months in advance of the current month.

For most caves only one permit per day is issued with a maximum of six people per permit. The exception is for work trips, where larger numbers of people will have beneficial outcomes on the cave resource that is, large groups of cavers doing restoration. A few of the larger caves like Cottonwood and Gunsight that are not as easily impacted by visitors may have more than one permit issued per day with the stipulation that no more than six people are in the cave at any one time.

The Trip Leader concept was implemented for some of the caves on the Guadalupe Ranger District, because they were being destroyed as a result of unacceptable impacts. The first cave to require a Trip Leader was Pink Panther Cave. One particular room in Pink Panther Cave had a floor covered in heligmites. Over the years, as more and more people found this room, multiple trails began to develop through the heligmites. In the early 1990s concerned cavers brought this to the attention of the USDA-Forest Service and it was obvious that a new approach had to be taken to prevent such a delicate resource from being destroyed. Rather than take the easy route and close the cave to everyone, a Trip Leader program was developed and implemented.

To become a Trip Leader to Pink Panther Cave a training trip is scheduled with a Guadalupe Ranger District Cave Specialist or Technician. Then after successfully completing one in-cave training trip the person's name is added to the Pink Panther Cave Trip Leader List and they can obtain permits and visit the cave anytime in the future (provided that a permit is available the month they request it).

As a result of active cave management utilizing tools such as the Trip Leader program, unacceptable impacts to Pink Panther Cave have been reduced. On a monitoring trip to Pink Panther Cave in the mid 1990s, when other caves were found to be suffering from unacceptable impacts, Pink Panther Cave was found to be in about the same condition as it was when first converted to a Trip Leader cave.

In the mid 1990s the USDA-Forest Service was finding evidence of egregious unacceptable impacts to other caves on the Guadalupe Ranger District. Like Pink Panther, some of these were gated caves suggesting that some people with permits were going off trail, breaking speleothems, and taking souvenirs. As a result, in January of 1996 Wonderland, Black, Hidden, Pink Dragon, Three Fingers, Virgin, and Hell Below Caves were withdrawn from the recreational permit system and reclassified from Management Class 3 to Management Class 4 while restoration, trail delineation, and enhanced monitoring strategies were completed. Cavers volunteered hundreds of hours and within three years Hidden, Black, and Hell Below were returned to the recreational permit system.

Hell Below Cave was withdrawn from the recreational cave permit system in August of 1986 through August of 1988 while restoration work was done. By January of 1996, Hell Below Cave had received so much unacceptable damage that it required being withdrawn from the recreational permit system again. Unethical visitors had kicked rock-lined trails into disarray, trampled flagging, disregarded conservation messages written on flagging, and tracked mud across flowstone and other speleothems that had been restored. There was photo documentation of speleothems (cave pearls) having been removed from the cave.

Concerned cavers suggested that Hell Below become a Trip Leader cave once the restoration was completed this time. The first time Hell Below was closed for restoration in the late 1980s cavers recommended that access to Hell Below be restricted to only those who helped with restoration. The cavers contended that people who worked to restore the cave would take care of the cave and the USDA-Forest Service would not have to close it again. This suggestion was not implemented in the 1980s because management felt that it would restrict access for too many people.

It was decided that persons who participated in at least three restoration trips would qualify as Trip Leaders. Cavers may also become Trip Leaders for Hell Below Cave through training trips with a USDA-Forest Service Cave Resource Specialist, USDA-Forest Service Cave Resource Technician, or approved Interagency Hell Below Cave Trip Leader Trainer. A combination of three restoration or training trips also qualify a person to be a Trip Leader.

Requiring an approved Trip Leader to accompany all groups into Hell Below Cave since it was reopened for recreational visitation in August 1999 has proven to be an effective way of protecting the resource while still allowing recreational visitation. In contrast, Hidden Cave reopened as Management Class 3 in November 1998. Anyone requesting a permit was issued one, and now monitoring trips are documenting unacceptable impacts in the form of muddy footprints across recently restored areas and speleothem breakage.

We remain very supportive of expanding our Trip Leader certification program. Cavers interested in becoming Trip Leaders can schedule Trip Leader training with the Guadalupe Ranger District, or participate in restoration projects. The last weekend of every month the High Guads Restoration Project works in the Guadalupe Ranger District caves on a variety of management tasks including restoration. We encourage interested volunteers to participate. A tremendous amount of restoration work has been done by the Project.

In 2000, 24 recreational permits were available for Hell Below Cave. Twenty-one permits were reserved and 11 were not used. Percentage wise this is similar to permits used and not used for Hidden Cave in 2000. Approximately half of the permits were used for both caves—Hell Below 48%, Hidden 56%. Compared to the all of the Management Class 3 caves listed in the cave calendar, a higher percentage of available visits were used for Hell Below, a Management Class 2 cave.

For the six caves that require a qualified Trip Leader, we currently have 30 Trip Leaders. Some of these cavers have received training and/or have done the restoration work and are qualified as Trip Leaders for more than one cave. Essentially there are 60 Trip Leaders listed for the six caves. Of the 30 Trip Leaders, 10 of these, 33%, are from New Mexico, and seven of these 10 are from the Carlsbad area. The other 20 Trip Leaders, 67%, are from other states including Texas, Arizona, Colorado, Oklahoma, California, and Maine. To provide access for even more visitors, options like a Cave Steward Program are being explored. As we continue the fine-tuning of the permitting process, we welcome your comments and suggestions.

We are proud of our long-standing permit process and believe it is one of the most proactive in the country. We are also proud of the partnership we continue to forge with the caving community. This partnership has resulted in hundreds of thousands of dollars worth of volunteer contributions toward the conservation and protection of caves on the Guadalupe Ranger District. In 1999 this partnership resulted in the National Speleological Society being recognized by the Chief of the USDA-Forest Service and receiving a national group volunteer award.

Management of Karst in Pleistocene Aeolianite

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Abstract

Solutional features including substantial caves are found in the very extensive areas of Pleistocene aeolianite dunes along the southern coast of Australia. This paper will review the interesting features of the karst and discuss the issues of management. The management of such soft limestones includes their land tenure and land use issues, the nature of the karst and the interpretation of such features. The rock is very friable and easily collapses; many caves have large amounts of very delicate calcite formation including huge areas of moonmilk; and many sites are close to areas of population and so can easily suffer from overuse. The interpretation of dune karst has suffered from the lack of understanding by many managers of syngenetic karst and some spectacular misinterpretation examples will be examined. The paper will concentrate on the dune karst of the Otway Basin in Victoria and South Australia in particular Bats Ridge and Codrington where intensive karst occurs in mid-Pleistocene dunes.

Introduction

Karstification is a complex process controlled by the nature of the lithology, tectonic structure and climatic conditions. In particular, lithological variation of porosity, chemical composition, and strength can be extremely high. Whereas massive, well-jointed, and relatively chemically pure limestones are traditionally perceived as having the best karst development, the extensive but relatively poorly consolidated Pleistocene dunes in southern Australia have developed extensive karst systems and can offer interesting insights into speleogenesis as well as insights into management of less well consolidated limestone systems

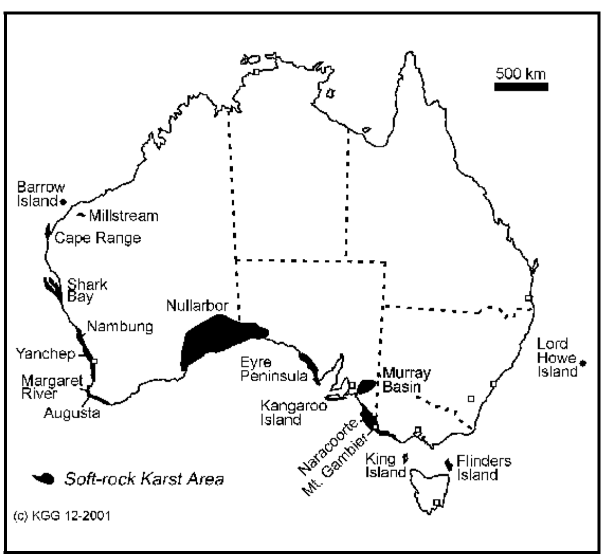

Figure 1. *Australian Karst Types: soft rock karst includes Oligo- Miocene marine and Pleistocene aeolianite (Grimes, 2001)*

Australia has extensive areas of dune limestone karst, described locally as soft rock karst, along the southern and southwestern coasts, sometimes extending inland for up to 100 kilometers. (Figure 1). Some areas such as the Nullarbor and Mount Gambier areas have Oligo-Miocene cool water marine carbonates underlying the Pleistocene aeolianites, but the "Soft-rock" Karst areas shown on Figure 1 indicate the distribution of the aeolianite karst in Australia. In cases such as Otway Basin, the aeolianite karst extends across the two Tertiary karst provinces.

Characteristics of Karst in Pleistocene Aeolianite

The particular issues of karst processes in young and relatively unconsolidated limestone such as chalk, coral, and dune calcarenite was highlighted in the 1960s by Jennings (1968) who discussed speleogenetic problems in rela-

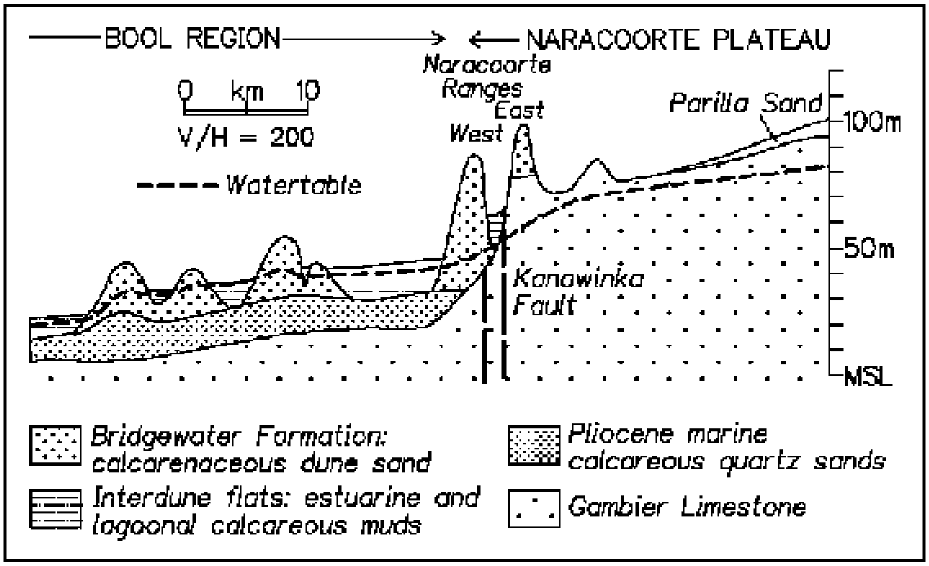

Figure 2. *Lithological relationships of the Pleisotcene dune ridges in the Ottway Basin (Grimes 2001)*

Figure 3. *Caprock in entrance at Milliways Cave (CD 28) Codrington.*

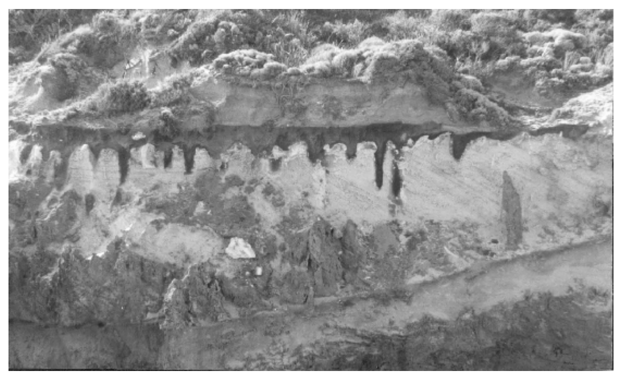

Figure 4. *Solution pipes filled with soil buried under younger dune. Features such as these are common.*

tion to the Pleistocene dune limestones of southern Australia and developed the syngenetic scheme of karst evolution. White (1989, 1994) has further developed this scheme. Carew and Mylroie (1988) have developed a similar scheme in the Pleistocene limestones of the Bahamas.

Karst development on coastal aeolianite ridges is dependent on several interrelated conditions: the purity of the limestone, its porosity, its ability to support a cavity and the availability of aggressive water capable of solution. The higher the proportion of carbonate, the more likely the karst features will develop. The aeolian calcarenites are well sorted fine to medium grained bioclastic carbonate dune ridge and beach facies of highly variable purity and cementation. Lithological relationships are shown in Figure 2. The development of underground karst features is dependent on the ability of the limestone to support a cavity. Insufficient strength in the limestone will result in solutional cavities collapsing before they are very large.

The simultaneous nature of the lithification processes, which convert the unconsolidated carbonate dunes into aeolian calcarenite rock, and the development of solutional karst features in the dunes, characterizes such karst areas. The dunes were deposited during the mid Pleistocene and the caves dissolved at times of higher water tables, not long afterwards. The lithification process involving solution by CO_2 enriched percolating water and redeposition of calcium carbonate, results in the formation of a hardened kankar/caprock layer in the dunes (Jennings, 1968; White, 1994).

It is the formation of this caprock of sufficient compressive and tensile strength to support cavities, which in turn is dependent on the interrelated factors of limestone purity, water chemistry conditions, and watertable position that has resulted in the rapid formation of karst features. Groundwater flows towards the coast with swampy areas between the calcareous dunes resulting in localized flow in the aeolianite areas. The karst is characterized therefore by shallow, sinuous, and maze cave systems

Figure 5. *Moonmilk development on cave walls, Bats Ridge.*

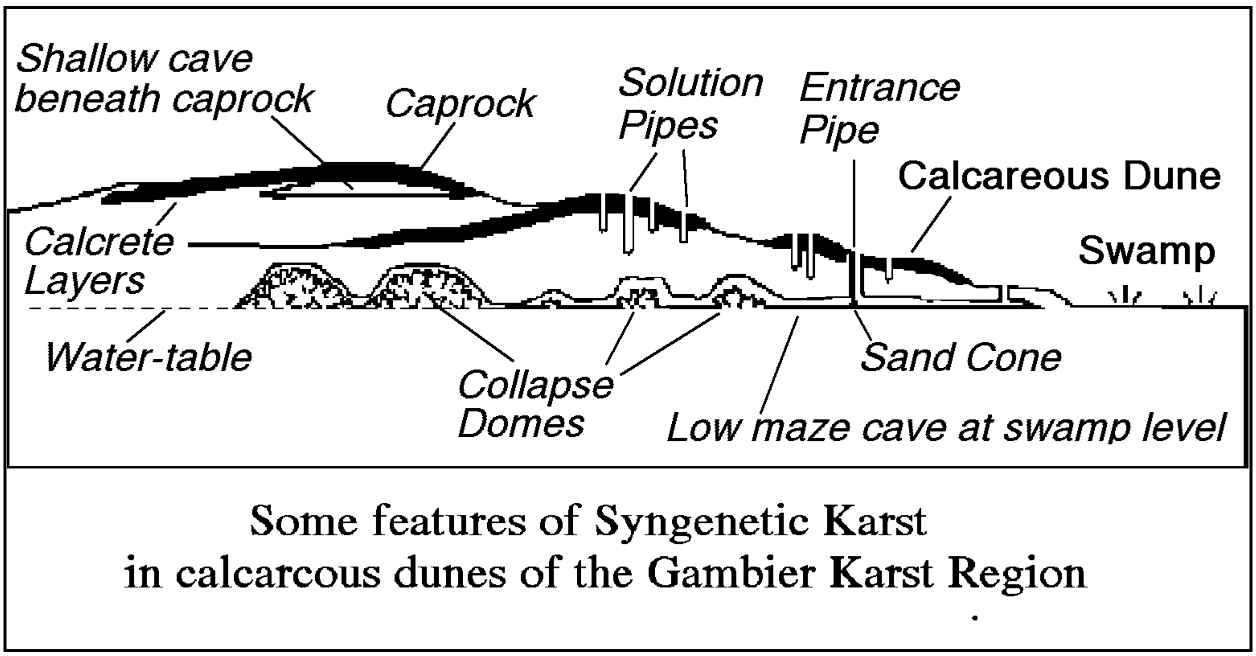

Figure 6. *Features and characteristics of aeolianite syngenetic karst (Grimes 2000)*

with multiple entrance. Low, flat, wide chambers and extensive horizontal development is common. Although collapse is very common, the cap rock (kankar) is an integral component of the cave development. Such a caprock feature is shown in Figure 3. Solution pipes are common (Figure 4).

The interdune lakes and swamps are modified by solution. In some areas such as southwest Western Australia extensive and complex speleothem development occurs, but in other areas this is less.

Extensive areas of moonmilk development are ubiquitous throughout the aeolianite karst (Figure 5). A diagrammatic characterization of the karst is shown in Figure 6.

So, What's the Problem?

Problems of management of such a relatively unconsolidated rock type can be grouped into three areas: problems associated with physical conditions, land use issues, and inappropriate and inaccurate interpretation. Primarily there are basic physical problems, which need to be addressed in management. The host rock is relatively soft and poorly consolidated and is prone to collapse. This problem is often only partially understood as being a natural if awkward process by cave area managers, but is even much less understood by the construction industry. From senior engineers to backhoe operators, the limited ability of dune limestone to support construction without collapse is usually ignored. The areas with such limestone have many examples of ground collapse, sometimes with very serious consequences such as the tragedy in Western Australia where school children sheltering under a small overhang were killed when it collapsed. A recent development of large windmills on a dune area gave insufficient attention to such risk management. Given that, to a large extent, sophisticated engineering solutions are available for many of such problems faced in Australia, the poor understanding of the issues by the industry is an ongoing problem.

Similarly, unsuccessful attempts to fill in solution pipes show poor understanding of the processes involved. Some places have fenced some soil pipe areas with better success, although careful assessment of the area to be fenced is required.

The caves are often small and many caves host extensive and delicate speleothems. In particular, the walls and ceilings of most caves have extensive moonmilk development. These can be easily damaged by overuse, although limited regeneration of moonmilk does appear to occur. Nevertheless, some better care by both managers and cavers is necessary in the more heavily visited areas.

Caves and karst can be compromised in a variety of ways both directly and indirectly and the usual range of issues including destruction, damage, or inappropriate use occurs for aeolianite as well as other karst areas. These threats involve quarrying; road and other construction works; rubbish dumping, especially in dolines and cave entrances; liquid waste disposal; land clearance; blocking up of caves and dolines; vandalism; and disturbance of cave dwelling biota. None of these are more prevalent in aeolianite areas than other karst areas although there are some particular local problems for some of these. The issues of pollution are not rare in karst areas but for Australia the dune karst areas are the main karst areas with any substantial population. The only state capital built on a substantial area of limestone is Perth, which has important areas of dune aeolianite. The issues of management are often related to inappropriate development and land uses and the inability of planning and development authorities to ensure suitable remediation or modification of development to more appropriate activities or places.

The final management problem is the seriously poor interpretation in many (most) of the areas controlled by the various park and reserve management agencies. Despite some outstanding examples of excellent interpretive material (such as at Naracoorte in South Australia), there are a large number of cases where out of date, incorrect information continues to be presented to the public. This is particularly the case with respect to the earth science component of interpretive material. The same level of inaccuracy in the biological sciences is not tolerated. In the case study below, not only is it tolerated but perpetuated as new signs have been produced perpetuating the incorrect information.

The "Petrified Forest" Cape Bridgewater/Cape Duquesne Victoria in southwestern Victoria near Portland, is a well visited tourist location with spectacular coastline landscape containing karst features. Pleistocene Bridgewater Group aeolianites (dune limestones) overlie the late Pliocene/early Pleistocene volcanics. The aeolianites developed solution pipes/ soil pipes as found in many other areas in the region. The limestone is now in a period of erosion, resulting in the exposure of some spectacular exhumed solution pipes, some of which are partially infilled. The Victorian Geological Survey produced a memoir on the Geology of Portland which described the features and interpreted them as a petrified forest (Boutakoff, 1963). By the mid 1980s there was literature (for example Trounson, 1985) disproving this interpretation. The Victorian Geological Survey geologists in general were not particularly interested in the material but certainly knew that Boutakoff was wrong in his interpretation. However, the signs that went up at about this time and subsequent upgrades, including during 2001, continue to perpetuate the myth.

The "Petrified Forest" is a large number of solution pipes, which were formed in one stabilised calcareous dune. The area was then subsequently buried and the pipes filled in. The filling is often "harder" or more cemented than the surrounding dunes because of the balance between solution and redeposition of $CaCO_3$ in the conditions, especially where there is casing on the tube. Subsequent erosion, currently still occurring, is exhuming these features. They are the same sort of features as found at The Pinnacles (Nambung, Western Australia) and on King Island. Small cemented roots or rhizomorphs are present but are not an indication of large trees as no evidence of a tap root exists. They are extremely common in the dunes along the southern Australian coast and indicate interesting concretionary processes in more recent and present conditions.

The challenge now is to how to get the erroneous material out of the signs and interpretive material. The signs were recently upgraded as signs but with the old interpretation and no attempt was made as far as I can ascertain to upgrade the interpretive material. The cost of such inaccurate information being presented to an increasingly educated public is serious, as the reputation of the management authority becomes compromised. Certainly, the understanding of what is presented there is so poor that there is concern that the management do not understand the processes involved.

Conclusion

Conservation challenges in poorly consolidated karst host rock presents a range of challenges for management. This is especially a challenge for the construction industry, which needs use knowledge of aeolianite karst to minimise risk from collapse. However there is also a major challenge for public land managers to improve their interpretation of such landscapes to an increasingly educated public.

Acknowledgments

Many thanks to Ken Grimes for permission to use his excellent diagrams and maps to illustrate points in this paper.

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The Geology and Management of Coyote Cave, Wind Cave National Park, South Dakota

Joel Despain
Sequoia and Kings Canyon National Parks

Abstract

Coyote Cave in Wind Cave National Park, Custer County, South Dakota, has long intrigued cavers and park managers. It exhibits strong barometric airflow implying the presence of a large cave system, but the cave passages near the entrance are very small and constricted. Recent discoveries in the cave have revealed much more cave passage and some unusual features. The cave is formed entirely in the Minnelusa Formation a Pennsylvannian-age body of rock that includes varied, thin-bedded marine sediments such as shale, sandstone, chert, and limestone. Non-carbonate rocks routinely appear in the cave walls, ceilings, and floors. Other caves in the Black Hills, including well known Jewel and Wind Caves, have formed in the more limestone-rich Mississippian-age Madison Formation. Coyote Cave appears to be structurally controlled by bedding partings and joints perpendicular to the beds. The cave has largely formed on dip in rocks that lie at an angle of 8°. The cave shows clear signs of fluvial processes, which are very rare in the caves of the Black Hills. The cave also has apparent manganese-rich deposits on its floors. Manganese is common in old (4 to 20 million years old), deeply-formed caves of the front ranges of the Rocky Mountains, such as Jewel and Lechuguilla Cave in New Mexico. But in Coyote Cave the deposits are inter-bedded with clays, a novel type of deposit. Coyote also shows clear signs of the presence of actively feeding invertebrates, including frass; worm casings; and "chewed" sticks, pine cones, and organic matter. The cave's unusual features and invertebrate wildlife will be considered in any management plan or procedures for the cave. Such procedures might include restrictions to protect the cave's many unusual features.

Restoration of Skull Ice Cave, Lava Beds National Monument

Kelly Fuhrmann
Lava Beds National Monument

Abstract

Lava Beds National Monument lies on the northern flank of the Medicine Lake Volcano in northern California. Lava flows emanating from multiple volcanic vents cover the landscape under the high-elevation desert ecosystem at 1,219 to 1,707 meters (4,000 to 5,600 feet). Numerous lava tubes and lava tube caves formed in these flows. One of these lava tube caves, Skull Cave, a lava tube ice cave, has become a popular attraction for visitors since the monument was established in 1925. Commercial development and heavy visitation in the cave has resulted in accumulation of sediment and larger material on its well-developed ice floor and along the main upper-level trail. Mitigation and restoration measures include removal of approximately 862 kilograms (1,900 pounds) of sediment and rock from the surface of the ice floor, rehabilitating the main trail leading up to and continuing through the upper-level of the cave, and remodeling existing stairway structures. The renovations have improved the condition of the ice floor and dust mitigation measures now limit dust production and transportation caused by foot traffic.

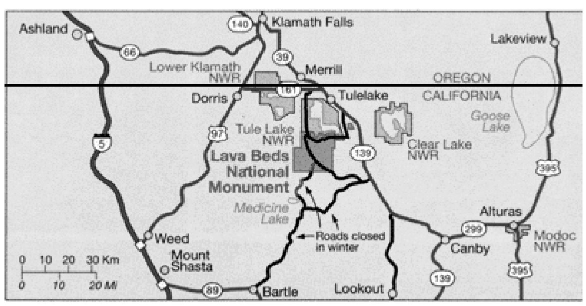

Figure 1. *Lava Beds National Monument location map.*

Background

Lava Beds National Monument is located along the California–Oregon border in northeastern California (Figure 1). The 18,842-hectare (46,560-acre) National Monument has the largest known concentration of lava tube caves in the 48 contiguous United States. The monument lava flows originated from a variety of volcanic vents and created lava tubes that stretch for miles under the landscape. Some of these lava flows reached the southern shoreline of a Pleistocene and Holocene lake, now called Tule Lake, that covered much of the Klamath Basin. Others flowed over the prehistoric landscape until they cooled and became frozen rivers of basalt. The flows formed extensive networks of lava tubes, jumbled aa lava flows, lava lakes, sag basins, and inflation plateaus. The diversity of the cave environments created between 1,100 and 62,000 years ago is comparable to the vast number of caves present. Field reconnaissance has located 436 lava tube caves and other lava tube features within the monument. The mapped caves total over 46 kilometers (27 miles) of underground passage to date with much more to be surveyed. The surrounding high-elevation desert that makes up the northern flank of the Medicine Lake Volcano lies at the juncture of the Sierra–Klamath, Cascade, and Great Basin Provinces. This region supports a patchwork of bunchgrass, sage, and juniper in the lower lying areas, while in the higher elevations ponderosa and lodge pole pine communities predominate. This diverse region of northern California encompasses an awe-inspiring landscape with elements of all three major geographic provinces.

Water is a scarce natural resource in this semiarid environment. There are no surface water sources present within Lava Beds National Monument. However, seasonal rains and winter snow melt replenish ice caves within the monument and provide critical sources of water for wildlife. Ice levels in these caves are measured several times annually to monitor the fluctuation of the ice from season to season and year to year.

Skull Cave was discovered in 1892 by E.L. Hopkins, one of the early settler-explorers in the area. On the earliest recorded visit to the cave, Hopkins, with the help of the Stonebreaker brothers from Alturas, California, made it to the lower level of Skull Cave where he found the bones of numerous antelope, bighorn sheep, mountain goats, and two human skeletons. It is assumed that the animals and humans fell to their death while attempting to gain access to ice and water deposits present in the lower level. The cave was aptly named after these remains.

As a premier attraction in Lava Beds National Monument, Skull Cave receives an average of 13,000 visitors per year.

Skull Cave has one of the largest main tubes in the monument at 137 meters (450 feet) long, 18 to 24 meters (60 to 80 feet) high, and 9 to 20 meters (30 to 65 feet) wide. Total length of the cave is over 305 meters (1,000 feet) of surveyed passage. Developments for visitor convenience in Skull Cave include a main upper-level trail that was initially constructed of basalt rock stairs and silty, pumice-rich soil trail tread fill, apparently all made during the Civilian Conservation Corps era of the early 1930s. A series of four metal stairways lead down to a well-developed ice floor on the lower-level of the cave.

The Cave Research Foundation conducted a sedimentology investigation in Skull Cave from 1989 to 1992. The study characterizes cave sedimentology in terms of depositional rate, depositional process, and provenance (source of sediment) (Tinsley, Miller, and Johnson; 1992). Results indicated that the main source of sediment accumulation throughout the cave was from the trail-tread material in the upper level of the cave. This material was being transported throughout the cave by visitor foot traffic. The heaviest deposition occurred in the vicinity of the main trail. Remediation measures proposed by the authors of this study were incorporated into the rehabilitation plan and restoration activities for Skull Cave.

Restoration was initiated in Skull Cave to mitigate the impacts of increased sedimentation from foot traffic. Impacts to the cave during many decades of use included dust accumulation on the upper and lower levels of the cave, trail degradation at the entrance of the cave, and impacts to the quality of the ice floor at the lowest level of the cave.

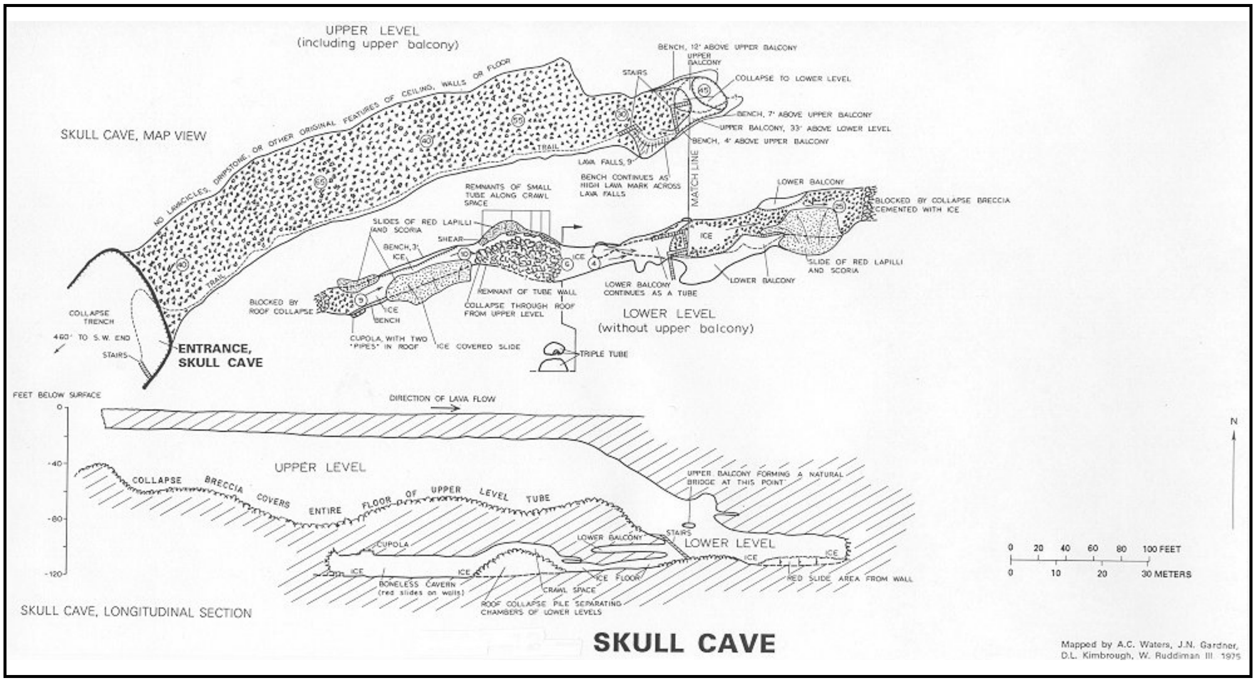

Figure 2. *Skull Cave Map (from A.C. Waters, J.M. Donnelly-Nolan, and B.W. Rogers, 1990)*

The initial stages of this project included redesigning existing stairways, constructing a gate at the ice floor, and installing an interpretive viewing platform in front of the gate on the lowest level. After the construction and renovation phase, the ice floor behind the gate was thoroughly cleaned. A new native lava rock trail tread was installed on the upper level trail of the cave, which covered the entire trail surface. A dust removal project focused on dust accumulations along the main trail was completed after the installation of the new trail tread.

Stairway Restoration and Viewing Platform/Gate Construction

During the first stage of the project, four stairways were refurbished. The original 47 steps that accumulated dirt and debris on three of the stairways were replaced with open mesh metal steps on stairway frames that allowed dirt and debris to filter through the stairs (Figure 3).

Since March 1999 a gate has served to eliminate foot traffic on the ice floor. The ice floor appears to be recovering from many decades of foot traffic and vandalism. The future quality of the ice floor in Skull Cave will depend on educational interpretive displays and limited access to the ice floor.

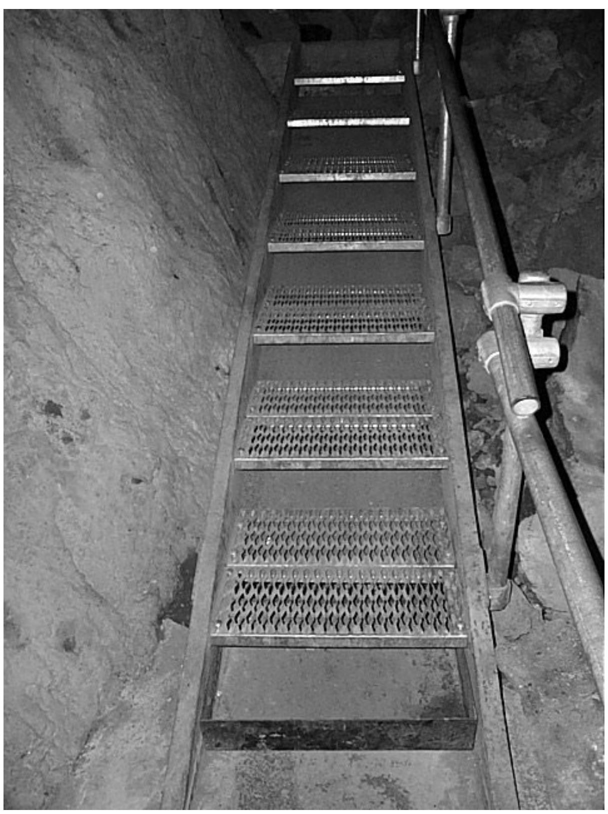

Figure 3. *New stairs in Skull Cave made of galvanized steel with ½-inch mesh. Also notice the steel tray under the structure and catchment trough at the base of the stairs (photo by Kelly Fuhrmann).*

An interpretive viewing platform was built in front of the gate to provide access for visitors to view the ice floor (Figure 4). This platform also provides an area for displaying interpretive signage explaining the processes of ice formation and cave conservation practices. A tarp was affixed under this platform to catch debris from foot traffic.

During the summer of 1999, accumulated rock and dust debris was removed from the ice floor. The cleaning of the ice floor involved removing 816 kilograms (1,800 pounds) of rock and 45 kilograms (100 pounds) of sediment from the ice floor. After all the larger debris was removed by hand picking, the surface of the ice was washed by sponging with chlorine-free water to remove remaining sediment from most of the ice in an attempt to restore it to a more pristine condition. With the addition of new ice, one can now see 20 centimeters (8 inches) into the ice floor, where before an opaque film of sediment in and on top of the ice obscured any view into the floor.

The lack of visitor traffic on the ice floor has allowed the cleaned ice to remain clear of debris from foot traffic and carelessness and prevented unnatural increases in ambient air temperatures from body heat in the ice floor chamber. New ice has begun to accumulate on top of the cleaned ice. Ice level monitoring has revealed the accumulation of 5.8 millimeters (0.23 inches) of new ice from February 1999 to February 2001 (Figure 5).

Figure 4. *Viewing platform and gate in lower level of Skull Cave. The gate spans the entire passage width of four meters (14 feet)(photo by Kelly Fuhrmann).*

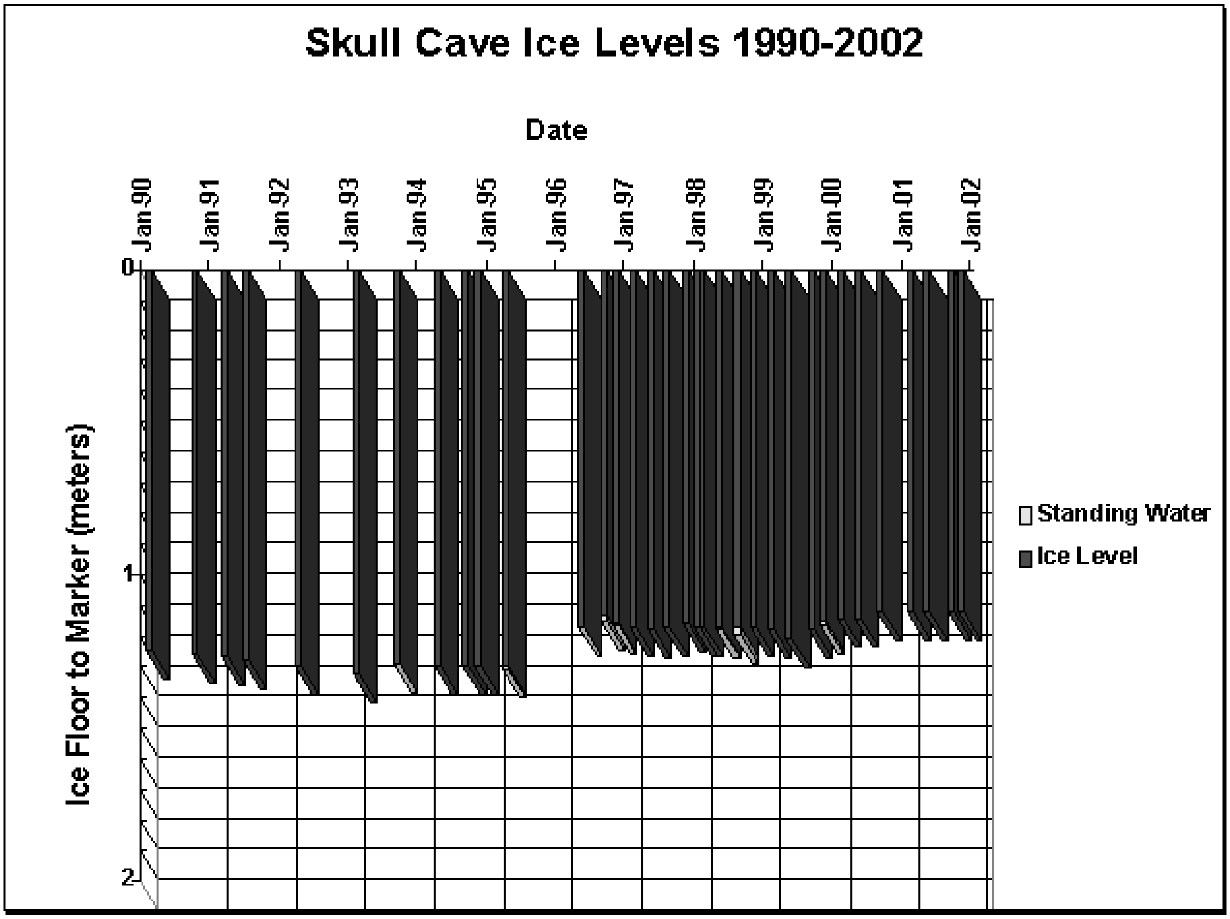

Figure 5. *Ice levels in Skull Cave 1990 to 2001.*

Figure 6. *Dust impact along the trail in the upper levelof Skull Cave.*

Trail Tread Restoration

Dust accumulation originating from the original dirt trail tread was impacting the upper and lower levels of the cave environment. The accumulation of dust along side the trail on the upper level of the cave had coated both breakdown and historical writing (Figure 6). An effort was made to remove this dust from the trailside rocks using water and light scrubbing during the summer of 1999. The cleaning revealed many historic writings covered up by dust deposition. However, traffic on the dirt trail tread continued to produce dust that was deposited on the same cleaned rocks. The cleaning process was repeated during the summer of 2001 to remove the dust that was deposited before the new trail tread was installed.

The installation of 84 square meters (900 square feet) of new trail tread on the existing upper level trail in Skull Cave was completed during the summer of 2000. To mitigate dust accumulations produced from visitor traffic on the main upper-level trail, flat lava rock was mortared in place over the entire length of the existing dirt trail tread. A local source was chosen as a supplier for this lava rock to provide local material that was compatible with the color and texture of the existing basalt rock in the cave.

Photomonitoring of the main upper level trail and ice floor was initiated before the start of the restoration project. The commitment to preserve the ice floor in Skull cave has resulted in the improved state of the ice floor as witnessed in the photographs. Continued monitoring in Skull Cave will determine the trends of ice levels and ice quality.

The following photographs (Figures 7 to 10) shows the inner ice floor from 1961 to November 2000. They depict the ice floor before heavy usage, the accumulation of 38 years of debris, and the restored ice floor in 1999.

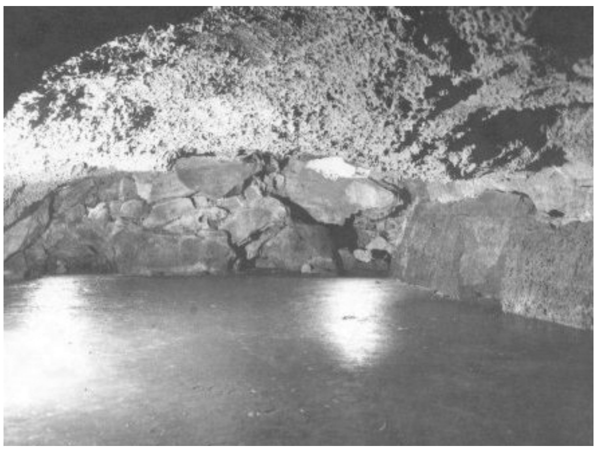

Figure 7. *View of the inner ice floor looking towards the back of Skull Cave in 1961. (National Park Service photograph)*

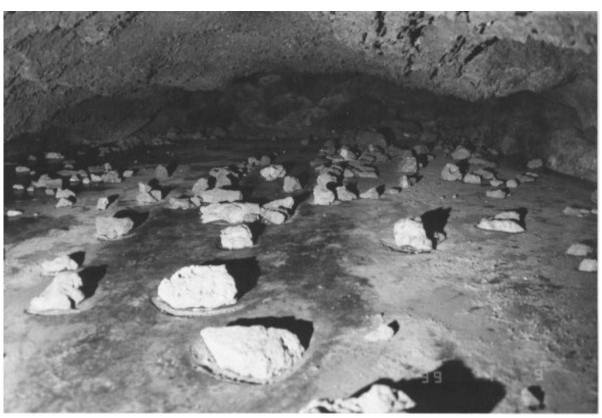

Figure 8. *View of the inner ice floor in Skull Cave. This photograph was taken just before cleaning started in April of 1999. It shows heavy accumulation of debris consisting of breakdown and dust mantle carried onto the floor by visitors to the cave. (Photo by Kelly Fuhrmann)*

Figure 9. *Same view of the inner ice floor as Figure 8 after clean up of nearly 862 kg (1,900 lbs) of debris and dust by the end of October 1999. (Photo by Kelly Fuhrmann)*

Figure 10. View of the inner ice floor in Skull Cave in June 2000. Note new ice layer on the floor. (Photo by Kelly Fuhrmann)

Upper Level Trail Construction

The upper passage trail was reconstructed by covering the original dirt trail with sand. Flat lava rock slabs were then laid on top of the sand. Dry mortar was added to the spaces between the lava rock and then water was used to set the dry mortar. This phase of trail construction was completed by September 2000. The following photographs (Figures 11 to 14) show both before and after views of this reconstruction process.

Surface Trail Construction

The surface trail leading into Skull Cave consisted of lava rock covered with gravel that had migrated down onto the trail from the trail head. This material proved to be a major source of dust and soil tracked into the cave on visitor's shoes.

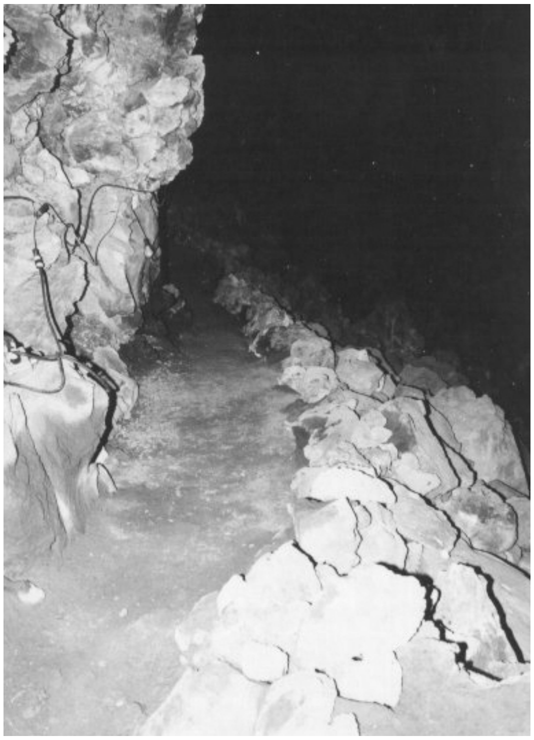

***Figure 11**. View of the upper level trail with the original trail tread. (Photo by Kelly Fuhrmann)*

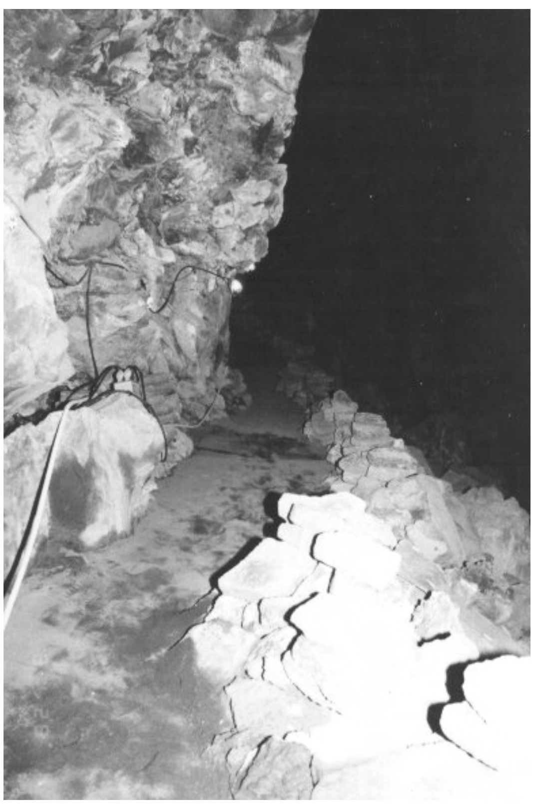

***Figure 12**. A basalt sand base was added over the original trail tread material. (Photo by Kelly Fuhrmann)*

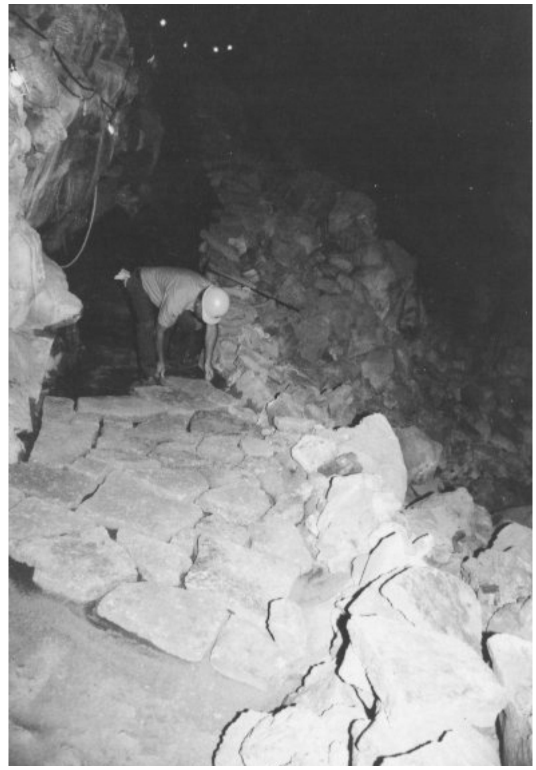

***Figure 13.** Park Service maintence employee placing lava slabs into basalt sand substrate. Lava rock was chosen to closely match existing breakdown and cave wall colors and textures. (Photo by Kelly Fuhrmann)*

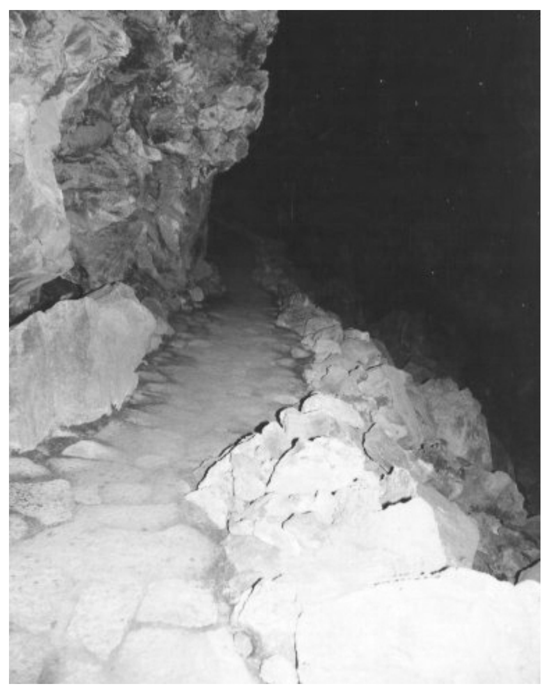

***Figure 14**. Dry and wet mortar was packed into spaces between slabs. The dry mortar was then wetted to cement the basalt slabs in place. (Photo by Kelly Fuhrmann)*

***Figure 15.** This photo, taken in June of 2000, shows the trail leading down into the collapse sink entrance of Skull Cave. This nearly 30-meter (100-foot) trail leads to the cave entrance just out of the picture to the upper right. The trail in the foreground is approximately a meter (three feet) wide. Note sagebrush (*Artemisia tridentata ssp. tridentata*), desert sweet (*Chamaebatiaria millefolium*), and rabbitbrush (*Chrysothamnus viscidiflorus*) plant community in and around the cave collapse. (Photo by Kelly Fuhrmann)*

***Figure 16**. Photograph taken in August of 2000 from the same location as Figure 15. All loose debris was removed, new basalt lava slabs added, and the trailhead renovated. (Photo by Kelly Fuhrmann)*

Conclusions

Restoration of the upper level trail and lower passage main ice floor was accomplished in Skull Cave in Lava Beds National Monument, California, in 1999 and 2000. Large amounts of debris and dust were removed from the ice floors by hand. The main trail leading into the cave was resurfaced with slabs of lava that were cemented into place. These renovation activities and the limited access to the ice floors have improved the condition of the ice floors. These actions have also led to a dramatic reduction in dust and debris in the cave. After a period of over a year the ice floors have improved dramatically from the conditions observed in photographs from 1999 and exceeded conditions observed in photographs from 38 years ago.

