July 1, 1993
LCMR Final Status Report - Detailed for Peer Review - Research
LCMR WORK PROGRAM 1991

I. **Mystery Cave Resource Evaluation**

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Department of Natural Resources
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A. M. L.92 Ch. 254 Article 1 Sec. 14 Subd:3(1)
Appropriation: $150,000
Balance: $ 3,130

Mystery Cave Resource Evaluation:
This appropriation is to the commissioner of natural resources to perform a resource inventory and study of Mystery Cave to include groundwater, cave meteorology, geology, and biology as part of the park plan.

B. Compatible Data - During the biennium ending June 30, 1993, the data collected by projects funded under this section that have common value for natural resource planning and management must conform to information architecture as defined in guidelines and standards adopted by the Information Policy Office. In addition, the data must be provided to and integrated with the Minnesota Land Management Information Center's geographic data bases with the integration costs born by the activity receiving funding under this section.

C. Match Requirement - not applicable

II. Narrative

A. Statement of the Problem: Mystery Cave was acquired by the State of Minnesota and made a part of Forestville State Park in 1988. It is one of the primary resources of the park and the only show cave in the outdoor recreation system. Although some prior research has involved the cave, major gaps in understanding the groundwater, geology and mineralogy, meteorology, and biology of the cave place limitations on the ability to develop interpretive programs and make sound management decisions.

B. Importance: The cave is one of the 100 longest caves in the world and the longest in Minnesota. It has the classic characteristics found in many caves and also somewhat unusual cave features. Mystery Cave has been an important facet of southeastern Minnesota tourism for fifty years. It is a natural laboratory for the intimate study and understanding of karst and groundwater flow which is of regional and national importance.

C. Extent of the Problem: No systematic examinations of Mystery Cave have integrated the major environmental components of groundwater, meteorology, mineralogy, and biology. Existing information on the cave is limited. The present information used for public tours, educational tours and management decisions is piecemeal with a significant portion being generic, extrapolated from studies in other caves.

III. OBJECTIVES

A. **Inventory present water chemistry and water quality throughout the cave system, attempt to identify the sources and sinks of the various cave waters, measure the response of various cave waters to seasonal precipitation events and to human activities.**

A.1. Narrative: Management of the unique and fragile Mystery Cave karst hydrologic system requires a detailed inventory of the drip, pool and stream waters of the cave and an understanding of how those waters respond to natural and human-induced changes on the surface. The focus of this objective is to inventory the cave's groundwater resources and to evaluate how those waters respond, in quantity and quality, to surface events.

A.2. Procedures: Water samples will be collected periodically from a variety of accessible cave drips, pools, and streams throughout the cave system. The

pools, and streams throughout the cave system. The samples will be analyzed for a variety of chemical parameters. In most cases the parameter list will include field determinations of pH, conductivity, and temperature, and laboratory analysis of common and trace cations and pesticides, and anions. Analytical techniques will include direct current plasma/atomic emission spectroscopy, immuno assay and ion chromatography. Selected samples will be analyzed for VOCs, pesticides, and bacterial parameters. The results of these analyses will define the current state of the water quality in the cave, seasonal variability and be used to look for evidence of human impact on the cave hydrology. If evidence of the human impact is found, the water quality will be correlated with overlying and adjacent land uses.

One digital data acquisition system will be installed on the surface above the cave and at least one system will be installed in the cave. The surface station will acquire continuous measurements of air temperature, precipitation, wind speed and direction, relative humidity, barometric pressure and river stage and water temperature. Additional parameters may be measured if feasible. The in cave station will acquire continuous measurements of water levels in a cave pool, drip rates in a cave drip, temperature, conductivity and other appropriate parameters. The comparison of the continuous data records from the surface and cave stations along with periodic sampling throughout the cave system will be used to determine the links between the surface events and the cave hydrology. The external and internal meteorologic stations will be developed and installed cooperatively with objective B below.

A.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$62,000	$15,000
b. Expended:	$62,000	$15,000
c. Balance:	$ 0	$ 0

A.4. Timeline, Products/Tasks:

	July91	Jan92	June92	Jan93	June93
Coordination with other objectives	.....				
Design and installation of data acquisition systems	.....				
Collection and analysis of water samples	.....				
Data analysis and interpretation	.....				
Quarterly reports					
Preparation of Technical final report and layman's report			.....		

A.5. Status: Water samples were taken from waterfalls, streams, pools, stalactite drips, flowstone flows and drips, bedrock drops, and in cave springs in Mystery Cave. The samples were analyzed for a variety of parameters.

Mystery Cave and associated waters exhibit a diverse water chemistry and water quality that varies with season and with the magnitude of recharge and discharge. The presence of atrazine (and its breakdown products), fecal coliform bacteria, elevated NO3-N, and elevated Cl, at varying sites distributed among most types of waters underscores the presence of ubiquitous permeable pathways that connect the surface directly to the waters of the carbonate aquifer and to the cave passageways.

Evaporation pans were installed in a variety of locations to test whether evaporation could successfully be measured in the cold (8.7 deg C) but humid cave. Monthly results indicate evaporation in some areas and condensation in others. Data from pans positioned at various heights in one passage are suggesting evaporation near lower portions of the passage and condensation near the ceiling. These results help explain the horizontal band of aragonite crystals near the lower portions. These crystals are believed to form only in dry wall areas where capillary solutions are drawn to the bedrock surface and evaporate.

Water levels were monitored at a lake and stream inside the cave and outside on the South Branch Root River. Drip rates were measured continuously at several locations. The data from these locations were examined with surface meteorologic events. The waters flowing

events on the surface, particularly to flows originating from leakage through sediment-filled fractures in the Root River. Water levels respond rapidly, and flow through times are rapid, such that chemical pollutants present on the surface are quickly transmitted into the cave. This fast response is not confined to leakage from stream beds; other types of recharge, such as flow into sinkholes and flow through macropores and other surface fissures, also contribute to the fast response time of some waterfall and drip waters.

