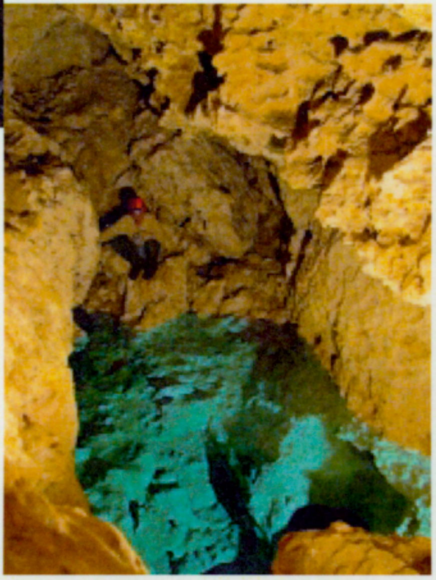
16th National Cave and Karst Management Symposium

Proceedings



October 13 – 17, 2003

Gainesville, Florida

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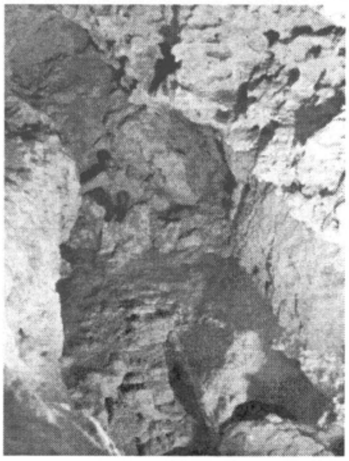

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Cover Photographs

Top Left: Roosevelt Cave, photo by Sean Roberts. Bill Walker in the Foreground and Becky Roberts further in.

Middle: The Paramount Resort and Conference Center, Symposium Headquartes. Photograph courtesy of Paramount Resort

Bottom Right: The blue, blue water in Ocala Caverns, photo by Sean Roberts. Bill Walker is in the background.

Proceedings of the 2003 National Cave and Karst Management Symposium

Gainesville, Florida
October 13–17, 2003

Symposium Organizers
Cave Diving Section of the
National Speleological Society

Proceedings Coordinators
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Proceedings Editor
G. Thomas Rea

Layout and Design by

GREYHOUND PRESS

Published by
The NCKMS Steering Committee

Printed in the United States of America

Host Organization

Cave Diving Section of the
National Speleological Society

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Ichetucknee Springs State Park
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Welcome to the 2003 National Cave and Karst Management Symposium

The theme of this year's symposium is "Protecting the Aquifer in Karst Regions." Florida contains the largest concentration of springs in the world with 33 first magnitude springs and over 600 lesser magnitude springs throughout the state. The springs and their cave systems are home to over 40 species of cave-adapted life and are crucial wintering habitats for the endangered Florida manatee. As windows into Florida's karst aquifer, the springs provide an important gauge of the health of our water supply.

Only thinly protected by the overlying soils and sediments, Florida's aquifer is particularly susceptible to the effects of the exploding population of the state. We face many threats and challenges to our water supply: point and non-point pollution, increased nitrate levels from fertilizer, spreading of exotic plant species, and depletion of the aquifer due to increased usage by an exploding population.

In the past few years, we have seen a drought unequaled in recent history. Wells and public water systems have run dry. Water restrictions are fast becoming a way of life. Many of our favorite springs have stopped flowing altogether. This brings our water resources to the forefront of public consciousness and the realization that they are finite and they are in trouble.

The 2003 Cave and Karst Management Symposium will bring special focus on the problems and solutions of managing the aquifer within karst areas. We look forward to this opportunity to share information aimed not only at the management of karst aquifers, but to the many areas of the world's cave and karst.

Michael Poucher
Chairman

Ground Water Asseessment

The Florida Aquifer Vulnerability Assessment Model: A Tool For Aquifer Protection In Karst Setttings

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Abstract

Ground-water resources within Florida's aquifer systems, as in many other karst hydrogeologic settings, are vulnerable to contamination due to the relatively open flow structure in carbonate rocks. This flow structure ranges from intergranular flow to conduit flow, as well as through perforations in confining layers due to sinkholes. In these complex hydrogeologic settings, models used in ground-water resource protection should reflect the dynamic and "dual porosity" nature of this flow system. Aquifer recharge and aquifer vulnerability models often serve as the scientific basis for land-use planning decisions. Commonly used for this purpose, DRASTIC is an expert-driven index model developed by the U.S. Environmental Protection Agency and the National Water Well Association. Although DRASTIC may be suitable for many hydrogeologic settings, it does not include a component critical to the understanding of aquifer vulnerability in Florida karst

The Florida Geological Survey is currently developing a geographic information system (GIS) - based model to estimate relative vulnerability within Florida's aquifer systems. Development of this model, the Florida Aquifer Vulnerability Assessment, is underway and five pilot counties have been completed with guidance from a multi-agency advisory committee. The overall intent of the Florida Aquifer Vulnerability Assessment is to develop a tool for environmental, regulatory, and planning professionals to facilitate the protection of Florida's ground-water resources. The model is based on a geostatistical method, Weights of Evidence, which quantifies relationships between spatial data layers and water quality parameters to predict vulnerability. For development of data layers in the Florida Aquifer Vulnerability Assessment model, a new, highly resolved statewide land-surface elevation model has been developed. From this surface model, two coverages are being created: a topographic depression coverage to reflect proximity to karst features, and a depth to water coverage, which is calculated relative to physiographic province. The Florida Aquifer Vulnerability Assessment also utilizes a statewide soil drainage coverage and a newly developed thickness of confinement coverage. If statistics in the model justify the need, the head difference between the surficial and Floridan aquifer systems will also be included for confined aquifer models.

Adaptability of the Florida Aquifer Vulnerability Assessment model allows for refinement to reflect "local-scale" datasets such as cave maps/conduits, lineaments, sinkhole types, and other hydrogeologic data. Incorporation of these datasets into the model can significantly enhance its application as a predictive tool at

the local scale, such as within a spring recharge area (springshed).

About the Author

Jon Arthur is a licensed Professional Geologist and graduate of Florida State University, where he received his B.S./honors and Ph.D. degrees in geology. His professional memberships include the Geological Society of America, Southeastern Geological Society, International Association of Hydrogeologists and the Hydrogeology Consortium. Jon is currently the President of the Florida Association of Professional Geologists. He began working at the Florida Geological Survey as a staff geologist in 1987 and currently supervises the Florida Department of Environmental Protection – Florida Geological Survey Hydrogeology Program. Jon's research focus includes hydrogeology and geochemistry. Current projects involve water-rock interaction during aquifer storage and recovery activities, regional hydrogeologic framework mapping, and modeling aquifer vulnerability. Devoted to environmental stewardship, Jon is also active in geology education and outreach. He is producer of the video curriculum, *Florida's Geology Unearthed*, which introduces students and public television audiences to Florida geology.

Investigation of Salinity Increases in Sulphur Spring, Tampa, Florida

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Abstract

Sulphur Spring is located along the Hillsborough River in an urban area of Tampa, Florida. Survey and water quality data were collected from the spring cave system as part of salinity control investigation. The City of Tampa initiated the study because the spring is an emergency water source when the water level in the Hillsborough River is low. When water is pumped from the spring pool for the city water supply, the hydraulic head of the system is drawn down and the chloride concentration of the spring discharge increases. Therefore, water can only be pumped from the spring intermittently.

Survey data show that 25% of the surveyed passages in the cave system have a height to width ratio greater than 1 compared to less than 10% for typical phreatic caves in Florida. In fact, the median height to width ratio of the Sulphur Spring cave system is 0.64 compared to 0.33 for typical phreatic caves, suggesting some fracture controlled passage development.

Water quality data show the water in the system is well mixed. The only change in water quality occurs at a penetration of 2,800 feet where the passage splits into the Orchid Tunnel and the Alaska Tunnel. The Alaska Tunnel has higher temperature, lower pH, and higher salinity than the Orchid Tunnel. Based on salinity of the two flows, about 70 to 80% of the flow is from the Orchid Tunnel and 20 to 30% is from the Alaska Tunnel. The Alaska Tunnel appears to be the source of the majority of the saltwater and, therefore, chloride entering the cave system.

Background

Sulphur Spring is located in Tampa, Florida, approximately 7 miles north of downtown Tampa. The spring is located on the north side of the Hillsborough River in the NE, SE, NE of Section 25, Township 28S, Range 18E. The spring water has a distinct sulfide odor. It was a popular bathing spot for people hoping to cure ailments in the late 1800s and early 1900s. Historic flows from the spring from 1917 to 1959 were 8.34 to 71.1 million gallons per day with an average flow of 37 million gallons per day. In the 1980s the average flow was only 25 million gallons per day.

As the City of Tampa developed around Sulphur Spring, stormwater runoff increased. In an effort to control runoff, stormwater was routed to sinkholes that are directly connected to the spring. This resulted in fecal coliform levels in the spring pool that exceeded Health Department standards. The spring was closed to swimming in June 1986; however, the City continued to use the spring as a source of drinking water during dry periods when flow in the Hillsborough River was too low to allow withdrawal.

Studies have shown that spikes in bacterial levels in the spring coincide with rainfall events and travel times from known sinkholes receiving stormwater runoff. Travel times have been

measured between 2 and 3 centimeters per second. (Historical data from Wallace RE, 1992.)

Current Study

Subsurface Evaluations, Inc. in cooperation with scientific research divers from the Coastal Karst Foundation have performed distance survey and water quality measurements in the Sulphur Spring cave system as part of the Sulphur Spring Salinity Control Investigation. The study was initiated because the City of Tampa uses the Spring as an emergency water source when the water level in the Hillsborough River is too low to meet demand. When the Spring discharge pool is pumped for the water supply, the hydraulic head in the pool is drawn down and the chloride concentration of the Spring water increases. As a result, water can only be pumped from the Spring intermittently to prevent excessive chloride levels in the City's drinking water. The purpose of this investigation is to identify discrete locations where high salinity water enters the cave system. The objective of the investigation is to assist in evaluating methods for obtaining freshwater with lower salinity and chloride concentrations from the spring.

Methods

K. Michael Garman, PG, PE, was the lead diver for survey and water quality data collection. Other volunteer certified cave divers assisting with data collection included Sherry Garman, Jitka Hyniova, Jakub Rehacek, Andy Conneen, Alex Warren, Brice McMinn, David MacDonald, and Doug Daniel.

Distance Survey

The distance survey was performed by placing a braided nylon guideline along the floor near the center of the cave passage. The guideline was tied and secured to rocks or PVC stakes placed by divers. At every line tie-off or change in line direction by rubbing the cave wall, a survey station was marked. At each survey station, the depth of the line was noted and a compass reading was taken along the line to obtain the azimuth to the next station. Distances between stations were measured with a fiberglass tape. The survey data were input into the Compass mapping program to create a scaled plot of the survey data.

Positions within the cave system were located on the ground surface by performing a cave radio survey. A three-person dive team carried a cave radio beacon composed of a barium-ferrite magnet wrapped by copper wire through which a small current was passed. The beacon was carried in a vertical position to allow accurate position readings at the surface. The dive team used diver propulsion vehicles to travel through the cave system and paused for about two minutes every 200 feet along the cave passage. When the divers paused, the beacon was held stationary in a vertical position to allow the surface team to obtain an exact position and catch up to the dive team. The lead diver, Jitka Hyniova, located the distance markers within the cave system and blocked the flow from moving the beacon at the pause locations. The second diver, Michael Garman, carried the beacon. The third diver, Sherry Garman, maintained contact with the guideline when the other divers were positioning the beacon at the pause locations.

On the surface, Brian Pease tracked the divers using a metal loop antenna receiver connected to an audio system with variable sound intensity based on proximity to the beacon within the cave system. Shane Dunn followed Mr Pease with a Trimble differential GPS system to record the locations identified by the cave radio system. Mr Dunn also marked the locations with orange spray paint.

Water Quality Measurements

Water quality data were collected using a DataSonde 3 data logger manufactured by the Hydrolab Corporation in Austin, Texas. The data logger measured temperature, pH, depth, specific conductivity, salinity, and dissolved oxygen concentration. The DataSonde 3 was attached to the front of the diver propulsion vehicle used by the lead diver or hand carried in front of the lead diver so that divers' exhaust bubbles, which have a high oxygen concentration, would not influence the readings.

The DataSonde 3 is serviced and calibrated at the factory regularly. Prior to each dive, the pH and specific conductivity meters were calibrated using standard solutions provided by the manufacturer and the dissolved oxygen sensor was calibrated using a water saturated air method. The manufacturer's reported accuracy for the DataSonde 3 is:

- Temperature ± 0.10C;
- pH ± 0.2 standard units;
- Depth ± 0.3 meters;
- Specific conductivity ± 1% of reading;
- Salinity ± 0.2 parts per thousand (ppt); and
- Dissolved oxygen ± 0.2 milligrams per liter (mg/L)

Results

Observations

The Sulphur Spring cave system is unique for spring cave systems developed in the Floridan aquifer. The Sulphur Spring cave system receives a high input of biogeochemical oxygen demand from contaminants and detritus carried directly into the cave system by stormwater discharged to sinkholes that are directly connected to the cave system. As a result, the cave system is anoxic to microoxic and dark gray microbial mats composed of anaerobic bacteria coat all hard surfaces within the cave system. The mats form finger-like projections that hang down from the walls and ceilings. Similar mats are frequently observed on the walls of anoxic sinkholes in Florida.

Discrete saltwater vents in the cave system are easily recognizable by the presence of white, filamentous, sulfur oxidizing bacteria, which surround the vents (Photo 1 through 3). This is an indicator that the vent water contains hydrogen sulfide. Sulfide is available to chemolithotrophic sulfur oxidizing bacteria as an electron donor in energy producing biologic reactions that use oxygen or nitrate as an electron acceptor.

Photo 1: Small saltwater vent, diameter is 5 centimeters.

Photo 2: Distortion from halocline is visible in close-up of vent.

Photo 3: Collection Hydrolab data from a vent.

One side room less than 300 feet penetration from the entrance has carbonate crystals actively precipitating underwater (Photo 4). This room is known as the Crystal Room. Just downstream of the Crystal Room is another small room, the Black Room, which is coated by black mineral precipitates, possibly metal sulfides (Photo 5).

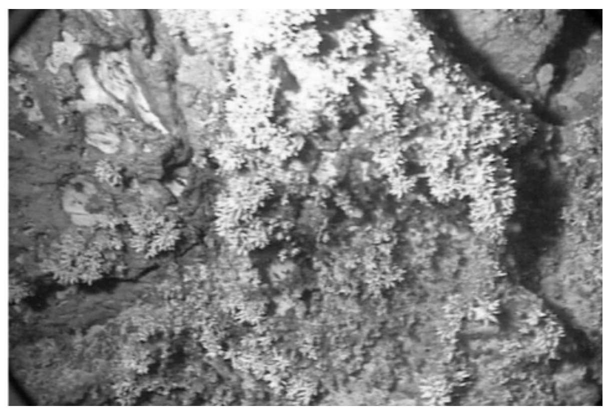

Photo 4: Low magnesium calcite crystals forming underwater in the Crystal Room in Sulphur Spring Cave System. Crystals are about 2 to 5 centimeters long.

Distance Survey

The 3,376 feet of survey data compiled to date show that the cave system generally trends north along Nebraska Avenue (Figure 1). At the main split in the cave passage in the Terminal Room 2,800 feet from the entrance, the Orchid Tunnel continues north while the Alaska Tunnel trends southeast. The survey statistics are shown in Table 1. The estimated volume of the surveyed cave is 327,134 cubic feet.

The cave conduit (passage) height distribution, width distribution, height to width ratio, and area distribution are shown on Figures 2 through 5 and Table 2. These data are particularly interesting because more than 25% of the

Photo 5: Black Room in Sulphur Spring Cave System. Possible deposition of metal sulphides may increase pH leading to calcium carbonate deposition in adjacent Crystal Room.

surveyed passages in the Sulphur Spring cave system have a height to width ratio greater than 1 compared to less than 10% for all phreatic caves in Florida (Figure 6a). In fact, the median height to width ratio of the Sulphur Spring cave system is 0.64 (Table 2) compared to 0.33 for all phreatic caves in Florida.

Water Quality Measurements

The water quality data collected with the DataSonde 3 on seven different days (Novem-

Figure 1. Location of Sulphur Spring Cave System based upon cave radio data points. Survey performed by Subsurface Evaluations, Inc. (SEI) on February 8th, 2003.

Table 1: Data Summary			
Number of Files =	1	Station Aliases =	3
Number of Surveys =	2	Number of Stations =	209
Included Shots =	212	Excluded Shots =	0
Ignored Shots =	0	Number of Loops =	0
Absolute Stations =	1		
Included Length =	3,376.0 feet	1,029.0 meters	0.64 miles
Excluded Length =	0.0 feet	0.0 meters	0.0 miles
Total Surveyed =	3,376.0 feet	1,029.0 meters	0.64 miles
Horizontal Length =	3,194.0 feet	973.5 meters	0.60 miles
Horizontal Excluded =	0.0 feet	0.0 meters	
Cave Depth =	117.0 feet	35.7 meters	
Surface Length =	412.9 feet	125.9 meters	
Surface Width =	2,573.9 feet	784.5 meters	
Surface Area =	1,062,814.0 feet^2	98,738.6 meters^2	
Enclosed Volume =	124,346,860.3 feet^3	3,521,111.0 meters^3	
Cave Volume =	327,134.0 feet^3	9,263.4 meters^3	
Average Diameter =	9.8 feet	3.0 meters	
Volume Density =	0.26%		
Average Inclination =	10.9 degrees		
Difficulty =	14.6		

Highest Station =	ss1	0.0 feet	0.0 meters
Lowest Station =	ss116	-117.0 feet	-35.7 meters
North Most station =	ss2088	10,177,114.6 feet	3,101,984.5 meters
South Most station =	ss1	10,174,540.7 feet	3,101,200.0 meters
East Most Station =	ss111	1,169,605.4 feet	356,495.7 meters
West Most Station =	ss36	1,169,192.5 feet	356,369.9 meters
Average Shot Length =	16.2 feet	4.9 meters	
Longest shot =	69.0 feet	21.0 meters	
Shortest shot =	1.0 feet	0.3 meters	

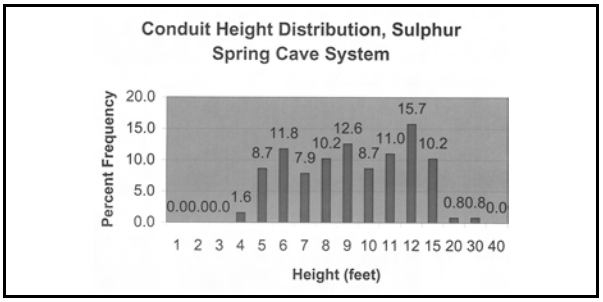

Figure 2

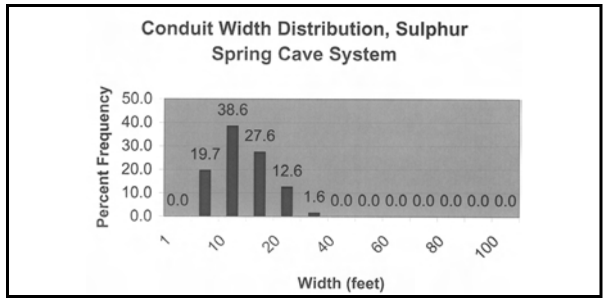

Figure 3

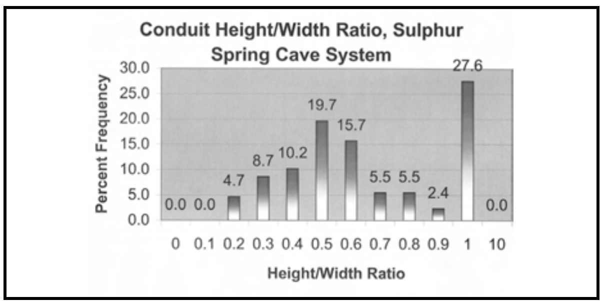

Figure4

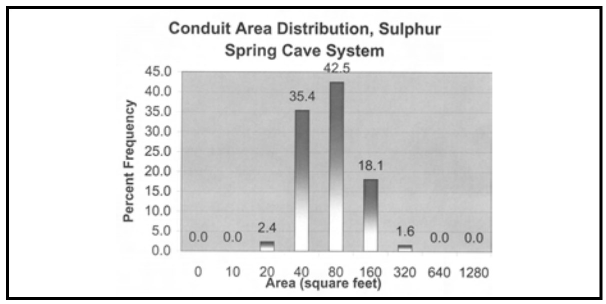

Figure5

Table 2: Sulphur Spring Cave System Water Quality Data			+
Parameter	**Main Tunnel**	**Orchid Tunnel**	**Alaska Tunnel**
Temperature (C)	24.3 to 25.2	24.3 to 25.15	24.3 to 25.3
pH (standard units)	6.73 to 7.12	6.73 to 7.25	6.62 to 6.97
Salinity (ppt)	1.1 to 2.2	0.9 to 1.4	1.8 to 4.4
Dissolved oxygen (mg/L)	0.00 to 0.08	0.00 to 0.08	0.00

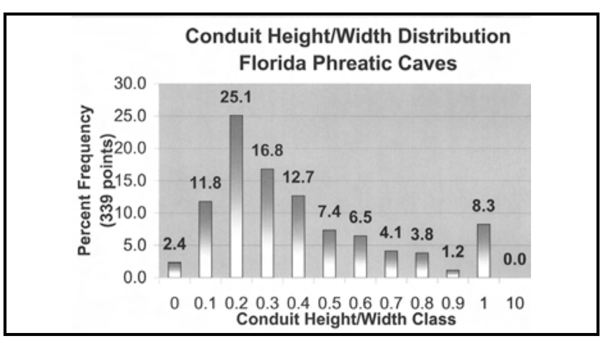

Figure6a

ber 15, 1998, June 27, 2001, July 7, 2001, July 21, 2001, October 14, 2001, December 22, 2001, and January 2, 2002) are summarized below. A typical data set, showing temperature, pH, salinity, and dissolved oxygen versus distance from entrance, is included as Figures 6 through 9. Typical values for these parameters are shown in Table 2.

From the spring discharge pool to the Terminal Room, the water in the cave system is well mixed. The only significant change occurs where the Main Tunnel splits into the Orchid

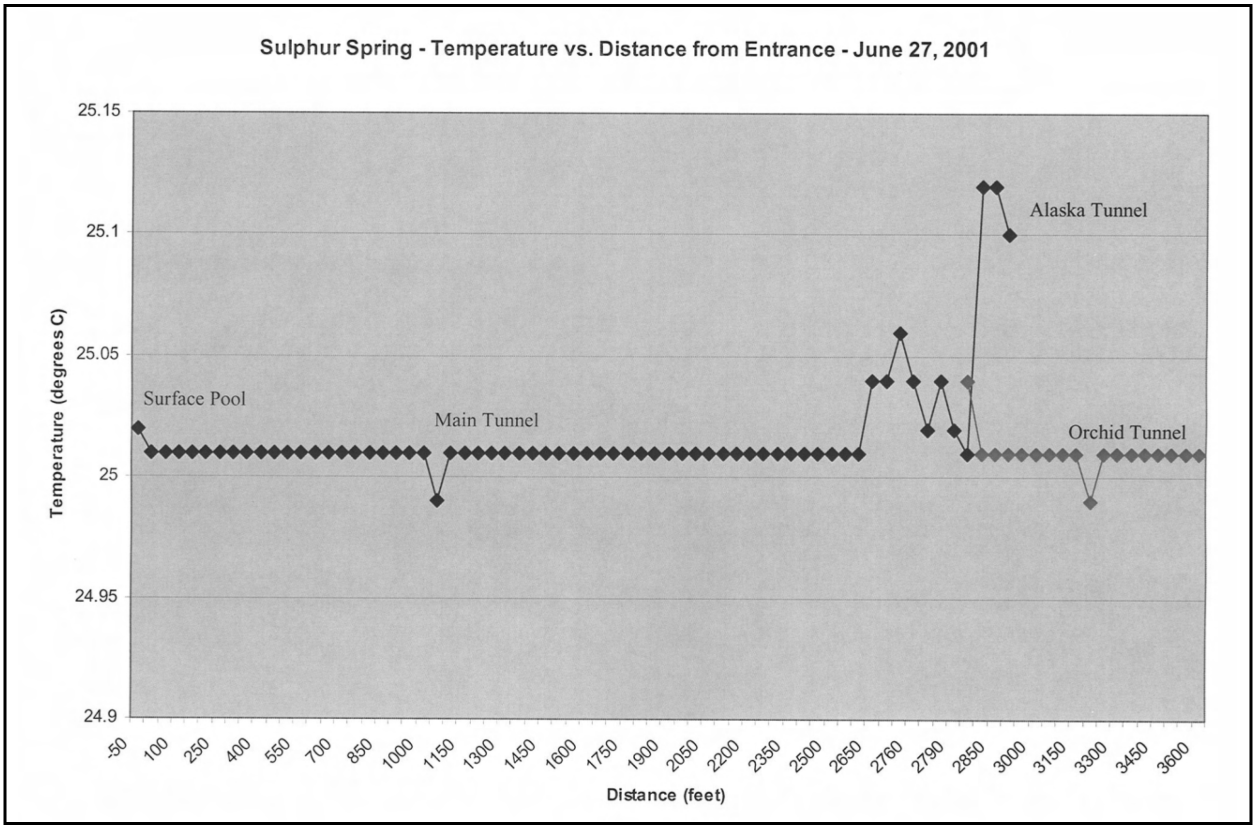

Figure 6

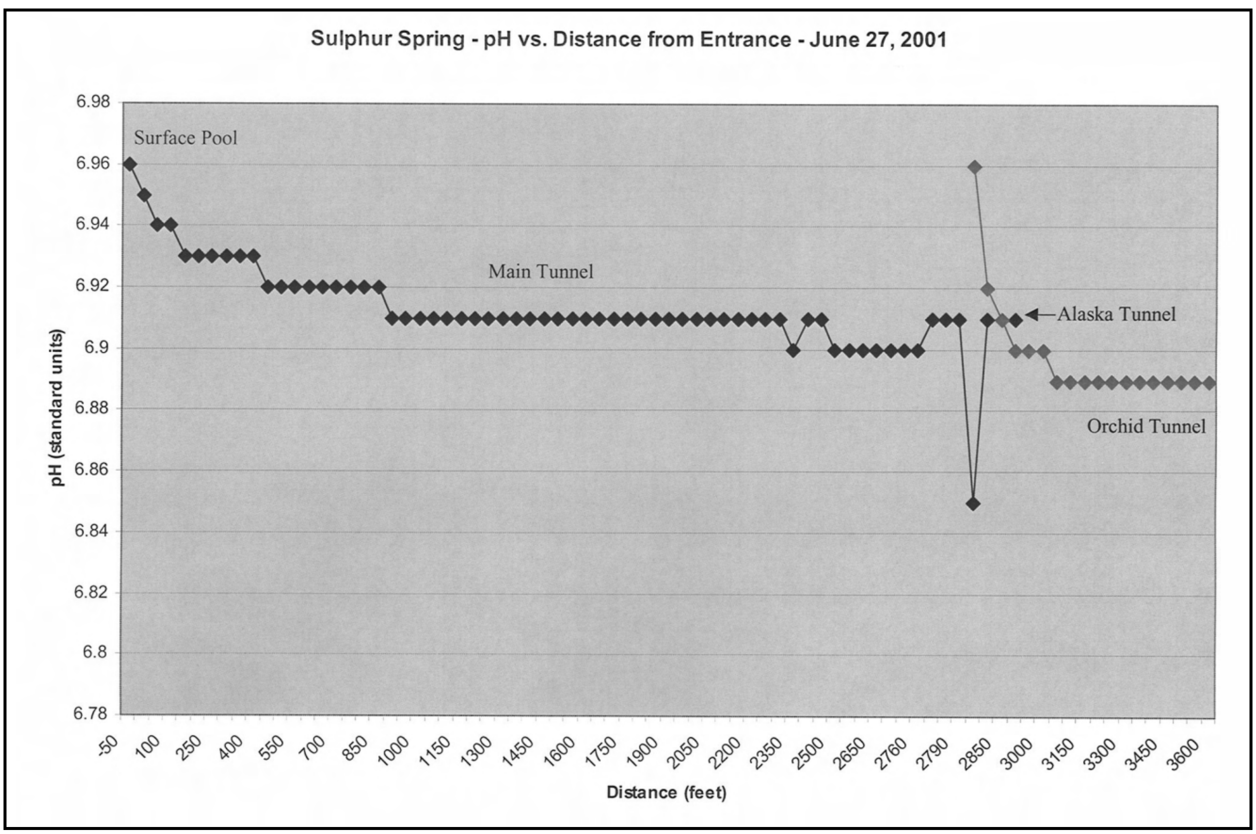

Figure 7

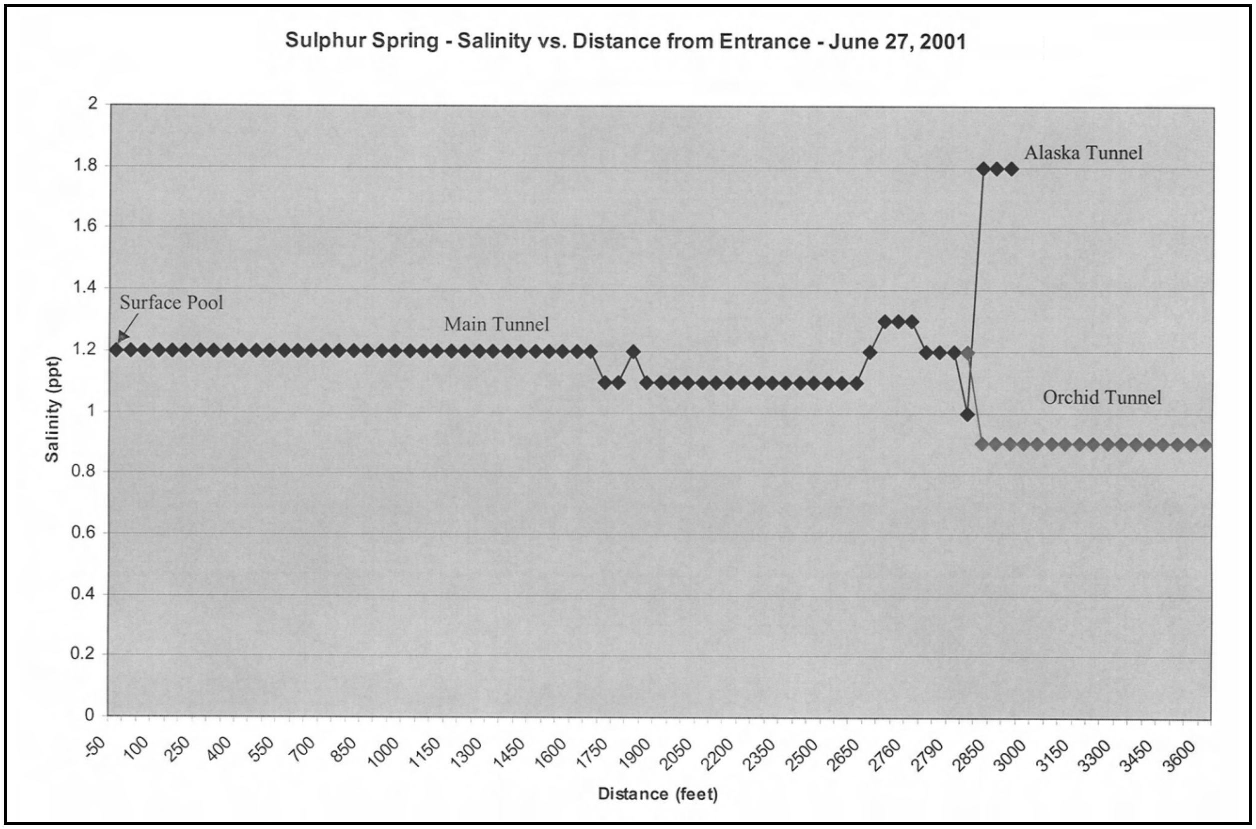

Figure 8

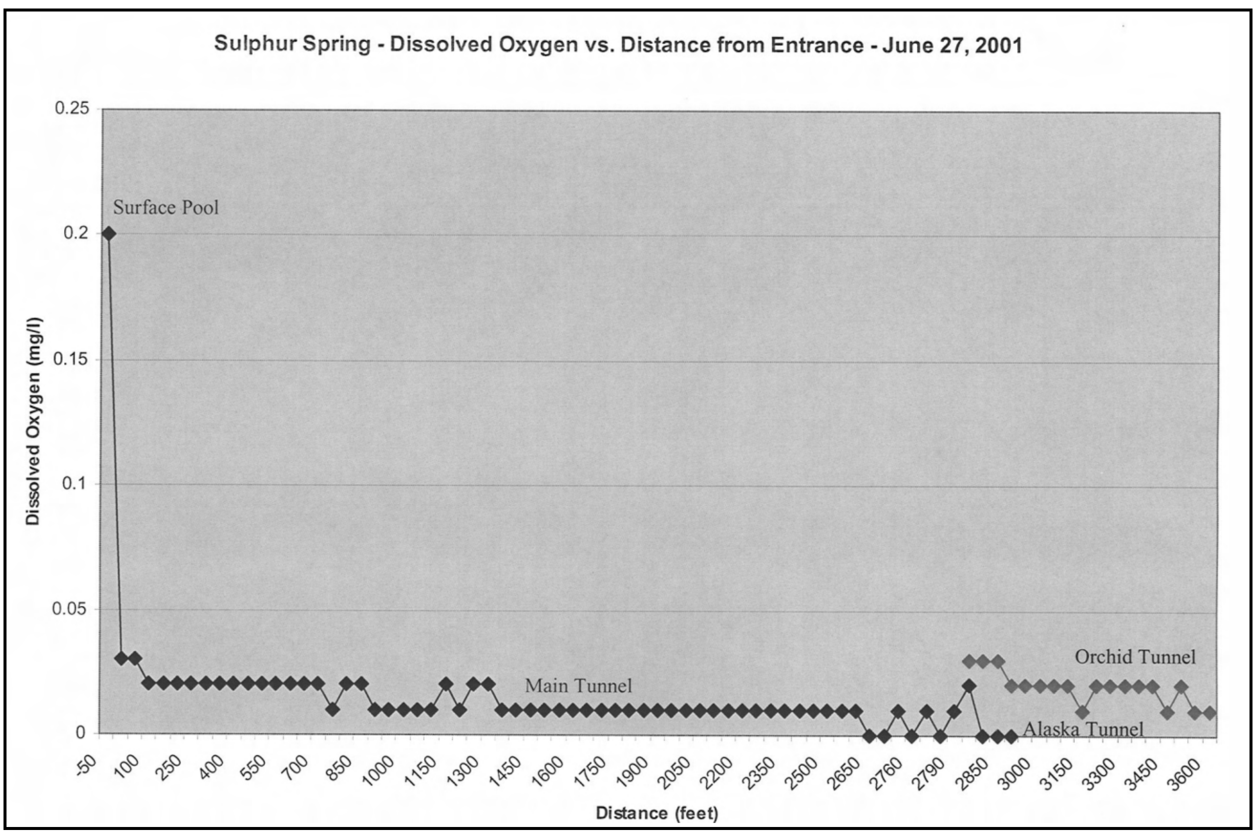

Figure 9

Tunnel and the Alaska Tunnel at the Terminal Room. The Alaska Tunnel generally has higher temperature, lower pH, and higher salinity than the Orchid Tunnel. The values vary some depending upon the influx of rainwater. Data-Sonde 3 data show that the flows from these two tunnels completely mix within about 200 feet of the junction because of the turbulent flow in the cave system. Based on salinity and conservative mixing of the two flows, about 70 to 80% of the flow is from the Orchid Tunnel and 20 to 30% is from the Alaska Tunnel (Table 2). The water in the entire cave system is anoxic or microoxic with values less than 0.10 mg/l in the cave system.

During 2001 and early 2002, one discreet saltwater vent was identified in the Alaska Tunnel approximately 3,017 feet from the entrance. The vent did not flow continuously and when saltwater was observed in the vent there was no measurable flow. The saltwater accumulated in the vent on the floor and was slowly mixed into the flow of the tunnel by the passing turbulent flow. The water quality from the active vent was measured on October 14, 2001, and January 6, 2002. Following a year of above normal rainfall, water quality data were collected on September 21, 2003. At this time, two discreet saltwater vents were identified in the Main Tunnel at penetrations of 144 and 335 feet. The values are shown in Table 3.