Since the completion of work inside the cave, a slight redesign of the parking lot trail head entrance to the cave has also been completed. Photo-monitoring, ice level measurements, and temperature and relative humidity conditions will continue indefinitely. In addition, dust accumulation and sediment studies are also continuing.

Acknowledgments

This project was a cooperative effort completed by the divisions of Maintenance, Resource Management, Fire Management, and Interpretation at Lava Beds National Monument and the Cave Research Foundation.

Protecting Privately Owned Caves

Heather Garland
Tennessee Chapter of The Nature Conservancy

Abstract

The protection of cave resources involves many facets of a community including federal, state, and local agencies and private landowners. The Nature Conservancy of Tennessee—as a private, non-profit organization—has the unique opportunity to work closely with many private landowners of biologically significant caves. Often, building relationships with private landowners can be a delicate process requiring both patience and attention. This slide show presentation will attempt to describe our tools and methods for constructing valuable partnerships with private cave owners with the goal of protecting their resources. The presentation will outline the steps from data collection to landowner contact and education and will provide several specific case studies that have resulted in the successful protection of a privately owned cave. In addition, an emphasis will be put on the need to cooperate with many other partners such as university experts, federal and state agencies, and local caving grottos in order to gather information critical to protection decisions.

Tennessee Caves Initiative

In 1995 The Nature Conservancy of Tennessee hosted a meeting to discuss the status of biologically significant caves in the state. Present were representatives from more than 12 public and private agencies and organizations, including the National Speleological Society, the U.S. Fish and Wildlife Service, and local university experts. Essentially, the goal of this meeting was to develop a list of caves for which protection efforts were needed.

Known biologically-rich caves were prioritized by the species present in the cave and the threats to the system. For example, a heavily-vsited cave containing a threatened species would receive a higher rating than a cave containing the same species but being more remote in location and infrequently visited.

From this meeting, a list of the "Top 100" biologically significant Tennessee caves was created. Using this list as a starting point, the Tennessee Caves Initiative was formed to begin the task of bringing protection efforts to these important caves.

Most of the biologically significant cave systems in Tennessee are on privately owned land, presenting an array of unique challenges. The Nature Conservancy as an organization is well suited to this task, having accomplished many of our successes throughout the past 50 years with private landowners. These successes are mainly due to a long-standing policy of working only with willing landowners.

Steps Toward Protection

Initial Contact

The natural first step toward the protection of a cave is initiating contact with the landowner. While a letter or a phone call are obvious methods, perhaps the best solution is enlisting the help of someone who already knows the person. Experience shows that landowners are much more comfortable when being introduced by someone with whom they are familiar. Neighbors, local cavers, or even other researchers can be invaluable in this capacity and can ease a new relationship.

Site Visit

The first visit to a site is an excellent chance to ask questions of a landowner. At this time, one can learn what the person knows about the cave (historical or biological facts) and what sorts of problems they might have encountered while owning the cave. By talking with the landowner, one can also get a sense of their general interest in the cave and its worthiness or unworthiness to them and their family.

Provide Information

It is essential to provide landowners with information about caves in general and the specific species that reside in caves. The Nature Conservancy of Tennessee's Cave Program has developed several materials used for this purpose, including a cave pamphlet and a biannual newsletter. The cave pamphlet outlines the importance of caves as unique ecosystems, species that live in Tennessee's caves, and threats to cave systems. Our newsletter gives information about the Cave Program's activities and upcoming projects, and also gives the landowner information about The Nature Conservancy. In addition, books such as *Bats of the United States* (Harvey, Altenbach, and Best, 1999) are appreciated by landowners, giving them a chance to see photos and read about bats that might be living in their caves.

Tools For Protection

Cooperative Management Agreement

Before any work is started on the ground at a site, a Cooperative Management Agreement is developed between the landowner, The Nature Conservancy of Tennessee, and usually other partners such as the U.S. Fish and Wildlife Service, Tennessee Wildlife Resources Agency, or a local caving grotto. This is a non-legally-binding document that outlines the protection targets at the cave, protection strategies and options for the site, and the responsibilities of the various partners. Partnerships are essential for cave conservation, facilitating funding, exchange of ideas, law enforcement capabilities, research and data sharing, management help, and labor for large projects like cave gates. Partners may include local, state, and federal agencies; caving organizations; local caving grottos; and local university experts.

Informational Signs and Periodic Clean-ups

Erecting informational signs at an important cave can be an effective tool in dissuading negative visitation. Such signs should go beyond the simple "no trespassing" statement and include reasons for a closure period, including a description of the species residing in the cave that are the protection targets. Many people will respect a sign if they understand the reasons for limited access to a cave.

Conducting periodic clean-ups at a cave has several benefits. For caves with unrestricted access, periodic clean-ups are one way to gauge negative visitation to the site. In addition, these projects often provide an opportunity to involve partners and volunteer groups. Perhaps the most important reason for these projects is that they show landowners a commitment to protecting their caves.

Sinkhole Fences and Cave Gates

When passive protection efforts fail in preventing vandalism and destruction of cave resources, more extreme methods are sometimes employed in the form of entrance barriers. While these projects are expensive, labor intensive, and occasionally unpopular, cave gates and sinkhole fences can be effective at controlling access at biologically important caves. It must be remembered, however, that such structures must be carefully and correctly designed to accomplish two goals; first to accommodate the species living in the cave and secondly to prevent unauthorized and inappropriate entry.

Beyond access control, cave gate projects serve other important functions. These projects provide an opportunity to share management of an important cave with local caving grottos, thus enhancing valuable partnerships. Bringing together volunteers from many walks of life for such projects is another way to nurture partnerships. Often a local community will aid in the construction of a cave gate either through direct labor, donations of drinks and snacks, or by providing equipment such as bulldozers. Inclusion in such important projects can invoke a sense of pride in the community surrounding the cave, which in turn can help with the ongoing protection efforts. Cave gating projects also provide excellent opportunities to spread the message of cave conservation, both in a local community and throughout the state by inviting local and regional media.

Long Term Protection

Long term protection is the key to cave conservation. Although the Cooperative Management Agreement is an effective tool to begin protection efforts, it is not permanent. This puts caves at risk when a land ownership or family situation changes. Therefore, it is important that other methods be considered and utilized if possible.

Conservation easements can offer an effective long-term protection solution. Since an easement will attach to a property deed, development and other restrictions may be passed along from landowner to landowner. One drawback to conservation easements is that since they generally restrict development and subdivision, they devalue the property.

The best long-term solution is to deliver an important property into the hands of an organization or agency whose only goal is to protect the resource. Land donation does occur, but more often the only option is fundraising to acquire a property. Partnerships between private organizations and public agencies are critical to this process. Fundraising is difficult and, for larger properties, raising acquisition dollars may be too challenging for a single organization. Therefore, finding partners willing to help is a necessity.

Cave Protection In Tennessee

The following case studies describe just a few of the projects in which The Nature Conservancy of Tennessee's Cave Program has been involved.

Holly Creek Cave Preserve

Hound Dog Drop Cave in Wayne County, Tennessee, has been known for several years to be a summer roost site for the federally endangered gray bat (*Myotis grisescens*) as well as a site for the southern cavefish (*Typhlichthys subterraneus*), a threatened species in Tennessee.

Conservationists discovered that the cave and surrounding property had recently been purchased by Forest Systems, Inc., a lumber company. This company was approached by The Nature Conservancy of Tennessee through a letter describing the cave and its importance. Forest Systems, Inc. responded and requested that The Nature Conservancy meet with them at the cave, as they were unaware of its location on the property.

After visiting the site and talking with a regional manager with the company, they decided that they would like to protect the site. They agreed that they would work with The Nature Conservancy's Cave Program to construct a management plan for the protection of the cave and its resources. However, their true wish was that this property be in the hands of someone more familiar with caves and their management. At this point, The Nature Conservancy contacted the Southeastern Cave Conservancy, Inc. and asked if there was any interest in acquiring this cave. Luckily, they were willing to take on the project.

Forest Systems, Inc. was unable to donate the property; but was willing to sell it at a reasonable price to the Southeastern Cave Conservancy, Inc. Through a generous grant from the Wallace Research Foundation, The Nature Conservancy of Tennessee was able to fund the purchase of this cave. Along with Hound Dog Drop Cave, several other caves and about 15 acres were purchased by the Southeastern Cave Conservancy, Inc. and named the Holly Creek Preserve.

As a result of the cooperative spirit between several concerned groups, this important cave can now receive the protection necessary for the survival of both rare species in the cave. In addition, there will now be opportunities to further study the cave and any fauna yet to be discovered there.

Caney Hollow Cave

Caney Hollow Cave in Franklin County, Tennessee, is another gray bat (*Myotis grisescens*) summer roost site. This cave was included in the "Top 100" list, but the landowners had not been approached by The Nature Conservancy of Tennessee. A Cooperative Management Agreement had existed between the Tennessee Wildlife Resources Agency and the previous landowners, but the old agreement lapsed when the property changed hands.

A biologist who was friends with the neighbors was able to talk to the landowners about the cave and advised a The Nature Conservancy staff member to pay them a visit. On the first site visit, The Nature Conservancy staff was able to visit the cave and spend some time with the landowners talking about their cave, the bats, and The Nature Conservancy's Cave Program. Information about caves and bats was left with them as well as a draft copy of a Cooperative Management Agreement. Luckily, the landowners had a good sense of the value of the cave and were happy to work with The Nature Conservancy to protect it.

In the following months, a Cooperative Management Agreement was signed and discussions about protection and problems at the cave continued. A The Nature Conservancy staff member was able to visit the landowners several more times and brought informational signs to erect at the various entrances to the cave. In the spring, before the bats arrived, a small group of volunteers conducted a cleanup of the cave.

During the summer, another biologist and a The Nature Conservancy staff member visited the landowners and brought them to the cave one evening to watch the emergence of more than 4,000 bats from the cave. This was a wonderful chance to show them first hand what they were helping to protect. They were delighted and have since taken many of their friends to the cave on summer evenings to watch their bats. Their pride in the cave and the life within has blossomed into a deep concern for all caves and bats in Tennessee.

New Mammoth Cave

The federally endangered Indiana bat (*Myotis sodalis*) once numbered in the thousands at New Mammoth Cave in Campbell County, Tennessee. Unfortunately, this cave and the bats have suffered tremendous and sometimes malicious vandalism over the years, leaving the numbers only in the hundreds.

The Nature Conservancy of Tennessee and the U.S. Fish and Wildlife Service, along with other partners, first began a relationship with the landowner of this cave nearly ten years ago when the first of three gates was constructed at the entrance. When this gate was breached and more vandalism occurred, a second gate was built. Eventually, the newer gate was also breached and stood open for some time.

In the winter of 2001, the landowner was re-contacted by The Nature Conservancy of Tennessee after years of silence. This was due in part to staff changes at The Nature Conservancy and the fact that there was no one in the office whose time could be completely devoted to cave issues. A The Nature Conservancy staff member spoke with the landowner about renewing our partnership with him and our commitment to the protection of New Mammoth Cave. Luckily, he was still very cooperative and interested in making another attempt to protect the bats. Plans were made to construct another gate, fashioned from much heavier steel and a more contemporary design, in the summer of 2001. Along with reinforcing the defense of the site, our other goal was to show to the landowner a recommitment to our partnership.

Through this project the East Tennessee Grotto, which had provided much volunteer work at the gating, stepped forward to offer their help in managing the cave. As well as easing the landowner's burden of managing access, a regular presence at the cave by grotto members will hopefully deter vandalism. It is our hope that this long-standing partnership with the landowner of this cave will continue for many more years.

Working with private landowners to protect important caves can be a long process of building trust and relationships and can lead to significant results. The Nature Conservancy of Tennessee's Cave Program has seen many successes over a decade of cave conservation. It should be noted, however, that none of these successes would have been possible without the help and support the many partners and volunteers who bring a dedication to the protection of one of Tennessee's finest resources, its caves.

The Nature Conservancy of Tennessee's Cave Program exists because of generous grant support by the Wallace Research Foundation and the United States Fish and Wildlife Service.

Developing a Cave Potential Map of Wind Cave to Identify Land Management Partners and Guide Land Management Decisions

Rodney D. Horrocks
Wind Cave National Park

Bernard W. Szukalski
ESRI Cave and Karst Program

Abstract

The known boundaries of Wind Cave are continually being expanded, reflecting on-going exploration and survey work by cavers. Many threats to this expanding cave system exist, including pressure from development within the cave watershed, existing and future Park facilities and infrastructure, and surface land uses. Due to the existence of direct hydrological connections between surface gullies and the cave system, it is logical to base surface land management decisions on the potential of Wind Cave being located below any given point or within the cave watershed boundaries. However, the boundaries are not sufficiently well-defined at present to be used to guide land management decisions for Wind Cave National Park, except directly over known cave. To promote better surface land management decisions above the entire cave system, a cave potential map was developed. This map serves several purposes, including: (1) determining the likely maximum extent of the Wind Cave system, (2) refining knowledge of cave watershed boundaries, (3) identifying potential land management partners, (4) estimating the length of the cave, and (5) guiding future land management decisions. To develop the cave potential map, several data sets were gathered, including: (1) structural geological factors, (2) a contour map, (3) GIS-generated Triangular Irregular Network Data Sets, (4) plan and profile views of the cave survey, (5) cave radio location data, (6) geology map, (7) blowhole location map, (8) water table contour map, (9) orthophotoquads, and (10) land ownership maps. It was determined that two land managers, the National Park Service and the USDA-Forest Service, manage lands covering the potential scope of Wind Cave. The maximum potential boundaries derived indicate that 98% of Wind Cave lies within the current boundaries of Wind Cave National Park.

Development and Management of Glenwood Caverns, Colorado

Bob Koper
Glenwood Caverns, Colorado

Abstract

Steve Beckley had read about Fairy Caves, an extensive cave system near Glenwood Springs, in an out-of-print book, *Caves of Colorado*, while he was in college. Fairy Caves had been open to the public as a tourist attraction in the late 1800s but had been closed since 1917. In 1982 Beckley contacted the owners of the caves to explore development of the caves to admit the public; however, Beckley and the owners were unable to agree. Steve persisted for the next 16 years and in 1998 reached an agreement with the owners under which he would be allowed to develop the property. During those years of negotiations, Steve continued to study what information was known about the caves. After a deal was made with the owners for development, Steve and Jeanne Beckley, with Bob Koper's help and the help of the caver community, began the substantial improvement projects necessary to allow the public to view this natural wonder. First, they graded and graveled a road up to the cave entrance and cleared the historic Fairy Caves of the debris that had collected there over 44 years. Because the purpose of development was to make the living cave accessible to the public and still not harm the cave, Steve and Jeanne decided to carve a new tunnel into the mountain, one that could control temperature and humidity and not harm the formations. The development team installed two airtight doors in the new tunnel to form an airlock. The doors are 50 feet apart so that when visitors enter the airlock, the door closes behind them. With the help of this airlock, the ideal humidity and temperature of the caverns can be maintained, ensuring the continuing growth of the ancient formations. The Beckleys also installed temperature and humidity monitors to ensure that the integrity of the fragile cave formations is maintained. Glenwood Caverns is now protected, able to continue to grow naturally, and yet is accessible to the public.

Leonard Springs Nature Park: A Karst Property Focusing on Conservation and Education

Kriste Lindberg
City of Bloomington, Indiana
Leonard Springs Nature Park

Abstract

Leonard Springs Nature Park is an 85-acre park with an emphasis on karst conservation and education. It is managed by the City of Bloomington in cooperation with the Indiana Karst Conservancy. The park contains three small caves, two impressive springs, and numerous secondary springs and seeps. From the early through mid 1900s, the property served as the city's water source. Currently, the old reservoir and surrounding land are in the process of being reclaimed by nature after over a century of use by farmers, millers, and others. Since 1999, together with various other local caving organizations, numerous cleanups have taken place on the property and in its caves. Collaborations with them have gone so well that more long-lasting commitments are being developed, including memorandums of understanding. Additionally, a mile-long trail was designed which passes a shelter cave and its associated overlook, the reservoir-turned-wetlands, and other significant features. Now that most of the work on the park itself has been completed, focus is shifting to cave and karst education, including efforts with local schools, agencies, planners, developers, and realtors.

Summary

Leonard Springs Nature Park is an 85-acre park with an emphasis on karst conservation and education. It is managed by the City of Bloomington Parks and Recreation Department in cooperation with various other agencies, including the Indiana Karst Conservancy. Throughout its 180 feet of relief, the property contains three small caves, two large and impressive springs with their associated waterfalls, and various other secondary springs.

The land was originally purchased by the city in the early 1900s and dammed to serve as their third water source. Later, it became apparent that the reservoir was not able to hold as much water as was anticipated for the growing population due to it being located in a well-developed karst area of the Mitchell Plateau. Water shortages ensued and the nearby, growing Indiana University threatened to move out of town. Eventually, the city and Indiana University came to an agreement to build a subsequent reservoir in a non-karst area northeast of the developing city. Leonard Springs ceased being used as a reservoir in the mid 1940s. It remained abandoned until a transfer from the Utilities Department to the Parks and Recreation Department took place in 1998.

Currently, the old reservoir and surrounding land are in the process of being reclaimed by nature after over a century of use by farmers, millers, and others.

Various grants were received and work began in the spring of 1999 to turn the once-abandoned property into a prosperous place for people to hike and appreciate the karst resource while at the same time preparing it as a karst education and outreach opportunity.

An emphasis has been placed on securing a sense of ownership in the park. Together with various other caving organizations such as the Ohio Valley Region, Bloomington Indiana Grotto, and Eastern Indiana Grotto, numerous cleanups have taken place on the property and in its caves as they had been used as trash dumps by nearby residents.

Once this process was accomplished to an acceptable level, a mile-long trail with a 100-stair steel walkway that brings one from the top of the reservoir to the bottom in order to reduce erosion was designed and added. It passes by the entrance to a shelter cave. In addition, numerous service-learning projects have taken place in the park, including maintenance of the trail system and so on. Since this time, there seems to be more pride in the park and surrounding area. For the amount of use it receives, very little vandalism has taken place and overall, visitors respect the property. Some have even been observed cleaning up candy wrappers and the like out of the parking lot on their own initiative.

Along the trail, interpretive signs have been placed in strategic areas to enhance the learning experience:

At the entrance to the park – includes a brief history of the park, do's and don'ts . . .

Near the shelter cave entrance – includes cave formation and conservation information . . .

Along the wetlands – includes the importance of wetlands as filtering systems . . .

On top of the dam – includes a brief history of the reservoir and city politics.

While the above was taking place, various school groups and others came to visit and enjoy the park as an educational facility or outdoor lab. For example, Harmony School undertook a Hoosier Riverwatch program sponsored by the Indiana Department of Natural Resources at one of the main springs, Shirley Springs. This program includes testing the water quality at various times and reporting it to the state. Many others have come for tours and other educational opportunities at the park.

Now that the park is in its final stages of development, more emphasis is being placed on education and outreach. Lindberg is currently working on collaboration between the city and county to further the park's efforts as well as working on common interests in the surrounding area. With the city growing and expanding outward toward the western karst regions, this emphasis is quite timely. People are becoming more and more aware of the importance of its karst resources.

The word is getting out. Local press has been supportive as well, and the karst/groundwater model, which the Indiana Karst Conservancy purchased a couple of years ago with a $500 NSS Conservation Committee grant, has been getting a real workout.

More education and outreach programs are in the process of being developed and refined, including those that emphasize Project Underground material and more work with school-aged children—public, private, and home-schooled children, 4-H, scouts, and so on. Of course, it's not limited to young people, those of all ages can benefit from these opportunities. For example, a septic system workshop is planned for the future and will include invitations to persons of other karst areas, a Storm Drain Marking Program is underway, as is a tour of the park by city and county planners as they continue their work on the growth policies plan. The City of Bloomington is being seen as a leader in karst conservation in the state of Indiana.

Thanks to the Bloomington Indiana Grotto, City of Bloomington, Eastern Indiana Grotto, Hoosier Hikers Council, Hoosier National Forest, Indiana Department of Natural Resources, Indiana Geological Survey, Indiana Karst Conservancy, Indiana University, Indiana University Spelunking Club, Monroe County Consolidated School Corporation, Monroe County Soil and Water Conservation District, Monroe County Solid Waste Management District, National Speleological Society, Ohio Valley Region, Project Underground, WonderLab, and all of the other fine organizations that have helped with the successful development of this important karst nature park.

Author

Kriste Lindberg has been an active member of the caving community since 1992. She was introduced to it while teaching for the Chicago Academy of Sciences. Having joined the Indiana Karst Conservancy in 1994, she has served on the board of directors since 1996, including two years as President. She is now focusing on developing their Education and Outreach Committee, of which she is Chairman. She has earned a BGS degree focusing on the earth and social sciences and an MSED. In addition, she serves as the Ohio Valley Region's Conservation Liaison, a Project Underground Facilitator as Indiana contact, and on the NSS Conservation Committee's national education team. She has been employed by the City of Bloomington as a coordinator for Leonard Springs Nature Park since its beginnings in 1999 and is currently working on collaboration between the city and other agencies, including the Monroe County Soil and Water Conservation District, focusing on education and outreach. She has written numerous articles for publication and has done presentations for grottos, schools, agencies, and conferences including the NCKMS 1999 where she presented a paper on "Recent Projects of the Indiana Karst Conservancy," which included a brief introduction to the developing Leonard Springs Nature Park.

Management Issues and Threats to the Longest Cave

Joseph Meiman
Mammoth Cave National Park

Hilary Lambert Hopper

Roger W. Brucker

Abstract

Impacts imposed from outside Mammoth Cave National Park's border by highways, sewage and farming runoff, industrial development, tourism development, and concomitant air quality problems create management challenges. Matching these external pressures is the fact that the cave system extends far beyond the park established by Congress in 1926. Exploration and scientific research has kindled a belief based on scientific understanding that Mammoth Cave will one day be mapped to at least 1,600 kilometers, perhaps extending from near Munfordville in the northeast to near Bowling Green in the southwest. Threats to the ecosystem health of Mammoth Cave have been repeatedly met over the decades and will be discussed. Since 1999 a new challenge has emerged in the Kentucky Trimodal Transpark. It is proposed that this facility will include a passenger and freight airport, a railroad and trucking node, an industrial park, and numerous new highway links. Plans are to situate this 1,600- to 2,400-hectare facility on privately owned farmland ten kilometers southwest of the park boundary within the Graham Springs drainage basin on the Sinkhole Plain between Bowling Green and Smiths Grove. This presentation will provide an update on the national cave and karst community's efforts to protect the karst of south-central Kentucky, including Mammoth Cave. Discussion will focus on the need for a comprehensive hydrological investigation to understand the characteristics of the underground drainage divide at all stages and to assess the risks to Mammoth Cave National Park.

Lechuguilla Cave Culvert Replacement Project

Jason M. Richards
Carlsbad Caverns National Park

Abstract

The Lechuguilla Cave breakthrough was in May of 1986. During the first week of exploration a 24-inch diameter road culvert with a locking gate was placed through the rubble to make entry into the cave safe and to add security. Due to the constant exchange of air (sometimes by winds up to 60 miles per hour) due to barometric pressure in the culvert, the Sandia Grotto replaced the locking gate with a counter-balanced lid and seal. The interior of the culvert was always either wet or dry depending on whether the cave was exhaling or inhaling. This constant variation of climate on the interior of the culvert created a very hostile environment and the perfect conditions for corrosion on metal surfaces. After several years, the mild steel ladder and the culvert were in a state of severe corrosion. For safety purposes, the management of Carlsbad Caverns National Park's Cave Resource Office, decided that the culvert should be replaced with a combined non-corrosive airlock and culvert. Various ideas and materials were discussed and they finally decided that stainless steel would be the best material for corrosion resistance and security for the cave. Basically, the project started in February of 1999 with the combining of ideas and the writing of an environmental assessment. Along with combined long hours, frustration, and hard work, the construction phase of the project ended June 18, 2001. The restoration phase of the project has begun with many volunteers and grottos donating their time and effort to return Lechuguilla Cave's entrance as closely as possible to what it was prior to the project. The presentation at the National Cave Management Symposium will cover the construction phase of the culvert and airlock from the very beginning through up to date on the restoration phase of the project.

Cave Management Plan for an Underground Laboratory: La Cueva de Las Barrancas, Prototype Site for Mars Studies

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Abstract

La Cueva de las Barrancas, a desert cave first entered in 1991, is managed as a pristine subterranean laboratory for speleological research. The cave management prescription, approved by the USDA-Forest Service in 1999, is designed to prioritize scientific investigation in the cave. In Barrancas, science goes first, before exploration, survey, or cartography. Sampling and investigation for microbial life is initiated in each new passage before other scientists or cavers are allowed to enter. Some areas are left untainted by human entry, preserved as virgin sites for future studies.

Because this cave offers a protected environment for scientific study, the management plan contains several innovative features. Limits of acceptable change are described. Protocols for exploration, survey, and research are defined. Included in the plan is a Minimum Impact Code of Conduct for cavers and scientists entering the cave, and Barrancas is managed cooperatively through a Memorandum of Understanding with cavers who assisted in writing the management plan.

Science in Barrancas has progressed from doing initial baseline studies of subsurface microbial life to establishing the site as a prototype for subterranean studies on Mars and other planets. Grants awarded by the NASA Institute for Advanced Concepts support research in using Barrancas as a test environment to develop low-impact operational logistics and no-impact *in situ* techniques for the study of microbial life in sensitive environments. These efforts will advance the study of other pristine and previously impacted cave sites as well as the study of fragile surface environments.

Introduction

La Cueva de las Barrancas presents a rare opportunity for scientists, cavers, and the USDA-Forest Service to establish baseline data on a pristine cave environment. Discovered by Mike Reid and Jim Werker in November of 1991, Barrancas was first entered by enlarging a fist-sized opening. Because Barrancas may have had little or no exposure to surface biota and the passages and pools had no evidence of human entry prior to 1991, potential exists for finding unique microbial communities in the cave.

Access to Barrancas is limited by rugged desert canyon terrain. The cave is entered through a solid steel gate. After a tight, 15-foot crawlway, the passage drops down a 350-foot pit. The descent is divided into three rappels and permanent bolts have been set for anchors and rebelays. Abundant bone fragments coated with calcium carbonate (cave velvet) are found at the second landing. Some of the known cave passages have mud layers as much as two feet thick. The thicker deposits are stratified with mud and sand. Many of the cave formations are mud-coated and some speleothems show unique patterns of solutioning and redeposition. Unusual mud formations are scattered through the known passage. Airflow at the entrance, often in excess of 40 miles per hour, indicates the potential for Barrancas to be a large cave. To date, less than half a mile of passage has been entered. Because of the scientific potential offered by the pristine passages of La Cueva de las Barrancas, extensive exploration and survey have not been initiated.

Discovery

Barrancas was discovered the day after Thanksgiving, November 27, 1991. (Hildreth-Werker, 2001) Mike Reid and Jim Werker were ridge walking and looking for caves, but they did not expect to find a fist-sized hole sucking in enough air to make loud whistling sounds. They heard wind-like noise from several hundred feet up the canyon. First, they thought of running water, but water sounds were unlikely in the rugged desert mountains of southeastern New Mexico. The hole itself was so small they walked past it and had to backtrack to find the source of the noise.

Over the next several months, a small crew spent their weekends backpacking to the entrance and mining the bedrock by hand. Squeezing through the new entrance slot, then through a natural 15-foot crawlway, the smallest team member peered down the drop into an unknown depth of dark vertical passage. "It goes."

After using a fishing reel and line to measure an estimate of the depth, the team returned with 600 feet of rope for the descent and found the drop to reach an actual depth of 350 feet. Beyond the drop, various forms of mudflow covered the floors of cathedral-like rooms lined with formations revealing sequential patterns of corrosion and deposition from drip, airflow, and potentially, microbial activity. Werker realized the unique potential offered by this deep virgin cave and conceived a vision for establishing Barrancas as a preserve for speleological research.

Protection Initiated

Before mining the bedrock, the volume of airflow through the initial fist-sized opening was documented so the gate could be designed to duplicate the natural air exchange. After four months of digging, the entrance slot could finally accommodate human passage. A solid, octagon-shaped gate, 18 inches by 24 inches, was constructed of quarter-inch solid steel plate. (Werker designed the gate and Reid built it.) The team backpacked the 80-pound gate into the canyon and installed it, attempting to replicate the original airflow and conditions inside the cave.

The first line of defense for protecting this cave was silence. Before starting the dig, the small team agreed to keep quiet about the find. Careful design and installation of the gate furthered the goals of protection and security.

The USDA-Forest Service then agreed to keep Barrancas closed until a cave management prescription could be written and implemented. The cave was entered only for a few administrative tasks. No extensive exploration was initiated because Lechuguilla exploration was in its heyday and the caving community was beginning to recognize that cave exploration should be carefully orchestrated to be compatible with cave conservation. With the advance of cave microbial studies, cavers were realizing that important scientific information can be inadvertently destroyed as easily as the fragile aesthetics of virgin cave passages can be damaged. By carefully considering actions before moving full-bore ahead, perhaps this cave could be established as a protected laboratory and a test-site for more prudent exploration. We were willing to go more slowly in Barrancas and allow time to develop the concept of protecting it as a preserve for speleological study.

The USDA-Forest Service supported Werker's vision for Barrancas and the creation of a new type of cave management plan. Serendipitous events between cave science and the approval of this plan resulted in a variety of Barrancas research projects being underway by Thanksgiving of 1999, eight years after discovery. Meanwhile, during less than a dozen initial administrative trips, only a few areas of the cave were entered. From the beginning, trails were established with continuous lines of flagging tape delineating both sides of the pathway. Cavers performed the first cursory inventories, taking care not to step beyond the trail boundaries. Rooms and passages visible from the trail were not entered—we left these chambers untainted for baseline microbial investigations.

Why Protect Cave Microbes?

Microbial data collected from cave passages that show no evidence of prior human visitation yield results that are more valid than data from human-affected caves (Moser and Martin, 2001). Wherever we go as cavers, we introduce a steady stream of surface microbes that constantly fall from our bodies. These microscopic organisms live with us and on us, forever feeding on anything organic—from our dermal matter itself to the normal flakes of debris that cling to our nails, hair, skin, and clothes.

In the early 1990s, microbiologists were developing techniques for advanced exploration of subterranean microorganisms on Earth and for seeking potential microbial life on other planets and in space. New information about the tremendous diversity and abundance of microorganisms was imminent—deep subsurface drilling was being conducted through projects sponsored by the Department of Energy (Fliermans and Hazen, eds., 1991), reaching deep below the surface to collect underneath the Antarctic ice and inside deep-sea ocean vents. Such exploration demands expensive and specialized equipment. Virgin cave passages, more easily accessible to humans, were attracting new attention, with a dawning recognition of their relevance to space science, medicine, microbe/mineral interactions, and origins of microbial life on Earth (Boston and McKay, 1991; Rusterholtz and Mallory, 1991; Chafetz and Buczynski, 1992; Cunningham, *et al*., 1994 and Northup, *et al*., 1997).

The lessons learned through studies in geomicrobiospeleology were applied to the conservation and management of Barrancas. By the time scientists recognized the significance of geomicrobial organisms in caves, the prime pristine areas within most caves had already received recurring human visitation. Werker realized that Barrancas offered a unique opportunity for this rapidly developing science—Barrancas was an unspoiled study site. The concept of protecting cave passages as microbial preserves was new on the horizon of cave conservation (Northup and Mallory, 1997).

Werker was thinking about a new paradigm for exploration in Barrancas. The need to investigate virgin passages for unique microbes and the importance of studying subsurface processes with no contamination from human-associated microorganisms or organic materials made it valid to rethink the traditional first step of cave exploration, survey and cartography. Jim wondered, "Can we do this cave differently and protect virgin passages for science to go first? Can we create a cave management plan that will allow sampling for native subterranean microbes as the first step, other scientific investigations and photomonitoring as the second step, with survey and cartography as the third step?"

Over the years between 1991 and 1999, cave microbiology progressed and Werker's questions matured into concepts for protecting Barrancas as a virgin cave laboratory with exploration standards that allow science to go first and conservation strategies that encourage minimum negative impact.

Cave Management Plan

In February of 1999—eight years after the discovery of a noisy, fist-sized hole—the management prescription for La Cueva de las Barrancas was approved. Because we were developing a novel concept for cave exploration, it took years of persistence to work out the details and finalize the plan. Jim Werker started writing the cave management plan in 1992. Several years later, Ransom Turner and Kevin Glover, both employed by the USDA-Forest Service, added to Jim's initial work. In 1997, Jim and Val Hildreth-Werker began to further develop the cave management document for Barrancas and requested additional review by USDA-Forest Service personnel. For reference, the first Barrancas management plan, Cave Implementation Schedule La Cueva de las Barrancas, is included as an appendix at the end of this paper.

Limits of acceptable change are defined in the cave management plan. As Barrancas is carefully studied and explored, the search for new knowledge is balanced with precautions to prevent unnecessary changes in the cave's ecosystem. Important baseline monitoring information is documented through meteorological records, photographs, and ongoing microbial sampling in each new area of the cave. Photomonitoring points are established to record changes in the cave over time. Geological, mineralogical, and paleontological resources are carefully inventoried and mapped with minimal disturbance to biologic resources. All study methods and human operations are designed toward preservation of native biota in the cave. See the "Minimum Impact Code of Conduct" and "Policies and Guidelines for Entering La Cueva de las Barrancas" in the Appendix for this paper.

Science and Monitoring Projects in Barrancas

Science in Barrancas has progressed from doing initial investigations of subsurface microbial life to establishing the site as a prototype for subterranean studies on Mars and other planets. Barrancas is a test environment for developing low-impact operational logistics and no-impact *in situ* techniques for investigations of microbial life. These efforts will advance the study of other pristine or previously impacted cave sites as well as the study of fragile surface environments.

Protocols and technologies include imaging at low and ultra-high resolutions, analyses of the minerals contained in cave materials, and a variety of biological analyses aimed at identifying the major microbial inhabitants of various materials. Minimum-impact microbiological studies are ongoing and will provide useful baseline data for monitoring programs. Experiments are conducted *in situ* when feasible, because cave organisms are relatively sensitive to tiny perturbations in their environment. When procedures cannot be done on site, specimens are stabilized before removal from the cave. Microbial samples are collected and analyzed first, because geochemical and mineralogical analyses are usually less sensitive than biological analyses.

Data gathered from microbial, mineralogical, and geological research in Barrancas will guide management decisions regarding subsequent exploration and scientific study. Methods include: long-term colonization studies, exoenzyme studies, culturing techniques, microbial percolation traps, molecular biology techniques, DNA analyses, scanning electron microscopy, transmission microscopy, energy dispersive spectroscopy, bulk chemical analysis, stable isotope analysis, meteorological monitoring, air analyses, pH monitoring, photographic inventory of macroscopic organisms, photomonitoring at permanent stations, and photodocumentation of methods and sample sites.

Prototype Site for Mars Studies

NASA is interested in caves on Earth and other planetary bodies as scientific targets for future missions and as potential resources for human use at extraterrestrial destinations (for example, a research base might be placed in a natural subterranean void on Mars). The critical operational logistics of our studies in Barrancas are being tackled with particular attention to planetary protection issues. Planetary protection refers to the need to protect possible organisms on another planet from contamination by Earth microbes while we study and explore. At the same time, we must also protect Earth from any contamination by possible alien species. Barrancas provides a suitable test environment for these challenging and competing goals.

Because Barrancas is protected as a pristine geomicrobiology cave site, it can serve as a model for hazardous and rigorous subsurface study sites on other planets. Barrancas provides a Mars prototype lab, where the working conditions are grueling and the challenges of exploration and research require on-site resourcefulness. Of paramount importance, the investigations must be performed without compromising the scientific value or ecological soundness of the cave microbiota—any life forms discovered must be preserved. Using the cave as a study site for astromicrobiology, methods are being developed to prevent our own human activities from contaminating this Mars prototype environment. Barrancas presents a suitable study site for protocol development toward future human Mars missions. The proposal to study this possibility was submitted to the NASA Institute for Advanced Concepts early in 2000. Penelope J. Boston (Principal Investigator) and the Barrancas team were awarded substantial Phase I and Phase II grants to work on the concepts and developments necessary for implementing Mars prototype studies in Barrancas (Boston).

In cave passages that are isolated from the surface, microorganisms have evolved through many generations of adaptation to subterranean conditions that can be radically different from any that we find on Earth's surface. The pristine passages of Barrancas provide a place to practice for future missions when we look for alien life forms in the subsurface of Mars or other planets (Boston, 2000). Werker's vision of protecting Barrancas as a pristine laboratory for speleological science, along with Forest Service approval of the innovative management plan, set the stage for using this cave as a prototype environment for Mars studies.

La Cueva de las Barrancas is a unique spelean testing ground where the speleologists and astrobiologists of the 21st Century can develop study techniques. The foundation of this research is the Barrancas cave management plan. We are in no way advocating this type of management structure for every cave. Cave environments can hold a variety of fascinating assets—some management prescriptions are written to protect specific resources, others are written to protect the people who visit a cave site, and many management plans are written to protect the visitors as well as the natural and cultural resources within. The efforts in La Cueva de las Barrancas will serve in advancing studies of other cave sites, exploring the potential for life on other planets, and protecting other fragile environments of Earth's surface and subsurface.

Acknowledgments

We extend many thanks for the months of cooperative effort that went toward the approval of the cave management plan for La Cueva de las Barrancas and the subsequent Memorandum of Understanding between the USDA-Forest Service, Jim Werker, and Val Hildreth-Werker. Forest Service personnel who helped bring the Barrancas dream to reality are Jose Martinez, Forest Supervisor; Johnny Wilson, Forest Recreation Staff Officer; Jerry

Trout, Forest Service National and Regional Coordinator/Cave Resources; Brent Botts, Forest Service Regional Deputy Director of Recreation; Jim Miller, Dispersed Recreation & Trails, Washington Office; Mike Baca, District Ranger; Richard Carlson, District Recreation and Lands Staff; Larry Paul, District Wildlife Staff; and Ransom Turner, District Cave Specialist. During the past decade, their commitment to the vision for Barrancas and their unified efforts have facilitated the development, approval, and implementation of this unique cave management prescription.

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Appendix

Cave Implementation Schedule La Cueva de las Barrancas

United States Department of Agriculture Forest Service

This Individual Cave Implementation Schedule is a working document to set specific guidelines and aid in the management of La Cueva de las Barrancas. As a result of this Schedule, quality management practices will be put into place to protect the unique, valuable, and finite cave resources contained in La Cueva de las Barrancas. Scientific research, exploration, inventory, and survey will be conducted in a well-planned, purposeful manner as outlined in this Schedule.

Document was approved and signed in February 1999.

Section 1

Introduction

La Cueva de las Barrancas presents a rare opportunity for scientists, cavers, and the USDA-Forest Service to investigate and establish baseline data on a pristine cave environment. Discovered by Jim Werker and Mike Reid in November of 1991, Barrancas was first entered by enlarging a fist-sized opening. Because Barrancas may have had little or no exposure to surface biota before 1991 and because the passages and pools were isolated with no evidence of human entry prior to 1991, potential exists for finding unique microbial communities in the cave.

This Schedule for Cueva de las Barrancas focuses on unique opportunities for scientific research in a pristine underground environment on the Lincoln National Forest.

The virgin passages of La Cueva de las Barrancas may provide an underground laboratory of great value. As Barrancas is carefully studied and explored, the search for new knowledge should be balanced with precautions to prevent unnecessary changes in the cave's ecosystem. Data gathered from initial research in this cave is facilitating informed management decisions regarding subsequent exploration and scientific study. Photographic documentation will be conducted prior to entry into each new area of the cave. Photomonitoring points will be established to record changes in the cave over time. Microbiologists have initiated ongoing studies in Barrancas and microbial sampling will provide useful monitoring information.

Scientific investigation and analysis of speleologic resources will continue in La Cueva de las Barrancas. Microbe investigators will be the first to enter virgin pool areas and establish study sites. Geologic and mineralogic resources will be carefully inventoried and mapped without disturbing biota. Paleontologic studies and invertebrate inventories will be conducted. Water analyses and hydrologic studies will be initiated. Research methods will be designed to address preservation of native biota.

Initial investigation has established Barrancas as one of several caves in the Guadalupe Mountain region that contain isolated microbial communities. These microbes are being studied to determine whether they produce toxins that are useful in cancer treatment research. Scientists have discovered new microbial communities in the pristine pools of Barrancas. For this research to continue, it is imperative that La Cueva de las Barrancas be thoughtfully protected and that exploration and research be carefully managed.

Description

The cave entrance is located in the southern section of the District. Access to Barrancas is limited by rugged desert canyon terrain. Access requires travel on four-wheel-drive roads, then a moderately strenuous hike. The cave is entered through a solid steel gate. After a tight 15-foot crawl-way, the passage drops down a 350-foot pit. The descent is divided into three rappels and permanent bolts have been set for anchors and rebelays. Water flowing into the cave has deposited mud and bone fragments. Some of the known cave passages are coated with mud up to one foot thick. Many of the cave formations are naturally mud coated. Some formations show unique patterns of solutioning and redeposition. Unusual mud formations are scattered through the known passage; at least one of these may be a unique or undescribed speleothem. Airflow at the entrance, often in excess of 40 mph, indicates potential for Barrancas to be a large cave. To date, approximately one-quarter mile of passage has been entered. Because of the scientific potential offered by the pristine passages of La Cueva de las Barrancas, extensive exploration and survey has not been initiated.

Classification

Based on the management classification system listed and described by the USDA-Forest Service Cave Ecosystem Management Direction, La Cueva de las Barrancas has been listed as Class 5-E-IV. Barrancas is classified as a hazardous vertical cave with biologic, paleontologic, geologic, mineralogic, and scientific significance.

Current Objectives

- Identify, protect, and preserve the natural cave system. Identify, protect, and preserve the ecosystems and native microbial communities within the cave.
- Establish a system of photomonitoring stations. Use photo inventory, photo documentation, and photomonitoring in managing, protecting, and preserving the cave's resources.
- Facilitate scientific study of the cave's resources.
- Develop new conservation protocol for cave exploration, inventory, and research.
- Assure that anyone who enters the cave is fully aware of and agrees to follow the "Policies and Guidelines for Entering La Cueva de las Barrancas."

Acknowledgments

As cavers and cave researchers learn more about spelean environments, we are in a continuing process of evaluating and redefining techniques for protecting cave resources. This Schedule, including the Policies and Guidelines, and the Minimum Impact Caving Code, comes from the experiences and thoughtful contributions of many cavers and speleologists. Policy statements are developed with input from many sources: Cave Management Plan for National Forest, 1972; National Forest Cave Ecosystem Management Direction, 1995; and the Cave and Karst Management Plan for Carlsbad Caverns National Park, Appendix E: Guidelines for Entering Lechuguilla Cave, 1995. Jim Werker drafted initial ideas for this Schedule in 1992. Ransom Turner and Kevin Glover compiled a beginning draft in the spring of 1996. Val Hildreth-Werker collected additional information and ideas from collaborators Brent Botts, Jerry Trout, Richard Carlson, Mike Baca, Johnny Wilson, Penny Boston, Larry Mallory, Diana Northup, Dave Jagnow, Dale Pate, and Jim Werker. Using this input, Hildreth-Werker revised the Schedule into working drafts during 1996-1998.

Section 2

Policies and Guidelines for Entering La Cueva de las Barrancas

Research Directives

A. Implement minimum impact techniques for all activities in the cave. Encourage standards of excellence in speleological research and in minimum impact protocol.

B. Continue microbial investigations and pool studies as the highest priority for developing research and protocol techniques in Barrancas.

C. Continue photographic documentation and photomonitoring. Photographs will be used as management tools for tracking and evaluating changes in the cave. Speleothems, cave passages, pools, paleontological resources, areas of impact, etc., will be inventoried and monitored. Virgin areas, geologic resources, etc., will be photo documented upon discovery, and periodically thereafter.

D. Allow appropriate research projects that will not interfere with microbial studies. Research will be conducted by experienced, careful cave investigators with scientific and conservation expertise.

E. Proposals will be submitted to the Forest Supervisor for approval. Proposals will include projected time frames for successful completion. Projects will require advance planning to focus on minimizing the number of cave entries.

F. Forest Supervisor decisions concerning La Cueva de las Barrancas will be based on review and comment provided by the Forest Service National Coordinator/Cave Resources, Forest Service Cave Management

Specialists, cave researchers, and interested parties.

G. Collection permits will be approved through the Forest Supervisor before taking samples from Barrancas. Written authorization is required from the collection permit holder if collecting is to be conducted by another researcher.

H. Inventories will be done from the trail rather than by walking across pristine surfaces. Inventory photographs will be made from the trail. Permission to extend trails to specific study sites may be requested and approved through the Forest Supervisor.

Cave Entries

A. Permits are required for cave entry. Permits will be issued only for conducting approved research projects or if necessary for emergency rescue.

B. Prior to entry, each person who intends to enter the cave must read and agree to follow the "Policies and Guidelines for Entering La Cueva de las Barrancas" Prior to entry, each person must sign the cave permit.

C. The Hazard Rating of Barrancas (IV) requires that teams entering the cave have a minimum of four (4) people. Permit requirements state that no more than six (6) cavers will occupy a single permit. However, if special needs for research can be proven, the Forest Supervisor may approve more than one permit per day. All trips shall have four (4) people as a minimum, with an exception being made for two teams of three (3) cavers simultaneously entering as part of one expedition.

D. A Job Hazard Analysis will be reviewed during safety meetings prior to cave entries.

E. Expedition Leaders are responsible for the actions of each person on the expedition.

F. Team Leaders are responsible for the actions of people in their group. The cave entry and activities must be geared to the least experienced member of the team. Each person is ultimately responsible for his or her own individual safety.

G. Trip reports from Team Leaders will be submitted to the Forest Supervisor immediately following each entry. Trip reports will include date, time in cave, names of personnel, sites visited, work accomplished, brief explanation or information about samples collected, and survey numbers referenced. Trip reports will be submitted before leaving the District or within twenty days of entry.

H. Detailed reports from Expedition Leaders will be provided to the Forest Supervisor and the Forest Service National Coordinator/Cave Resources, during the course of every project. Detailed reports will include cave entries, photo documentation, research results, and future objectives.

I. Currently, there is no need for overnight camping in Barrancas. Each expedition will plan to exit the cave on the day of entry. If distance becomes a factor, see the section below titled Policy Changes.

Exploration

A. Exploration will be conducted with prudence and deliberateness for the purpose of discovering new microbial research sites. Microbe investigators will be given access priority to enter virgin areas for testing. Through approval by the Forest Supervisor, research areas may become off-limits until scientific investigation in those areas is completed.

B. Virgin passages are valued resources for the undisturbed microbial communities they contain. Science teams will precede exploration teams in unexplored areas of Barrancas. Virgin passage will be reserved for science teams and will be protected from human impact or human entry prior to biologic investigation.

C. When entering unexplored areas, trails will be established immediately to minimize impact to the cave. A path will be marked that will cause the least impact. Cavers will not be allowed off the trail unless approved by the Forest Supervisor in order to achieve specific management or research objectives.