Drip rate trends appear to represent the influence of daily temperature and heat conduction cycles. Water temperature data at a cave stream shows clear daily fluctuations superimposed on the larger seasonal and precipitation-driven fluctuations. (such temperature fluctuations could be important influences affecting the cave biologic community.)

Electrical power and equipment availability from the manufacturer delayed implementation of some of the monitoring equipment. Power outages caused periodic data loss on the recording equipment. Battery operation with a power line battery charger eventually solved the problem. The harsh environment underground occasionally caused equipment to malfunction.

A spring snow melt flood on March 31, 1993 over-pressurized devices used to record water levels in the cave and on the South Branch Root River. A second lesser flood in April damaged one of the devices. Although the equipment was taxed beyond it's capacity, much important data were recorded and coupled with on-site observations presents a picture of dramatic changes during this ten-year frequency event. (The water level in one stream passage rose some thirty feet within a few hours.)

The researchers shared their cave expertise with the Forestville State Park interpretive staff by providing a field and classroom training session.

Material gleaned from this study has and is being shared with the public on a daily basis at park interpretive programs in the summer. The findings from this work assisted researchers of the geology and mineralogy section (C) in interpreting facets of their work. The study has provided a baseline of hydrologic data from which to compare with anytime in the future. One of the great strengths of this study is the continuous hydrologic readings gathered with periodic water samples. A longer observation period means a larger data base from which to make statistically sound determinations with. The Division of Parks and Recreation has recognized the value of continued water monitoring and in order to gain a better understanding of the hydrologic system is funding a one year downscaled continuation of the study.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

A.6. Benefits: Determining the water chemistry, flow paths and underground effects of surface precipitation will have direct and immediate benefits in the form of public education on cave tours and other interpretive activities in Forestville State Park. The focus of this objective will answer a multitude of fundamental and specific groundwater questions frequently asked by the public about Mystery Cave. It will also provide invaluable baseline data which will help gauge hydrologic changes resulting from human activity or natural occurrences.

B. **Cave Meteorology: Investigate the cave meteorology in Mystery Cave and study its relationship to radon environment and air exchange and assess the impact of cave renovation on the cave meteorologic system.**

B.1. Narrative: Elevated radon concentrations in Mystery Cave make it necessary to monitor the exposure of persons spending long periods in the cave. Radon levels, which are controlled in part by meteorologic conditions outside and inside the cave have not been systematically studied, making it difficult to accurately monitor employee or other exposures. Present direction and rate of air movement through the cave is unknown. This objective is intended to gather baseline data by continuously monitoring radon and meteorologic conditions within selected parts of the cave system over a two year period. It will seek to determine air flow

relating to seasonal and daily weather events. It will also compile existing radon data (from the cave) to assist with developing the measurement system. An examination of the ventilation and air flow in Mystery Cave, both as they relate to radon levels and to changes that might result from cave renovations, will be performed. An attempt to correlate temperature and humidity levels with air movement will be made.

B.2 Procedures: A comprehensive system of radon and radon daughter product monitoring will be deployed along sections of the commercial (tour) routes in Mystery Cave. This will include at least 4 continuous radon monitors, 2 weather stations recording barometric pressure, relative humidity and temperature in separate parts of the cave, and a possible third station outside recording barometric pressure, relative humidity, temperature, wind speed and direction and rainfall. Two locations will also continuously record radon daughter product concentrations. The radon monitors, radon daughter monitors and weather stations will be located on the tour routes. Grab sample radon and radon daughter measurements will be collected throughout the undeveloped portions of the cave system. Seasonal measurements of air movement and exchange within the cave will be carried out using PET (tagged perflurocarbon tracer) gasses. Quarterly measurements of aerosols, which affect the distribution of radon daughter products will also be made, as will emanation rates of radon from the various rock types within the cave. Data reduction will include time series analysis of the continuous radon and radon daughter record and correlation with the various meteorologic parameters, aerosol and air exchange measurements. Data from the radon and air flow measurements will be used to assess the effects of renovation on the air system. Other characteristics of the cave air such as carbon dioxide levels will be measured as time and budget permit.

B.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$43,000	$0
b. Expended:	$43,000	
c. Balance:	$ 0	$0

B.4. Timeline for Products/Tasks:

	July 91	Jan 92	June 92	Jan 93	June 93
Analyze existing radon data	. . . .				
Design monitoring program	. .				
Implement monitoring program	. . . . .				
Analysis of data		. . . . .			
Quarterly reports		. .	. .		. .
Final report	.....				

B.5 Status: The cave meteorology results from the radon measurements indicate that the annual average radon concentration in the cave is about 200 pCi/L. For comparison, the Environmental Protection Agency guidelines for radon and radon decay products in buildings is 4 pCi/L. However there is a significant seasonal difference in the averages. Summer averages can be as high as 350 pCi/L. Daily changes in radon concentration can be as much as a factor of 60 in the winter and less than two in the summer. In the winter, radon was observed to increase with decreasing barometric pressure, the opposite was also observed. In the summer, the radon was less sensitive to changes in barometric pressure. Outside temperature was also observed to correlate with some variations in radon concentration.

Radon decay product concentrations (the non-gaseous decay products of radon with short half-lives, 30 minutes), were measured continuously at four hour intervals with special detectors. The radon progeny were measured continuously to provide a comparison with the parent radons. These continuous measurements are not directly convertible into working levels, the units used to assess radiation exposure for people.