The salinity and temperature from the vents were higher than the Alaska Tunnel water and the pH was lower.

The temperature and pH readings from the Crystal Room are extremely high compared to the rest of the cave system and the salinity is lower. Just downstream of the Crystal Room in the Black Room, the pH values are the same as the typical readings from the cave system but the temperature and salinity are elevated.

Table 3: Sulphur Spring Cave System, Vent Water Quality Data

Parameter	Alaska Tunnel Vent	Main Tunnel Vent
Temperature (°C)	25.67 to 26.05	25.49
pH (standard units)	6.39 to 6.47	6.41
Salinity (ppt)	14 to 17.7	15.1
Dissolved oxygen (mg/l)	0.00	0.02

Table 4: Sulphur Spring Cave System Crystal and Black Room Water Quality Data

Parameter	Crystal Room	Black Room
Temperature (°C)	26.63 to 26.72	25.42 to 25.50
pH (standard units)	8.54 to 10.3	6.78 to 6.81
Salinity (ppt)	1.3 to 1.6	5.5 to 6.6
Dissolved Oxygen (mg/l)	0.00	0.00

Discussion

The unusually high height to width ratio of the Sulphur Spring cave system is probably because it is located in an area of proposed faulting along the Hillsborough River. This would cause the cave passages to develop along vertical fractures resulting in passages that are taller than they are wide. Typically, bedding plane features control phreatic cave development in Florida, resulting in cave passages that are wider than they are tall. Even though Sulphur Spring is located in an area of possible fractures, bedding plane development still dominates the cave passages, as the majority of the passages are wider than they are tall.

The Alaska Tunnel appears to be the source of the majority of the saltwater and, therefore, chloride entering the cave system. Even though only one discreet saltwater vent has been identified in the Alaska Tunnel, the water in the Alaska Tunnel is typically more than twice as saline as the water in the Orchid Tunnel, whether saltwater was flowing from the vent or not.

The presence of discreet saltwater vents in the Main Tunnel did not appear to affect the water quality of the Main Tunnel flow. Water from the vents does not flow into the cave system but slowly mixes in the turbulent flow. No changes in the water quality of the flow in the Main Tunnel are detectable between locations downstream and upstream of the vents.

It seems likely that the fractures in the area allow saltwater from deep in the aquifer to leak upward into the Sulphur Spring Cave System, which is in the freshwater zone of the aquifer. The fact that the saltwater vents remain active

after above-normal rainfall during 2003 indicates that the aquifer, which is the source of the sulfidic saltwater, is receiving above normal recharge just like the shallow Floridan aquifer, which is the primary water source for Sulphur Spring.

The chemistry of the Crystal Room appears to be related to the production of sulfide-rich water from anaerobic respiration of organic matter by sulfate reducing bacteria. When the hydrogen sulfide degasses by reaction with oxygen or metals, the pH increases, the carbonate anion is the dominate form in solution, and calcium carbonate precipitation occurs. The degassing and precipitation reactions appear to be occurring in the Crystal Room. If chemolithotrophic sulfur oxidizing bacteria were present, such as are present at the saltwater vents, they produce sulfate and sulfuric acid by using sulfide as an electron donor resulting in pH decrease and, thereby, preventing calcium carbonate precipitation (Castanier S *et al*, 1999).

Recommendations

Based upon the data collected to date, it does not appear to be feasible to seal discrete saltwater vents and have a noticeable reduction in the salinity of the water in the cave system as a result. It appears that the best method for collecting fresh, less saline, water from the cave system would be to install a well in the Orchid Tunnel upstream of the junction with the Alaska Tunnel.

Acknowledgements

The Coastal Karst Foundation coordinated the volunteer research diving in Sulphur Spring. The research diving was supported by the National Association for Cave Diving (research and exploration fund), American Underwater Lighting (lights, line, line arrows), Liquid Fit (wet suits), Watermark Scuba – Sea Soft (hoods, booties, gloves), Advanced Diver Magazine, Cochran Undersea Technology (dive computers), and Clay Creek Products (dive bags).

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"Through the Roof" Monitoring Water Quality In Manatee Springs

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Abstract

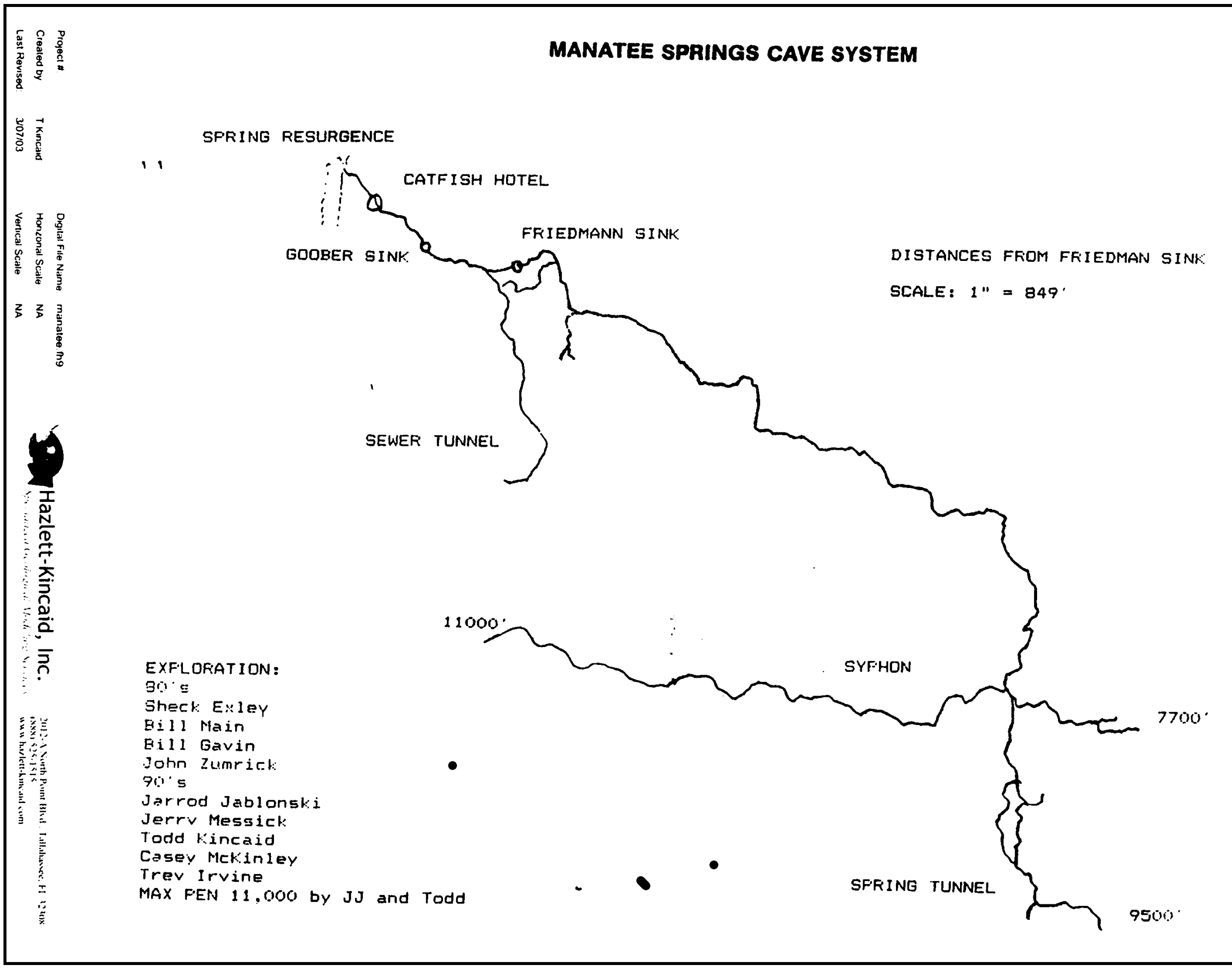
Manatee Springs is a first magnitude spring near the City of Chiefland in Levy County, Florida, and the centerpiece of Manatee Springs State Park. In April of 2001, a local mining company initiated the process of obtaining permits to mine 160 acres on its property that is adjacent to the state park and a high density subdivision. Significant local opposition to the mine mounted including public protests and rallies that were covered by the media.

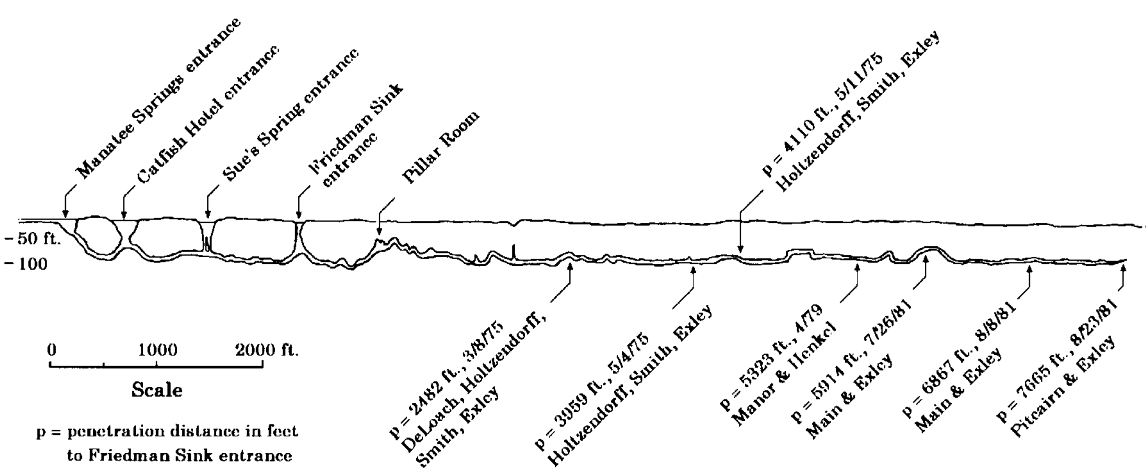
In its permit application, the mining company utilized a map of Manatee Springs Cave system generated in the 1980s. Subsequent exploration of the cave system had identified conduits branching to the north and east toward the proposed mine site; however, most of these conduits do not allow divers to penetrate into the aquifer system very far. The exception is the "Blue Water Tunnel" named because it remains clear when other conduits in the cave system are not. A serious sand restriction had precluded further mapping of this conduit using back-mounted tanks; however, cave divers utilizing side-mounted tanks pushed the restriction and added several hundred feet to the survey. This new survey data indicated the conduit trends to the northeast toward the proposed mine site which contains a large karst feature.

Upon receipt of the additional cave survey data, the Park management coordinated with the cave diving community to have water quality samples obtained from Manatee Springs and the conduits providing flow to the spring. In August of 2001, 12 cave divers obtained water samples from nine locations within the cave system. These samples were analyzed by the Department of Environmental Protection's Chemistry Lab for the following parameters: pH, temperature, conductivity, turbidity (NTU) and nitrate/nitrite (nitrate). Subsequently, in April of 2002, the Suwannee River Water Management District collected water samples from the conduits and split them with the United States Geological Survey. In addition to standard parameters, isotopic analyses are being performed by the U.S. Geological Survey on these samples.

The data obtained from the sampling of the cave conduit system indicates significant differences in water quality in the individual contributing conduits. Nitrate concentrations in the Blue Water Tunnel were found to be nearly four times greater than those in other conduits in the cave system. These data and the potential to gain insight into the flow dynamics of the cave system including possibly being able to identify sub-basins within Manatee Springs' springshed supported the installation of monitoring wells into the conduits contributing flow to the spring. Another factor considered in the installation of the conduit monitoring wells was the expense and logistics as well as the potential danger to cave divers in obtaining frequent samples from the various conduits.

In April of 2003, the land surface locations for monitoring wells that would intersect the conduits: Sewer Tunnel, Blue Water Tunnel,



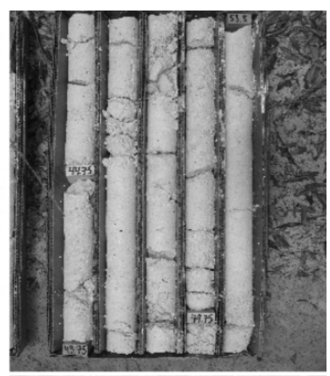


MANATEE SPRINGS CAVE SYSTEM
Levy County, Florida, USA
Profile view

Manatee Springs				
Field ID	Date Sampled	Analysis	Result	Units
#1 HEADSPRING	8/12/2001	TURBIDITY	0.55	NTU
#1 HEADSPRING	8/12/2001	W-NO2NO3	1.7	mg N/L
#2 SEWER TUNNEL	8/12/2001	TURBIDITY	3.8	NTU
#2 SEWER TUNNEL	8/12/2001	W-NO2NO3	1.3	mg N/L
#3 MILK TUNNEL	8/12/2001	TURBIDITY	0.5	NTU
#3 MILK TUNNEL	8/12/2001	W-NO2NO3	1.4	mg N/L
#4 BLUE WATER TUNNEL	8/12/2001	TURBIDITY	0.1	NTU
#4 BLUE WATER TUNNEL	8/12/2001	W-NO2NO3	4.5	mg N/L
#5 UPSTREAM MAIN TUNNEL	8/12/2001	TURBIDITY	0.2	NTU
#5 UPSTREAM MAIN TUNNEL	8/12/2001	W-NO2NO3	1.4	mg N/L
#6 SNACK BAR TUNNEL	8/12/2001	TURBIDITY	0.25	NTU
#6 SNACK BAR TUNNEL	8/12/2001	W-NO2NO3	1.7	mg N/L
#7 SUE SINK	8/12/2001	TURBIDITY	0.5	NTU
#7 SUE SINK	8/12/2001	W-NO2NO3	1.5	mg N/L
#8 CCC TUNNEL	8/12/2001	TURBIDITY	0.5	NTU
#8 CCC TUNNEL	8/12/2001	W-NO2NO3	1.2	mg N/L
#9 GEOTHERMAL VENTS	8/12/2001	W-NO2NO3	0.86	mg N/L

and the Main Tunnel were obtained utilizing cave divers and radio location techniques. By the end of May 2003, the Florida Geological Survey completed the drilling and monitoring well installation into the three conduits.

Water quality probes, sampling tubes, and flow meters have been purchased for each of the conduit monitoring wells and are to be installed in the near future. Once in place, real-time water quality and flow information can be obtained continuously.



About the Author

Tom Greenhalgh is a Professional Geologist with the Florida Geological Survey's Hydrogeology Program where he focuses on springs research. He obtained a BS in Geology from Florida State in 1984 and began a career in environmental consulting conducting contamination assessments at petroleum and hazardous waste sites. In 1988, he began working for the Department of Environmental Regulation in Petroleum Reimbursement and a year later moved to the Petroleum Cleanup. In 1991, he joined the Pesticides Section where he performed ground water environmental fates studies on pesticides known and/or suspected to contaminate ground and surface water and served on the Pesticide Registration and Evaluation Committee. In 1997, he was transferred to the Bureau of Watershed Assessment to work on Total Maximum Daily Loads where he focused on the nitrate contamination in the Suwannee River Basin.

Outside of work, he enjoys outdoor activities including hunting, fishing, and diving for artifacts. In addition, he is a weekend farmer and is working diligently to restore native longleaf habitat on the family's farm in Suwannee County, Florida.

Results of Sampling for Selected Wastewater Constituents In Ground Water In the Silver Springs Basin, North Central Florida

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Abstract

During January through July 2002, 35 wells in the Silver Springs groundwater basin, north central Florida, and three vents of Silver Springs were sampled for a suite of compounds commonly found in wastewater. Of the 67 compounds analyzed, 38 were detected, nearly all in very low concentrations. The most frequently detected compound was the insecticide DEET (N,N-diethyl-meta-toluamide), which was evident in 27 wells and all three spring samples. Estimated concentrations of DEET ranged from about 0.03 to 5.8 micrograms per liter. Other commonly detected compounds were phenol (evident in 24 wells and two spring samples in concentrations ranging from 0.3 to 1.4 micrograms per liter) and bisphenol A (evident in ten wells in concentrations ranging from 0.05 to 4.4 micrograms per liter).

DEET was developed by the U.S. Army in 1946 for direct application to the skin to repel, rather than kill, mosquitoes. The U.S. Environmental Protection Agency has determined that DEET is in Toxicity Category III (slightly toxic, the second lowest of four categories). DEET enters the wastewater when the user bathes. The chemical is of low solubility and does not break down easily; thus, DEET appears to be a useful tracer for the presence of reused water. In a karst area, such as the Silver Springs groundwater basin, the presence of DEET in numerous ground water samples is indicative of the widespread recharge characteristic of karst areas. The presence of DEET also may result from the use of septic tanks throughout much of the basin.

The geology surrounding the wells seemed to affect the presence or absence of DEET in the water samples; land-use type generally did not affect the occurrence of DEET. Of the 35 wells sampled, nine were in the outcrop area of the Ocala Limestone, the principle water-bearing unit of the Upper Floridan aquifer. DEET was detected in all nine samples. The estimated concentrations ranged from 0.7 micrograms per liter to 0.2 micrograms per liter. Of the 35 samples, DEET was not detected in eight samples, all of which were in areas where the Ocala Limestone is covered by younger sediments. Samples in which DEET was not detected were collected in the following land-use types: low density residential, commercial, crops and nurseries, tree plantations, and other upland forests. The highest DEET concentration was from a well in a commercial urban area where the Ocala Limestone is overlain by sediments of the Hawthorn Group. Local sinkholes may breach the Hawthorn Group confining unit, allowing surface water to recharge the aquifer in the immediate vicinity of the well sampled.

Only one or two compounds were detected in most of the wells and spring vents sampled; however, several compounds were detected in two wells. In downtown Ocala, water from one well contained DEET (5.8 micrograms per liter) and 19 other compounds including caffeine (0.14 micrograms per liter). Caffeine breaks down quickly and is considered an

indicator of relatively recent recharge by wastewater. The concentration of cholesterol, a fecal indicator, was 5.2 micrograms per liter. Phenol was detected at a concentration of 6.3 micrograms per liter and the concentration of bisphenol A was 4.4 micrograms per liter. Another well, located at a site formerly used as a pasture but surrounded by residential areas, contained three fecal indicators: 3beta-coprostanol (2.4 micrograms per liter); cholesterol (7.2 micrograms per liter); and an estimated detection of 3-methyl-1(H)-indole (0.23 micrograms per liter). The concentration of nonylphenol, diethoxy- (total; NPEO2), a nonionic detergent metabolite and a known endocrine disrupter, was estimated at 2.7 micrograms per liter. The concentration of DEET in this sample was estimated at only 0.4 micrograms per liter.

Resource Management

Florida Spring Glossary and Classification System

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Abstract

In the spring of 2002, a number of Florida's hydrogeologists met in Ocala and discussed the significance and importance of protecting Florida's springs from contamination related to man's landuse activities. Many of the participants argued that in order to efficiently protect Florida's springs, a firm understanding of them is critical. It was decided that a glossary of spring terms should be developed. The Florida Geological Survey assumed the lead role in its development. The Survey organized a Spring Nomenclature Committee made up of representatives of governmental agencies, the state university system, hydrogeologists from around the state, and private citizens. The glossary consists of the most commonly used spring terms, along with their synonyms. Whenever possible, existing terminology was taken from professional dictionaries and glossaries. It is anticipated that the glossary will enable both the scientific community and the public to use a set of standardized terms. During the development stage of the glossary, it became apparent that a spring classification system should also be developed. This newly developed classification system is a model that enables one to envision the relationship of one spring to the others within the state. As it turns out, all of Florida's springs can be grouped into only a handful of different classes. This was fortunate in that it greatly reduces the complexity in the way we think of our springs.

About the Author

Rick Copeland He received a B.S. and a M.S. in Geology from the University of Florida and a Ph.D. in Geology from Florida State University. He worked as a hydrogeologist with the Suwannee River Water Management District for several years where he conducted a variety of ground-water quality and quantity studies. Since 1984, he worked for the Florida Department of Environmental Protection. During that time he administered a statewide surface-water and ground-water quality monitoring program, and evaluated ground-water quality data. Currently he works in the Department's Hydrogeology Program at the Florida Geological Survey. He can be contacted at rick.copeland@dep.state.fl.us or 850-488-9380. Rick compiled the glossary and classification system, based on efforts of the Florida Springs Nomenclature Committee. The committee was made up of representatives from state and federal agencies, the Florida university system, the general public, and hydrogeology consultants.

Management Controversies at Oregon Caves National Monument

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ABSTRACT

The 1909 proclamation of a national monument to protect "the unusual scientific interest and importance" of the so-called Marble Halls of Oregon was the result of a misunderstanding; in southern Oregon and in California, marble caves now are known to be common. Oregon Cave is not "a natural feature so extraordinary or unique as to be of national interest and importance" and should never have become part of the National Park System. Its 1934 transfer from the Forest Service to the National Park Service was an irresponsible political action; the National Park Service was not prepared to accept responsibility for its protection. The cave never has been managed as a scientific resource as directed by President Taft in 1909. Until 1934, the monument was administered as a recreational area, primarily for the benefit of the people of southwestern Oregon. The National Park Service did not implement a management strategy until the tour route and most of the rest of the cave were damaged beyond reasonable expectations of restoration. It retains value as a show cave, however. Its management should be returned to the Forest Service for resumption of its pre-1934 management. strategy with off-trail areas designated as Research Areas to protect possible biological and known paleontological resources not yet inventoried. The transfer should be by Executive Order. The name Oregon Caves National Monument should be retained.

Introduction

Controversy has dogged the management of Oregon Cave for more than a century. Rather ludicrously, 19th century adventurers attempted to develop it as a private show cave on an unimproved mountain trail miles from even a dirt road. Poorly informed pioneer conservationists soon urged its protection as a cave uniquely in marble: "The Marble Halls of Oregon." They teamed with shrewd Oregon businessmen. With charismatic conservationist Gifford Pinchot as its first Chief Forester, the 1905 creation of the Forest Service added impetus. The first map depicting "Oregon Caves National Monument" appeared in August 1907, before such a monument existed. For President William Howard Taft, Pinchot's staff prepared a presidential proclamation of the monument, not quite in time for Taft to announce it during his February 1909 visit to nearby Grants Pass, Oregon. Later in 1909 his proclamation created the national monument because of its supposed "unusual scientific interest and importance." Taft specifically prohibited logging and mining, "and any (other) use of the land which interferes with its preservation or protection as a national monument," but left its management to the capitalist-oriented Forest Service.

In 1909, the Siskiyou National Forest had no advance guidance on how to achieve so grand an objective, and few relevant resources. Respected scientific academics, however, evi-

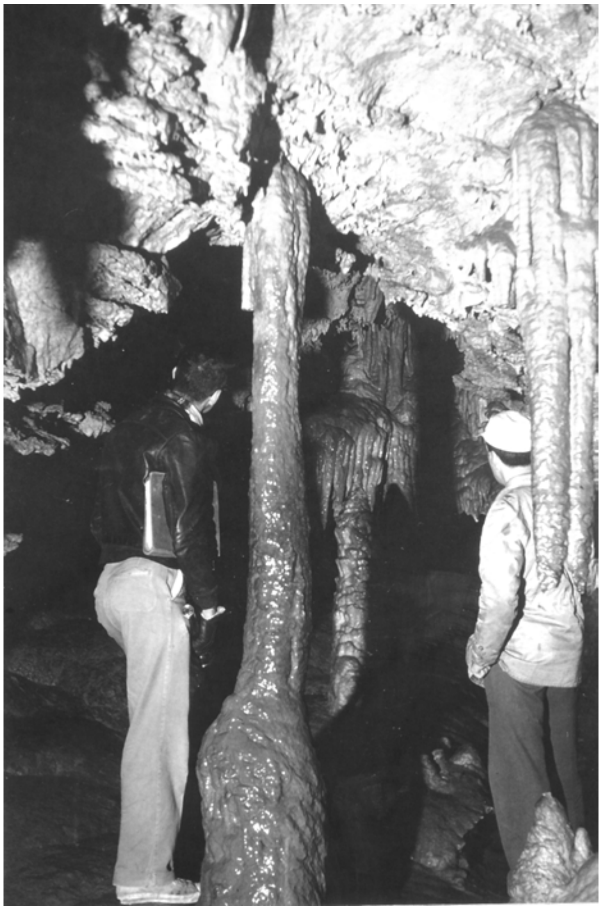

Figure 1. *Joaquin Millers Chapel, considered one of the largest and best decorated rooms in Oregon Cave. Even here, it is almost impossible for visitors to avoid touching speleothems and walls. (1959 photograph by William R. Halliday. On left, Richard M. Brown, Crater Lake National Park Assistant Naturalist. On right, Ron Stanford, Cascade Grotto of the National Speleological Society.)*

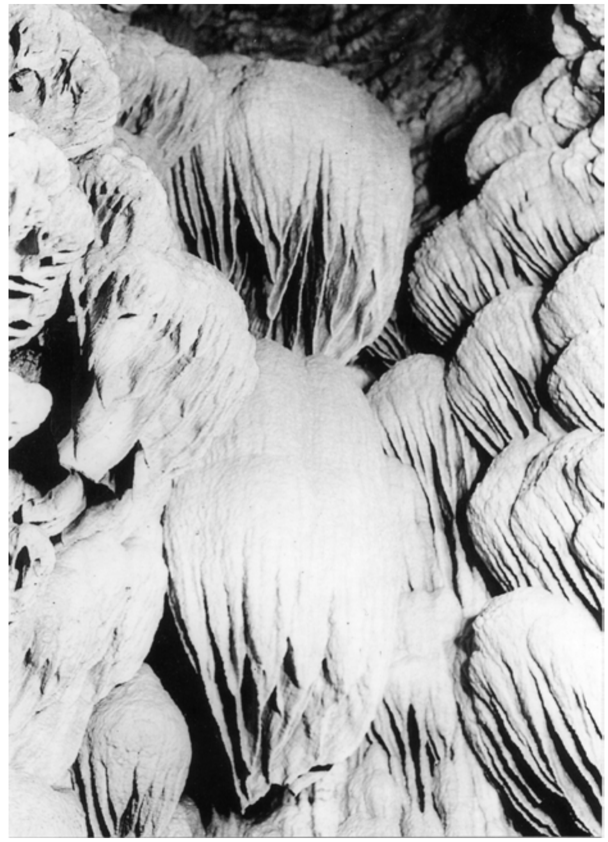

Figure 2. *Paradise Lost is the most heavily decorated room in the Oregon Caves. Preserved primarily through location, breakage and discoloration have still marred its beauty. It is not possible for guides to prevent visitors from touching while in this room as the floor space is inadequate to allow for a buffer zone around the visitors. (From the collection of The Friends of the Oregon Caves, Frank Patterson, Photographer.*

dently provided important input, including John C. Merriam, fresh from notable scientific achievements at California's Samwel Cave (Merriam, 1906). Eventually, however, national forest managers decided to let local entrepreneurs run it as a show cave and to build a resort next to it after a road had been built.

In these days before recognition of human impacts on caves, this management strategy was supported enthusiastically by residents of the region, but the cave suffered. This was not entirely the fault of the Forest Service. The resort's cave guides lectured visitors about not breaking off souvenirs and pointed out shameful earlier vandalism. But most of the cave route was so narrow that everyone necessarily brushed against the walls and touched speleothems they were trying to protect, and guides were known to take up to 400 visitors on a single tour. For a long time, candles were the primary light source. Smoke damage and wax drippings caused speleothems to lose much of their original beauty. And it was some 70 more years until the cave was securely locked at night against determined vandals (Knutson, 2003). Further damage was inevitable.

In 1933, newly-elected President Franklin Roosevelt used Executive Order 6166 to transfer all national monuments to the comparatively new National Park Service. Some considered this irresponsible, including part of the staff of the National Park Service itself. We agree. Although as expansionist as most federal agencies, the National Park Service

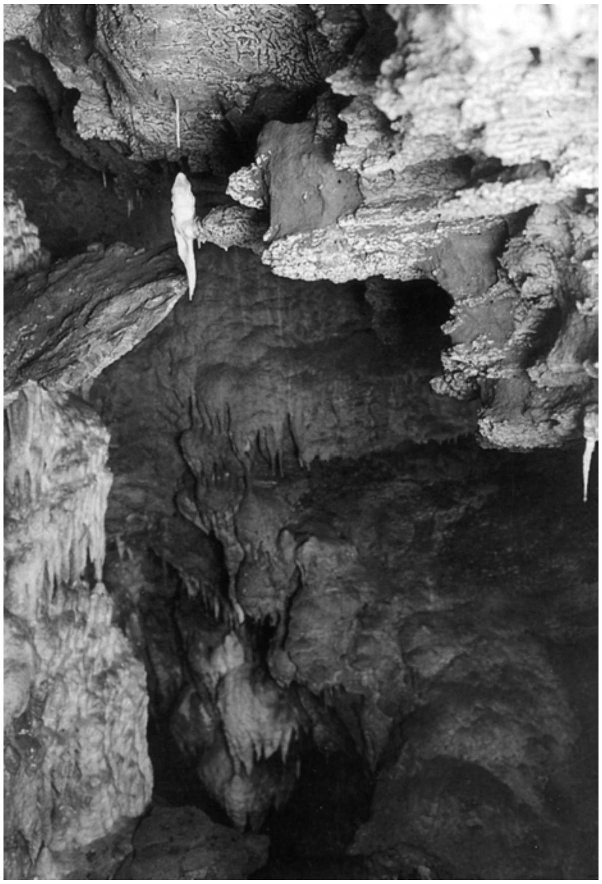

***Figure 3.** The Bird of Paradise. This formation was stolen July 22 or July 23, 1997. At the time of the theft, one entrance to the cave was completely unprotected (Icebox Cave Entrance) and the National Park Service installed non-functional electronic locks on the existing gates. Several weeks after the theft, the junior author of this paper worked as a volunteer in the park to fix the locks on the existing gates. Later a gate was installed at the unprotected entrance. Superintendent Ackerman was apparently unaware of these issues when he provided the* Medford Mail Tribune *information on the theft, as he reported, "Entrances to cave tours are locked when tours are not in progress, and all other known entrances are secured." (http://www.mailtribune.com/archive/97/august/80997n5.htm) (From the collection of The Friends of the Oregon Caves, Frank Patterson, Photographer.)*

then was primarily seeking jurisdiction over Civil War battlefields and other military parks. Oregon Caves National Monument did not meet the Park Service's criteria for additions to the National Park System (Unrau and Willss, 1983). Perhaps because of the anti-capitalist ideology of President Roosevelt's principal advisors, Interior Secretary Harold Ickes and Agriculture Secretary Henry Wallace, Oregon Cave and the other national monuments were taken away from the "capitalist" Forest Service and dumped in the collective lap of an unprepared National Park Service.

The National Park Service quickly removed much overhanging rock, filled passages for easier travel, rerouted streams, and created artificial tunnels for easier tourist travel. On the basis of recommendations by a young naturalist self-described as "inexperienced" (Finch, 1934), it otherwise maintained the status quo for many years. Uncontrollable crowds grew larger and larger and the cave's few attractive speleothems were decimated.

Nominally, the National Park Service managed the monument as an unimportant outlier of Crater Lake National Park, a park long notorious for its staff's disdain for caves and their resources (for example, filling the entrance of unique Hematite Cave with a truckload of rock and gravel only a few years before enactment of the Federal Cave Resource Protection Act). A full time administrator was not appointed for 35 years. A Resource Manager followed in 1989, but much of his time was diverted to other activities (see Roth, 1997). As a result, for almost 70 years, the Service essentially presided over destruction of the cave.

Innumerable postcards show that isolated areas of unspoiled beauty still existed along the tourist trail in the 1930s and 1940s, but destruction continued until the cave was secured at night in 1997. During extensive mapping in the 1960s, the senior author of this paper found only two scenes he thought worth photographing: massive Joaquin Miller's Chapel (Figure 1) and part of the dome called Paradise Lost (Figure 2) which is out of visitors' reach. Last to disappear (in 1997) was the little white "Bird of Paradise" (Figure 3), some bones and the "Crystal Club" vanished about the same time.

Although less than half the cave's passages are on the current tour route, only one other "through route" exists in the cave. In seeming violation of NPS-77 provisions on cave management (see section VI, paragraph 1) this carries the 1997 electric cable system and is heavily travelled. Most of the rest of its passages consist of short parallels and cutarounds within easy reach of vandals. A few remote, obscure areas preserve pristine milk-white flowstone and clumps of crystal-clear sodastraw stalactites as much as 22 inches long. But on and near the tour route, almost the sole surviving scenic

Figure 4. *A plutonic dike exposed by the dissolution of the surrounding marble. (From the collection of The Friends of the Oregon Caves, Jay Swofford, Photographer.)*

resource is high overhead in Paradise Lost, the scenic climax of the tour.

Current Controversies

In theory the National Park Service thus has managed Oregon Cave for almost 70 years. Yet it still lacks inventory data essential for a meaningful cave management plan. Paleontologist James Mead of Northern Arizona University found so rich a yield in a scant sample that he recommended an extensive paleontological investigation. It has not happened, but controversy escalated when an Environmental Assessment of July 24, 2002, seemed to assert that it had been done.

The Environmental Assessment also referred to "two large mammal bones older than 10,000 years." But when cavers submitted a Freedom of Information Act request for its documentation, no record of such dating was found.

Still further, this Environmental Assessment referred to a "review" of a proposed route of a "spelunker" off-trail tour by National Park Serv-

Figures 5 and 6. *A tree root in the cave.The tree root has been practically destroyed by trampling and visitor breakage. Figure 5 was taken just a few years before the National Park Service began managing the cave; figure 6 was taken by the junior author in 2001. The National Park Service refused on several occasions between 1985 and 1991 to investigate, talk to, or otherwise interact with visitors caught destroying this root by concession guides. (From the collection of The Friends of the Oregon Caves. Figure 5, Frank Patterson, Photographer. Figure 6, Jay Swofford, Photographer.)*

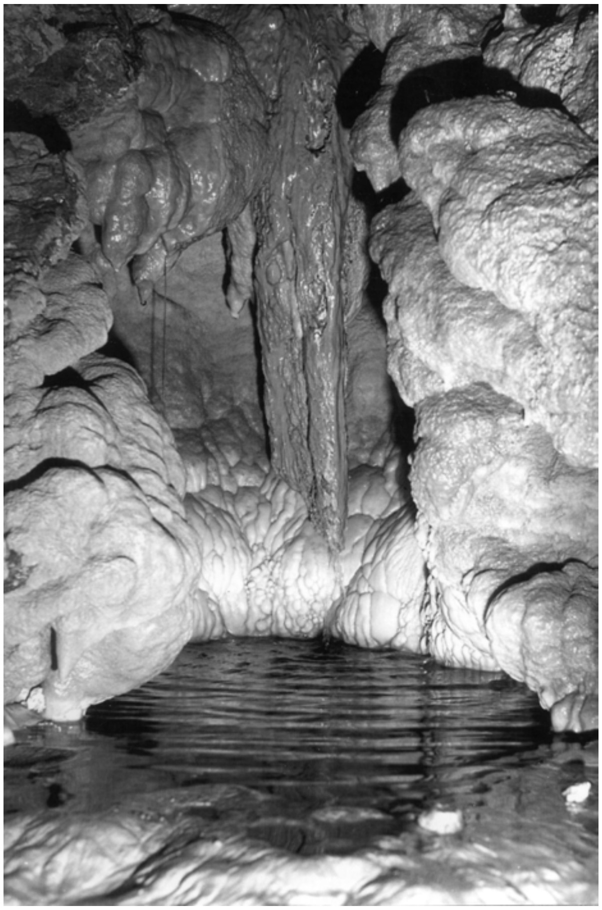

***Figure 7**. This is an example of the small, undamaged sections of the cave that still exist and need protection. Recently, a new species of water mite was discovered here, indicating the presence of an unknown crustacean somewhere upstream. (From the collection of The Friends of the Oregon Caves, Steve Talent, Photographer.)*

ice paleontologist Greg McDonald. He has denied conducting any such review.

In part because it extends through obvious paleontological sites, this "spelunker tour" continues to spawn controversies. All the monument's environmental documents show a single explicit route for it. But the monument's website currently informs potential visitors that they may reserve "spots on the 'off-trail tour' during summer months," with each tour being different, "exploring different parts of the south end of the cave" where no Environmental Assessment has been done.