D. When sensitive areas are discovered, cavers will stop and should not proceed. If aragonite bushes block the path or if other noteworthy speleothems deter progress, cavers will stop and report to the Forest Supervisor for decisions on how and whether to proceed.

E. The primary objective of this Schedule for La Cueva de las Barrancas is to provide unique opportunities for scientific research in a pristine underground environment. Survey will support scientific research and exploration. Exploration will proceed in a slow, prudent and deliberate manner. The first priority of exploration will be to identify potential sites for microbial research.

1. The first team entering an area will take photos of the pristine passage, carefully choose a path, and lay double flagging tape to define the trail. Trail width generally should be 18 inches or less, depending on the purpose, destination, and speleothems present in the path. Consideration for wider trail definition shall be given to include handholds on climbs and crawls.
2. Exploration will stop upon finding areas with potential for microbial studies.
3. The microbiologist will be the first to enter the area and will set up testing sites and do photographic documentation.
4. Photomonitoring points will then be installed as determined appropriate.
5. Inventories and surveys will eventually be initiated using technology that allows all participants to stay on the flagged trail. All survey stations will be accessible without getting off the flagged trail. Inventory notes and maps will refer to survey stations. All survey stations will be set permanently. Some permanent stations will require an offset and reference to protect resource values. All cave surfaces off the flagged trail will be preserved in the original pristine state.

F. Advanced technologies in survey, mapping, and cartography will be used in order to achieve the highest standards for minimum human impact in the passages of Barrancas. Survey, a discipline within speleological research, will also require the proposal, review, and approval process.
1. Survey in Barrancas will not be conducted until it can be done exclusively from the flagged trails. Precision mapping of Barrancas will begin when survey instruments and techniques become available to surveyors and cartographers so they can remain on the flagged trails. In order to preserve microbial resources within the cave, off-trail survey and mapping will be conducted using improved technologies such as range finders, laser devices, 3-D imaging equipment, etc.
2. Carlsbad Caverns National Park (CCNP) has established acceptable survey standards for traditional tape and compass survey technique. These standards are listed in the most current revision of Appendix F: Cave Management Plan for CCNP. In the event that policy changes require survey to be initiated using tape and compass, the CCNP survey standards will be used in Barrancas until advanced technologies become available.

Policy Changes

A. Management policies, guidelines, and codes will be evaluated and adjusted as necessary to protect the resource. Changes will be approved through the Forest Supervisor. Approval will be based on review and comments made by the Forest Service National Coordinator/Cave Resources, Forest Service Cave Management Specialists, cave researchers, and interested parties.

B. All parts of the Schedule for La Cueva de las Barrancas shall be reviewed and updated annually, and/or as necessary to protect the resources.

Section 3

Minimum Impact Caving Code for La Cueva de las Barrancas

The overall goal of the USDA Forest Service for La Cueva de las Barrancas is to allow limited scientific access and to identify and minimize impacts to the cave. Every person entering the cave is responsible for his or her own actions and safety and for the actions of team members. Expedition Leaders and Team Leaders have tremendous responsibility for the caving ethics of their personnel and for impacts to the cave. If problems persist, the Leader must abort the trip and the team will leave the cave.

As more is learned about cave environments, there is a continuing process of evaluating and redefining caver ethics. The following statement of conduct for Barrancas comes from the experiences and thoughtful contributions of many cavers. Think safety; take care of yourself and your team. Move with stewardship; avoid microbial, biological, and environmental impacts; and give utmost importance to the preservation of all cave resources.

- All clothing and equipment must be freshly washed to avoid transfer of microbes from other environments. Additionally, research is being conducted to determine whether boot soles and gloves should be treated with a disinfecting solution just prior to cave entry.

- Use boots and flowstone shoes with non-marking soles. If in doubt, scrape the boot over a white floor, concrete, or limestone rock. Marking soles will definitely leave a mark.
- The cave entrance is at an elevation of 6,000 feet. Cavers not accustomed to the area should plan on spending a couple of days at this elevation to acclimate before entering the cave.
- Only cave packs or internal frame packs will be used. No external frame packs or ammunition boxes.
- Electric lights are required. No carbide is allowed.
- Always travel through the cave with your team. Do not get separated. Only an emergency might require different actions.
- Each team must have a minimum of four (4) cavers. Regulations on cave permits state that no more than six (6) people may enter the cave per permit.
- Be willing to discuss and report unsafe or damaging behavior so it can be corrected. It is every caver's responsibility to ensure that Barrancas remains as pristine as possible and that every team member is safe.

- Drink plenty of water. Watch for signs of dehydration.
- Use layered clothing and insulating pads to protect yourself from cold. Watch for signs of hypothermia and fatigue. Take corrective measures before symptoms escalate.
- Do not enter the cave if you know you are sick or injured.
- Do not enter the cave if you are not well rested.
- Report any accidents to the Forest Supervisor as soon as possible. Fill out an incident report for any injury or accident.

- Wear gloves. Check your gloves for mud, dirt, and holes to avoid extra impact. Rather than grabbing handholds along the trail, use a gloved knuckle for balance where possible.
- Pack in powder-free, non-latex surgical gloves for use in gloves-off areas and in pristine sections.
- Carry freshly washed flowstone shoes and protective covers for boots. Some trails in Barrancas are very muddy. Do not wear muddy boots across clean or pristine areas. Do not use bare feet or socks. Always use clean flowstone shoes. Check and clean mud from flowstone shoes frequently.
- Move carefully through the entire cave. Move slowly and gently through delicate areas. Always move slowly enough to avoid kicking up dust. Avoid new impacts to floors, walls, and muddy areas.
- Stay on established flagged trails. Do not impact the cave beyond designated trails. Sit within the trail. Be careful not to set your pack outside the trail. Always look for and use the most impacted areas of the trail when stopping.
- Trails with double flagged boundaries will be marked immediately upon entering any new area of the cave.
- Approval must be obtained from the Forest Supervisor before entering virgin territory, making new trails, or flagging new areas.

- No smoking and no use of tobacco in the cave.
- No consumption of alcohol.
- No illegal drugs.

- Obtain experience in vertical caving practices and become proficient in Single Rope Technique before entering the cave. Rebelay anchors will be encountered in the cave. Clip into all safety and traverse lines.
- Austinetic stainless steel bolts and hangers will be used exclusively when bolting. Any bolt that will not be used again will be removed.
- Check ropes and rigging before clipping in. Everyone entering the cave is responsible for the care and safety of ropes, bolts, carabiners, etc. Notify the Trip Leader of any problems. The Trip Leader will fix the problem immediately and/or notify the Forest Supervisor of the concern or change. If necessary, leave a note with the rigging to explain the problem or change.

- Leave all scientific instruments alone. Avoid touching instruments or cases. Avoid going near flagged-off microbe research areas. Remember, thousands of flakes of skin and debris fall from each of our bodies every hour.
- Assume all pools are off-limits. Avoid touching pools. Avoid standing over pools. Water may be collected only if the Forest Supervisor has validated a collecting permit. Pools must remain pristine for microbial research. Contamination may destroy valuable microbial resources.
- Do not enter off-limits areas unless you have specific authorization from the Forest Supervisor. Be certain you know which areas are off-limits resource protection zones.
- Special-attention areas require clean clothes, shoes, and gear. Do not enter special-attention areas wearing general caving attire. Perform extra efforts to keep these

areas pristine. Clean tyvek suits may be required when entering virgin areas or research sites.

- No cave materials, minerals, speleothems, bones, etc. may be removed without a valid collecting permit approved by the Forest Supervisor. No digging may be performed without a permit from the Forest Supervisor approving such actions.
- Remove all solid and liquid wastes from the cave. Contain and carry feces, urine, vomit, spit, etc. out of the cave and dispose of properly. Plan for adequate container space. Never leave burrito bags along the trail while traveling. Adequate wrapping will make travel more pleasant for everyone. Always ask for updates on proper procedures for disposal of burrito bags outside of the cave.

- Care must be taken to avoid dropping crumbs or food particles in the cave. Always eat over a large disposable plastic bag. Carry out all crumbs and debris. Do not eat on the move.
- If stoves are needed for scientific application, use only alcohol or propane fueled stoves.
- Do not comb or brush hair in the cave. Use nylon swim cap, hair net, or bandanna to contain long hair and catch sweat.
- Avoid spreading pencil eraser particles in the cave.
- Develop caving practices that will reduce the input of organic carbons.

- An "out time" must be left with a responsible person and the Forest Service. All teams must inform the District Cave Specialist or other designated FS representative of an "out time;" the specific time they intend to be out of the cave and back at their vehicles or at the Administration Site. Search will be initiated for any team that is six hours late. Don't be late.

House Joint Resolution No. 161: A Legislative Mandate to Study Karst Groundwater Monitoring in Virginia

Terri Brown
Terrane Environmental

Abstract

As the only state in the U.S. without an EPA-approved Wellhead Protection Plan or program, Virginia places the onus for development and implementation of groundwater protection strategies entirely upon local governments. While localities struggle with familiar infrastructure and social concerns, less tangible problems such as growth management, source water protection, and drought and flood mitigation fall to the wayside. The situation is especially acute in the 27-county karst region of the Commonwealth, where population growth rates and the rapid conversion of farmlands and forests to urban and residential land use increasingly compromise sensitive karst resources and specifically water quality. The conflict between local and state responsibility for groundwater protection recently came to a head in the Shenandoah River watershed as public outcry over non-point-source pollution and a total lack of groundwater data convinced state legislators to delve into the geopolitics of water law. In 2000, western Virginia representatives successfully sponsored House Joint Resolution No. 161 establishing a special subcommittee to study karst groundwater monitoring and protection in the Shenandoah Valley. The Joint Sub-committee was formed under the authority of the State Water Commission, the branch of the General Assembly that addresses public water resource matters. House Joint Resolution No. 161 allowed the Sub-committee to name an *ad hoc* technical advisory group chaired by hydrogeologist Terri Brown which convened throughout the year to discuss the feasibility and economics of data collection relative to water table levels, surface water interactions with groundwater, and water withdrawals. The collection and compilation of this type of information is a minimum requirement for the long-term prediction and analysis of trends in water supply and quality regarding urban, residential, commercial, industrial, and agricultural land uses. Given that the study area is one of karst, many other aspects of water monitoring were considered, such as the need for tracer testing and sinkhole and karst outcrop maps, the limits of pumping tests, and the use of lineament and fracture trace analyses for recharge area delineation. The State Water Commission will report its findings and recommendations to the Governor and the 2002 Session of the General Assembly in January.

The Mapping and Classification of Cave Geomorphic Processes within the United States

David Alan Ek
Chattahoochee River National Recreation Area

Abstract

Terms utilized to describe caves are often based upon landscape morphological and/or anthropomorphic features. The emphasis is on form, not function. Since various processes can produce landscapes with similar appearances, this has led to a diverse, complex, haphazard, and sometimes confusing lexicon. Similarly, most cave classification systems focus upon management of caves as a recreational resource, or rank the hazards they pose to the visiting public. Many other scientific disciplines have taken a more scientific-based, process-oriented approach to classification. A similar approach for caves would aid analyses, cave assessments, the development of protection strategies and the development of protection and restoration priorities. Various researchers have produced national cave or karst distribution maps. However, these maps primarily depict the presence of carbonate rocks. The presence of suitable lithology is only one of five necessary criteria for solution cave development. These maps do not incorporate the other criteria, nor do they incorporate the processes necessary for cave development of the other seven cave types.There are 85 physiographic sections within the 48 contiguous United States. Section boundaries are based upon similar geology and geomorphic processes. Since these are critical components of cave-development, physiographic sections were found to form usable boundaries for mapping cave-forming processes. This national, regional, and landscape-scale approach proves useful in understanding local cave-forming processes and why caves occur where they do, assessing the dominant limiting factors in cave development, as well as providing a more analytical and systematic framework for karst researchers working on a regional or national scale.

Introduction

Terms utilized to describe caves are often based upon landscape morphologic and/or anthropomorphic features. The emphasis is on form, not function. Since various processes can produce landscapes with similar appearances, this has led to a diverse, complex, haphazard, and sometimes confusing lexicon. Similarly, most cave classification systems focus upon management of caves as a recreation resource, or rank the hazards they pose to the visiting public. Many other scientific disciplines have taken a more scientific-based, process-oriented approach to classification. A similar approach for caves would aid analyses, cave assessments, the development of protection strategies, and the development of protection and restoration priorities.

Various researchers have produced national cave or karst distribution maps. However, these maps primarily depict the presence of carbonate rocks. The presence of suitable lithology is only one of five necessary criteria for solution cave development. These maps do not incorporate the other criteria nor do they incorporate the processes necessary for cave development of the other seven cave types.

This paper is a summary of the on-going effort by the author in the development of a process-oriented classification system and national map of these processes. This goal is that one may better able to recognize and assess the active cave-forming processes within any given area within the United States.

Cave Types

A diverse array of names is in common usage to describe cave types. However, many of these names refer to morphologic features and not any speleogenetic process. There are times however, where similar processes can form widely divergent landscape features, especially under different environmental conditions (Daoxian and Zaihua, 1998). Conversely, widely divergent processes can form similar looking landscape features. As such, confusing terminology results. For instance, the term "pseudokarst" has been used to describe landscape features in situations where processes not even remotely similar or analogous to karst processes were involved in their formation. It is confusing and imprecise to use terminology that implies otherwise.

In pursuit of an understanding of current geomorphic processes affecting a cave's ecosystem, it is imperative that we understand the processes affecting the landscape during the initial creation of the cave. As in many other efforts, it is perhaps easier to understand complex and interrelated processes by breaking these parts into isolated components. In the case with caves, what were the processes that created the cave in the first place? Since a cave is in essence a hole, what created the hole? Was there something there originally? Many caves were formed after the original host material (rock, for example) was formed. Space that had once been occupied by solid matrix was changed or altered in a manner that locally and/or preferentially removed material leaving a void in its place. An important aspect of cave geomorphology is the assessment and evaluation of the processes that could have removed or altered this solid material. At the most basic level, caves may be formed either as primary features where the cave is formed at the time that the host rock is formed (for example a lava tube), or as a secondary features where a portion of the solid material was removed (Daoxian, 1991).

There are two types of primary caves: those formed by the cooling of molten rock, and those formed by the growth and crystallization of soluble rock that forms a roof over an existing void. The majority of primary caves are formed in and around molten lava, hot ash, and other material that originated from volcanic eruptions.

Many of the better-known caves, such as Mammoth Cave and Carlsbad Cavern, were formed long after the surrounding host substrate (limestone) was deposited. The removal of the solid material necessary to form secondary caves is by either: (1) mechanical separation; (2) solid material going into, and then being removed by, solution; (3) melting of solid matrix, or (4) by the physical excavation by erosion or other processes.

However, there is another form of secondary cave, which is formed by the unique juxtaposition of discreet solid material that is arranged in a manner that creates a void. An example is large blocks of stone that have fallen from a cliff and arranged themselves at the foot of the cliff in a manner that the spaces in between the boulders form a cave and provide an uniquely discreet microclimate from surface environments. These caves are typically called talus caves. However, since "talus" refers to a rock size smaller than boulders and since "talus caves" form more commonly in boulder fields, the term "spatial cave" is used to be more precise.

The countless variety and diversity of cave types are all variations of these seven basic cave-forming mechanisms. As in many other aspects of the natural world, cave-forming processes operate along a continuum, not in discreet units. Of the many and diverse factors that affect cave development, whether climate, geology, or the like, they operate within the context of these seven basic cave-forming mechanisms in tandem, which result in the creation of the many diverse caves known to exist.

Based upon these seven processes, the author has identified eight processes-oriented cave types. These eight cave types are as follows:

1. Caves that are formed by the recrystallization of soluble rock over an edge, much like a frozen waterfall, whereas there is airspace between the main cliff edge and the recrystallized roof. This type of cave is very rare, however they have been found in certain travertine deposits, therefore are called "Mineralization Caves." Mineralization Caves are likely quite small, being formed by the chance occurrence of an air space sufficiently large between a small cliff and travertine deposits that has cascaded over the cliff edge.

2. Caves that are formed during the process of molten material changing from liquid to solid form are called "Solidification Caves." The term Solidification Cave refers to all type of caves formed by the cooling of lava, such as lava tubes, blister caves, gas injection caves, pressure ridge (Larson and Larson, 1993) caves, and the like. The term "lava cave" is more precise than the term "lava tube." Many solution caves display more "tube" like morphology than do "lava tubes." Additionally, some caves are formed during the cooling/solidification process by means other than the crusting over process common in "lava tubes." The term "lava cave" is more precise due to not describing only one particular form. However, some caves formed by the cooling/solidification proc-

ess are formed in ash and other non-lava material, therefore, the awkward but more appropriate "solidification cave" is used.

3. Caves that are formed by chemical processes that dissolve and relocate by solution the surrounding substrate are called "Solution Caves." Solution processes are involved in both solution and mineralization caves, however one is a primary process and the other is a secondary process.

4. Caves that are formed by wind, water, wave, and other erosional excavation processes are called "Erosion Caves."

5. Caves formed by air and/or water melting of glacial ice, firn, or permanent snowfields are called "Phasic Caves." Caves formed in glacial ice and solidification (lava) caves are in some ways created by similar processes, since they both involve the melting of solid material. However, one is a primary process and one is a secondary process.

6. caves formed by the unique juxtaposition of discreet blocks, boulders, or talus are called "Spatial Caves."

7. Caves formed by geologic stress, pressure, gravity, or other physical force which displaces two or more sections of surrounding substrate are called "Tectonic Caves."

8. Caves formed by the actual excavation by biologic organisms are called "Biologic Caves." This is similar to erosion caves, however the erosion agent for one is physical, while the other is biological.

A schematic model representing these cave types and the processes leading up to them is depicted in Figure 1.

Cave Geomorphic Classification System

Classification systems are common for a variety of resources, even for more specific aspects pertaining to karst (Chilinger *et al.*, 1967a and b). In an effort to develop a more systematic and resource-based classification system for caves, much can be learned from these other classification systems. For example, the National Wetland Inventory developed by the United States Fish and Wildlife Service. The National Wetland Inventory breaks wetlands into a series of systems, subsystems, classes, and subclasses, as well up to four modifiers. For instance, "Riverine" is one of five wetland systems. "Intermittent" is one of five subclasses of Riverine wetlands. "Unconsolidated Bottom" is one of eight

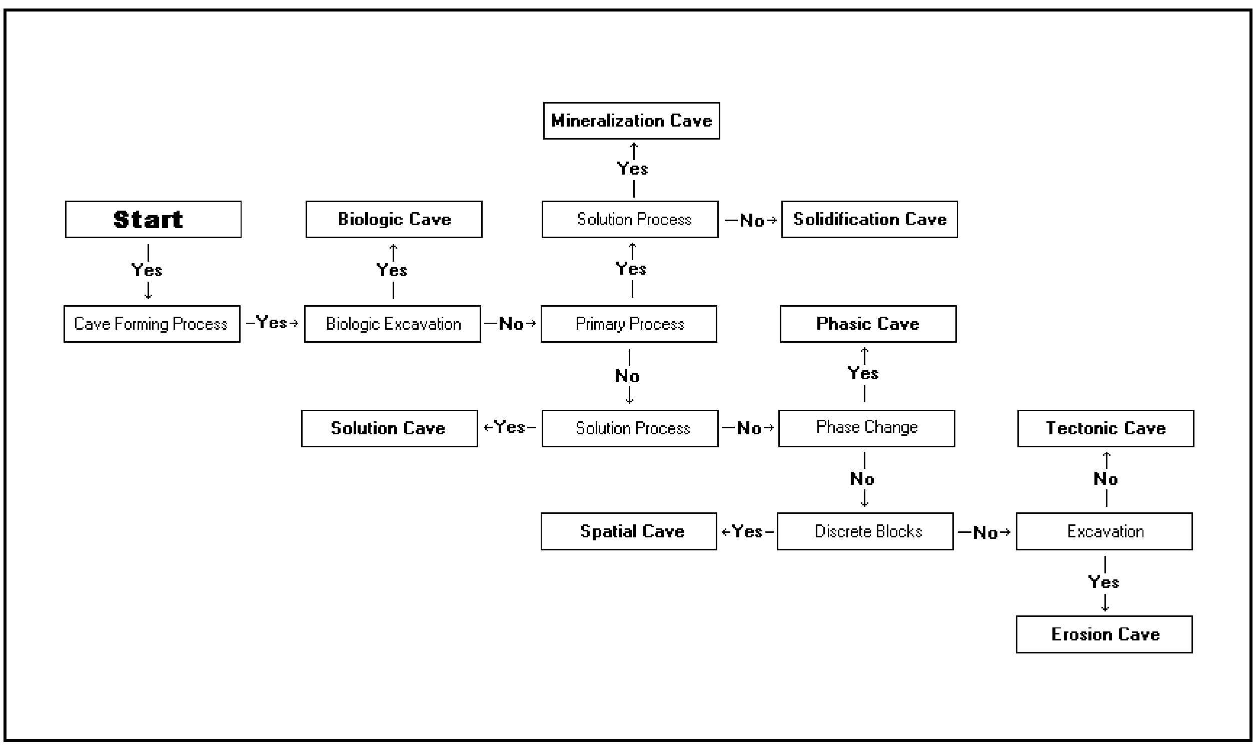

Figure 1. *Process-oriented cave types*

classes, and "mud" is one of four subclasses within the Unconsolidated Bottom class. Therefore, in this example, the wetland classification "R4UB3" wetland stands for:

```
System–Riverine (R)
  Subsystem–Intermittent (4)
     Class–Unconsolidated  Bottom
       (UB)
```

Subclass–Mud (3).

As mentioned earlier, there are up to four modifiers that could be used: Water Regime, Water Chemistry, Soil, and Special Modifiers. An example of a Water Regime modifier is "C–Seasonally Flooded." An example of a Water Chemistry modifier is "7I–Hyperhaline, alkaline." An example of a Soil modifier is "g–Organic." Lastly, an example of a Special Modifier is "h–Diked/Impounded." Therefore, if a wetland was determined to be a diked/impounded, seasonally flooded, intermittent riverine wetland with a muddy, unconsolidated bottom, it would be coded as "R4UB3Ch." Therefore, no matter what part of the country one is in, or whatever habitat one encounters, the same logical hierarchical wetland classification system is in place. Therefore, useful comparisons may be made between wetlands containing similar processes. Conversely, one would also be able to differentiate two nearby wetlands that may look alike, but in actuality may be quite different. If different processes are occurring in these two nearby wetlands, conducting an analysis of these two wetlands with the assumption that they are within the same population set may lead to disparate results.

A classification such as this would be equally useful for caves, based upon similar physiographic and genetic characteristics. For example, Worthington (1991) found that combining water chemistry data from different spring types, such as overflow and underflow, brings disparate results. However, upon separate classification and analysis, appropriate comparisons could be made and relevant trends observed.

A proposed classification system is as follows:

SYSTEM — I. Primary Process
SUBSYSTEM — A. Solidification
CLASS — 1. Solidification Caves
SUBCLASS — a) lava tubes

- I. Primary Process
  - A. Solidification
    - 1. Solidification Caves
      - a) lava tubes
      - b) casts
      - c) pressure
      - d) eruptive
  - B. Recrystalization
    - 1. Mineralization Caves
- II. Secondary Processes
  - A. Physical Movenent/Relocation of Matrix
    - 1. Spatial Caves
    - 2. Tectonic Caves
      - a) gravity slip
      - b) gravity joint
      - c) fault
      - d) expansion
  - B. Excavation
    - 1. Erosion Caves
      - a) littoral
      - b) aeolian
      - c) frost wedging
      - d) crumbling
      - e) suffosion
    - 2. Phasic Caves
      - a) normal heat exchange
      - b) external heat
    - 3. Solution Caves
      - a. dissociation
      - b. carbonic acid dissolution
      - c. sulfuric acid dissolution
      - d. other acid dissolution

Modifiers

A. Matrix

1. Salt	8. Sandstone
2. Gypsum/Anhydrate	9. Other Sedimentary
3. Limestone	10. Basalt
4. Dolostone	11. Plutonic
5. Marble	12. Other Igneous
6. Coral Reef	13. Other Metamorphic
7. Other Solutional	

B. Climate

1. Arctic	5. Temperate
2. Alpine	6. Subtropical
3. Arid	7. Tropical
4. Subarid	

C. Setting
   1. Terrestrial
   2. Carbonate Island/Sea Coast
   3. Marine

D. Water Temperature
   1. Natural/Environmental
   2. Thermal

E. Activity
   1. Speleogenesis Process Active
   2. Speleogenesis Process Relic
   3. Both Active and Relic components

F. Structure
   1. Bedding Plane Parting Dominated System
      a. strike dominated
      b. dip dominated
      c. complex/combination dominated
   2. Joint/Fracture Dominated System
      a. strike dominated
      b. dip dominated
      c. complex/combination dominated
   3. Intergranular Dominated System (Palmer, 1991)
   4. Complex/Combination/Other Dominated System

G. Hydraulics
   1. Vadose Dominated System
   2. Phreatic Dominated System
   3. Complex/Combination/Other Dominated System

Cave Geomorphic Mapping

The mapping of current cave-forming processes within the United States will not completely depict the distribution of all caves, since many caves are residual features of former and relic processes. However, to map even the current cave-forming processes, one must break these processes into individual components. For instance, five separate processes are required for solution caves to form: suitable lithology, solvent, gradient, structure, and time. Lithology refers to rocks such as limestone that are soluble enough in relatively weak acids to form caves, yet not too soluble that surface processes do not erode the entire rock away before the cave has time to develop. Solvent refers to a naturally-occurring acid such as carbonic acid that is strong enough to dissolve rocks, yet abundant enough to play a significant role in cave development. A gradient is necessary to carry saturated water away from freshly dissolved rock so that fresh acid may take its place for further dissolution. Structure—such as bedding plane partings, faults, joints, or fractures—are necessary to allow the solvent to penetrate and dissolve caves within the interior of a rock rather than just lower surface exposures (Jakucs, 1977). Structure is also important in the development of preferred flow paths that lead towards conduit/cave development (Sasowsky, 1999). Time is needed, since the majority of naturally occurring solvents are weak enough that they may take thousands or

Figure 2. The Components Necessary for Cave Development

Cave Requisites/ Cave Type	Solution	Erosional	Spatial	Phasic	Solidification	Tectonic
Lithology	✓	4	4	4	4	
Solvent	4			4		
Gradient	4	4	4	4	4	
Structure	4	4	4			4
Time	4	4	4	4		4
Erosive Agent		4	4			
Topography			4		4	
Temperature Gradient				4	4	
Heat					4	
Force						4

tens of thousands of years to form a cave (White, 1988; Daoxian and Zaihua, 1998).

There are four necessary components for the development of a solidification cave: suitable lithology, gradient, topography, and a heat source. The requirements for a suitable lithology are the proper chemical constituents of the molten rock, suitable temperature, and proper viscosity (Peterson and Tilling, 1980). For instance, lava tubes appear to form more commonly within lavas with the proper temperature, viscosity, and chemical composition, such as calc-alkaline basaltic lavas (Mertzman, 1977) with an alkali-lime index between 55 and 61 (Clynne, 1999; Anderson, 1941). These lavas need an elevation gradient so that they may flow down slope and they require a suitable environment that would enable them to lose temperature and degas, thus beginning the solidification process.

Each one of the eight cave types requires its own unique components for cave development. These various factors are summarized in Figure 2. If only one of these components stops, cave development will cease. For instance, why are there not many caves in southern Florida? Suitable rock, such as limestone, is abundant. Similarly, abundant rainfall and carbon dioxide exist to form a suitable solvent. There are enough bedding plane partings and joints to serve as suitable geologic structure. The combination of the limestone, carbon dioxide, rainfall, and structure have been around long enough (time) for caves to develop (Ford and Williams, 1989). Upon closer look, one notices that the flat and low-lying limestone surface shows solution features (Mylroie and Vacher, 1999). However, the limestone is being dissolved and recrystallized in nearly the same place, for the saturated water often has no place to go. In this situation, a suitable gradient is the critical missing factor. If there were to be a small uplift, or if the sea level dropped, there would become a point in which all the factors necessary for solution cave development would occur simultaneously, thereby solution cave development would commence. Attempting to figure out which are the active cave-forming processing going on in a particular area, and which critical factor(s) are missing, is fundamental in understanding cave geomorphology and for the proper management of cave ecosystems. Such a thought process could be termed the "Concept of Limiting Factors."

In order to map the current cave-forming processes it would be necessary to map the necessary components of cave development. Preferably, this mapping should be conducted in as quantifiable means as possible. Each area of the country could be assigned points for the suitability of its lithology, solvent, gradient, structure, and time. These points could be tabulated and the results mapped. Such a map would depict the relative abundance of active solution cave-forming processes within the United States. More accurately, the map would represent the relative probability and distribution of active solution cave-forming processes. Such a map could be used in research, land management, and hazard management. It could also be used by land managers to understand the processes occurring within areas they manage so that they may better ensure that activities that they permit or oversee do not unknowingly impact these natural physical and biological processes.

In order to produce a map such as this would require the selection of the proper map unit

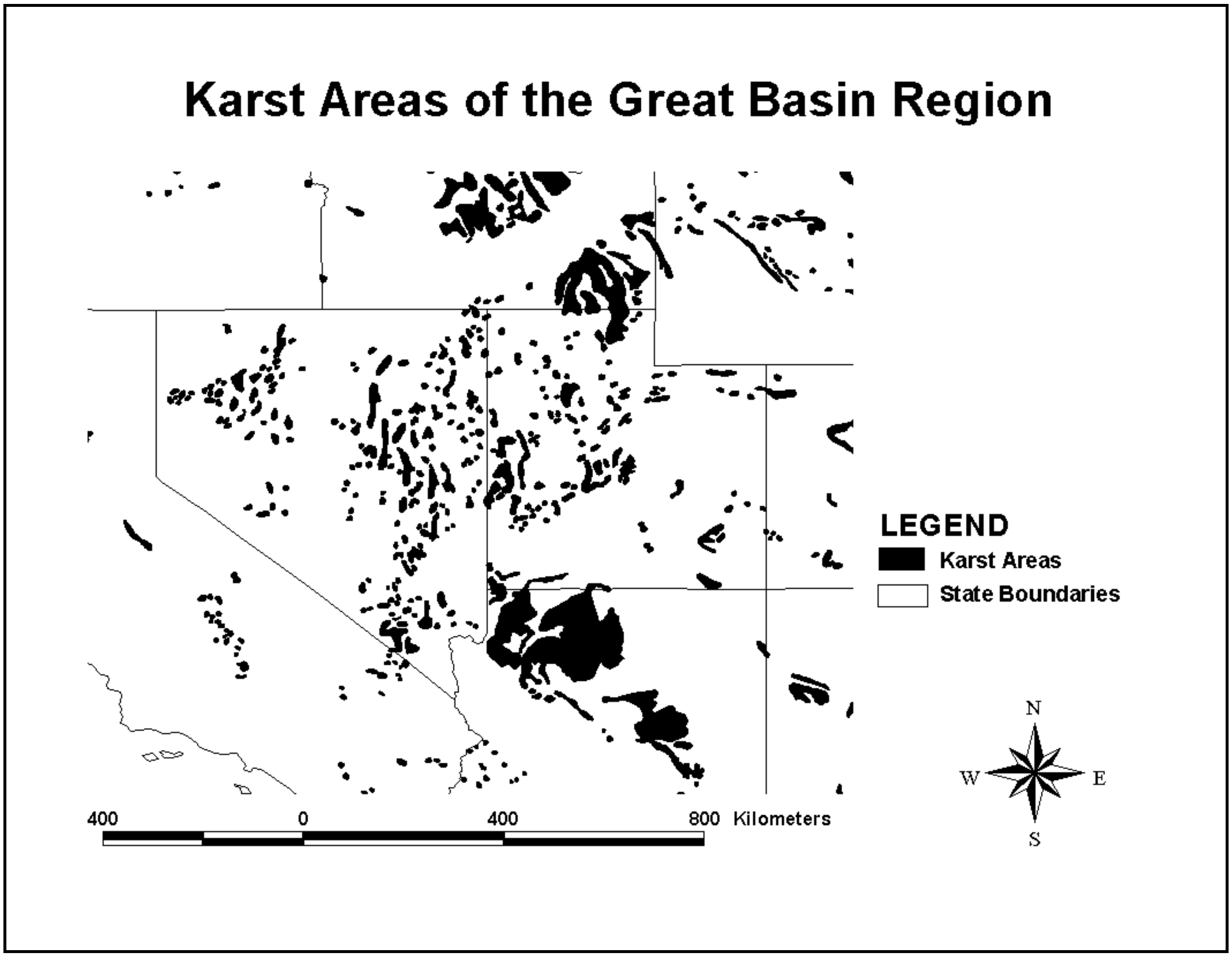

Figure 3

and scale. Units that are too large would not have sufficient detail to be useable. Conversely, units that are too small and detailed would be too cumbersome and one would lose within the detail the local and regional trends that would be necessary to understand important relationships.

To aid in this effort, the author digitized the soluble rocks depicted in the Engineering Atlas of Karst map (Davies *et al.*, 1984) included in the National Atlas. This map aided this effort, but was not utilized to represent the location of soluble rocks due to three limitations: accuracy, the loss of trends and commonalties, and differences in cave-bearing potential between individual rock units. As for accuracy, this map is useful, but it needs updating. The trends and commonalties issue is represented by the author's digitized version of the Great Basin Province portion of Davies' map (Figure 3). As shown in Figure 3, the cluster of the numerous carbonate rock units throughout eastern and northwestern Nevada shows a clear relationship between the individual rock units. This relationship between adjacent rock units indicates a grouping/clustering within the region that is not represented by showing only the individual components. Lastly, the connection between a large carbonate unit may physically exist, however differences in climate, elevation, soil cover, slope, and aspect, as well as numerous other factors may make one portion of the carbonate rock behave much differently than another portion of the same rock unit in regard to cave-forming potential. Due to these limitations, as well as needing a base map that transcends all the necessary components needed for all cave types, a different approach is needed to serve as the basemap.

There are 85 physiographic sections and 24 provinces (Figure 4) within the 48 contiguous United States (Fenneman, 1928a, 1928b, and 1931). Fenneman and McNab and Avers (1994), developed these 85 section boundaries based upon similar geology and geomorphic processes. Since cave development is also depended upon geology and geomorphic processes, it follows that these sections may be used

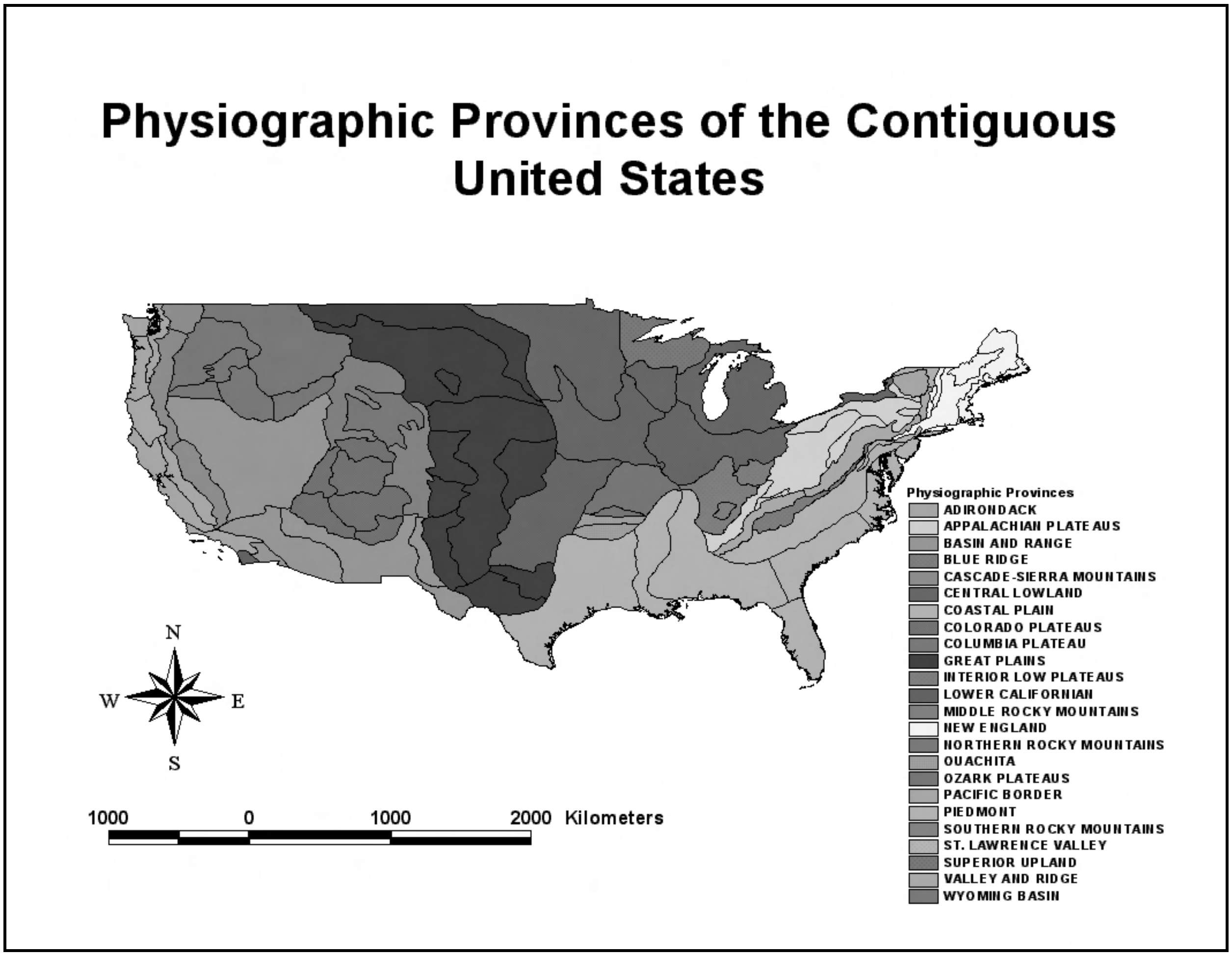

Figure 4

to describe and summarize current cave forming processes within the United States. If one could quantify the amount, degree, and distribution of cave-forming processes, then a map could be developed that would provide a good representation of the actual potential or likelihood of caves being formed within each particular section.

This national, regional, and landscape-scale approach proves useful in understanding local cave-forming processes and why caves occur where they do, in assessing the dominant limiting factors in cave development, as well as providing a more analytical and systematic framework for karst researchers working on a regional or national scale.

Therefore, to produce a solution cave "potential" map; it would be necessary to assign lithology, solvent, gradient, structure, and time values for every map unit within the United States. Ideally, these values would then be weighted depending upon the relative importance each value played in the development of solution caves. Based upon these combined attributes, a map could then be produced. For the lithology component, it is important to assess the regional trends and not just the exact occurrences of soluble rock types. For instance, if there were a small body of limestone in a given area, it would be relevant to know if this is a rare occurrence or is most of the region made up of hundreds of these scattered but widely distributed small soluble rock units. Each of the 85 sections were ranked "high," "medium," or "low" probability of containing suitable rocks for solution cave development. These values were assigned by investigating available literature for references of having exposed soluble rocks present.

Suitable solvent was mapped using national precipitation Geographic Information System maps.

Areas of known active cave systems were plotted along with mean precipitation data. This was conducted to assess where the threshold precipitation values are located, and where

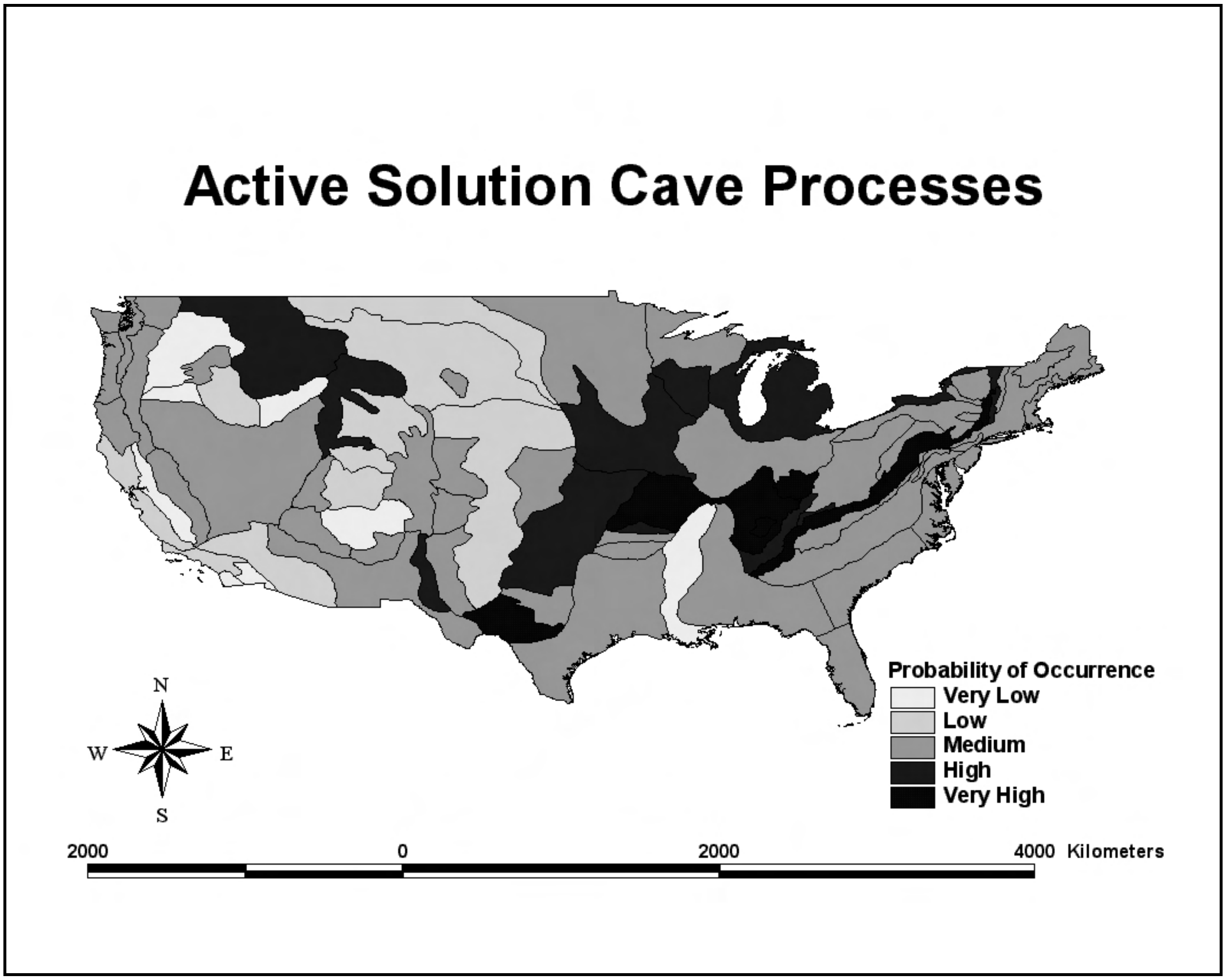

Figure 5

precipitation no longer becomes a limiting factor for solution cave development. Recognizing that it is highly variable, based upon allogenic versus autogenic recharge, form and duration of precipitation, size of basin, and the like, preliminary analysis has indicated that an upper threshold of total precipitation is approximately 0.5 meters (20 inches) per annum. Based upon these variables, the lower threshold appears to be approximately 0.4 meters (17 inches) per annum. Within the solution cave matrix, physiographic sections containing mostly 0.5 meters or more of precipitation were assigned a "High" value. Areas with 0.4 to 0.5 meters of precipitation were assigned a "Medium" value. Those areas with less than 0.4 meters of precipitation were assigned a "Low" value. Areas assigned a "Low" rating could still produce solution caves, however its potential is limited. Similarly, areas with a "Medium" rating could still produce solution caves; however, the conditions suitable for their development would typically be more scattered. Areas with a "High" rating were found not limited with regard to precipitation.

The completion of the matrix for gradient, structure and time was much more subjective and much less variable. Only five sections were given a rating that reflected limitations for gradient, three for structure, and four time. More refined, accurate, and quantifiable technique needs to be developed in the future for these elements.

Currently, no weights were applied to any of the factors in the matrix. This would be needed for future updates and refinements; however, not enough is currently known to appropriately assign weights. Which is more important, suitable structure or suitable gradient, and by how much? Until these questions can be answered, each factor was given equal weight. The totals were summed and these sums were mapped depicting the probability of active solution cave processes occurring within the 48 contiguous states (Figure 5).

Similarly, a map could be produced that is a combination of all the cave-forming processes occurring within each section. In essence, such a map would be a combination of the following:

- a carbonate distribution map;
- an evaporate distribution map;
- a spatial cave distribution map;
- a tectonic cave distribution map;
- an erosion cave distribution map;
- a phasic cave distribution map;
- a solidification cave distribution map;

This would then be a complete and summarized depiction of all current cave-forming processes operating within the United States.

Conclusion

Future improvements in this project could involve the following:

- Replace the 85 physiographic sections as the basemap with the more refined and numerous state-level physiographic sections or perhaps replace or combine this with cluster analysis or other similar spatial statistical analysis technique to more accurately identify regional trends and commonalties;
- update and refine a national map of soluble rocks to use to depict the presence of cave-forming soluble rocks. This would need to be carefully attributed to reflect the many geomorphic aspects affecting the rock's solubility;
- develop a reliable means of quantifying geologic structure, gradient, and time in regards to cave-forming potential.
- develop a reliable means of quantifying the various factors for all cave types;
- develop a reliable means of weighting factors within each cave type;
- develop a reliable means of weighting factors among cave types so that maps could be made that reflect the total combined cave potential within the United States for all cave types;
- and lastly, integrate the process-oriented cave classification system with the process-oriented cave map.

It is not only important to look at geomorphic processes from a landscape or regional scale, it is also important to assess them in relation to other processes operating in the same areas. Looking at a map of karst regions of the United States does little to explain the other processes operating in the same areas. Additionally, it does little to explain or describe the cave-forming processes operating within the blank areas on the map. The logical next step is a shift towards a more comprehensive and system-wide approach.

Another benefit of taking a comprehensive approach is it is perhaps easier to appreciate the wide diversity of cave-forming processes that are acting upon the landscape. Cave-forming processes are of course not disjunct from other processes operating upon the landscape. Processes that form a cave in one environment may form a mountain, rock spire, river, canyon, plateau, dune, or soil layer in another. Researchers must be aware of the similarities and dissimilarities of the processes within their study area. At the same time, managers must understand processes within their administrative unit in order to properly manage landscapes without unintended consequences. By classifying and mapping the processes one is better able to understand, study, and manage these processes.

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Interagency Cooperative Sinkhole Protection and Karst Remediation in Virginia

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Abstract

Federal, state, and private cost share programs fund sinkhole clean outs and other karst protection work in Virginia. The Virginia Karst Program—in the Virginia Department of Conservation and Recreation's Division of Natural Heritage—commonly acts as project coordinator and liaison between landowners, contractors, volunteers, and funding entities. The Karst Program also provides tools for assessing sinkhole dumps, prioritizing sinkholes for remediation, and executing projects in a low-impact manner. Sinkholes are prioritized based on degree of degradation, hydrological function, biological significance, and use as water supplies. The United States Fish and Wildlife Service's Partners for Fish and Wildlife Program funds habitat restoration for species listed under the Endangered Species Act. The U.S. Department of Agriculture's Natural Resources Conservation Service manages the Wildlife Habitat Incentive Program and the Environmental Quality Incentive Program to improve the quality of wildlife habitat and encourage beneficial conservation practices by landowners. The Conservation Reserve Enhancement Program and Virginia Agricultural Best Management Practices, administered by Natural Resources Conservation Service and local Soil and Water Conservation Districts are joint Federal–State land retirement conservation programs that apply to lands currently under active agricultural use. The Cave Conservancy of the Virginias sometimes funds sinkhole clean-outs in significant cave and karst areas. These programs can pay up to 75 percent of project expenses and some provide additional tax credit and land rental incentives. Landowner and volunteer labor and materials commonly serve as in-kind match to meet cost share requirements. Management agreements, typically 10 to 15 years in duration, accompany most projects.

Summary

Virginia's karstlands are found along the valley and ridge province extending from Frederick County in northern Virginia to Lee County in the far southwestern part of the state. More than 3,300 caves are found in Virginia, some containing globally significant biota adding to Virginia's biodiversity. Karst landscapes in Virginia and elsewhere suffer from many years of sinkhole dumping and other improper management practices. Landowners commonly water their livestock in streams flowing directly into karst aquifers. Sinkhole dumping often results in pollution of groundwater in karst terrains. These actions may lead to destruction of the critical habitats of the troglobitic and stygobitic organisms inhabiting caves. The Virginia Karst Program, a part of the Virginia Department of Conservation and Recreation's Division of Natural Heritage is working to correct some of these problems by using a variety of federal, state, and private cost share and grant programs.