The results of the radon progeny measurements show that in some instances the decay products track well with changes in radon. At other times, usually in the warmer periods of the year, this correlation does not exist.

Aerosol monitoring was not continuous, but conducted during different seasons over periods of 4 to 16 hours. The results indicate that the cave is relatively free of aerosols greater than 0.3 microns in diameter. A typical home may have 10,000 particles per cubic centimeter, while the cave has less than 0.01 particles

per cubic centimeter. Equipment was not available to measure particle sizes below 0.3.

Both the results from the radon measurements and the meteorologic measurements, particularly temperature and barometric pressure indicate that air-flow within the cave is connected to outside meteorologic conditions. The correlation observed between short and long term changes of air temperature at a location 700 feet in the cave (the Bomb Shelter) and the surface temperature when taken as a three day average, indicates that air moves into the Bomb Shelter from the surface on a regular basis.

A marked seasonal change in radon concentration was observed in the fall of 1991 and 1992. When the average surface temperature dropped below the cave temperature and stayed there, radon concentrations fell rapidly. The pattern of radon variations also went from high ambient summer levels and small peaks to low ambient winter levels and brief high peaks related to barometric pressure changes.

Rapid fluctuations of radon concentrations, observed to correlate with barometric pressure changes and in some instances temperature, support the idea of rapid and frequent exchange of air between the cave and surface.

Relative humidity levels measured in the cave with the electronic sensors were not reliable. The sensor was incapable of accurate measurement above 90% relative humidity.

In order to obtain some information on general air movement within the cave system five PFC tracer gas sources were placed at different locations within the cave and up to 18 detectors were placed around the cave at five different times between May 1992 and May 1993. Results from the first two tracer tests indicate general air motion from west to east, with occasional flow from east to west. The results from the other three test have yet to be compiled. These are long period tests and do not correlate directly with the observed short-term, rapid variations observed in the radon concentrations or temperature.

Purchasing equipment and electrical power availability delayed implementation of some of the monitoring equipment. The corrosive environment and cave temperatures rendered occasional/periodic problems with battery equipment operation. Battery operation with a power line battery charger eventually became the solution. The 10-year flood event of March 31, 1993 inundated much of the meteorological equipment as well as the tour routes.

A key factor in downloading data from equipment, changing batteries, and checking equipment during the entire study were the efforts of park volunteer, Konrad Elliot. The researcher shared his cave expertise with the Forestville State Park interpretive staff by providing a classroom training session.

Baseline data was collected during the study that shows trends which were unknown previously. Variations in radiation levels recorded, although not directly comparable to records kept for safety purposes, will assist in cave operation planning efforts that consider radiation exposure of personnel.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

B.6. Benefits: This objective develops and implements a program of basic research that will provide baseline data on environmental conditions within Mystery Cave. The data can be used to help guide policy decisions on cave renovations, improve radon exposure information for employees and help guide policy on exposure limits. Both the radon and meteorologic environments in the cave are sensitive issues, in terms of long-term health risk and alteration of the physical and biological cave environment through public use and/or management, that require adequate information which to base decisions.

C. **Narrative: Geologic mapping of Mystery Cave, and determination of mineral types, their distribution, geochemical stability, and origin.**

C.2. Procedures: A leveling survey through the main passages of the cave system (with hand level and engineer's

level, using the existing map of the cave for horizontal control;) will be run. Elevations of cave ceilings and floors, geologic contacts, sediment levels, water levels (past and present) and mineral locations will be measured. From the leveling data a geologic map will be constructed. Mineral and mineral types, shall be analyzed using in-cave observation and lab analysis of broken specimens (leaving no visible impact on the cave). Analytical techniques will include X-ray diffraction, scanning electron and light-transmission microscopy, and chemical tests. Geochemical analysis of pool and drip waters in which the cave minerals occur will be performed cooperatively with objective A. to evaluate mineral stability. Mapping and interpretation of sedimentary deposits and flow indicators such as solutional scallops shall be performed. On the basis of mineral types and their range of stability, management strategies will be determined. A report will be compiled on the geologic history setting of the cave that can be used for interpretive purposes by park staff will be assembled.

C.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$39,500	$0
b. Expended:	$39,500	
c. Balance: (12/24/92)	$ 0	$0

C.4. Timeline for Tasks/Procedures:

	July91	Jan92	June92	Jan93	Jun93
Geologic mapping mineral ident	.....		..		
Analyze rock, mineral samples		.....	.....	.....	
Prepare interim reports		...	...	..	
Quarterly reports		..	..	..	
Final report & map					.....

C.5. This research has resulted in the most detailed geologic mapping of any cave to date. The map, with detailed profiles and cross sections, was completed from leveling surveys in the cave. This stratigraphic work is an important facet to explaining the history and evolution of the cave. It has demonstrated the favorable beds for cave system development, structural changes in the middle of the cave and the relation between predominate cave development and jointing patterns.

Refraction seismic surveys have shown the bottom of the valley fill outside the cave, is approximately the same as the level of the bedrock floors in the cave. Scallop measurements (cave wall corrosional features that indicate water velocity) were not as useful as hoped because there are so few available, however work from a previous sediment study was augmented and verified what the scallops indicated for flow conditions.

The leveling work in the cave included placing dozens of bench marks. These are valuable reference points and serve a multitude of needs. For example, researchers of the groundwater section utilized these in their work; park interpreters are making use of them on public cave tours.

Lab analysis of pool deposits has shown very unusual formation; the type of which is generally only found in southwestern U.S. caves such as Carlsbad Caverns and Lechuguilla Cave. The shape of the crystals in such deposits vary from needle-like to blunt and is related to the chemistry of the water.