Further controversy has arisen out of the staff's acknowledged long-standing policy of distributing scoping notices only to National Speleological Society members listed in the three Pacific Coast states. Apparently obsolete NSS lists have been used and the staff admit-

***Figure 8**. A bear claw mark in the clays of the south end of the Oregon Caves. The top mark was destroyed in 1985 by Ranger Bruce Muirhead. Ranger Muirhead was providing an "off-trail" experience for the concession cave guides. He identified this set of marks as "solution rills or possibly contraction crevices from drying clay." He then scooped clay from the top mark to allow each member of the tour to "feel its consistency" between their own fingers. The hope was to allow the tour members a better understanding of the cave through tactile interaction. The junior author was a member of that tour. (National Park Service File Photo, Steve Knutson, Photographer.)*

tedly did not follow up when mail was returned. This selection process systematically excluded some of the most knowledgeable persons about Oregon Caves National Monument and about marble caves in general. Some of those excluded from input on recent management documents are Dr James Moore (expert on marble caves, as published in the 2003 NSS Convention Guidebook), Dr Stephen Cross (who has conducted bat studies in parts of the cave and recommended others), Dr James Mead (cited above) and the two authors of this paper. The National Environmental Protection Act requires that scoping notices be sent to such knowledgeable persons. The senior author prepared the first geological report on Oregon Cave (Halliday, 1969) and the first modern map of the cave, and also is co-author of a very popular booklet sold at the cave. He received no scoping notice of any of the National Park Service documents cited in the list of references for this paper. The junior author is Director of Friends of Oregon Caves. He maintains the largest known reference library about the cave, and guided there for years. He was included in the scoping list for the General Management Plan but not for the ensuing En-

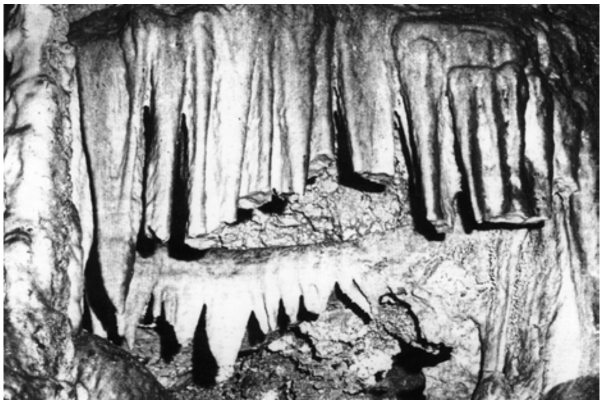

Figure 9. Regrowth of speleothems occurs very slowly in Oregon Cave. This vandalism of Niagara Falls (against which visitors brush) is evident in an 1899 photograph but not in another taken between 1889 and 1891. A 1991 study showed that the maximum regrowth here was 1/8 to 1/4 inch at the leading edges. Of several hundred measured, the longest soda straw regrowth was less than 2 inches. (National Park Service File Photo, Roger Contor, Photographer.)

vironmental Assessments, supposedly mailed from the same list.

Subsequently, ill-founded assertions and absurd errors of fact have appeared in some of these documents, and in on-line statements derived from them. Contrary to these supposedly authoritative documents, Oregon Cave does not have "one of the most adventurous cave tours in North America," nor is it "more like real cave exploring than perhaps any other cave in the country" (National Park Service, 1999). Nor was it, as asserted, the longest solutional cave "within 1,000 miles" prior to the discovery of Bigfoot Cave (Lilburn Cave in California was and is several times as long). Nor did its speleogenesis begin "220 million years ago" by "collisions of continental and ocean rock" (Connor, 1998). The senior author of this paper did not investigate the cave's bats in 1952 as asserted in the online Environmental Assessment for the controversial spelunking tour (he was not even in the region at that time). Many other errors of fact attributable to this lack of input can be cited.

Important geological interpretations in Connors (1998) and other documents seem strained and clearly were not reviewed by knowledgeable karstologists. A statement that "the marble outcrop appears to have formed on this volcanically active island chain . . ." reveals a fundamental misunderstanding of metamorphism of limestone into marble. And contrary to repeated assertions, metavolcanic and metasedimentary rocks alongside the Oregon Cave marble are not part of the cave just because they are exposed by breakdown or solution of adjacent marble. See below. Certainly, such noncarbonate rocks do not "decorate" the cave as asserted.

Perhaps the most important current controversy, however, has arisen from the overall thrust of the monument's 1999 General Management Plan. Comparatively little of this long document relates directly to Oregon Caves National Monument. Most of it is a hodgepodge of misorganized historical perspective together with explications of management concepts that seem intended to apply to all caves of all units of the National Park System (including Hawaiian lava tube caves). Those parts clearly identifiable as primarily pertaining to Oregon Caves National Monument, however, clearly establish multiple use management for the monument, excluding only the logging and mining prohibited in 1909. (Normally, multiple use management is considered the function of the Forest Service, not the National Park Service.) Further, they establish that management of the monument primarily is for the economic and recreational benefit of the people of southwestern Oregon as did the Forest Service's management prior to 1934. This role reversal refocuses the long-standing question of which agency should manage Oregon Caves National Monument.

Significance of Oregon Cave

Oregon Cave is one of hundreds of dissolution caves in the numerous narrow marble roof pendants within the Klamath and Sierra Nevada Mountains of Oregon and California—a topic discussed in detail by Stock and Moore (2003). Throughout the Grants Pass Quadrangle, this pattern is especially clear in Wells' preliminary geological map of the quadrangle (Wells, 1940). Depending on the local lithology, various non-carbonate rocks are commonly exposed in the walls of such caves. Their speleogenesis, however, uniformly began with dissolution of marble, not the volcanism or metamorphism which produced the non-carbonate rock (Halliday, 1969). Thus these other rocks are not features of the caves just because they may be seen in their walls (Halliday, 1953). Caves merely serve as windows through which limited exposures of these non-carbonate rocks may be viewed. Roadcuts are better than caves for this because exposures of the rocks are far larger, and the lighting is better.

Oregon Cave is one of the larger examples of such roof pendant caves. Its shape and pattern generally are quite similar to those of well-known Lilburn Cave, a day's drive to the south in Kings Canyon National Park, but Oregon Cave is far smaller (currently 4.87 kilometers to 32 kilometers for Lilburn Cave). In size, Oregon Cave is more comparable to Crystal Cave, another National Park Service show cave in marble, located a few miles from Lilburn Cave but in Sequoia National Park.

Both Oregon Cave and Crystal Cave are resurgence caves located beneath steep hillsides. Oregon Cave is slightly longer than Crystal Cave—4.87 kilometers vs 4.2 kilometers, not 5 miles as currently asserted on the monument's website. Excluding the Exit Tunnel, its tour route is slightly shorter—1,700 feet vs 1,800 feet in Crystal Cave. (Both are much shorter than those in Kazumura Cave, Hawaii; Ape Cave, Washington; Lava River Cave, Oregon; and several others in the western United States.)

But meaningful comparison stops here. In striking contrast to the passages of Crystal Cave, most of those of Oregon Cave are grubby squeezeways, with evidence almost everywhere of decades of abuse and neglect. In glorious contrast, Crystal Cave is notable for spacious, sweeping vistas of near-pristine white speleothems, with crystal facets sparkling even in the dim tour light. On a 1:10 scale, the scenic resources of Crystal Cave rate 9. Those remaining in Oregon Cave are 3 at most. Among the numerous other caves of the Klamath Mountains, at least one sizeable example rates 7, and protection of several other Klamath Mountains caves appears at least as important as Oregon Cave. One of these caves is within the area that the National Park Service has been vainly seeking since 1934 for an enlargement of Oregon Caves National Monument. But the Park Service evidently has no management strategy at all for the other caves presently within the monument, so there seems to be no reason to bring it into the monument.

But all this matters little to the average visitor to Oregon Cave, drawn to the site by decades of publicity and the magic phrase "national monument." Visitors typically take justifiable pride in visiting this, the largest marble cave in either of the two Pacific Northwest states, a huge area where soluble rocks and hence dissolution caves exist only on its fringes. After all, this is an impressively extensive cave with a scenic climax at Paradise Lost. And its narrow, sinuous passages are fun even if more than a trifle muddy. Hardly any of today's visitors know nor care how the cave looked in 1933, much less in 1833 before the coming of civilization. And indisputably it is a major financial and recreational asset to the people of the Illinois and Rogue River Valleys—their pride and joy. Such deep convictions cannot be dismissed lightly.

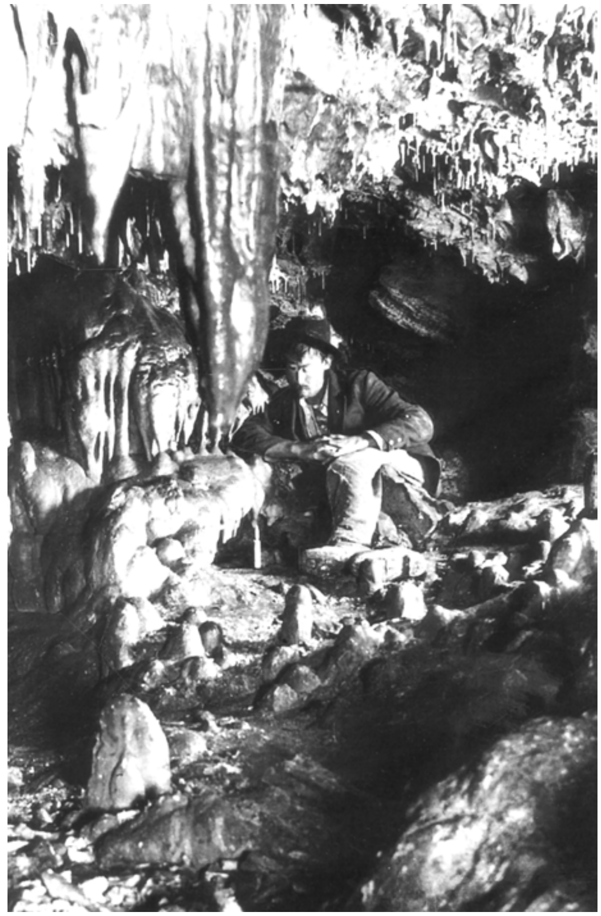

***Figure 10**. An early explorer in the Oregon Caves. (From the collection of The Friends of the Oregon Caves, B.L. Singley, Photographer.)*

Looking Forward

In the past few years, the National Park Service has developed a series of planning documents for the monument, not yet complete (National Park Service; 1997, 1998, 1999, undated). Some of the planned actions have disturbed influential segments of the local population (see National Park Service; 1998, Volume 2) just as predicted by Finch (1934). Nearly everyone considers some of its other actions to show really good intentions, however (securely locking the cave at night in 1997, for example). The resource impact of still other "improvements" is less clear. Physical modifications to the tour route may be harmful by destroying remains of small animals in the ma-

terial that was excavated and discarded; no environmental impact study preceded recent work. Nor was such a study conducted before opening a new entrance which may have altered the cave's air flow significantly. It is difficult to continue supporting management of a national monument that repeatedly disregards the need for environmental impact studies.

Past failure to follow through with good intentions also is an ominous sign for the future. In 1997, the General Management Plan Draft asserted that inventorying cave resources was "90% complete," and "cave deposits are currently being examined for small vertebrate fossils." The latter was restated in the 1999 General Management Plan, but neither has progressed beyond the stage of good intentions. Despite 70 years of National Park Service management of the monument, the inventory is nowhere near "90% complete." About ten years ago, some 10,000 biological specimens were sent to the University of Washington for identification. At the 2003 NSS Convention, the monument's Resource Manager acknowledged that more than 97% of them remain unidentified, due to a lack of funding by the National Park Service. The monument's inventory of both biological and paleontological resources thus is far insufficient for development of a meaningful Cave Management Plan or for confidence in its management.

Currently, high-tech photomonitoring and cave restoration are being touted as solutions for some of the management problems here. But the reasons espoused for photomonitoring and statements about the expected outcomes of restoration are so vague that these seem to fall into the category of good intentions which lack accountability. The junior author hopes that discovery of fresh vandalism through photodocumentation will lead to a prompt beginning of investigation and enforcement. On the basis of 70 years of history, the senior author fears that nothing useful will come of it (except perhaps praise for someone doing something which looks commendable, regardless of outcome). Steve Knutson hopes that it would be a useful demonstration project, valuable in other Park Service caves (R.S. Knutson, e-mail communication 2003). But in the absence of statements of purpose so clear that outcomes can be measured against them, such projects seem likely to merely produce additional controversies.

Even cave restoration projects seem likely to provoke still more controversy. Serious questions remain unanswered:

- Considering the vulnerabillity of restored speleothems in its narrow, twisting passages, would the cave be better off without the additional impact of restoration efforts necesssarily repeated every few years? Or every year?
- Are enough speleothem remnants present for meaningful restoration without unacceptible creation of new, largely artificial speleothems?
- How many of its speleothems were unaesthetic originally, with mud and silt embedded during their formation? And does that matter?

Under its present management strategy, Oregon Cave seems likely to continue indefinitely as a lightning rod for controversy.

Recommendations

To the surprise of many of us who long have been National Park Service advocates, the Forest Service recently has demonstrated clear ability to manage national monuments. Its Mount St. Helens National Volcanic Monument could be a model for Oregon Caves National Monument. Oregon Cave retains considerable value and wide public support as a show cave within a recreational area. In our opinion, the public and the cave would be served best by returning this ill-fated national monument to the Forest Service to again be managed as it was before 1934. Except for privately-owned Wilderville Quarry Cave, this would permit all the caves of the Klamath Mountains to be managed as a unit, something which we consider very desirable.

But in doing this, the 1907 scientific mandate for the monument should be applied in a new way. At least until inventories are complete, the untravelled sections of the cave should be designated Research Areas where even administrative access is severely restricted. This can be entirely compatible with management of the rest as a show cave.

With this proviso, another Executive Order should transfer the national monument back to the Forest Service at least by the end of the 2004 tourist season. Otherwise, with the passage of more and more time and more and more controversy the basic problem will merely become more and more obvious: Oregon Cave simply lacks the characteristics necessary for a National Park Service show cave.

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Proactive Cave Management on the Hoosier National Forest

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Abstract

The Hoosier National Forest encompasses a significant part of the karst of southern Indiana. Over 130 caves have been found on National Forest Service lands including the Lost River Cave System (17 miles of mapped passages) and Gory Hole (deepest pit in Indiana). Many caves have been given enhanced conservation status due to their location within designated forest service special areas or designated wilderness areas. Examples are Dillon Cave (Grease Gravy Special Area), Gypsy Bill Allen Cave (Gypsy Bill Allen Special Area), Gory Hole (Tincher Karst Special Area), Lost River Cave System (Wesley Chapel Special Area) or Patton Cave (Charles Deam Wilderness Area). Proactive management involves a detailed understanding of the caves with documentation of the complex resources involved. Through cooperation with the Indiana Karst Conservancy caves and karst features are being inventoried and mapped. A detailed bioinventory of caves on the Hoosier National Forest is being conducted and is providing a data-intensive basis for cave management plans. As a result of the cave bioinventory over 60 species have been placed on the Region 9 Regional Forester List of Sensitive Species. For each of these species a detailed conservation assessment is prepared as well as an assessment of the habitat and community in which it occurs. These assessments include a list of the caves from which each species is known, habitat requirements, analysis of threats, conservation actions currently being taken and provisions for the management of the species and their unique habitats.

The Hoosier National Forest encompasses a significant part of the karst of southern Indiana. At present 136 caves have been found on National Forest Service lands including the Lost River Cave System (17 miles of mapped passages) and Gory Hole (deepest pit in Indiana). Proactive management involves a detailed understanding of the caves with documentation of the complex resources involved. A multi-faceted approach has been developed for conservation management of caves and karst on the Hoosier National Forest

Cave resource inventory

Through cooperation with the Indiana Karst Conservancy caves and karst features are of the Hoosier National Forest are being inventoried. The cave resource values inventory includes characterization of the cave as well as biological, geological and cultural features. The cave information is placed on the Indiana Cave Survey database (http://www.caves.org/survey /ics/).

Subterranean bioinventory

A detailed bioinventory of subterranean habitats including caves, springs and wells on the Hoosier National Forest is being conducted and is providing a data-intensive basis for cave management. Between 2000 and 2003 a total of 120 caves have been sampled for fauna, of which 51 species were classified as obligate subterranean species and 73 were of significant global rarity, that is G1-G3 (Lewis, Burns, and Rafail, 2003).

Regional Forester's List of Sensitive Species

As a result of the cave bioinventory over 40 species have been placed on the Region 9 Regional Forester List of Sensitive Species. For each of these species a detailed conservation assessment has been prepared. Each includes an executive summary, includes a list of the caves from which each species is known, habitat requirements, analysis of threats, conserva-

tion actions currently being takens and provisions for the management of the species and their unique habitats. These assessments are available on the internet at, for example for the troglobitic beetle *Pseudanophthalmus youngi*: http://www.fs.fed.us/r9/wildlife/tes/ca-overview/docs/insect_Pseudanophthalmus_youngi-YoungsCaveBeetle.pdf

Community conservation assessments have also been prepared for: (1) cave streams, (2) riparian cave habitat, (3) non-riparian terrestrial cave habitat, (4) cave guano habitats, (5) springs, (6) epikarstic aquifer habitat, (7) intersitital aquifer habitat, and (8) hyporheic habitat.

These assessments include an: (1) executive summary, (2) description of the habitat and community, (3) environmental conditions, (4) current community condition, distribution and abundance on the Hoosier National Forest, (5) Regional Forester Sensitive Species, (6) potential threats, (7) summary of land ownership and existing habitat protection, (8) summary of mangement and conservation activities, (9) research and monitoring, and (10) pertinent references. An example of a community conservation assessment can be found at:

http://www.fs.fed.us/r9/wildlife/tes/ca-overview/docs/riparian_cave_habitat.pdf

Cave management plans

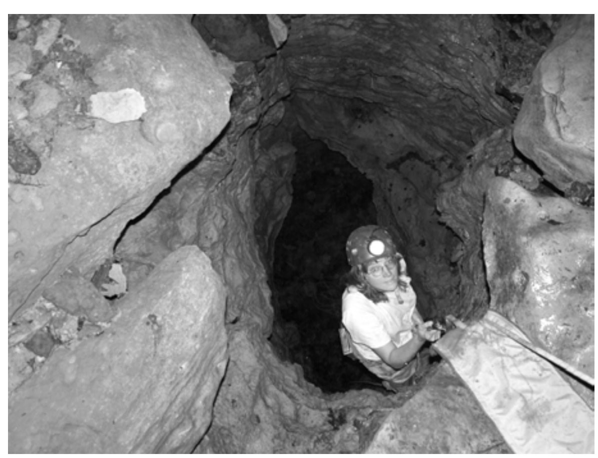
Cave and karst habitat located on the Hoosier National Forest are subject to standards and guidelines for caves and karst protection and management as outlined in the Hoosier National Forest Land and Resource Management Plan (Forest Plan) (USDA Forest Service 1991, 2000). These standards and guidelines include the following:

- Caves are protected and managed in accordance with the Federal Cave and Karst Resources Protection Act of 1988, Forest Service Manual 2353, Memorandums of Understanding between the forest service and the National Speleological Society, the Indiana Karst Conservancy, Inc., the Forest Cave Management Implementation Plan, and individual specific cave management plans.
- Except where modified by an existing cave management prescription, vegetation within a 150- to 200-foot radius of cave entrances and infeeder drainages with slopes greater than 30 percent will generally not be cut. No surface disturbing activities will be conducted on any slopes steeper than 30 percent adjacent to cave entrances. Similar protection areas will be maintained around direct drainage inputs such as sinkholes and swallow holes known to open into a cave's drainage system of any streams flowing into a known cave.
- Allow no sediment from erosion of access roads and drilling sites to wash into caves or karst features.

In addition, management plans are being prepared for every cave in the Hoosier National Forest. These plans include resource inventory in the following categories: (1) biological, (2) geological, (3) paleontological, (4) hydrological, (5) cultural, (6) recreational, and (7) educational. For each cave a management and monitoring plan is specified.

Proactive Management Examples

Planning for the new I-69 linking Indianapolis and Evansville proposed several prospective corridors for the construction. The path for Alternative 5 runs from Indianapolis to Bloomington, then south to Bedford and swings through southern Lawrence County before turning to the southwest and ending at the junction of I-64 and I-164 north of Evansville. This proposed route goes through the Hoosier National Forest Tincher Karst Special Area. The Tincher Karst is characterized by the presence of hundreds of sinkholes, caves and springs. Many of the caves in the area are pits, for example, Gory Hole, the deepest pit in Indiana. As part of the cave bioinventory of Lewis, *et al*. (2003), the fauna of 24 caves had been sampled in the Tincher area revealing the presence of 23 species of troglobites and stygobites. Most of these species were of high global rarity



Biologist ascending the drop in Turtle Plunge, a typical pit in the vicinity of the Tincher Karst Special Area.

(Global Rank of Rarity 1-3) and included taxa endemic to the area, some new to science. Based on this information I-69 Alternative Route 5 was rejected.

The Lost River Cave System is centered around Wesley Chapel Gulf Cave, the third longest cave in Indiana with 17 miles of surveyed passages. The caves of the Lost River System have been rather thoroughly sampled (Lewis 1994; Lewis et al. 2003) and were known to contain a globally significant subterranean fauna of 20 obligate subterranean species. This knowledge was in hand at the time that the Blanton Property was offered for sale. This biological treasure was immediately purchased by The Nature Conservancy based on the proactive data and will be transferred to the Hoosier National Forest.

The Packards Cave Pseudoscorpion (Kleptochthonius packardi) *is an example of an ultrarare troglobite found in caves on the Hoosier National Forest.*

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Using ESRI ArcPad to Inventory Cave Features

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Abstract

Many locations of findings, project activities, and research in the caves have been lost due to a lack of a good system for organizing spatial data. Using a georeferenced map of the Timpanogos Cave System, significant features throughout the cave such as electrical wiring, historic artifacts, rare formations, biology sightings, and monitoring stations are being mapped and inputted in the field using ESRI ArcPad and a Pocket PC iPAQ. This system will be created so that spatial relations can be studied, data can be quickly found through hotlinks, and management activities can be documented.

Portable GIS solution

Cave researchers have the problems of large inventory, monitoring, and restoration projects that occur in the most unthinkable places. The documentation of these projects has been performed using paper maps and notes that leave a confusing and labor intensive amount of computer input. Carrying laptops loaded with GIS applications created complete and accurate datasets, but was very cumbersome and limited in where you could go. The solution was using to a very portable iPAQ Pocket PC running ArcPad.

A Pocket PC had many advantages for being used in a cave. The HP iPAQ 3970 is compact. It is 5.3 by 3.3 by 0.6 inches and weighs only 6.5 ounces. Used with the rugged case accessory, the iPAQ is reasonably protected. With a fast XScale 400 Mhz processor without a bootup sequence, the iPAQ is a fast, efficient field platform. The battery life far exceeds the life of laptop batteries. The 1,400 mAh Lithium polymer battery with Power Management features will last a full work shift—up to 10 hours of continuous use. And the best part is a rechargeable, auto-sync cradle that automatically recharges and synchronizes your shapefiles so they can immediately be used in desktop GIS applications.

ESRI created ArcPad as a simple mobile mapping solution. The software allows creation and editing of points, lines, and area features with associated attributes. It is very similar in use and function as the better-known ArcView. ArcPad makes data collection fast, easy, and significantly improved with immediate data validation and availability.

Cave GIS Setup

Setting up ArcPad from existing layers is

Inventorying signatures with ArcPad

simple. The shapefiles can just be added to the synchronized <Pocket PC My Documents> directory. Large raster images, such as georeferenced cave maps, may need to be converted to work under the Pocket PC system. ArcPad

comes with an extension that allows views to be exported into a georeferenced JPEG image supported by ArcPad.

For Timpanogos Cave National Monument, a cave inventory was already in process using a georeferenced map of the cave. Others will find creating the layer of the cave map is the most difficult task in creating a mobile cave GIS. First, the survey data and map of the cave must be available. The line plot of the cave is then imported using CaveTools (http://www.mind spring.com/~bszukalski/cavetools/cavetools.html). This line plot then is registered to survey station with a high-accuracy GPS location. The cave map is then scanned, arranging the map so true north is up. One needs to be sure that the data has been adjusted correctly to account for magnetic declination. In a photo editing software, the image is cleaned and the background painted to a different color than the passage fill. Later in ArcView, the Image Editor is used to adjust the Color Map so that the image's background is transparent. This transparent background will allow other layers to be seen with the cave map layer. Save the image into a format that can be recognized by ArcView, such as a 256-color TIFF image. Using the Image Georeferencing Tool (http://arcscripts.esri.com/details.asp?dbid=11140), painstakingly adjust the image until it best matches the line plot.

The map of Timpanogos Cave is being completely reworked by Brandon Kowallis using Adobe Illustrator. This new map will include all of the detail collected from the original survey by Rod Horrocks. The map will then be imported as a layered vector map.

Jasper3 - Sample of Cave Inventory Map

Cave Inventory

Most of the knowledge of cave features and past management actions is known only by that park's cave managers. GIS technologies can be used to preserve the knowledge about the cave resources. The Science and Resource Management division at Timpanogos Cave National Monument is using ArcPad to inventory types of cave formations, the history of monitoring efforts, biological sampling and sightings, cave infrastructures, and management actions. These mapped features will be created so that spatial relations can be studied, data can be quickly found through hotlinks, and management activities can documented.

The following list shows some the features that are being or are planned to be mapped:

Formations
- Tubules
- Helictites
- Anthodites
- Frostwork
- Flowstone
- Shields/welts

Formation Coloration
- Green
- Yellow
- Red

Recording Stations
- TMP/rH
- Drip rates
- Past Stations

Hydrology
- Pools
- Streams
- Drips
- Water sampling

History
- Artifacts
- Signatures
- Place names

Biology
- Wildlife sightings
- Bones
- Vouchers
- DNA sampling
- Suitable habitats
- Middens

Electrical System
- Lights
- Fuses
- Electric lines
- Switches
- Outlets
- Old systems

Infrastructure
- Doors
- Catwalks
- Handrails
- Old infrastructure

Interpretation Needs
- Switches
- Lighted areas
- First Aid locations
- Accidents
- Incidents

Cave Potential
- Leads
- Airflow
- Walled passages
- Digs
- Sumps
- Roots/Crickets/
- debris

Management Actions
- Cave cleaning
- Algae removal
- Development
- Proposed actions
- Restricted areas
- Drainage problems

Routes
- Tour routes
- Historic routes
- Wild tours

Geology
- Faults
- Strike/Dip
- Scallops
- Geologic Units

A Comprehensive Cave Management Program at Carlsbad Caverns National Park

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Abstract

Carlsbad Caverns National Park in southern New Mexico contains some of the world's most spectacular, yet fragile, cave resources. The cave management program that has evolved at the park strives to balance protection, preservation, and conservation of these non-renewable resources with access at varying levels for recreational and educational values, and scientific research and management needs. The tour routes in Carlsbad Cavern with a yearly average of 500,000 visitors and the management of Lechuguilla Cave with its current length of over 110 miles (177 kilometers) are examples of the different management challenges faced by the park. This paper will present a look at the current programs that help achieve the balance mentioned above.

Carlsbad Caverns National Park is located in Eddy County, New Mexico, and contains 46,753 acres of rugged canyons and ridges. The park is found within the Guadalupe Mountains, an uplifted portion of the Permian-aged Capitan Reef Complex and lies within the northern Chihuahuan Desert. Comprising back-reef, reef, and fore-reef deposits of primarily limestone and dolomite, the Guadalupe Mountains are world-famous for its spectacular and very fragile cave resources. Within Carlsbad Caverns National Park there are 106 documented caves, of which Carlsbad Cavern, at 30.9 miles in length, and Lechuguilla Cave, at over 110 miles in length, are, by far, the longest and deepest. The cave management program that has evolved at the park strives to balance protection, preservation, and conservation of these non-renewable resources with access to these resources at varying levels for recreational and educational values and for scientific research and management needs. This paper will delve into current management strategies as well as discuss some of the challenges we face today and into the future.

A Quick Look at the Past

Cave management is not a new idea. In fact it has been around ever since we started going into caves. The difference today is that we recognize the impact humans can have on these fragile resources and work to minimize our impacts for the long-term protection of the caves. Almost any cave manager will be quick to tell you that we don't manage caves, they do fine by themselves. We manage people. It is how we manage people who go into caves that make all the difference. At Carlsbad Caverns National Park, cave management actually started the day that Jim White "discovered" and entered Carlsbad Cavern. Early "management" focused on the commercial aspects of the caves of the area, first by mining bat guano and then later by encouraging people to see the great wonders found deeper in the cave. While not deliberately wanting to destroy the cave and its features, the early entrepreneurs did things that we would not even conceive of today. A prime example was the sinking of two shafts directly into the top of the bat roost. This enhanced the efficiency of the guano mining operation, but in the process made the bat roost unsuitable for bats to live in. Fortunately, with the change in their roost area, the bats did not totally abandon the cave, but they could have. The shafts have since been sealed and the bats have returned to their original roosting area.

Management Today

One way to look at management of the park is that we (the National Park Service) have to

take care of our customers. In this case though, some of our customers are not what the average person would think of. Some of the customers are people, whether they are visiting the park to enjoy the underground wonders, whether they are working or volunteering their time at the park, or whether they are scientists helping park management learn more about these amazing places. But the customers that are often overlooked are the resources themselves. The sky, the rocks, the plants, the animals, and the empty spaces in the rocks we call caves are all customers that depend on us for their survival. The resources are every bit as important as the people. They have to be.

Today's management must look to the past to see where we have come from and what we have done to get to where we are today. We must learn from the past and head to a future that insures the conservation and preservation of these resources while somehow allowing access to our other customers, the people. This is no easy task especially with the knowledge that cave resources in the Guadalupe Mountains tend to be very fragile and non-renewable. Once they are changed, they are changed forever. By not taking care of our customers, the resources, we will lose our other customers, the people.

In an effort to balance this seemingly impossible task (access versus conservation), a broad spectrum of cave experiences is available at the park while still protecting caves and cave areas. A listing of these experiences is as follows.

Tours Along Paved, Lit Trails in Carlsbad Cavern

Begun in the early 1970s, the self-guided tours in Carlsbad Cavern cover about two miles of paved, lit trails that the visitor, employee, or researcher can walk along at their leisure during the hours that the main trail is open for touring in both summer and winter. The areas covered by the self-guided tour are the Main Corridor and the Big Room.

Guided tours are offered in Carlsbad Cavern along a three-quarter-mile section of paved, lit trail into the Kings Palace area also known as the Scenic Rooms. Once part of the self-guided tour, increasing vandalism made the park return this area to a guided tour in 1995.

Off-Trail Guided Tours in Carlsbad Cavern

Guided tours are offered into three "off-trail" areas in Carlsbad Cavern. The trails along these routes have few improvements to them and no electrical lights. A few improvements, such as providing flagged trails to help protect floor features, have been added for safety or resource protection reasons. These tours are designed to give visitors a range of experiences in off-trail areas.

In Carlsbad Cavern, the Left-Hand Tunnel Tour is through large, easy walking passages with candle or oil lanterns used for lighting. The Lower Cave Tour descends a series of stainless steel ladders to mostly large, easy walking passages also. Helmets and lights are provided to those on this tour. The Hall of the White Giant Tour offers visitors a more rugged caving trip and includes crawling and climbing as part of the experience. Helmets and lights are also provided for this tour.

Guided Tours in Three Other Park Caves

Guided tours are also offered to three other park caves that provide a range of experiences for the visitor. The tour routes through these caves are similar to the "off-trail tours" in Carlsbad Cavern in that they have had few improvements and have no electric lights. The Slaughter Canyon Cave Tour is through large walking passages where everyone brings a flashlight to light his way. The Spider Cave Tour also includes areas of crawling and climbing. The park provides helmets and lights for those on this tour. Those taking the Ogle Cave Tour must be able to safely descend and ascend a 180-foot-deep entrance pit to reach the cave tour route which is a large, well-decorated walking passage. Because of the vertical entrance drop, this tour is only available to experienced cavers who have their own gear and have experience using it.

Caving On Your Own

Eight caves on the park are available for cavers with proper equipment to visit on their own. These caves range from an easy walking cave with a large passage (Goat Cave) to a cave with a 300-foot-deep entrance drop (Deep Cave). These caves have few improvements that include flagged trails to help protect floor features and no electrical lights. Those visiting these caves must provide their own lights and equipment.

Research and Management-Related Trips

All park caves, including Lechuguilla Cave, and all areas of Carlsbad Cavern, Spider Cave, and Slaughter Canyon Cave, including those areas not along the visitor tours routes, are available for approved research and management-related trips.

Research is essential for knowing what resources the park contains and understanding how to manage them in a way that will protect and perpetuate the resources themselves and the processes that allow them to exist. Management related trips are important because they allow us to document passages and features, help keep assigned staff informed of resource conditions (an example would be assessing an area for the need to restore it to more natural conditions), and to provide infrastructure maintenance (an example would be monitoring or replacing ropes). This includes employee orientation trips along visitor tour routes and occasionally to some areas beyond the tour routes in Carlsbad Cavern, Slaughter Canyon Cave, and Spider Cave.

Much of the work to document passages and features cannot be done by park staff alone. Hundreds of experienced cavers have worked with our Cave Resources Office to volunteer thousands of hours to help the park explore, survey, and inventory numerous areas and caves. Included in these volunteer efforts have been restoration and conservation projects, particularly in Carlsbad Cavern where significant portions of the cave were impacted from early exploration and visitation trips and from building and maintaining an infrastructure in the cave.

Education and Special Use

Mentioned last, but certainly not least, is education and special use. Education is essential for the long-term protection and survival of caves and their features. Education must reach everyone from the park managers and staff, the researchers and cavers, to the visiting public. Without education on all 1evels, the caves of the park stand to lose the essential ingredients that make them special, that give joy, astonishment, and beauty to the millions that have come to see them. The park has a good education program, including a developed curriculum for all school grades.

Special Use is a term the park uses for permitting uses on the surface or in caves that are not covered by other general guidelines. Commercial filming tends to be the one activity that is most often covered by Special Use provisions. Numerous films, mostly for television, have featured caves of the park and have been an excellent way to help educate the public about park caves and their fragile features. We work closely with film crews to help them get the film footage they need while assuring that the resources are not further impacted during the film shooting. Additionally, we encourage filmmakers to promote safety and to include preservation and conservation messages in their films.

Impacts Versus Conservation and Protection

The fact that caves of the park and the features they contain are very fragile has been well documented. It has also been well documented that the more people that travel into a cave passage, the more that passage will be impacted. The impacts can be very visual such as crushed minerals covering the floor where once popcorn and other crystals grew intact. The impacts can also be more elusive and harder to detect. Virtually undetectable impacts to microbial ecosystems are made just from the amount of organic carbon breathed into a cave passage or room that has been entered for the first time. To go there, changes it. The more people who go there, the more it changes.

The cave management program at Carlsbad Caverns National Park tries to balance this dual-purpose mandate by providing access to various caves and locations for various reasons. Some caves and areas are impacted more because of the large numbers of people allowed there while some caves and areas are impacted less so because of the fewer numbers of people allowed there and some caves or areas are impacted very little because of the even smaller numbers of people allowed there. By managing in this way, some caves and areas can evolve over time following natural processes with few disruptions while some caves and areas evolve over time with more disruptions effecting their evolution and some caves and areas receive many more disruptions and evolve over time with less ability for their natural processes to influence their evolution.

Is this a perfect system? Only time will tell. At the very least, this system does reflect the need to provide access to fragile, non-renewable resources while conserving them for future generations.

Management Challenges and the Future

The ultimate challenge that management faces now and into the future is how to protect and conserve fragile, non-renewable resources while allowing access. Perhaps the more critical challenge is how to preserve these resources for far distances into the future. Providing access is relatively easy. Keeping too many people from visiting everywhere is the challenge. Every individual must know and understand that if they go there, they will impact it. If enough individuals go there over the next 20 years, the next 100 years, and even the next 10,000 years, they will have changed it and the natural processes that sustain the area forever.

As more and more people populate this earth, more and more people will want more and more access to more and more places. It is certainly not just a challenge we face with these cave resources. It is a challenge the entire world faces with what is left of its natural features.

Carlsbad Cavern

Management of Carlsbad Cavern began before anyone knew what the cave really was and how fragile the cave really is. In many ways, Carlsbad Cavern was changed forever before any of us were born. The challenges that management faces over Carlsbad Cavern now are worth noting and worth fighting for. The first challenge is to understand the cave and our relationship to it. The second challenge is to identify past actions that were mistakes and to correct them. The third challenge is to look to the future, the near and far future, and to initiate actions that will keep the cave out of harm's way as much as possible.