A number of tools are used to identify karst features in need of attention. A sinkhole classification scheme and sinkhole dump assessment form and associated training is being developed to enable conservation professionals with little background in karst to work effectively to protect karst resources. A sinkhole clean out procedures guide is used to ensure proper attention is paid to engineering procedures, safety, and business arrangements with contractors and landowners. It is important to prequalify excavation contractors used for karst remediation work. Contractors are often chosen based on a low bid, but differences in equipment and experience should be taken into account. Any contractor must demonstrate compliance with state contractor licensing and insurance requirements. Agreements should stipulate payment be made only for work performed. A typical clean out involves removal of trash and other debris from the sinkhole and the proper disposal of materials at a landfill or recycling center. Measures to stabilize the sinkhole's land surface and the establishment of an appropriate ground cover with native plants are usually preferred. Sinkholes are often fenced to exclude livestock and casual visitors.

The Division of Natural Heritage Karst Program staff manages sinkhole clean outs using external funding sources. Volunteer assistance and the cooperation of local government organizations are also important elements for the success of the program. Expenses associated with sinkhole clean outs include costs of heavy equipment and hauling, landfill tipping fees, and supplies such as erosion control materials and fencing. Priority of sinkhole projects is based on the presence of natural heritage resources including state or federally listed species, the sensitivity of the sinkhole to environmental damage, and the nature of the refuse present in the sinkhole.

The Cave Conservancy of the Virginias is a private nonprofit conservation organization that funds some of the sinkhole clean out work administered by the Virginia Division of Natural Heritage Karst Program. A large sinkhole clean out project in Rockbridge County during the spring of 2000 known affectionately as "the Sinkhole from Hell" was performed using Cave Conservancy of the Virginias funds. The "Sinkhole from Hell" project removed 500 tires, kitchen appliances, and vehicles from the site with the assistance of 20 volunteers from the Virginia Region of the National Speleological Society. Another clean out project funded by Cave Conservancy of the Virginias during the fall of 2001 was the Neel Sinkhole clean out in Giles County. The Neel Sinkhole clean out removed more than 15 tons of debris including an old house trailer that had directly discharged sewage next to the sinkhole. Numerous tires and several old batteries were also removed from the site. The Neel Sinkhole project was accomplished with help from 35 volunteers and workers including many members of the VPI Cave Club. The Giles County Public Works Department provided a backhoe and operator for the project.

The United States Fish and Wildlife Service plays an active role in karst protection in Virginia. The Partners for Wildlife Program, administered by U.S. Fish and Wildlife Service with some technical assistance from the Division of Natural Heritage, has funded bat friendly cave gates, cave and sinkhole clean outs, and sinkhole fencing projects. During fiscal year 2001 the U.S. Fish and Wildlife Service spent approximately $43,000 on Upper Tennessee River Karst Projects (personal communication with Gale Heffinger of USFWS). Landowners who participate in the Partners for Wildlife Program must sign a contract agreeing to cease all dumping and adopt certain specified management practices for a defined period of time, usually ten years. Agreements of this nature are typical of most cost share programs. The Partners for Wildlife Program is unique in that the federal money can cover from 75% to 90% of the cost of a project (and sometimes 100%). This program is concerned with increasing habitat for federally listed species.

Several sinkhole clean out projects in Virginia have been accomplished using U.S. Fish and Wildlife Service Partners for Wildlife funds. A large amount of coal ash and garbage was removed from a sinkhole near Rye Cove High School in Scott County. Rye Cove is designated as one of Virginia's Significant Karst Areas. The educational value of having a high profile project near a school provided an added bonus. In other projects Tipton Sinkhole in Scott County and Bull Cave in Lee County were both cleaned out and erosion and sedimentation control measures installed using U.S. Fish and Wildlife Service money. The Tipton Sinkhole contained an estimated 75 tons of debris. The sinkhole at Bull Cave contained approximately 500 tires and 20 to 30 tons of other debris. Both Bull Cave and Tipton Sinkhole contain the Lee County cave isopod *Lirceus usdagalun*, and Tipton Sinkhole contains the Rye Cove cave isopod *Lirceus culveri*. These projects will help to restore the quality of the groundwater in karst aquifers and provide habitat protection for associated cave biota.

The Conservation Reserve Enhancement Program is funded through the federal farm bill. The Program is administered jointly by the Virginia Department of Conservation and Recreation and the Natural Resources Conservation Service through the Soil and Water Conservation District Offices. The Conservation Reserve Enhancement Program program seeks to protect water quality and to improve wildlife habitat by establishing a cost-sharing program with landowners to install and restore vegetated buffers around streams. The Conservation Reserve Enhancement Program targets croplands and marginal pasturelands. The Program may be used to establish a buffer around a sinkhole if the sinkhole is receiving a perennial stream or is a significant groundwater recharge location. Various Soil and Water Conservation District professionals sometimes interpret the rules for the Conservation Reserve Enhancement Program differently. The program provides a 50% federal cost share for establishing forested riparian buffers, filter strips, and wetland restorations meeting minimum Natural Resources Conservation Service standards paying up to $200 per acre to implement the practice. An additional 25% toward reimbursable costs may be eligible through the state if certain criteria are met. The Conservation Reserve Enhancement Program requires a landowner to sign either a ten or fifteen year contract with an annual rental payment to the landowner of up to $100 per acre per year. One provision from the state of Virginia with Conservation Reserve Enhancement Program lands offers to pay an additional $500 per acre after installing conservation practices for recording a permanent open space easement to protect the buffer in perpetuity (personal communications with Gary Moore, Manager of the Division of Conservation and Recreation Conservation Reserve Enhancement Program).

Other cost share programs can potentially be used for conservation work in karst areas. The Environmental Quality Incentive Program is administered by the Natural Resources Conservation Service. The Environmental Quality Incentive Program is a cost share program targeted to "priority areas" identified by the federal government or by the state. Similar in some ways to the Conservation Reserve Enhancement Program, "priority areas" tend to be in the watersheds of impaired streams or streams exceeding their total daily maximum load limits.

The Wildlife Habitat Incentives Program is another program administered by the Natural Resources Conservation Service. The Wildlife Habitat Incentives Program is a cost share program to help private landowners to install practices to improve wildlife habitat. This program provides a 75% cost share program to install practices with a $10,000 maximum cost share per applicant with a ten-year contract and maintenance agreement. The Wildlife Habitat Incentives Program has a continuous sign-up period; Program sign-ups are for a particular period of time. The complexities of all the cost share programs require applicants to maintain close coordination with the appropriate agencies in order to become successfully enrolled and meet sign-up deadlines.

In Virginia an exciting option is being proposed for an existing cost share program. The Virginia Best Management Practices Program is studying a proposal by the state's cost share Advisory Committee to include some funding for sinkhole clean outs as part of the state Best Management Practices. The proposed cost share would pay 75% toward a given project with the maximum state contribution set at $2,500. Volunteer labor contributions and in kind supplies and labor provided by the landowner typically count toward the landowner's cost share contribution. The proposed sinkhole clean-out Best Management Practice will hopefully provide Virginians with a powerful tool for karst protection.

The Virginia Department of Conservation and Recreation and the Natural Resource Conservation Service are both adopting sinkhole protection standards for use in Virginia. Priority for remediation work would be given to sinkholes actively taking water from perennial streams, intermittent streams, or other channeled flow. Sinkholes containing an obvious opening into the subsurface or with exposed bedrock in the sinkhole would be good candidates for protection. Steep internal slopes (30°) or soil slumps exposed in the side or bottom of a sinkhole would rank highly as well. Protection practices would include establishing natural vegetation buffers around sinkholes accompanied by installation of soil erosion and sedimentation control measures as required. The previous Natural Resources Conservation Service sinkhole practices were based on a standard developed in Pennsylvania that involved the filling of sinkholes with graded stone filters. Discussions between Natural Resources Conservation Service representatives and Virginia Karst Program staff recently led the Natural Resources Conservation Service in Virginia to actively discourage the filling of sinkholes except in rare and extreme cases. It should be emphasized that documentation of any filled sinkholes is critically important. A "paper trail" such as a deed book record should serve constructive notice to future potential landowners that a risk for subsidence exists at a defined location. The Natural Resources Conservation Service staff is working with the Virginia Karst Program to develop the new standard.

Karst landscapes are a fragile and valuable part of our natural heritage and deserve protection. Karst aquifers provide 75% of the drinking water supply for 27 of Virginia's western counties. Much can be accomplished by using existing state and federal programs for karst projects. The task ahead is so large that environmental professionals with little experience in karst will be called upon to do much of the protection work. Educating these same professionals about karst protection issues and

Towards a Comprehensive Sinkhole Classification Scheme for Land Use Planning

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Abstract

As awareness of karst grows throughout Virginia's land use planning community, the need has arisen for tools to assist planners in evaluating and ranking karst features. A classification scheme for sinkholes is one such tool. Concern over impacts to and from sinkholes exists in a variety of arenas including nutrient management, storm water management, highway and utility corridor construction, on-site waste disposal, wildlife habitat protection, and stream protection. In many counties, development is practically restricted to karst areas and planners need to prioritize most sensitive karst features for protection. Furthermore, as cost-share programs increasingly address karst issues, it is critical that agencies expend these limited funds where they can do the most good. The Sinkhole Classification Scheme under development by Virginia Karst Program staff rates the environmental significance of sinkholes using six intrinsic and three extrinsic factors. Intrinsic factors are (1) connection to surface hydrology (larger watersheds and channeled drainages are worse), (2) shape of sinkhole (sensitivity increases with slope), (3) morphology of the sink bottom (openings or secondary collapses are red flags), (4) degree of vegetation (lack of vegetation is problematic), (5) exposure of subsurface material (exposure of soil indicates active erosion; bedrock exposure may provide a direct connection to groundwater), and (6) drainage (permeability) of sinkhole. Extrinsic properties are (1) proximity and geometric relationship to other sinkholes (sinkholes in belts reflect major subsurface conduits), (2) biological significance (sinkholes near rare, threatened, or endangered species prioritized), and (3) relationship to drinking water supplies (sinkholes connected to drinking water supplies are prioritized).

Apokryptic (Concealed) Karst—A Problem for Resource Management and Rurban Development in Southern Arizona

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Abstract

Historically, potential cave-bearing limestones have been seen to have such limited and xeric exposures in the Sonoran Desert life zone of southern Arizona that little thought or effort has been directed towards determining the actual extent or state of karst development within these "exotic" blocks. Consequently, these same terrains have also been of little concern for either the resource managers of agency lands or the developers of rurban "estates" at the burgeoning urban fringe. However, over the past decade, geological and biological observations in the area of Colossal Cave Mountain Park in eastern Pima County, Arizona, and other sites in the region have begun to reveal some of the details concerning the presence of an undescribed biome hidden at depth within a presently active karst zone of unknown extent. This is an "apokryptic" (a new term from the Greek *apokryphos* – hidden, concealed, obscure) form of karst created by complex geological relationships involving faults, lithologies, aquatards, debris fans, pediments, and more. This karst phenomenon apparently develops over greatly protracted periods of time and operates with such a low frequency of "active" surface events that it has escaped detection until the present. Because of their concealed nature, such apokryptic karst areas may be prone to future conflicts arising between adjacent land owners over water supply or pollution issues or with resource managers over underground habitats.

Evidence of Paleoseismicity in the Caves of Arizona and New Mexico (USA)

(Originally published in Academy of Sciences, Paris, France, 1999, Académie des sciences/Elsevice, Paris)

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Abstract

Several caves were visited in different parts of the western USA to observe speleothems that could have been affected by ancient earthquakes. In Arizona, it seems possible to find evidence of the 1887 Sonora, Mexico, earthquake in Sutherland Peak Cave. In New Mexico, caves in the Guadalupe Mountains contain broken speleothems showing evidence of at least one old unknown earthquake.

Karst Groundwater Model Demonstration

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Abstract

This is a presentation using a groundwater model to simulate the movement of water and various pollutants from the surface through karst to caves, movement through soils to aquifers, and the resulting effect as these waters are retrieved for various uses. After a brief introduction to groundwater and its importance the remainder of this presentation provides instructions for use and maintenance of the model, concepts the model can demonstrate, and the mechanics of a demonstration. The level of information for the would-be presenter can be adjusted from basic to very technical. This presentation will focus on the basics of "how-to" utilize the model in a presentation designed to educate, inform, and enlighten your intended audience on any or all aspects of ground or surface water and its impact on karst, caves, aquifers, and the like. Topics covered will be: (1) "Target your Audience," (2) "Mechanics of Presentation," (3) "Materials List," (4) "Handouts," (5) "Using your Mistakes to your Advantage," (6) "Question and Answer Period."

Introduction

This presentation is a basic "How-To" guide for presentations using a groundwater model exhibiting loam vs. karstic soils and observation of the movement of surface water through these soils. Following an introduction to groundwater and the importance of hydrology to caves, the remainder of this presentation provides instructions for the use and maintenance of the model, concepts the model can best demonstrate, and the mechanics of a demonstration.

Definition

groundwater: The simplest definition is that groundwater is water contained in saturated soil and rock materials below the surface of the earth. groundwater is not "new" water; it is "recycled" water that is related to all other water on earth by a process known as the hydrologic cycle.

The source of groundwater is precipitation. As moisture falls upon the earth's surface, a portion runs off the land into lakes, streams, rivers, and other reservoirs and a portion soaks into the ground. That portion travels through several zones. It first travels through an unsaturated zone consisting of soil materials or layers of sand and gravel. Below this zone is the saturated zone called groundwater.

Discussion

The groundwater model simulates movement of water and various pollutants from the surface through karst to caves versus the movement of water and pollutants through soils and gravel to an aquifer (stored water). Eastern caves provide up to 80% of water for human usage in both urban and suburban areas. While western caves provide much less, there are many caves providing water for private use and for communities. Therefore, it is apparent we must educate the public on the careful conservation of this most valuable of resources as well as the protection of people.

YOU ARE WHAT YOU DRINK . . . springs, wells, and caves are the most common water sources. It is rare to drink water that does not go through a cave system. Water contains minerals as well as pollutants. *Surface* pollutants can be observed almost immediately, that is, rain water runoff from pavement, hillsides, buildings, and also from sewer drains. *Sub-surface* pollutants might take months and, in some cases, years to observe pollutants at the subsurface. A few ways to observe the degree of pollution is from observation wells and caves. Karst and cave hydrology is becoming increasingly important as gauges to determine levels of pollutants in our water supply.

The groundwater model demonstrates pollutants traveling from the surface and is a dramatic "eye-opener" for the general populace. Most people, no matter their age, have never heard the term "karst" and have never thought about drinking water coming from a cave. This model creates a wonderful opportunity to educate, inform, and demonstrate the importance of clean water to them and to our caves.

Mechanics of the Model Presentation

1. Target your audience: know your audience, be it children, teachers, or professional hydrologists this model and presentation can be geared toward that audience. Set your goal and adjust the style of the presentation. Ask questions and wait for answers.

2. Cover your model while using visual aides, (slide show, video, and the like) and while discussing your subject. Your audience will be fascinated by the model and its impact should be reserved for your "grand finale."

3. Use of slides and/or video with your presentation is very effective. They are readily available for purchase or rent from Project Underground, the city or county water department, or the like.

4. Use posters showing caves, karst, and the water cycle. These may also be obtained from various sources such as, American Cave Conservation Association, Project Underground, National Speleological Society, Cave Softly, or government agencies, to name a few.

5. Materials needed vary from food coloring, towels, syringes, containers, buckets, and pitchers, depending on your objective and audience. Experiment with more than one color of food dyes to represent different types of pollutants. You might consider using a darker shade of food dye if your audience is large so that it can better be seen; however, keep in mind this technique requires more cleaning time.

6. Handouts are always informative and educational and are something your audience may take with them to refresh them on the information you have given and may also be obtained from the above sources.

7. Involve your audience . . . use volunteers where possible. Example: have several people on hand to pump water from your model as you speak. Show and explain the action taking place.

8. Use your mistakes to your advantage. Many, many "unknowns" occur in our environment. Example: red groundwater in the loamy soil section of the model has leached into your green cave/karst section and it looks brown? Great! No problem! This occurs in nature. Use your "accident" to your advantage to explain this to your audience.

9. Clean-up is very important. Flush the model numerous times until all traces of food coloring are gone and water runs clear.

10. Have a question and answer period. You will be asked questions during the demonstration; however, ask that questions be reserved until the end of the presentation.

This will end the presentation. It is very effective and educational. Protecting the quality of our water is becoming urgent and education is the key. Clean water is not only crucial to the preservation and protection of our caves, but is crucial to the preservation of people everywhere.

Karst in Arid Australia

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Abstract

This paper presents an overview of some of Australia's arid and semiarid karst and its management. Australian climatic conditions are characterized by exceptionally high rainfall variability especially in areas of irregular low rainfall. Definitions of arid are an important component when discussing such karst development and management.

The areas discussed include the arid karsts of the Nullarbor Plain and Cape Range. The arid monsoonal areas of Northern Australia, include the Chillagoe Karst, the Camooweal Karst, the Katherine Karst, the Bullita Karst of Gregory National Park, which contains Australia's longest cave, and the karst of the Western Kimberley Region.

This paper discusses the effects of arid climates on the processes of karst development and the effects on present cave biota. Australia is a Federation of States. The States each have their own legislation governing the use, protection, and ownership of land. The effects of this will be discussed in relation to land tenure and karst protection in these remote and sparsely settled areas of Australia. In particular, many of the caves and karst areas have traditional aboriginal uses such as for occupation and for spiritual purposes. Some caves and many shelters and overhanging cliffs have rock art engraving and painting. In recent time, Native Title and indigenous land use have had to be taken into account by management agencies and by cave groups desiring access to sites for recreation or scientific purposes.

Introduction

Australia is a dry continent with extreme variability in rainfall. Many of its karst areas reflect this aridity. The arid karsts of Northern Australia all exist in what is known as the Wet Dry Tropics characterized by a Summer Monsoon from December to March. Travel and cave exploration is precluded during the wet season. These areas have intense but variable rainfall during this wet season but practically no rainfall for the balance of the year with a very high

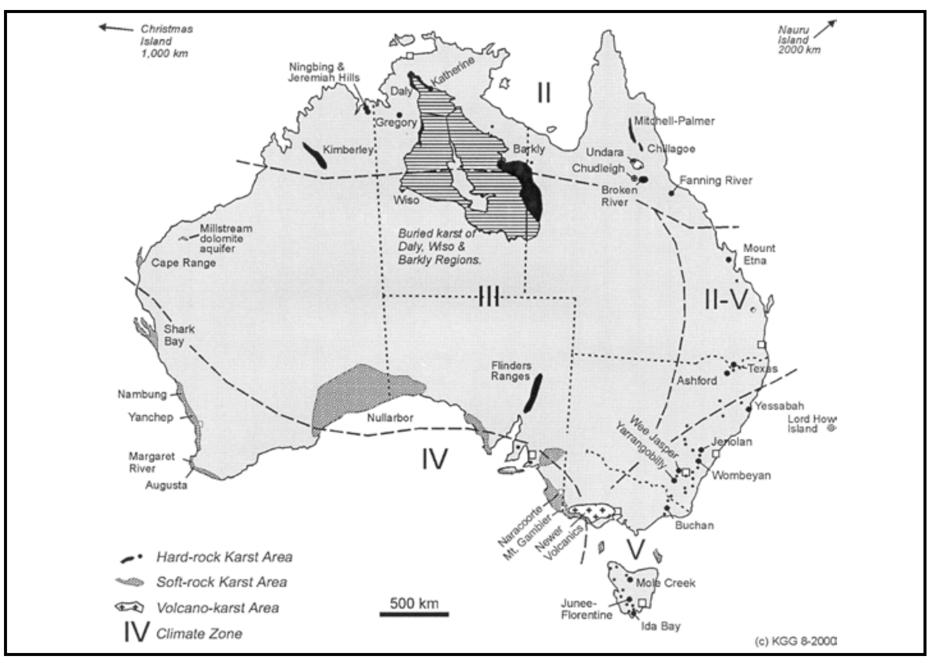

Figure 1: *Australian karst areas, showing climatic zones. Zone II Monsoonal wet-dry tropics; Zone III Arid; Zone IV Mediterranean-winter wet/ summer dry.*

evaporation potential. In contrast, Cape Range on Northwest Cape in Western Australia and the Nullarbor Plain are arid with less than 250 millimeters of rain per annum. This paper will restrict itself to the karst at Bullita in Gregory National Park, Northern Territory, and the semi-arid karst of the Nullarbor Plain which bridges the Western Australia and South Australia borders on the Southern Coast of Australia (Figure 1). These two karst areas will be used to exemplify some of the contrasts in management of karst areas in Australia and also because they have very active speleological investigation programs.

Gregory Karst

The Gregory Karst is located within the Gregory National Park and is some 45 kilometers south of Timber Creek. The karst is on the boundary of the desert to the south and the wetter area to the north, which is subject to a tropical monsoon season from December to March. Most of the rainfall occurs during this period and total annual rainfall is about 600 millimeters. The evaporation potential is about 2,500 millimeters per annum. The Gregory Karst is in PreCambrian dolomite that has been exposed since the Tertiary as a result of the down cutting of rivers across the Victoria River Plateau. The karst is exposed along the East Baines River. The only macrofossils in the formation are stromatolites. Caves occur in the Supplejack Member of the Skull Creek Formation. They are network maze caves in grike fields with numerous entrances at both the edges of the limestone and there are many skylights along the grikes (Figure 2). The relief of the limestone is about 60 meters.

Modern knowledge of caves in the area followed a British led expedition in 1988 (Storm and Smith, 1989). Following this trip, the Canberra Speleological Society has conducted trips to the area for two or three weeks each year during June and July, the winter period. Local cavers from the Top End Speleological Society also conduct trips and have explored and mapped numerous caves. The karst extends for some 20 kilometers north-south and up to one kilometer wide. There are many outlying exposures, which have not been investigated to date and exposures along other rivers outside the Gregory National Park. The total length of known caves now exceeds 150 kilometers. The Bullita Cave System is currently the longest cave in Australia at 81 kilometers. Each year the explored and surveyed length of this cave system is increased in length by three to ten kilometers.

The aboriginal inhabitants of the area knew caves in the Gregory Karst. Shelters were used for occupation and many have associated cave art. In only one instance has rock art been found well within a cave, all other art is in overhang, rock shelter, and entrance locations. The art consists of ochre paintings of animals and mythical beings. Many of these sites have important cultural and spiritual significance. Cave exploration has led to the discovery of numerous important sites, which are documented, but the locations are made known only to National Park personnel. Many of these sites are vulnerable to damage, particularly natural weathering. Only one or two sites are visited frequently by tourists. No photographs of these are included in the paper due to respect for aboriginal sensitivities.

The caves have not been investigated biologically although bats are known to roost in some of the caves during the wetter times of the year. Vertebrate fossil deposits have not been found. Many of the caves flood in part during the wet season. Given the richness of

Figure 2: *Cave passage in Bullita Cave with fig tree roots.*

fauna found elsewhere, for example Cape Range and Chillagoe, there is potential for important biological work.

The area was a leasehold cattle station from the 1920s until the 1980s when it was gazetted as the Gregory National Park which is administered by the Northern Territory Conservation Commission. To date, development of the Park has been limited; access is by a two-wheel drive road from Timber Creek to Bullita but all other roads require four-wheel-drive vehicles. Cave exploration has been conducted with permission from the Conservation Commission. Casual cave exploration is not encouraged since the karst is rugged and remote and climatic conditions are harsh. As yet there is not an operational management plan for the Park although the two caving clubs have contributed information and advice for planning purposes.

Nullarbor Plain

The Nullarbor Plain is one of the largest limestone regions in the world at about 200,000 square kilometers in area. It is a flat-lying, shallow marine plain of Miocene age overlain with some Pleistocene dunes particularly near the coast. It is so named because of the lack of trees (null arbor). All the northern part of the limestone is virtually without trees and only has saltbush and grasses up to one meter in height. The climate is arid to semi-arid with rainfall of 260 millimeters per annum close to the coast but only 180 millimeters per annum at the railway on the northern edge of the exposed limestone. The Nullarbor Plain has no surface streams and little relief. A number of deep caves exist. These occur at the bottom of large collapse dolines and a number of these caves intersect the watertable at about 90 meters (Figure 3). It was not until 1970 that successful cave diving trips were undertaken with modern scuba gear. Cocklebiddy Cave is 6,260 meters long; with about 5,200 meters underwater, the longest cave dive in the world. Other long caves include Mullamullang Cave (12,000 meters) and Old Homestead Cave (8,000 meters). The other feature of the plains are the "blowholes" so named because they breathe in and out depending on atmospheric pressure. There are currently about 1,000 of these known. Many are very short but some are quite extensive. They are generally less than 20 meters deep. They are mainly concentrated on the broad, low ridges (two to five meters) about the plain. A recent innovation has been to locate these using an ultralight aircraft to position sites by GPS and then systematic exploration using the GPS locations to find entrances. Most of the deep caves have probably been discovered as these were known from local information followed by systematic visiting of all sites on aerial photographs of the area in the late 1950s to early 1960s (Dunkley and Wigley, 1967).

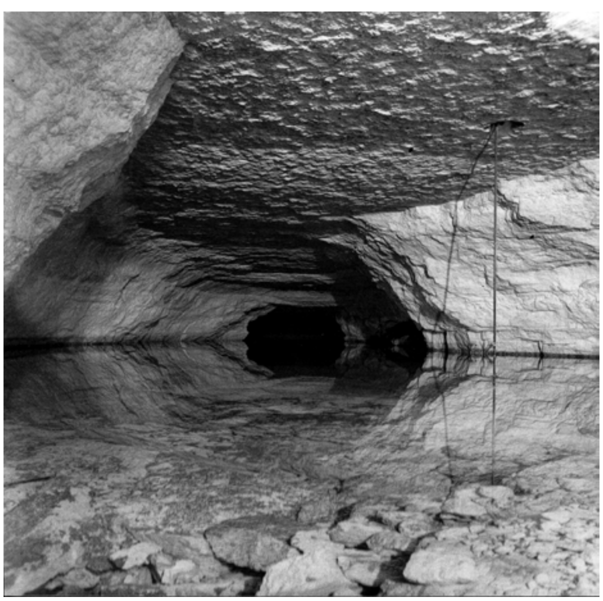

Figure 3: *Lake in Weebubbie Cave with water supply pipe, subsequently removed.*

Numerous troglobytes have been found in the caves. Some of the caves have extensive vertebrate fossil assemblages, which have only been minimally examined to date. There has been considerable geomorphic investigation of the Plain and its caves. Aboriginal use of the plain involved hunting and travelling routes. Caves were used as a water source (high in $MgSO_4$), for occupation, for mining of flint nodules, and for cultural purposes. Some of the caves have etched engravings and others ochre paintings.

The Nullarbor forms part of Australia's mythology. It was the barrier between Western Australia and the eastern states and was not crossed until 1840 to 1841. It was not until the telegraph line was constructed (1877) close to the coast and the railway further north that the plain became more accessible. Both Western Australia and South Australia leased the land for sheep and cattle grazing. In South Australia, all the leases have been revoked and the limestone portions are now in National Park or on aboriginal land. In Western Australia, a number of grazing leases have lapsed but on the richer, higher rainfall areas near the coast there are still leasehold cattle properties. Some years ago planning to have the whole of the Plain put forward as a World Heritage Area was initiated but this lapsed due to the politicization of such initiatives. The caves are thus inadequately protected and there is little management on the ground. This is despite the Plain and its caves being outstanding in a national and international context.

Most caving is conducted responsibly and only a couple of the caves receive very many visitors. Amongst these is Mullamullang Cave where damage in the Easter Extension to the Salt Cellars and "Coffee and Cream" sections is excessive. The rare troglobitic spider, which only occurs in and around the "Dome," 4.5 kilometers into the cave, is extremely vulnerable to disturbance and collecting. At one stage, it was thought that it was extinct but more recently active webs have been observed. This spider is at the end of a very tenuous food chain at the far end of the cave.

Caving trips to the Nullarbor are generally of an expedition nature for several weeks. Cavers need to be self-sufficient for all needs including water. Rescue services are thousands of kilometers away. This is particularly relevant to diving parties where decompression chambers are very long distances away.

Landscape Fragility

Australia has an old landscape. Its soils are shallow. There has been little or no rejuvenation through uplift and other mechanisms. Abuses of land from overgrazing and the introduction of exotic plants and animals have caused regional extinctions of many species. On the Nullarbor rabbits, foxes, and cats have reduced the populations of many animals. Grazing by sheep and cattle have similarly reduced the condition of native pastures. Areas that are not now subject to sheep and cattle pressure are reverting to the original condition but there will remain a legacy of a reduced number of vertebrate species on the Nullarbor. It is not known whether these changes on the surface have endangered cave biological populations due to changes in food chains. There appear to be a number of bat roosts that have not been used for many years. It is not known whether these reflect the changes of surface tenure and usage or are part of much longer term responses to climate change.

Underground conditions on the Nullarbor reflect the arid environment. Caving contributes to damage, particularly surface trampling. Natural processes of rejuvenation such as flooding, as occur in higher rainfall karsts, are most infrequent in arid karsts and, except for wind deposited sand and for fretting from the walls, damage from trampling lasts a very long time. Many calcite speleothems exhibit damage due to salt wedging and it is not uncommon to see piles of broken formations shattered by this salt wedging. In some places quite magnificent halite and gypsum speleothems occur (Figure 4). There is no evidence of deliberate vandalism but problems of track widening and indiscriminant tracking occur.

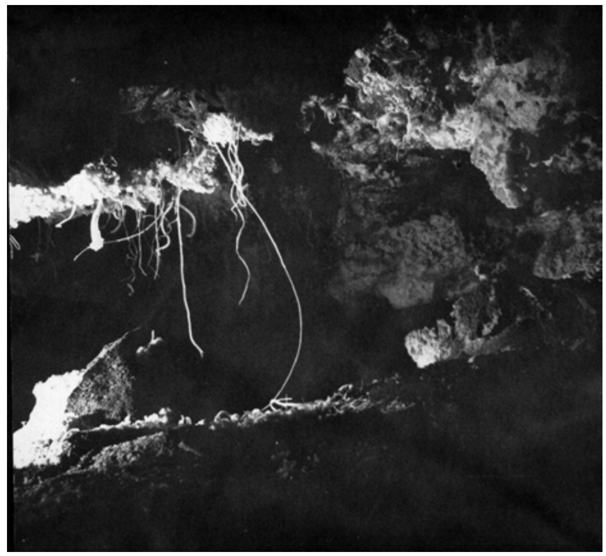

Figure 4: *Halite salt formation, Easter Extension, Mullamullang Cave.*

In Gregory National Park, there are less dramatic changes than on the Nullarbor; however, there are exotic weed infestations and feral horses and donkeys continue to affect vegetation recovery. The caves have not had very many visitors and tracking or other damage is minimal. Visits to the cave art sites are limited. Problems may emerge if cave usage were to go up. The greatest problem faced by management would be if inexperienced cavers got lost in what are very extensive caves.

Conclusions

Arid karsts in Australia are very fragile and the caves need careful management to prevent trampling of floors particularly. Mechanisms of track marking are in use in many sensitive caves; however, the single most pressing need is for deliberate management of the deep caves on the Nullarbor Plain. The Nullarbor Plain in Western Australia needs legislative protection and more focussed management attention. For the South Australian section, more on-ground management would prove beneficial. The Plain is now visited extensively, particularly to watch whales at the Head of the Great Australian

Bight. Also visitation by both cavers and cave divers results in change within the caves despite subscribing to minimal impact caving codes.

At Bullita, some long term management strategies need to be formulated to contend with people with karst interests, be they casual visitors on “Round Australia” trips or more serious speleological visitors. The present access through very restricted access permits cannot continue for long, given that the Bullita Cave System is now the longest cave in the country.

Acknowledgments

Many thanks to Ken Grimes for the use of Figure 1 showing karst areas in Australia.

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Temporal Variation in the Emergence Flights of the Bat, Myotis velifer, from Caves in Southern Arizona

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Abstract

It has generally been shown that for many temperate insectivorous bats, the time of evening emergence from their day roosts is approximately parallel to sunset. Although this emergence time may vary between species, within species the bats are known to have similar activity patterns. A maternity colony of *Myotis velifer* (cave bat) in southern Arizona was monitored for four years and an interesting deviation from the emergence pattern was observed. These bats appeared to emerge sooner in the early spring and autumn than in late spring and summer. Besides this variation in the time of emergence, the character of the outflight also changed through the summer period. This roost was then compared to a roost of *M. velifer* approximately 20 miles south of the maternity colony. The differences and similarities are discussed and possible justification for the pattern variations are proposed. A potential explanation for the different activity patterns could be the reproductive condition of the females at the maternity colony. Other factors such as ambient temperature may also play a role. Probably no one element is the trigger for emergence, but rather a combination of factors may impact bat activity patterns.

An Incidental Take Permit for Endangered Karst Invertebrates in Bexar County, Texas

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Abstract

Nine species of cave invertebrates presently known only from karst topography in north and northwest Bexar County, Texas, were listed as endangered on December 26, 2000. Species listed include: two troglobitic ground beetles, *Rhadine infernalis* and *R. exilis,* a mold beetle, *Batrisodes venyivi,* an eyeless harvestman, *Texella cokendolpheri,* and five eyeless spiders, *Cicurina baronia, C. madla, C. Venii, C. vespera,* and *Neoleptoneta microps.* A local landowner with three small caves, all occupied by one or two of the listed species, has recently applied for a Section 10(a) incidental take permit to close one of the caves and preserve, in perpetuity, each of the other two caves in small (one-acre) preserves. The applicant and the authors worked with the United States Fish and Wildlife Service (Austin, Texas, Ecological Service Field Office) to establish guidelines for evaluating the specifics of incidental take for the project, as well as establishing mitigation criteria and long-term protection guidelines for designated mitigation preserves. The preserves that will be established include nine caves, on 179 acres, each occupied by at least two and up to five of the listed species. This presentation will provide details of preserve establishment, maintenance and monitoring and comments on the distribution and demographic characteristics of some of the listed species.

Introduction

Section 9 of the Endangered Species Act, as amended, prohibits the "take" of listed wildlife species. Take, as defined by the Act, means "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or to attempt to engage in any such conduct" (Endangered Species Act, 16 U.S.C. 1531 *et seq*.). Amendments to the Endangered Species Act in 1982 provided provisions in Section 10 that allow for the "incidental take" of endangered species, by non-federal entities, as long as the take is incidental to "otherwise lawful activities." Section 10(a)(2)(A) of the Act requires that an applicant for an incidental take permit detail in a "conservation plan" the impacts that are likely to result from the taking and the measures that will be taken to minimize and mitigate for such impacts. The administration of the Endangered Species Act and responsibility for issuing take permits for non-marine wildlife species is the responsibility of the United States Fish and Wildlife Service.

This paper provides a brief description of an incidental take permit (Permit No. TE044512-1) and supporting habitat conservation plan for three species of listed karst invertebrates. The activity requiring the permit is the commercial development (La Cantera) of approximately 1,000 acres in Bexar County, Texas, just northwest of the City of San Antonio. On December 26, 2000, the U.S. Fish and Wildlife Service published a final rule and determined nine cave-dwelling invertebrates from Bexar County, Texas, to be endangered species under the authority of the Endangered Species Act. These invertebrates are all endemic, obligate troglobites of local distribution in karst terrain in Bexar County. The species listed are: *Rhadine exilis* (no common name) and *Rhadine infernalis* (no common name), small, eyeless ground beetles; *Batrisodes venyivi* (Helotes mold beetle) a small, eyeless beetle; *Texella cokendolpheri* (Robber Baron Cave harvestman) a small, eyeless harvestman; *Cicurina baronia* (Robber Baron cave spider), *Cicurina madla* (Madlas cave spider), *Cicurina venii* (no common name), *Cicurina vespera* (Government Canyon Bat Cave spider), and *Neoleptoneta microps* (Government Canyon cave spider), all small, eyeless or essentially eyeless spiders (USFWS, 2000a).

Background

The life history and taxonomy of the Bexar County listed invertebrates is not represented by definitive studies. In 1993, the Service contracted two studies to summarize the known information on these species. One study focused on the overall karst geography in the San Antonio region and the potential geological and geographical barriers to karst invertebrate movement and limits to their distribution (Veni and Associates, 1994). The other study summarized the distribution of the nine invertebrates as understood at that time (Reddell, 1993).

The karst geography report (Veni and Associates, 1994) delineates six karst areas or karst regions within Bexar County. These regions are as follows: Stone Oak, University of Texas at San Antonio, Helotes, Government Canyon, Culebra Anticline, and Alamo Heights. The boundaries of these karst regions are geologic or geographic features that are thought to represent obstructions to invertebrate movement and which have resulted in the present-day distribution of invertebrates. Whether or not these karst region boundaries are truly barriers (past or present) to invertebrate distribution is presently uncertain. Additional studies are required before the relationship of invertebrate distribution and karst regions is fully understood.

The La Cantera property is located within the University of Texas at San Antonio karst region, which is bounded by Helotes Creek to the west, Leon Creek to the east, and the limits of exposure of the Edwards Group and Glenrose Limestone Formation to the north and south. The 1993 studies determined that only two of the nine listed species were present in the University of Texas region, *Rhadine exilis* and *Rhadine infernalis*. Subsequent studies have also documented occurrence of *Cicurina madla* in the region outside the La Cantera property (USFWS, 2000a). Biota surveys conducted by SWCA in 1994, 1995, and 2000 in three La Cantera caves resulted in discovery of eyeless *Cicurina* spiders and *Rhadine exilis*, but no *Rhadine infernalis*. Based on the best available scientific information, the *Cicurina* spider found on the La Cantera property is most likely the listed *Cicurina madla*. It is possible that this spider is an undescribed species of *Cicurina* (Cokendolpher, pers comm). Although an adult La Cantera eyeless spider sufficient for positive identification has not been collected, based on the fact that *Cicurina madla* has been verified as occurring in two caves within two to three miles of La Cantera, and no other eyeless *Cicurina* are known from the University of Texas karst area, this spider was assumed, for purposes of the incidental take permit, to be the federally listed species *Cicurina madla* (USFWS, 2001).

La Cantera Caves

Quality of caves on La Cantera

Over 400 potential karst features have been evaluated on the property. Three primary geological assessments have been performed in the past, and their combined scope has included the entire property (Raba-Kistner, 1993a and 1993b; SWCA, 2000; Horizon Environmental Services Inc., 2000).

During extensive karst surveys beginning in 1993 three caves (La Cantera Caves #1, #2, and #3) containing habitat for the listed karst invertebrates were found on the La Cantera property. Two of these caves (La Cantera Caves #1 and #2) are known to contain *Rhadine exilis* and *Cicurina madla.* The entrances to both caves lie within 200 feet of the west-bound frontage road of Loop 1604, a heavily traveled highway. Both caves are immediately south (approximately 100 feet) of a two-lane road designed to serve traffic to and from the commercial development. The entrance to La Cantera Cave #3, which contains *Cicurina madla,* lies within 100 feet of another internal thoroughfare. Because of the existing disturbances, none of the La Cantera caves is considered high-quality habitat for the invertebrates under consideration (USFWS, 2000b). The U.S. Fish and Wildlife Service has determined that all three La Cantera caves were of medium-quality.

None of the listed endangered invertebrates is known from other karst features present on the La Cantera property. However, the occurrence of *Rhadine exilis*, *Rhadine infernalis*, and/or *Cicurina madla* (the only known endangered karst species within the University of Texas karst region), or any of the other listed invertebrates elsewhere on the property cannot conclusively be ruled out given the potential for these species to occur in subsurface voids lacking obvious surface expression (Veni and Associates, 1994).

Karst Invertebrate Preserve Guidelines

In an effort to provide guidelines for the protection of endangered karst invertebrates, the U.S. Fish and Wildlife Service has determined that the minimum total area needed to protect caves or cave clusters containing karst invertebrates is 69 to 99 acres (USFWS, 2000b). Further, the agency suggests that an area within that area a minimum 100- to 200-meter (328- to 656-foot) radius from all karst features containing listed invertebrates should be preserved. This includes a core area encompassing the minimum 50-meter (164-foot) cave cricket foraging range and an additional buffer against edge effects. Also, since roads may hinder movement of several species of invertebrates and small mammals, no internal roads or other permanent habitat fragmentation should occur within the protected area. It is the current policy of the U.S. Fish and Wildlife Service that disturbances that approach closer than the standards detailed above, are likely to constitute take.

La Cantera Habitat Conservation Plan

On-site and Off-site Preserves.

As part of the habitat conservation plan's development, La Cantera will assure that seven karst preserves totaling approximately 181 acres will be protected in perpetuity by appropriate legal mechanisms (conservation easements, deed restrictions) before clearing or construction begins on undeveloped portions of the property. The karst preserves include one-acre on-site preserves for La Cantera Caves #1 and #2, and five off-site preserves totaling approximately 179 acres. These off-site preserves include: an approximately five-acre area encompassing Madlas Cave; an approximately four-acre area encompassing John Wagner Ranch Cave #3; approximately 70 acres encompassing Hills and Dales Pit; approximately 25 acres encompassing Helotes Hilltop and Helotes Blowhole Caves; and approximately 75 acres encompassing Scenic Overlook, Canyon Ranch Pit, and Fat Mans Nightmare Caves. All of the off-site caves within the proposed karst preserves contain endangered karst invertebrate species as well as other cave-adapted species. A summary of endangered invertebrate species known from each of the proposed on- and off-site preserve caves is provided in Table 1.

The U.S. Fish and Wildlife Service considered the La Cantera caves to be of medium quality with regard to habitat for listed invertebrates. For each of these caves, the habitat conservation plan provides for mitigation by preserving caves of similar or higher quality. For each La Cantera cave, the following mitigation has been provided: La Cantera Cave #1 – Hills & Dales Pit (approximately 70 acres, four listed species, one high-quality cave); La Cantera Cave #2 – Helotes Hilltop, Helotes Blowhole, Madlas Cave, and John Wagner Ranch Cave #3 (approximately 34 acres, five listed species, four medium-quality caves); La Cantera Cave #3 – Canyon Ranch Pit, (approximately 75 acres, five listed species, three high-quality caves).

In addition to providing 181 acres of cave preserves, the La Cantera habitat conservation plan also provides for participation with the U.S. Fish and Wildlife Service in the development of an outreach program, and provides for a $20,000 grant to support DNA research of *Cicurina* taxonomy. The outreach program has the goal of raising awareness, understanding, and appreciation for Bexar County endangered karst invertebrates. Under this program information materials will be produced by public relations professionals and will be designed to reach the broadest possible audience (including school children, landowners, and the public at large). The intent of these materials will be to impress upon the audience the importance of preserving the threatened karst resources and their invertebrate inhabitants. These materials will be designed to render technical information relating to karst habitats and their inhabitants in non-technical terms and graphics.

U.S. Fish and Wildlife Service Assessment of Development Impacts to Listed Species

It is the U.S. Fish and Wildlife Service's opinion that take of *Rhadine exilis* will occur in La Cantera Caves #1 and #2, and take of *Cicurina madla* will occur in all three La Cantera caves, as a result of the development and occupation of the La Cantera property. Although the Fish and Wildlife Service recognizes that the existing quality of endangered species habitat presently provided by the three La Cantera caves is not optimal, development of the property would likely reduce the amount of such habitat present in the project region. Take of endangered karst invertebrates could also occur elsewhere on the property in the event previously undiscovered habitat is encountered. Although no endangered karst invertebrates are known to occur on the property in areas outside of the three La Cantera caves, potential exists for listed species to be present in subsurface void spaces lacking obvious surface expression. Such spaces could be destroyed or significantly disturbed by construction activities. As all portions of the property outside of the two proposed on-site karst preserves (at La Cantera Caves #1 and #2) are expected to be developed, any endangered karst invertebrates occurring on the property outside of these preserves are expected to be taken by completion of the development; however, such take will be fully mitigated for through the conditions detailed in the habitat conservation plan. Due to the extensive karst surveys of the property, the likelihood of discovering previously undetected habitat is considered low.

Protecting La Cantera Caves #1 and #2 within one-acre preserves will significantly reduce the risk of disturbing karst invertebrate habitat during construction. The U.S. Fish and Wildlife Service, however, believes that reduction of native vegetation to one-acre patches surrounding these caves will reduce the amount of nutrients entering these features, the amount of organic material available to be washed into the features, and the amount of habitat supporting cave crickets and other trogloxene species. According to the U.S. Fish and Wildlife Service, increased intensity of fire ant infestations within the karst preserves and/or introduction of other exotic species that could be detrimental to the karst ecosystem may also result from clearing, construction, and development activities. Due to cave depth (roughly 60 to 115 feet) and existing edge along the nearby Loop 1604 right-of-way, potential preserve edge effects (such as increased drying of woodland, with concomitant drying of cave habitat, and increased temperature fluctuations) are expected to be negligible. While proposed development may not result in elimination of *Rhadine exilis* and *Cicurina madla* from these two caves, it is anticipated that numbers of these two species within these caves will be reduced over time. (To put the existing density of invertebrates in perspective, the authors have visited Caves #1 and #2 approximately four times in nine years searching for karst invertebrates for a period of two hours per visit and have found an approximate total of five to six *R. exilis* and 20 to 30 eyeless *Cicurina*.) A monitoring program included in the habitat conservation plan will provide long-term data on the accuracy of these predictions.

The U.S. Fish and Wildlife Service believes that the overall impact to *Rhadine exilis* and *Cicurina madla* resulting from development of the La Cantera property will neither prevent nor seriously impact the long-term conservation of each species within the University of Texas at San Antonio karst region. The U.S. Fish and Wildlife Service desires that a minimum of three karst preserves for each species within each karst region be set aside to provide for long-term conservation of karst invertebrates (USFWS, 1994). Assuming development of the property will preclude on-site survival of the two species (which is not certain), sufficient habitat will likely remain within the University of Texas karst region to provide necessary conservation. Within the University of Texas karst region, two suitable preserves are now inhabited by *Cicurina madla*. Future exploration of Mastodon Pit (less than 0.5 mile south of the property) will probably also yield this species. Moreover, extensive conservation of known, occupied *Cicurina madla* habitat is provided outside the University of Texas karst region. The U.S. Fish and Wildlife Service believes that strict adherence to the "three occupied caves per species" rule may not be biologically required to ensure conservation of a species where the species' range includes several karst regions. Such is the case for *Cicurina madla.* One of the present anomalies of the karst region configuration as currently proposed (Veni and Associates, 1994) is the fact that *Cicurina madla* occurs in four of the six karst regions. The presence of this single taxa in multiple karst regions may call into question the hypothesis of geologic or geographic features obstructing invertebrate movement between karst regions.

Within the University of Texas at San Antonio karst region, at least five caves are known to be inhabited by *Rhadine exilis*. For *Cicurina madla*, positive identifications have been made in two large cave preserves (Hills and Dales Pit and Robbers Cave), and another four caves have produced eyeless *Cicurina* thought to be *Cicurina madla*, though positive identification requires further study.

Other University of Texas at San Antonio karst region caves known to have eyeless *Cicurina* spiders that are most likely *Cicurina madla* include: Mastodon Pit, Kamakazi Cricket, John Wagner Ranch Cave #3, and Three-fingers Cave. Outside the University of Texas at San Antonio karst region, *Cicurina madla* is known to occur in Christmas Cave, Madlas Cave, Madlas Drop Cave, and Helotes Blowhole Cave in the Helotes karst region; Lost Pothole Cave in the Government Canyon karst region; and Headquarters Cave in the Stone Oak karst region. Of these known localities, at least four sites are either in preserves now (Lost Pothole Cave, Headquarters Cave) or will be preserves as a result of the La Cantera habitat conservation plan (Madlas Cave, Helotes Blowhole Cave). Thus, actions effected as a result of the La Cantera permit are not likely to preclude the long-term conservation of either *Rhadine exilis* or *Cicurina madla.*

Because the habitat conservation plan would protect approximately 181 acres of on- and off-site land, the U.S. Fish and Wildlife Service has determined that the project is expected to provide an overall benefit to Bexar

County endangered karst invertebrates. The identification of species, evaluation of take, and design and configuration of the karst preserves are based on the best scientific information available. Protecting off-site karst ecosystems as provided in the habitat conservation plan would represent a major recovery action for other listed species besides *Rhadine exilis*, and *Cicurina madla*, particularly *Rhadine infernalis*, *Batrisodesvenyivi*, and *Texella cokendolpheri*, and the undescribed *Texella* new species and *Neoleptoneta* new species.

Summary and Conclusion

This document has summarized the conditions of the first incidental take permit involving the nine listed Bexar County karst invertebrates. We anticipate that many more will follow, and that the La Cantera permit will serve as a model for future permits. We believe that the La Cantera habitat conservation plan will provide significant conservation opportunities for the subject invertebrates. We are concerned, however, that the existing U.S. Fish and Wildlife Service standard of requiring 69 to 99 acres of habitat per cave or cave cluster could prove to be counterproductive to efforts to preserve cave habitat. We believe there are presently insufficient data to validate the need for these relatively large preserves.