Most previous studies have examined such crystals on material where processes ceased long ago. The crystals in Mystery Cave are remarkable for forming today. By integrating the results of crystal analysis and data from the groundwater study, additional insight of cave processes was made.

A much clearer understanding of the environment during deposition of the rock layers is also a result of this study. Analysis has discerned much on the geologic background of dolomite/limestone. Such information may benefit future geology researchers. For example, X-ray diffraction techniques show the percent of dolomite while thin-sections analysis has shown the relationships between crystals e.g. such as crystal replacement.

Lab and field work have shown unusual chemical environments involving reduction of gypsum as opposed to the normal replacement of limestone by dolomite. This

environments involving reduction of gypsum as opposed to the normal replacement of limestone by dolomite. This provides understanding of cave wall textures within the cave.

Vibration studies have demonstrated normal vehicle traffic and heavy trucks on overlying roads offers no problem for mechanical cave disturbance though the effect of heavy machinery on the road may.

The geomorphic interpretation of the cave is determined to represent a floodwater feature related entirely to the history of the South Branch Root River. This is a different understanding of the cave development than the accepted view prior to the research.

No delays occurred during this project. Although weather conditions required adjustments in field work plans, it did not impede work progress.

Flooding of the cave in April was a fortuitous event for this study, which coincided with the researchers field work. Water measurements taken and observations made, provided additional supporting evidence of the geological history of the cave. Processes that occur only during flood events were observed and quantified.

The researchers have shared their cave expertise with the park interpretive staff by presenting classroom and field training sessions on Mystery Cave, caves and their research. The Palmer's fielded questions on a multitude of speleology concerns of the staff and also provided lengthy written narratives of each topic.

This study has elucidated the geologic history of the cave. It relates the cave origin and evolution to the way features look underground today. It has identified highly unusual cave deposits that should be preserved and explained the significance of other formations in the world of caves. The study included a wide variety of investigative work such as: stratigraphic mapping, seismic surveys, direct measurements of cave features, water chemistry measurements, photography, sediment interpretation, observations of processes, mineral identification, formation dating and a host of technical lab analyses. It addressed concerns for cave conservation. The result of this project is site-specific knowledge of the cave resources that are related to the public every day on cave tours. A good understanding of the importance of Mystery Cave in relation to the surrounding area and other caves of the region and world was made.

The Division of Parks and Recreation has recognized the value of integrating the results of all the studies of the Mystery Cave Resource Evaluation into an expanded more holistic final version of the research efforts and is providing funding an additional year. The product will be a report to assess the geologic data in terms of the geochemistry, hydrology, cave meteorology and invertebrate study.

Technical, interpretive and management reports generated by this discipline of the study is being filed in the Legislative Reference Library.

C.6. Benefits: Knowledge of the minerals in the cave, their origin, stability, and significance will provide management guidelines for their protection. The geologic mapping and interpretation will provide interpretive information for use by Park personnel in presenting the cave to the public. The cave origin and surrounding area, geologic history, regional significance, and comparison to other caves will be fully discussed in this report.

D. **To determine the occurrence and distribution of aquatic invertebrates in Mystery Cave.**

D.1. Narrative: The aquatic microinvertebrates within cave systems have recently begun to receive more attention from biologists, and a number of endemic species have been found in various caves. The kinds and distribution of aquatic invertebrates in Mystery Cave remains relatively unknown. The information collected will provide a basis for integrating biological resources and water quality and be used in developing cave interpretive programs and other management activities.

D.2. Procedures: Aquatic invertebrates will be quantitatively and qualitatively sampled in various

waters throughout the cave. Over 800 meters of underground river corridors in four separate locations and eight pools or lakes will be examined. Sampling methodology may include the use of core samples from sediments, drift nets, activity traps, plankton net tows, or qualitatively picking of substrate. Due to the unique physical constraints of the habitat, sampling will be modified as necessary.

D.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$5500	$0
b. Expended:	$2370	
c. Balance:	$3130	$0

D.4. Timeline:

	July91	Jan92	June92	Jan93	June93
Refine collecting and initiate sampling techniques	.....				
Taxonomic lab work		.....	.....		
Quarterly reports		..	..	..	
Compile data and write reports			.....		

D.5. Status: The aquatic invertebrates were qualitatively sampled from six sites within Mystery Cave and two sites proximal to inflow and outflow of the cave waters. Both, macro and microinvertebrates were collected. This effort represents the first methodical and published survey of invertebrates sampling from Mystery Cave.

Nine micro-crustaceans, three rotifers, and 25 insect taxa were collected from the cave sites. Two species of Collembola not previously reported from Minnesota were collected from pools along a tour route.

Additionally, fish were collected from two cave stream locations and in the South Branch Root River proximal to major cave stream inflow. The fish survey was part of a continuing study of Forestville State Park fishes by Konrad Schmidt. Although a fish survey was not intended at the implementation of this aquatic work, it largely fulfills the initial needs to examine the entire aquatic community of Mystery Cave.

The underground fish community was smaller in species composition and population size than the surface community (seven species underground versus twice that many in the surface waters). Cursory observations showed many of the fish appeared emaciated. It is assumed the fish were swept from crevice openings of the surface stream bottom into the cave. None of the fish collected are cave adapted and are unable to reproduce in the cave.

Some of the micro-crustaceans and rotifers had eggs attached, displaying evidence of reproducing populations. Adult mayflies, stoneflies, and chironomids were found on walls of cave passages; however, it is doubtful that reproduction of the aquatic insects is occurring in the cave.

It seems likely that the aquatic insect fauna in Mystery Cave represents a dead end channel from the community of the South Branch Root River. While drifting insects can enter the cave waters and potentially grow and emerge, reproducing populations are unlikely. At this time, only the microinvertebrates (Collembola, micro-crustaceans) appear to be a reproducing part of the Mystery Cave waters.