We are well on our way to understanding Carlsbad Cavern, the processes that created it, and our relationship to those processes and features. While much remains to be done in this regard, the park has taken major steps forward by not allowing any new structures to be built above the cave and by completing the Carlsbad Cavern Resource Protection Plan. This plan identifies the more serious problems associated with the infrastructure built on top of the cave and commits the National Park Service to removing, replacing, or providing mitigative measures concerning these structures for the cave's long-term protection.

The Carlsbad Cavern Resource Protection Plan has, in essence, identified some of the past mistakes that have been made and commits the National Park Service to correcting these actions. There will always be a need to continually look at everything we do in and above the cave and to make decisions and, ultimately, changes based on the long-term needs and protection of the cave. This is not to say that we should stop people from getting to see the cave in order to protect it. Rather, it means that in the long-term, the cave must survive as intact as possible. In order for this to happen, the cave, itself, must be given considerable weight in any decisions or actions that affect it.

While government agencies are only funded from year to year and the park's General Man-

agement Plan is a 15-year document, a challenge for management will be to look beyond these years to the far future and make rational decisions and actions that will allow the Carlsbad Cavern that we know today to be there for many generations to marvel at. One of the obvious challenges is to protect the cave from our own infrastructure and our own perceived need for conveniently placed buildings. The more numbers of buildings and infrastructure that are used and maintained directly above the cave for a longer period of time, the greater the potential will be for a catastrophe event to occur. The cave will remain somewhat at risk from possible catastrophe events and also from possible long-term chronic problems as long as much of the infrastructure remains over the cave. With the present infrastructure over the cave dating from the 1920's and 30's, we have had 70 to 80 years of relatively good luck. Hopefully, this will continue while much of the infrastructure remains.

Lechuguilla Cave

Access to Lechuguilla Cave is through an approved research permit process that includes the physical exploration, survey, and inventory of the passages and rooms; applied and direct research; and for needed management related trips, such as replacing aging ropes in the cave. There are no recreational opportunities for entering the cave. Management at Lechuguilla Cave has evolved over the years since the breakthrough discovery that led to the main portion of the cave in 1986. In the last couple of years, the Cave Resources Office has taken a much more active role in directing exploration, survey, and inventory of the passages and rooms and in the development of maps for all areas of the cave. Experienced caver volunteers are the backbone of the program and are involved with fixing past survey problems as well as the exploration and survey of new passages. Survey and inventory teams work closely with cartographers to thoroughly check and document all areas in the cave. Survey errors have been significantly reduced and a high quality of documentation is obtained from all survey teams entering the cave. Additionally, an active educational program for those working in the cave has significantly reduced unwarranted impacts.

The present program for Lechuguilla Cave works well by balancing park needs and goals with the recognition and preservation of the fragile and pristine nature of the cave. The challenge now and into the future is how to allow limited access to the cave for the above-mentioned reasons or others that management in the future may deem important while still preserving its pristine nature. As in the other aspects of the cave management program, the present program means that some areas will be impacted more than others by human visitation.

Lechuguilla Cave belongs to the world and it has been and will continue to be a challenge to include foreign cavers and scientists in the limited numbers of people who are allowed to work in the cave. Scientists and cavers from many countries have been able to work in the cave and it is hoped that this can continue.

Summary

Carlsbad Caverns National Park contains spectacular, world-class caves and associated features. There are numerous challenges that face the park in meeting its goals and mandate of conserving resources while allowing access. The present cave management program provides a broad range of experiences and opportunities for visitors, employees (including volunteers), and scientists and still allows some caves and cave areas to exist without much human contact or manipulation. By learning from the past and looking to the future, decisions and actions made today can and will influence how well caves and cave areas of the park survive for future generations.

About the Author

Dale L. Pate began his caving career in 1970 as a student at Southwest Texas State University and became the Cave Specialist for Carlsbad Caverns National Park beginning in July 1991. He has continued in that position through the present. Duties for the position include direct involvement with park management concerning Carlsbad Cavern and supervision of all entry into Lechuguilla Cave. The direction of his paper is a summation of the cave management program that has evolved at the park.

Biology

Gray Bat Trends in Missouri: Gated vs. Ungated Caves

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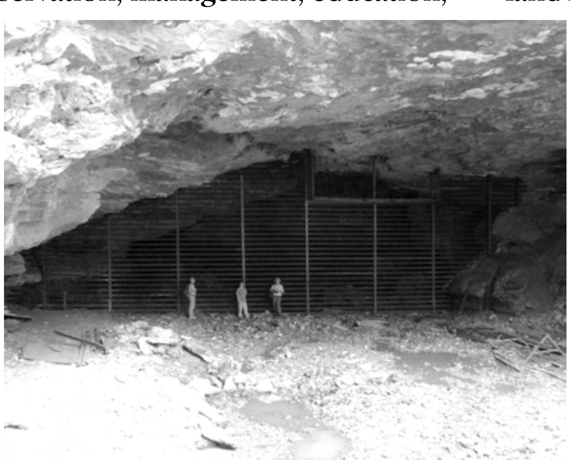
Abstract

I have reviewed over 25 years of census data on gray bats, Myotis grisescens, from Missouri's Natural Heritage Database and Cave Life Database. The data were taken in numerous caves, both gated and ungated. Examination of the census data and information on cave structure, type of management, type of gate, and other factors shows that cave gates are not always needed to protect this species. However, a proper cave gate often is needed if there is no vigilant owner or manager living nearby and the cave is vulnerable to unauthorized intruders. Vulnerability arises from different factors, but public ownership is an important one. I shall present several case histories and graphs to illustrate typical and extreme situations for maternity colonies. A summary graph will also be presented. Despite my findings, we utilize the latest cave gating techniques to protect important, vulnerable gray bat caves. That is why Missouri now has the first and second largest cave gates at Rocheport (Boone) Cave and Great Spirit Cave, respectively. A Missouri Cave Gate Working Group is being established to bring together cave owners, state and federal agencies, cavers and conservationists who can work together on cave protection issues and funding.

About the Author

Dr William R. (Bill) Elliott has been the cave biologist for the Missouri Department of Conservation since 1998. His duties include research, conservation, management, education, and recreation in 220 caves owned by the Department and cooperative work with cavers and cave owners of all types. His published studies have included cave biogeography, invertebrates, fishes, salamanders, bats, karst land management, and bad-air caves. He devel-



The world's largest cave gate, Rocheport (Boone) Cave, Boone County, Missouri, weighs 24 tons. It was built in 2002 by Roy Powers and Kristen Bobo with support from the U.S. Army Corps of Engineers and the Missouri Department of Conservation for the protection of endangered gray bats and Indiana bats. At least 50,000 gray bats used the gate in 2003. (photo by William R. Elliott).

oped the Cave Life Database in Missouri, which is adaptable to other states. His photographs of cave life appear in his international web site, **Biospeleology**, at http:www.utexas.edu/depts/tnhc/.www/biospeleology

In his spare time he flies sport airplanes, photographs, describes new species of millipedes, travels, hikes, and canoes.

Quantitative Real-Time PCR Assays of Bacterial DNA in Sediments of the Flint-Mammoth Cave System with Evidence for Nitrospira Spp. At Sites Undergoing Limestone Dissolution and Karst Aquifer Evolution

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Abstract

Quantitative Real-Time PCR (qRT-PCR) is used to compare the densities of eubacterial 16S rDNA in sediments from the Flint-Mammoth Cave System while DNA sequence information and restriction fragment biomarkers demonstrate the presence of *Nitrospira spp*. in bacterial communities. Thirteen samples were collected from sites with a range of hydrologic conditions and compared with respect to nanograms of DNA per gram of sediment by amplification of environmental DNA relative to *E. coli* genomic DNA with universal primers for eubacterial 16S rDNA. Saturated clastic stream sediments where the process of limestone dissolution and cavern enlargement processes were active displayed high DNA levels with the associated presence of a eubacterial clone closely related to *Nitrospira spp*. Two sediment samples from an inactive and dry cave environment were assayed and shown to contain 45 ppm nitrate, but were negative for detectible bacterial DNA. It is concluded that *Nitrospira spp*. are associated with bacterial communities in actively evolving karst aquifers and may contribute to cavern enlargement by consumption of carbonate minerals as chemolithoautotrophs in the absence of other carbon sources in the cave environment. Also, nitrates in dry sediment do not appear to be attributable to active bacterial nitrification.

1. Introduction

Nitrifying bacteria are capable of colonizing biofilms in karst environments including limestone surfaces, terrestrial and subterranean streams and their sediments, sinkholes, bedrock walls, ceilings, and floors of caverns, in addition to being found within the limestone matrix itself (5, 7, 20, 22). *Nitrobacter* found in cave biofilms are more abundant (10^5 cells/gram of sediment) and of a different species (*N. agilis*) than those found in the surface soil and rhizosphere (*N. winogradsky*, 10^3 cells/gram of soil) as shown by classical microbiological techniques of culturing and morphological identification of species (7, 17). An extensive study in Catherines and Olivias Domes in Mammoth Cave and another at Charons Cascade were successful in culturing and identifying a diversity of bacterial species, but many could not be identified (24, 26).

Modern DNA analysis techniques have revealed the existence of previously unknown bacterial species in the environment that cannot be grown under laboratory conditions in pure culture, and revolutionized our understanding of biogeochemical community diversity. It is now known that environmental bacteria are two orders of magnitude more diverse than previously revealed by culturing

techniques, and that bacteria thrive under conditions previously thought to be unfit for life. Many have evolved specialized genetic systems and strategies for survival (1, 10, 12, 18, 19, 22, 28).

Among the bacterial species now identified are chemolithoautotrophs such as *Nitrospira spp.* and relatives capable of deriving energy by the oxidation of nitrite ions (NO_2^-) to NO_3^- using only the inorganic carbon found in carbonate minerals (CO_3^{2-}) as a food source. Nitrifying bacterial communities consisting of structured biofilms with *Nitrosomonas, Nitrobacter, Nitrosospina,* and *Nitrospira spp* are responsible for the operation of municipal wastewater treatment plants and detoxifying bioreactors (3, 7, 10, 11, 15, 27).

Such bacteria are particularly interesting in the context of speleology as important ecological modulators, but also they may contribute to NO_3^- production and distribution by deriving energy from nitrification while consuming carbon in the form of inorganic CO_3^{2-} in lieu of organic carbon sources, thus contributing to karst aquifer evolution, cave formation, and cavern enlargement, and sinkhole collapse. The same processes may be accomplished by nitrifying bacteria flushed into the cave from the surface with the genetic potential to switch their genetic machinery and adapt as troglophilic species utilizing CO_3^{2-} as a food source and deriving energy by the oxidation of NO_2^- in the absence of consumption of NO_3^- by plants, thus leading to the accumulation of nitrates in sediments where hydrological conditions have altered over time so that no flow or other movement of water displaces nitrate while evaporation concentrates it in place.

Cave sediments have been an important source of potassium nitrate, or saltpeter, since the Middle Ages via the process of leaching soluble nitrate minerals from sediment and conversion to the potassium salt by filtration through wood ash. The potassium nitrate (KNO_3) thus produced is recovered for use after evaporation of the water used for the leaching process, and serves as the primary ingredient of gunpowder when combined with sulfur and charcoal. During the eighteenth and nineteenth centuries throughout the eastern parts of North America, significant industrial operations were installed in the more accessible entrance passages within limestone caves where mining, leaching, and pumping processes could be accomplished using nearby sources of water and manual labor. Mammoth Cave in Kentucky was extensively mined for dry sediments during the war of 1812 and the saltpeter produced there eventually contributed to the success of the E. I. DuPont deNemoirs and Company (DuPont) as the principal producer of gunpowder for the United States (6, 16, 17, 23, 25).

Nitrate minerals are minor constituents (less than 1% by weight) of some sulfate speleothems, but the high solubility of all nitrate salts limits their persistence in speleothems to extremely dry cave passages where they cannot be transported by drainage, dripping, or movement of water. Nitrates are found primarily in dry, porous, aerated floor sediments with low carbon content, relatively little phosphorus (0.1 to 1.4% by weight), and low total nitrogen (0.08 to 0.13% by weight). Distribution of nitrates in floor sediments is topographically evenly distributed and is concentrated within the upper one meter of depth, and sediments depleted of nitrates can be regenerated within several years. Cave sediments protected from surface drainage have concentrated nitrates in the range of thousands of parts per million (ppm) due to evaporation of moisture from the sediment into the cave atmosphere, while surface and sinkhole limestones subject to rainfall and subsurface drainage are depleted of nitrates to a concentration of 1 or 2 ppm as solution processes leach the salts into the subsurface. Intermediate levels of 10 to 100 ppm nitrates are found where surface drainage exchanges with the subsurface and nitrate concentration increases dramatically at the boundary of the subsurface-cave atmosphere independently of limestone type or stratigraphy (16).

Early observations recognized that nitrates are produced by electrochemical oxidation of atmospheric nitrogen gases by lightning discharges. More importantly, atmospheric nitrogen cycling by rhizospheric and other topsoil bacteria is a major global biogeochemical process widely recognized as a dominant production mechanism of nitrates that are primarily utilized by plants, particularly in regions with lush vegetation. Some of these nitrates not utilized by plants can percolate through porous karst vadose zones and be rapidly discharged and distributed in cave sediments consistently with the observed spatial distribution and concentration of nitrates in cave sediments. Evaporation of water in the cave atmosphere leaves behind pockets of solutes including nitrates throughout the cave system in varying concentrations, further distributed by hydrological drainages containing soluble nitrates. Theories about the origin of nitrates in cave sediments include decomposition of nitrogenous organic compounds in bat guano, deposition of nitrates by evaporation of leachates from surface

sources, or in situ oxidation of ammonium ion (NH_4^+) to nitrate ion (NO_3^-) by nitrifying bacteria such as *Nitrobacter* and *Nitrosomonas spp*. (7, 17, 23).

Typical saltpeter caves in the southeastern United States have temperatures between 10 and 18°C and humidities between 90 and 99%. Geochemical analysis has shown that nitrate minerals can be found at various concentrations throughout networks of cave passages and they are not limited to the entrance zones where historical mining operations were installed. Nitrate minerals are minor constituents (less than 1% by weight) of some sulfate speleothems, but the high solubility of all nitrate salts limits their persistence in speleothems to extremely dry cave passages where they cannot be transported by drainage, dripping, or movement of water (7, 17, 23).

Nitrates are found primarily in dry, porous, aerated floor sediments with low carbon content, relatively little phosphorus (0.1 to 1.4% by weight), and low total nitrogen (0.08 to 0.13% by weight). Distribution of nitrates in floor sediments is topographically evenly distributed and is concentrated within the upper one meter of depth, and sediments depleted of nitrates can be regenerated within several years. Cave sediments protected from surface drainage have concentrated nitrates in the range of thousands of parts per million (ppm) due to evaporation of moisture from the sediment into the cave atmosphere, while surface and sinkhole limestones subject to rainfall and subsurface drainage are depleted of nitrates. Historical saltpeter mining operations were usually associated with bat hibernacula thus giving rise to the theory that nitrates result from decomposition of guano. This theory is inconsistent with volumes of more recent evidence showing chemical composition, distribution, and regeneration rate of nitrates in cave sediments where bats did not deposit guano or where bats had abandoned hibernacula (16, 17, 23).

Samples of saturated clastic sediments and moist deposits from 13 sites in the Flint-Mammoth Cave System are shown in this study to contain eubacterial 16S rDNA genes in cave sediment DNA relative to the 16S rDNA gene of *E. coli* genomic DNA at levels from zero to over 5000 nanograms of 16S rDNA genes in environmental bacterial genomic DNA per gram of sediment using a quantitative Real-Time Polymerase Chain Reaction technique (qRT-PCR). This quantitative data is a useful indicator of bacterial density in the sediments. Furthermore, *Nitrospira spp*. are identified in some bacterial communities using a combination of DNA fragment analysis and correlation with a Mammoth Cave bacterial 16S rDNA clone database. The particular *Nitrospira sp.* associated with Mammoth Cave is represented by clone CCU23. The entire nucleotide sequence of CCU23 eubacterial 16S rDNA has been determined and posted on GenBank (accession AY221079) allowing phylogenetic classification with restriction enzyme mapping by computer analyses. Fluorescent DNA fragment standards for BssHII and HhaI cleavage fragments have been measured experimentally for CCU23 and other clones in the database. The combination of fragment and DNA sequence data provides a confident genetic biomarker for CCU23 also shared by other members of the genus *Nitrospira* as determined by alignment of CCU23 with multiple closely related *Nitrospira spp*. 16S rDNA sequences downloaded from GenBank (http://ncbi.nlm.nih.gov) and the Ribosomal Database Project (RDP; http://rdp.cme.msu.edu) genetic databases.

In contrast to the saturated clastic sediments from hydrologically active sites, a comparison is made with Turner Avenue on Level 4 in the Flint-Mammoth Cave System where it has been evidently inactive with respect to limestone dissolution and hydrological evolution for millions of years (25). Duplicate samples of very fine, dry protected sediments were collected from the upper 5 cm in a virgin deposit of silt under a rock overhang recessed approximately 1 m and 0.5 m in height at Albright Junction. These dry sediments show no evidence for the presence of bacteria using quantitative DNA analysis, however low levels of NO_3^- (45 ppm) were detected using ion chromatography. Thus the nitrates at Albright Junction do not appear to be attributable to *in situ* production by chemolithoautotrophic *Nitrospira* bacteria like those found in sediment samples collected from saturated clastic sediments in hydrologicaly active cave passages where limestone dissolution is contributing to karst aquifer evolution and cavern enlargement.

2. Materials and Methods

2.1 Site description and sample collection methods

Samples were collected using aseptic technique wearing latex gloves. Sterile centrifuge tubes were opened at the time of collection and used to scoop sediment. The closed tubes were enclosed within the inverted latex gloves used for collection by tying the wrists in a knot and sealing in a Ziploc plastic bag. Samples were kept on ice upon exiting the cave and until DNA was extracted from the sediment within 24 hrs.

For quantitative data on a variety of sites throughout the Flint-Mammoth system, qRT-PCR was performed on an archived set of DNA samples (Figure 2) collected and extracted in association with expeditions in June 2002 and October 2002 including saturated clastic sediments in the Flint-Mammoth System from Unknown Cave in Pohl Avenue at Three Spoons Inn (POHL3SP) and saturated limestone paste collected from the ceiling in Turner Avenue near Brucker Breakdown (TURNPST); sediments in Colossal Cave at Grand Avenue (COLGRND), at Dyer's Dome (COLDYER), Colossal River and along the Colossal-Salts link passage (COLSALT); Salts Cave dry wall deposits in the main chamber containing mirabilite crystals (SALTMIN); along with four samples of sediment from Charons Cascade (MCCC1, MCCC2, MCCC3, and MCCC4) and two from Cathedral Domes (CATHDM2, CATHDM3) collected in historic Mammoth Cave. Albright Junction samples (ALBRJCT1, ALBRJCT2) were collected in June 2003 from protected, dry, extremely fine-grained virgin sediments under a rock ledge approximately 10 m into a side passage leading north from Albright Junction. Samples other than ALBRJCT1, ALBRJCT2, TURNPST, and SALTMIN were in the upper 5 centimeters of saturated clastic sediments where persistent flowing water or standing pools were predominant (an individual *Oronectes sp.* crayfish was observed in a 10-centimeter-deep pool at the time POHL3SP was collected, and smaller invertebrates such as isopods and arthropods were observed at many sites).

2.2 Extraction and quantification of nitrates from ALBRJCT sediments

Water-soluble nitrate salts were leached by addition of 10 milliliters sterile deionized water (Barnstead Nanopure) to 10 gam sediment in a sterile 50 milliliters polypropylene centrifuge tube. Samples were placed horizontally and agitated in a rotary shaker at 250 rpm at a constant temperature of 25C for 18 hours. Sediment particles were removed from the extract by centrifugation at 7000 x g at 4 for 30 minutes. in an IEC PR-7000M centrifuge with a number 766 swinging bucket rotor. Aqueous supernatants were removed with a sterile serological pipette, transferred to new sterile 50-milliliter centrifuge tubes, and centrifuged again. The second supernatant was decanted and stored in a sterile 15-milliliter centrifuge tube. The leachate contained the soluble nitrates from 1 g sediment per ml of H_2O. Both leachate samples were submitted to the Materials Characterization Center at Western Kentucky University for detection and quantification of nitrate using ion chromatography. The official results returned for the duplicate samples were 47.79 ppm and 42.64 ppm for an average of 45.22 ppm.

2.3 Extraction of DNA from sediment samples

All procedures with DNA were carried out using aseptic technique with sterile reagents and materials. Saturated clastic sediment samples were filtered to remove water before weighing by centrifugation in a CoStar centrifugal microfiltration device (number?) through a 0.2 m membrane for retention of bacteria. DNA was extracted directly from sediments using the Ultraclean Soil DNA Kit (MO Bio Laboratories, Solana Beach, CA) by adding a known mass of 0.5–1.0 grams of sediment to the kit using aseptic technique and following the manufacturer's instructions. The sediment DNA was recovered in a volume of 50 uL and was visualized by loading 5 L (10% of total yield) on a 1.5% agarose gel (10 cm, Tris-Acetate-EDTA buffer) run at 6 V/cm stained with 1 mg/ml ethidium bromide for 16 hrs at 4°C, rinsed with deionized H_2O, and photoanalyzed using a Kodak EDAS 290 gel documentation system. Yields and molecular weights of environmental DNA samples were estimated by comparison to a

known amount of size standard (1 kb ladder, New England Biolabs, Beverly, MA).

2.4 Quantitative Real-Time PCR (qRT-PCR)

Reaction mixtures with a final volume of 50 L consisted of 25 L SYBR Green Supermix (Bio-Rad Laboratories, Hercules, CA), 5 L of 5M eubacterial universal primer 27f (5'-AGAGTTTGATCMtggctcag-3'), 5 L of 5M eubacterial universal primer 1492r (5'-TACGGYTACCTTGTTACGACTT-3'), and sediment DNA extract plus sterile nanopure water containing up to 100 ng template (estimated by agarose gel photoanalysis) in 15 L template volume. Pprimers were custom synthesized by Sigma-Genosys Biotechnologies, The Woodlands, TX. Thermocycling and optical monitoring during qRT-PCR were performed on an iCycler Real-Time PCR machine (Bio-Rad Laboratories) with fluorescent monitoring at 490 nm during the extension step of a thermocycling program consisting of an initial denaturation at 95°C; 50 cycles of 1 min. at 95°C (denaturation), 1 minute at 55°C (annealing), and 1 minute at 72°C (extension, monitor SYBR Green fluorescence at 490 nm); followed by a final extension step of 72°C for 10 minutes.

Graphs showing SYBR Green fluorescence as a function of cycle number are shown in Figures 2A, 3A, and 3B, and quantitative assays with *E. coli* genomic DNA as a standard are shown in Figures 2B and 3C. The technique of qRT-PCR allows direct observation of the PCR amplification process, and the logarithmic accumulation of double stranded PCR products (amplicons) can be monitored using a variety of fluorescent techniques. In these experiments the increase in the fluorescent signal of SYBR Green, an intercalating dye specific for double stranded DNA, is monitored as increasing numbers of copies of double stranded eubacterial 16S rDNA (amplicons) are produced during PCR. Furthermore, there is a linear mathematical relationship between the logarithm of the amount of target DNA (template) in the reaction and the number of thermal cycles required to reach a calculated threshold level of fluorescence, called the threshold cycle (C_t). This relationship can be used to determine the concentration of DNA in the original sample with a high degree of accuracy and specificity over more than five orders of magnitude (refs). In these experiments DNA extracted from cave sediments and *E. coli* genomic DNA were amplified with 27f and 1492r universal primers. The standard curve of *E. coli* DNA displays a linear relationship extending beyond the range of 0.01 ng to 100 ng of genomic DNA as shown in Fig. 2B and Figure 3C. Quantitative results are summarized and normalized to represent ng DNA per gram of sediment in Figure 4.

2.5 DNA sequencing

Sequencing reactions contained approximately 100 ng cloned plasmid DNA with 4 uL Big Dye Terminator mix (Applied Biosystems) and 1.6 picomoles of sequencing primer per 10 uL final reaction volume. Thermocycling conditions were as recommended by the manufacturer with reaction cleanup by isopropanol precipitation. Fluorescent capillary electrophoresis was carried out on an Applied Biosystems Prism 310 Genetic Analyzer. Sequencing primers were T7 and SP6 located outside the cloned 16S rDNA in the plasmid vector sequences, 27f and 1492r universal bacterial primers (21) at the termini of the cloned sequences, and 530f and 1100r universal bacterial primers to provide overlapping complementary fragments internally in the cloned sequences (21).

2.6 Sequence alignments and genetic analysis

DNA sequences from eubacterial 16S rDNA genes cloned from DNA extracted from Charon's Cascade were assembled from raw data, stored, and manipulated within a database created using the Vector NTI Suite 8.0 (Informax). Vector NTI sequence database management and analysis tools included ContigExpress for editing raw data, AlignX for ClustalW alignments and similarity relationship trees, and BLAST searches against the GenBank nucleotide sequence database (http://ncbi.nlm.nih.gov). Sequences were also analyzed with software available from the Ribosomal Database Project (http://rdp.cme.msu.edu) for identification and alignment using the SEQ_MATCH and SEQ_ALIGN online software tools, and Check_Chimera to eliminate cloning artifacts from the database.

2.7 Fluorescent DNA fragment analysis

A fluorescent-labeled 27f primer (6FAM-27f) was used to detect DNA fragments cleaved at a specific DNA sequence by restriction enzymes HhaI or BssHII. The lengths of these fragments can be measured accurately and are a function of the DNA sequence, determined by the number of nucleotides from the fluorescent terminus to the restriction enzyme recognition and cleavage sequence. Specific restriction fragment lengths are measured with internal standards by fluorescent detection and are correlated with cloned cave bacterial DNA sequences in a Mammoth Cave bacterial 16S rDNA database (WKU ref). For analyses specifically intended for fragment analysis, only 30 cycles of PCR were used to ensure product purity.

Samples were processed after the qRT-PCR reaction by transferring the contents of the qRT-PCR reaction to a sterile 1.5-milliliter microcentrifuge tube. Excess primers, nucleotides, and buffers were removed with the Ultraclean PCR Cleanup Kit (MO Bio Laboratories) following the manufactuer's instructions. From the total yield of 50 L from the PCR cleanup kit, 25 L was cleaved with HhaI at 37C and the other 25 L was cleaved with BssHII at 50°C. Each restriction digest was carried out in a total volume of 50 L with 20 units enzyme for 6 hours. in the manufacturer's recommended buffer (New England Biolabs, Bedford, MA). After digestion was complete, samples were ethanol precipitated by the addition of 5 L 3M NaOAc (0.1 volume) and 165 L ethanol (three volumes). Samples were chilled at -20°C and centrifuged at 13,000 x g for 15 minutes at 4C to precipitate the DNA. After decanting the supernatant, pellets were rinsed by the addi-

tion of 500 L cold 70% ethanol followed by centrifugation, decantation of the supernatant, then dried *in vacuo*. Dry DNA samples were dissolved in 25 L deionized formamide (Amresco) containing 1% (0.25 L) of the internal standard fluorescent marker ROX500 fragments (Applied Biosystems). Samples were denatured at 95C for 4 minutes and quick chilled to 4C in a themocycler (MJ Research, Cambridge, MA) in the sample rack of an ABI Prism 310 Genetic Analyzer. Fragment electrophoresis detection, and length measurement were performed an ABI 310 running GeneScan software (Applied Biosystems). Raw fragment peak data, diluted with formamide containing ROX500 if necessary not to overload the capillary and detector, was refined for presentation as histograms using the Genotyper DNA profiling software package (Applied Biosystems).

3. Results and discussion

3.1 Quantification of eubacterial 16S rDNA in sediments

Quantification of DNA by qRT-PCR is shown in Figures 2 and 3. The qRT-PCR data derives from the measurement of an increase in fluorescence of the intercalating dye SYBR Green, which is specific for double stranded DNA and produces a strong fluorescent signal proportional to DNA concentration. The increase in DNA concentration results from the specific amplification 16 rDNA extracted from eubacterial communities in the cave sediments. Fluorescence is plotted on the Y axis as a function of the number of thermal cycles, plotted on the X axis, in which the reactions are heated from 55C to 72C to 95C repeatedly to geometrically amplify the number of copies of a specific gene determined by the DNA sequence of the primers used in the reaction As the number of qRT-PCR cycles increases, fluorescence of SYBR Green increases in the reaction mixture as more copies of double-stranded copies of cave eubacterial 16S rDNA are generated.

The greater amounts of target DNA added to qRT-PCR reactions, fewer cycles are required to amplify the target DNA geometrically above a specified threshold. Therefore, the number of cycles required to reach the threshold, termed the threshold cycle or C_t, is inversely proportional to the amount of DNA added to the reaction. Figures 2B and 3C illustrate the linear relationship that exists between the log of the starting quantity (SQ) of target DNA (X axis) and the C_t (Y axis). The starting quantity was normalized to represent the amount of DNA in nanograns per gram of sediment as follows:

Highest normalized concentrations of eubacterial DNA (Figure 4) were measured at Charons Cascade in the historic section of Mammoth Cave. The site receives much input from upstream tributaries and empties into River Styx, and it is subject to periodic backflooding from the Green River that results in a rich sandy deposit punctuated by a waterfall approximately 10 meters in height creating a permanent pool at its base (12, 13, 14, 30, 31). Four samples collected at Charons Cascade at the base of the waterfall and around the pool (MCCC1, MCCC2, MCCC3, MCCC4) had 3480.00, 5506.67, 14.93, and 762.67 ng DNA per gram of sediment, respectively. High DNA levels were measured in POHL3SP, COLSALT and COLGRND sediments where persistent active drainages were occasionally dammed into pools, with 610.67, 409.33, and 14.93 ng DNA per gram of sediment respectively. Pools at the bottoms of vertical shafts and high drainage areas but little accumulated clastic sediment such as CATHDM2, CATHDM3, and COLDYER, had concentrations of bacterial DNA in the sediments ranging from 0.05, 0.06, to 69.87 ng DNA per gram of sediment, respectively. TURNPST contained 0.87 ng DNA per gram and consisted of paste on a ceiling found where capillary seepage into the ceiling is sufficient to dissolve limestone and leave behind mineral solutes after water has evaporated in the cave air producing a moist, gray punk rock material. SALTMIN contained 0.21 ng DNA per gram of sediment and consisted of fine, dry particles with visible crystals of mirabilite. No evidence for DNA was seen in either ALBRJCT1 or ALBJCT2, despite attempts to increase detection by increasing the amount of DNA added to the qRT-PCR reaction and magnifying the fluorescent signal. In the same experiment, CATHDM3 and CATHDM2, both known to give positive results but with very low levels of DNA, were used as positive controls and a qRT-PCR reaction without any added DNA was used as a negative control (Figure 3).

3.2 DNA sequence data

Environmental DNA from a samples collected in October, 2000 at Charons Cascade were used to create a clone library with a random sampling of individual copies of cave bacterial 16S rDNA spliced into a plasmid cloning vector. The recombinant DNA molecules thus produced were used to transform *E. coli* cells, and those *E coli* cells are frozen for storage and revived to prepare plasmids carrying individual molecular copies of cave 16S rDNA for detailed sequence analysis. A view of the identities and relationships among the bacte-

rial community has been developed by matching and aligning approximately 1,500 bp of cloned cave 16S rDNA genes to produce a molecular similarity tree with 62 representative individuals from the cave community (11). Among the clones of particular interest was CCU23 that carried a cave eubacterial 16S rDNA sequence closely related to the same gene among members of the genus *Nitrospira*.

Clone CCU23 (Charons Cascade, Upstream, clone 23) was identified using the BLAST search engine available on the GenBank website () and the SEARCH and MATCH tools on the Ribosomal Database project website () as a close relative to the nitrifying genus *Nitrospira*, a characteristic of which is autotrophic growth by utilizing inorganic carbonate or bicarbonate as a food source with chemical energy for growth supplied by the oxidation of nitrite to nitrate. An alignment of the first 100 nucleotides of the CCU23 and related sequences is shown in Figure 5A, and similarity between CCU23 and its closest genetic matches over the full length 16S rDNA gene sequence (~1500 bp) are illustrated in Figure5B.

A distinguishing feature of the sequences is shown in Figure 5A and is utilized in this study to survey for CCU23 and other *Nitrospira spp*. by the use of two restriction enzymes which cut DNA at specific nucleotide sequences (10; Section 3.3). The enzyme HhaI cleaves DNA at the four-nucleotide sequence 5'-GCGC-3' while the enzyme BssHII cleaves DNA at the six-nucleotide sequence 5'-GCGCGC-3' which is statistically less frequent and is further underrepresented in bacterial DNA, making the BssHII fragment of 34 nucleotides in length a very specific feature of CCU23 and other *Nitrospira spp.* 16S rDNA sequences. Hha I cleavage sites occur much more frequently and virtually every eubacterial 16S rDNA sequence is cleaved at some position within 1500 nucleotides from the fluorescent terminus, therefore a profile generated by HhaI cleavage displays many fragments representing the broad bacterial community. Note also, the HhaI cleaves twice within the outlined six nucleotide BssHII sequence and cleavage there results in a pair of DNA fragments differing in length by two nucleotides. The lengths of these fragments can be measured with accuracy and great sensitivity. This combination makes them useful as biomarkers for CCU23 and *Nitrospira spp.* in environmental DNA samples (10, 11).

3.3 Fragment analysis data

DNA samples from clastic sediments at sites where limestone dissolution is an ongoing process were subjected to PCR with 6FAM-27f forward primer and 1492r reverse primer to create amplicons of eubacterial cave 16S rDNA labeled at the 5' end with the 6FAM fluorescent reporter. After cleavage with restriction enzymes, fragments were separated by length. Cleavage with BssHII produced the unique 34 bp fragment diagnostic for *Nitrospira* while HhaI produced a mixture of fragments including a pair of 36 and 38 bp in length as shown in Figure 6. The fluorescent fragment cleaved at the site most proximal to the 6FAM reporter is measured for each cleaved amplicon.

The specific fragments characteristic of CCU23 are evident in the fragment profiles shown in Figure 6, constituting strong evidence that *Nitrospira spp.* are present at these sites. The HhaI digests of the same samples show the HhaI biomarker fragment pair associated with the outlined sequences, and also display community diversity by revealing many other fragments generated by cleavage of 16S rDNA amplicons from other eubacteria.

3.4 Determination of NO_3^- in Albright Junction samples

Nitrate concentrations were determined for extracts of sediments collected at Albright Junction by ion chromatography. The average between two duplicate sediment samples was 45.22 ppm. The site of collection in Turner Avenue at Albright Junction was an undisturbed site beneath a rock overhang, although the sediments may have been subject to deposition of nitrates by evaporation or bacterial nitrification in the past. Our data and site observations suggest no current mechanism for regeneration of nitrates *in situ*.

4. Conclusions

The data show that greater numbers of bacteria are present in communities where processes of limestone dissolution and cavern enlargement are ongoing (2, 4, 8, 9, 12, 13, 14, 29, 30, 31, 32), and that restriction fragment biomarkers diagnostic for *Nitrospira spp.* are present in active communities of the Flint-Mammoth Cave System. Also, two sediments from an inactive and relatively dry cave passage in Turner Avenue (ALBRJCT1, ALBRJCT2) did not show evidence of any bacterial DNA but were shown to contain 45 ppm nitrate. Thus, nitrate in this particular sediment does not appear to be attributable to active bacterial nitrification.

Quantitative DNA measurements using Real-Time PCR amplification of 16S rDNA were made in reference to *E. coli* genomic DNA as a standard and stated as nanograms of DNA per

gram of sediment (dry weight). It is known that the *E. coli* genome (all chromosomal DNA in one cell) consists of 5.2 x 10^6 base pairs (bp) in length with seven 16S rDNA copies per genome. Other groups and individual genomic sequences are being added to a growing database showing a wide range of 16S rDNA copy numbers per genome across many taxa, ranging from one to 15 with an average of four copies per genome among the eubacteria (rrndb database ref). One copy of 16S rDNA is approximately 1,500 bp, thus it is possible to estimate the number of genomes or cell number (assuming genome size the same as *E. coli*) and four 16S rDNA copies per genome on average.