While it is the responsibility of the U.S. Fish and Wildlife Service to err on the side of the species, smaller preserves may, in fact, provide

Table 1. Summary of Endangered Species Known to Occur in the La Cantera On-site and Off-site Preserve Caves.

Preserve Cave	Karst Region	**Endangered Species Present**	**Other Rare Karst Species Present**
La Cantera Cave #1	University of Texas at San Antonio	*Rhadine exilis*	eyless *Cicurina* sp. (probably *C. madla*)
La Canter Cave #2	University of Texas at San Antonio	*Rhadine exilis*	eyless *Cicurina* sp. (probably *C. madla*)
Hills and Dales Pit	University of Texas at San Antonio	*Rhadine exilis* *Cicurina madla*	*Neoleptoneta* new sp. *Texella* sp. (possibly *T. cokendolpheri*)
John Wagner Ranch Cave #3	University of Texas at San Antonio	*Rhadine exilis* (type location) *Rhadine infernalis* *Texella cokendolpheri*	*Neoleptoneta* new sp. eyless *Cicurina* sp. (probably *C. madla*)
Helotes Blowhole Cave	Helotes	*Rhadine exilis* *Rhadine infernalis* *Cicurina madla*	
Helotes Hilltop Cave	Helotes	*Rhadine exilis* *Batrisodes venyivi* (type location)	eyless *Cicurina* sp. (probably *C. madla*)
Madlas Cave	Helotes	*Rhadine infernalis* (type location) *Cicurina madla*	
Canyon Ranch Pit	Government Canyon	*Rhadine infernalis*	eyless *Cicurina* sp. (probably *C. madla*)
Fat Mans Nightmare Cave	Government Canyon	*Rhadine infernalis*	eyless *Cicurina* sp. (probably *C. madla*) *Texella* sp. (possibly *T. cokendolpheri*)
Scenic Over Look Cave	Government Canyon	*Rhadine infernalis* *Batrisodes venyivi* (third known location)	eyless *Cicurina* sp. (probably *C. madla*) *Texella* sp. (possibly *T. cokendolpheri*)

the same measure of protection for these troglobitic organisms. It is important, therefore, that relevant research be focused on this issue as soon as possible. Landowners may be far more willing to provide a five- to ten-acre buffer around significant karst features and our fear is that the 69- to 99-acre requirement will result indestruction of the vary resource we are trying to protect.

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Reasons Why We Should be Mindful of Microbes When We Consider Karst Systems: Impacts on Karst Development

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Abstract

A 1998 study of interstitial fluid geochemistry within Charonís Cascade in the Echo River/River Styx area of the Mammoth Cave System found carbon dioxide pressures higher than that of the fluids of the cave stream itself. This was confirmed by a limestone weight loss experiment in which samples dissolved at various levels below the streambed despite the low fluid velocities. The high CO_2 pressures appear to influence both conduit dissolution rates and geometry and presumably result from the microbial degradation of organics within the sediments. To explore the relationship between the geochemical environment of fluids and microbial ecology, additional samples were collected from the same location. Eight *Coliform* bacteria were identified to species level and inoculated in 65 milliliters of thioglycollate broth along with a calcite crystal of known weight and incubated at 12°C for 92 days. In the presence of five of the bacterial species, calcite dissolved more than the control, ranging up to 18.1 milligrams per square centimeter per year for *Escherichia coli*. Preliminary results suggest that in typical southeastern U.S. cave environments, bacteria within cave sediments may influence limestone dissolution. Further experiments are underway to better understand the relationships between microbial ecology and limestone dissolution kinetics.

The Missouri Cave Life Survey

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Abstract

The purpose of this project is to assess the status of common cave-dwelling animals in Missouri. The Missouri Department of Conservation began systematic surveys of cave life in 1978. James E. and Treva Gardner visited 436 caves and 10 springs, where they collected specimens for identification, recorded observation, and counted vertebrates. The invertebrate data were published by James E. Gardner (1986). The vertebrate count data are the focus of the current study. We incorporated Gardner's records on 483 species into the Missouri Biospeleological Database from which we produced candidate lists of caves to visit in all seasons and from a wide geographic area. We obtained a "Partnerships in Wildlife" grant from the U. S. Fish and Wildlife Service to conduct follow-up surveys of 40 caves, utilizing volunteers from the Missouri Caves and Karst Conservancy, Missouri Western State College, and the University of Missouri/Columbia. Dozens of cavers were trained to identify and record species and other observations in the caves using a pictorial guide, data forms, rulers, and digital thermometers. A water sampling program is being led by Dr Robert Lerch. Samples are analyzed for typical parameters and selected contaminants. Prelilminary data will be presented, and at project's end, we will provide a summary report on the status of eastern pipistrelle bats, grotto salamanders, pickerel frogs, and other species. The results will be used for making land management decisions regarding cave communities.

Introduction

The purpose of this project is to assess the status of common cave-dwelling animals in Missouri. This study is an example of the Missouri Department of Conservation's mission to monitor the status of wildlife populations in the state. The Missouri Department of Conservation began systematic surveys of cave life in 1978. James E. Gardner and Treva Gardner visited 436 caves and ten springs, where they collected specimens for identification, recorded observations, and counted vertebrates. The invertebrate data were published by James E. Gardner (1986). An important baseline study on cave bats was begun by LaVal and LaVal (1980). Gardner's vertebrate data were not published, and are the focus of the current study. In this study we also record observations of invertebrates.

Materials and Methods

We incorporated Gardner's published and unpublished records into the "Missouri Biospeleological Database," which now contains information on 843 species and more than 800 caves. We produced candidate lists of caves to revisit. More than 200 caves had count data for at least one species. Caves were prioritized for higher counts, multiple species counts, and species of special interest (such as the grotto salamander, *Typhlotriton spelaeus*). A semifinal list of 81 caves was then evaluated by a committee of biologists and cavers to obtain a final selection of 40 caves with a representative geographic and seasonal spread.

We obtained a "Partnerships for Wildlife" grant from the U.S. Fish and Wildlife Service to conduct follow-up surveys of these 40 caves, utilizing volunteers from the Missouri Caves and Karst Conservancy, Missouri Western State College, and the University of Missouri/Columbia. This type of grant requires a sponsoring agency (Missouri Department of Conservation) and volunteers, who contribute time and expenses to carry out a wildlife study. The hours and travel expenses are carefully recorded to meet or exceed the minimum contribution required to obtain the grant. In this grant $20,000 worth of work will be contributed by Missouri Department of Conservation, Missouri Caves and Karst Conservancy, and two researchers, part of which is used to pay a part-time salary for the Project Leader (Lawrence Ireland), who schedules and leads the trips, quality-controls the field work and manages data. William R. Elliott, cave biologist for Missouri Department of Conservation, is the Project Director and designer.

The study began in July 2001, and will end in June 2002. Training sessions were held on two weekends in July and September 2001, at Reis Biological Station, operated by Saint Louis University, near Steelville, Missouri. Forty-five cavers were trained by the authors and David C. Ashley, Missouri Western State College, to identify and record species and other observations in the caves.

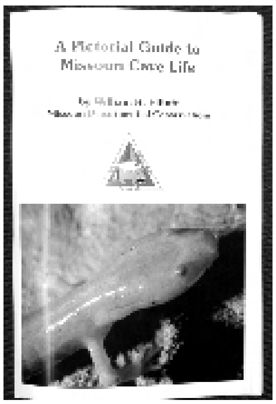

Figure 1. *This identification guide was desktop published for team members to use in the field. The Grotto salamander,* Typhlotriton spelaeus, *is on the cover.*

Training included slide lectures to acquaint cavers with 66 recognizable species and subspecies, their ecology, and methods of identifying roosting bats without touching them. However, more than 800 different species have been recorded from Missouri caves, so it is not feasible for the volunteers to accurately identify most species. Trips were quality-controlled by experienced naturalists who led the teams. Team members did not handle or collect fauna, but the leaders were authorized to collect small invertebrates when needed for identification.

We provided a desktop-published pictorial guide to the species for field use (Figure 1). Images and text from this guide may be seen in the Biospeleology web site under "Missouri Cave Life," at: http://www.utexas.edu/depts/tnhc/.www/biospeleology.

Rulers were provided so that teams could measure animals without handling them. In addition, high-resolution digital cameras were used to document some of the species and the survey work. We captured interesting and potentially valuable macrophotographs of color variation in some amphibians. The digital photos were shared via e-mail with biologists who identified or confirmed identifications of the species.

Students were taught how to use a field-tested data form (Attachment 1 and 2), which tied the cave life survey to numbers placed on a cave map, thus pinpointing locations of observations. The form has fields to record the cave's name, time in and out, and directions to and location of the cave. For purposes of satisfying the terms of the grant, team members recorded their names and the time and mileage contributed for that trip. The team collected trash in the cave and counted it up at the end of the trip. At the end of the trip the team evaluated the cave for six types of use and abuse, comparing to the many caves they have visited (Attachment 1).

The back of the form (Attachment 2) is a spreadsheet in which each row is a new observation or a water sample, or a continuation of the previous row if space is needed for tallying or for notes. A record number is marked on the cave map in the cave for each different species' occurrence, but teams may pool data within a 50-meter reach of the cave. There are columns for the place in the cave, distance from the entrance, type of habitat, temperature, number observed, and the initials of the observer or collector.

We purchased four Taylor digital pocket thermometers for the study. We calibrated the thermometers in a freezing water bath to within 0.1°F of each other, and they were periodically checked against each other in water to see if they still agree (Figure 2). In November 2001, we added a wet-dry bulb psychrometer to the study to record relative humidity because a long-term drought was affecting the humidity in many caves.

Figure 2. *Jeff Briggler uses a Taylor digital pocket thermometer.*

Since many bats and amphibians use caves seasonally, we revisited each cave within two weeks before or after the original date that it was visited. The original surveys were carefully recorded by Gardner and we tried to match the time and effort that were spent in each cave.

Typically each team had a leader with a camera; a data recorder; "spotters," who traveled abreast to find fauna on left and right walls, ceiling, and floor; and members who were responsible for the trash bag and a rugged container that had a digital pocket thermometer, rulers, and small items. The roles were sometimes swapped to allow team members to learn different aspects of the study (Figure 3).

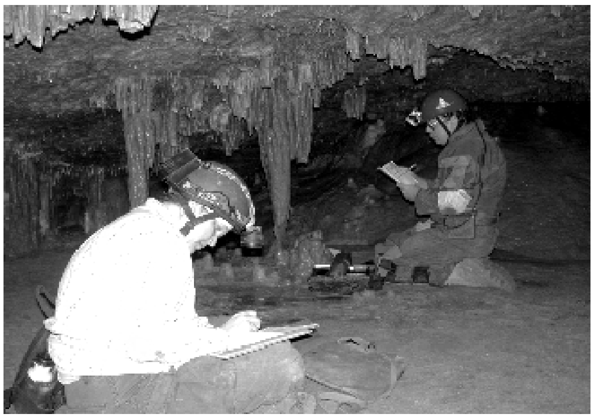

Figure 3. *Sally Kula and Bill Elliott collecting data.*

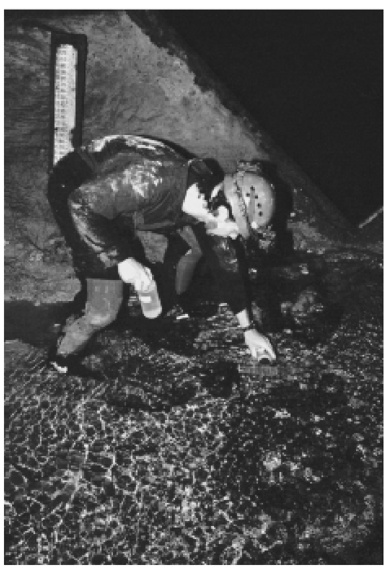

Figure 4. *Bob Lerch takes a water sample for analysis.*

Robert Lerch, U.S. Department of Agriculture and the University of Missouri/Columbia, led a water sampling program in conjunction with our study. Teams were issued prenumbered, analytically clean water sample bottles (Figure 4). Samples were sent on ice to Dr Lerch's laboratory, where they are being analyzed for typical water-quality parameters and selected contaminants. Those results are not yet available.

Results

The 14 caves studied to date in 2001 are given in Table 1. Volunteers contributed a total of 377 man-hours and 3,570 miles to carry out the 14 surveys we have done, for a mean of 27 man-hours and 255 miles per cave trip. These figures do not include paid time and mileage contributed by the agencies and universities involved. About one-third of the trainees have participated in trips so far. Reimbursements to volunteers for their work are all contributed to the Missouri Caves and Karst Conservancy for future cave conservation projects.

Table 1. Caves studied to date.

County	Cave	Date
Camden	Moles Cave	09/07
Carter	Blue Spring Cave	10/10
Carter	Lower Camp Yarn Cave	07/10
Carter	Secesh Cave	07/23
Christian	Math Branch Cave	08/09
Crawford	Jagged Canyon Cave	09/22
Crawford	Mud River Cave	09/22
Madison	Marsh Creek Cave #1	08/12
Oregon	Bockman Spring Cave	10/06
Oregon	Willow Tree Cave	10/06
Pulaski	Ryden Cave	08/10
Shannon	Marvel Cave	08/30
St. Louis	Woods Cave	07/17
Wright	Bill Dyer Lead Mine Cave	07/28

Preliminary data from 14 caves are presented, involving 17 common species and subspecies: cave salamander (*Eurycea lucifuga*, Figure 5), dark-sided salamander *(Eurycea longicauda melanopleura*), western slimy salamander (*Plethodon glutinosus or albagula*), Ozark salamander (*Plethodon angusticlavius*), southern redback salamander (*Plethodon serratus*), grotto salamander (*Typhlotriton spelaeus*), pickerel frog (*Rana palustris*, Figure 6), green frog (*Rana clamitans*), dwarf American toad (*Bufo americanus charlesmithi*), eastern American toad (*Bufo americanus americanus*), eastern pipistrelle bat (*Pipistrellus subflavus*, Figure 7), big brown bat (*Eptesicus fuscus*, Figure 8), little brown bat (*Myotis lucifugus*), northern long-eared bat (*Myotis septentrionalis*), gray bat (*Myotis grisescens*, Figure 9), Indiana bat (*Myotis sodalis*), and eastern phoebe (*Sayornis phoebe*). Other species, such as the herald moth (*Scoliopteryx libatrix*, Figure 10), will be evaluated in the final report.

Figure 5. *The Cave salamander,* Eurycea lucifuga, *is commonly seen in wet Missouri caves.*

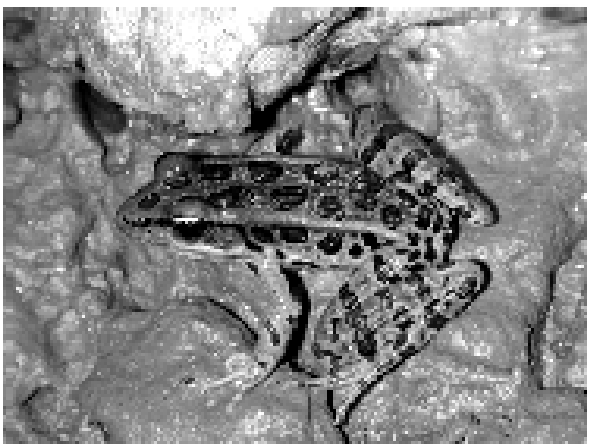

Figure 6. *The Pickerel frog,* Rana palustris, *takes refuge in Ozark caves during winter and drought.*

Figure 7. *The Eastern pipistrelle bat,* Pipistrellus subflavus, *is tolerant of humans, but we surveyed it to see if heavy traffic has reduced its use of caves.*

Figure 8. *The Big brown bat,* Eptesicus fuscus, *is a typical winter resident in chilly entrance areas.*

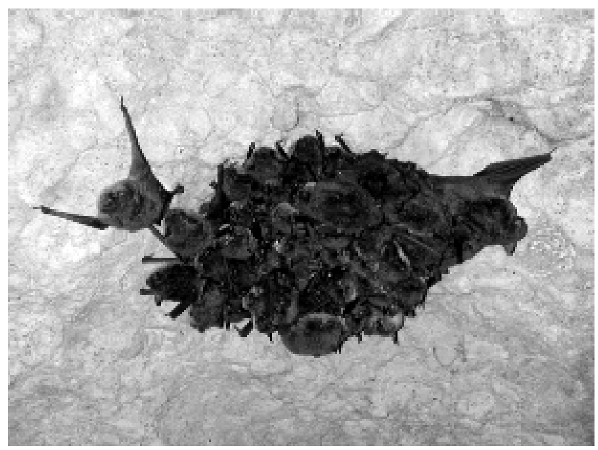

Figure 9. *A small, late summer cluster of Gray bats,* Myotis grisescens. *This endangered species is recovering in many caves where they are protected well, but may never reach its former numbers again.*

A bar graph (Figure 11) depicts the pooled count data for the above species from the first 14 caves visited. Black bars represent the initial surveys done around 1980, and hatched bars represent the current study. These are only preliminary data, which probably are not sufficient to warrant the statistical analysis that we plan to do at the conclusion of the study.

In general, however, since 1980 there has been a noticeable reduction in counts for many species. This is particularly true for grotto salamander, big brown bat, little brown bat, Indiana bat, and eastern phoebe. Gray bats are not graphed because the data would have greatly

Figure 10. Scoliopteryx libatrix, *the Herald Moth, overwinters in eastern U.S. caves.*

changed the Y-axis of the overall graph. Thirty-seven gray bats were observed in the first 14 caves in the earlier study, but we found about 2,747 gray bats in the current study, mostly from discovering an undocumented maternity colony in one cave. The latter discovery is good news for this species, which is slowly recovering in sites where it is well-protected (Elliott and Clawson, 1999).

Discounting gray bats, whose counts would obscure trends in the other data, total counts were down 34% (262 versus 172), amphibians were down 23% (165 versus 127), and bats were down 54% (93 versus 43). However, counts of pickerel frogs, which take refuge in wet caves in large numbers during drought and winter, held steady. Counts for a key species, the stygobitic grotto salamander, were down 67% (24 versus 8). Eastern pipistrelles, the most commonly seen bat, were up 233% (15 versus 35), while big brown bats were down 93% (54 versus 4).

Discussion

We emphasize that these are preliminary results only. Some species are not accurately represented in this data set because of their seasonal use of caves, for example big brown bats, which hibernate in caves but are not usually found there during the July 10 through October 10 time period of this data set. We expect that some of the "trends" will disappear or reverse after data for a full year are collected.

In one species with less seasonality, however, we see a suggestion of a downward trend that may be the result of three years of drought in the Ozark Region. Because of the drought, stygobitic grotto salamanders may have burrowed into moist, inaccessible microhabitats where we could not observe them, or they could have declined. Many cave streams are at extreme lows as we write this paper. Of the five caves where we counted grotto salamanders, three counts were down, one was up, and the species was found for the first time in one cave.

That drought may have affected some of the cave fauna is suggested by the apparent trend in two frogs, which take refuge in wet caves

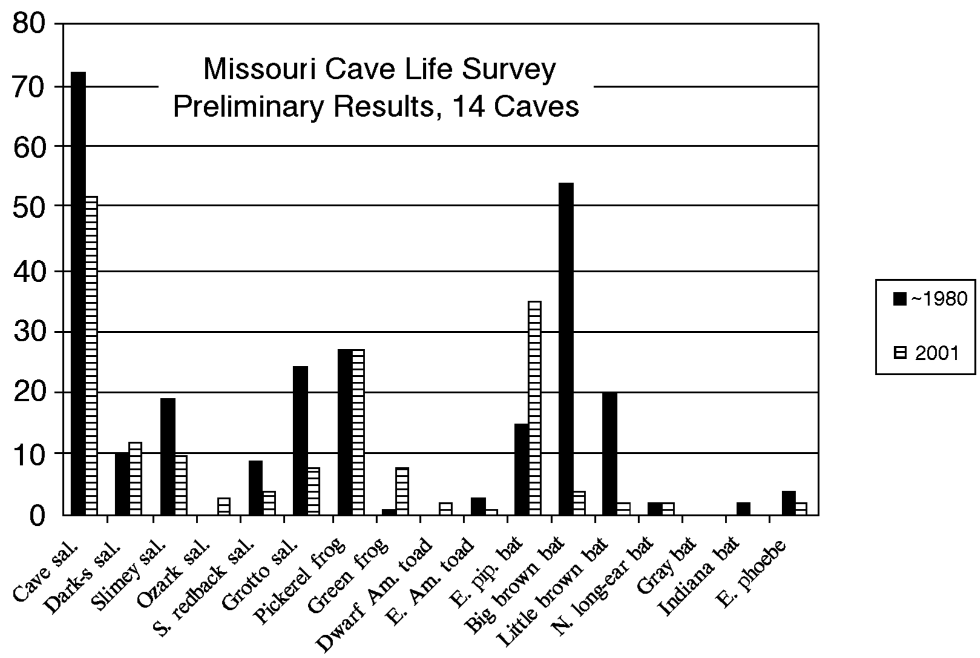

Figure 11. Graph of preliminary results from 14 caves and 17 species. Grey bats are omitted (See Results paragraphs).

during drought and winter. Pickerel frogs held steady (27 and 27), and green frogs increased (1 versus 8). For these frogs, relatively dry caves would still be wetter than dry, epigean habitat.

Conclusions

We are concerned that a key species, the grotto salamander, may have declined severely in Missouri, possibly as much as 67%. At the end of our study we may have sufficient data to confirm if this decline is true and to determine if drought, overuse of some caves, or both have contributed to such a decline. The grotto salamander formerly was a species of concern in Missouri, but it was removed from the state list in 1999.

Caves are not just habitat for troglobites and stygobites. Many trogloxenic and troglophilic species utilize caves for refuge, mating, or nesting. If common species have declined in caves, it would be important to identify if humans have caused the declines and to restore habitat. This study may not determine all the causes of declines, but it may provide direction for further study of certain species or land management activities that could restore wildlife populations in caves.

Other benefits of this study are the knowledge and resources gained by cavers and the Missouri Caves and Karst Conservancy for future projects. The booklet, data form, and procedures will be used in other projects. We probably will add new caves to the study to increase our baseline information for the future.

Acknowledgments

We are grateful to the U.S. Fish and Wildlife Service for their support of this study. David Urich, Natural History Division, Missouri Department of Conservation, was essential in making this grant possible. Data for designing this study were obtained from the Natural History Division's Missouri Biospeleological Database. We thank James E. Gardner for his contribution of data. Dr David C. Ashley, Missouri Western State College, and Dr Robert Lerch, U.S. Department of Agriculture and the University of Missouri, Columbia, provided essential training and field work. We thank Saint Louis University for the use of Reis Biological Station for training and planning. We are grateful to the USDA-Forest Service, National Park Service (Scott House), Missouri Department of Natural Resources (Parks Division), and private landowners for access to caves and staff time. Missouri Department of Conservation biologists Brian Loges and Rob Chapman assisted in the field. A hearty thanks goes to the Missouri Caves and Karst Conservancy, whose officers and members volunteered many hours of hard work, food, and transportation for this study: Brian Andrich, Mark Andrich, David Ashley, Hal Baker, Bill Bantel, Jonathan Beard, Robert Bilbrey, Michael Carter, Jeffery Crews, Jim Donley, John Drew, Deb Dumont, Rick Haley, Tim Harrison, Gary Hart, Todd Heintz, Peddgie Heinz, Scott House, Amy Johnston, Rusty Jones, Steve Kaub, Jennifer Kinkead, Cheryl Kinsel, Sally Kula, Lorely Lather, Ron Lather, Robert Lerch, Alicia Lewis-Miller, Matt Marciano, Brian McAllister, Cheryl McEnany, Adele Ming, Philip Newell, Tom Panion, Wayne Pierce, James Potts, Joe Roberts, Jack Rosenkoetter, Jim Ruedin, Jo Schaper, Joe Sikorski, Robert Stratford, Trevor Stroker, Carl Thayer, Lisa Thayer, Don Toole, Jason Trussell, Joe Walsh, Lois Walsh, David Webster, and Rita Worden.

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Attachment 2

MDC/MCKC CAVE BIOINVENTORY FORM

Note: Use a new line for each different place that a species is observed or a water sample is taken (usually you may merge places within 50 m of each other). Record numbers can be marked on cave map. Write comments on line(s) under each record.Use additional sheets as necessary.

Record No.	Species (describe, if unknown) or Water Sample No.	Place in Cave	Dist. from Ent. (in m)	Habitat	Temp (air or water)	Number Observed (note immatures /larvae, if app.)	Observer/ Collector

Attachment 1

MDC/MCKC CAVE BIOINVENTORY FORM

TIME IN: TIME OUT: DATE:

SHEET#: OF:

COUNTY: CAVE NAME:

AREA:

OWNER: MSS#:

ADDRESS:

CITY: STATE: ZIP:

DIRECTIONS (use highway numbers, odometer distances, landmarks, etc.):

UTM COORDINATES (if possible): E N
DATUM (circle one): NAD27 NAD83
UNCERTAINTY OF LOCATION: (radius in m, EPE, or no. of satellites on GPS receiver):

TEAM MEMBERS, HOURS FOR EACH and MILEAGE FOR DRIVERS (include prep., travel and clean-up) (e.g. Joe Caver – 7h, 220 mi.):
LEADER:
RECORDER:
TOTAL MAN-HOURS: TOTAL MILES:

EVALUATION OF CAVE USAGE—Describe damage (type, age, distribution, etc.) and circle corresponding number on scale at right that describes the cave's overall degree of human impact – 0=no damage, 5=severe. Please remove trash and make notes on signs.

1. BONFIRES / CAMPING:0 1 2 3 4 5

2. LOOTING / DIGGING:0 1 2 3 4 5

3. GRAFFITI:0 1 2 3 4 5

A DNA Fingerprinting Technique to Survey Microbial Diversity in Caves

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Abstract

A comprehensive survey of microbial species from cave sediments and karst aquifers is needed in order to appreciate their role in cavern formation, aquifer evolution, and cave ecology. The time consuming practice of culturing organisms from the environment has had limited success for only a few species, and those organisms that cannot be grown in the lab are omitted. We extract DNA directly from cave sediments and amplify bacterial, fungal, or algal 16S rDNA using the polymerase chain reaction and selected primers labeled with fluorescent dyes. Genetic libraries of bacterial 16S rDNA have been generated from cave sediments at selected sites in Mammoth Cave, and hundreds of cloned 16S rDNA sequences from cave bacteria have been analyzed. Species are being identified or taxonomically classified by phylogenetic sequence analysis and comparison to electronic nucleic acid databases, and characteristic fragment lengths have been tabulated for cloned or cultured cave bacterial 16S rDNA and standards. The 16S rDNA sequence and fragment database constitutes a reference to which DNA profiles of cave sediment bacterial communities can be compared.

Introduction

Mammoth Cave in Kentucky, with over 500 kilometers of surveyed passages, is the longest known cave system in the world. It has been the focus of much research into the formation and evolution of limestone caves and karst aquifers and it harbors a unique subterranean ecosytem. Earlier studies in our laboratories have examined the rate of limestone dissolution in stream sediments at the lowest level of Mammoth Cave where carbon dioxide partial pressures are an order of magnitude higher than in the stream itself. The higher levels of carbon dioxide presumably result from the action on organic materials by microorganisms in the sediment. Some of the microorganisms may be producing other acids that accelerate limestone dissolution and thus contribute to cavern enlargement and aquifer evolution (Vaughn, 1998; Vaughn *et al.*,1998)

Before the impact of microbial action on cave formation and cave ecology can be assessed, a thorough census of microorganisms of caves and karst aquifers is required. Some attempts have been made to survey and identify bacteria associated with Mammoth Cave sediments by selective culturing and morphologic characterization; but, of the strains that could be isolated and grown on a dish in the laboratory, the majority could not be identified (Rusterholz and Mallory, 1994). Current efforts in our group are addressing bacterial involvement in limestone dissolution by growing cave bacteria in liquid culture (Elliott *et al.*, 2000).

There are difficulties in using direct culturing methods for the study of microbial ecology in environmental settings. Traditional methods rely on the ability to culture any bacterial species present under laboratory conditions using classical microbiological techniques. In natural environments bacteria do not live alone in isolated culture, but instead they form interdependent communities of bacterial species called biofilms. Environmental strains have unknown nutritional requirements and less than 1% of those actually present are ever isolated in the laboratory (Amann *et al.*, 1992; Siering, 1998). The unknown factors are magnified greatly when attempting to culture microorganisms from extreme environments such as hydrothermal springs or volcanic vents (Moyer *et al*., 1994; Hugenholz *et al*., 1998), deep-sea sediments (Vetriani *et al*., 1999), salt lake beds (Minz *et al*., 1999), and subterranean ecosystems (Rusterholtz and Mallory, 1994; Elliott *et al*., 2000).

However, modern DNA analysis techniques are revolutionizing our understanding of bacterial diversity in the environment and have been applied to extreme environments including particular caves known to harbor bacterial communities in isolated and unusual geochemical conditions. New genera of bacteria capable of expressing genes with medical and practical applications have been discovered and are now the focus of many cave microbial studies (Angert *et al*., 1998; Holmes *et al*., 2001; Northtup *et al*., 2000).

We have begun a survey of microorganisms inside Mammoth Cave using modern DNA analysis techniques for the first widespread inventory of its microbial communities. The method described below is suitable for a broad survey of bacterial communities throughout the vast cave system and is applicable to a large number of samples. Our technique relies upon comparison of bacterial DNA fingerprints to a cave bacterial database of detailed genetic information derived from cultured and cloned organisms from selected cave sediments. We invite collaborations with other caves nationwide to contribute to the growth of our cave biomarker database.

Description of the Technique

Genetic identification of environmental strains.

Using modern DNA technology, bacteria can be identified and classified according to the sequences of their genes encoding 16S ribosomal RNA (16S rDNA). Different species of bacteria possess characteristic 16S rDNA sequences. Bacterial 16S rDNA sequences may be selectively amplified from the mixture of DNA fragments extracted from the environment to create many copies for more detailed studies (Figure 1). With this technique, bacterial species can be identified and their genetic relationships can be determined without the need to culture individual strains in the laboratory. Furthermore, environmental bacteria that cannot be grown in the laboratory can still be detected by the presence of 16S rDNA (Siering, 1998; Angert *et al*., 1998; Holmes *et al*., 2001).

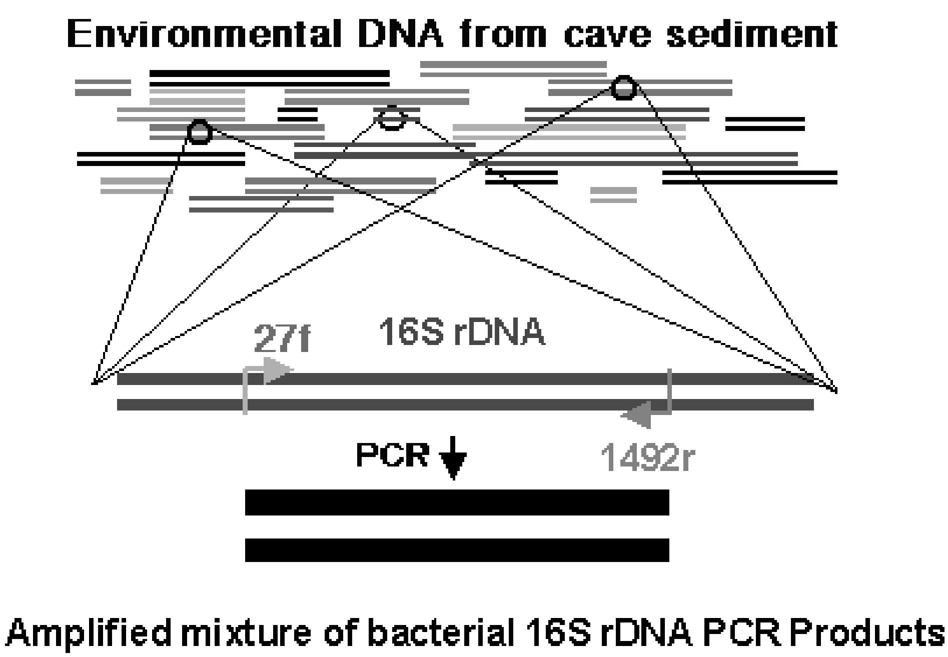

Figure 1. *Diagram showing how specific DNA sequences extracted from cave sediment can be targeted for analysis using the Polymerase Chain Reaction (polymerase chain reaction).* Some of the many different fragments of environmental DNA encode bacterial 16S rDNA (top). The 27f and 1492r short DNA sequences are conserved among the bacteria (middle), and they can be used as primers to amplify a mixture of bacterial 16S DNA sequences (bottom) while incorporating fluorescent dyes for analysis.

Sampling and DNA extraction

Sediment samples were collected from upstream, middle, and downstream points within Charons Cascade, along Echo River at the lowest level of Mammoth Cave. Sediment was scooped wearing latex gloves into sterile centrifuge tubes (Figure 2A) and kept on ice until DNA was extracted. DNA was extracted from one gram of cave sediment using a simplified procedure, and the mixed environmental nucleic acids were visualized by agarose gel electrophoresis (Figure 3). Cave sediment contains many microorganisms, including bacteria, fungi, protozoans, and even larger cave invertebrates (Figure 2B) with small particles of dead plant and animal material. All of these things contribute to the mixture of DNA fragments that can be extracted directly from cave sediment.

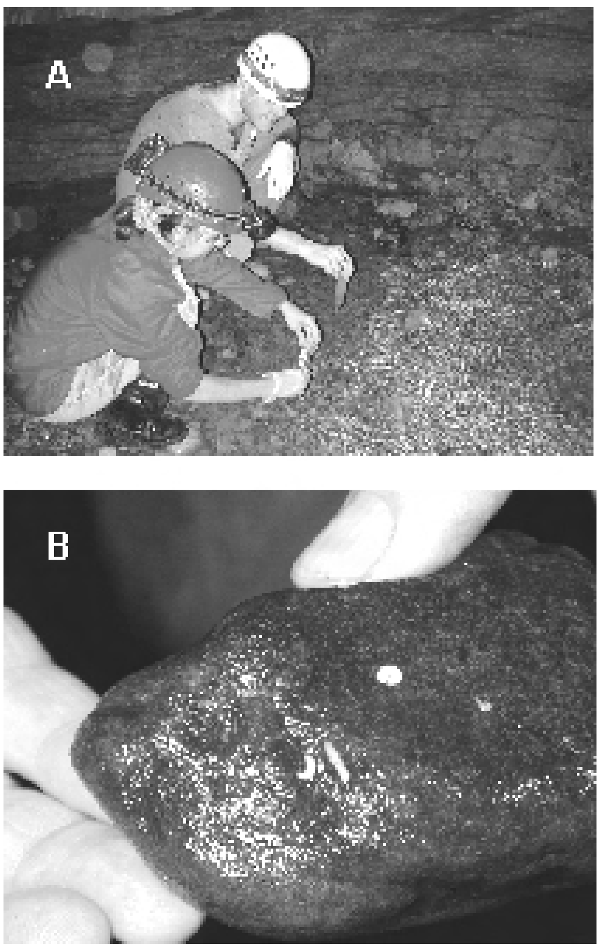

***Figure 2**. Sample collection in Mammoth Cave.* Sediment was scooped wearing latex gloves into sterile tubes (A) and kept on ice until DNA was extracted. In addition to bacteria, environmental DNA contains sequences from fungi, protozoans, and even cave invertebrates (B) with decomposed plant and animal material.

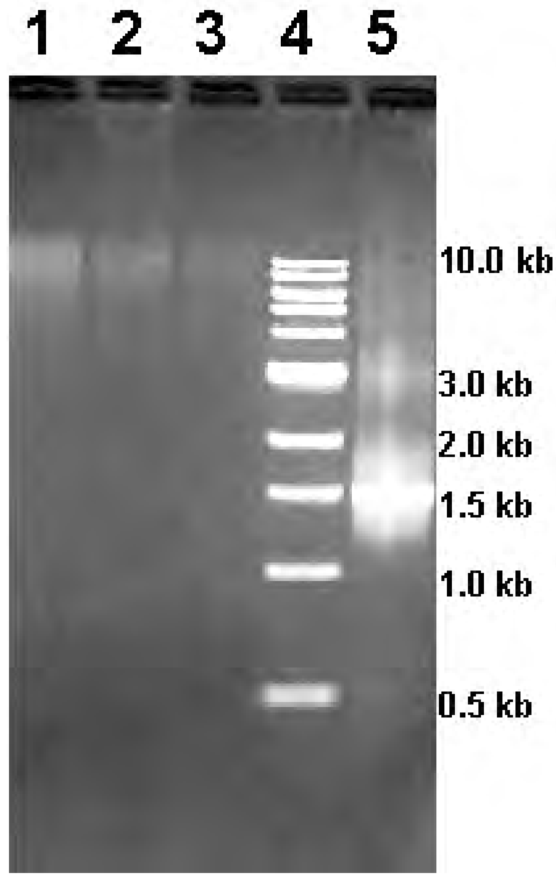

Figure 3. *Agarose gel showing cave sediment DNA and 16S rDNA polymerase chain reaction product.* DNA fragments at approximately 10.0 kb were extracted from 0.5 g sediment collected at upstream (lane 1), middle (lane 2), and downstream (lane 3) sites near Charons Cascade. DNA was amplified by polymerase chain reaction to

Amplification of 16S rDNA

In order to study the DNA of cave bacteria among all the DNA fragments present, specific DNA sequences were amplified out of the mixture using the polymerase chain reaction with specific bacterial primers. Our study focuses on the bacterial community in general thus we are using primers 27f and 1492r, short sequences that are conserved among a broad range of bacteria (Lane, 1991; Layton *et al*., 1994).

A polymerase chain reaction product from cave sediment representing the cave bacterial community was seen by agarose gel electrophoresis with the expected size of about 1.5kb (Figure 3). The environmental polymerase chain reaction product consists of a mixture of 16S rDNA from all bacterial species that have in common

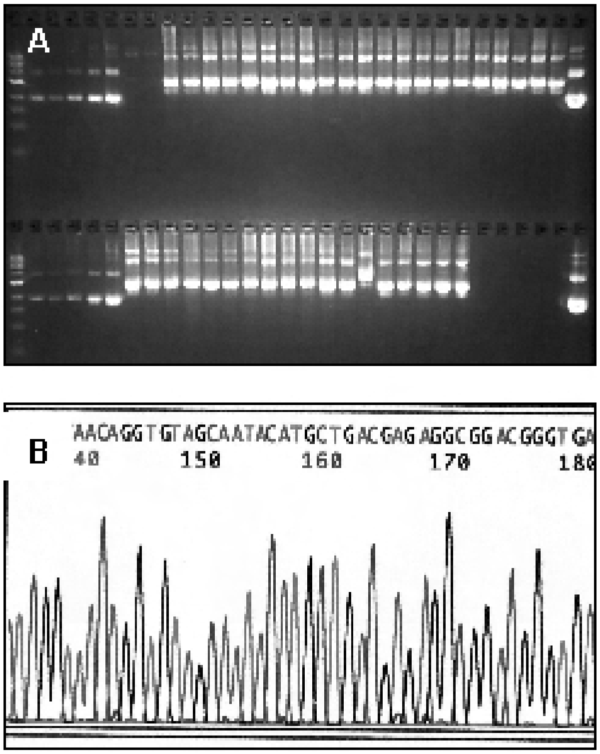

Figure 4. *Agarose gel (A) showing plasmid DNAs from a cave clone library and automated DNA sequencing data (B).* Each of the cloned plasmid DNA molecules shown on the gel carries one kind of bacterial 16S rDNA from the cave sediment (A). The DNA sequence of each cloned 16S rDNA was determined using automated fluorescent DNA sequencing with capillary electrophoresis (B) to generate data that was compared to online genetic databases. Table 1 shows a summary of the taxonomic groupsof the nearest genetic relatives using the Ribosomal Database Project online (http://rdp.cme.msu.edu).

the 27f and 1492r primer sequences. In order to differentiate among the many types of bacteria in the community, we must sort the amplified genes by molecular cloning and DNA sequencing or distinguish them by their terminal restriction fragment lengths.

Cloning and Sequencing

The amplified 16S rDNA was spliced into a cloning and sequencing vector plasmid DNA. The circular recombinant plasmid molecules thus produced were used to transform *E. coli* for studies of individual copies of the environmental genes. A cave clone library of *E. coli* host cells carrying cave DNA sequences was created and plasmid DNA was purified from each clone. Each clone harbors just one type of recombinant plasmid DNA representing one bacterial 16S rDNA sequence originating from the cave sediment (Figure 4A).

Table 1. Nearest genetic relatives within clone library of bacteria from Mammoth Cave.

Taxon:	No. of clones (%)
Nitrospina sub dv.	8 (18%)
Proteobacteria	
Alpha	6 (14%)
Beta	8 (18%)
Gamma	1 (2%)
Delta	3 (7%)
Gram-positive	4 (9%)
Environ. clone WCHB1-31 grp.	4 (9%)
Unclassified/Unaligned	4 (9%)
Planctomyces and relatives	3 (7%)
Environ. clone PAD1 grp.	1 (2%)
Green non-sulphur and relatives	1 (2%)
Flexibacter/Cytophaga/Batteroides	1 (2%)

Nucleotide sequences of bacterial 16S rRNA genes from the clone library and cultured bacteria have been determined (Figure 4B) and compared to DNA sequence databases to find the taxonomic classification of the nearest genetic relative (Table 1). Four subgroups of Proteobacteria representing a high degree of diversity corresponded to 41% of the clones sequenced. It is noteworthy that 18% of the clones were closely related to the Nitrospina subdivision with few species previously known. Nitrospina may contribute to cave geochemistry and acid production through nitrification reactions that accumulate nitrate, particularly in the absence of plants. Other clones were related to Gram positive species, Planctomycetes, and various uncharacterized bacteria commonly found in soil. Some of the matches raised ecological red flags by indicating the presence of bacteria that derive energy through biodegradation of petroleum, creosote, heavy metals, or sewage.

Fragment Analysis

Rather than commit to cloning and sequencing from every cave sample examined, a snapshot of bacterial diversity can be generated easily and quickly for a larger number of samples by terminal restriction fragment length polymorphism (TRFLP) analysis. Snapshots from environmental samples depict multiple types of bacteria within the community in a given sediment sample, and the profile generated is a "fingerprint" with information about the types of bacteria present and their relative abundance.

Environmental DNA from cave sediments, plasmid DNA from the cave clone library, and

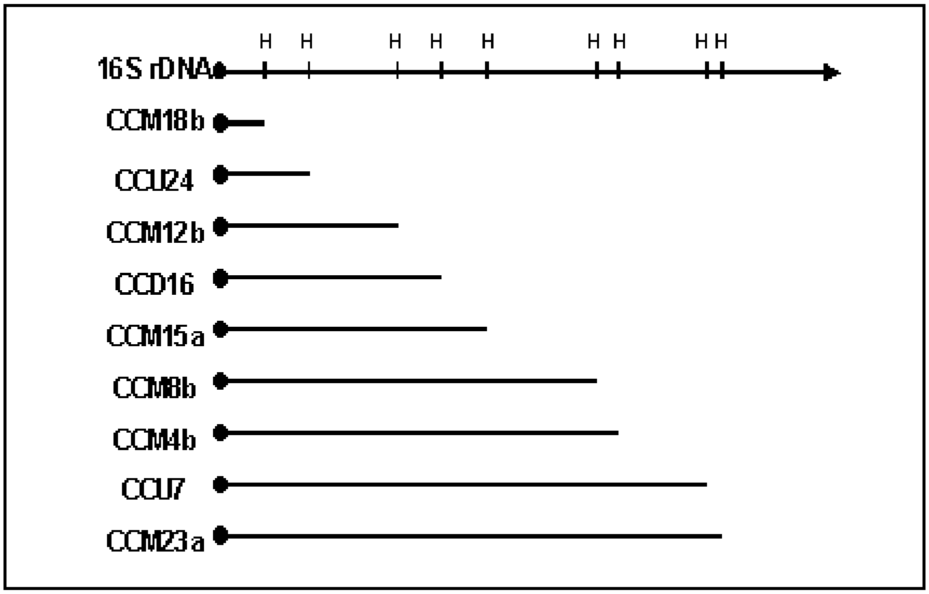

Figure 5. *Diagram showing fluorescent fragments that can be used as biomarkers for bacteria.* Fluorescent 27f primer was used to produce a mixture of labeled bacterial 16S rDNA sequences from cave sediment (top). Depending upon their individual DNA sequences, the fragments are cleaved by the enzyme HhaI (H) at some specific distance from the fluorescent terminus. A profile of the fragments derived from cave sediment is called a fingerprint. Fragment lengths with DNA sequence data from cloned and cultured bacterial 16S rDNA can be used to interpret the fingerprints.

Environmental DNA profiles are interpreted with the aid of the tabulated fragment data. DNA fingerprints of cave bacterial communities are labeled blue with 27f primer, while cloned or cultured standards are labeled green or yellow. Digestion of both environmental and cultured or plasmid DNA with HhaI followed by simultaneous capillary electrophoresis allows the corresponding peaks in the environmental profile to be directly superimposed with the 16S rDNA data from cloned and cultured bacteria (Figure 6).

genomic DNA from cultured organisms was amplified with fluorescent-labeled primer 27f and non-labeled 1492r. We obtained copies of 16S rDNA labeled at the 5' end of the 27f primer sequence with blue, green, or yellow fluorescent dyes. The end-labeled fluorescent polymerase chain reaction products were then digested with the restriction enzyme HhaI to generate fragments which were analyzed on a fluorescent genetic analyzer. Only the fragment from the fluorescent terminus up to the most proximal HhaI site is labeled and therefore observed by the fluorescence detector.

When TRFLP analysis is applied to the purified plasmid DNA samples in the clone library, each clone yields a single peak in the electropherogram with a characteristic defined fragment length determined by that particular DNA sequence. A total of 103 bacterial 16S rRNA genes have been analyzed by TRFLP including 87 from Charons Cascade in Mammoth Cave, along with nine cultured organisms from Mammoth Cave, four cultured from Lost River Cave, and three ATCC standard cultures. Their fragment sizes have been averaged over multiple determinations and tabulated in a database along with the corresponding DNA sequences and phylogenetic data.

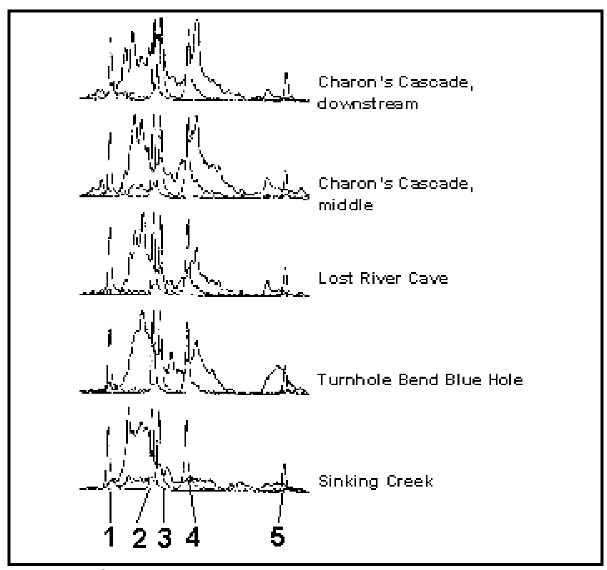

Figure 6. *Bacterial DNAfragment profiles from various cave and karst sediments superimposed with DNA fragments from the cave bacterial database. Bacterial 16S rDNA fingerprints labeled with blue fluorescent dye were mixed with yellow and green 16S rDNA fragments from cloned and cultured bacteria in the database. Standards are (1) MCNP clone CCU10, (2) Pseudomonas env. str. MCNP-CCCO12, (3) Pseudomonas env. str. MCNP-CCCO8, (4) MCNP clone CCU8, and (5) Staphylococcus aureus from a* standard depository (ATCC).

Summary

Our technique, summarized in Figure 7, allows many different bacterial types to be surveyed in a single DNA test that can be applied to a larger number of cave sites. Of particular interest are those sites known to be undergoing limestone dissolution and cavern enlargement and where geochemical and hydrological data are being collected. The growing database of DNA sequence and phylogenetic information along with fragment sizes from the cave clone database provides a means for recognizing and monitoring bacterial species in cave sediments, without the need to isolate and culture the organisms.