The insect fauna in the flowing waters of the cave likely originate as drift above a sink hole in a nearby surface stream, and represent loss from the surface waters.

Both of the Collembola are reported as cave forms, although one is occasionally found on the surface.

Recommendations are made to continue regular systematic collections in search for isopods and amphipods to examine the micro-crustacean community which tend to have short-life cycles and may have been missed by this studies sampling.

The survey is remarkable for absence of isopods and amphipods. These groups are commonly found in caves.

This study has answered one of the commonest questions

Recommendations have been made to continue regular systematic sampling in search of species missed. Also, recommendations are given for underground and surface management considerations in order to maintain the cave aquatic community.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

D.6. Benefits: This study will identify what lives in the cave waters; fundamental resource information that may also help define the range of species found in other caves. It will be used to determine limits of recreational caving and integrate surface land management with underground management to assure adequate protection to the invertebrate fauna. This inventory will function as a baseline data barometer for future surveys.

IV EVALUATION

The cave resource evaluation can be assessed by its ability to:

1) determine the chemistry of the cave water, where it arises from, and how it moves through the cave system.

2) identify the overriding influences of cave air movement and radon levels and how they are affected by these influences.

3) provide interpretive staff information to address frequently asked questions from the public concerning the cave's meteorology, groundwater, minerals, geology and aquatic invertebrates.

4) identify what minerals and aquatic invertebrates exist in Mystery Cave and their distribution.

5) provide reports that can assist managers in making sound resource management decisions.

6) provide a starting point of base line data from which possible future changes to the cave environment may be gauged.

V CONTEXT; RELATED CURRENT AND PREVIOUS WORK

A. This project begins to answer fundamental questions about what minerals and organisms exist in Mystery Cave. A preliminary survey has identified only a portion of the aquatic invertebrates. Such a basic inventory has not been accomplished before. Although previous studies have examined water flow through the cave, the results provide a partial view of hydrologic connections. A current water chemistry study is providing important limited preliminary data, but it does not begin to provide the picture of groundwater conditions in the cave system which this project addresses. Existing park data hints at cave meteorological occurrences that require an on site study to understand.

B. To date, studies at Mystery Cave have focused on a)clastic sediments (including radiometric dating of speleothems), b)major hydrologic flow paths, c)limited water chemistry, d)bat censuses. The research conducted in a, b, and c provides valuable initial information from which to launch this integrated study. These earlier accomplishments reflect a logical progression of important preliminary studies that will save field time for this project.

C. No funding from LCMR has been provided for Mystery Cave studies previously. The biological component of this project is very limited and does not include bats or terrestrial invertebrates that use the cave. It is anticipated that LCMR funding beyond the fiscal year 92 - 93 biennium will be sought.

D. Not applicable.

E. Biennial Budget System Program Title and Budget: Not available at this time.

VI QUALIFICATIONS

1. Program Manager

Warren Netherton
Cave Specialist
Forestville State Park-Minnesota Department of Natural Resources

B.A. Field Biology, 1978, Evergreen State College, Olympia, Washington

The program manager has been involved with cave surveys and exploration in the United States and Mexico since 1972. He performed field cave evaluations for the Illinois Natural Areas Inventory and was formerly employed at Wind Cave National Park in a cave management position. Since 1988 Mr. Netherton has worked in his present capacity, charged with the resource management and interpretation of Mystery Cave. Mr. Netherton's primary role will be coordination of team efforts of objective A, B, C, D and provide limited on site assistance for objectives A, B and C.

Netherton, W. N., Where the Sun Doesn't Shine: A Developing Cave Interpretation Program. Proceedings of the 1989 National Interpreters Workshop, St. Paul, MN pp 292-294.

Netherton, W. N., Mystery Cave Trails: Past, Present and Future. 1989 National Cave Management Symposium Proceedings, New Braunfels, TX, in press.

2. Cooperators/other investigators:

A. Dr. E. Calvin Alexander, Jr.
Professor, Department of Geology and Geophysics, University of Minnesota

Ph.D. Chemistry, University of Missouri at Rolla, 1970
B.S. Chemistry, Oklahoma State University, 1966

Dr. Alexander has conducted research on the groundwater pollution problems of southeastern Minnesota karst for fourteen years. He has been engaged in research in Mystery Cave throughout this period. Dr. Alexander is responsible for the production of the current maps of the cave, for what is know of the flow systems involving the cave, and the initial water quality information form the cave. His primary role will be in the acquisition of the groundwater quality and quantity data in and around the cave, listed under objective A. Selected from a long list of Dr. Calvin Alexander, Jr.'s karst related publications are five titles below.

Milske, J.A., Alexander, E. C. Jr. and Lively, R. S., 1983, Clastic sediments in Mystery Cave, southeastern Minnesota. NSS Bull., v. 45, pp. 55-75

Wheeler, Betty J., Alexander, E. Calvin Jr., Adams, Russell, S., Jr. and Huppert, George N., 1989, Agricultural land use and ground water quality in the Coldwater Cave groundwater basin, Upper Iowa River karst region, U. S. A. Part II in Gillieson, D. and Ingle Smith, D. (eds.) Resource Management in Limestone Landscapes: International Perspectives. Spec. Pub. #2, Univ. College, Aus. Def. Force Acad., Canberra, Australia, 11pp.