About the Author

Rick Fowler was trained in chemistry and biology before attending graduate school at the University of Tennessee. He received a Master's Degree in Biomedical Science while employed as a research associate in the Biology Division of Oak Ridge National Laboratory, and later pursued doctoral studies in environmental toxicology while working as a research associate at the Center for Environmental Biotechnology. Currently he is Laboratory Coordinator in the Biotechnology Center at Western Kentucky University and is assembling a multidisciplinary team to arrive at applied solutions for cave and karst management and environmental monitoring using the tools of biotechnology. He has 13 publications covering a variety of topics in biotechnology, and he has managed core labs in industry, academia, medical schools, and hospitals. He is a member of the National Speleological Society and the Cave Research Foundation.

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Mercury and Methylmercury in the South Central Kentucky Karst: its Transportation, Accumulation, and Potential Effects on Vulnerable Biota

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Abstract

Toxicity and bioaccumulation studies of mercury (Hg), the most toxic nonessential heavy metal, on karst ecosystems are virtually nonexistent. Available data suggest organisms at higher trophic levels generally biomagnify Hg at a similar rate and, once it is stored in their tissue, excrete it very slowly. Further, biota with a slow metabolism and long life span likely bioaccumulate high levels of Hg. The data presented here are studies of other nonessential heavy metals taken from extensive literature searches. Bats are vulnerable to Hg bioaccumulation because they are mobile and generally consume 40-100% of their body mass in prey each night. Bats that feed heavily on emerging aquatic insects (e.g., Trichoptera), which spend their larval stages in contaminated sediments, are particularly susceptible to biomagnification of Hg. Bats exposed to cadmium have been found with damage to their heart, kidneys, and lungs. Another study indicated cadmium concentration was higher in a troglobitic (i.e., obligate cave-dwelling) crayfish (i.e., *Orconectes australis australis*) than in a troglophilic (i.e., facultative cave-dwelling) crayfish (i.e., *Cambarus tenebrosus*). The authors also attributed significantly higher (p.05) concentration of nonessential metals in almost all *O. a. australis* tissues, relative to *C. tenebrosus*, to its increased longevity. A vigorous research program on the toxicity and bioaccumulation of Hg would enable wildlife managers to better predict the effects of future increases in Hg deposition on vulnerable biota.

Introduction

Atmospheric deposition of mercury from power plant emissions, a major input of mercury into the environment, is coming under close scrutiny by concerned agencies. With increasing demands for power applications for many new power plants, including over twenty new applications in the Commonwealth of Kentucky, are currently being considered around the country. An understanding of the current levels of mercury is critical, particularly in a karst aquifer system (such as in South-central Kentucky) where transport of contaminants can be rapid.

The proposed Thoroughbred Generating Station is a potentially large source of mercury (Hg) deposition on South Central Kentucky Karst ecosystems. Indeed, according to Peabody's own estimates absence of baseline knowledge of environmental concentrations of Hg's most toxic molecular form (that is, methylmercury) in South Central Kentucky Karst ecosystems, the author recommends a vigorous research program be initiated.will be the fourth largest Hg emitter in the state of Kentucky (Table 1). Because prevailing winds tend to blow northeast, Thoroughbred Generating Station would likely have the *second* largest impact in the state, in terms of Hg deposition, on South Central Kentucky Karst ecosystems. Currently little data are available that would enable researchers to predict the effects of such a large increase in Hg deposition on South Central Kentucky Karst ecosystems.

While research into the toxic effects of Hg bioaccumulation on organisms has increased recently, largely on commercial species, the toxic effects on ecosystems are not well understood. Further, knowledge of the toxic effects of Hg and bioaccumulation on susceptible South Central Kentucky Karst ecosystems ranges from poor (surface ecosystems) to nonexistent (subsurface ecosystems). Due to the threat of increased Hg deposition and the absence of baseline knowledge of environmental concentrations of Hg's most toxic molecular form, methylmercury, in South Central Kentucky Karst ecosystems, the author recommends a vigorous research program be initiated.

Plant Name	City	**Utility Owner**	**Estimated Hg Emissions (Pounds)**
Paradise Fossil Plant	Muhlenberg	Tennesee Valley Authority	519
Big Sandy	Lawrence	Kentucky Power Co	485
Ghent	Carroll	Kentucky Utilities Co	480
Thoroughbred Generating Station	Muhlenberg	Peabody Energy	420

Table 1. *Rank estimated output of four top mercury emitting facilities in Kentucky. Note Paradise and Thoroughbred are in close proximity. Data for top three emitters were compiled from Environmental Protections Agency and Department of Energy data by the Environmental Working Group (Coequyt* et al. *1999). Estimated emissions by Thoroughbred Generating Station are from Thoroughbred PSD/Title V/Phase II Application, 10/25/2001.*

Transportation of Mercury and Methylmercury to Ecosystems

The abundance and distribution of pollutants in the environment, their bioavailability, and their toxicity to aquatic and terrestrial organisms are best understood in terms of molecular form (Witters 1998). Methylation is the important step that influences the ecological fate and effects of Hg. This is because all forms of Hg (for example, Hg(II), Hg^0, $(CH_3)_2Hg$) can be converted to methylmercury (MeHg) by natural processes in the environment [(Figure 1) (Keating *et al.* 1997)]. **MeHg is the most toxic form of mercury, has a remarkable ability to pass through biological membranes, high chemical stability, and is excreted from most organisms very slowly (Micallef 1984, Eisler 1987, Keating** ***et al.*** **1997, Downs** ***et al.*** **1998, French 1999, Boening 2000, Mason** ***et al.*** 2000).

Methylation of Hg is strongly influenced by biological and chemical processes that occur in soil and water (Figure 1). An extensive literature review of the factors that affect methylation indicates Mammoth Cave National Park's riparian habitats and rivers possess most of the attributes that enhance methylation. Soil is a major reservoir for anthropogenic mercury emissions and ambient conditions determine the rate of MeHg produced in soils. For example, soil fertilization increases the availability of Hg for methylation and so waterways with high levels of anthropogenic nitrogen deposition also show increased production of MeHg (Keating *et al.* **1997, Guimarães** *et al.* **2000, Cooper and Gillespie 2001, Matilainen** *et al.* 2001). These conditions already exist in the South Central Kentucky Karst due to its receipt of nitrogen loads through long-range transport and subsequent deposition (Division for Air Quality 2001). In aquatic ecosystems, anaerobic sulfur-reducing bacteria in sediments are a major source of MeHg (Zillioux *et al.* **1993). Indeed, sediments contaminated with Hg can also serve as important reservoirs, with sediment-bound Hg recycling back into the aquatic ecosystem for decades or longer (Keating** *et al.* **1997, French** *et al.* **1999, Mason** *et al.* **2000). Mammoth Cave National Park's Green and Nolin Rivers sediment deposits increase in the impoundment zones created by Lock and Dam #6 increased, relative to non-impounded zones, due to reduced flow (Olson and Leibfreid 1999). If these deposits are already contaminated with Hg, they are likely a significant source of MeHg production in the Green and Nolin Rivers.**

Hg and MeHg input from groundwater can be relatively constant temporally and spatially (Zelewski 1999), but increased Hg concentrations and production of MeHg in streams and rivers is highly seasonal. Indeed, most Hg and MeHg input to waterways is associated with snowmelt, storm-generated runoff (bound to suspended soil/humus or dissolved organic carbon), and throughfall or rainwater that passes through a vegetation canopy (Keating *et*

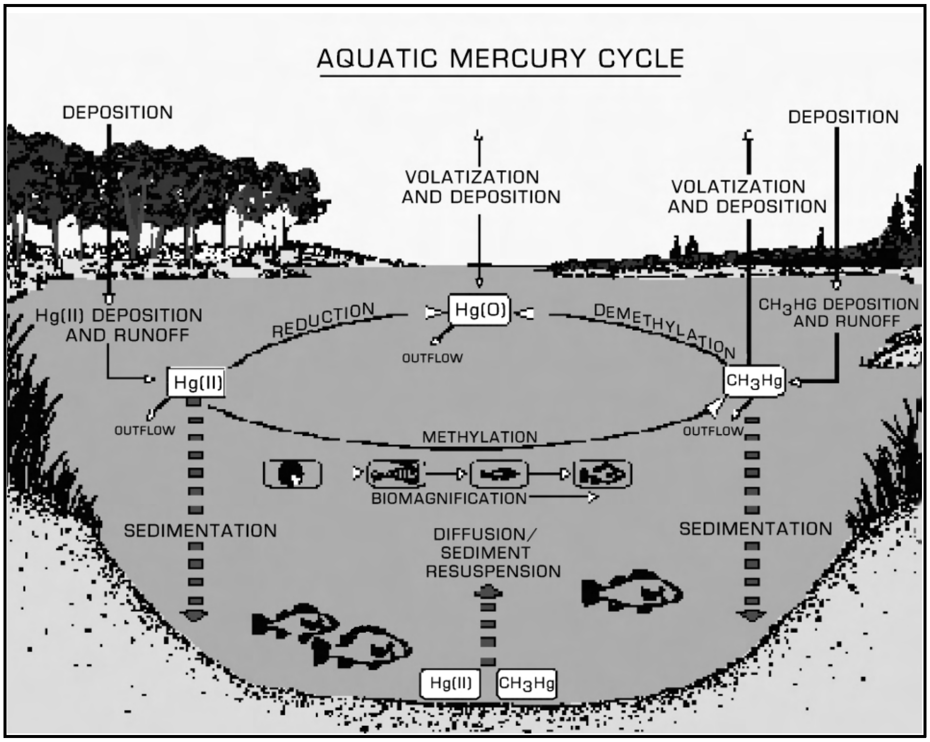

Figure 1. *The cycling of various molecular forms of Hg through an aquatic ecosystem. Deposition occurs in several ways: rainwater that passes through a vegetation canopy (throughfall, left), direct deposition (wet, right), and dry deposition. Hg also readily adsorbs onto surfaces and so aquatic organisms may also take in MeHg adsorbed to the surface of contaminated prey.*

al. 1997, Allan and Heyes 1998, Balogh and Johnson 1998, Mikac *et al.* 1999, Mason *et al.* 2000). In summer, high levels of MeHg in aquatic sediments are a result of elevated temperatures and increased activity of methylating microbes (Weber 1993, Hintelmann and Wilken 1995, Watras *et al*. 1998, Cooper and Gillespie 2001) and so production of MeHg coincides with the most productive periods in aquatic ecosystems. Mammoth Cave National Park is heavily forested and possesses extensive riparian habitat and so likely MeHg production in aquatic habitats is also highly seasonal.

Bioaccumulation of Hg and MeHg

Hg and MeHg are bioaccumulated rapidly because organisms are exposed through multiple pathways. Bioaccumulation refers to an organism's net uptake through all possible pathways including bioconcentration and biomagnification. Bioconcentration refers to the accumulation of Hg and MeHg that occurs when an organism is in direct contact with its surrounding medium (for example, uptake from water through a fish's gills) and only accounts for a small percentage of an organism's total accumulated Hg and MeHg. However, Hg and MeHg are highly toxic and so even exposure to low levels can lead to toxic effects and death. Biomagnification is the largest contributor to the accumulation of MeHg in living tissue (Eisler 1987, Keating *et al.* 1997, Watras *et al.* 1998, Boening 2000, Mason *et al.* 2000). Biomagnification refers to increased concentration in organisms at successively higher trophic levels through ingestion of contaminated organisms at lower trophic levels.

Exposure Pathways of Hg and MeHg in Mammoth Cave National Park's Ecosystems

A. Surface aquatic ecosystems

In aquatic ecosystems MeHg concentration generally increases with trophic level (Figure 2). Primary producers accumulate MeHg within their cytoplasm at levels several orders of magnitude higher than water (Bloom 1992, Keating *et al.* 1997, Boening 2000, Mason *et al.* 2000, Simon *et al.* 2000). Phytoplankton are ingested by zooplankton which biomagnify MeHg approximately 3-10 times that amount (Downs *et al.* 2000, Mason *et al.* 2000). Organ-

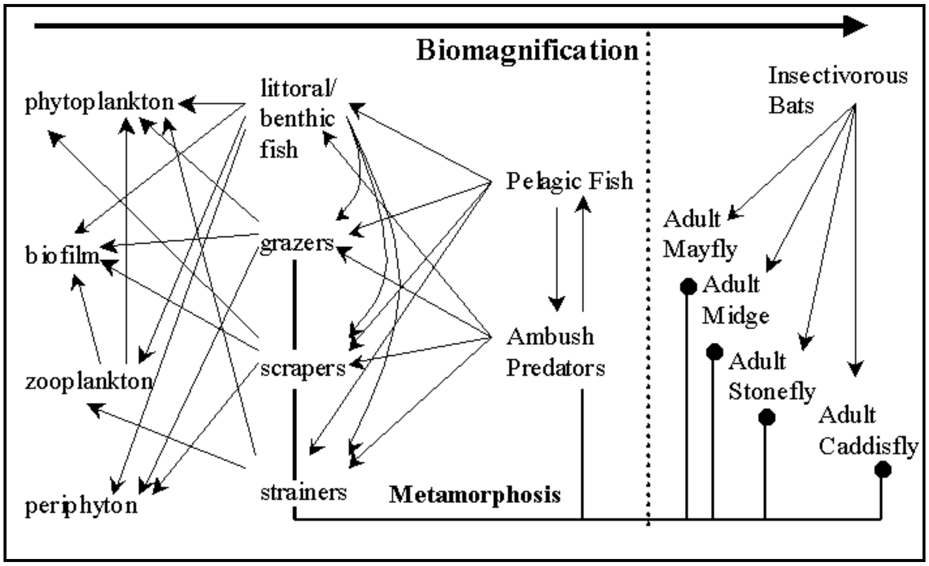

Figure 2. *Hypothesized food web for biomagnification of Hg and MeHg within aquatic community and between aquatic and terrestrial communities. Note insectivorous bats accumulate Hg and MeHg from terrestrial (i.e., adult) forms of contaminated aquatic insects.*

isms at higher trophic levels generally biomagnify MeHg at a similar rate and, once it is stored in their muscle tissue, excrete it very slowly (Downs *et al.* 2000). Hg also has a high affinity of surface adsorption and so organisms that feed on seston (that is, suspended particulate matter such as plankton) or detritus (that is., dead organic matter) can also ingest it in this manner (Keating *et al.* 1997, Ledin *et al.* 1997). Uptake of Hg can also occur through skin or gills and is heavily influenced by a consumer's size (that is, surface area/volume ratio) and functional group (Boening 2000, Downs *et al.* 2000, Canivet *et al.* 2001).

B. Subsurface aquatic ecosystems

Mammoth Cave's subsurface aquatic ecosystems are subsidized by the storm-generated influx of runoff and detritus from the surface, so transport of contaminants is most likely episodic (Meiman and Hall 1995). Storm-generated subsidies that enter through sinkholes or vertical shafts mostly acquire Hg from throughfall and detritus (Watras *et al.* 1998, Mason *et al.* 2000). These periodic subsidies likely form the basis for methylating conditions in accumulated sediments between storm events (Barr 1985). Further, during upstream floods on the Green River, backflooding through spring orifices brings the direct influx of river water into the cave (Hess *et al.* 1989) which also contributes MeHg contaminated water and sediment.

Subsurface aquatic organisms may accumulate MeHg in much the same manner as their epigean congeners. However, it is not known which exposure pathway determines the toxic effects of contaminants. Laboratory experiments indicated long-term exposure (10 days) to low concentrations of toxic metals (.5 milligrams/Liter) were lethal to subsurface amphipods (*Niphargus rhenorhodanensis*) and that surface and subsurface amphipods (*Gammarus fossarum* and *N. rhenorhodanensis*, respectively) bioaccumulated pollutants at the same rate (Canivet 2001). However, cave biota undoubtedly biomagnify Hg and MeHg through absorption and feeding on detritus and/or prey (Figure 3). In addition, the life history of subsurface organisms may make them particularly vulnerable to Hg and MeHg contaminated water and detritus. Indeed, due to their slow metabolism and long life span subsurface invertebrates likely bioaccumulate high levels of Hg and MeHg. Finally, invertebrate larval stages are particularly sensitive to Hg and MeHg (Boening 2000). Some subsurface invertebrates (for example, Cave crayfish, *Orconectes pellucidus*) may take years to reach maturity which increases the length of time they are most vulnerable to contaminants.

C. Surface terrestrial ecosystems

Several possible exposure pathways to Hg and MeHg exist for terrestrial organisms: ingestion of contaminated food or water, direct contact with soil, and inhalation (Keating *et al.* 1997). The most important exposure pathway for terrestrial organisms is biomagnification because Hg and MeHg can accumulate at increas-

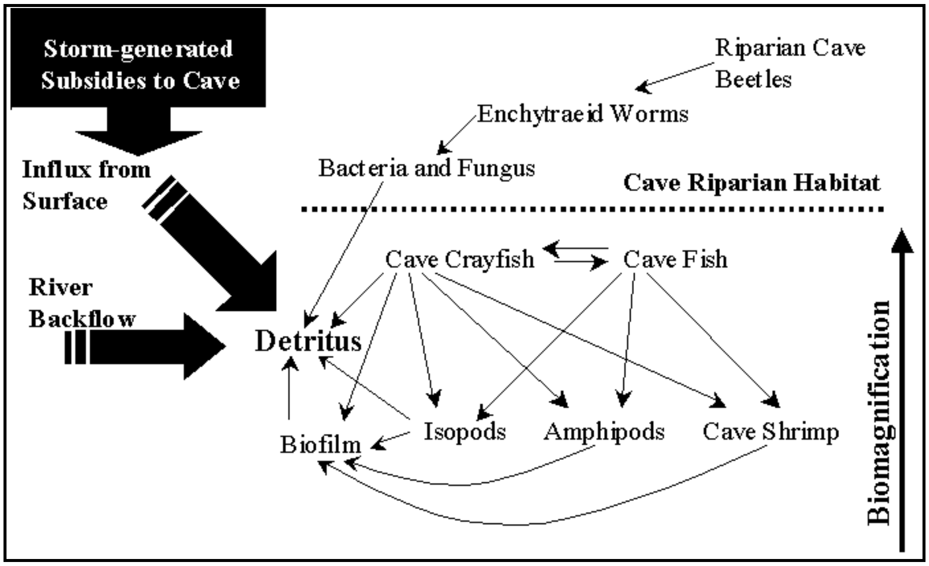

Figure 3. *Hypothesized exposure pathways for biomagnification of Hg and MeHg within cave aquatic community and between cave aquatic and cave terrestrial communities.*

ing concentrations with successively higher trophic levels. Terrestrial carnivores that consume prey from aquatic sources (for example, insectivorous bats) are particularly vulnerable to biomagnification of Hg and MeHg [(Figure 2) (Hickey *et al.* 2001)].

Potential Effects of Hg and MeHg on Biota of Special Concern in Mammoth Cave National Park

I. Surface aquatic biota

A. Mussels

Freshwater mussels readily bioaccumulate Hg and MeHg because they ingest contaminated organisms, sediment, and have direct contact with contaminated water and sediment (McMahon 1991, Hickey *et al.* 1995, Keller 1989). Transplant experiments using *Elliptio complanata* indicated mussel growth was negatively correlated with tissue concentrations of total Hg (Beckvar *et al.* 2000). Further, exposure to Hg has been shown to disrupt gill function and may interfere with the respiratory system at every level of organization (Spicer and Weber 1991). Finally, experimental evidence suggests heavy metal contaminated water may affect Unionid mussel populations by reducing the ability of obligate parasitic larvae (glochidia) to close their valves and therefore attach themselves to host fish (Huebner and Pynnönen 1992). These results are particularly alarming because in natural populations only .0004% of released glochidia successfully encyst in fish hosts (McMahon 1991).

Indirectly, Hg may contribute to the decline in mussel species by affecting population viability of the host fish that disperse their glochidia (Havlik and Marking 1987, Hardison and Layzer 2001). Fish are typically at the top trophic levels and so accumulate high levels of Hg and MeHg in their tissue (Downs *et al.* 1998, Boening 2000, Mason *et al.* 2000). Indeed, concentration of MeHg in larval walleye (*Stizostedion vitreum*) was positively correlated with MeHg concentration in eggs and so demonstrated maternal transference (Latif *et al.* 2001). Further, hatching success of walleye eggs was significantly negatively correlated with MeHg concentration in water (Latif *et al.* 2001). Hg has also been shown to alter the processes that regulate the magnitude and specificity of fish immune response to environmental pathogens, decrease growth rate, and decrease prey capture ability (Nicoletto and Hendricks 1988, MacDougal *et al.* 1996, Zhou *et al.* 2001). Three known host fish (that is, largemouth bass *Micropterus salmoides*, walleye *S. vitreum*, and bluegill *Lepomis macrochirus*) for two species of mussels federally listed as endangered in Mammoth Cave National Park rivers are known to accumulate Hg and MeHg (Pinkney *et al.* 1997, Olson and Leibfreid 1999, Gilmour *et al.* 2000, Latif *et al.* 2001). Finally, preliminary data from a study of the occurrence and distribution of Hg in Mammoth Cave National Park indicates *M. salmoides* muscle tissue contained average Hg concentrations three times higher (that is, .6 milligrams per

gram or parts per million) than is recommended by the United States Environmental Protection Agency (Berryman *et al.* 2003).

II. Subsurface aquatic biota

A. Decapod Crustaceans

Like other subsurface arthropods, the decapod crustaceans in Mammoth Cave (cave shrimp and cave crayfish) are long-lived and so likely bioaccumulate high concentrations of MeHg in their tissue over their lifetime. The author is aware of only one study that compared tissue concentrations of heavy metals between a troglophilic and a troglobitic crayfish (*Cambarus tenebrosus* and *Orconectes australis australis*, respectively); the study indicated heavy metal concentration was higher in *O. a. australis*' tissues (Dickson *et al.* 1979). The authors hypothesized that *O. a. australis* and *C. tenebrosus* were exposed to heavy metals primarily by preying on isopods and amphipods and exposure to water (Dickson *et al.* 1979). The higher concentration of heavy metals in *O. a. australis*' tissues, relative to *C. tenebrosus*, was attributed to its increased longevity (Dickson *et al.* 1979).

Many contamination studies conducted on surface crustaceans rely heavily on Cambarid crayfish, a family that contains Mammoth Cave's troglobitic crayfish (*O. pellucidus*). The surface crayfish *Astacus astacus* demonstrated both biomagnification (via food intake) and bioconcentration (via gills and carapace) of Hg(II) and MeHg (Simon *et al.* 2000, Simon and Boudou 2001). Indeed, MeHg had a higher assimilation efficiency than Hg(II), and was accumulated in both the tail muscle and the green gland [(approximately 1000 nanograms/gram and 2500 nanograms/gram, respectively) (Simon *et al.* 2000)]. Hg was also detected in the tail muscle (220 nanograms/gram) of crayfish (*O. virilis*) inhabiting a prairie stream in Saskatchewan (Munro and Gummer 1980). Clearly, accumulation of MeHg in the crayfish tail muscle indicates biomagnification of MeHg is possible through predation and scavenging. In addition, accumulation of MeHg in the green gland may affect a crayfishes' ability to maintain fluid and solute balance. Finally, one study compared the ability of males and females in two species of crayfish (*Procambarus clarkii* and *Faxonella clypeata*) to withstand increasing concentrations of mercuric chloride to cause 50% mortality expressed in days (LC_{50} hour). The authors found significant differences between species and sexes exposed to relatively low concentrations of mercuric chloride [(Table 2) (Heit and Fingerman 1977)]. These data indicate significant variability both within and among species and so without further studies, some uncertainty exists as to the levels of bioaccumulation and toxicity of Hg and MeHg in subsurface species.

Contamination studies conducted on surface crustaceans have also utilized Palaemonid shrimp, a family that contains Mammoth Cave's troglobitic shrimp (*Palaemonias ganteri*). Palaemonid shrimp have been shown to bioaccumulate high concentrations of heavy metals in their tissue (Abdennour *et al.* 2000). In addition, of three metal salts tested for toxicity on the shrimp *Palaemon elegans*, LC_{50} levels (that is, concentrations needed to kill 50% of shrimp) for mercury were lowest relative to copper and cadmium; mercury toxicity also increased with time [(Table 3) (Lorenzon *et al.* 2000)].

Crustaceans' physiological processes (for example, molting, limb regeneration, blood glucose levels, and reproduction) are often coordinated by hormones and exposure to heavy metals can induce rapid changes in hormone levels that interfere with these processes (Fingerman *et al.* 1998). Experimental data show Hg decreased fecundity in Red Swamp Crayfish (*Procambarus clarkii*) through inhibition of maturation in ovaries (Reddy *et al.* 1997). Freshwater prawn (*Macrobrachium kistenensis*) exposed to Hg exhibited high variations in blood glucose

Species	Sex	LC_{50} hr (20 µg/L)	LC_{50} hr (10 µg/L)	LC_{50} hr (.2 µg/L)
P. clarkii	Male	6	24	72
	Female	48	72	—
F. clypeata	Male	48	48	72
	Female	24	72	—

Table 2. *Determination of LC_{50} hr (ability of crayfish to withstand increasing concentrations of mercuric chloride to cause 50% mortality expressed in days) for males and females in* P. clarkii *and* F. clypeata*. Note at .2 µg/L females of both species were apparently healthy for the duration of the 30-day experiment (taken from Heit and Fingerman 1977).*

	24-hour , LC_{50} (mg/L)	48-hour, LC_{50} (mg/L)	96-hour, LC_{50} (mg/L)	n
$HgCl_2$	9.54	3.54	0.67	20
$CdCl_2$	49.77	8.91	1.46	20
$CuCl_2$	249.46	12.79	3.27	20

Table 3. *LC_{50} levels (that is, concentrations needed to kill 50% of shrimp) in* P. elegans *of both sexes. Hg was the most toxic metal in the 96-hour assay, followed by Cd and Cu. The order of toxicity did not change during the experiments (taken from Lorenzon et al. 2000).*

which indicated a stress response (Lorenzon *et al.* **2000). Finally, Hg has also been found to inhibit limb regeneration and molting in the horseshoe crab [(***Limulus polyphemus*) (Itow *et al.* **1998)]. Undoubtedly the potential exists for deleterious effects on subsurface crustaceans due to bioaccumulation of Hg and MeHg.**

III. Terrestrial Biota
A. Indiana and Gray Bats

Bats are vulnerable to Hg and MeHg bioaccumulation because they are small, mobile, long-lived, and generally consume 40-100% of their body mass in prey each night (Hickey and Fenton 1996). In addition, bats are also exposed to contaminants through the placenta, nursing, breathing, and drinking water (Keating *et al.* **1997, Straube 1998, Clark and Shore 2001). Insectivorous bats that feed heavily on emerging aquatic insects (for example, Trichoptera), which spend their larval stages in contaminated sediments, are particularly susceptible to biomagnification of Hg and MeHg (Miura 1978, Massa and Grippo 1999, O'Shea** *et al.* **2001). This is worrisome because two insectivorous bats in Mammoth Cave National Park are federally listed endangered species (that is,** *Myotis grisescens* and *M. sodalis*). Non point-source contamination was responsible for Hg levels in bat hair (that is, *M. lucifugus*, *M. septentrionalis*, *M. leibii*, and *Eptesicus fuscus*) that exceeded the threshold (that is, 10 milligrams/kilogram) at which deleterious effects are detected in humans (Hickey *et al.* **2001). High levels of Hg have also been found in guano deposits beneath** *M. grisescens* colonies (Ryan *et al.* **1992).**

The toxic effects of Hg and MeHg on bats are not well researched. However, bats exposed to other nonessential heavy metals (for example, cadmium) have been found with damage to their heart, kidneys, and lungs (Clark and Shore 2001). In addition, exposure to heavy metals has been associated with reproductive failure, neurological disorders, and death in bats (Clark and Shore 2001). Heavy metals may also indirectly affect insectivorous bats by affecting their prey's behavior, prey populations, and composition of prey communities (Winner *et al.* **1980, Cain** *et al.* **1992, Kiffney and Clements 1993, Beltman** *et al.* **1999, Groenendijk** *et al.* **1999). Given the high toxicity of Hg and MeHg relative to well-studied heavy metals, the sensitivity of small carnivorous mammals (for example, minks) to Hg, and the relative paucity of toxicological data on Hg and MeHg with respect to bats, a research and monitoring program must be initiated (Keating** *et al.* **1997).**

Conclusion

The data presented in this briefing paper are based on an extensive literature search and represent the best available knowledge on Hg and MeHg bioaccumulation and toxicity in aquatic and terrestrial biota. All studies indicated long-term exposure to Hg and MeHg produces deleterious effects and even death in affected organisms. Most of the cave and karst taxa discussed in this briefing paper are long-lived and so particularly vulnerable to the deleterious effects produced by long-term exposure to Hg and MeHg. However, data on Hg and MeHg bioaccumulation and toxicity for taxa of special concern are either sparse (for example, bats and mussels) or practically nonexistent (for example, decapod crustaceans). Consequently, baseline data are required on Hg and MeHg levels in cave and karst surface and subsurface ecosystems. Further, long-term monitoring of Hg and MeHg levels in cave and karst surface and subsurface species that may be affected. In addition, results were highly variable in those bioaccumulation and toxicity studies that examined species comparable to cave and karst species of concern. Therefore, Hg and MeHg bioaccumulation and toxicity studies must be performed on cave and karst ecosystems to determine which species are affected. Thus, valuable resources and mitigation efforts will not be "wasted" on cave and karst species less or unaffected by Hg and MeHg, if any.

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Development of an Index of Biological Integrity for Endangered Species Monitoring in Southern Illinois

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Abstract

The Illinois cave amphipod, *Gammarus acherondytes*, is known only from caves in the karst of Monroe County in southwestern Illinois. Extirpated from the one cave where the amphipod was formerly found in adjacent St. Clair County and apparently declining across the rest of its narrow range, in 1999 the Illinois cave amphipod was added to the U.S. Endangered Species List. A yearly census of caves in all groundwater basins in which the Illinois cave amphipod remains is sponsored by the U.S. Fish & Wildlife Service to monitor the species. The census data is being analyzed in a number of ways, including the development of an index of biological integrity (IBI) for cave stream invertebrates. The IBI is a biomonitoring protocol that was first published in 1981 using data on fish to characterize the degree of human impact on surface streams. The variables (metrics) in the IBI were chosen as indicators of the level of impact. The protocol has been modified to adjust for regional differences and other kinds of aquatic communities. In the Mammoth Cave area an IBI was developed by Thomas Poulson and William Pearson primarily using metrics concerning cavefish and cave crayfish. Neither of these organisms is present in Illinois caves, thus presenting a challenge in creating metrics that use data primarily concerned with amphipods, isopods, snails or flatworms. A preliminary IBI for cave communities in southwestern Illinois incorporating data for 10 metrics has been constructed and is undergoing testing.

The Illinois cave amphipod, *Gammarus acherondytes*, is known only from caves in the karst of Monroe County in southwestern Illinois (Lewis *et al*., 2003). Extirpated from the one cave where the amphipod was formerly found in adjacent St. Clair County and apparently declining across the rest of its narrow range, in 1999 the Illinois cave amphipod was added to the U.S. Endangered Species List.

Methods

A yearly census of caves in all groundwater basins in which the Illinois cave amphipod remains is sponsored by the U.S. Fish & Wildlife Service to monitor the species. The census methodology has been detailed elsewhere, (Lewis 2000, 2001; Lewis *et al*. 2002), but in general in each cave a transect 100 feet in length is selected. This transect is divided into 10 subtransects, each 10 feet in length (feet rather than meters are employed to accommodate the use of a square foot Surber sampler). In each 10-foot subtransect a random number is selected to designate the placement of a sample quadrat. For example, the random number 49 would indicate that the quadrat would be placed at a spot 4 feet up the length

of the transect and 90% of the distance across the width of the stream.

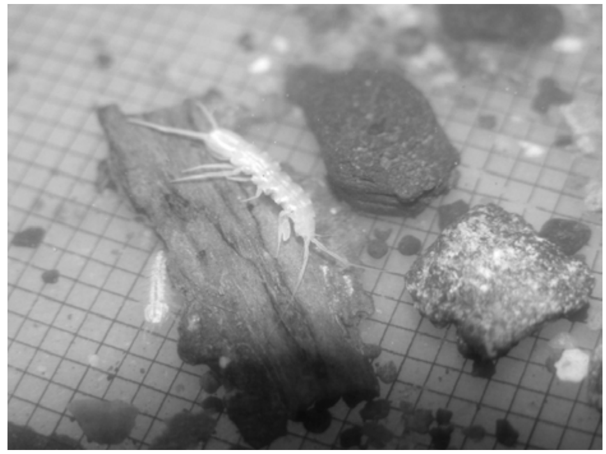
The Surber sampler is placed on the designated spot and the substrate gently agitated to release the invertebrates present. All of the animals are placed into a plastic bowl, where each is identified to species and measured. Within a few minutes of the sample being taken the animals are released alive back into the stream.

This method produces a census of 10 samples within a 100-foot transect. Mapping of the transects produced a square foot area for the complete transect from which can be extrapolated a population estimate for *Gammarus acherondytes* as well as the other species present within the area.

Bringing the Surber Sampler out of the stream transect in Reverse Stream Cave, Monroe County, Illinois.

Another way of analyzing the census data has been the development of an index of biological integrity (IBI) for cave stream invertebrates. The IBI is a biomonitoring tool that was first published by Karr (1981) using data on fish to characterize the degree of human impact on surface streams. The variables (metrics) in the IBI were chosen as indicators of the level of impact. The protocol has been modified to adjust for regional differences and other kinds of aquatic communities. In the Mammoth Cave area an IBI was developed by Thomas Poulson and William Pearson primarily using metrics concerning amblyopsid cavefish (*Amblyopsis, Typhlichthys*) and crayfish (*Orconectes, Cambarus*) although a small invertebrate component is also used.

Amblyopsid cavefish are absent from the caves of Monroe and St. Clair Counties, as are stygobitic crayfish, although stygophilic or stygoxenic species are present in some communities. In creating an IBI for western Illinois cave communities this presented a challenge in creating metrics, since the data almost entirely comprised information concerned with amphipods, isopods, snails, or flatworms. Several categories of variables were utilized to comprise a total of 10 metrics.



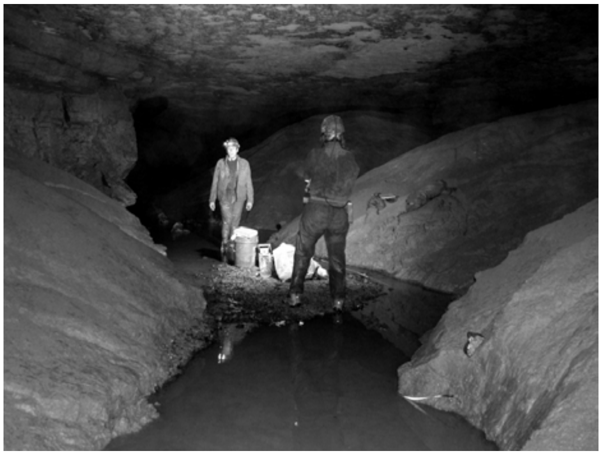
The isopod Caecidotea packardi *is a stygobite endemic to western Illinois caves.*

Metrics 1-4 (table 1) each concern the numbers of individual species present in the sample quadrats, specifically tthree stygobites, the amphipod *Gammarus acherondytes*, isopod *Caecidotea packardi*, and flatworm *Sphalloplana hubricti*, and the stygophilic isopod *Caecidotea brevicauda*. The concept behind these metrics was that stygobitic species typically dominate natural aquatic cave communities, whereas in situations where nutrient enrichment has impacted a community stygophilic or stygoxenic species become dominant.

Metrics 5-6 concern the size class distribution of *Gammarus acherondytes* and *Caecidotea packardi*. In aquatic cave communities, the populations are characteristically skewed toward dominance by larger, older individuals. Metrics 7-8 involve the dominance of stygobites as an assemblage in the community, in both the raw numbers of stygobites present as well as the richness of the community in stygobite diversity.

Metrics 9-10 concern habitat degradation. Caves are sensitive to the soil management on the surface with sedimentation being a major concern in cave communities where gravel riffles and their interstices are of importance. In situations where nutrient enrichment has occurred the rocks, normally clean and rough on the bottom where invertebrates hide, can become covered with biofilms ranging from a thin microbial layer to a filamentous scum.