Acknowledgments

This work was supported by the Western Kentucky University Biotechnology Center and a Junior Faculty Research Award to S. Sahi. Tricia Coakley and Larry Elliott provided cultured organisms. Wes Braden, Roger Greenwell, and Matt Honaker collected samples and performed laboratory work. Mark DePoy, Rick Olson, and Joe Meiman coordinated sampling expeditions, processed permit applications, and were responsible for scientific supervision at Mammoth Cave National Park.

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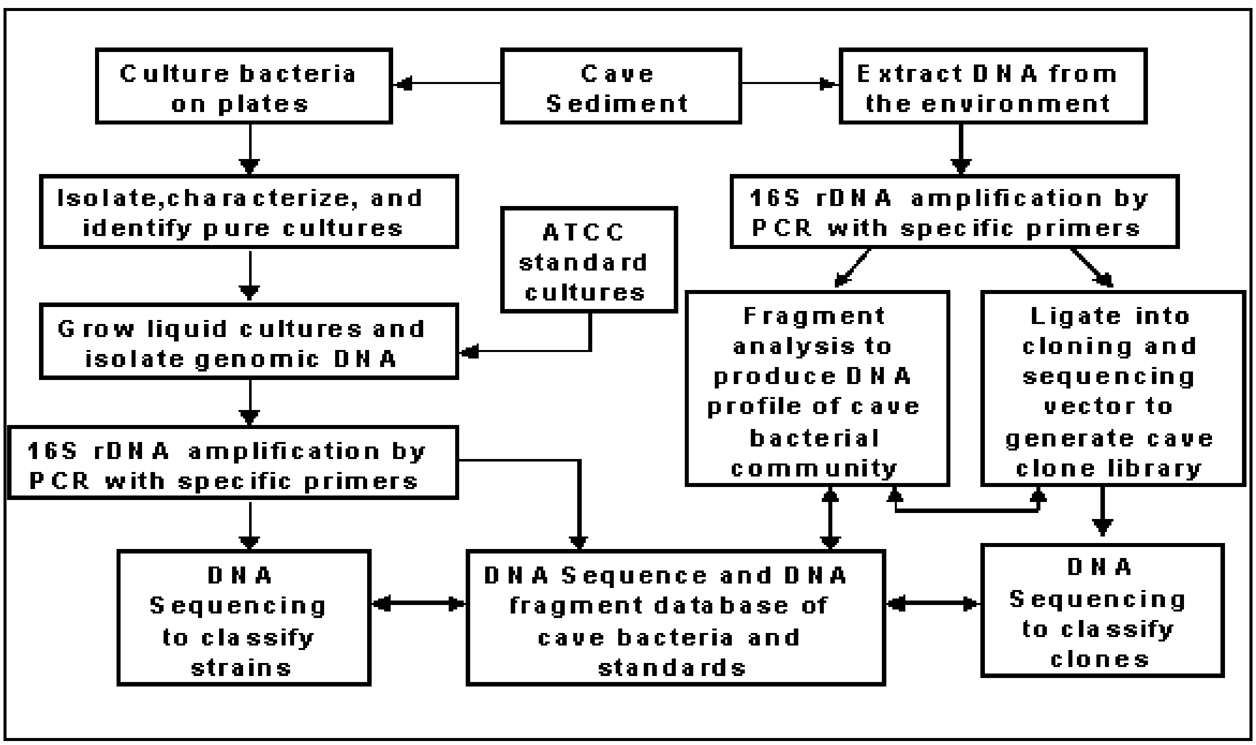

Figure 7. *Flow chart of information leading to the creation and growth of the database of genetic markers for cave bacteria.* On the left, cave sediment is the source for bacteria cultured and identified on plates. Isolated bacteria from the environment and from standard collections can be grown in liquid culture to yield DNA that can then be analyzed by DNA sequencing and fragment analysis to contribute to the database.On the right, environmental DNA can be extracted directly from cave sediment and subjected to polymerase chain reaction with specific bacterial primers. The amplified mixture of polymerase chain reaction products can be individually sorted and identified by cloning and sequencing the cave bacterial 16S rDNA. To survey a larger number of samples, the amplified polymerase chain reaction mixture is labeled with fluorescent dye and subjected to fragment analysis to produce a profile that is interpreted with the aid of the database.

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Caves and Mine Adits as Wildlife Resources in the Sonoran Desert Region

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Abstract

Natural caves are rare in the Sonoran Desert region and anthropogenic mine adits are abundant and similar to caves in many respects. Both caves and mines are important resources for several wildlife species that live in the Sonoran Desert region. Wildlife uses include short-term shelter from variable ambient temperature and humidity and long-term uses such as maternity roosts, den sites, and nest substrates. Some predatory species also use mines and caves as hunting sites. Animals that use these resources include mammals (several species of bats, bighorn sheep, collared peccaries, ringtails, foxes, packrats, mice, mountain lions, and others), birds (turkey vultures, rock wrens, Say's phoebes, barn owls, and others), herpetofauna (several species of rattlesnakes, toads, lizards), and invertebrates. Many of these sites are also used by people for recreational or economic uses. The wildlife values of these sites have prompted their inclusion as protected sites in the Sonoran Desert Conservation Plan, a county government plan for the long-term protection of biodiversity in the Tucson area and 5,000,000-acre Pima County. This paper will describe wildlife uses of caves and mines in this area, list species known to us to use caves and mine adits, give examples of especially important sites, discuss management approaches, and review the process of including them in the Conservation Plan.

Introduction

Natural caves are very rare in the Sonoran Desert region. Mine adits are abundant and similar to caves in many respects. Pima County, Arizona, an area of over 5,000,000 acres has only a handful of natural caves but hundreds of mines. The State of Arizona estimates some 100,000 inactive mines statewide. More often than not, mines are found in areas devoid of natural caves, under geological conditions that do not foster cave development. Mines may be the only accessible subterranean features under these circumstances and they provide important resources for native wildlife.

Very few species of true troglobites have been described from Arizona and none are also known from mines. Many species of trogloxenes are known to use both caves and mines. In some instances, simplified ecosystems resembling those found in natural caves in other parts of the world have developed in mines in the Sonoran Desert.

Because of their rarity and locations on public lands, most Sonoran Desert caves are protected. The wildlife values of mines warrant consideration for protection also. The wildlife values of caves and mines in the Sonoran Desert sites have prompted their inclusion as protected sites in the Sonoran Desert Conservation Plan, a Pima County government plan for the long-term protection of biodiversity in the Tucson area and the 5,000,000+-acre county.

Wildlife Uses of Caves and Mines

Both caves and mines are important resources for several wildlife species that live in the Sonoran Desert region. They provide shelter from hot, dry conditions and from predators. There are few currently known species of troglobites in the Sonoran Desert region. Most wildlife species use caves and mines as short-term shelter, occupying a site for only a few hours or days during adverse weather conditions. Several species of bats use caves and mines as maternity roosts, day roosts, night roosts, or courtship areas. Some species of birds use caves and mines as shelters in which they build nests. Several mammal species use caves and mines as den sites. Table 1 lists the wildlife taxa using caves or mines observed by one or more of the authors.

Table 1. Wildlife Species Known to Use Caves and Mines in the Sonoran Desert Region

Invertebrates
- camel crickets
- daddy longlegs
- flies
- mosquitoes
- springtails

true troglobites– *few described, not known from mines*

Amphibians
- red-spotted toad
- barking frog
- lowland leopard frog
- tiger salamander

Reptiles
- tree lizard
- side-blotched lizard
- eastern fence lizard
- Clark's spiny lizard
- desert spiny lizard
- alligator lizard
- Gila monster
- desert tortoise
- western diamondback rattlesnake
- Mojave rattlesnake
- tiger rattlesnake
- black-tailed rattlesnake
- rock rattlesnake
- speckled rattlesnake

Birds
- great horned owl
- barn owl
- white-throated swift
- cliff swallow
- violet-green swallow
- Say's phoebe
- canyon wren
- rock wren
- house wren
- turkey vulture
- black-throated sparrow

Mammals
- Townsend's big-eared bat
- Allen's big-eared bat
- spotted bat
- pallid bat
- cave myotis
- southwestern myotis
- small-footed myotis
- fringed myotis
- California myotis
- Yuma myotis
- western pipistrelle
- big brown bat
- California leaf-nosed bat
- lesser long-nosed bat
- Mexican long-tongued bat
- Mexican free-tailed bat
- western mastiff bat
- cactus mouse
- canyon mouse
- brush mouse
- white-throated woodrat
- desert woodrat
- Mexican woodrat
- porcupine
- rock squirrel
- black bear
- ringtail
- bobcat
- mountain lion
- gray fox
- kit fox
- coati
- spotted skunk
- striped skunk
- hognosed skunk
- mule deer
- bighorn sheep
- collared peccary

Biological Exploration of Caves and Mines in the Sonoran Desert

Few of the known caves have been well studied over a period of years. Unique species have been found. Other caves have had very little, if any, biological exploration. Some caves receive some level of recreational use. One known cave is strictly protected and only accessible to researchers.

Most mines have never been examined by biologists. Of those that have, about one in ten (on average) are used by bats as day roosts and about four in ten are used as night roosts. In one recent survey of 21 adits four had no evident use by wildlife, five were used by bats, eight were used by other mammals, eight were used by birds, 11 had rattlesnakes of three species, and nine had evidence of vandalism, including beer cans, shotgun and cartridge shells, and other trash.

The wildlife values of inactive mines are so important that they should be studied and protected. Most government agencies that manage land with inactive mines now require surveys before any officially sanctioned disturbance occurs. Few efforts have been made to protect mines from vandalism.

Exploring inactive mines can be much more dangerous than cave exploration. Walls and ceilings are unstable, support timbers may be rotten, hazardous materials (including explosives) may have been left behind, booby traps may have been set, and some wildlife species may react defensively to human intruders.

Caves, Mines, and The Sonoran Desert Conservation Plan

The Sonoran Desert Conservation Plan is an ongoing process being developed by Pima County to guide future development and management of land while ensuring continued high biological value and protecting the biodiversity of the County. The process includes designation of Conservation Lands within the County, including all known caves as well as mines that are known to be used by bats. Several species of cave and mine roosting bats are included as species covered by the plan process. Known roosts of these bats are included in the planning process as constraints, to be protected under all alternatives for the plan. Protective measures will be developed for each as appropriate and necessary.

How Much Surface Habitat is Enough? Preserve Design and Application for Cave-Limited Species

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Abstract

Central Texas supports some of the world's most biologically rich and diverse cave ecosystems. The rapid pace of urban expansion threatens many of these ecosystems and has led to the federal listing of 16 cave-limited invertebrates as endangered. Due to their rarity and endemicity, destroying even a very few caves means certain extinction for many cave species, as these environments cannot be recreated. To avoid this outcome and assist developers in complying with the Endangered Species Act, we have developed preserve design recommendations to promote the species' survival in perpetuity. Historically, conservation efforts have focused solely on protecting cave entrances and drainage basins. Here, we take a broader perspective and consider population viability requirements of the surface plants and animals that are intricately intertwined with the life support system of each cave. We conclude that long-term protection entails a minimum preserve size of 69 to 99 acres (0.27923 to 0.40064 square kilometers) around a given cave or cave cluster, as well as maintenance and adaptive management to ameliorate other insidious threats, such as infestations of red, imported fire ants (*Solenopsis invicta*). Problems associated with setting these preserve standards in rapidly developing areas include inflated land values, public response, limited data on the species of interest, and the improbability of re-populating a cave once the species is extirpated.

Managing Endangered Species: Charting the Course of the Illinois Cave Amphipod with Non-lethal Censusing

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Abstract

In 1940 the Illinois Cave Amphipod, *Gammarus acherondytes*, was described as a new species. The only obligate subterranean amphipod of the genus *Gammarus* in North America, this unique crustacean was described from two caves in southwestern Illinois. By 1988, cave bioinventories had revealed *Gammarus acherondytes* in a total of six caves just southeast of metropolitan Saint Louis. Over time, groundwater quality deteriorated in the area as land use changed. In 1995 *Gammarus acherondytes* could not be found in two previous sites and was barely present in two others. The amphipod was listed as a federally endangered species in 1998. In 1999 bioinventory by The Nature Conservancy revealed six additional cave populations, two in groundwater basins where the amphipod was previously unknown. As an endangered species, *Gammarus acherondytes* presented a censusing dilemma. There was no way known to monitor the 12 cave populations of *Gammarus acherondytes* without killing the amphipods to count them. In 2000 a project was initiated to see if it would be possible to measure the population sizes without killing the tiny endangered animal. Experimental census transects were established in several caves. To eliminate sampling prejudice, quadrats were randomly placed within the transects. Using a hand-held 15X microscope it was possible to separate *Gammarus acherondytes* from three other species of co-occurring cave amphipods. All animals were identified, measured, and released immediately back into the stream. The method was painstaking and labor intensive, but successful. Full-scale censusing of the endangered species commenced in 2001.

Introduction

The subterranean amphipod, *Gammarus acherondytes,* was described by Hubricht and Mackin (1940) from specimens collected by Leslie Hubricht from Morrisons Cave (Illinois Caverns) and Stemler Cave in the karst of southwestern Illinois. Bousfield (1958) redescribed the species but added no new localities. Based on collections in the mid-1960s, Peck and Lewis (1978) added Fogelpole, Krueger/Dry Run, and Pautler Caves to the list of localities from which this amphipod was known. In 1976, Lewis visited Illinois Caverns and Stemler Cave to evaluate the sites for the Illinois Natural Areas Inventory. The cave communities were inspected and appeared intact at that time, but no collections were made. However, over the next 20 years the land use of the area began to change from primarily agricultural and second growth forest into a region with an increasing suburban component. Webb (1995) reported that *G. acherondytes* could no longer be found in Stemler Cave and only small numbers of the amphipods were present in the other sites (Pautler Cave was reportedly closed by the owner). Fueled by the growing interest in *G. acherondytes*, The Nature Conservancy conducted a bioinventory of caves in Monroe and Saint Clair Counties (Lewis, Moss, and Tecic, 1999). This project resulted in the report of six additional caves with populations of *G. Acherondytes*. During that same year, *Gammarus acherondytes* was added to the U.S. Endangered Species List.

During the bioinventory by The Nature Conservancy it became apparent that little had been done to provide a basis by which the populations of *Gammarus acherondytes* could be measured. Webb (1995) had collected amphipods in various parts of several caves using a biased sampling technique that considered only the amphipod subset of the total community. Lewis, *et al*. (1999) collected samples in a similar manner to produce results that could be compared to what had already been done. These samplings of the populations provided little data that could be duplicated to determine the ongoing situation with *G. acherondytes*, while killing the endangered animals that were purportedly being "saved."

Thus was born the *raison d'etre* for developing a non-lethal method for estimating populations: to provide a yardstick by which the status of *Gammarus acherondytes* could be measured in the future to see if the situation was getting better, getting worse, or staying the same. The best method for censusing anything is to count the entire population. This is obviously not possible with a cavernicolous invertebrate, therefore leading to the alternative of examining a subset of the population. Many methods are known for preparing population estimates. We have chosen to use one that was suggested to Julian J. Lewis by cave ecologist Thomas L. Poulson for population biology studies in the aquatic communities of the Flint-Mammoth Cave System of central Kentucky.

Population Estimate Methodology

In general, the method consists of counting and measuring all species present (not just a target organism of interest) in multiple, randomly-selected quadrats along a series of transects. Analyzing the entire community, rather than merely a population within it, provides a much more complete picture of what is happening in the ecosystem. Concerning measurement of the animals, many stygobitic organisms have populations that are skewed toward older (larger) individuals with fewer juveniles (smaller) or ovigerous females. Although it might be impossible to glean the exact size of an amphipod, an estimate of six millimeters for an amphipod places the animal in a subadult cohort that obviously differs from a two-millimeter brood release or an 18-millimeter adult. This provides important information when the entire community is measured.

The fauna

Aquatic cave communities are usually relatively simple, comprising a handful of species that can frequently be identified easily, even in the field by the naked eye. Unfortunately this is not the case in western Illinois cave streams in which there are four species of amphipods that are of approximately the same size and shape. Non-lethal identification of the amphipods was the most challenging part of the project.

Cave stream communities in the western Illinois karst of Monroe and Saint Clair Counties typically comprise an assemblage of species: the flatworm *Sphalloplana hubrichti* (stygobite); snails *Fontigens antroecetes* (stygobite); *Physella* sp. (stygobite or stygophile); isopods *Caecidotea packardi* (stygobite); *Caecidotea brevicauda* (stygophile); and amphipods *Gammarus acherondytes* (stygobite), *Gammarus troglophilus* (stygophile), *Bactrurus brachycaudus* (stygobite), *Crangonyx forbesi* (stygophile). Detailed analysis of the identification of these animals was presented by Lewis (2000).

Census transects

The first priority in the establishment of transects was the presence of a landmark felt to be of an enduring nature, such that a researcher desiring to repeat the census a century from now would have an excellent chance of finding the same spot again. For each riffle transect, when facing upstream the census start point was the point at which the riffle ended and pool habitat started on the right-hand side of the riffle. A square foot (30 by 30 centimeters) Surber sampler was used to collect samples. Randomization of the sample sites was done by selecting each sample site with a number taken from a random numbers chart (available in most statistics books). The starting spot in the random numbers chart was selected first by random selection on the chart. From the point selected, the numbers were read down the column and the first two digits used to select the sample spot. A flexible plastic tape measure was stretched down the right hand side (facing upstream) of the riffle. Using the random number, the first digit was used to select the number of feet up the tape for the first quadrat. The second digit was the percentage across the stream from the right hand bank. For example, if the first number was 4268, and the stream was 10 feet wide, the first quadrat would be placed four feet up the riffle and 20% (two feet) across the stream from the right bank. After the Surber sampler was placed, a ruler was placed in the shallowest and deepest part of the quadrat and the depth recorded. If the water depth was less than about 2.5 centimeters the animals present were censused *in situ*. If the water was deeper than 2.5 centimeters the gravel was dislodged and animals allowed to wash into the sampler. All rocks were visually inspected for animals clinging on them.

Several large plastic beverage cups were carried into the cave and used to wash any animals or other material clinging onto the net of the sampler into the plastic container on the bottom of the sampler. Usually 8 to 12 washings were adequate. The contents of the sampler were released at streamside into a plastic bowl. On the first day of censusing a four-inch square bowl was used and was immediately recognized as inadequate in size. That evening an 8- by 12-inch Rubbermaid plastic bowl was purchased and was found to be an ideal size for carrying into the cave as well as containing the samples. All animals except amphipods were identified immediately visually, measured with a millimeter grid placed in the bottom of the bowl, and released back to the stream. Amphipods were placed in a dish with a millimeter grid prepared by photocopying graph paper (five grids per centimeter) onto 8½ by 11 inch 3M Transparency Film. Initially an 8X Loop was utilized for identification of the amphipods, but the 15X magnification provided by a Waltex hand microscope was found to give better viewing of animals less than six millimeters in length. A 2.5X Optivisor was found to be ideal for identification of amphipods greater than ten millimeters and the other aquatic invertebrates present in the samples. Immediately after identification all invertebrates were released back into the stream.

As-noted habitat was characterized by measuring the water depth in centimeters and giving an approximate description of the composition. Small particle size was characterized as clay if it was smooth when rubbed between the thumb and forefinger, and sand if it was gritty to the touch. Gravel was anything larger than sand up to three centimeters in size, cobbles were larger than three centimeters. Pieces of breakdown present were measured and noted.

It was noted that some animals, particularly flatworms and snails, occurred mostly under larger pieces of rock. Thus, in each transect it was decided to use a timed census rock count. This method consists of picking up larger rocks, identifying all of the fauna present on them, sight-estimating the size, then returning the rock and animals immediately to the stream. It was decided to do five-minute timed counts and to lift rocks larger than about ten centimeters throughout the transect. The number of rocks surveyed and an estimate of the size of the rocks were included in the census data.

Results

The raw data was recorded in the cave and then transcribed into a standardized spreadsheet format. On this datasheet is contained the name of the site, the location within the cave of the census area, date and personnel conducting the census, random numbers used to generate the quadrats, a description of the quadrat microhabitat, and the lengths of all animals found.

Population size of the Illinois Cave Amphipod can be estimated by extrapolating the area sampled to encompass the total area of the transect. Alternately, the relative proportions of the populations in different caves (or different parts of the same cave) can be compared by analyzing the mean number of amphipods per quadrat (square foot), which requires no extrapolation. For example, areas censused in Fogelpole Cave ranged from 0 amphipods per quadrat in the nature preserve entrance area to 1.7 amphipods/quadrat in the upstream part of the caves. The largest populations were found in Pautler Cave (up to 1.3 amphipods per quadrat), Fogelpole Cave (1.7 amphipods per quadrat) and Frog Cave (up to 3.3 amphipods per quadrat).

The data can be analyzed in a variety of other ways. For example, microhabitat preference of *Gammarus acherondytes* was examined as a function of substrate versus water depth, with the data indicating that the amphipod strongly prefers gravel/cobble substrates in shallow water.

These are just a few examples of results. Complete data was presented by Lewis (2000, 2001).

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Limiting Lamp Flora in Developed Passages Within Mammoth Cave

Rick Olson
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Abstract

Lamp flora—a European term for the algae, mosses, and ferns that grow near electric lights—are a problem in nearly all show caves. These growths have been regarded as a "nuisance," but are actually a serious distortion to cave ecosystems. Control has been achieved largely via chemical treatments, which are indiscriminate killers. Ecological impact has been limited through careful application, but the safety of people doing this work remains as an issue. The idea of limiting lamp flora growth by wavelength selection is not new. This concept has arisen independently around the world over the past two decades. Though early tests were somewhat disappointing, recent advances in lighting technology, particularly Light Emitting Diode lamps, have made this approach feasible. Testing of yellow (595-nanometer) Light Emitting Diode lamps in Mammoth Cave has resulted in no re-growth of lamp flora in a former problem area over a 1.5-year period at an intensity of 4.6 foot-candles (49.5 Lux).

Cave Management at Fort Huachuca Successfully Protects Endangered Bats

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Abstract

Lesser long-nosed bats, *Leptonycteris curasoae*, were known from two cave roosts on Fort Huachuca prior to their federal listing in 1988 as endangered species but little was known regarding population numbers. Collection reports from the 1950s through 1970s listed no more than 20 lesser long-nosed bats at sites on Fort Huachuca. Following endangered listing, the Army assessed the status of lesser long-nosed bats and their potential food plants, Palmer agaves (*Agave palmeri*), on Fort Huachuca. Surveys were conducted in 1990 and a monitoring program was initiated on Fort Huachuca. From the beginning, low disturbance methods were used at potential roosts. Counts of individual bats during evening emergence flights provided population estimates of various bat species at cave roosts. Skeletal material of lesser long-nosed bats was found at Pyeatt Cave, a popular recreational cave showing conspicuous damage, but only one live bat was observed there during the first six years of monitoring. Before 1991, protective actions were initiated by the Army. Actions included temporary closure of potential roost sites, removal of gates and other obstructions at cave entryways, posted closure signs, fenced closure of caves and roads leading to caves, and prescriptions to prevent damage to fields of agaves during military operations. Following these actions, there was an immediate increase in population numbers of cave myotis (*Myotis velifer*), insect-feeding bats that share the roosts of lesser long-nosed bats. In time, lesser long-nosed bats re-colonized the old Pyeatt Cave roost, and their maximum numbers on Fort Huachuca increased from 50 bats before protective actions to over 3,000 bats for the past three years. With protection of roost sites during the past 11 years, population numbers of bats at roosts have increased and stabilized.

The Karst Fauna Region Concept and Implications for Endangered Karst Invertebrate Recovery in Bexar County, Texas

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Abstract

Nine Species of karst invertebrates known only from caves in Bexar County, Texas, are currently listed as endangered by the U.S. Fish and Wildlife Service. Although a recovery strategy has not been developed for the Bexar County species, accurately delineating the distribution and range of each species is a vital first step. A study contracted by the U.S. Fish and Wildlife Service indicated that the distribution of these rare species has been influenced largely by geologic controls on their habitat imposed primarily by faulting and the down-cutting of streams. Preliminary data based on local geology and the distribution of endemic fauna known at the time suggested that up to six areas, referred to here as karst fauna regions, might exist in Bexar County. They include the Culebra Anticline, Alamo Heights, Government Canyon, Helotes, University of Texas at San Antonio, and Stone Oak karst fauna regions. However, recently collected species distribution data indicate that the number of karst fauna regions in Bexar County may only be four or even as few as three. This presentation will explore the karst fauna region concept and the implications of new data for a Bexar County endangered karst invertebrate recovery strategy.

Introduction

Northern Bexar County, Texas, is underlain by multiple Cretaceous carbonate formations cropping out along the Balcones Escarpment. During the Miocene, as the ancestral Gulf of Mexico was subsiding to the southeast, the escarpment was created along a belt of weakness where episodic faulting produced more than 1,000 feet of displacement. The resultant Balcones Fault Zone consists of a series of northeast-trending, predominantly normal, nearly vertical, *en echelon* faults, which are down-thrown toward the coast (Shaw, 1978). In the roughly 20 million years since faulting ceased, river systems adjusted to this change in elevation by carving a series of steep canyons along the escarpment. The juxtaposition of older, harder limestones to the northwest with younger, softer sediments and sedimentary rock to the southeast has produced a landscape with a multitude of niches for biota including endemic cave-, aquifer-, and spring-adapted species found nowhere else on the planet.

Many of these species find their habitat within or above the karstic Edwards Aquifer system. The Edwards Aquifer Recharge Zone is composed primarily of exposures of the Edwards Group and overlying Georgetown Formation. The Edwards Group is divided into the Person and Kainer Formations which are further subdivided into seven members of relatively heterogeneous lithology (Stein and Ozuna, 1995). The Edwards Aquifer Contributing Zone, or the area from which surface runoff sheds to the recharge zone, is composed largely of the Glen Rose Formation and erosional remnants of the Kainer Formation. Caves in Bexar County occur primarily in the Glen Rose and Edwards Group Limestones as well as in the Austin Chalk formation, which lies stratigraphically above the upper confining units to the Edwards Aquifer (Veni, 1988).

On December 26, 2000, nine species of karst invertebrates known only from caves in Bexar County, were listed as endangered by the U.S. Fish and Wildlife Service under the authority of the federal Endangered Species Act. These species are Madla's cave spider (*Cicurina madla*), Robber Baron Cave spider (*Cicurina baronia*), Vesper Cave spider (*Cicurina vespera*), *Cicurina venii* (no common name), Government Canyon Bat Cave spider (*Neoleptoneta microps*), Robber Barron Cave harvestman (*Texella cokendolpheri*), Helotes mold beetle (*Batrisodes venyivi*) and two ground beetles lacking common names (*Rhadine exilis* and *R. infernalis*) (USFWS, 2000).

That these unique species exist and that their habitat is threatened by the rapid urbanization of the City of San Antonio is enough information to justify their listing as endangered species. But much of what is known about the Bexar County karst invertebrate fauna has been derived from a relatively small number of specimens collected from an as yet unknown portion of each species' range. Despite diligent efforts of a small number of researchers, the logistical challenges in accessing karst habitat inherently limits the amount and type of information which can be directly gathered regarding the natural history of these often elusive fauna. Very little known of the species' behavior, population trends, and general ecology is not based on anecdotal observations or inferences based on other taxa in other ecosystems.

Conservation and recovery of these species depends upon the protection, in perpetuity, of a sufficient number of caves inhabited by each species, thus preserving genetic diversity and ensuring long-term survival. As the great majority of land in Bexar County likely to contain caves is privately owned, conservation and recovery of these species also depends to a large extent on cave preservation through consultations with the land-owning public. Urbanization has proceeded largely unchecked before and since the listing, and the number of potentially suitable cave preserve sites is dwindling.

The Karst Fauna Region Concept

The Karst Fauna Region concept was first published in 1994 in the recovery plan for endangered karst invertebrates in Travis and Williamson Counties, Texas (USFWS, 1994). It was based on "karst geologic areas" (karst areas) described in a report to the U.S. Fish and Wildlife Service and the Texas Parks and Wildlife Department (Veni, 1992). A companion study of similar form was conducted for the San Antonio area (Veni, 1994). The premise of these studies is that geologic and structural controls within the karst have resulted in the present distribution of troglobitic fauna by restricting their movement through the karst. These structural controls come in two basic forms. One is a barrier caused by the absence of cavernous strata due to the down cutting of streams or fault juxtaposition of non-cavernous strata with cavernous strata. The other is a restriction that may be a temporal limitation to terrestrial troglobite movement such as saturation of voids beneath an intermittent stream, or a spatial limitation such as a narrow outcrop of cavernous strata between karst areas. This theory of "structural controls" was validated using an "endemism index" whereby a number of species thought to be restricted to a karst fauna region was compared to a number of species thought to occur across multiple karst fauna regions. The delineation of karst fauna region boundaries was based on various observed geologic controls. The degree of endemism present within the boundaries was based on faunal distribution data available at the time. As a relatively small number of caves were surveyed in several of the karst fauna regions, refinements to the results of these studies were expected to occur as new data became available.

In the Travis and Williamson County recovery plan, karst fauna regions are further delineated into "karst fauna areas" which are defined as areas supporting one or more populations of listed invertebrates separated from other karst fauna areas within that karst fauna region by barriers to the movement of water, contaminants, and troglobitic fauna. These karst fauna areas are intended essentially as recovery units, which, if preserved in appropriate numbers, may lead to down listing of the species from endangered to threatened in a particular karst fauna region. Although a recovery strategy for the Bexar County invertebrates has not yet been formulated, it is likely to follow the model of the Travis and Williamson County recovery plan.

Six karst fauna regions are currently considered for Bexar County (USFWS, 2000). The Culebra Anticline and Alamo Heights karst fauna regions occur in outcrops of the Austin Chalk which are isolated from other cavernous strata. The other four karst fauna regions occur in the relatively contiguous outcrops of the Glen Rose and Edwards Group Limestones in an area roughly coincident with the Edwards Aquifer Recharge Zone. From west to east they include Government Canyon, Helotes, University of Texas at San Antonio, and Stone Oak. They are divided from one another by Los Reyes Creek, Helotes Creek, and Leon Creek, respectively. Each of these creeks has down cut through a significant portion of the karst and each frequently dries during arid weather.

The utility of the karst fauna region concept as a management tool is to further the recovery goals of protecting isolated populations and preserving genetic diversity across each species range. In other words it functions as a predictor of the spatial distribution of genetic diversity among troglobites so that appropriate areas can be targeted for conservation and so that the minimum standard for down listing and recovery can be identified.

Complications to the Karst Fauna Region Concept

As with any model, the karst fauna region concept is based on a number of assumptions and uses inference to bridge gaps in the available data. Complications to the six karst fauna region model for Bexar County arise when new data are introduced to the original endemism index calculations and when alternatives to its assumptions are considered.

One significant complication stems from the fact that it is unknown whether boundaries between karst fauna regions are more significant to troglobite gene flow, and therefore genetic diversity, than barriers within karst fauna regions but between karst fauna areas. Little conclusive data are available about the extent of interstitial voids or mesocaverns in Bexar County as it pertains to their role in troglobite ecology and movement. No molecular data are currently available on the genetics or phylogenetic relationships between Bexar County karst fauna populations. Recently collected species distribution data seem to have conflicting implications.

As taxonomic work on specimens from Bexar County advances, new species are described and revisions and range extensions of previously identified species are made. Much of this work has been conducted on behalf of private landowners by various researchers while the most intensive study has been made on Camp Bullis (Veni, 1999). The number of new species discoveries in recent years, especially those within the same genus as listed taxa (Cokendolpher, pers. comm., 2001; Veni, 1999; Reddell, 2000; Reddell, 2001), suggests that the heterogeneity and complexity of local geology may provide many more barriers to troglobite gene flow than previously thought. Each cave, cave cluster, or fault block may represent its own isolated community of fauna. This possibility may have negative implications for the broader goal of cave conservation in Bexar County as the more restricted in range federally protected fauna are the smaller the geographic are is that may be afforded regulatory protection.

On the other hand, range extensions of at least two listed species may provide evidence to the contrary. One of the most significant range extensions is that of *Cicurina madla*. Once thought to be restricted only to its type location, it has now been positively identified from eight caves. Its known range now includes caves formed in both the Edwards and Glen Rose Limestone Formations located in the Government Canyon, Helotes, University of Texas at San Antonio, and Stone Oak karst fauna regions (SWCA, 2001).

Another significant range extension is that of *Batrisodes venyivi*. Once thought to be restricted to two caves, two new locations have been documented on private lands (Chandler; Reddell pers. comm., 2000). The range of *B. venyivi* has now been shown to span the proposed Government Canyon and Helotes karst fauna regions. Incidentally, one of the original locations and one of the new locations have since been purchased as mitigation preserves, and a third is proposed to be included in a mitigation preserve.

These range extensions may indicate that geologic controls have no influence on the distribution of most listed troglobites across the contiguous Edwards and Glen Rose karst fauna regions. In fact, four of the six listed invertebrates known to occur in those karst fauna regions are now known to range across karst fauna region boundaries. These data, if integrated with the endemism index as originally calculated for these karst fauna regions, would significantly shift the results for the individual karst fauna regions toward non-endemism. This may indicate that, as was noted by the original investigator, the boundaries between the Government Canyon, Helotes, and University of Texas at San Antonio karst fauna regions "are only moderately effective and so the areas lend themselves for consideration as a single unit" (Veni, 1994, p 75). It may additionally indicate that the boundary formed by Leon Creek between the University of Texas at San Antonio karst fauna region and the Stone Oak karst fauna region is similarly only moderately effective. In this case the number of karst fauna regions in Bexar County could be four or even three. There is a precedent for this consideration as during the development of the Travis and Williamson County recovery plan two karst geologic areas were combined into one karst fauna region because of their similar faunal assemblages. However, it should be noted that new karst fauna data from Camp Bullis and its effect on the endemism of the Stone Oak karst fauna region is not considered here save one exception with regards to *C. madla*.

Such range extensions have been difficult to come by for a variety of reasons. Only adult female *Cicurina* spiders are currently identifiable to species level. Although many caves in Bexar County are known to contain troglobitic *Cicurina* spiders, most of those populations remain unidentified as to species because only juvenile specimens have been collected. Adult females have rarely been collected. Adult males are currently required to identify *Neoleptoneta* spiders to species level. *Neoleptoneta microps* is known only from a single female specimen. They are also much smaller than *Cicurinas* and are thus more easily overlooked during biological surveys. *Batrisodes* mold beetles are also easily overlooked due to their size, which averages about two millimeters in length. Of the nine federally listed invertebrates, five are known from fewer than ten specimens that are identifiable to species level, and four of those five are known from three specimens or fewer. *Cicurina venii* and *C. vespera* are known only from one identifiable specimen each. The result is that, with the exception of the *Rhadine* beetles, the current state of knowledge as to the status and distribution of the listed Bexar County taxa is based on only a handful of data points.

Alternatives to the theories and assumptions on which the karst fauna region concept is based may also be viable. One assumption is that the troglobites reached their current distribution by dispersal through the sub-surface. This assumes that biologically open corridors exist (or existed on an evolutionary time scale) and are (or were) integrated between caves on a scale at least as spatially extensive as the smallest karst fauna region. In the case of the *Rhadine* beetles, biological corridors would have to have been integrated across the far ends of all four northern contiguous karst fauna regions. In the case of *Rhadine infernalis*, the Culebra Anticline would have to have been integrated as well. The karst fauna region concept also assumes that populations diverged genetically as their ranges become truncated or segmented by the imposition of geologic barriers to gene flow. Thus genetic diversity between populations may follow a relationship based on proximity to the origin of dispersal and the orientation of imposed barriers.

Not all troglobites known from Bexar County are assumed to have followed this evolutionary pathway, however. *Eidmanella rostrata*, for example, is a troglobitic spider which is known from caves in Bexar, Bandera, Burnet, Comal, Kendall, Kinney, Medina, Travis, Uvalde, and Williamson Counties (Cokendolpher and Reddell, 2001). This wide ranging distribution, across broad expanses of non-cavernous rock, is unlikely to have occurred through sub-surface dispersal. Rather, *Eidmanella rostrata* is likely a recent troglobite whose various populations simply have not diverged enough from a surface ancestral species to be divided into separate species (Cokendolpher pers comm., 2001). Each isolated population functions ecologically as a separate species due to geographic isolation, but retains an anatomy lacking morphological differences sufficient to justify taxonomic re-classification. The spatial distribution of genetic diversity among populations of *E. rostrata* may then follow a more random pattern related more to the distribution of the surface ancestral species and independent of sub-surface structures.

Other troglobites including the harvestman *Hoplobunus madla* are thought to be older troglobites due to their degree of troglomorphic adaptation and apparent lack of closely related surface taxa. Like *E. rostrata*, they are known to range across many Texas counties in both the Edwards Plateau karst and the Balcones Fault Zone karst. Populations of these species have also not been divided into separate taxa because of an apparent lack of distinct anatomical characters. If their current distribution is a product of sub-surface dispersal, it would have occurred long before currently considered karst fauna region boundaries formed when the Edwards Plateau karst and Balcones Fault Zone karst were contiguous. This highlights another potentially faulty assumption implicit in the six karst fauna region concept which is that the Bexar County troglobites have rates of genetic mutation which are consistent with speciation occurring in the time since the impositions of karst fauna region barriers.

As Bexar county troglobites may have followed multiple evolutionary pathways and taxonomic conclusions have not been reached in the same manner for each taxa, it is difficult to know with absolute confidence whether taxa considered in the endemism index are being compared as "apples to apples."

Discussion

The purpose of this article is not to prove or disprove the validity of the karst fauna region concept, and it is certainly not intended to second guess the taxonomy. Both are works in progress and are herculean tasks. The purpose of this article is simply to illustrate that if applied inflexibly as a management or recovery tool, the karst fauna region concept has the potential to undermine steps toward cave conservation, and that sufficient uncertainties exists to warrant flexibility in its application.

With the exceptions of Government Canyon State Natural Area and Camp Bullis Military Reservation, almost all of the Bexar County karst is privately owned. Endangered Species Act enforcement on private lands is far more complicated than on federal or state lands. Funding does not currently, and will not likely in the foreseeable future, allow for significant purchase of karst invertebrate habitat by the U.S. Fish and Wildlife Service. Although the City of San Antonio has made significant progress in allocating taxpayer funds to purchase land for the sake of aquifer protection, those funds are limited and many caves containing endangered taxa are located outside of the aquifer recharge zone where purchase by the city is not allowable. Accordingly, recovery of the Bexar County karst invertebrates depends largely on private sector mitigation through purchase or donation of preserve lands as part of the Edwards Acquifer/HCP process or informal consultations with the U.S. Fish and Wildlife Service.

Such mitigation is only required by federal law where "take" is demonstrated. Take is a legal term used in the Endangered Species Act to describe harm to protected species and may result from permitted or non-permitted actions. In many cases irreparable damage to a cave ecosystem may already have been done by the time a non-compliant permit applicant engages in consultation with the U.S. Fish and Wildlife Service. In these cases on-site mitigation may not be a viable option and an opportunity for the purchase of off-site karst invertebrate habitat may exist. Given that a finite number of potentially suitable mitigation options remain in Bexar County, obstructions to taking advantage of those mitigation options should be avoided, where possible.

A recent case study in the University of Texas at San Antonio karst fauna region involved a development project for which a section 10(a) permit was issued for the incidental take of listed karst invertebrates. It was demonstrated to the satisfaction of the U.S. Fish and Wildlife Service that the long term survival of the species involved would not be jeopardized within the University of Texas karst fauna region by the issuance of the permit. The mitigation plan provided by the applicant as a condition of permit issuance included the establishment, in perpetuity, of two on-site and five off-site cave preserves containing a total of ten caves on 181 acres. The entrance of one on-site cave was filled and the resident population of troglobitic spiders may be extinguished. The two other on-site caves remain in approximately one-acre preserves and will provide monitoring sites to study the effects of small preserves on troglobitic communities. The off-site mitigation preserves were distributed across the University of Texas, Helotes, and Government Canyon karst fauna regions. They will provide protection, in perpetuity, for other populations of the species impacted by the permitted development as well as dozens of populations of other rare and endangered karst invertebrates. Subsequent to the issuance of the permit, a legal challenge was brought against the U.S. Fish and Wildlife Service by an environmental group based, in part, on a claim that mitigation should not have been allowed across karst fauna region boundaries. Had a recovery plan been in place at the time of consideration of that permit, and had the service chosen to adhere strictly to a more narrow mitigation standard, then what was arguably the greatest private sector contribution to cave conservation in Bexar County may never have occurred. Furthermore, the development may well have occurred anyway.

As the City of San Antonio expands and property taxes rise, increasing development pressure is brought to bear on private land owners such as those who sold their lands for the above mentioned mitigation. Largely as a result of that plan, several San Antonio land owners have begun to speculate in budding private cave mitigation ventures. In essence, environmental features previously considered liabilities from a development perspective are beginning to be seen by some landowners as assets. It is likely in the interest of cave conservation to encourage this trend and to avoid creating obstacles to it that are not clearly warranted. Assigning economic value to caves by encouraging a market for mitigation preserves has been a more effective motivation for cave conservation on private lands than has been the threat of injunctive relief under the Endangered Species Act.

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Lidar Applications in a Temperate Rainforest Environment - Case Study: Kosciusko Island, Southeastern Alaska, Tongass National Forest

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Abstract

As part of ongoing environmental impact statements for proposed timber sales in the Tongass National Forest on Kosciusko and Tuxekan Islands, west of Prince of Wales Island in southeast Alaska, URS Corporation utilized Light Detection And Ranging (LIDAR) technology as part of field data collection in the temperate rainforest. EagleScan Remote Sensing Services/3Di, a subcontractor to URS, collected the data utilizing a combined LIDAR and digital camera unit. Data were generally collected utilizing a last pulse mode in order to map the "bald earth" for the majority of the study area. In addition, a test area was established within which both first and last pulse data were collected. A digital elevation model was developed from the LIDAR point data. Contour maps developed from the digital elevation models were successfully utilized to identify steep slopes, landslides, and karst features. The method also allowed for the characterization of canopy structure in conifer stands. The maps generated from the LIDAR data were found to be instrumental in better understanding the landscape for the variety of disciplines involved in the environmental impact statement process with significantly less effort and improved resolution than pre-existing methods. The LIDAR data aided in karst resource inventory and karst vulnerability classification of the project area.

Sub-meter Position Accuracy With Garmin Handheld GPS Units

(Real Accuracy, Real Cheap)

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Tucson, Arizona

Abstract

GPS has provided a means to easily determine the approximate geographic location. Consumer grade GPS units, costing less than $150, now have typical accuracy of 15 meters (49 feet). Dedicated survey GPS systems costing $5,000 to $10,000 can achieve accuracies of a few millimeters. In the past year it has become possible to increase the accuracy of certain Garmin GPS models by an order of magnitude and achieve sub-meter accuracy. This is accomplished by obtaining and then post processing the data stream received by the Garmin GPS. Data is collected on a laptop computer in the field, converted to a standard RINEX format and later post processed using data collected at a reference GPS station. The reference data is readily available from a network of continuously operating reference stations. This is similar to post-processing differential GPS but uses additional signal phase data to achieve a much higher accuracy. Several commercial programs are available to perform the position calculations. One, GeoGenius 2000, is available in a basic configuration suitable for performing the required calculations for free.

Intensive Water Quality Monitoring in Two Karst Watersheds of Boone County, Missouri

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Abstract

Karst watersheds with significant losing streams represent a particularly vulnerable setting for ground water contamination because of the direct connection to surface water. Improvement of water quality in this type of karst setting faces many of the same management challenges as typical surface watersheds with regards to implementation of best management practices and responsible development in urbanizing areas. Because of the existing agricultural land-use and future threat of heavy urbanization, two losing stream karst basins were chosen for intensive monitoring in Boone County, Missouri: Hunters Cave and Devils Icebox Cave. Land use within both watersheds is similar with nearly equal percentages of row-crops, grasslands, and forest. Year-round monitoring was initiated in April 1999 with the objective of characterizing the water quality status of the main cave streams relative to herbicide, nutrient, and coliform bacterial contamination. Water sampling for contaminants entails grab samples at regular intervals and runoff event sampling using automated sampling equipment. In the first year, at least one herbicide or metabolite was detected in 60% of Hunters Cave samples and 72% of Devils Icebox samples. Total and inorganic nitrogen and phosphorus concentrations were generally much higher than existing Environmental Protection Agency guidelines for nutrient contamination of streams. Fecal coliform bacteria levels were generally above the whole body contact standard (200 cfu/100 ml^{-1}) in the Icebox, regardless of flow conditions. Under runoff conditions, fecal coliform levels in both caves can exceed 10,000 cfu/100 ml^{-1}. Prevailing land management has significantly degraded the water quality in both watersheds.

Materials and Methods

Cave Watersheds and Land Use

The watershed of the Devils Icebox and Hunters Caves are both located within the Bonne Femme Creek watershed located due south of Columbia, Missouri, USA. The caves were formed in the Mississippian Burlington Formation, a crinoid-rich limestone with distinct chert nodules in sub-horizontal layers (Halihan *et al.*, 1998). The upper (eastern) portions of both cave watersheds are covered by glacial and loess deposits and these glacial-derived soils coincide with the areas of most intense row cropping (Figures 1 and 2). Lower (western) portions of each watershed are characterized by residual soils (that is, aluminosilicate minerals remaining after bedrock dissolution) and associated karst features, such as sinkholes, caves, and springs.

The Devils Icebox watershed has been delineated by dye-tracing (Crunkilton and Whitley, 1983; St. Ivany, 1988), and other hydrologic studies have proven the link between the main cave stream and Bonne Femme Creek, as well as the hydrologic connection to the Pierpont sinkhole plain (Wicks, 1997) (Figure 1). The Devils Icebox watershed is approximately 12.5 square miles, and it icomprises two distinctive hydrologic areas: (1) surface drained upper watershed corresponding to Bonne Femme Creek; and (2) internally drained lower watershed encompassing the Pierpont sinkhole plain. Bonne Femme Creek is the primary source of water to the main cave stream (Wicks, 1997). Land-use/land cover data

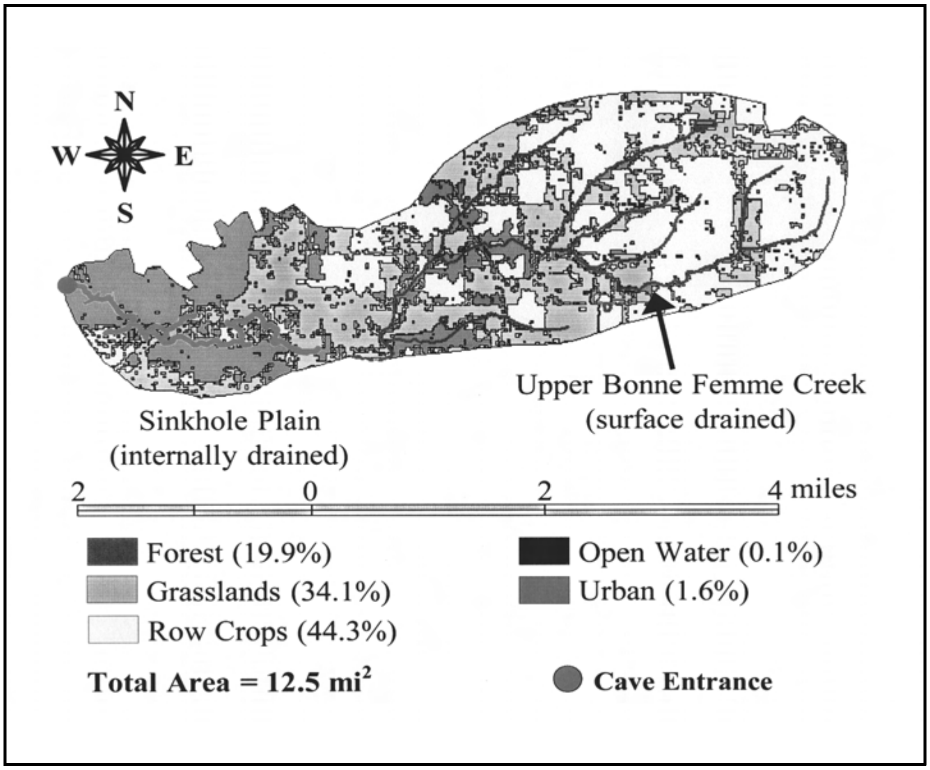

Figure 1. *Land use/land cover data for Devils Icebox recharge area based on 30-meter LANDSAT data from 1999.*

were determined using ArcView GIS (version 3.2) and 1999 LANDSAT data with 30 meters resolution (Figures 1 and 2). This recent land-use data is a major improvement in resolution and in distinction between different land-use categories, most notably the distinction between row-crop and grassland areas. Predominant land uses within the Devils Icebox watershed are row-crops (44.3%), grasslands (34.1%), forest (19.9%), and limited urban (1.6%) areas along U.S. Highway 63. Row crops are mainly corn and soybeans.