B. Richard Lively
Scientist, Minnesota Geological Survey

M. S. Isotope Geology, Michigan State University, 1977

Mr. Richard Lively has been studying the occurrence of natural environmental isotopes since arriving at the Minnesota Geological Survey in 1977. Studies have included U-series dating of speleothems in caves in the Upper Midwest, including Mystery Cave, studies of radon in Mystery Cave, radioactive isotopes in ground water, radon in soil gas and indoor radon as it relates to local geology. Mr. Lively has authored papers in peer reviewed journals, refereed publications and proposals and presented papers at national meetings. His primary role will be radon data analysis and interpretation of objective B.

Milske, J. A., Alexander, E. C., Jr. and Lively, R. S., 1983, Clastic sediments in Mystery Cave, southeastern Minnesota. NSS Bull., v. 45, pp. 55-75.

Lively R. S. and Morey G. B., 1982 Hydrogeochemical

distribution of uranium and radon in east central Minnesota, in Isotope Studies of Hydrologic Process (edited by E. C. Perry Jr. and C. W. Montgomery), pp. 91-107 (DeKalb, Il: Northern Illinois University Press).

Lively, R. S., 1983, - Late Quaternary U-Series Speleothem Growth Record from Southeastern Minnesota; Geology II; 265-262.

Lively, R. S., Bettis III, E. A., Hallberg, G. R. and Hobbs, H., Exposure of the Songamon Soil in southeastern Minnesota, Proceed of Iowa Academy of Science, Vol 94, No. 4, pp. 111-115, 1987.

Lively, R. S. and Ney, E. P., Surface radioactivity resulting from the disposition of radon 222 daughter products, Health Physics, Vol. 52, No. 4, pp. 411-415, 1987.

C. Dr. Brian Krafthefer
Staff Engineer, Honeywell, Inc.
Working on Ph.D., University of Minnesota
M. S. University of Minnesota, 1985

Mr. Brian Krafthefer has expertise and more than eight years experience in environmental measurements, measurement systems and has conducted research on indoor air movements, environmental air pollutants indoors and indoor radon. Mr. Krafthefer has authored publications and presented papers on indoor air environments at national and international meetings. His primary role will be design and set-up of instrumentation and data analysis of objective B.

Krafthefer, B. C., and Janssen, J. E., Control of Radon Decay Products, Proceedings of the Second International congress on Building Energy Management, IA, 30 May 3-June 1983.

Krafthefer, B. C., et at., On the Life and Performance of Zr02 Based Oxygen Sensors, Second International Conference eon the Science and Technology of Zirconia, Stuttgart, W. Germany, June 21-23, 1983.

Woods, J. E. and Krafthefer, B. C., Filtration as a Method for Air Quality Control in Occupied Spaces, Fluid Filtration: Gas, Volume 1, ASTP STP 975, R. R. Raber, Ed., American Society for Testing and Materials, Philadelphia, 1986.

Krafthefer, B. C., Filtration or Ventilation for Indoor Air Quality Control, First Congress on Housing Technology, St. Paul, MN April 13, 1987, pp.15.

Krafthefer, B. C., Effect of Filtration on Particle Size Distribution, ASHRAE Transactions, V. 94, Pt. 2, 1988.

D. Dr. Arthur N. Palmer, Ph.D.
Professor of Geology, Director of Water Resources Program, State University of New York College at Oneonta, NY Ph.D. in Hydrogeology, Indiana University, 1969
M. A. in Geology, Indiana University, 1965
Dr. Palmer has thirty years experience in the study of cave geology and origin throughout the world. He has performed geologic mapping and interpretation of such caves as Mammoth Cave - Kentucky, Wind Cave and Jewel Cave - South Dakota, Lechuguilla Cave - New Mexico, and Blue Spring Cave - Indiana. He has written interpretive guidebooks for the first three caves listed above, plus approximately 30 journal articles, book chapters, and published reports on cave geology and origin, a sampling is listed below. He is also the author of computer software used in geochemical analysis of mineral stability. Dr. Palmer's primary role will field and lab work designed to accomplish objective C.

Palmer, A. N., 1984, Geomorphic interpretation of karst features, in LaFleur, R. G. (ed.), Groundwater as a geomorphic agent: Boston, Allen and Unwin, pp. 173-209.

Palmer, A. N., 1989, (1) Stratigraphic and structural control of cave development and groundwater flow in the Mammoth Cave region; and (2) Geomorphic history of the Mammoth Cave System, in White, W. B., and White, E. L. (eds.), Karst hydrology: concepts from the Mammoth Cave area: New York Van Nostrand Reinhold, pp. 293-316, 317-337.

Palmer, A. N., 1983, Karst research in North America: Karstologia (France), v. 1, pp. 39-46.

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Davis, D. G., M. V. Palmer, and A. N. Palmer, in press, Extraordinary Subaqueous speleothems in Lechuguilla Cave, New Mexico: Natl. Speleol. Soc. Bulletin.

E. Margaret U. Palmer
Geologic consultant in Carbonate Petrology

M. A. in Geology
State university of New York, Oneonta, 1976

Ms. Palmer has 25 years of experience in geologic studies of caves, including those listed for A. N. Palmer. She has extensive laboratory experience in the analysis of cave minerals. co-author of several journal articles, book chapters, and guidebooks on the geology, mineralogy, and origin of caves.

Palmer, M. V., and Palmer, A. N. 1989, Palekarst of the United States, in Bosak, P., ed., Paleokarst: Prague, Academies/Elsevier, 337-363.

Palmer, M. V., in press, Geologic history of caves in the Black Hills, South Dakota: Natl. Speleol. Soc. Bulletin, v. 52.

Palmer, M. V. and Palmer, A. N., 1975, Landscape development in the Mitchell Plain of southern Indiana: Zeits. Geomorph., v. 29, no. 1, pp. 1-39.

Dakalowicz, J. J., D. C. Ford, T. E. Miller, A. M. Palmer, M. V. Palmer, 1987, Thermal genesis of dissolution caves in the Black Hills, South Dakota: Geol. Soc. Amer. Bulletin, V. 99, pp. 729-738.