Table 1. Index of biological integrity for Illinois Cave Amphipod sites in western Illinois			
	5	3	1
(1) *Gammarus acherondytes* element occurrence	>=2 per ft^2	1-2 per ft^2	<1 per ft^2
stygobitic species dominate aquatic cave communities			
(2) *Caecidotea packardi* element occurrence	>=2 per ft^2	1-2 per ft2	<1 per ft2
stygobitic species dominate aquatic cave communities			
(3) *Sphalloplana hubrichti* element occurrence	>0.5 per ft^2	0.1-0.5 per ft^2	0
stygobitic species dominate aquatic cave communities			
(4) *Caecidotea brevicauda* element occurrence	<1 per ft^2	1-2 per ft^2	>2 per ft^2
stygophilic/stygoxenic species should be minor components or absent in aquatic cave communities (an index of community disturbance frequently attributable to degradation by nutrient enrichment in which non-stygobites outcompete stygobites)			
(5) *Gammarus acherondytes* size class distribution	>50% >=7mm	25-50% >=7mm	<25% >=7mm
stygobitic species populations are characteristically skewed toward older, larger individuals			
(6) *Caecidotea packardi* size class distribution	>50% >7mm	25-50% >7mm	<25% >7mm
stygobitic species populations are characteristically skewed toward older, larger individuals			
(7) Community stygobite dominance	>75% of animals present (#) are stygobitic	25-75% of animals present (#) are stygobitic	<25% of animals present (#) are stygobitic
Stygobitic species dominate aquatic cave communities, with stygophilic/stygoxenic species absent or in small numbers (an index of disturbance in which non-stygobites out-compete stygobites)			
(8) Community diversity	3 stygobites present	2 stygobites present	1 stygobite present
Major community niches should be filled by stygobitic species in aquatic cave communities			
(9) Stream substrate	>90% gravel, breakdown or bedrock	67 - 89% gravel, breakdown or bedrock	<67% gravel, breakdown or bedrock
Most of the substrate should be rock rather than sediment (an index of habitat degradation by sedimentation)			
(10) Rock Substrate	clean rock surface	observable biofilm present	filamentous biofilm
Substrate should be macroscopically clean (an index of habitat degradation by nutrient enrichment as evidenced by microbial overgrowth)			



Stream transect in Pautler Cave, Monroe County, Illinois

Results

A list of the eight caves that were censused in 2003 are presented in Table 2, rank-ordered by the size of the populations estimated in each 100-foot transect. Compared with these population estimates are the square-foot censuses from each cave as well as the Index of Biological Integrity (IBI). Examination of the table reveals that there is a more or less proportional relationship between the size of the *Gammarus acherondytes* population and the IBI of the site and its community. The correlation of IBI and ICA/ft^2 is 0.698, which illustratesapositiveifnotstrongrelationship betweenthevalues.

This tells us that the IBI indicates information in some ways different from the raw census data. The site that stands out is Pumphouse Cave, which with a value of 40 has the highest IBI despite having relatively low numbers of the Illinois cave amphipods per square foot and a transect population that falls near the median. This cave lies on private property in an area that is largely wooded and has relatively little human surface disturbance, at least when compared with other caves in the range of *Gammarus acherondytes* that lie near subdivisions or commercial developments. The habitat within the Pumphouse Cave appears to intact and the community is diverse. In contrast, there is a strong correlation between caves in which problems have occurred and low numbers of *Gammarus acherondytes* occurring in the census samples.

In Spider Cave, a pollution episode of unknown origin in 2000 created a microbial mat that has eliminated the Illinois cave amphipod from subsequent censuses. In 2003 heavy rainfall caused a pond to overflow into the upstream section of Fogelpole Cave. The subsequent census revealed a significant number of pond species, for example, sunfish, leeches, surface flatworms, frogs, with a concomitant drastic decline in the number of *Gammarus acherondytes* present.

In some cases the metrics used for the IBI have potential problems. In particular, metrics

Table 2. List of sites at which censusing was conducted in 2003, rank-ordered by the size of Illinois Cave Amphipod (ICA) estimated populations in 100 linear foot transects (Reverse Stream Cave extrapolated to 100 foot transect length), compared with the raw census sample data per square foot and the Index of Biological Integrity for each site (IBI).

Groundwater Basin/Locality	ICA Population Estimate	ICA ft^2	**IBI**
Annbriar Spring Basin Reverse Stream Cave	1840	2.3	36
Frog Spring Basin Frog Cave	1066	2.0	34
Pautler Cave Basin **Pautler Cave**	895	1.8	34
Luhr Spring Basin Pumphouse Cave	338	0.7	40
Illinois Caverns Basin Illinois Caverns	254	0.4	30
Dual Spring Basin Snow White Cave	87	0.2	26
Fogelpole Cave Basin Fogelpole Cave NW	87	0.1	18
Krueger/Dry Run Basin **Spider Cave**	0	0.0	16

5 and 6 are based on size class distributions for the *Gammarus acherondytes* and *Caecidotea packardi*. These metrics are based on observed data in the cumulative censuses of the last three years, as actual life history data is not available for these species. Substitution of one or more other metrics might be recommended. For example, substituting a metric that concerns the presence of exotic pond species in the cave communities might be more valuable than metric 6 involving the size class distribution of *Caecidotea packardi*.

Acknowledgments

This project was funded by the U. S. Fish & Wildlife Service, administered by the Endangered Wildlife Program, Illinois Department of Natural Resources.

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Mapping Presumptive Habitat for Subterranean Aquatic Species of Concern

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Abstract

Generally, populations of species of concern are located by direct observation or capture. This is a severe limitation when dealing with cavernicoles, since a very small percentage of potential habitat is accessible to investigators. The Ozark Underground Laboratory is promoting the concept of presumptive habitat; that is all groundwater that has subsurface hydrological interconnections should be presumed to contain the aquatic species of concern that are found in accessible parts of the groundwater system and that the entire groundwater system be managed accordingly. Groundwater tracing using fluorescent dyes is a powerful, empirical tool for delineating groundwater basins and demonstrating hydrological interconnections between groundwater basins. The recharge area boundaries representing known and presumptive habitat are important tools for biological analysis and conservation management. Dye traces help evaluate tested portions of the groundwater system; dye passes readily only through relatively open conduits; a significant requirement for most aquatic cavernicoles. Aquatic cavernicoles can generally move against the hydraulic gradient and cross drainage divides under more variable flow conditions than does tracer dye. The migration of fauna against the hydraulic gradient permits more gene flow than may be suggested by dye tracing.

Generally, subterranean, aquatic species of concern are located by direct observation or capture. This is a severe limitation when dealing with aquatic cavernicoles, since a very small percentage of their potential habitat is accessible to investigators. Even large caves typically have a relatively small "footprint" within their groundwater basins. A few examples from caves containing important communities for which recharge areas have been delineated are listed below. The values represent the cave stream area divided by the recharge area multiplied by 100. Each of these caves has been demonstrated to have the distal reaches of their respective recharge areas connected to them via conduit flow.

- Tumbling Creek Cave (Taney County, Missouri) permits examination of approximately 0.01% of its 9.1-square-mile groundwater basin.
- Fogelpole Cave (Monroe County, Illinois) permits examination of approximately 0.40% of its 7.2-square-mile groundwater basin.
- Stemler Cave (St. Clair County, Illinois) permits examination of approximately 0.036% of its 6.7-square-mile groundwater basin.
- Cave Spring Cave (Benton County, Arkansas) permits examination of approximately 0.004% of its 19-square-mile groundwater basin.

These values are probably representative of the relationship between accessible subterranean aquatic habitat and the size of the groundwater basin in which it is located. These numbers are low, in part, because they imply that the entire groundwater basin is potential habitat.

Karst is often considered to have three porosities—matrix porosity, fracture porosity, and conduit porosity. Only the latter two porosities have large enough voids and have sufficient interconnectedness to provide habitat for macroscopic fauna. Worthington *et al.* (2000) provided calculations of matrix, fracture, and conduit porosity in the Mammoth Cave area of Kentucky as representative of Pa-

leozoic carbonates. The sum of their values for fracture and conduit porosity (0.093%) around Mammoth Cave is lower than the values for the accessible conduits provided in the examples above. However, porosity is a three-dimensional characteristic and may not correlate well with the two dimensions of area, which is the subject of this paper. Worthington *et al*. (2000) also present the percentage of void represented by known cave divided by the minimum area required to contain the cave. These values ranged from 0.5% to 7.5%. The range is inherently lower than the sum of fracture and conduit porosity, since the measurements are restricted to conduits large enough for human traverse. However, these values appear more representative of the potential habitat void percent for a groundwater basin in carbonate rocks.

If we assume that fracture and conduit porosity occupies a generous 10% of a groundwater basin, then the values of observable cave stream area provided in this paper increase by an order of magnitude. However, the highest presented is Fogelpole Cave, which would permit examination of approximately 4% of the potential habitat.

Within a groundwater system we may have access to springs, cave streams, karst windows, or wells. These all provide observation points in somewhat different habitats and none may be representative of the complete biological community inhabiting the groundwater system. In total, these sampling points access a very small percentage of the groundwater basin.

We know that there are both unknown populations of cavernicolus aquatic species and that a given population's habitat extends into parts of the groundwater system inaccessible to observers. We know that there are unknown populations because new populations are often found by qualified investigators while conducting bioinventories. We also occasionally discover a new population when a spill flushes fauna out of inaccessible parts of the groundwater basin. A liquid fertilizer spill demonstrated populations of southern cavefish (*Typhlichthys subterraneus*) and Salem cave crayfish (*Cambarus hubrichti*) not previously known at Maramec Spring, Missouri (Crunkilton, 1984).

From a conservation perspective, we must recognize that the area to be managed for subterranean, aquatic species of concern is the recharge area for their groundwater system. We know that degraded water recharging the groundwater system is likely to negatively impact the aquatic community. By protecting the entire recharge area, we protect the observable population and we also protect the inaccessible habitat within the groundwater basin.

It is well-established practice to presume that most species observed in cave streams occupy all the available, appropriate habitat within the entire groundwater basin. As new caves are discovered within a groundwater basin or new cave passages discovered in well-known caves, the same fauna is generally found in these previously unknown sections as in the long-known sections. Lewis *et al*. (2003) demonstrated similar fauna in separate caves within both the Annbriar Spring and Pautler Cave systems in Illinois.

We need to recognize that some fauna classified as stygobites would probably be better classified as phreatobites if we had more complete information on their preferred habitat. As in the case of cavefish and cave crayfish being flushed out of Maramec Spring, the fauna were not observed at the spring, even by cave divers, but lived in unobserved and perhaps inaccessible parts of the groundwater system. Examining the spring did not demonstrate the presence of cavefish or cave crayfish, despite their presence in the groundwater basin. This suggests that both of these species may be phreatobites.

Because of previous pollution events, Hidden River Cave (Kentucky) had areas devoid of cave-adapted life, but when water quality was rehabilitated, cave life came back relatively quickly. The quick recovery is almost certainly due to colonization from biologic reservoirs in the groundwater basin (Lewis, 1993).

The Ozark Underground Laboratory has conducted many recharge area delineations to help land managers design and apply protective strategies to all lands that contribute water to important groundwater. These recharge area delineations perform two functions:

1) They show where to be especially protective of water quality, and

2) They define the groundwater basin that presumably provides habitat outside the known cave passages.

While tracing groundwater flow, we commonly find that there are interconnections between groundwater basins that are not simple distributary systems (Aley *et al*. 2000; Aley and Moss 2001a; Aley and Moss 2001b). Dye only flows readily through relatively open groundwater systems; the same kind of conduit systems that provide habitat for aquatic species of concern. Some of these interconnections are perennial interconnections, some are overflow routes, and some are difficult to characterize beyond the fact that they share recharge areas.

With the constraints of time and budget, it is unlikely that dye tracing reveals all of the hydrologic interconnections between groundwater basins. It is quite probable that there are frequently both air-filled and water-filled interconnections between groundwater basins. Interconnections demonstrated by dye tracing represent the minimum number of interconnections between groundwater basins.

Aley and Moss (2001b) demonstrated subsurface hydrologic interconnections between two adjacent groundwater basins in Monroe County, Illinois. These were the Annbriar Spring basin and the Pautler Cave basin. Lewis *et al*. (2003) demonstrated very similar communities in both basins including both the regional endemic and Federally endangered Illinois cave amphipod (*Gammarus acherondytes*) and the only two known populations in the region of the Illinois cave millipede (*Ergodesmus remingtoni*). This suggests that the groundwater flow paths may permit terrestrial species such as millipedes to migrate between the groundwater basins in addition to aquatic species like the Illinois cave amphipod.

We have concluded that if a groundwater basin has hydrologic interconnections with another groundwater basin containing species of concern, it should be managed as if it were known to contain the same biological community. We have taken this position because of the strong presumption that aquatic species are moving between the groundwater basins, at least under some flow conditions.

In the case of a road corridor study (Aley and Moss, 2001a), the Ozark Underground Laboratory's investigation demonstrated subsurface hydrological interconnections between the Reed Spring groundwater basin and the Cave Spring Cave groundwater basin, which is known to provide habitat for Ozark cavefish. The Arkansas State Highway and Transportation Department accepted our conclusion that the Reed Spring groundwater basin presumably provided habitat for Ozark cavefish (*Amblyopsis rosae*) and that it was prudent and protective of the Ozark cavefish to not permit the road corridor to cross either the Reed Spring or the Cave Spring recharge areas.

Another example is found in the case of the designation of Tumbling Creek Cave system as a significant cave system under the provisions of the Federal Cave Resources Protection Act. No known cave passage exists under Federally-owned property. The closest known cave passage is approximately 1.75 miles away from the closest National Forest land, yet the Forest Service has recognized that part of the Tumbling Creek Cave system underlies land administered by them.

Aquatic species of concern can move more freely between groundwater basins than does dye. Dye is passive and flows down the hydraulic gradient at the water levels that exist during the trace. In contrast, fauna can propel themselves upstream, sometimes in just a film of water. The fauna are present for all ranges of flow conditions. It is almost certain that they move between the basins upon occasion and in some systems they may be able to move between groundwater basins under all flow conditions.

GIS themes representing dye traces, hydrologic interconnections, and recharge area boundaries are created by Ozark Underground Labratory for the use of land mangers and investigators. These can be integrated with other GIS data to better understand and manage lands to be protective of subterranean, aquatic species of concern.

If we accept the concept of presumptive habitat, then these areas must be identified before protective strategies can be effectively implemented. Dye tracing is a scientifically credible and legally-defensible tool for identifying some presumptive habitat. Dye tracing can be used to delineate recharge areas, groundwater basins, and hydrologic interconnections between groundwater basins. It cannot identify presumptive habitat without a known population nearby. However, the data generated by dye tracing supports prudent land management over greater areas than are currently identified as habitat.

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Biographical Sketch

Philip Moss is Senior Geologist at the Ozark Underground Laboratory. He is a licensed professional geologist in the states of Missouri and Illinois. As a geologist, he has conducted geotechnical, hazardous waste, or karst investigations in ten states over the past 14 years.

The Foraging Range of a Central Texas Cave Cricket, *Ceuthophilus secretus* (Orthoptera: Rhaphidophoridae)

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Abstract

We documented the nocturnal foraging range of the cave cricket *Ceuthophilus secretus* (Orthoptera: Rhaphidophoridae) at a cave in Coryell County, Texas. During 17 nights between May 8 and July 10, 2003, we marked more than 1,000 emerging crickets at the cave entrance with UV-bright paint. Using battery powered ultraviolet lights, we searched the area around the cave logging our search path with a GPS receiver. Over the course of this study, 291 marked crickets were located. Preliminary analyses show that the crickets were found at 38.5 meters from the cave on the average, with distances varying from 2.3 meters up to 105.7 meters. Ninety percent of the crickets were found within 72 meters of the cave entrance. Crickets were active from about 9:00 P.M. to at least 3:00 A.M.

Ceuthophilus secretus is important in central Texas cave communities because it brings significant energy into the cave through its surface forays. On the surface, the red imported fire ant, *Solenopsis invicta*, is an important introduced predator. Possible interactions (competition and/or predation) between cave crickets and red imported fire ant could, therefore, have significant impacts on cave communities. Thus, the foraging range of the cricket has significance for land managers who may wish to control red imported fire ant populations around caves that contain federally endangered terrestrial cave invertebrates.

Education

Going for the Gold Award: Girl Scouts, Cavers, and Government Working Together for Cave and Karst Sourcewater Protection

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Abstract

Good things can happen when diverse groups of people work together. This is one example. The Girl Scouts of the Virginia Skyline Council Adventurers have provided many opportunities to educate young people and the public about the importance of cave conservation and karst sourcewater protection. Involvement with the Adventurers began with a few Girl Scout Caving Trips led by the author with assistance from members of the VPI Cave Club. Presentation of a strong safety and conservation message and basic information on cave science was a major element of every trip. Over the years, as the program's reputation gradually became established, opportunities to spread the word about karst-related environmental issues presented themselves. Occasional feature stories in area newspapers provided an excellent venue to inform the public about why karst sourcewater protection and cave conservation are essential. The scout trips continued at a rate of two or three trips per year. The aim was to allow small groups of motivated young people to learn about and experience caves without appreciably increasing the number of new cavers. One particularly enjoyable media experience was a project to produce a piece on the Adventurers Caving Program for the National Geographic Today Show. The National Geographic Television segment delivered a strong cave conservation message to a national audience. A recent project to clean out a trash dump from Nellies Cave in Blacksburg, Virginia, involved cooperation between girl scouts, members of the Virginia Region of the NSS, local and state government agencies, and the news media.

About the Author

Joey Fagan started caving in 1966 in Virginia. He works as a Karst Protection Specialist for the Virginia Department of Conservation and Recreation Division of Natural Heritage Karst Program. Joey currently serves as the Secretary of the Virginia Cave Board. He is one of the founding members of the Blue Ridge Grotto, a member and Conservation Chairman of the VPI Cave Club, and active in the Virginia Region of the NSS. He was VAR Conservation Chairman and Secretary/Treasurer during the 1970s as well as a past Director of the Cave Conservancy of the Virginias and of the Virginia Speleological Survey. He serves as the Caving Coordinator for the Girl Scouts of the Virginia Skyline Council Adventurers Program and is on the NSS Youth Group Liaison Committee. Joey has been a member of the NSS for more than 35 years and became a Fellow of the Society in 2003.

National Cave and Karst Research Institute 2003: Working Through Partnerships Towards America's Future

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Abstract

Congressional legislation directed the National Park Service (NPS) to establish the National Cave and Karst Research Institute in the Carlsbad, New Mexico, area to further speleological research, enhance public education, and promote environmentally sound cave and karst management. The legislation further requires that the NPS jointly administer the Institute with "a public or private agency, organization, or institution." The Institute has a national, even international, mission.

Currently, Institute funding primarily comes from two sources: The National Park Service and the State of New Mexico. As the Institute must at least equally match federal funds with non-federal funds, an important issue for the success of the Institute is establishing an extended network of non-federal funding sources, which might include non-federal grants, partnership initiatives, fee-based services, product sales, and public donations.

Determining the exact functions and organizational structure of the Institute within these requirements constitutes a major component of the current "Gearing Up" phase. The Institute staff has made major strides in extending the base of participants in this effort over the last six months, involving major academic, government, and non-profit organizations and several national laboratories nationwide. The goal remains to develop a broad coalition of diverse cave- and karst-related partners working together towards improving our national understanding and stewardship of these sensitive terrains.

Pre-Institute Enabling Act History

In 1990, Congress passed Public Law 101-578 (NCKRI, 2003a) directing the Secretary of the Interior, through the Director of the National Park Service, to establish and administer a Cave Research Program and prepare a proposal for Congress that examined the feasibility of a centralized National Cave and Karst Research Institute. The Secretary sent the National Cave and Karst Research Institute Study Report to Congress in December 1994. The 1994 Report made several key recommendations:

- The National Park Service and another entity, probably academic in nature, should jointly administer the Institute;
- The National Park Service would have ultimate responsibility for the Institute and would retain indirect control over its activities and programs, while the academic entity/managing partner would plan, coordinate, and administer the Institute and its programs;
- The Institute should be located in the vicinity of Carlsbad Caverns National Park;

- Its three essential missions would be information management, research, and education.

The National Cave and Karst Research Act of 1998

Congress passed the National Cave and Karst Research Institute Act of 1998 generally following the recommendations of the 1994 Report (U.S. Congress, 1998). The stated purposes of the Institute are:

- to further the science of speleology;
- to centralize and standardize speleological information;
- to foster interdisciplinary cooperation in cave and karst research programs;
- to promote public education;
- to promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
- to promote and develop environmentally sound and sustainable resource management practices.

The legislation directed the Secretary of the Interior to create the Institute, acting through the National Park Service. It designated the Carlsbad, New Mexico, area as the home for the Institute and also stated that the Institute could either lease or build a suitable facility. Although the National Park Service would establish the Institute, Congress directed that the National Cave and Karst Research Institute be jointly administered by the National Park Service and a private or public partner and operated in accordance with the 1994 Report to Congress. A key "matching funds" provision was inserted by Congress, directing that the Secretary of the Interior may spend federal funds for the Institute only to the extent that they are matched by an equal amount from non-federal sources. The Institute may accept grants from private persons and transfers of funds from other federal agencies. However, the current interpretation of the legislation requires that funds provided by any federal agency (That is, USGS, USDA, EPA, NSF, NPS, and so on.) to support Institute programs must also be equally matched by non-federal funds.

Initial Development Phase

The National Park Service assigned responsibility for implementing the Act jointly to the Intermountain Regional Office and the Geologic Resources Division, a national office. An initial challenge was that while the Act provided authority, Congress did not appropriate any funding for the Institute at that time. In July 2000, the Geologic Resources Division hired Interim Director Zelda Chapman Bailey on a term appointment to begin developing the Institute by defining the scope of operations, forming initial partnerships, securing both federal and non-federal funding, and developing proposed organizational structures and plans for a physical facility.

Interim Director Bailey's assignment emphasized developing collaborative relationships and she traveled extensively, networking with a variety of groups. Bailey also started a tradition of e-mailing monthly summaries of Institute activities to interested individuals (NCKRI, 2003b). She launched a Web site for the Institute in September 2001 to provide general information on the Institute to a wider audience and to solicit input into the formational process of the Institute (NCKRI, 2003c).

Federal Working Group

As part of this initial effort, the National Park Service established the National Cave and Karst Research Institute Federal Working Group. Twelve cave and karst land management experts represented the National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service, U.S.D.A. Forest Service, U.S. Environmental Protection Agency, and U.S. Geological Survey. They also communicated with cave and karst interest groups to provide their perspectives and to keep them informed on Institute activities.

The Working Group met twice yearly between December 2000 and February 2003. Meetings took place in different cities to allow individuals with interest in the development of the Institute to attend. During those two-plus developmental years, the Working Group provided guidance to the Interim Director concerning all aspects of establishing the Institute and worked on a wide range of issues ranging from the Institute's mission and goals to building requirements, funding sources, and research priorities. The Federal Working Group also looked at the Institute's possible organizational structure, management issues, and potential models for advisory boards. In December 2002, the National Park Service hired Dr Louise Hose as the Institute's Director. The Interim Director's position tenure ended in April 2003.

Why Carlsbad? Why New Mexico?

The Institute's enabling act specifies that it must locate in the vicinity of Carlsbad Caverns

National Park, but not within the boundaries. This directive followed the recommendation of the 1994 report, which also considered sites at or near Mammoth Cave, the Black Hills of South Dakota, Ozark Plateau, and the Colorado Plateau. The Carlsbad setting offered many advantages:

- The community has traditionally provided strong support for Carlsbad Caverns National Park and, more recently, Guadalupe Mountains National Park;
- Dozens of world-class caves in the area attract a stellar list of top cave and karst researchers from around the world each year;
- Dozens of caves in limestone and gypsum lie within a half-hour drive from town;
- Lava tubes are less than three hours away, providing a remarkable diversity of cave types nearby;
- The local economy has close ties with karst as the local aquifer and petroleum production occurs in karst.

However, probably the most compelling reason is that the City leaders and the New Mexico Congressional delegation aggressively sought support for establishing the Institute. They continue to provide strong, proactive support.

Summary of Some Recent Activities

Funding the Institute presented the biggest initial challenge. The State of New Mexico stepped forward and provided the first formal funds for the National Cave and Karst Research Institute starting July 2001. The National Park Service equally matched the state's $350,000 during the next federal fiscal year, FY2002. Both entities have continued to provide similar support in the following years.

Most of the State funds support the development of a Cave and Karst Studies undergraduate and graduate program at New Mexico Institute of Mining and Technology (New Mexico Tech) in Socorro, New Mexico. The National Park Service funding supports the development of the Institute and its activities in Carlsbad as well as provides support for a variety of collaborative projects with cave and karst programs across the country. Among the larger projects are the National Karst Map Project with the U.S. Geological Survey and a land managers' graduate program with Western Kentucky University.

The February 2003 signing of a Memorandum of Understanding by the Institute's three primary partners, the National Park Service, The City of Carlsbad, and New Mexico Tech, paved the way for the design and construction of a headquarters building for the Institute. Among other issues, the Memorandum established a basis for cooperation in planning the "Institute's physical facility" as well as any individual cooperative agreements related to the financing, construction, and operation of the Institute building.

How Funding Works

Current operational funds derive from three sources: (1) the National Park Service has an annual appropriations line of about $350,000 to support the Institute; (2) the State of New Mexico also has an annual appropriations line of approximately $350,000 to support cave/karst programs related to the Institute through New Mexico Tech; and (3) donations and other support provided by non-federal partners. A building fund for the Institute's headquarters building in Carlsbad currently contains about $4,306,900 from three sources: (1) the State of New Mexico has appropriated $1,350,000 to the City of Carlsbad for NCKRI headquarters; (2) the City of Carlsbad has promised an additional $1,000,000 "in-kind" donation of land, roads, and utilities for the building; Congress has appropriated $1,956,900 for the building to be passed from the National Park Service to the City of Carlsbad.

Role of the National Park Service's Geologic Resources Division

The National Cave and Karst Research Institute shares a home within the Geologic Resources Division (Division) of the National Park Service in Denver, Colorado, with the National Park Service Cave and Karst Program. The Division provided the seed funding to bring in the Interim Director in 2000 and continues to supply a variety of support services and advice to the Institute, especially concerning policy, legal, and National Park Service and federal-related issues/efforts. Division Chief Dave Shaver administratively oversees the Institute for the Park Service.

Summary of Current Staffing and Activities

The National Park Service hired Louise D. Hose as a permanent Institute Director in December 2002. Roger Scott, an National Park Service employee on intermittent status has worked part-time for the Institute throughout most of 2003. New Mexico Tech is currently

searching for a Chief Scientist to hire through a one-year, renewable contract. In addition, New Mexico Tech has a karst hydrologist, Lewis Land, assigned to the Institute. These four positions are stationed in Carlsbad. In Socorro, Penelope J. Boston has a half-time appointment to the Institute, which she uses to develop New Mexico Tech's Cave and Karst Studies academic program.

The current focus of the Institute lies in three areas: Working with the City towards designing the headquarters building, determining what NCKRI will do in the future, and addressing the jointly administered legislative mandate.

The City of Carlsbad will receive and manage all funds for the building project and they will own the building upon completion. However, the National Cave and Karst Research Institute Director, in consultation with the City, National Park Service, and New Mexico Tech representatives, is directing the interior building design. The City anticipates ground-breaking in early summer 2004 and building completion about the end of 2005.

While the purposes for creating the National Cave and Karst Research Institute are provided in the legislation, the language allows a broad range of interpretations concerning how the Institute will implement its mission. The core of many recent discussions revolves around whether the Institute will have in-house projects or should it limit itself to facilitating and supporting efforts by other organizations? Should the Institute initiate and lead efforts? If so, in which areas?

The 1994 Report to Congress suggested that the Institute would be administered on a daily basis by an academic entity with oversight by the National Park Service. There are no models within the Park Service or even the Department of Interior for such an organizational structure. Hence, the National Cave and Karst Research Institute has considered and extensively discussed with representatives of the broad cave/karst community a variety of models from other departments of the federal government.

Potential Models for a Jointly Administrated Institute

Models associated with other federal departments include:

- Government-Government Model
  - o An example would be the Leopold Institute, which operates through an interagency cooperative agreement between USDA-FS, BLM, NPS, USFWS, and USGS
    - § Focuses solely on all aspects of research and management for a single type of natural resource (wilderness)
    - § Partners with non-federal scientists through research projects, exchange programs, supporting visiting experts, sponsorships of lectures, workshops, and symposia, and involvement in professional activities and societies
  - o Biggest disadvantage to this model appears to be that it provides little opportunity to aggressively seek the mandatory minimum of 50% non-federal funding
- Government-Owned, Contractor-Operated

- o Abundant examples in other federal departments
  - § National Aeronautics and Space Administration: Jet Propulsion Laboratory/California Institute of Technology-operated (one university)
  - § Department of Defense: Stanford Linear Accelerator/Stanford University-operated (one university)
  - § National Science Foundation: NCAR/UCAR (consortium of PhD-granting universities)
  - § Federal Aviation Administration: Center for Advanced Aviation System Development/ MITRE (non-profit corporation)
  - § Nuclear Regulatory Commission: Center for Nuclear Waste Regulatory Analyses/Southwest Research Institute (non-profit corporation)
  - § Department of Energy: Sandia Laboratories/Lockheed Martin (for-profit corporation)
  - § Treasury: IRS Research & Development Center/MITRE
- o All of these examples are mostly or entirely funded by federal funds and do not provide significant opportunity for raising the non-federal match

- Government-University Partnership Network - Cooperative Ecosystem Unit Network
  - o Based on biogeographic divisions, not thematic
  - o Each unit has a "Host" university (Level 1, PhD-granting institute) and network of affiliates
  - o National Park Service provides a full-time coordinator, other agency representation varies
  - o Units and governing councils comprise:
    - § Other universities and colleges
    - § Non-profit and for-profit corporations/organizations
    - § Other federal agencies
    - § Other government agencies
  - o Once again, most funding is federal and administration is mostly controlled by the Park Service, not jointly operated
- NSF - Science & Technology Centers
  - o Federal oversight and review, but they do not set the agenda
  - o A PhD-granting, research academic institute serves as lead
  - o Core of several other partners
    - §Variety of other academic institutes
    - §National laboratories
    - §Private industry
    - §Non-profit organizations
  - o Must actively address 3 purposes through partnership efforts
    - §Cutting-edge research
    - §Knowledge transfer (industry, general public, etc.)
    - § Formal education
  - o Must raise at least a one-third match from non-federal funds
  - o STCs are thematic, but none focus on resource management issues
  - o The model is markedly different from anything currently within the National Park Service domain

Developing Collaborative Relationships

The enabling legislation requires that the Institute will be "jointly administered" by the National Park Service and another entity, the National Park Service will have "indirect control," and the organizational model and operational plan must promise opportunities to raise at least 50% of the funding from outside the federal government. This last requirement demands that non-federal stakeholders play a major role towards developing and operating the National Cave and Karst Research Institute, including participation in the decision-making process. The Institute must develop true, collaborative partnerships to flourish. In order to address this need, it is useful to review the factors influencing the success of collaborations. Mattessich *et al.* (2001) identified them, in order, as:

1. Mutual respect, understanding, and trust between partners
2. Sufficient funds, materials, and time
3. Appropriate cross-section of members
4. Multiple layers of participation
5. Members see collaboration in their self-interest
6. Development of clear roles and policy guidelines
7. Open and frequent communications

Seeking to develop a sense of broad community investment and participation in the National Cave and Karst Research Institute, the Institute and two of its primary partners, New Mexico Tech and the National Park Service, invited a diverse group of representatives from eight federal programs, two state agencies, five non-profit organizations, and six academic programs to a two-day scoping session in Shepherdstown, West Virginia, in early October 2003. A professional facilitator led the Developing the Vision Workshop and worked through ideas on what the institute should do

and how it should be "jointly administered" (LEAD Alliance, 2003).

Plans for the Future

Immediate plans for the future include continuing work on the building design (including a science library, museum, laboratories, and offices), producing the Institute's first Annual Report for 2003, and drafting a five-year business plan covering issues including how the National Cave and Karst Research Institute will be administered, prioritize what activities the Institute will pursue, staffing, and fund raising. The exciting future will present unique challenges and opportunities for the entire cave and karst community and the Institute could place the United States as the clear leader in karst research and management.

Acknowledgments

The authors wish to acknowledge the more than two years of dedicated efforts by members of the Federal Working Group during the initial development phase of the National Cave and Karst Research Institute as well as the hardwork and leadership provided by Interim Director Zelda Chapman Bailey during that time. During this past year, Jon Tully and Bob Forrest of Carlsbad; Van Romero and Richard Cervantes of New Mexico Tech; and Ron Kerbo, Ed Kassman, and, especially, Dave Shaver of the National Park Service Geologic Resources Division have provided critical support and encouragement towards the further development of the Institute.

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Creative Partnerships for Water Quality in Karst Areas

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Abstract

Partnerships are helpful, if not essential, for karst protection. As the use of such areas is on the rise, particularly in the way of development, increased efforts need to be made to protect it. This can pose a challenge, mainly as those involved may see things differently. However, steps can be taken to help bridge the gap. Education is a valuable tool in this endeavor as it has the potential to assist parties in reaching understandings without feeling threatened. Thus, increasing cooperation, decreasing duplication of effort, and inviting camaraderie. For example, Lindberg has brought many together for their mutual benefit by presenting them with the knowledge they need to understand karst areas and how and why it is important to work together for its, and their, protection. She has found that working with them has produced positive results. Serving as a liaison between area agencies, land trusts, planners, developers, the public, etc., she has helped them see how karst areas function—just because their features may be out of sight, they should not be out of mind. In the City of Bloomington, Indiana, efforts are being made to help all understand the way karst fits into daily life. For example, inter-related programs involving natural (karst) and man-made (storm drain) drainage systems have been developed and are being implemented. They include initiatives with Hoosier Riverwatch, Project Underground, storm drain marking programs, and so on. Viewers will learn not only what is being done but also how to go about doing it.

Partnerships are helpful, if not essential, for karst protection. As the use of such areas is on the rise, particularly in the way of development, increased efforts need to be made to protect it. This can pose a challenge, mainly as some of those involved may see things differently. However, steps can be taken to help bridge the gap. Education is a valuable tool in this endeavor as it has the potential to assist parties in reaching understandings without feeling threatened. Thus, increasing cooperation, decreasing duplication of effort, and inviting camaraderie. Many can be brought together for their mutual benefit by presenting them with the knowledge they need to understand karst areas and how and why it is important to work together for its, and their, protection.

Lindberg has brought many together on all levels—federal, state, and local government, businesses, individuals, etc—for their mutual benefit by presenting them with the knowledge they need to understand karst areas and how and why it is important to work together for its, and their, protection. Not all may see eye-to-eye at first, but a mutual trust can be established, diversity can be an ally. She has found that working *with* them has produced positive results. Just because karst features may be out of sight, they should not be out of mind.