Approximately 40% of the grasslands

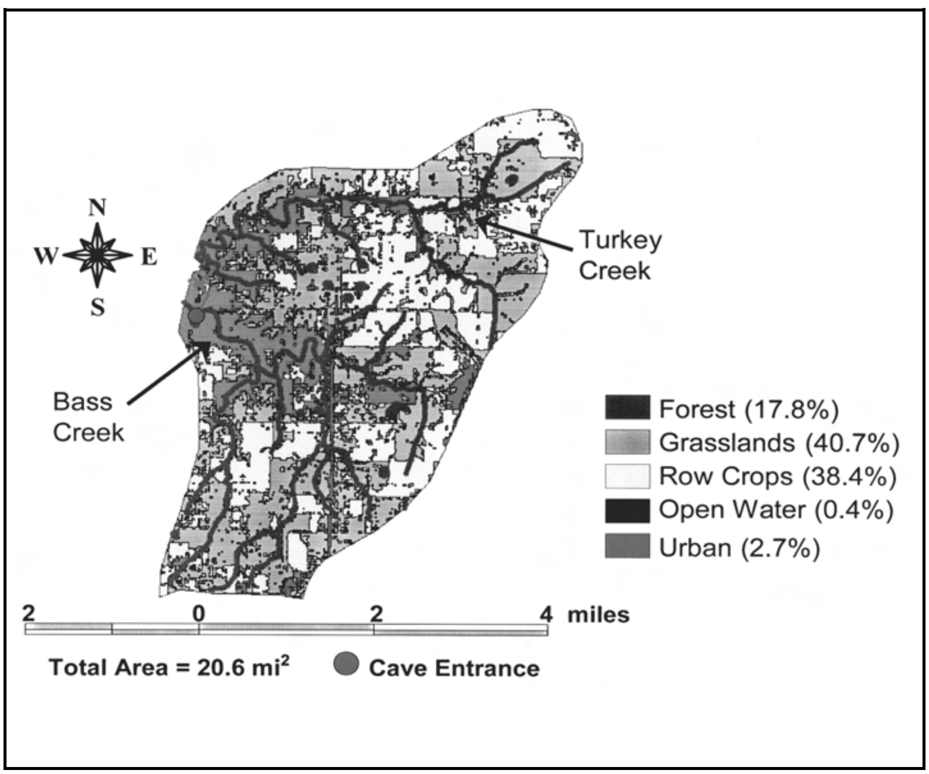

Figure 2. *Land use/land cover data for Hunters Cave recharge area based on 30-meter LANDSAT data from 1999.*

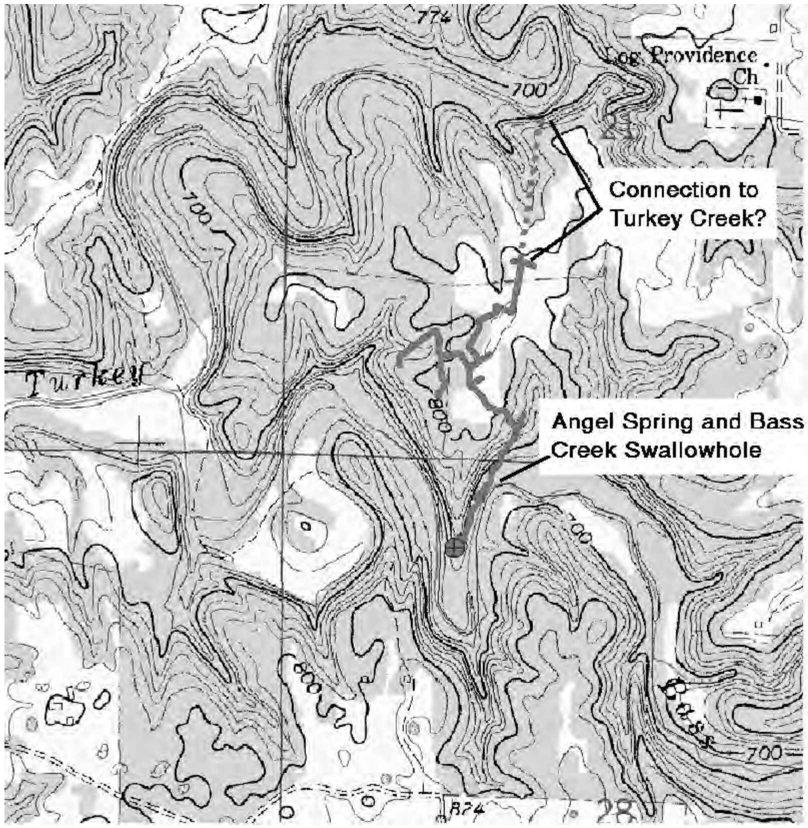

Figure 3. *Overlay of the 1958 Hunters Cave survey on the Ashland topographic map.*

are rangeland, with cattle and horses the predominant livestock. The remainder of the grasslands represent forage production for hay. Forested areas mostly lie within Rock Bridge Memorial State Park and they are mainly oak-hickory forests typical of the Ozarks region.

Hunters Cave watershed has not been delineated with dye-tracing. However, existing evidence, based on overlaying a line plot from the 1958 survey on the topographic map of the area, strongly suggests that both Turkey and Bass Creeks contribute to the Hunters Cave stream (Figure 3). From this overlay, it can be seen that Bass Creek comes in very close proximity to the cave passage. The estimated distance of this near intersection corresponds to the location of Angel Spring, suggesting a swallow hole and/or significant losing reach of Bass Creek upstream from this point. In addition, the un-mapped portion of the cave stream beyond the Big Room will almost assuredly place the cave in close proximity to Turkey Creek (Figure 2). Members of Chouteau Grotto are currently re-mapping Hunters Cave in order to produce a complete map. Contaminant transport data also support this delineation (data not shown). The estimated watershed of Hunters Cave is 20.6 square miles, an area 1.6 times greater than that of the Devils Icebox.

Using this tentative delineation for the Hunters Cave watershed, land-use/land-cover data showed that the area comprises grasslands (40.7%), row-crops (38.4%), forest (17.8%), and urban (2.7%), with the former two land-uses accounting for nearly 80% of the watershed (Figure 2). The Hunters Cave watershed has more grassland and urban areas but less row crops than the Devils Icebox watershed. Urban areas are composed of commercial development along U.S. Highway 63, the Columbia Regional Airport in the eastern portion of the watershed and residential development in Ashland, Missouri. Of particular interest to water quality in the cave stream is the distribution of row-crop areas within Turkey and Bass Creeks. Within the Turkey Creek watershed there is a distinct concentration of row-crop area in the eastern portion of the watershed extending into the northern portion of Bass Creek as well. In general, row-cropping intensity appears to be lower and more randomly distributed within the Bass Creek watershed, but some of the row-crop areas are in closer proximity to the cave than those within the Turkey Creek watershed.

Water Quality Monitoring Protocols

Year-round monitoring was initiated in April 1999 at the stream resurgence of each cave. Stream discharge is monitored at five-minute intervals using pressure transducers to measure the height of the water column. At the Devils Icebox, a rating curve was developed for the site (Halihan, 1998; Vandike, unpublished) so that stream height can be related to discharge. Hunters Cave cannot be accessed during high flow periods because of dangerously high flow in Bass Creek, so a reliable rating curve covering the upper range of observed stream heights could not be developed. Therefore, the flow velocity has been estimated with Manning's equation,

$$V = \frac{1.49}{n} \times R^{2/3} \times S^{1/2}$$

where V = velocity (ft/s), n = roughness coefficient, R = hydraulic radius [R = A/P, where A = cross sectional area of the channel and P = wetting parameter, with P = w+2d (w = channel width and d = channel depth or stream height)], and S = channel slope. Since we have measured the channel slope, width, and stream height (or channel depth), the only unknown variable is the roughness coefficient, n. Typically, one assumes a constant n, but direct measurements of flow velocity versus stream height, indicated n was not a constant for the range of stream heights observed. Therefore, a variable n was used as a function of stream height. By combining stream height data, channel geometry, and flow velocity (based on Manning's equation), the discharge can be estimated.

Geochemical parameters are continuously monitored at both caves using a YSI 6920 probe. Data are collected at 15 minute intervals for dissolved O_2, specific conductance, pH, temperature, and turbidity. For nutrient and herbicide analyses, grab samples are collected at regular intervals: (a) weekly from April through June and (b) twice monthly from July through March. Storm runoff events are monitored using Sigma 900 automatic samplers (autosamplers). Autosamplers are programmed to take samples with decreasing frequency through the course of an event. Sampling intervals range from five minutes to four hours, and the program was designed to collect samples at approximately equal proportions relative to the average time for runoff events at each site (24 hours at Hunters Cave; 36 hours at Devils Icebox). Samples collected for bacterial coliform analyses were collected on a quarterly basis from June 1999 to September 2000 at seven sites within Devils Icebox and five sites within Hunters Cave. Sites within the Devils Icebox included three locations along the main cave stream plus four significant tributaries. Sample sites within Hunters Cave included three sites along the main cave stream and two significant tributaries. Data are presented as the average of all sites for the quarter sampled.

Contaminant Analyses

Samples analyzed for nutrients, herbicides, and bacteria were transported to the laboratory on ice and refrigerated (2° to 4°C). Herbicide and dissolved nutrient samples were filtered through 0.45 m nylon filters within 48 to 72 hours of collection. Nutrient analyses included total and dissolved nitrogen and phosphorus species. Total nitrogen and phosphorus were determined on thoroughly mixed, unfiltered 60 millileter samples by autoclave digestion with potassium persulfate (Nydahl, 1978). For total nitrogen and phosphorus determination, persulfate digestion quantitatively converts all nitrogen forms to nitrate (NO_3^-) and all phosphorus forms to orthophosphate (PO_4^{3-}) which are then determined colorimetrically by a Lachat flow injection system (Lachat Instruments, Milwaukee, Wisconsin) as described below. Dissolved nitrogen and phosphorus were also determined by Lachat flow injection. For nitrate+nitrite-nitrogen, nitrate is quantitatively reduced to nitrite using a copperized Cd column. Nitrite is then determined by diazotizing with sulfanilamide followed by complexation with nitrogen-(1-napthyl)ethylenediamine dihydrochloride. The resulting magenta color is then read at 520 nm (Lachat Instruments, QuikChem Method 10-107-04-1-A). Since nitrite would not be expected to be significant in these samples, the nitrate+nitrite-nitrogen will be subsequently referred to as nitrate-nitrogen (NO_3-nitrogen). Ammonium-nitrogen (NH_4-nitrogen) was determined by heating with salicylate and hypochlorite in an alkaline phosphate buffer to produce an emerald green color. The color is subsequently enhanced by complexation with sodium nitroferricyanide and the color is read at 660 nm (Lachat Instruments QuikChem Method 10-107-06-2-C). Orthophosphate-phosphorus (PO_4-phosphorus) was determined by reaction with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex. The complex is then reduced with ascorbic acid to produce a blue color which is read at 880nm

(Lachat Instruments QuikChem Method 10-115-01-1-A).

Herbicide analyses were conducted for several of the commonly used soil-applied corn and soybean herbicides: atrazine, alachlor, acetochlor, metolachlor, and metribuzin (Lerch *et al.*, 1995; Blanchard and Lerch, 2000). The stable atrazine metabolites deethylatrazine, deisopropylatrazine, and hydroxyatrazine were also analyzed. For all herbicides and metabolites, analyses were conducted by passing 200 ml samples through C_{18} solid-phase extraction (SPE) cartridges. A sequential elution SPE procedure was used in which 2.4 ml of ethyl acetate is the first eluant followed by 3.4 ml of 9:1 methanol: 0.05M KH_2PO_4, pH.7.5. All herbicides and metabolites, except hydroxyatrazine (HA), are eluted in the ethyl acetate fraction, and HA is eluted in the methanol/phosphate buffer fraction. For all herbicides and metabolites, except HA, the herbicides were quantitated using gas chromatography/mass spectrometry. HA was quantitated by high performance liquid chromatography with ultraviolet detection. Method detection limits were (in ng/L or ppt): atrazine, 8.00; alachlor, 3.00; acetochlor, 6.00; metolachlor, 2.00; metribuzin , 8.00; deethylatrazine (DEA), 4.00; deisopropylatrazine (DIA), 8.00; and HA, 25.0. More detailed descriptions of the herbicide analyses were provided by Lerch and Donald (1994), Lerch *et al.* (1995), Donald *et al.* (1998), and Lerch *et al.* (1998).

All bacterial analyses were conducted within 24 hours of collection. Fecal coliform analyses were determined by membrane filtration and incubation using specific growth media (Greenberg *et al.*, 1992; Procedure 9222 D). For samples with high coliform densities, dilutions were made as necessary to facilitate accurate counting of colonies. All bacterial densities are expressed as colony forming units (cfu) per 100 ml of sample.

Results and Discussion

Hydrology

Estimated discharge for Years 1 and 2 showed very different seasonal distributions (Figure 4) because of the large differences in total precipitation and rainfall distribution during the first two years of the study. Year 1 showed typical seasonal trends of significant discharge through the spring and winter months, with this period including the major rainfall and runoff events for Year 1. However, discharge for the five months from July through November 1999 was extremely low in both caves because of prevailing drought conditions. Total discharge for Year 1 was approximately 52,000,000 cubic feet for Devils Icebox and 23,000,000 cubic feet for Hunters Cave. Thus, Devils Icebox had about 2.3 times more discharge than Hunters Cave. Average monthly flow rates were 0.7 cubic feet per second at Hunters Cave and 1.7 cubic feet per second at Devils Icebox. Total precipitation for Year 1 was about 28 inches in each watershed. The greater average flow rate of the Icebox reflected its much greater peak discharge during runoff events, and its consis-

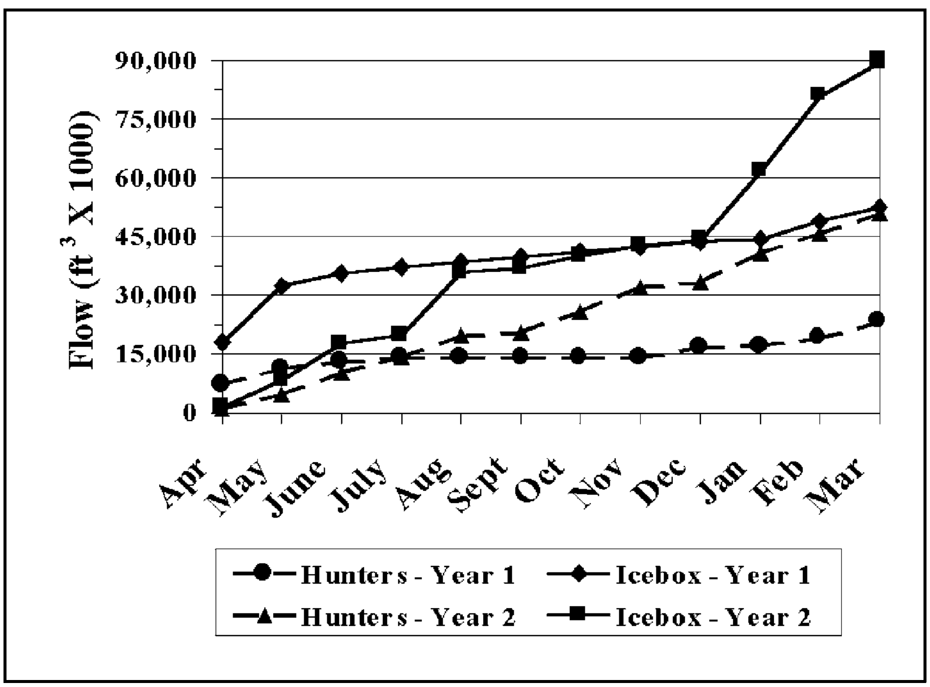

Figure 4. *Cumulative monthly discharge at Devils Icebox and Hunters Cave. Year 1 = April 1999 to March 2000. Year 2 = April 2000 to March 2001*

tently greater discharge during the drought period. Apparently, the Devils Icebox watershed has a much larger storage capacity than that of Hunters Cave.

In Year 2, discharge was very low during April and early May 2000. For example, discharge estimates for Hunters Cave were just under 7,000,000 cubic feet in April 1999 but only 1,100,000 cubic feet in April 2000. The differences were even more extreme for Devils Icebox with an estimated discharge of 18,000,000 cubic feet in April 1999 compared to just 1,400,000 cubic feet in April 2000. However, unlike most years, the summer of 2000 was characterized by frequent and intense rainfall, resulting in steady increases in cumulative discharge through the period. In fact, Hunters Cave showed an almost linear increase in cumulative discharge throughout Year 2. The largest event of Year 2, and so far in the study, occurred from August 7 through 9, 2000. Estimated discharge for this event was just over 7,000,000 cubic feet at Devils Icebox, with a peak flow rate of about 200 cubic feet per second, and 1,700,000 cubic feet at Hunters Cave, with a peak flow rate of 55 cubic feet per second. From the hydrograph and in-cave observations at Hunters, it appeared that Bass Creek flowed into the cave for about an hour, leaving deposits of organic matter-rich surface sediments about 200 feet into the cave. Another interesting feature of Year 2 hydrology was the number of significant runoff events during January through March 2001. At least six significant runoff events occurred during this period at each site, with corresponding increases in discharge. During February 2001, the Devils Icebox had 19,300,000 cubic feet, the highest monthly discharge to date. Total discharge for Year 2 was about 90,000,000 cubic feet at Devils Icebox and 51,000,000 cubic feet at Hunters Cave, indicating that the Icebox had about 1.8 times as much discharge as Hunters in Year 2. Average monthly flow rates were 2.7 cubic feet per second at Devils Icebox and 1.6 cubic feet per second at Hunters Cave. Total precipitation for Year 2 was about 42 inches in each watershed. As in Year 1, the greater average discharge at Devils Icebox resulted from the much greater peak runoff flow rates and greater duration of runoff events. However, Hunters Cave can exhibit monthly average discharge equal to or greater than that of the Devils Icebox stream. For example, Hunters had consistently greater average and total discharge from October through December 2000 apparently due to slightly greater rainfall and more intense precipitation events.

Contaminant Transport – Nutrients

Concentrations of total nitrogen and phosphorus were consistently higher in Devils Icebox compared to Hunters Cave from April 1999 to March 2000 (Figure 5). Presently, land use within the Hunters Cave drainage basin is not resulting in significantly elevated levels of these nutrients except under high flow conditions in winter and spring. Total nitrogen and phosphorus levels in Devils Icebox indicate a more significant and negative impact of land management on water quality within this watershed. Median and peak nutrient concentrations in Devils Icebox were consistently higher than Hunters indicating higher nutrient inputs to the watershed as a result of prevailing farm practices and possibly greater impact of on-site

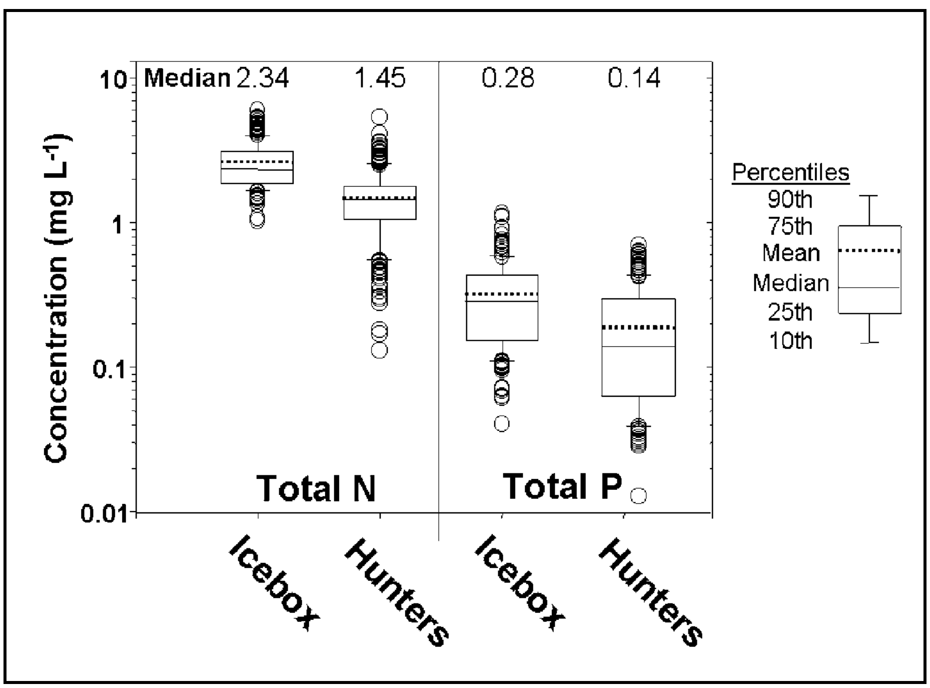

Figure 5. *Total nitrogen and phosphorus concentrations in Devils Icebox and Hunters Cave, April 1999 to March 2000.*

sewer systems. A previous unpublished study at Devils Icebox from 1982 to 1984 showed average nitrate (total nitrogen was not determined) of 2.1 ppm and average total phosphorus of 0.1 ppm. In the current study, nitrate has accounted for about 60% of the total nitrogen in samples collecting during Year 1. Assuming this same proportion for the 1982 to 1984 study, estimated average total nitrogen would have been 3.5 ppm. Thus, average total nitrogen at Devils Icebox has decreased 25% since 1982 to 1984. While total nitrogen levels have decreased over the last 17 to 19 years, total phosphorus levels have increased by about three fold over this same time period (Figure 5).

In the first year of the study, high nutrient concentrations were always associated with runoff events. Maximum total nitrogen concentrations were 6.0 ppm at Devils Icebox and 5.4 ppm at Hunters Cave, and maximum total phosphorus concentrations were 1.1 ppm at Devils Icebox and 0.7 ppm at Hunters Cave. Total nitrogen and phosphorus often closely correspond with each other and are directly related to stream flow and sediment transport. A major portion of the total nitrogen and phosphorus is transported in organic form bound to sediment particles. Partitioning of the total nutrient loads into inorganic and organic components indicates that 40 to 50% of the total nitrogen is in organic form with the remainder as nitrate. The fraction of the total nitrogen as nitrate has been consistently higher at Devils Icebox than Hunters Cave, providing further indication of greater inorganic nitrogen inputs in the Devils Icebox watershed. Ammonium-nitrogen accounted for 2% or less of the total nitrogen at either site. Partitioning of total phosphorus showed that both sites had about 60% organic phosphorus and 40% inorganic phosphorus.

Herbicides

Herbicides were frequently detected at both sites (Figure 6). Overall, 94.5% of Hunters Cave samples and 99.6% of Devils Icebox samples collected from April 1999 to March 2000 had a detection of at least one herbicide or metabolite compound. At the Icebox, atrazine was the most commonly detected herbicide with atrazine present in 96% of all samples. Because of the frequent detections of atrazine, its stable metabolites were also commonly detected. Atrazine metabolites were detected in 50% to

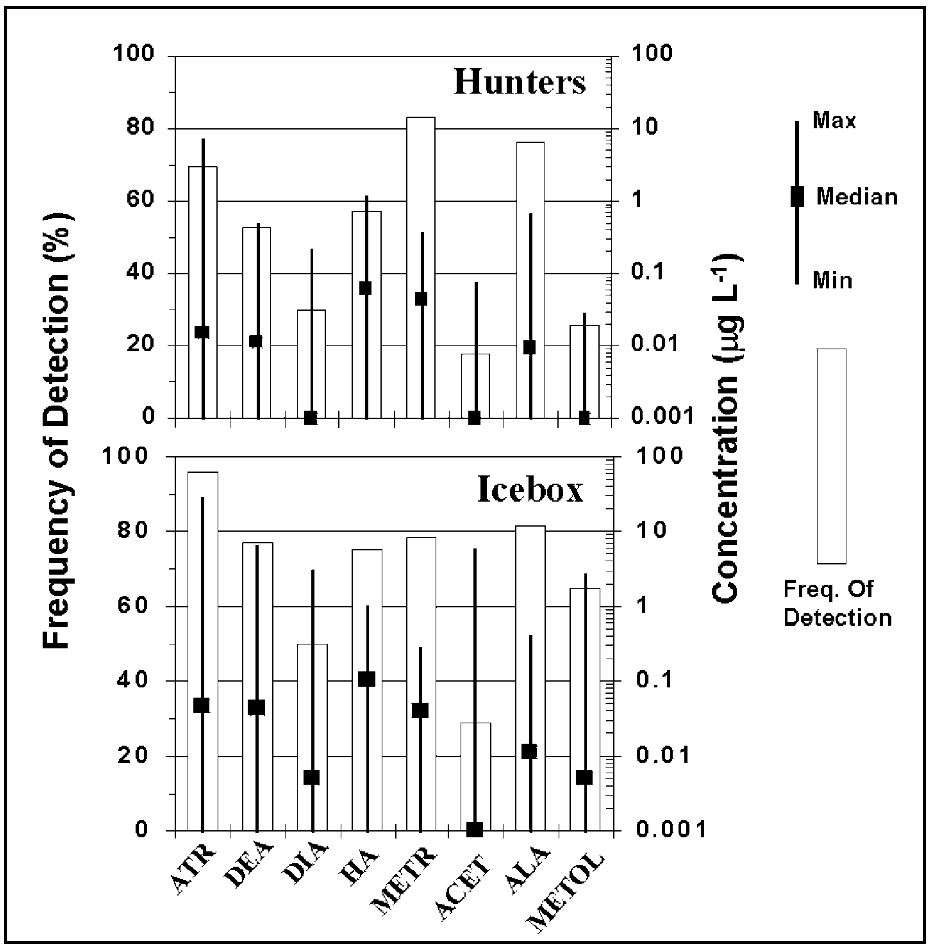

Figure 6. *Frequency of detection (bars) and concentration ranges (lines) of herbicides and atrazine metabolites in Devils Icebox and Hunters Cave from April 1999 to March 2000.*
ATR = atrazine, DEA = deethylatrazine, DIA = deisopropylatrazine, HA = hydroxyatarzine, METR = metribuzin, ACET = acetochlor, ALA = alachlor, METOL = metolachlor

77% of all samples. Alachlor was the next most frequently detected herbicide (81%) followed by metribuzin (79%) and metolachlor (65%). These results were typical for Missouri and midwestern streams, with atrazine, alachlor, and metolachlor all frequently present in Devils Icebox stream (Thurman *et al.*, 1991; Blanchard and Lerch, 2000). However, the high frequency of detection for metribuzin was greater than previously reported. The lower detection limits of the method employed in the present study represents a five- to ten-fold improvement over the earlier studies, and this is likely the primary reason for the higher detection frequency observed for metribuzin. In addition, the frequent detections of metribuzin may reflect greater usage than is typical for most watersheds within Missouri or the Midwest.

At Hunters Cave, metribuzin was the herbicide most often detected. Metribuzin was detected in 83% of the samples followed by alachlor (76%) and atrazine (69%). Acetochlor and metolachlor were detected much less frequently in Hunters Cave compared to Devils Icebox. The lower detection frequency of atrazine in Hunters Cave led to a commensurate decrease in detection of its metabolites. Atrazine metabolites were detected in only 30% to 57% of samples collected. The high detection frequency of metribuzin was unusual for northern Missouri streams. While improved analytical methods can partially explain the increase in metribuzin detections, higher than normal metribuzin input to the Hunters Cave recharge area appears likely. This further implies that soybean acreage is the dominant row-crop within the recharge area, which is also supported by the lower detection frequency of corn herbicides, atrazine and acetochlor, compared to the Devils Icebox and other northern Missouri streams (Blanchard and Lerch, 2000).

Although herbicides were frequently detected in both cave streams, the median concentrations for the first year (April 1999 to March 2000) of the study were rather low except in the spring (Figure 6). Median concentrations at both sites were at or below 0.1 ppb for all compounds studied. At both sites the persistent atrazine metabolite, hydroxyatrazine, had the highest median concentrations.

At the Devils Icebox, median concentrations were in the order: hydroxyatrazine > atrazine metribuzin > DEA > alachlor > DIA ≈ metolachlor > acetochlor. At Hunters Cave, median concentrations were in the order: hydroxyatrazine > metribuzin > atrazine > DEA > alachlor > DIA ≈ metolachlor ≈ acetochlor. With the exception of metribuzin, maximum and median concentrations of all herbicides and metabolites were greater at Devils Icebox than Hunters Cave. This indicated that prevailing row crop production practices were having a greater impact on Devils Icebox than Hunters Cave. In addition, the Devils Icebox recharge area apparently has proportionally more corn production than Hunters Cave as indicated by the greater concentrations and detection frequencies of the corn herbicides atrazine, atrazine metabolites, acetochlor, and metolachlor. The higher median metribuzin concentrations at Hunters Cave compared to Devils Icebox was a further indicator of its greater usage within the Hunters recharge area.

Maximum herbicide and metabolite concentrations were observed during the “spring-flush” period from late April through June. This period represents the most vulnerable time for herbicide transport to surface water and consequently to losing streams. Several factors contribute to the spring-flush: (1) application of herbicides generally occurs in April and May; (2) intense thunderstorms are most common during this period; (3) mitigating processes of sorption and degradation have not had sufficient time to significantly reduce the mass of herbicides available for transport; and (4) degradation that does occur during this period results in the formation of mobile metabolites susceptible to surface transport. At both sites, high parent compound levels were observed in only one or two spring runoff events. Other than atrazine and its metabolites, the levels tend to quickly return to low levels (ppb) because of the relatively short half-life of most of these compounds. Atrazine may persist in soils for 30 to 60 days and thus it will maintain higher levels for a longer period of time than the other parent compounds. In addition, atrazine metabolite levels may remain high (0.1 ppb) until late summer or even into the fall in the case of hydroxyatrazine, the most persistent of the compounds analyzed in this study. Although not measured in this study, stable metabolites of alachlor, acetochlor, and metolachlor were likely present at significant levels from late May through early fall given the high levels (1 ppb) of the parent compounds observed during the spring-flush. Alachlor, acetochlor, and metolachlor represent the most commonly used compounds in a class of herbicides known as acetanilides. The acetanilides all degrade via common pathways to their respective oxanilic acid and ethane sulfonic acid metabolites in soils. These metabolites are then quite mobile in soil, and their presence has been reported in ground and surface waters

(Kalkhoff *et al.*, 1998). Median annual herbicide concentrations reported for this study were lower than levels reported for samples collected at pre-plant (February to early April) in several other studies (Thurman *et al.*, 1991; Donald *et al.*, 1998; Blanchard and Lerch, 2000). Donald *et al.* (1998) reported average annual atrazine levels in Goodwater Creek, a stream located about 30 miles to the north of the sites reported here, of 3.88 ppb in 1993 and 2.6 ppb in 1994. These levels are about two to three times greater than the average annual atrazine concentrations at Devils Icebox and 20 to 30 times higher than average annual atrazine levels at Hunters Cave.

Fecal Coliform Bacteria

Levels of fecal coliform bacteria exceeded the U.S. Environmental Protection Agency whole body contact standard (126 cfu/100ml) in four of six quarters at Devils Icebox and two of six quarters at Hunters Cave (Figure 7). Fecal coliform concentrations varied from 60 to 21,920 cfu/100 ml at Devils Icebox, and the highest levels were observed during the second quarter of 1999 and 2000. At Hunters Cave, fecal coliform concentrations varied from 17 to 11,750 cfu/100 ml, with the highest observed levels occurring in the second and third quarters of 2000. In general, fecal coliform levels were similar between sites, but Devils Icebox was higher in four of the six quarters. Furthermore, both cave streams are vulnerable to periodic pulses of high fecal coliform concentrations that may endanger human health because of recreational caving. The large difference in fecal coliform levels observed for the second quarter 1999 sampling were due to differences in flow conditions at the time of sampling. Hunters Cave samples were collected on June 23, 1999, under very low flow conditions; the average daily flow was 0.09 cubic feet per second. Subsequently, there was a runoff event that prevented access to Devils Icebox until June 29, 1999, and this sample set was collected at the tail end of the event when the average daily discharge was 0.96 cubic feet per second. Although the event only reached peak discharge of 5.4 cubic feet per second, the change from baseflow to runoff conditions at this time of year was sufficient to cause the large differences in observed fecal coliform concentrations. The seasonal variations observed at both sites are similar to those reported by Edwards *et al.* (1997) for several small streams in northwest Arkansas in which the highest fecal coliform levels occurred in spring and summer. The range of fecal coliform concentrations reported in this study were within the ranges reported for other studies in similar karst settings in West Virginia (Boyer and Pasquarell, 1999) and Kentucky (Howell *et al.*, 1995). In the study by Boyer and Pasquarell (1999), highest fecal coliform concentrations in The Hole Basin Cave System were associated with a tributary known to be directly impacted by dairy cattle production. Median fecal coliform levels in the dairy-impacted tributary, and a site immediately downstream, were the highest in the cave system. However, Edwards *et al.* (1997) reported high fecal coliform (10^2 to 10^6 cfu/100 ml) and streptococcus levels in runoff from grazed or ungrazed fields in northwest Arkansas.

In general, variation in fecal coliform levels was related to stream discharge and water tem-

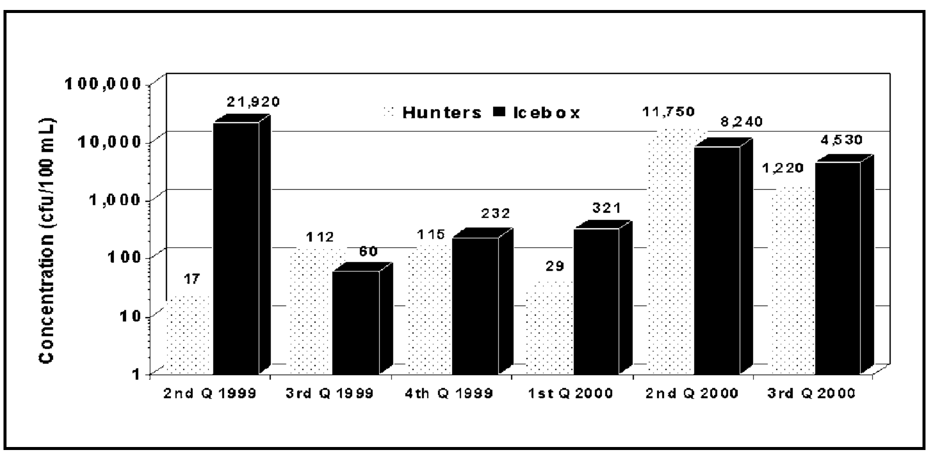

Figure 7. *Quarterly fecal coliform concentrations in Devils Icebox and Hunters Cave from June 1999 to September 2000. Data represents average of seven sites in Devils Icebox and five sites in Hunters Cave. EPA whole body contact standard is 126 cfu/100 ml.*

perature. The highest observed levels occurred under moderate to high flow conditions during warm months, when the stream water temperatures were at or near their annual maxima. There is a strong interaction between these variables. A given amount of discharge results in different levels ofbacteria transported, depending upon the time of year. For instance at Devils Icebox, the second quarter 1999 sample set resulted in 21,920 cfu/100 ml when average daily discharge was 0.96 cubic feet second. Thus, the average fecal coliform density per unit discharge was 22,830 cfu/100ml/cubic feet second, or stated another way, a 1 cubic feet second discharge rate would resulted in an average fecal coliform density of 22,830 cfu/100ml for the second quarter of 1999.For the first quarter 2000 sample set collected on March 21, 2000, the average daily discharge was 1.7 cubic feet second and the fecal coliform density was 321 cfu/100 ml, giving an average bacterial density per unit discharge of 189 cfu/100ml/cubic feet second. Hence, a given unit of discharge transports varying amounts of bacteria based on the season of the year. Since the input sources of fecal coliforms do not vary significantly by season in these watersheds, the interaction between flow and stream water temperature on fecal coliform concentrations must reflect differences in coliform survival in the soil and water. It is important to note that the data presented here do not provide any direct indication ofbacterial sources. However, the two watersheds collectively have a population of approximately 38,000 people, based on the 2000 census, and the majority of the residences have on-site sewage systems. It is therefore reasonable to assume that a significant proportion of the fecal coliforms are derived from humans. Other significant sources include livestock, particularly cattle and horses, and wildlife.

Summary and Conclusions

The combination of greater flow and consistently greater contaminant concentrations within the Devils Icebox watershed results in considerably greater annual transport of contaminants compared to Hunters Cave watershed. As a crude estimate, the median concentrations of total nitrogen and phosphorus, atrazine, and acetanilide herbicides were multiplied by the total annual flow in order to compute contaminant mass transport through each cave on an annual basis (Figure 8). The Devils Icebox has about four times as much nitrogen, phosphorus, and acetanilide herbicides and seven times as much atrazine transported through its cave stream compared to Hunters Cave on an annual basis. Computation

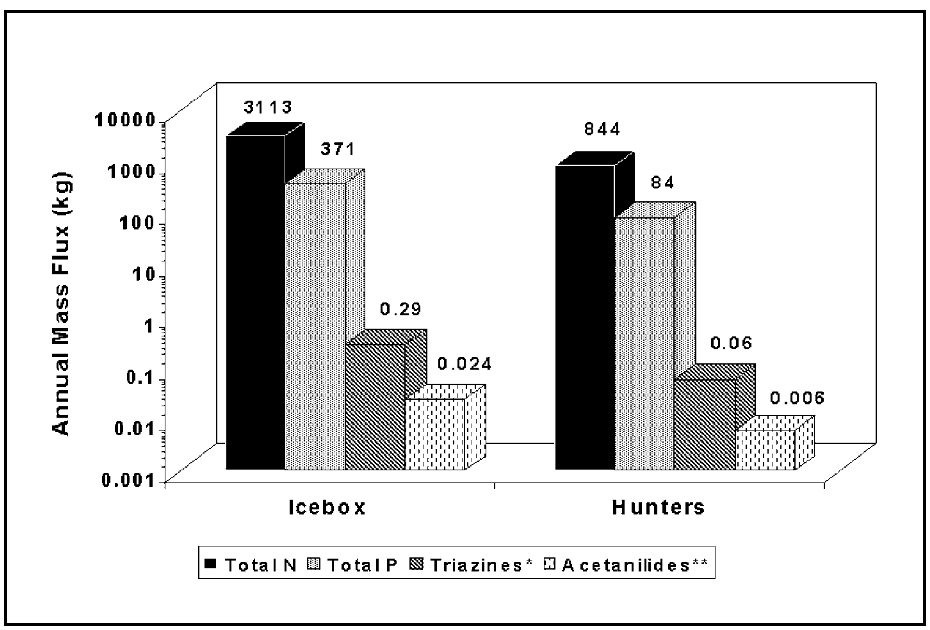

Figure 8. *Estimated annual mass flux of nutrients in Devils Icebox and Hunters Cave for year one (April 1999 to March 2000). *Sum of atrazine plus metabolites. **Sum of alachlor, acetochlor, and metolachlor.*

of mass flux is also useful for providing perspective to the relative mass transport of nutrients compared to herbicides. Nutrient transport in either watershed is three to five orders of magnitude greater than herbicide transport. Given the similarity in land-use and land cover in the two watersheds, it is apparent that prevailing agricultural and land-use practices are resulting in consistently greater water quality degradation in the Devils Icebox watershed. Furthermore, targeting and implementation of best management practices needs to be more strenuously pursued in the Devils Icebox watershed, but Hunters Cave watershed will require continued vigilance to prevent further water quality degradation. The first full year of nutrient and herbicide data indicates that, overall, contamination is generally as low or lower than most of the agricultural watersheds of northern Missouri, particularly with respect to herbicide contamination. However, the observed levels are still a cause for concern given the greater sensitivity of cave-adapted aquatic species that are impacted by the contamination.

To date, the contaminant of greatest concern to water quality in both watersheds is fecal bacteria. Existing data clearly show that excessively high fecal bacteria levels occur in both cave streams and these high levels are associated with runoff events during warm weather when bacterial survival is apparently greater. Because of the recreational uses of the caves, the levels of bacteria present potential human health threats. Likely sources of fecal bacteria are livestock, improperly functioning on-site sewer systems, and wildlife. The data presented in this report do not provide bacterial source-tracking information.

From a management and education perspective, there are several implications that stem from this work. First and foremost, it needs to be made clear to land managers, politicians, farmers, and homeowners that caves in losing stream basins are directly affected by surface land-use activities. The notion that caves are isolated systems protected from surface activities must be dispelled in order to manage losing stream basins in a manner that preserves the cave ecosystem and protects human health. This research adds to a growing body of literature regarding the impact of surface land-use activities on water quality in karst basins. In this study, the current land-use activities that are having the most negative impact on the cave streams are agricultural production and on-site sewer systems. Current management efforts should focus on implementing agricultural best management practices that reduce contaminant transport from row-cropped fields and minimize negative impacts of livestock on streams. Improved maintenance and design of on-site sewers also needs to be vigorously pursued to mitigate fecal bacteria inputs to these basins.

Future management considerations for these basins should focus on impending urbanization. Since 1990, the greater Bonne Femme watershed, which encompasses both of the karst basins reported in this study, has experienced a 40% increase in population, and future growth from the cities of Columbia and Ashland, Missouri, are anticipated to heavily impact these basins. Urban land-use management planning should include the following components: (1) local governments need to adopt policies and procedures for new development that provide special protections for karst basins; (2) developers, builders, and homeowners need to implement best management practices (for example: erosion control during construction, storm water control strategies, minimizing impervious surface, environmentally friendly lawn care, and the like.); and (3) technical and financial assistance should be provided to developers and homeowners to further encourage adoption of best management practices. These basic objectives were incorporated into a Section 319 grant submitted by the Boone County Commission for the purpose of comprehensive land-use planning to protect water quality in the Bonne Femme watershed.

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GIS Applications for Cave Management at Jewel Cave

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Abstract

Jewel Cave's length and complexity offer unique challenges for cave data managers. With over 21,000 survey stations and several databases tied to these stations, combining this data in a usable format can be an unwieldy task. Geographic Information Systems (GIS) technology provides the tools necessary to quickly search for and graphically display relationships between data sets. It can also easily determine and display the cave's location in relation to other GIS layers (including surface features). At Jewel Cave, a more accurate cave-surface overlay was generated by adjusting the cave survey to fit 35 control points. Once this was done, the overburden of the cave was determined by joining surface and cave layers. Data sets tied to survey stations were linked to the survey data and displayed in relation to each other and to other layers in the GIS. It is now possible to perform complex queries across these large data sets and search for relationships which help us to better understand and manage the cave.

Introduction

South Dakota's Jewel Cave, over 127 miles long, is well-known for its size and complexity. The cave is a network maze with several distinct levels of passage in a vertical extent of 631 feet. The survey data consists of over 21,000 survey stations under a surface area of just three square miles. It is challenging to visualize the location of a cave this size in relation to surface developments, overlying topography, and political boundaries.

In the past, a rough topographic overlay has been created by processing the cave survey data (using SMAPS 4, a DOS-based cave survey program), printing a scaled line plot, then overlaying the print-out on a topographic map. Depth below the surface could only be calculated by adding the Z values in SMAPS to the elevation of the cave entrance, then subtracting this value from the surface elevation above the station in question. The surface elevation was manually determined by finding the closest topographic contour to the survey station on the overlay. This was a time-consuming process and could not easily be done for all survey stations.

Cave radio locations tied to survey stations have been established over the last 15 years. This data set has been used to adjust the cave survey by entering control points into COMPASS cave survey software, but in the past there has been no easy way to graphically compare corrected and uncorrected data. Such a comparison can help data managers narrow down blunders and/or identify compounding errors.

Data tied to cave survey stations, such as radon concentration and feature inventory data, has previously been difficult to interpret without being placed in its spatial context. For example, the current inventory database (Visual dBASE) can perform queries and return lists of stations nearest to specified combinations of inventoried items, but the list is not very useful without a graphical representation of both the cave and the inventory data.

Geographic Information Systems (GIS) technology has provided the link between such databases of information, cave survey data, and surface features. Any information that is geographically referenced (such as data tied to survey stations) can be incorporated in GIS. This has provided managers with the ability to view and analyze spatial relationships of features inside the cave as well as spatial relationships between cave passages and overlying surface features.

Control Point Adjustment and Cave–Surface Overlay

Once the cave has been surveyed, the survey can be registered to a known surface location (the entrance), and a line plot of the cave can be overlain on other GIS layers. The accuracy of this overlay relies on the accuracy of the cave survey and, in a large cave system, compounding errors can lead to imprecise overlays. To correct for errors in the survey, cave radio locations were used.

Coordinates of 35 radio-located surface control points were determined by surveying from benchmark locations. These latitude-longitude values were used to create an ArcView GIS theme, then were projected and displayed together with their corresponding cave survey stations. As expected, the surface and in-cave points closest to the origin of the cave survey (the entrance) overlap almost perfectly. Offset between the pairs of points becomes greater as the survey moves farther from its point of origin. (Figure 1)

In COMPASS, the X and Y coordinates of the radio locations were entered as control points, using the Z coordinate from the original cave survey. The depth determined by the cave radio is subject to large, non-systematic errors, and was therefore not used to calculate a new Z coordinate. The cave was then re-plotted and exported to ArcView.

Once the cave data set was corrected, it was combined in the GIS with Digital Line Graphs representing hydrography, roads, political boundaries, and topographic contours (Figure 2). It was also overlain on images supported by ArcView, such as Digital Raster Graphics and Digital Orthophotoquads.

Overburden Determination

Determining the depth of cave passages beneath the local surface is an important cave management tool. Prior to the use of GIS, vertical relationships with the entrance could be easily calculated from the cave survey, but overburden could not. GIS layers such as Digital Line Graphs of topographic contours or Digital Elevation Models provide the elevation at any point on the surface. The cave survey data layer provides the elevation for every survey station in the cave. Joining the two data sets together, then subtracting the surface and cave elevations, yields the depth.

The accuracy of this depth determination is limited by the accuracy of the surface elevations and the accuracy of the cave survey. Since Digital Line Graphs of 20-foot topographic contours were used to determine surface elevations, the accuracy of the surface elevation can conservatively be given as ± 10 feet.

The radio locations discussed in the previous section have revealed a relatively accurate cave survey, however survey error cumulatively increases far from the entrance. Although the survey was corrected in the X-Y direction to match the radio locations, using the elevations determined by the original cave survey could introduce error to the depth determination in

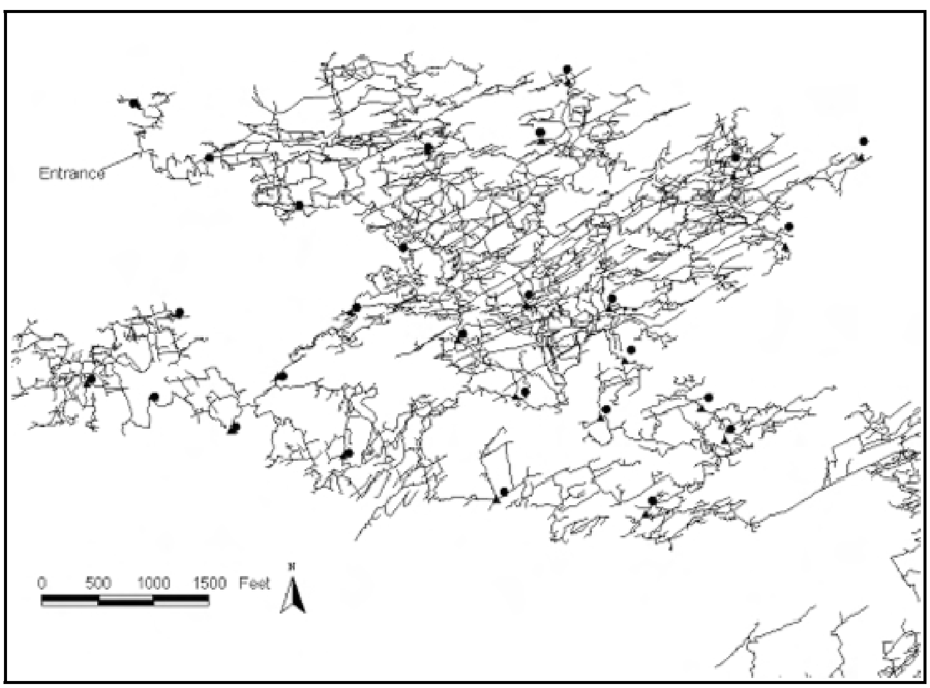

Figure 1. *Surface control points (circles) and corresponding in-cave points (triangles) for a portion of Jewel Cave.*

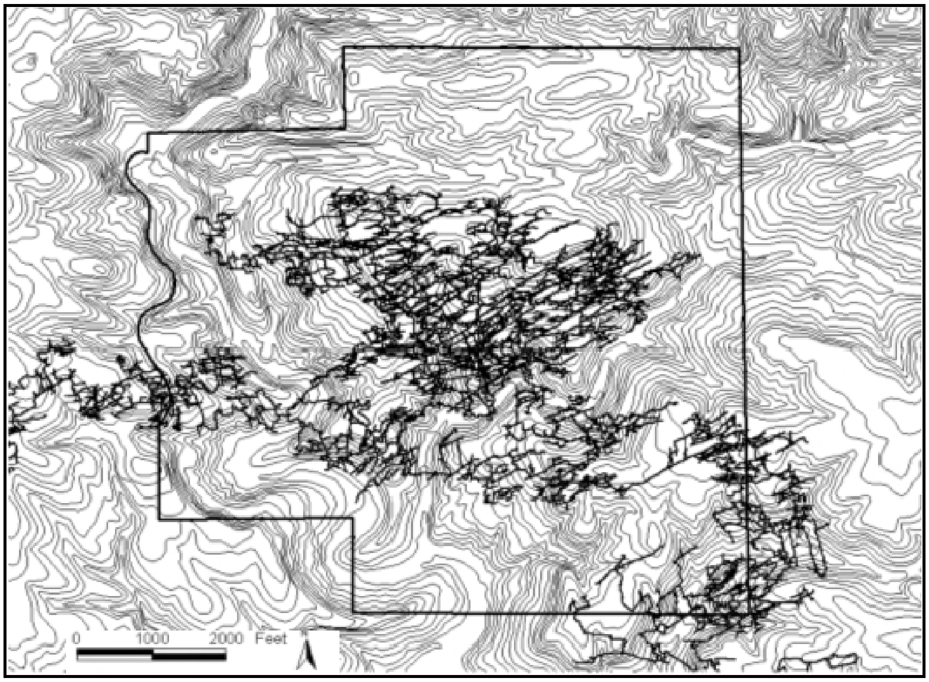

Figure 2. *Portion of Jewel Cave line plot overlain on Digital Line Graphs of topographic contours and the National Monument boundary.*

the far southeastern part of the cave, where survey error is greatest.