Davis, D. G., M. V. Palmer, and A. N. Palmer, in press, New Extraordinary subaqueous speleothems in Lechuguilla Cave New Mexico: Natl. Speleol. Soc. Bulletin.

F. Gary Montz
Invertebrate Specialist
Ecological Services - Department of Natural Resources

M. S. Fisheries Aquatic Biology, 1986
Thesis title: The Littoral Benthos of the Apostle Islands National Lakeshore.

Mr. Montz is the DNR's main liaison for mosquito and black fly control programs in the metro area. He is developing a program to address the infiltration of zebra mussels. Mr. Montz performs field sampling and laboratory work in river surveys throughout the state and has done preliminary surveys of aquatic invertebrates found in Mystery Cave in 1989.

Montz, G., The Occurrence of Ripistes parasita (Oligocheeta:Naididae) in Minnesota and its implications for benthic sampling., Jour. of the North Am. Benth. Soc. Vol. 7 (2): 160-162, 1988.

Montz, G., Biological Survey of the St. Croix River - Invertebrates Special Publication, Minnesota Department of Natural Resources, in press.

Montz, G., Geological Survey of the Rainy River - Invertebrates Special Publication, Minnesota Department of Natural Resources, in press.

VII REPORTING REQUIREMENTS

Semiannual status reports will be submitted not later than January 1, 1992, July 1, 1992, January 1, 1993, and a final status report by June 30, 1993.

3(2)

The Waters of Mystery Cave

Forestville State Park, Minnesota

Mystery Cave Resource Evaluation (Groundwater)

MANAGEMENT REPORT

E. Calvin Alexander, Jr.
Roy A. Jameson

Department of Geology and Geophysics
University of Minnesota
Minneapolis, MN 55455

January 1994

The Waters of Mystery Cave

Mystery Cave Resources Evaluation (Groundwater)

MANAGEMENT REPORT

E. Calvin Alexander, Jr. and Roy A. Jameson
Department of Geology and Geophysics
University of Minnesota
Minneapolis, MN 55455

INTRODUCTION

This is the management portion of the final report for the LCMR project **Mystery Cave Resources Evaluation (Groundwater)** and is one part of the Mystery Cave Resource Evaluation. Funding for this project was approved by the Minnesota Legislature M. L. 91, Chapter 254, Article 1, Section 14, Subd. 3(1), as recommended by the Legislative Commission on Minnesota Resources, from the Future Resources Fund. This project concerns the waters and geohydrology of Mystery Cave in Forestville State Park. A summary of these topics in non-technical terms is given in a separate Interpretive Report, and technical aspects are covered in a separate Technical Report. This Management Report contains recommendations meant to protect and improve the water quality in Mystery Cave, as well as recommendations for education and future research.

PROTECTION AND IMPROVEMENT OF CAVE WATER QUALITY

Water is of central importance to any cave in limestone or dolomite. Water forms the caves, decorates, and then ultimately destroys them. Mystery Cave was formed and shaped by the dissolution of the carbonate bedrock by water. Water carried sediments into Mystery and deposited the speleothems that decorate the cave's interior. Most of the biology in the cave is dependent on the water flowing into and through the cave. Caves allow unique access to the flow of water in the subsurface. Visitors to a cave can directly and personally observe, enjoy, study, and learn about how groundwater moves in the unsaturated zone of karst aquifers. A fundamental goal of the management of Mystery Cave is to protect and improve the quality of that water. The management, protection and improvement of water quality in Mystery Cave will be a complicated and challenging task.

As documented in the Technical Report, water quality in Mystery Cave reflects a variety of natural processes. In many cases, water quality is being significantly impacted by human activities both inside and outside of the cave. The current management philosophy and policies are directed at maintaining and improving the water quality in Mystery Cave and its surface environs. In general, those policies are working well. The following recommendations are meant to reinforce and strengthen those management practices.

Management policies need to reflect an understanding of the natural hydrologic and chemical processes at Mystery Cave. Policies should minimize changes to natural processes, whether in the cave or on the surface. Management practices further need to be based on the knowledge that some human impacts to the water quality result from activities well removed from the cave proper. There are three different scales at which to manage water quality in Mystery Cave: The first is in the cave itself. At this level, we consider the direct impact of human visitation and in-cave management practices on water quality. The second scale includes the cave and the areas above the cave and immediately adjacent to it. At this level, we are concerned with human activities on the surface which primarily affect water quality in the upper levels of Mystery Cave. The third scale includes the cave, the nearby surface, and the rest of the Mystery Cave surface basins. At this level, we are concerned with the impact of distant human activities which primarily affect the water quality in the lower stream levels; these streams are directly fed by the South Branch of the Root River. The following management recommendations are discussed within the context of these three different scales.

Activities inside Mystery Cave

The policies of cave management already emphasize minimizing the impact of the public, management, sport, and scientific visitation on water quality in the cave. All visitors are forbidden to discard anything in the cave. We recommend that these policies be maintained and strengthened.

We recommend that the disposal of anything in the cave continue to be forbidden. Anything artificial that is installed or placed in the cave should be viewed as temporary. Plans for its ultimate removal should be an integral part of the installation permits. The current policy of removing obsolete wiring and other artificial material from the earlier show-cave phase should be continued. The chemical and physical interactions of all activities with the cave waters should continue to be a management consideration.

The waters in the cave are moving *through* the cave. Very little of the water remains in the cave for very long. Removal of modest amounts of the water for management or scientific purposes will not significantly impact the cave (see Education and Research Recommendations below). The current policy of allowing water sampling for scientific, management, and educational purposes should be continued.