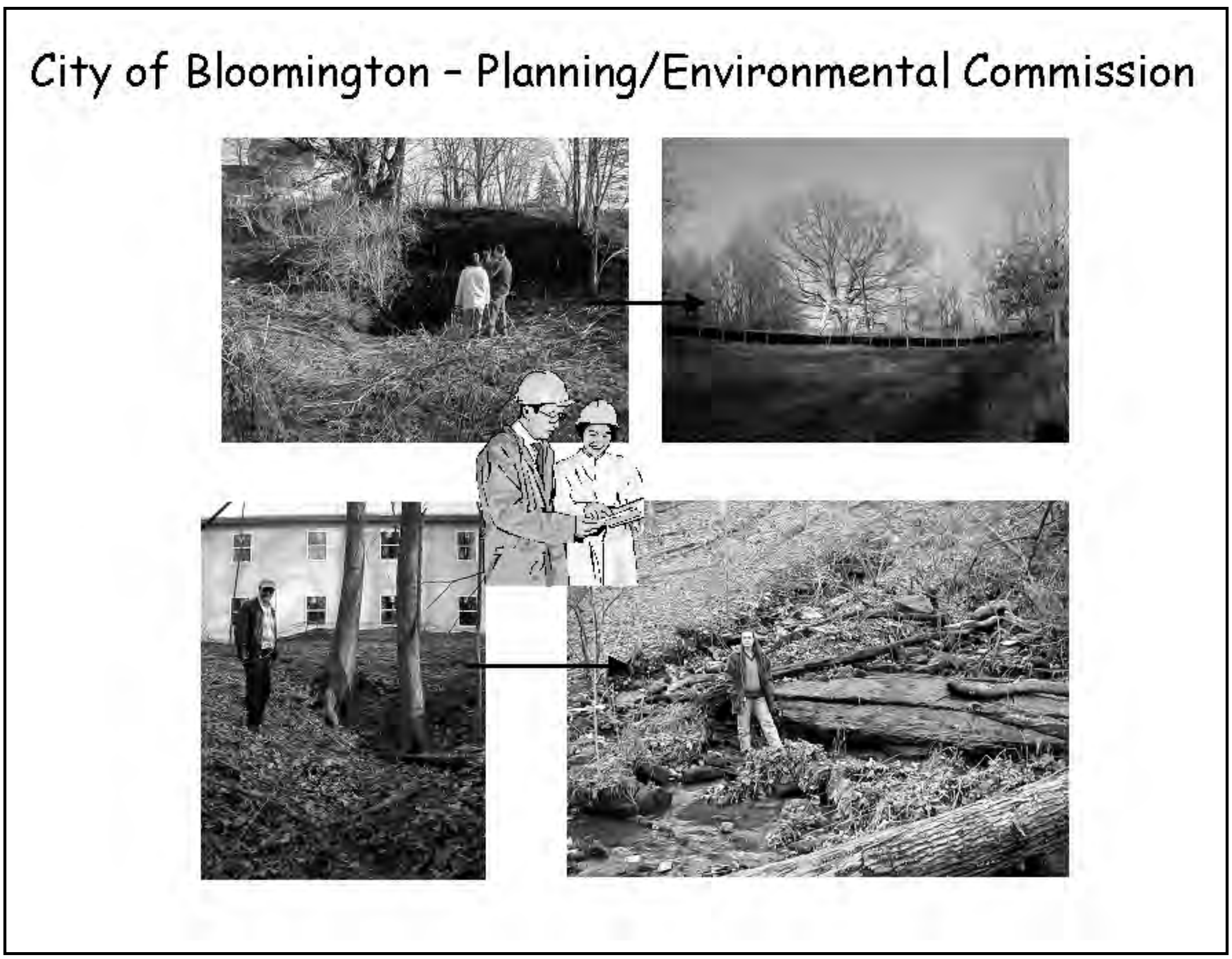
Take for instance the City of Bloomington, Indiana: efforts are being made to help all understand the way karst fits into daily life. For example, inter-related programs involving natural (karst) and man-made (storm drain) drainage systems have been developed and are being implemented. They include initiatives with storm drain marking programs (stenciling and/or placeing "buttons" near storm drains with messages such as "Dump no waste, drains to stream"), Hoosier Riverwatch (water quality

monitoring in streams), Project Underground (cave and karst conservation education), Adopt-a-Trail (trail maintenance to alleviate erosion), and so on. These "service-learning" or "citizen scientist" programs give members of the public a chance to get involved in their community while learning about the resources they are protecting. This can create or enhance a feeling of ownership and hence drive to protect the resource; therefore, making ordinances such as those involved in zoning more palatable and more likely to be followed.

Serving on an environmental commission can also help with the karst protecton process. Lindberg was appointed to the Bloomington Environmental Commission by the Mayor of the city. Bloomington lies in a transition zone with karst being primarily on the west side. In addition, she now serves on the Commission's Planning Subcommittee. This committee interfaces directly with the Planning Department. City and state inspectors are involved as well, including an Indiana Department of Natural Resources, Division of Soil Conservation, Storm Water Specialist. All work together in order to review petitions from developers and make recommendations that ultimately protect karst areas.

Speaking of drainage, a group of local agencies has been put together by Monroe County to work on the Environmental Protection Agency's Phase II (storm water quality) requirements. This focus group includes the county as well as the City of Bloomington and Indiana University. A committee has been formed to address the educational component—the Storm Water Environmental Education Team (SWEET). It is invaluable for us to work together on these and related efforts. By doing so, we do not duplicate efforts but rather draw upon each other's strengths to create a whole that is stronger.

The City of Bloomington's karst conservation and education park, Leonard Springs Nature Park, is used extensively in these efforts. It is a model park for karst, showing visitors a window in karst systems—cave entrances, springs, streams, and the like. For more information on the park, see Lindberg's NCKMS 1991 and 2001 presentations. The current presentation is an outgrowth of development of the park, a natural evolution.



Other lands, such as the Hoosier National Forest, are also helpful. A karst inventory program has been underway there for the past decade. Much has been learned about karst on the forest and a good partnership has been established. Rare, endangered, and new species have even been discovered. As a result, additional acreage has been purchased and proposed roadways have been steered away from sensitive karst areas. The Indiana karst Conservancy and The Nature Conservancy partnered with the USDA-Forest Service on many of these accomplishments. Awards for the project were received in 1998 (Environmental Protection) and 2003 (For Protecting and Enhancing the Nation's Natural Resource Base). Positive education and outreach such as the above has a positive effect on karst protection.

It is our hope that folks will learn from our positive examples on the local level and use them where applicable on their own areas, wherever they may be. Future presentations and papers will focus not just on what can be done, but how to do it.

It takes many to accomplish what we do. Thanks to everyone that has helped. Special thanks to IKC's Don Ingle and Bob Vandeventer, Ray Sheldon of the Indiana Cave Survey, and agency partners Steve Grubbs, Josh Campbell, Steve Cotter, Joey Fagan, Lynne Friedmeyer, Sam Frushour, Sharon Hall, Kelle Reynolds, Todd Stevenson, and Carol Zokaites.

About the Author

Kriste Lindberg has been an active member of the caving community since 1992, mainly in the fields of conservation, education, and inter-agency cooperation, having been introduced to it while working with the Chicago Academy of Sciences after receiving BGS and MSEd degrees in natural resources. She has served on the Indiana Karst Conservancy board as a Director, Secretary, and President, is currently a Director and Chairman of the Education and Outreach Committee, which she created. She is employed by both the City of Bloomington's Parks and Recreation and Utilities Departments as an Education Specialist, has recently been appointed by the Mayor to serve on Bloomington's Environmental Commission, and has done numerous articles and presentations for cave-related venues, including the NCKMS 1999, 2001, and 2003. In 2002, she received the NSS Conservation Award and was honored as Fellow of the NSS. In 2003, she was elected to the board of Project Underground.

The Importance of Education in Karst Protection: the Virginia Experience

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Abstract

By the early 1990s, it became apparent that Virginia needed to protect its karst landscape. Twenty-seven Virginia counties depend heavily on karst aquifers for water supply. Industrial, agribusiness, and rural residential development were placing increasing stress on karst aquifers already impacted by traditional agricultural land use. The problem was convincing government agencies and local citizens of the need for karst groundwater protection. Education proved to be the solution. This paper examines the many ways education has furthered the cause of karst protection in Virginia. Educational materials from government agencies and the caving community have increased citizen awareness of Virginia's karst resources. The Cave Conservancy of the Virginias produced the widely distributed book *Living on Karst*, which explains basic karst science in layman terms and makes a strong case for karst protection. The Virginia-based Project Underground curriculum brought karst issues into primary and secondary school classrooms, as well as to environmental educators at museums, state parks, and soil and water conservation districts. The bench-scale karst groundwater model, produced by the University of Nebraska – Lincoln, is a visual tool that demonstrates surface water and groundwater interactions in karst. Numerous Virginia agencies and non-profit organizations now use this model. Numerous presentations and workshops have helped planning district commissions, local governments and state and federal agencies create new standards and ordinances protecting karst watersheds. Ten years ago most citizens in Virginia's limestone regions had never heard the word karst. Today, awareness of karst is widespread, and stakeholders are taking concrete steps toward karst protection.

Introduction

Caves have been a prominent part of Virginia culture since colonial times. Organized cave exploration began in the 1940s, and many old cave maps date from the 1950s. By 2003, over 4,000 caves in 27 counties were known to the caving community. Underlying about a quarter of the state, karst aquifers supply water for drinking, agriculture, and industry, and stream and river recharge. In the early days of Virginia caving, most of the karst landscape supported an agrarian economy with a low population that relied on springs and shallow wells for water supply. As the population grew and land use patterns changed, it became clear that many land use practices had negative impacts upon karst. Citizens, state and local officials, and agency staff alike lacked knowledge about the hydrologic importance and environmental sensitivity of karst water supplies.

By the early 1970s, members of the caving community recognized the need for karst protection and became advocates for such efforts, spearheaded by the Richmond (Virginia) Area Speleological Society (RASS). Lobbying by these dedicated cavers led to a significant state role in cave and karst protection. In 1975, a committee comprising cavers, agency staff, representatives from commercial caves, and a legislator began discussing potential roles for the state in cave conservation (Wilson, 1981). Though the initial committee disbanded, Richmond caver John Wilson worked with Delegate Bill Axselle to draft a resolution forming a temporary cave commission, which passed in 1978 (Wilson, 1981). This commission, composed dominantly of cavers and chaired by

Wilson, drafted the Virginia Cave Protection Act (aka Virginia Cave Law), which passed in 1979.

The Cave Law established the Cave Commission for an additional year, outlawed the sale speleothems, removal of material from a cave without a Cave Board permit, and dumping in sinkholes. Landowners were exempted from the final two restrictions, and shielded from liability for caving accidents as long as the owner did not charge for access to the cave. During its first year, the Cave Commission compiled a list of 220 significant caves and seven significant karst areas and completed an inventory of caves on public land. In 1980, the Cave Commission was given nonfunded, permanent status within the Department of Conservation and Economic Development. Since then, reorganization of state government led to name changes leading to the current (2003) nomenclature: the Virginia Cave Board of the Department of Conservation and Recreation.

The establishment of the Cave Commission as a state agency came without funding from the General Assembly. In 1980, members of the Cave Commission responded by establishing the Cave Conservancy of the Virginias to promote the conservation, scientific study, and responsible management of caves. The Cave Conservancy was also to serve as a non-profit fund-raising organization to help achieve the above purposes and to provide grants to other organizations devoted to similar goals.

The Cave Protection law said the Cave Board would act as an advisory board to any requesting state agency on matters relating to caves and karst, maintain a significant cave list and report any real and present danger to such caves, assist in publishing materials on caves and cave-related concerns, and inform the public about the value of cave resources and the importance of conserving them for the citizens of the Commonwealth. The Cave Board worked with the caving community to fulfill these duties and Virginia agencies started hearing the word "karst" and the importance of its protection.

Education projects by the Virginia Cave Board included producing a cave conservation poster titled "In Karstlands . . . What Goes Down Must Come Up." The poster was distributed to earth science teachers across the state and is now distributed in Project Underground workshops. The Cave Board also produces an informative Cave Owner's Newsletter, periodically mailed to over 1,500 landowners in Virginia who have caves on their property (Kastning, 1995) The Cave Board also established "Virginia Cave Week" in 2000 to bring attention to cave and karst education and protection. During Cave Week the Cave Board sends packets of materials to interested teachers, members give talks at media events, and show caves present educational displays. The general public is encouraged to visit show caves, many of which offer special discounts and host special cave week events. Members of the Cave Board also serve as consultants with other Virginia cave organizations on conservation projects.

Several other organizations have also contributed to karst education and protection in Virginia. The Cave Conservancy of the Virginias has initiated many karst education projects including two museum displays. In a joint project with the Richmond Area Speleological Society, the Cave Conservancy of the Virginias sponsored a man-made cave at the Children's Museum in Richmond, Virginia, allowing thousands of children to explore and experience the wonderment of a cave, coupled with a strong cave conservation message (the Cave Conservancy of the Virginias web site). In a joint project between the Cave Conservancy of the Virginias and the Virginia Natural History Museum, a mobile mini-theater and exhibit were created to tour various locations in the Virginias and educate the public on the geology, biology, hydrology, history, and ecology of caves and karst (the Cave Conservancy of the Virginias web site). The Cave Conservancy of the Virginias also produced the *Living on Karst* publication talked about later in this paper. The Virginia Speleological Survey has established and maintains a database of cave resources, from which the significant cave list was developed. The Virginia Region of the National Speleological Society, as well as local grottoes (cave clubs), has lead numerous cave conservation activities, including restoration of degraded caves and sinkholes. Many cavers in Virginia have also lent time and expertise when needed to cave education and conservation activities. All of these activities continue today.

As significant as the efforts of these volunteer groups were (and continue to be), by the early 1990s, the demand for karst education greatly exceeded their capacity. Karst education needed to be brought into classrooms, boardrooms, and living rooms.

Three initiatives of the mid-1990s help to make this possible: (1) the initial development by the Richmond Area Speleological Society of Project Underground, (2) the establishment of a salaried, state position in karst protection in the Virginia Department of Conservation and Recreation's Natural Heritage Program, and (3) the publication of *Living On Karst – a Reference Guide for Landowners in Limestone Re-*

gions by the Cave Conservancy of the Virginias. The Richmond Area Speleological Society worked together with several groups to produce the Project Underground Natural Resource Activity Guide. The Virginia Department of Conservation and Recreation received a grant to start a Karst Protection Program within the agency. These three programs provided a means to increase cave and karst education, which in turn has led to many new protection strategies in Virginia.

Project Underground

The Richmond Area Speleological Society initially developed the Project Underground Activity Guide in 1993 in response to a lack of educator training materials available on cave and karst resources (Figure 1). A writing workshop brought together cavers and environmental educators to develop activities to teach about cave and karst resources. Titles and objectives of some of these activities are shown in Table 1. These activities were field tested by educators and revised to best meet the needs of educators. To encourage incorporation into lesson plans, each activity includes information on the objectives, subject, skill level, group size, time required, and key vocabulary words. Following the successful model of other national environmental education programs, Project Underground activities are hands on and lead to participant discovery of the objectives. These lessons and activities are both interdisciplinary and adaptable, covering many subject areas and all grade levels.

Table 1. Examples of Project Underground Exercises

Activity	**Objective**
Lost River Village	Illustrates potential impact to karst of land development, teaching participant importance of careful planning.
Sinkhole in a Cup	Shows students how sinkholes are formed via collapse of voids.
Hungry Cave Critters	Demonstrates that cave animals compete for limited food resources. Explains the concepts of food generalist vs. food specialist and the food web.
Hello, Who's There?	Demonstrates that caves provide suitable habitats for wildlife species.
Belly-Crawl Mapping	Recognize and apply simple map-making and map-reading skills.

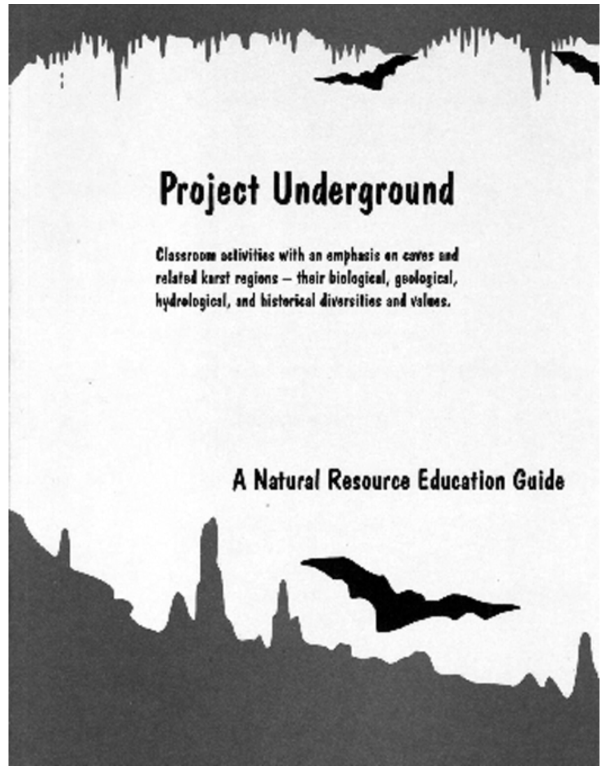

Figure 1. The Project Underground Activity Guide

The challenge became developing an environmental education program using the Project Underground activity guide. In 1996, a non-profit corporation for Project Underground was established and a Board of Directors elected. Carol Zokaites was hired to create and direct the Project Underground program. Carol established a workshop format for the program using a "train the trainer" model to establish a facilitator, or workshop leader, network. Following the example of other highly

successful national environmental education programs, Project Underground materials are only distributed through these workshops. This provides a level of quality control not present in many environmental education curricula.

Project Underground staff holds trainings for facilitators, who in turn hold workshops for teachers. This two-tiered approach in training facilitators and educators through workshops is a good avenue for reaching a large number of students with cave and karst information. If ten facilitators each lead one workshop with ten educators then 100 educators are trained to use the Project Underground materials with students in classrooms. If each educator has a class with 20 students then 2,000 students will be introduced to these materials. These students will learn the importance of protecting the valuable cave and karst resources.

Facilitators first provide workshop participants with a primer on cave and karst science, using background discussions and slide shows to explain to participants both what they need to know about karst resources, and why it is important, emphasizing the connections between surface and groundwater and the need for groundwater protection. Facilitators not only provide educational materials, but also instruction on the use of these materials in the classroom. Using the Project Underground Activity Guide as the focus, workshops supply teachers with lesson plans, posters, fact sheets, brochures, and reference books.

One component of project underground that makes it attractive to classroom teachers is its compatibility with state and national science education standards. In Virginia, the karst education coordinator (see below) has developed charts for teachers that correlate specific Project Underground activities with state Standards of Learning. This is critical because these Standards of Learning drive what goes on in the classroom.

Project Underground trainings and workshops incorporate materials, tools, and experiences in addition to the Project Underground Activity Guide. A wide range of brochures and posters on cave, karst, and groundwater topics from a variety of sources are distributed to participants. Of particular importance is the *Living on Karst* pamphlet produced by the Cave Conservancy of the Virginias (see below). One of the most effective visual aids used in workshops is the University of Nebraska Karst Groundwater model (Figure 2). The plexiglass tabletop model is a good visual tool emphasizing the differences between karst and non-karst aquifers. Participants see how fast surface water can interact with groundwater in karst. Many ambivalent adult Virginians have become advocates for karst protection after seeing the groundwater model. For workshops in Virginia, project underground staff coordinates with karst program staff to provide field trips to sinkholes, sinking streams, and springs. Many participants have never seen these features in the field, or if they have did not realize their significance. Use of these additional resources greatly enhances workshops, helping to make educators into advocates.

Though the Project Underground Activity Guide and curriculum were initially designed for K-12 education, it quickly became apparent that its usefulness extended to adults as well. Activities such as "Lost River Village" help

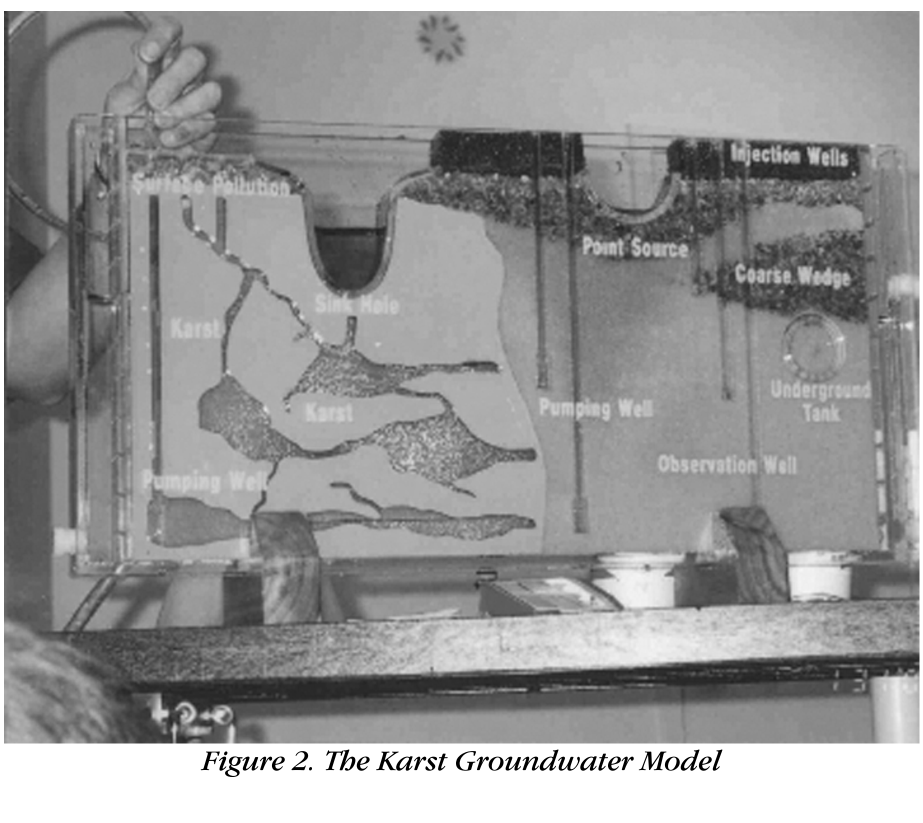

Figure 2. The Karst Groundwater Model

adults understand the risks of improper land use on karst, and the importance of careful planning. Future development of more advanced versions of Project Underground activities should go even further to educate local government officials and agency staff about the importance of karst protection.

Project Underground has worked closely with the Department of Conservation and Recreation 's Virginia Karst Program since its inception in 1994. In May 2000, the Virginia State Corporation commission held hearings on a proposed high voltage power transmission line to be constructed across one of Virginia's more significant karst areas. The State Corporation Commission approved construction of the line, but required a much higher degree of water quality protection where it crossed sensitive karst areas. The hearings brought karst concerns to the attention of then Department of Conservation and Recreation director David Brickley, who established the karst education coordinator position in the Virginia Karst Program. This three-quarter-time position has been filled since its creation by National Project Underground Coordinator Carol Zokaites.

Project Underground was developed in Virginia and has worked closely with the Virginia Department of Conservation and Recreation for the last eight years. The program is growing nation wide and has reached over 3,500 teachers in 14 states. In 2002 the Project Underground program held 30 workshops reaching 540 teachers and educators. The teachers used these lesson plans and activities with over 11,000 students and targeted members of the general public. And Project Underground should exceed that number in 2003.

Living on Karst

The Cave Conservancy of the Virginias recognized the need for information about karst resources for the layman and worked with the Virginia Karst Project to produce *Living on Karst - A Reference Guide for Landowners in Limestone Regions* (Figure 3). Carol Zokaites, coordinator for Project Underground, edited the publication, with significant help from Terri Brown, the VA-DCR Karst Program Coordinator. Written in an easily understandable fact sheet format, the *Living on Karst* guide targeted a very large, general audience. To quote from the guide:

"This guide will be helpful to homeowners, farmers, cave entrance owners, business people, and anyone who lives, works, or plays in karst areas. Additionally, the guide will be useful to educators, developers, park managers, watershed, and conservation groups. Karst is an important resource in your state. Not only does karst contain beautiful features such as fragile cave formations, it also may hold the key to health of an entire town or city by its links to drinking water."

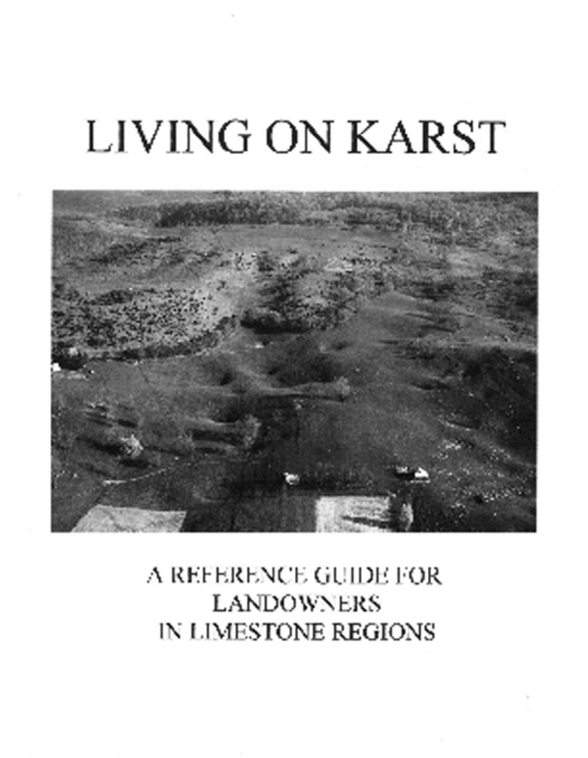

Figure 3. Living on Karst: a Reference Guide for Landowners in Limestone Regions

The *Living On Karst* guide became a general primer for karst education. Topics like "What is Karst" and "Karst and Groundwater Protection" defined karst and made the case for its protection. Topics relevant to the homeowner included "How's Your Septic System Doing," "Pollution and Protection of Karst Wells and Springs," and "Pesticides on the Home and Farm." Thousands of copies of this guide have been distributed across Virginia leading to many discussions on karst and groundwater protection. Such published information has increased awareness and led to better karst protection practices. Stakeholders began asking two questions: "What can be done to protect our karst resources?" and "Why aren't we doing it?" The result has been that numerous localities and state agencies have or plan to revise their ordinances and policies to address karst protection needs.

The Virginia Karst Program

By 1993, the Cave Board's efforts had opened the eyes of the Department of Conservation and Recreation's Natural Heritage program staff to the importance of protecting karst resources through education, outreach, and technical assistance. Natural Heritage submitted a successful Projects of Statewide Importance Grant Proposal as part of Virginia's proposal to the Environmental Protection Agency Section 319 Clean Water Act fund. The resulting karst project educated the legislature and the public about the importance of protecting karst areas in order to protect groundwater and to promote the development of karst protection regulations. In 1994, the Department of Conservation and Recreation hired Terri Brown as Karst Protection Coordinator and established an office in Blacksburg, the center of Virginia's 300-mile belt of karst. Terri gave talks across the state at agency meetings, conferences, and local governments. She worked very closely with the Virginia Cave Board and enlisted the help of local cavers, Project Underground, and The Cave Conservancy of the Virginias. Fact sheets on karst areas and karst biota were developed and disseminated across the state through the soil and water conservation districts. Workshops have been held in several karst watersheds bringing stakeholders with varying interests to the table, including government officials, citizens, developers, consultants, and agency staff.

The Department of Conservation and Recreation's Karst Project continued to be supported by successful annual grant applications from 1995 through 2000. During this period, Virginia's karst received increasing consideration from state and federal agencies, local governments, and citizens. The karst protection coordinator served as Virginia's full-time, on-call karst expert. Informal networks sprung up, and people began working across agency boundaries on karst protection problems. Numerous partners in karst protection have emerged, including the U.S. Fish and Wildlife Service, the USDA Natural Resources Conservation Service, the Nature Conservancy, and the Virginia Departments of Transportation, Environemental Quality, Health, and Game and Inland Fisheries.

This networking facilitated the equally important technical assistance and data development aspects of the Karst Project. Working with the Cave Board and the Virginia Speleological Survey, the karst project has provided technical assistance to the Department of Conservation and Recreation environmental project review staff, identifying potential impacts to cave and karst resources and working to develop and implement avoidance, mitigation, and compensation strategies. The karst project has also helped revise state stormwater and nutrient management policies to better address karst concerns, provided training to agency staff, and assisted localities in development of ordinances, project review, and long-term planning.

The karst project has made substantial strides in watershed delineation via dye trace studies, inventory of karst resources, and biological inventory of Virginia's caves. Work has concentrated in areas rich in biological resources that were threatened by both existing and proposed land use practices.

In 2000, the Karst Project became the Virginia Karst Program, adding a second full-time Karst Protection Specialist and the three-quarter-time Karst Education Coordinator. The expanded Karst Program has continued to work on the same basic set of issues. Current projects include the development of conservation site boundaries for Virginia's significant caves, and the compilation of a GIS-based karst hydrology atlas.

Since 1994, karst education, technical assistance, and data development efforts have worked synergistically to make them collectively stronger than the sum of parts. For instance, results from hydrological investigations are integrated into Project Underground trainings and workshops at the local level. Project Underground lessons are used to illustrate karst principles to participants in technical assistance workshops, and the karst groundwater model is deployed at nearly every event.

Conclusions

The Virginia experience illustrates what can happen when education is used to increase the knowledge of citizen groups, public officials and students. At the heart of Virginia's success lies environmental education about karst, which led to a greater awareness about karst and a willingness to prioritize its protection. Following the lead of the volunteer caving community, the state of Virginia has pursued an increasingly significant role in both education about karst and karst protection. Ultimately, the success of this education program will be measured by the attitudes and actions of the planners, government officials, developers, and land managers working Virginia's karstlands.

About the Author

Carol Zokaites started caving in 1973 while attending Virginia Tech. She participated in many cave mapping and conservation projects. She has helped create several karst publications including *Living On Karst*, educational materials for the IMAX film, "Journey into Amazing Caves," and the guidebook for the 1995 NSS Convention "Underground in the Appalachians." Carol is a Fellow of the NSS and has received the NSS Conservation Award. She is now the National Coordinator of Project Underground and Karst Education Coordinator for the Virginia Department of Conservation and Recreation.

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Management

Restoration, Not Just Conservation, of Bat Caves — Need, Methods, and Case Study of a Myotis Sodalis Hibernaculum

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ABSTRACT

The Indiana bat (*Myotis sodalis*) is a federally endangered species reliant on very cold Eastern caves. Many historic roosts are no longer suitable due to saltpeter mining, commercial development, and excessive disturbance. Disturbance can be controlled through well-designed gates and other protective measures. However, physical changes to the cave, such as enlarging passageways and modifying entrances, can alter the microclimate inside the cave so that it is no longer suitable for Indiana bats, even with gating. In 1998 Bat Conservation International and the U.S. Fish and Wildlife Service began a long-term project to monitor and better characterize the temperatures and microclimates of some of the most important current and former roosts. This led to the discovery that many of the sites traditionally considered important and protected, were in fact marginal roosts to which the bats retreated when their primary roosts were no longer available or suitable. Further microclimate research in one cave, Saltpetre (Carter County, Kentucky) led to a predictive model of changes in microclimate throughout the cave system and throughout the year. In the summer of 2003 the first modifications to restore former habitat conditions were completed. Potential impacts to public tours and cultural material were considered and accommodated. Continued microclimate monitoring and future bat counts will provide additional data necessary to adjust the initial modifications in order to achieve the desired 3° C drop in the overall cave temperature.

Background

The Indiana bat ranges throughout the Appalachians and much of the Central Plateau. It was placed on the Federal Endangered Species list in 1967 due to its vulnerability and dramatic declines at its known roosts (32 FR 4001). It is a roost specialist, using a small number of particularly cold caves (3° to 6°C) as hibernacula. This behavior is possibly a strategy to avoid competition with other colonial hibernating species such as M. lucifugus and M. grisescens. However, it makes them more vulnerable to disturbance and roost loss. Indiana bats possibly numbered in the millions during pre-settlement times (Tuttle, 1997), but the numbers have been plummeting in recent years, from 883,300 in the late 1960s to early 1970s to 353,185 by the 1995 through 1997 winter surveys (U.S. Fish and Wildlife Service, 1999).

The 1983 Recovery Plan for the Indiana Bat (U.S. Fish and Wildlife Service, 1983) divided the known hibernacula into three categories: Priority 1 (30,000 *M. sodalis*), Priority 2 (500–30,000), and Priority 3 (500). The limited roost availability and preferences of the species are well understood when we see that 51.8% of the population was found in eight sites in only three states (Priority 1 caves). Another 44.7% were found in 69 sites in 11 states (Priority 2). The vast majority of known Indiana bat caves,

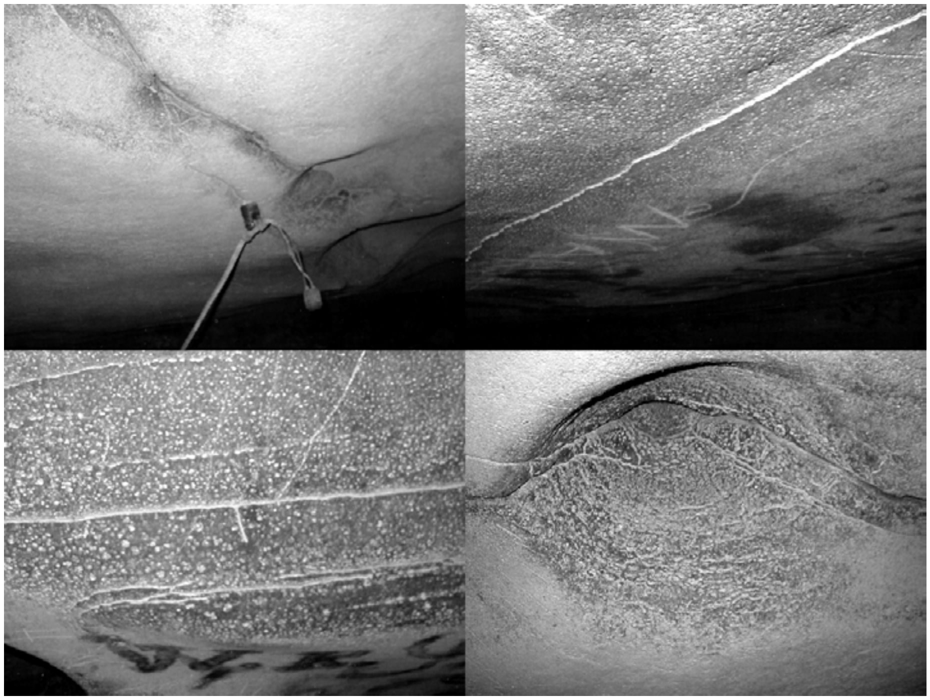

Figure 1. Obvious roost staining in Saltpetre Cave from hibernating Indiana bats. Note also the graffiti and remnants of old lighting. Photos by Jim Kennedy, © 2000 BCI.

259, only held 3.6% of the population (Priority 3). Clearly, even caves that are somewhat suitable for the species are not conducive to large colonies and population growth.

To further exacerbate the problem, the best caves for Indiana bats, that is the largest, deepest, and most complex, are often the caves most likely to be visited by recreational cavers or worse (for the bats), developed as a show cave. While disturbance is detrimental to the long-term success of the hibernating colony, the physical changes wrought upon the site through passage enlargement, entrance modification, and so on change the very airflow and temperatures which made the site so attractive to the bats in the first place (Tuttle and Stevenson, 1978).

In 1998, with support from the U.S. Fish and Wildlife Service and many partners, Bat Conservation International began a study of 12 of the most important Indiana bat hibernacula in six states. This program has received extensive cooperation from cavers, state and federal agencies, and others, and we now have temperature, humidity, and population data from over 40 sites in 10 states.

Our main goal was to categorize hibernacula as ideal (stable, cold temperatures), marginal (stable, high temperatures or sometimes cold but fluctuating temperatures) or risky (wildly fluctuating and sometimes too cold) (Tuttle and Kennedy, 2002). But we were also able to note human-induced changes in the cave microclimate in several cases and work to restore those conditions to something more preferred by the bats in hopes that the populations would slowly increase. One of these sites was at Carter Caves State Resort Park in eastern Kentucky.

Case Study—Saltpetre Cave

The Carter Caves State Resort Park karst contains at least 28 caves, four of which are known to have hibernating Indiana bats. These are former Priority 1 Bat Cave (3, 681 meters of passage), the Priority 2 Saltpetre Cave and Laurel Cave (3,005 and 1,091 meters, respectively), and the Priority 3 Cascade Cave System (over 3,200 meters, incompletely mapped). Historically, all have had public access year-round, with Bat and Laurel undeveloped (that is lights and walkways) and Saltpetre and Cascade developed. All were used for ranger-led tours except Laurel, which had unlimited permit access.

Bat Cave at one time held over 51,000 Indiana bats. Populations fluctuated erratically in the years since winter counts began, with little correlation to the known bat kills caused by flooding and vandalism. In addition, upper and lower entrances to the cave in an active stream valley cause warm air to flow up out of the cave in the winter, drawing colder air into the lower entrance, and reversing in the summer. This means that cave and roost temperatures are entirely dependent on the ambient (outside) temperature. Our 1998 visit confirmed our earlier conjecture: Bat Cave was a marginal roost. We had been protecting the wrong site for many years.

But what was the prehistoric site that was abandoned in favor of Bat Cave? And what caused the abandonment? An important clue came from the interpretive signs outside the

Welcome Center. Visitors were told that the Bat Cave tour was 13–16°C (55–60°F), but that Saltpetre was 8–9°C (47–49°F), clearly closer to the ideal roosting temperatures than Bat Cave. A brief inspection discovered extensive roost staining throughout the cave (figure 1), most of which was obscured by soot and graffiti. None of this was noticed before, and indeed, the multi-entrance cave was unrecognized as an important bat roost. Despite extensive modifications and visitation, it was still better on paper than nearby Bat Cave (Tuttle, 1998; Tuttle and Kennedy, 1999).

The years between 1998 and 2003 saw many extended visits to Saltpetre Cave to further study its historical changes and current microclimate. Dataloggers indicated that while the cave temperatures were still fairly stable, they were approximately 3°C (5.4°F) warmer than Indiana bats needed (figure 2). We also convinced Carter Caves State Resort Park to suspend winter tours in the cave to lessen disturbance. This action alone brought the Indiana bat numbers in the cave from 13 in 1983 to 3,100 by January 2003. This was a good indication that the cave was still attractive to Indiana bats, but we wanted to try to bring back the tens of thousands that must have once roosted there.