The deepest point in Jewel Cave was determined to be nearly 750 feet below the surface. Due to the errors described above, one survey station was found to be 8.2 feet above ground.

Feature Inventory and Radon Linkages

Nearly half of Jewel Cave's 127 miles of passages have been extensively inventoried. The ability to quickly query this data and display the results on the cave line plot is extremely useful. Relationships between the inventoried items and other layers in the GIS (such as hypsography, hydrography, and surrounding geology) can be revealed, as well as ways in which the queried items spatially relate to each other.

The inventory data was added to ArcView as a table then linked and cross-linked to the cave survey stations theme. Complex queries for any combination of inventory items can now be performed, and the results of the queries can be highlighted on the cave line plot. (Figure 3)

A table of radon concentration values for several survey stations was also added to ArcView, then joined to the survey stations theme. The stations were then colored based on ranges of radon concentration in order to look for any trends in radon related to location. Although more data is needed, it appears that radon concentration decreases far from the cave entrance.

A Management Tool

Developing an accurate cave-surface overlay for Jewel Cave has allowed us to identify cave passages that run beneath surface developments such as roads, buildings, and parking lots. This can tell us which areas of the cave are most vulnerable to contamination and redirected runoff associated with these developments.

A graduate student conducting research at Jewel Cave has also used the monument's GIS to determine which cave passages run beneath faults and fractures he has identified on the surface. He has then been able to look for fractures and evidence of faulting in those passages to better determine surface–subsurface geological relationships.

Currently, over 40% of Jewel Cave lies beneath USDA-Forest Service land, and GIS has allowed management to more precisely determine where the cave leaves the national monument boundary. An important first step in managing any cave is knowing where it is, and GIS can determine this to a great degree of accuracy.

Estimating overburden is also a very useful management tool. Identifying shallow areas of the cave, particularly in locations vulnerable to

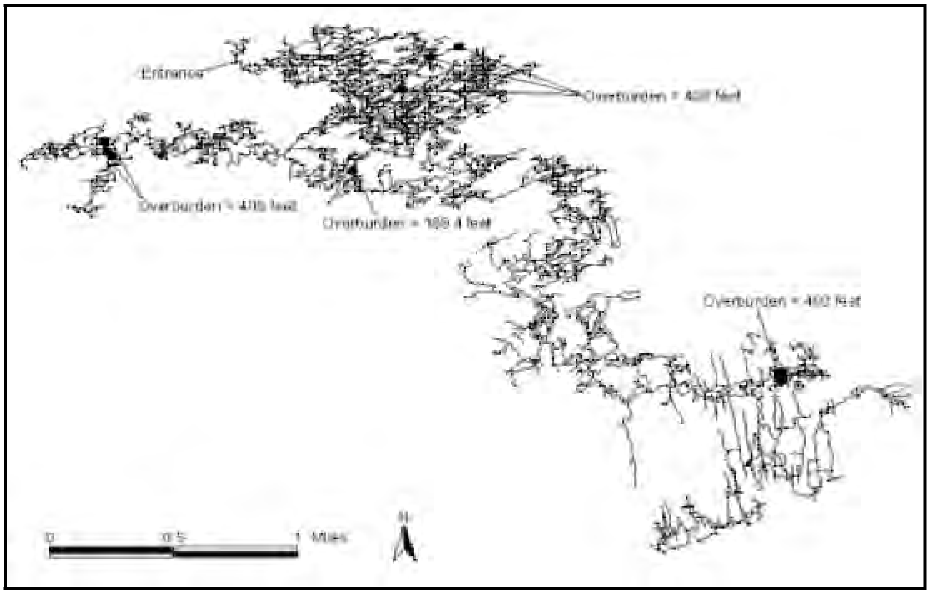

Figure 3. *Location of bat scratches in Jewel Cave as determined by cave feature inventory linkage. These may be locations of old entrances that have since been naturally filled. Note overburden for each area.*

potentially harmful surface activities, can help to guide management decisions. Overburden information can also be used to choose the shallowest possible sites for new radio locations in order to receive the strongest magnetic signal possible.

GIS analysis has helped the resource management staff make better-informed decisions regarding the use of herbicides to treat non-native plants. It has been used to determine the location of noxious weed sites relative to Jewel Cave, to calculate the depth of the cave below these sites, to evaluate their proximity to drainages and other potential infiltration zones, and to find locations of in-cave water drips near these sites.

In the Future

GIS is only as useful as the data available. Jewel Cave looks forward to incorporating more data into the GIS, which will allow for more complex analyses. Structural geologic contours have recently been determined and will be included as will a detailed surface geologic map of the area. The cave maps, which are currently hand-drafted, will be digitized in the coming years. Relationships between constricted, large, or complex parts of the cave and other GIS layers can then be determined. Such information will contribute to our understanding of the cave, and may help to guide continuing exploration.

The Use of Cave Inventory Systems as a Cave Management Tool: An Overview

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Abstract

Cave inventory systems have been developed by a number of different groups, including cave survey and exploration projects, privately owned caves, and state/federal land management agencies. The diversity of the inventory systems developed reflects the diversity of the groups conducting cave inventories. However, two basic inventory styles are in use throughout the United States in a basic inventory of caves and detailed resource inventories. Cave inventories are an incredibly valuable tool to aid in management of cave resources. This paper examines two case studies in cave inventory systems: the cave inventory of Lava Beds National Monument and the detailed resource inventory of Wind Cave National Park. Each offers insight into the benefits of inventory systems to cave managers and the value of well-designed data management systems. In addition, a brief discussion of other cave inventory systems currently in place throughout the U.S. is presented.

Raster Geographic Information System for the Management of Cave Reconnaissance Information

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Abstract

There are two ways in which to manage geographic information with a computer, as vector objects or as raster cells. Vector systems dominate the industry and are what most people think of when they hear, or read, the term Geographic Information System (GIS). Raster systems, however, are growing in popularity for complex map analyses. This paper will describe the application of a raster GIS to the management of topographic, hydrologic, and geologic information in the search for undiscovered caves on the eastern slope of the Santa Catalina Mountains, Arizona. The success of the procedures will be measured by their ability to "discover" the known caves in the area.

Introduction

To many people the term geographic information system or GIS is synonymous with the vector-based GIS packages that are popular with government agencies and businesses. The overwhelming market share occupied by these expensive systems eclipses the raster GIS software that is sold by smaller vendors.

The power of raster GIS systems lies in their ability to rapidly perform mathematical and logical operations on individual map layers. The layers can be considered as variables in an equation and they may be manipulated by operations of map algebra. This paper is a demonstration of the application of a raster system to the management of data that are useful in cave reconnaissance.

The focal point for this work is an area on the northeastern flanks of the Santa Catalina Mountains, which form a dramatic backdrop to the Tucson skyline (Figure 1). A number of caves in that area share a morphology that suggests a common genesis. Extensive solution is confined to a limited vertical interval at what was once at or just below the paleo water table. Joints and faults exert some control on passage direction so resulting caves begin as two-dimensional mazes. If solution is extensive, the overlying rocks collapse and large rooms form as a result of upward stoping. Continued solution of the breakdown sometimes creates dramatic, flat-floored rooms.

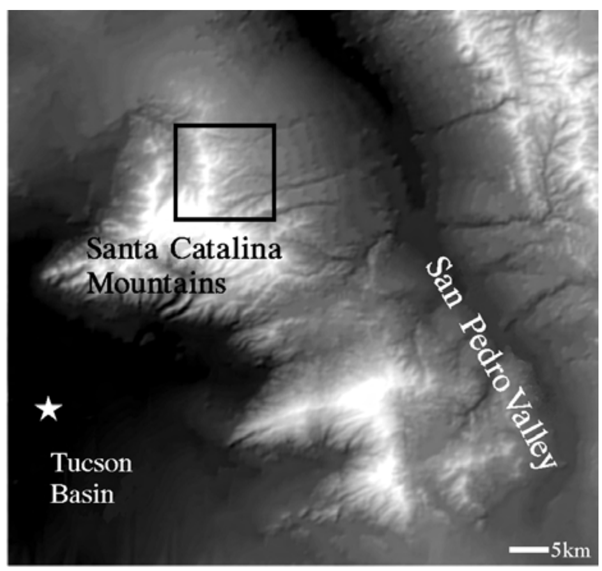

Figure 1. *Location of research area on the northeastern flank of the Santa Catalina Mountains indicated by the black square. Star indicates the site of the Symposium in Tucson, Arizona. Original scale about 1:500,000.*

Scroll Cave is a good example of this morphology. It is a horizontal maze covering an area of approximately 75,000 square meters. A large entrance room has a floor that is 20 by 30 meters in size. The cave is located directly below a flat, gently-sloping erosion surface capped by older Quaternary sediments. Kartchner Caverns, 75 kilometers southeast of Scroll Cave, also exhibits strong water-table control of solution. At Kartchner Caverns it appears that a stable water table was associated with the maximum filling of the San Pedro River Valley by the late Pleistocene St. David formation (Hill, 1999).

Information

Information for this search for caves comes from three sources: geologic mapping, digital elevation models, and information on cave morphology and speleogenesis. Utilizing this information in a cartographic model (Figure 2) will define areas with the highest potential for new cave discoveries. In addition to the above information the 1:100,000 metric topographic maps of the Mammoth, Tucson, and Fort Huachuca Quadrangles were used to provide general regional information.

The geology and tectonics of the Santa Catalina Mountains have been studied in some detail, particularly by Force (1997) and Dickinson (1991). The range is a classic metamorphic core complex in the south but is dominated by a Laramide, basement-cored uplift in the north. Here, 1.1 kilometers of middle Proterozoic to Paleozoic sedimentary rocks rest unconformably on a basement of Oracle Granite and Pinal Schist. Three Laramide aged concordant intrusions distort and partly metamorphose the sedimentary stack. Laramide and Tertiary faulting in the area is typically high-angle and normal, most notably along the Geesaman and Mogul Faults.

The 1:48,000 scale geologic map prepared by Force (1997) is of particular interest to this study since it breaks out the Paleozoic carbonates that host caves in southeastern Arizona. Also shown on the map is an area of older, Quaternary alluvium (Qa2) which may be correlated with the St. David formation exposed near Kartchner Caverns. Dickinson (1991, page 66) regards the St. David formation near Kartchner Caverns and the older Quaternary alluvium in this study area to be part of the Quiburis Formation. Even though the St. David is younger than the Quiburis, both formations are representative of the period of maximum basin filling in the San Pedro Trough; thus they define a period of water table stability on the flanks of their respective mountain ranges.

Digital elevation models of the Campo Bonito and Mount Bigelow 7.5-minute Quadrangles were acquired on line. The elevation data is in raster format with a 30-meter cell size. Information on the caves was obtained from the published maps of Scroll Cave (Thayer, undated) and Deadman Cave (Brod, 1977 survey) from visits to Scroll, Deadman, Peppersauce and Nugget Caves, and from conversations with Lang Brod of the Escabrosa Grotto.

All the information used in this work was converted to raster format for management by the geographic information system. The digital elevation model data uses a cell resolution of 30 meters. Using a cell size of less than 30 meters creates only an illusion of precision. Geologic maps at 30-meter resolution looked "blocky" and were difficult to digitize. In the end 20 meters was found to be workable for data input and processing. All data files were less than one megabyte in size. Data layers were all warped to UTM zone 12N with NAD27 and registered to each other.

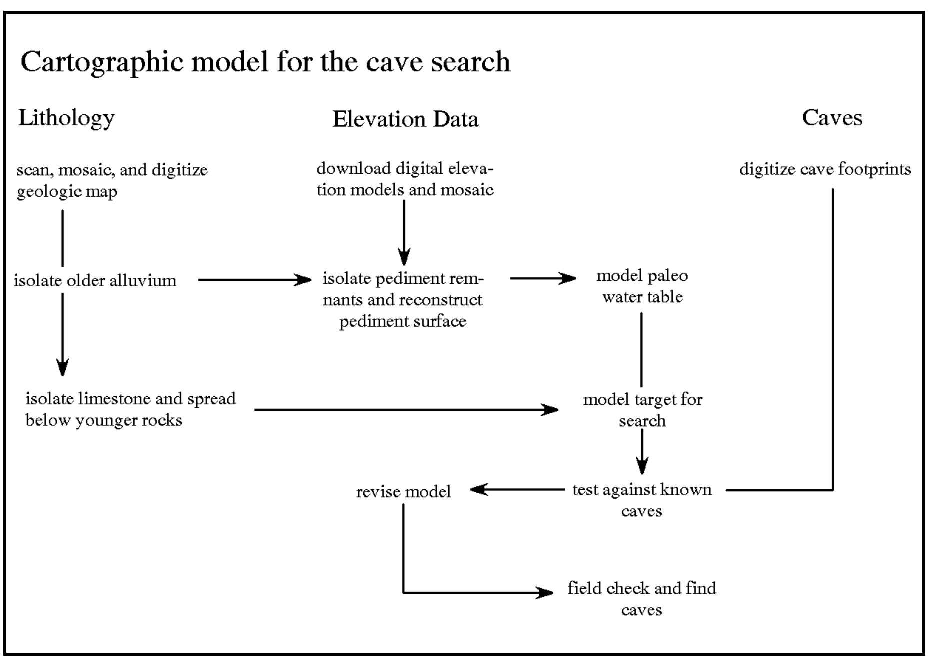

Figure 2. *Cartographic model used to guide the operations of the geographic information system.*

Data management

After the data are assembled, the process of extracting useful information can begin. Recall that the objective of this work is to define areas in which searching for undiscovered caves will be most successful. The overall search region has an area of 132 square kilometers. Even without a geographic information system it is easy to use the geologic map to eliminate areas that do not contain limestone. This reduces the search region to 9.8 square kilometers; but this is still a large area to search carefully on foot.

Developing an effective cartographic model, based on the speleogenesis of known caves, one can effectively reduce the search area within the limestones. The morphology of caves suggests that a stable water table, associated with a stable erosion surface, is important to the genesis of caves. The basic elements of the model then include soluble limestone and a stable water table (Figure 2). Discovering areas where these two factors coincide in space is the key to reducing the search area.

Solution of the limestone is controlled to some degree by faulting and joints and we felt that mapped faults would be a useful part of the cartographic model. However, filed observations show that faults are so ubiquitous in the map area that virtually every cell in the GIS will contain faults and/or joints. Limiting the model to the vicinity of mapped faults is excessively constraining.

The first step in the application of the model is to select areas containing Horquilla (Ph), Escabrosa (Me), and Mescal (Ym) Limestones from the digitized geologic map (Figure 3). Escabrosa Limestone is the most common host rock for caves in southeastern Arizona but the other limestones in the area should not be ruled out as possible hosts. The geologic map shows places where the limestones outcrop but the rocks are present beneath younger formations and there is no reason not to expect caves there. To accommodate this possibility, the extent of limestones was spread 100 meters beyond their outcrops, beneath all younger rock units.

Modeling the paleo water table presented a more challenging task. In order to accomplish this it was necessary to recreate the pediment surface that existed at the time the water table was stable. Since remnants of the pediment surface remain as geomorphic features today, the first step was to isolate these remnants on the digital elevation models.

The slopes of the remnant pediment surfaces range from almost horizontal to as much as 15 percent toward the cores of mountain

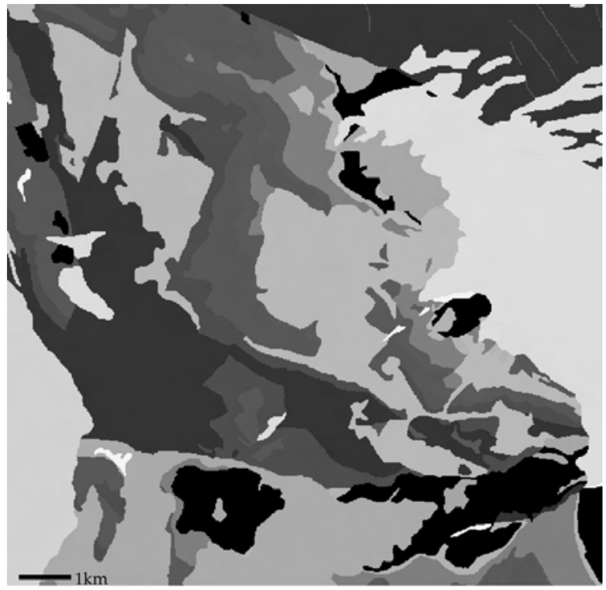

Figure 3. *Geologic map of the research area. Lithologic units are shown in shades of gray, oldest units are the darkest. Horquilla (Ph), Escabrosa (Me) and Mescal (Ym) limestones are shown in black.*

ranges. Slopes in this range, with extents greater than 200 by 200 meters were isolated from the digital elevation data. These were further processed to remove those slopes that occurred at the bottoms of arroyos. The remaining areas, representing erosional remnants of the older Quaternary pediment surface, were used as seeds for an interpolation operation. The interpolation effectively replaced those parts of the pediment that had been removed by erosion. The interpolated surface was trimmed to fit any topography that extended above the surface and the result is shown in Figure 4.

The preserved pediment surface at Scroll Cave is approximately 20 meters above the level of extensive maze development. This distance was used as an estimate of the depth of the paleo water table below the older Quaternary pediment surface. Creating a model of the stable water table at the time of extensive solution of the limestones was simply a matter of subtracting 20 meters from the elevation of the restored pediment surface.

With the extent of the limestones and the level of the paleo water table modeled, it remained to find places where the two intersected. The first step in this process was to isolate the topography of areas containing limestone. The elevations of cells in these areas were subtracted from the elevations of cells in the water table surface. Negative or positive values in the result indicated that the lime-

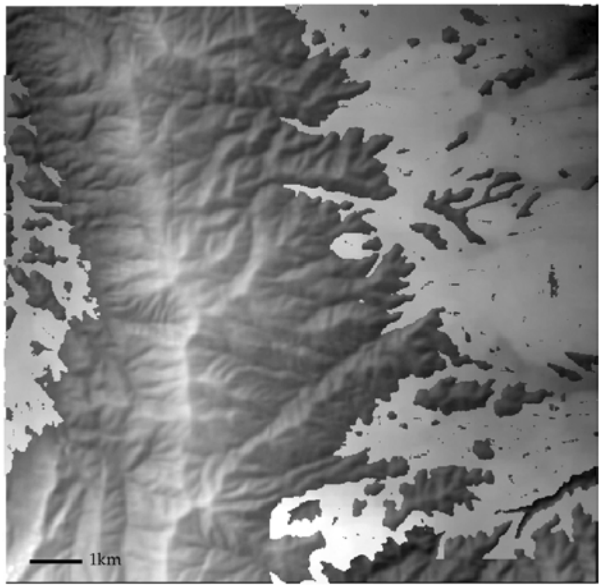

Figure 4. *Restored older Quaternary pediment surface shown in light gray tones on shaded dem background.*

stones were below or above the water table, respectively. Allowing ± five meters for margin of error, the cells at zero and above or below zero were selected as areas where the water table was in contact with the limestone, much as a lake is in contact with its topographic shore (Figure 5).

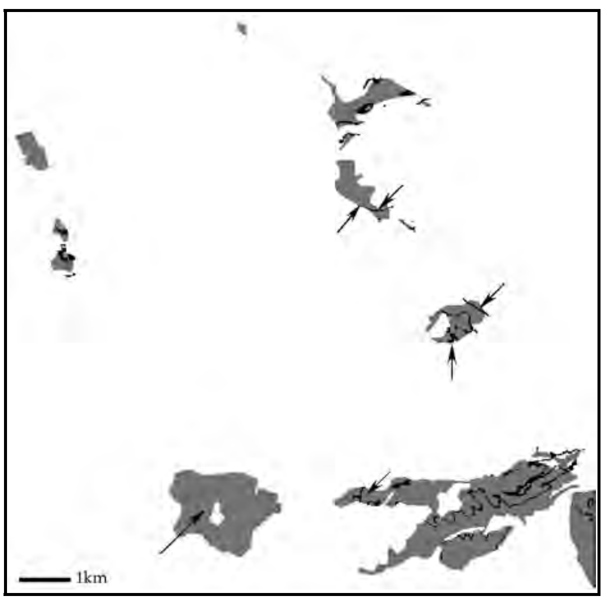

Figure 5. *Target areas shown in black. Areas of limestone outcrop, in gray are shown for reference. Targets that extend beyond the limits of limestone outcrops show potential in limestones covered by younger rocks. Tips of arrows indicate the locations of presently known caves.*

The success of the cartographic model in predicting the locations of undiscovered caves can be tested by comparing the model with the locations of known caves. The locations of entrances of known caves are indicated at the tips of arrows in Figure 5. With the exception of one cave, the entrances to known caves are within or very near the target areas. The exception is a cave that does not exhibit a strong water table control of its speleogenesis.

Since the objective of this effort is to define areas for optimum field exploration the model can be "tweaked" a bit by using the locations of known caves as evidence for the location of the paleo water table. If this were done before the model was tested it would be considered a self-fulfilling effort—the model "finds" the caves that were used in its creation. If the known solution levels in the caves are used after the model has been tested and shown to be accurate, the improvement will only improve the precision of an already accurate model.

Conclusions

Caves within a 132-square-kilometer area on the northeastern slopes of the Santa Catalina Mountains are known to contain caves with strong water table control on their speleogenesis. Simply selecting areas of limestone for field checking in this area would require the examination of 9.8 square kilometers for the existence of cave entrances.

Instead, a two component cartographic model consisting of limestone host rocks and a stable paleo water table was used. The model was developed with some trial and error but in its ultimate form it used only a geologic map and digital elevation models for input. One and one half pages of script were used to execute the cartographic model in the MFWorks raster GIS.

The application of a raster format geographic information system to the task effectively reduced the search area to 0.8 square kilometers. Most of the targets are on hillsides so ridge walking in the strictest sense would have been ineffective in finding new caves.

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Biographical Sketch

Dr Truebe started caving in the iron mines of New York State and in the cold, wet caves of the Schoharie Plateau. An education at Colorado School of Mines introduced him to the Rockies, the Black Hills, and the Guadalupes. A career in mineral exploration and a tour in the Peace Corps has taken him throughout the western U.S. and Oceania. He currently teaches map and aerial photo interpretation as well as providing remote sensing and raster GIS services to clients in mineral exploration and other fields.

GIS Modeling of Significant Karst Areas for Purchase and Protection

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Abstract

In May 2000, the voters of San Antonio, Texas, approved a sales tax increase to raise $65 million over four years to purchase land over the recharge zone of the karstic Edwards Aquifer and local streams. A team of karst, hydrogeology, wildlife, GIS, and land management specialists was assembled to develop a strategy for identifying properties with highest hydrologic and aquifer protection value for possible acquisition. GIS methods were determined the most effective means of assessing the properties. A GIS model was constructed of three components: vulnerability, watershed, and biology. Each component comprised spatial data layers weighed according to their significance. Vulnerability layers were land slope, faults, caves, sinkholes, and the permeability of the geologic units. Watershed layers were property size, properties adjacent to existing preserved or protected areas, and areas that drain into known caves. Biology layers were the distribution of federally listed endangered bird and karst invertebrate species. The three components were respectively weighted at 50%, 30%, and 20% and combined. Sensitivity testing was conducted to assure the optimal quality of the model's output, which was presented in three tiers of priority for acquisition based on the numerical values for the properties. The results were provided to land agents working for the city who checked the availability of the highest tier properties first. To date, approximately 11 square kilometers have been purchased and are creating what may prove an important buffer to mitigate impacts from the extensive urbanization occurring on the Edwards Aquifer recharge zone.

Introduction

The San Antonio Segment of the karstic Edwards (Balcones Fault Zone) Aquifer (hereafter called Edwards Aquifer) is the primary water supply for the City of San Antonio and approximately 1.5 million people. The aquifer has been the subject of intense political and public debates on the management of its water quantity and quality. The growing population and demand for aquifer water in the region has led to efforts to increase the volume of recharge entering the aquifer, such as the construction of recharge enhancement structures (for example, Bader, Walthour, and Waugh, 1993). However, some of this growth and its urban development have been on the recharge zone, where water enters the aquifer, and has prompted concern about potential groundwater contamination and recharge reduction (for example, Kipp, Farrington, and Albach, 1993).

On May 6, 2000, the citizens of San Antonio voted to approve the ballot item listed as "Proposition 3," a ⅛-cent sales tax to raise $65 million over four years for the purchase of environmentally sensitive lands within the city's limits and extra territorial jurisdiction within Bexar County. $20 million was allocated for the creation of linear parks along Leon and Salado creeks. $45 million was allocated for the purchase and management of land over sensitive zones of the Edwards Aquifer. The purpose of the land purchases is to reduce adverse impacts on surface and groundwater quality by preserving critical, undeveloped lands to maintain natural, uncontaminated flows into the aquifer and creeks. Given the land values at the time of the vote, an estimated 40 square kilometers of Edwards Aquifer land were hoped to be purchased. This paper describes the process used by the City of San Antonio to identify the tracts of land that would be most favorable to purchase for aquifer protection.

To accomplish this task, the City organized a Scientific Evaluation Team to provide scientifically based information that will assist in the identification of properties for possible acquisition. The Team comprised scientists and managers expert in the hydrogeology and karst of the Edwards Aquifer, threatened and endangered species in the region, wildlife habitat management, and in the City's administrative processes. They represented the following agencies and organizations:

- City of San Antonio Public Works Department
- City of San Antonio Parks and Recreation Department
- Edwards Aquifer Authority
- George Veni and Associates
- San Antonio River Authority
- San Antonio Water System
- Texas Parks and Wildlife Department
- U.S. Geological Survey (USGS)
- U.S. Natural Resource Conservation Service
- University of Texas at San Antonio

Approximately 2,000 volunteer manhours were spent by the members of the Team, who donated their time and services to the City.

Methodology

During the first meeting of the Scientific Evaluation Team, it became quickly apparent that the most effective means of analyzing the complex and multiple data sets for this process would be through Geographic Information System (GIS) modeling. All of the data were spatial or could be spatially represented in an ordered series of layers that could be combined for analysis and decision making. The spatial representation was technically effective but also offered a clear and intuitively understandable process for the general public to see that their tax dollars were well spent. ArcView Spatial Analyst and Model Builder were selected as the software to process the data. ESRI, Inc., ArcView's producer, provided substantial volunteer support to facilitate construction and processing of the GIS model.

The Scientific Evaluation Team identified three primary scientific layers of spatial data for the GIS model: geologic, biological, and watershed. Each layer was composed of sublayers, spatial data that were assigned point values and combined to give an overall value to the primary layer for a given location. Data for the layers and sublayers were derived from several sources and at different scale resolutions. Much of the data were originally established as 30-square-meter blocks to match the resolution of the digital elevation data for the area (Clark, 2000). All spatial data were subdivided to a common scale of one-square-meter areas to allow uniform and proper overlay of the data. Following is a discussion of the data entered into the model and how they were analyzed.

Geologic data layer

The foundation for this layer was an Edwards Aquifer groundwater vulnerability map prepared by the U.S. Geological Survey (Clark, 2000). In cooperation with Clark and other members of the U.S. Geological Survey, that map was modified for the GIS model by adjusting values based on new information and expanding it north into the aquifer's contributing zone (also called the drainage zone or catchment zone) to the county line (the legal limit authorized by Proposition 3 for purchasing properties). Sublayers used in the development of this geologic layer were land slope, faults, caves and sinkholes, and the permeability of the exposed geologic units. Soils were also used by Clark (1999) but not included in this model because they are locally thin to nonexistent, often patchy, and due to their similarity they would likely have little overall impact on the model.

Land slope relates directly to groundwater recharge. Areas of higher slope have a greater propensity for runoff than recharge. Veni (1997) found that recharge-formed caves are more likely to occur along streambeds or interstream uplands that have slopes of less than 5%. A digital elevation model for the county was analyzed, and areas were subdivided and assigned point values according to Table 1, with higher ratings reflecting greater potential for groundwater recharge.

Table 1: Recharge potential ratings for land slopes

Slope	Rating
Greater than 18%	1
Greater than 12% and less than 18%	3
Greater than 6% and less than 12%	5
Greater than 2% and less than 6%	9
Less than or equal to 2%	10

Mapped faults within the study area were added to the model. Their locations were imported from existing U.S. Geological Survey digital maps. The Scientific Evaluation Team recognized that many of the faults were not single isolated fractures but zones of fractures and drew the faults as 50-meter-wide areas in the GIS model. The width was selected based on field experience to include the zone where most fault-associated fractures were likely to occur. Since the full lengths of the faults were not precisely mapped in the field but interpreted from air photos and topographic maps, the 50-meter-wide fault areas are more likely to include the faults and most significant associated fractures where minor deviations from the mapped fault traces might occur. Fault areas were assigned the highest value of 35 points in the GIS model due to their potentially high permeability.

Caves and sinkholes are features of highest permeability and were also given the highest 35-point value in the GIS model. These features were defined in the model as 100-meter-diameter circular areas, which roughly approximate the horizontal extent of most local caves above the water table and capture most associated sinkholes and solutionally enlarged fractures. Satellite recharge features often form around caves and sinkholes in response to high permeability gradients (Kemmerly, 1982). The 100-meter-areas also comply with the 100 to 150-meter-areas used by the U.S. Fish and Wildlife Service to establish critical zones for the protection of caves in the area with federally listed endangered invertebrate species (USFWS, 2000a). Few sinkholes were included in the model because most are locally small, low relief features, and few appear on the 7.5-minute topographic maps of the study area.

The caves included in the model were those known to the U.S. Geological Survey. The Texas Speleological Survey was contacted for additional cave locations; but instead of specific locations, Texas Speleological Survey provided cave zones reflecting areas where one or more caves are known to occur. The zones were delineated based on geology, specific cave and karst feature locations not released to the model, security of the cave locations, and the extent of the caves. In general, larger zones suggest more known caves and karst features, and/or better understanding of the geology that gives confidence to extend the borders further to where caves have a high probability of existence. Since parts of these zones may not contain caves, they were given 30 points in the model, slightly less than maximum assignable value. Where known cave locations overlapped these zones, the higher 35-point value was used. Zone boundaries drawn along limestone quarries extended to the quarry walls as shown on the topographic maps. Some of the walls were probably excavated into the cave zones since the topographic maps were published. Cave zones were not drawn within existing parks or military bases since those areas are already preserved and/or unavailable for acquisition, although some zones were drawn outward from those boundaries.

The Scientific Evaluation Team recognized that significant recharge into karst aquifers occurs throughout the outcrop and not solely through features such as fractures, caves, and sinkholes. In order to model this recharge, the U.S. Geological Survey mapping of the study area's lithology was added to the model. This comprised mapping by Stein and Ozuna (1995) for the Edwards Aquifer recharge zone and by Clark (in review), which is the basis for recent, currently unpublished mapping of the aquifer's contributing zone. Inclusion of the contributing zone was considered important because, though not yet formally designated as part of the recharge zone by the State of Texas, significant recharge into the Edwards is known to occur in this area (Veni, 1995).

Five stratigraphic formations occur in the study area and have been mapped as 15 different lithologic units. These were grouped into four categories according to their mean permeability, which is highly affected by their degree of karstification. The most permeable units were assigned higher point values, the confining units received the fewest points, and the remaining two categories of units were assigned low and moderate values as appropriate.

Biological data layer

This layer is composed of data related to the distribution of federally listed endangered species. The species fall into two groups: karst invertebrates and birds. Maps developed through the U.S. Fish and Wildlife Service (Veni and Associates, 1994) were used in the model to delineate the areas known to be occupied by the karst invertebrates or the varying potential for their presence as rated in Table 2. These maps were updated to include the most recent available information on the species' distribution. Highest point values were given to known endangered species zones, no points were given to zones that do not contain the species, and low to moderate values were assigned as appropriate to the intermediate zones. At the time the model was constructed, the karst invertebrates were proposed for endangered listing (Rappaport, 1998) and were listed by the end of the year (USFWS, 2000b). Since some endemic invertebrates in the area are rarer than some of the listed species, the zones also consider the probability of those animals being present should they ever be listed.

Table 2: Classification of karst invertebrate zones

Zone	Classification
Zone 1	Contains endangered cave species
Zone 2	High probability of endangered or endemic cave species
Zone 3	Low probability of endangered or endemic cave species
Zone 4	Requires further study
Zone 5	Does not contain endangered cave species

Maps showing the distribution of the endangered bird species were unavailable, but USFWS provided vegetation maps of the county from which potential bird habitat could be deduced, as described by Campbell (1995). The areas were classified as:

- water
- ashe juniper or mixed ashe juniper oak forest
- ashe juniper or mixed ashe juniper or mainly deciduous forest
- ashe juniper or mixed ashe juniper oak woodland
- ashe juniper or mixed or mainly oak savanna
- grassland
- urban vegetated
- barren, sparsely vegetated
- no data (outside the study area)

To relate these areas to endangered bird species, the Scientific Evaluation Team reclassified them with diminishing point values as:

- potential endangered species habitat
- grassland
- water, barren, urban
- no data (outside the study area)

Since endangered bird habitat was not definitively delineated by this mapping, its highest point value was set equal to Zone 2 for the karst invertebrates.

Watershed data layer

The geologic data layer identifies important recharge features such as caves. However, the Scientific Evaluation Team recognized that protection of recharge water quality and quantity requires the preservation of watersheds. Maps of only large watershed boundaries were available and were not at a scale useful to the GIS modeling. Digitizing smaller watersheds in the county was beyond the scope of the Scientific Evaluation Team, so property size and connectivity were combined for use as watershed surrogates.

Undeveloped properties greater than 242,820 square meters (60 acres) in size were valued higher in the model than smaller properties. This factor was determined from the fact that generally larger properties will encompass larger portions of watersheds. Undeveloped land allows unimpeded and uncontaminated recharge and also buffers the adverse impacts of surrounding developed land by dilution. Schuleler (1994) summarized the results of multiple studies on the relationship between impervious cover and streams. He found that watersheds with more than 10% to 20% impervious cover suffered significant degradation in water quality, biodiversity, stream temperature, and stability of stream channel shape and position. However, since there was no specific size area that had been demonstrated as critical to maintaining groundwater quality, the 242,820-square-meter area was selected as the minimum size for its effectiveness in managing and preserving wildlife habitat (Adams, 1994). This area also approximates the minimum size of the endangered karst species preserves per the protocols of the U.S. Fish and Wildlife Service (2000a). Property boundaries and attributes such as size and land use were provided for the model by the Bexar Appraisal District.

In order to capture larger portions of watersheds, property connectivity was added as a sublayer to the model. This element gave high point values to properties that are adjacent to existing preserved or protected areas (parks, flood control dam reservoirs, and military installations). Adjacency was determined as undeveloped properties within 60 meters of the preserved or protected properties to account for streets and slightly mis-matched boundaries drawn from different mapping sources.

Within the watershed layer of the GIS model, value was also given to areas that drained into known caves and could be mapped at the scale of the 7.5-minute topographic maps. Drainage areas for caves located in the beds of large creeks were drawn to encompass the parts of the watershed nearest those caves that, based on field experience, would likely contribute runoff into the caves. The upper reaches of such watersheds were excluded since much of that water recharges the aquifer before reaching those caves. Also, there is less need to protect those areas, relative to the caves, since any contaminants in their runoff would be significantly diluted during large storms where upstream flows extend to the caves.

Processing the GIS Model

ArcView Model Builder was used to process the data for the GIS model. Point values for the sublayers of each square meter of the study area were summed to generate the value of those areas for the primary geologic, biological, and watershed layers. Rather than simply summing the primary layers, they were first weighted according to importance and then summed to produce the model's map of the area. The geology layer was weighed as 50%, the biology layer as 20%, and the watershed layer as 30%. While protection of endangered species is important, biology was not given greater weight since the purpose of Proposition 3 was the protection of Edwards Aquifer groundwater. The biology was used to identify hydrologically important lands that were also ecologically important. The points and weighting of the layers were tested with different values to determine which numbers gave results that appeared the most technically accurate. Figures showing the model's output map and its component layers are not presented with this paper. These maps require color reproduction, unavailable for these proceedings, to be understood.

Results, Interpretation, and Use of the Model

The GIS model calculated total scores from the layers and output a point ranking for each square meter of the study area. These areas were divided into eight categories and color-coded for visual display. The six highest categories were recommended by the Scientific Evaluation Team for consideration for acquisition; the two lowest categories may not have sufficient hydrogeologic and biological qualities to warrant their acquisition unless all higher scoring properties have been exhausted. The six categories were grouped by twos to create three tiers to simplify targeting properties for potential acquisition. Tier 1 contains the highest point-scoring areas and was recommended for first examination for acquisition. The model easily highlights the tiers as groups and can list the target properties by size, value, owner, or other desired attributes.

Although the model provides a simple and effective means of identifying hydrologically and ecologically important properties, the Scientific Evaluation Team offered several comments to the Conservation Advisory Board, which reviewed the properties for acquisition by the city. These comments explained how the model was developed, its limitations, and how it can be enhanced and better used.

One important factor in understanding the model's output is that the nature of the model required subdividing the aquifer area into several ranks. However, the nature of the aquifer is that all aquifer recharge and contributing areas are important to protect. The purpose of the model is to distinguish between small differences to facilitate the most effective purchases. Areas that rank low in the model should not be misconstrued as unimportant to the aquifer or not vulnerable to contamination.

The GIS model is dynamic. The Scientific Evaluation Team recommended that the model should be updated and run again as each new property is acquired or as protected properties are established in the area by other organizations. Connectivity of watersheds and habitat is an important factor in the model, so the establishment of new protected areas will generate new high priority areas to target for acquisition.

Several additional mapable features can be overlain on the model and should be considered in the decision making process. Weighing the importance of these features was considered a management decision and outside the scope of the Scientific Evaluation Team. Following is a list of some features and recommendations in their consideration.

- Census data: This information can be used to determine areas of growth and where land acquisitions may preferentially encourage or discourage growth in a manner that supports protection of the Edwards Aquifer.
- Golf courses: Hydrologically, these areas may produce poor quality runoff and should not be considered for hydrologic connectivity. However, some may provide biological

connectivity and should be considered if connectivity for endangered bird species is needed or available.

- Hazardous materials sites: These sites include but are not limited to landfills, quarries, leaking and non-leaking underground storage facilities, sewage lift stations, and sewer lines. Where a property has sufficient undeveloped land, it could be strategically used to ameliorate the impacts of such sites on that property or surrounding properties. These properties will need case-by-case evaluation to determine if they are worth purchasing. "Sufficient undeveloped land" will need to be determined case-by-case by the degree of known or potential impacts and the property's size and ability to significantly ameliorate the impacts. Only properties that are large enough to significantly ameliorate the impacts, or where the impacts are small enough to allow significant amelioration by the property's size, should be considered for acquisition.
- Development Plans: Existing development plans should be among the first factors evaluated in targeting properties for acquisition. The occurrence of such plans does not mean that a property should not be considered for acquisition. While some properties are far enough along in the development process to make them financially unavailable or hydrologically and/or biologically undesirable for acquisition, others may be viable and attractive for purchase. Additionally, acquisition of these properties may be strategically useful to discourage growth in certain areas and/or buffer the impacts of adjacent developments.
- Property improvement values: Undeveloped properties were identified for the model by including only properties with no added improvement value. However, a property may still be attractive for acquisition if it is largely undeveloped. The model can be run with a filter to identify low-value improvements, so that properties with only an old ranch house or similar structures might be included. High values can be used as a filter to try and locate properties with small strips of intensive development but otherwise undeveloped. However, these will require considerable effort to distinguish them from predominantly developed properties.

Properties primarily within 100-year floodplains should receive less priority for acquisition.

Those lands are generally undevelopable and, in the San Antonio area, existing regulations will preserve them as recharge sites. Efforts should focus on developable lands to protect the quality and quantity of water entering the floodplains and the aquifer.

Properties less than 242,820 square meters in size but adjacent to an existing preserve property should be given consideration equal to those properties greater than 242,820 square metes in size if they contain important hydrologic or biological features.

The model ranks properties based on their highest scoring square meter area. In some cases a small part of a property may rank the entire property higher than generally warranted. Any property considered for acquisition should first be reviewed on the output map of the GIS model that shows the point and not tier values to determine if the tier rank is representative of the property. It may be appropriate to negotiate acquisition for only the high-scoring part of a property, although in such a situation, as much of the undeveloped watershed as possible for that area should be included.

In some cases, a property may receive a high priority ranking based on the existence of endangered species habitat or a cave. Since those features are marked by areas that include buffer zones, the actual features of concern could instead be on an adjacent property. If a property is ranked highly by such a feature near its edge, the occurrence of the feature on the property should first be confirmed.

Conclusions

The GIS modeling of the karstic Edwards Aquifer area has proven a valuable and flexible tool in sorting through several complex factors involving a tremendous volume of information to identify properties that offer highest value for acquisition in the protection of the aquifer and its associated resources. As of the date this paper was presented at the National Cave and Karst Management Symposium, approximately 11 square kilometers were purchased with the Proposition 3 funding. Probably about 70% of the original 40 square kilometers acquisition goal will be met due to subsequent increases in land prices, but the citizens of San Antonio are satisfied with the efforts and are pressuring City Hall for another land bond election with even greater funding.

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The Role of Suspended Sediments in the Transport of Atrazine in Mammoth Cave, Kentucky

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Abstract

Atrazine is a triazine herbicide used to control broad-leaf weeds and grasses in corn and other agricultural products, and is one of the most commonly applied herbicides in the United States. Atrazine has been assessed by the Environmental Protection Agency as a potential carcinogen and endocrine disrupter, and so may pose a threat to human or animal life. One of the characteristics of atrazine is that it can bond to sediments via adsorption, which prevents it from reaching the groundwater in typical diffuse flow aquifers. Due to the highly developed karst landscape of the Mammoth Cave area, however, there is extensive interaction between surface and sub-surface environments, including the transport of sediments from the surface into the karst aquifer. This study examines the role of sediments in the transport of atrazine into the Hawkins River during a spring storm event. The Patoka Creek sub-basin, which is drained by the Hawkins River, is approximately 71 square miles and has a substantial amount of agricultural activity, including the cultivation of corn. Initial results show that while little atrazine was found in the water, higher concentrations were found on the sediments collected. These findings indicate that sediments can be a factor in transporting atrazine into the cave environment.

Threats to Public Health and Safety from the Proposed Kentucky Trimodal Transpark, Warren County, Kentucky

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Abstract

The Kentucky Trimodal Transpark is a proposed 5,000-acre industrial park being planned by the government of Warren County, Kentucky. The philosophy behind the development is to create a transportation-based industrial park with access to highway, rail, and air transportation. For the development, the Warren County government has selected a location between the City of Bowling Green and Mammoth Cave National Park. The entire proposed development and surrounding area is situated on a highly-karstified sinkhole plain. All drainage is through the subsurface. Numerous public health and safety issues have arisen during the site's feasibility and planning phase. Public safety issues include sinkhole flooding, surface and groundwater contamination, cover collapse, collapse of lagoons resulting in waste spills, air quality degradation, increased congestion along roadways, urban sprawl (pressure on public health and safety infrastructure), radon, and noise. Health threats from the proposed industrial airport include cancer, asthma, liver damage, lung disease, lymphoma, depression, myeloid leukemia, and tumors. Furthermore, many of these public health and safety concerns are exacerbated by the presence of the highly-karstified landscape. For this investigation, a Geographic Information System has been developed using ESRI ArcView 8.1 to describe, analyze, and predict public health and safety issues and their relationship to the area's karstlands. Digital data from this report are available at: http://hoffman.wku.edu

Panama Ranch Garbage Dump Cave—Toxaphene and DDT Remediation

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Abstract

Pesticide contamination in the Panama Ranch Garbage Dump Cave was discovered during a volunteer clean-up effort by the Southwest Region of the National Speleological Society, the White Sands Grotto, and the United States Forest Service. Analytical testing of the dump debris and soil indicated high concentrations of Toxaphene, Lindane, and DDT. The contaminant of highest concentration, Toxaphene (an insecticide banned in the early 1980s), is a known mutagen and suspected carcinogen. Zenitech personnel, knowledgeable in cave conservation practices and trained to work with hazardous materials, conducted clean-up (remediation) of the contaminated material. Remediation efforts commenced at the level of contamination discovery, approximately 25 feet below the surface, and continued to the cave basement, approximately 110 feet below the surface. Soil and debris were found scattered on ledge surfaces down to the basement floor, where a large debris pile was found. Remediation efforts were suspended and samples were collected from the basement to assess the extent of contamination. Analytical results indicated Toxaphene concentrations two to five times higher than those near the surface. Additional sampling for the Toxicity Characteristic Leaching Procedure indicated that the Toxaphene and DDT did not exhibit the toxicity concentrations to be considered a characteristic hazardous waste. However, the contamination concentrations exceeded the maximum thresholds defined for the protection of human health and groundwater. Further remediation was recommended to remove the contaminated soil and debris. Funding for the final phase was requested under the New Mexico State Superfund, requiring an Engineering Evaluation/Cost Analysis of several alternative remediation methods and remediation action levels. Removal of the soil and debris to the removal action level of 5.0 mg/Kg by vacuum was recommended in the final evaluation. Six months after the initial remediation efforts, Zenitech personnel completed the remediation efforts. Approximately 23 cubic yards of soil were removed (approximately 40 cubic yards total) and 60 bags of debris collected during the final phase, bringing the residual contamination down to less than 5.0 mg/Kg. The entire project was completed for a cost of only $88,000.

Planned Spill Retention and Runoff Filtration Structures on Interstate 65 in the South–Central Kentucky Karst

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Abstract

In December of 1994, following a meeting with Kentucky Transportation Cabinet staff, a letter was sent to the Cabinet from the Superintendent of Mammoth Cave National Park. Anticipating widening of I-65, the letter outlined ecological justifications for retention and filtration structures designed to mitigate pollution. In May of 1997, Kentucky Transportation Cabinet staff and Ecologist Jim Keith of Earth Tech Environmental Consulting in Bloomington, Indiana, were invited to Mammoth Cave National Park for discussions on runoff mitigation structures. To build support for highway runoff retention structures, the south-central Kentucky karst was nominated for inclusion on the Karst Waters Institute's global list of the "Ten Most Endangered Karst Communities for 1998." In June of 1998, a meeting with Kentucky Transportation Cabinet and Federal Highway Administration staff was held at Mammoth Cave National Park. Agreed upon were basic measures to filter routine runoff and temporarily contain major spills. These will be low crushed rock check dams originally built as silt checks needed during construction. Basin capacity will be 10,000 gallons with grass waterways to and through retention basins underlain with geotextile fabric to minimize soil piping. The basins are designed to slowly filter routine runoff while greatly retarding spill entry into the cave aquatic ecosystem. The design and implementation of runoff retention structures along I-65 was a major precedent for the Kentucky Transportation Cabinet. Formerly, roadway runoff was deposited into the nearest sinkhole for quick surface water removal. Additionally, a sinkhole was often capped if it received no roadway runoff and was found within designated right-of-way areas. A cooperative, multi-agency effort in this endeavor has led the Kentucky Transportation Cabinet to review its drainage policy in karst areas and to formally initiate discussions on this policy.

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