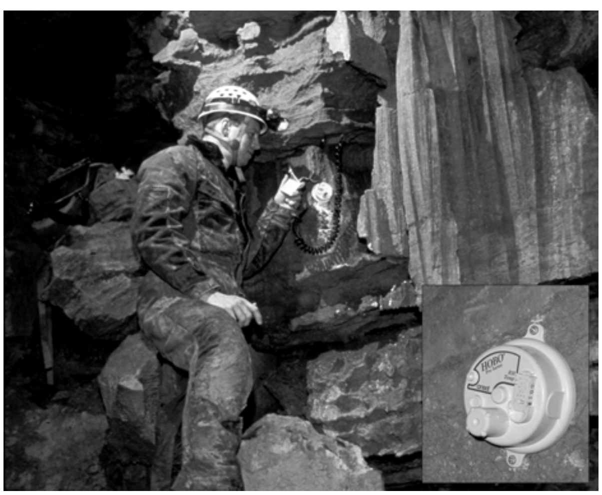

Figure 2. The author checking calibration temperatures at a datalogger in Saltpetre Cave. Inset is one of the Onset Computer Corporation HOBO Pro temperature/humidity dataloggers used in this study. Photo by Jim Kennedy, © 2001 BCI.

Part of our research was a collaboration with world-renowned cave microclimatologist, Australian Dr Neville Michie (figure 3), who undertook a detailed investigation into the atmospheric conditions in the cave, developing a temporal (year-round) and spatial (throughout the cave) model of the cave's microclimate. We had hoped that such a model would be predictive, allowing us to predetermine the effects of any changes we made in our attempts to restore cave conditions to those of 200 years past. Traditional trial-and-error methods were too lengthy and uncertain for the type of restoration we envisioned.

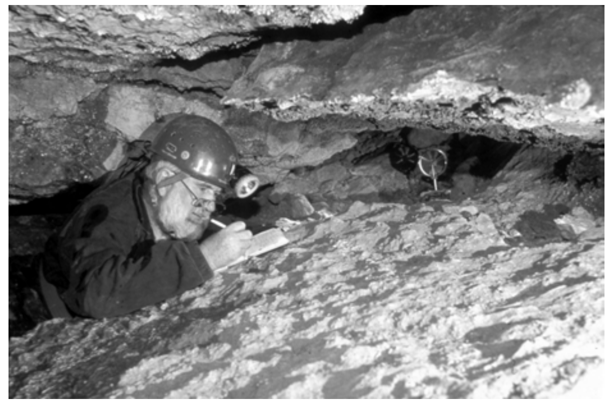

Figure 3. Dr Neville Michie recording airflow with a custom-built micro-anemometer at the S&M Breakdown in Saltpetre Cave, the connection to the Moon Cave section of the system. Photo by Jim Kennedy, © 2001 BCI.

Problems With Saltpetre Cave

Saltpetre Cave (figure 4) was extensively mined for saltpeter for the manufacture of gunpowder, probably as early as the War of 1812. Extensive passage modifications were made to facilitate this industry. Sporadic rural tourism began at the cave after the war, with small parties being guided through the enlarged passages but likely few other changes being made to the cave. A full-blown commercial operation soon was in place, with electric lighting and other modifications being made to the cave to facilitate groups. Some buildings, roads, and other "improvements" were made to the area in and around the cave in the Civilian Conservation Corps style. In 1946 the property was purchased by Kentucky State Parks, which further modified the surface and the cave, and continued to offer tours.

Specific changes to the cave included the enlargement of the fissure at the Main Entrance and construction of a building over the entrance (figure 5). This not only altered the original airflow patterns but further diverted cold winter air from flowing downhill into the cave. The building was secured by a very bat-unfriendly gate. A concrete staircase immediately inside the Main Entrance added to the natural-collapse rubble and en-

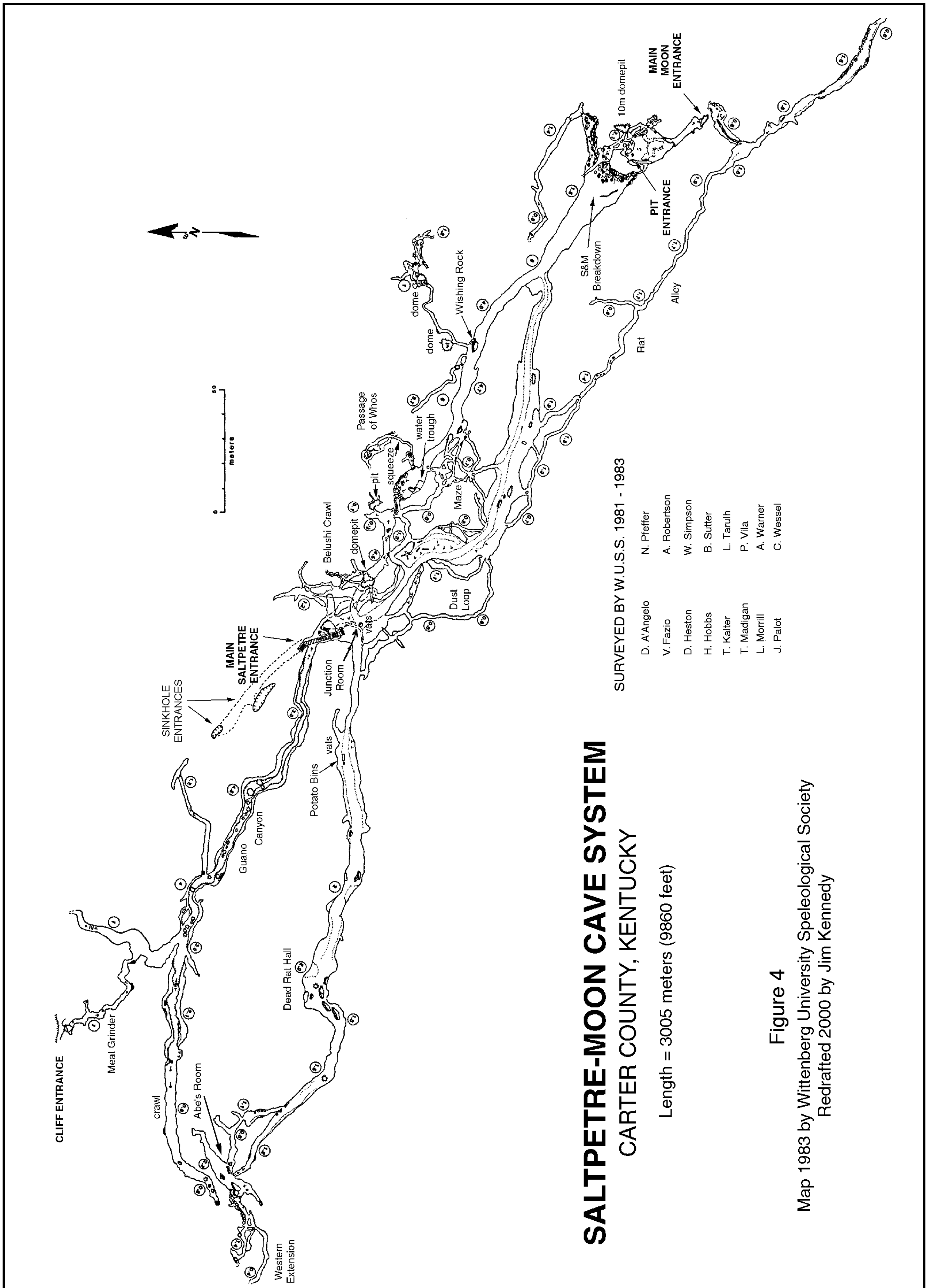

Figure 4

Map 1983 by Wittenberg University Speleological Society
Redrafted 2000 by Jim Kennedy

Figure 5. Building over Main Entrance to Saltpetre Cave before restoration work. The sinkhole entrances are just to the right, out of sight in this picture. Photo by Jim Kennedy, © 2001 BCI.

Figure 6. Volunteer caver Nick Booth clearing logs and brush from one of the sinkhole entrances to Saltpetre Cave. Photo by Cat Whitney, © 2003.

trance-enlargement rubble to create a very effective air dam, preventing cold air input from the lower Cliff Entrance during the winter (but allowing cold air leakage from the Cliff Entrance during summer). Two other fissure/sinkhole entrances (ungated) near the Main Entrance had been used as trash pits for generations (figure 6). Carter Caves State Resort Park continued this practice, disposing of logs, branches, and other landscaping waste into the sinks. This also reduced winter cold air input into the cave. Finally, within the cave, numerous passages were enlarged by saltpeter miners and tour route developers (figure 7), channelizing airflow through the cave and negatively reducing its transit time. Cold air flowing through the cave more quickly was not able to reduce the overall cave temperatures as

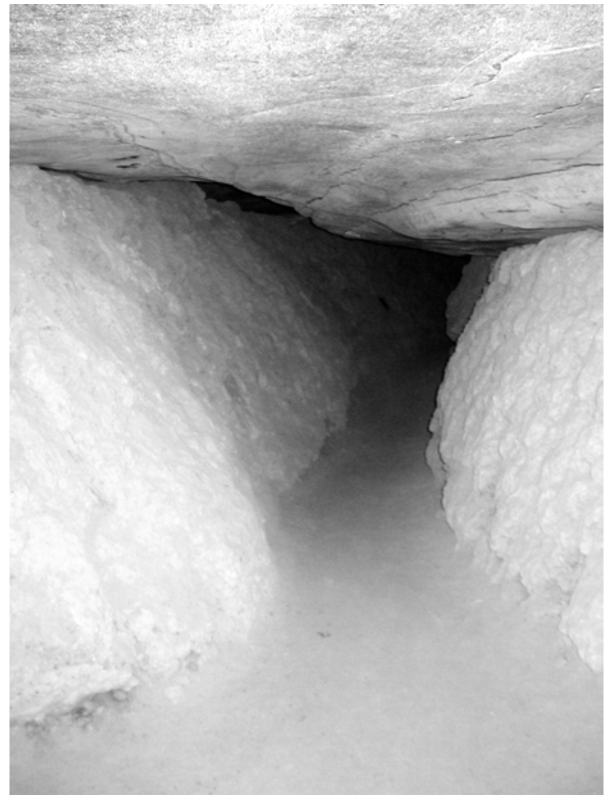

Figure 7. Heavily modified tourist trail in Saltpetre Cave. Original fossil stream passage is approximately 10m (33 feet) wide and up to 0.4m (1.3 feet) high. Current dimensions of the tourist trail are approximately 1.7m (5.5 feet) high by 1.2m (4 feet) wide, with excavation spoil piled to the sides of the tourist trail blocking access to the remaining original passage. Photo by Jim Kennedy, © 2000.

much as air with slower transit times. The air also no longer flowed into many of the side passages and loops it once did, reducing the "cold storage" capacity of the cave, a concept akin to the loss of "bank storage" in stream channelization.

Initial Restoration Attempts

Through Michie's work and the additional data gathered from our network of dataloggers, we proposed several restoration efforts to take place in the summer of 2003. They included modifications to the Main Entrance building, specifically removal of the old vertical-bar entrance gate; construction of a modern angle-iron, bat-friendly gate incorporating a larger interior flight area; removal of the solid wooden sides of the building and securing it with bat-friendly gates (allowing for more winter airflow to enter the cave); and building up

the hillside grade at the back of the building so that winter air would flow directly into the entrance rather than be diverted around it by the stonework. We also planned to clear the two sinkhole entrances by the Main Entrance and secure them with gates to allow for increased airflow. The low crawlway passage leading to the main cave from these entrances would be cleared of debris and slightly enlarged (to approximate prehistoric dimensions) in order to facilitate air flow. The last task on our agenda was the creation of a temporary wall in the cave to recreate a former passage restriction on a current tour trail, forcing the air out of its "channel" and through a longer, more complex path.

Many hurdles had to be overcome before the work could take place. A proposal was submitted for the work and approved, after a meeting and several modifications, by Kentucky State Parks and Kentucky Department of Fish and Wildlife Resources. One of the more unusual and difficult problems we faced was getting approval from Kentucky Heritage Council, the state archeological and historical agency. Because Saltpetre Cave is on the National Register of Historic Places, the Kentucky Heritage Council was very nervous about anything that proposed "digging" and other changes. During a planning meeting we had a walk-through with a state archeologist and had to agree to pay another state archeologist to monitor our work during the three days we were actually working on the sinkhole entrances. Unlike Kentucky Department of Fish and Wildlife Resources and Kentucky State Parks, Kentucky Heritage Council charged for time spent on the project. This unforseen expense was about 1/10 of our total project costs. We had to raise approximately $13,000 for the initial restoration work alone, not including Michie's research, five years of datalogger monitoring, planning meetings, and office time.

One of the biggest tasks in any project of this magnitude is always logistical planning. Scheduling between Carter Caves State Resort Park, Roy Powers (master gate designer), and me gave us relatively little time to order materials, recruit volunteers, and secure funding. We were very fortunate to have many talented cavers from a wide region come out to help. Carter Caves State Resort Park donated lodging for our crew, Kentucky Department of Fish and Wildlife Resources provided materials and additional manpower, and several organizations and agencies assisted with additional funding. Seven days later, phase 1 of our restoration work was finished.

It all came together the week of May 11–18, 2003. The building at the Main Entrance was

Figure 8. Building over Main Entrance to Saltpetre Cave after restoration work. Note bat-friendly horizontal bar gates. Photo by Traci Wethington, © 2003.

Figure 9. Caver volunteers Dale Lofland and Tanya McLaughlin constructing the temporary wooden wall for air flow diversion along a tourist route in Saltpetre Cave. Location is approximately same as in Figure 7. Photo by Jim Kennedy, © 2003.

made more bat friendly and modified to allow additional winter airflow into the cave (figure 8), the sinkhole entrances were cleaned out and secured with welded grating to allow enhanced airflow, and a temporary wooden wall and door were erected in the main channelized tour path to force winter air through former routes in other passages (figure 9). All of our primary objectives were accomplished. We even took the volunteers on an extended tour through the cave one evening, downloading the dataloggers and pointing out some of the geology, biology, and microclimate of the cave.

Future Work

More remains to be done. In summer 2004 we will download the dataloggers once again

to determine how effective our initial efforts have been. During the upcoming year, we also want to finish grading the rear hillside to the top of the stonework at the Main Entrance building. We need to build up a "lip" at the downhill side of the sinkhole entrances to replicate the former configuration (long since leveled) in order to "funnel" more cold winter air into these entrances. And while not directly impacting airflow, we also should re-gate the Cliff Entrance in order to make it more bat-friendly.

A bigger but potentially more important project is to perform radio location work on a former biological entrance (probably not human-sized) in Abes Room. There is an obvious sinkhole/hillside collapse terminating the cave in this direction, and ample evidence from bats and woodrats, such as roost stains, droppings, and old woodrat food caches, indicate that there was a connection to the surface in this area. This has since been plugged by either natural causes or by construction of the park road. Reopening this surface connection would restore airflow in that whole branch of the cave and increase humidity to former levels, allowing the recolonization of that area by the thousands of bats that once must have overwintered there.

Finally, we hope to be able to remove the concrete stairs and associated rubble at the Main Entrance and replace then with a more "transparent" design, such as an open-grate metal staircase. This would facilitate winter air input from the Cliff Entrance and increase contributions from the sinkhole entrances. Of course, we will continue monitoring temperatures and humidities throughout the cave and census the bats every other winter to gauge results. Our work at this cave will be used as a model for microclimate restoration at other impacted, formerly important hibernacula, such as Coach Cave (Kentucky), Mammoth Cave (Kentucky), and Wyandotte Cave (Indiana).

Conclusion

This paper represents a new way of looking at bat cave protection. Too often, we think that if we just put up a gate or avoid the cave when the bats are present, then the population will be protected and therefore successful. However, recent studies are showing that many of the caves being protected are marginally suitable or no longer suitable for bats due to physical changes made by humans in the recent past. Other marginal "bat caves" are being protected when more ideal roosts nearby, abandoned because of human disturbance, are unrecognized. It is important to identify these sites and protect them, even if bats are not currently using them. If there have been negative changes to the cave's microclimate (and by extension, the entire ecosystem) from human alterations, it behooves us to fix those problems. Small changes, such as those described at Saltpetre Cave, Kentucky, can have huge positive impacts on the populations of all cave bats, and especially the endangered Indiana bat.

Acknowledgements

The author would like to offer sincerest thanks to the many people involved in this project over the years. Especially former Park Naturalist John Tierney for his passion in doing the right thing; also Sam Plummer for onsite observations, labor, and much help during our research; and Carey Tichenor of Kentucky State Parks for smoothing the way at the state capital. Traci Wethington of the Kentucky Department of Fish and Wildlife Resources provided invaluable departmental support, funding for materials, and labor during the initial restoration project. Many cavers donated long days of labor as well. They are Allen Blair, Chuck Donaldson, Dale Lofland, Tanya McLaughlin, Lisa Pruitt-Thorner, Stephan Stidham, Daniel Vichitbanda, Dave West, Cat Whitney-Annable, Keith Wethington, Karen Wilmes, and the late Nick Booth, who drowned in a cave in Carter Caves State Resort Park not more than a month after this project. Most of these cavers are from the local ESSO Grotto, but some were from Maryland, and Virginia. The indomitable Roy Powers and his assistant Kenny Sherrill designed the gates and did the majority of welding. I also want to thank Rick Clawson of the Missouri Department of Conservation and Bob Currie of the U.S. Fish and Wildlife Service for data; Dr. Horton Hobbes and the Wittenberg University Speleological Society for the map of Saltpetre Cave and the elevation data; and Elaine Acker of Bat Conservation International, Cat Whitney, and Traci Wethington for the additional photos included here. Finally, this project would not have been possible without financial support from National Wildlife Federation, Kentucky Department of Fish and Wildlife Resources, Kentucky State Parks, East Kentucky Power Cooperative, and Slade Chapter of the Kentucky Society of Natural History. I apologize for anyone left off this list.

About the Author

Jim Kennedy has worked as a camp counselor, environmental educator, and Interpre-

tive Director at Laurel Caverns, a show cave. He began working with bats as a non-game wildlife technician for the Pennsylvania Game Commission. For the past eight years he has worked for Bat Conservation International, where he is Cave Resources Specialist. He advises federal and state resource managers on cave inventory and protection methods, leads training workshops, and is involved with the recovery of the endangered Indiana and gray bats. He is active in cave exploration and mapping, and was past Chairman of the Mid-Appalachian Region and the Texas Speleological Association of the National Speleological Society. He has been Editor of the Texas Speleological Survey for the last six years. He currently sits on the National Cave and Karst Management Symposium Steering Committee, and is Bat Conservation Liaison for the National Speleological Society.

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Don't Mess With Mammoth Days in the Pike Spring Basin of Kentucky

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Abstract

Don't Mess With Mammoth Days is a cooperative effort among private and governmental organizations to clean up groundwater recharge of the Pike Spring Basin in and near Mammoth Cave National Park. In alphabetical order, the organizations consistently involved are the Cave Research Foundation, Hart County Solid Waste, Mammoth Cave National Park, and the National Speleological Society. It is important to keep in mind that the horsepower within these organizations is provided by people who match their rhetoric with hard work. Bill Hack, the previous director of Hart County Solid Waste, was particularly helpful in getting this project off the ground.

Water within the basin is carried by cave passages to Pike Spring on the Green River within Mammoth Cave National Park. Neither water nor cave passages are mindful of the park boundary which crosses the basin, and the wildlife within cannot tell if pollution comes from within or beyond the park. Aquatic cave life in the Pike Spring Basin includes blind fish, crayfish, and many other specialized cave species, most notably the Kentucky Cave Shrimp. This shrimp is on the Endangered Species List, and Pike Spring Basin may have the largest shrimp population known. This is why Pike Spring Basin has the highest priority.

*Figure 1. The cave crayfish (*Orconectes pellucidus*) from Mammoth Cave.*

On the first field day, which was held in March 1996, more than 30 volunteers removed tangles of wire, sheet metal, broken glass, appliances, and automobiles that had been discarded in sinkholes. Seven truckloads of rubbish and recyclable metal were removed, and remedial work was performed on gullies to stop erosion. In Subsequent years, participation in *Don't Mess With Mammoth Days* events has varied from 25 to 45 volunteers from up to eight states, with similar impressive outcomes. To date, approximately 175 tons of rubbish and 35 tons of recyclable metals have been recovered from dumps within the Pike Spring Basin. Much of this is non-toxic, but many agricultural chemical containers with residual product have been recovered as well. Ecologically, sinkholes funnel food into caves, and if they are clogged with trash, then the organic matter needed by wildlife such as the Kentucky Cave Shrimp cannot get in.

The most recent events were held January 13 to 15 and March 3 to 5 of 2003 in cooperation with Trinity Christian College (Palos Heights, Illinois) and Waynesburg College (Waynesburg, Pennsylvania) respectively. In both cases education on karst conservation issues was incorporated with the hard cleanup work on dumpsites.

One dump, selected for us by Jerry Matera (Hart County Solid Waste), had a rich array of unwanted resources including tires, washing machines, ranges, and refrigerators of various vintages, an abundance of household trash, and a nice collection of fluorescent lamps (fig-

Figure 2. Fluorescent lamps, which contain mercury, on a dump site at left. Students from Trinity Christian College working on hillside dump over Fisher Ridge Cave System near Mammoth Cave National Park at right.

ure 2). Warned to watch out for potentially hazardous items as part of the safety talk, one participant found a half-full propane tank. The dump was located on the road between the park and Northtown at a site over the Fisher Ridge Cave System, which has a surveyed length of over 100 miles.

Figure 3. Volunteers hauling an appliance up a steep hill, and a discarded Ford Mustang car door.

It is miraculous how people can warm up to the monumental task of cleaning up a big mess for the common good. Moving heavy appliances up a steep hill is a challenge, an opportunity for teamwork, and a chance to see results in a short time frame. Household waste that went into the trash can one item at a time many years ago once again sees the inside of a garbage bag, courtesy of diligent volunteers. Gradually, progress made over the hours becomes apparent as a highly visible problem gradually gets solved.

Challenges remained: tractor and truck tires to pry out of the ground, a wringer washer looking like a half buried monument from a civilization gone by, and soda bottles no longer made. Metal to be recycled was lined up on the road shoulder along with 50 tires destined for a 30-cubic-yard rolloff dumpster provided by Hart County Solid Waste. Bag after bag of small items was carried to the dumpster and these materials headed for the landfill were hefted up and over the side. Tires were moved up the hill with toil and rolled to the rolloff dumpster. Women outnumbered men in this effort and their spirits were unbent at the end of the day. In addition to the rubbish, two truckloads of metal to be recycled were loaded and hauled off by Hart County Solid Waste staff.

The Waynesburg College group was equally impressive. They knocked out two dumpsites in one day. Both were on roadsides, one near

Figure 4. Trinity Christian College crew loading tires into the 30 cubic yard dumpster at left. Still smiling at the end of the day, women volunteers pose with "corrected" sign at right.

Figure 5. Waynesburg College volunteers 'mining' household waste from roadside at left. Victory after washing machine was dug, pried, and hauled out on rope at right.

Figure 6. Girls with garbage bags at left. Drug container with syringe at middle. Waynesburg College crew at right after cleaning up a quarter mile long roadside dump.

a sinking stream and the other in a sinkhole. There were big items like a tractor axle and appliances and many more small things. Some small things can be very significant, such as discarded spray cans.

Some items, like an old washing machine, were partially buried by boulders in the dry streambed and had to be dug and pried out. The team approach of doing "tug-of-war" with big items proved very useful, and provided a great sense of accomplishment when working together. As is always the case, there are a lot of small items that need to be picked up and bagged. Laborious, but gratifying work. In one case a medication bottle with syringe was recovered. The group had outstanding "espirit de corps," even at the end of the day.

Lest we fall into the trap of harshly judging those who left this mess, let me explain that until recently trash pickup and sanitary landfills were unavailable. So refuse was dumped into sinkholes and ravines since these areas had apparently little other practical use. Historically, much of what was discarded would have little effect on the quality of drinking water as it percolated down to the caves below, but that changed in more recent decades as toxic chemicals became more prevalent in both agricultural and household products. With the benefit of 20/20 hindsight, we now know that what goes down can come back up water wells, much to the dismay of those on the receiving end. Both people and wildlife can be seriously affected.

Ecosystem Management, Education, and the Idea of Cave Wilderness In Protecting Karst Resources

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Abstract

In planning for the use and allocation of, as well as the protection of, natural resources, land managers must consider both social variables and biophysical factors—an ecosystem approach. The sole use of ecological information in the protection and restoration of natural resources, such as karst aquifers, may be self-limiting, as it does not present a holistic understanding of an area, its people, and its resources.

Findings from a recent study on cave wilderness indicate the need for an ecosystem management approach in the stewardship of caves and karst resources. Education was emphasized as an important tool in such an approach

Introduction

Land use pressures now require protected lands to be linked to and managed in concert with decisions that affect the ecosystem of surrounding lands (Gray & Davidson, 2000). Managing the ecosystems of wilderness recognizes that most are too small to effectively be protected, (Christensen, 2000). The protection or enhancement of wilderness that will insure the continued existence of the values for which a wilderness is protected will depend on the development and implementation of an encompassing, ecologically oriented approach to management (Gray & Davidson, 2000).

The human dimension of ecosystem management, whether on managed land or in wilderness, is more difficult to articulate. Ecosystems are open to flows of matter and energy and to the flows of human values (spatial and temporal) (Christensen, 2000). In planning for the use and allocation of, as well as the protection of, natural resources, land managers must consider both social variables and biophysical factors—an ecosystem approach. The sole use of ecological information in the protection and restoration of natural resources, such as karst aquifers, may be self-limiting, as it does not present a holistic understanding of an area, its people, and its resources.

Ecosystem Management and Cave Wilderness

An ecosystem management approach is a merging of the understanding of the biophysical components of an ecosystem and the human dimensions, providing a holistic perspective in developing management goals for the region. The human dimensions include a variety of people-oriented management considerations and a cross-disciplinary range of inquiry. These include culture, economics, history, and looks at the communities of place as well as the communities of interest.

Findings from a study on cave wilderness (Seiser, 2003) indicate the need for an ecosystem management approach in the stewardship of karst and cave resources. Education was emphasized as an important tool for the management and protection of karst and caves.

Wilderness exists regardless of legal designation. In establishing ecosystem management goals for karst and cave regions, it is the idea of cave wilderness that should be utilized in stewardship of cave and karst resources. If we cannot protect wilderness environments, how do we know that we are adequately protecting caves and karst resources for other uses? By providing for the potential of wilderness, it is possible to establish management plans that adequately protect the cave and karsts resources for other uses.

Education and Community Outreach

Ecosystem management is participatory and knowledge-based (Gray & Davidson, 2000). "Public awareness of ecosystem potential is critical in developing achievable 'desired future condition' strategies for land management" (Jensen & Everett 1994, p 9). Education is critical in protecting caves and the potential of cave wilderness (Seiser, 2003).

"If we go through the process of trying to pursue some kind of designation, it should be for the purpose of creating broader community outreach and a broader forum for education about caves and karst, obviously, for the protection of cave and karst. But in order to protect you've got to educate" (research participant, Seiser, 2003).

The 1997 National Report Card on Environmental Knowledge, Attitudes, and Behaviors by the National Environmental Education and Training Foundation (NEETF) and Roper Starch, underscores the need for environmental education. In the study, only 32% of the survey participants received a passing grade (43% men and 20% women) for environmental knowledge. The 45 to 54 age group were the most knowledgeable. Those 65 and above showed the lowest levels of knowledgeable (NEETF, 1997). It is important to note that the level of knowledge is not simply age associated, these groups reflect the environmental education of their times. These groups encompass the baby boom generation, a significant portion of the population; they tend to be the ones who have the greatest impact on environmental decision-making processes (via votes and financial support). Although women, in general, scored the lowest on environmental knowledge, women generally displayed more support for air and water quality regulation and the protection of endangered species, wetlands, and natural areas (NEETF, 1997).

Research and education are critical for protection and management of our natural resources. The first step is the interpretation of scientific findings, defining what it means for management and to the public. For scientific research to have meaning we need to find ways to relate the findings to individuals' experiences and knowledge. The next step is to pass on this knowledge through education.

Educational programs need to be developed for natural resources managers (current and future) and local communities. They also need to be developed for regional visitors (tourists and others) and nation-wide. These last two groups are often overlooked. Developing an understanding of karst and cave ecosystems in people who are not from such regions can impact how they behave when visiting these areas. It may also affect whether they will support program funding and legislation on a national level for karst and cave regions.

Karst and cave based environmental education needs to address both adult and child audiences. Project Underground is one program that can easily be adapted to reach a variety of audiences and age groups. Avenues in which educational programs can occur in are varied: schools, university based programs, agency and extension service programs, and community partnerships. The National Park Service and the U.S. Geological Survey are two agencies that have developed educational programs for school-aged children. In all cases, community involvement is essential for the programs to be effective.

Successful karst and cave environmental educational programs engage the audience in a variety of ways. Capturing the audiences' imagination is an important educational tool. The video *Water's Journey. The Hidden Rivers of Florida* is an example of linking adventure and fun with environmental knowledge. *Water's Journey* as well as Project Underground, does not advocate caving in teaching about karst and caves. While not promoting caving is one way to protect caves, there is value (time and expense) in these programs providing avenues for learning about karst and caves ecosystems without requiring a trip underground (especially appealing to those who do not care to visit caves).

In addition to teaching about karst and cave ecosystems, community outreach programs need to provide people with tools for protecting karst and cave resources as well as the knowledge of how to use them. Knowledge and access to tools to address environmental problems provide opportunities for citizens to take ownership and responsibility in resolving negative environmental situations.

Conclusion

The human dimensions of an ecosystem change over time as values and understandings change. Education is an essential component of ecosystem management regardless of the environment. Activities that protect karst and cave environments help to protect cave wilderness, aid in the restoration of potential wilderness and may reduce the loss of existing wilderness sites.

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Developing Conservation Sites for Virginia's Significant Caves

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Abstract

About 360 (approximately 9%) of Virginia's 4,100 documented caves are designated "significant." The Virginia Speleological Survey maintains the significant cave list for the governor-appointed Cave Board, established by the Virginia Cave Protection Act of 1979. Though affording no specific legal protections, significance designation confers importance from a conservation perspective. Potential impacts to significant caves are considered during the state environmental review process. Virginia Speleological Survey upkeep of the list has advantages, including protection of cave entrance locations and incorporation of recent cave exploration. This arrangement has, however, hindered Cave Board involvement and placed a greater burden on the Virginia Speleological Survey.

Virginia's Natural Heritage Program defines "Conservation Sites" as areas where land use activities could potentially impact natural heritage resources - rare plants, animals, or natural communities, or significant caves. Conservation sites are assigned a biodiversity ranking based on the number, rarity, and quality of biological elements. "Conservation Sites" have no state regulatory function, and are simply landscape areas worthy of stewardship and protection. Two major functions of conservation sites are environmental project review and prioritization of land to incorporate in the Natural Area Preserve System.

Currently, 66 conservation sites encompass 136 significant caves. These conservation sites allow the Cave Board access to the significant cave list without revealing entrance locations, providing instead more useful landscape information. Dye tracing has played a major role in development of conservation sites for hydrologically significant caves. The remaining 200+ significant caves are represented as 3-kilometer-diameter circles, replaced by conservation stes as they are developed.

About the Author

Wil Orndorff is the Karst Protection Coordinator for the Virginia Division of Natural Heritage. His professional duties include designing conservation site boundaries for significant caves, conducting karst hydrology investigations, performing inventories of karst features, sampling caves for biological resources, monitoring water quality and cave habitats, reviewing development projects for potential impacts to karst, and serving as a staff resource for the Virginia Cave Board. In his copious spare time, Wil is active in cave exploration as well as cycling, music, gardening, and parenting.

Poster Sessions

The Western Kentucky University Source Water Protection Program

Educating Water Resource Managers and the Public about the Vulnerability of Rural Karst Drinking Water Supplies

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Abstract

Since 1998, the Western Kentucky University Technical Assistance Center for Water Quality, with funding from the U.S. Environmental Protection Agency, has been working to provide technical, managerial, and financial assistance to rural drinking water providers in Kentucky. To improve public health within Kentucky, the Center's Source Water Protection Program assists water providers, their customers, and other local stakeholders with an approach that assumes that the better the quality of source water when it reaches the treatment plant, the easier and cheaper is to treat.

The roughly 50% of Kentucky underlain by karst aquifers present special challenges as these waters are especially vulnerable to contamination by rural land use, including bacteria, pesticides, and nutrients. Since land use is closely tied to groundwater quality in these areas, education about the functions of such systems can be a powerful tool for protecting vulnerable drinking water sources. A major component of this program provides education to landowners, local government officials, utility managers, citizens groups, and the public about source water issues.

This poster describes educational tools we are developing, with the module *Impact of Karst on Source Water Protection* as an example. Similar to other modules in the program, this has been designed as a workshop, but also includes printed materials and a website for wider dissemination. Subsections of the module include Concepts of Source Water Protection, Karst Landscapes and Aquifers, Karst Related Environmental Problems, Best Management Practices for Source Water Protection in Karst, GIS in Source Water Protection, and Partnerships for Source Water Protection.

A Systems Approach for the Understanding of Agricultural Contaminant Sources and Transport within a Karst Groundwater Drainage Basin

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Abstract

The sources and transport of pesticides, nitrates, and bacterial contaminants in an Iowa karst groundwater basin will be determined using isotopic analysis, antibiotic resistance analysis, and general water quality testing, coupled with a detailed evaluation of the extent and land use of the recharge area and surface and groundwater movement in the basin. The basin under study is a shallow karst aquifer in an agricultural area of northeastern Iowa and southern Minnesota. Previous analyses of water quality results have shown that both surface streams and groundwater within the basin contain anomalously high concentrations of nitrates, waste-related bacteria, and pesticides. The high nitrates imply that sources other than soil organic matter have contributed nitrates to the shallow karst aquifer. High fecal coliform levels suggest an influx of waste products from humans and/or livestock and/or wildlife. Pesticide levels in the study area fluctuate seasonally and are a reflection of seasonal application on row crops. Water quality testing conducted during normal and high-flow conditions indicates that contaminant movement through the basin is rapid and temporary degradation of water quality is significant after storm events. In order to address these problems of contamination of karst aquifers, a systems approach is required in which the function of the aquifer and its relationship to the recharge area, and the sources of contamination, are considered separately and as integrated parts of a karst groundwater study. The development of effective management practices to preserve water quality, and remediation plans for areas that are already polluted, requires identification of the actual sources of contaminants and understanding of the processes affecting local contaminant concentrations. In particular, a better understanding of hydrologic flow paths and solute sources is required to determine the impact of contaminants on karst groundwater basins.

Survey of Microbial Diversity within Wind Cave Using DNA Analysis

Wind Cave National Park, South Dakota

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Abstract

Microbiology is one of the newest frontiers in cave research. Cave bacteria have been shown to influence primary speleogenesis by raising carbon content and producing higher acid levels in streambed. Also they precipitate or influence the formation of secondary mineral deposits. The major problem in studying cave bacteria is that they evolve and live in interdependent communities and most often cannot survive alone. This is a problem for the traditional microbiologist because they need to isolate and culture individual bacteria to be able to study them. Using DNA analysis techniques allows us to study bacteria that cannot be cultured in addition to making possible new types of analysis. Currently there is a need for a broader background database before specific research can be meaningfully conducted or reliable. Genetic fingerprinting is ideal for creating this background database because it is economical for use on a large scale and enables us to distinguish species within a community. Using this technique in conjunction with real time PCR quantitatively monitor unidentified species within karst microbial communities.

About the Author

I began studying speleogenesis and biospeleology doing an independent study as a senior at Rockbridge County High School in 1996–1997. Since then I have developed an interest in many forms of karst research. Next I studied Speleology under Dr Kenneth Thompson at Southwest Missouri State University. Currently I am a senior at Western Kentucky University perusing a BS in Geography with a minor in Biology. At western I volunteer for the Biotechnology Center as an undergraduate researcher, as well as the Center for Cave and Karst Studies. Since attending western I have studied Hydrogeology under Dr Nick Crawford and Karst Microbial Genetics with Rick Fowler. I have been an active caver since 1995 and am currently Chairman of the Green River Grotto. Also I am a member of the National Speleological Society and Cave Research Foundation.

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