The bedrock, sediments, and speleothems in the cave should be protected. However, the Mystery Cave System contains a important and unique record of the speleogenesis of the cave and a detailed, regional climate record that extends back at least 150,000 years. We recommend that a carefully controlled and monitored permit system for sampling of the bedrock, sediments and speleothems for scientific research purposes be established. A scientific research advisory committee might be a good mechanism to allow the Park Managers access to expert advice to help evaluate permit applications.

The full extent of the Mystery Cave System is not known. A complete map of the known cave does not exist. A *complete* working map of the cave at a scale suitable for most scientific work does not exist. Although we never know just how much of the real extent of a cave is known or surveyed, it is usually desirable to have as complete a map as possible. Exceptions occur; some caves have passages so well decorated and fragile that complete exploration and mapping would result in unwarranted degradations. Nonetheless, for Mystery Cave we recommend additional surveying to increase our knowledge of the cave's extent. That knowledge is essential if we are to have a chance of protecting the entire cave system. Thus, we recommend that policies designed to encourage exploration and mapping of the cave system be implemented. The sport caving community represents a significant source of volunteer expertise and should be utilized in the exploration and mapping efforts.

Low but elevated concentrations of zinc in Frozen Falls Pool, which is directly below a major bridge, are up to eight times the background values measured in Frozen Falls Drips and other sources feeding the pool. Some leaching of zinc from the galvanized steel bridges and railings is indicated. We recommend that zinc should be monitored on an infrequent but periodic basis at any sites where zinc concentrations might build up and significantly impact water quality.

The zinc sampling has been relatively modest to date due to budgetary constraints. We recommend that zinc sampling be extended to previously unsampled sites as well as the sampled sites. Frozen Falls Pool and Turquoise Lake are reservoirs with short residence times. They are flushed during recharge events (mostly associated with storms) sufficiently often that zinc is unlikely to build up to significant concentrations, at least for the present time, while the railings and bridges are young and the galvanized coatings are intact. Frozen Falls Pool and Turquoise Lake also are flushed infrequently when the Root River floods into Mystery I, as happened in late March, 1993. Sites at small flowstone pools along the Mystery I tour route where zinc might build up have not yet been sampled. These pools are adjacent to galvanized steel railings used to separate visitors from flowstone and other speleothems. These pools appear to have low fluxes and long residence times for the water recharging them, but zinc may enter via splash processes off the railings. We plan to sample these areas for zinc during the 1993-1994 Mystery Cave Geochemistry project. The small flowstone pools are reported to occasionally harbor springtails, so the zinc concentrations there may be of biological significance.

No sediment samples or biological materials were checked for zinc during this study. Zinc can be adsorbed on sediment, accumulate, and then be released at later times. Zinc can also build up to detrimental concentrations in organisms. We recommend that the zinc sampling be extended to include sediments and biological materials.

We recommend that modifications of the tourist trails in Mystery II be limited to the removal of objectionable existing artificial material and limited restoration efforts to reverse the effects of past commercialization. The "wilder" caving experience with hand held lights in Mystery II is popular with the tourists, is an appropriate tour experience, and minimizes the potential impact of massive modification associated with accessible trails and lighting.

One necessary modification of the Mystery II tourist trail involves the bridge over Blue Lake. During periods of high stage at Blue Lake, most of the wood bridge support piling is inundated. At low stage, during some of the fall and winter of a typical year, the wood piling may be completely dry. If the water level is sufficiently high, a set of seeps and springs in the tourist trail are active. Blue Lake Springs are about 60 ft east of the lake. Similarities in chemistry, and the correlation of flow with high stage, indicate that Blue Lake Springs water is derived from Blue Lake. That water seeps and flows out of the gravel in the middle of the trail, spreads out as a thin sheet, and then collects in a ditch on the north side of the passage. The water flows about 100 ft downslope before disappearing into a hole between the breakdown and gravel along the north wall. Blue Lake Springs are usually active in the winter or spring, but may become active anytime water level is sufficiently high. Blue Lake Springs were active most of the spring and summer of 1993, a particularly wet period.

When the water level in Blue Lake is high, there is a distinct odor of creosote around the Lake and to the east in the passage leading to Diamond Caverns. The wood bridge piling has a similar smell, as does a black sticky substance that can be scraped from the wood. The odor is strongest when Blue Lake Springs are active and is objectionable to many visitors. We believe the odor derives from semivolatile organic compounds in the impregnated bridge piling. The compounds dissolve in the lake water and are volatilized as the water flows down the trail and ditch from Blue Lake Springs. During dry years the odor may be detectable only in the late winter and spring, but during wet years it can be expected throughout the summer tourist season. Volatile compounds were not detected in the single sampling for volatile organic compounds at Blue Lake,

but a careful resampling for the appropriate semivolatile compounds may detect them. We recommend an additional sampling at both Blue Lake and Blue Lake Springs for organic compounds associated with creosote. Such sampling could be conducted during the spring of 1994, when recharge refills Blue Lake.

Regardless of the results of the sampling, we recommend that all impregnated wood pilings be replaced. This will require significant reconfiguration of the bridge, but may entail little modifications to the support systems at the ends of the bridge. If possible the replacement bridge should not use pilings. If such a bridge is not feasible for engineering, economic, or management reasons, we recommend that replacement pilings should be chosen that are compatible with the hydrogeochemistry of Blue Lake.

Blue Lake and Blue Lake Springs have a significant educational value as hydrologic features. Blue Lake is also important because it has excellent examples of raft cones; indeed it has the only ones visible along the Mystery II commercial trails. Although the springs wet the trail and constitute an occasional annoyance, they do not present a major management problem. Minor modifications could be made to better direct the water to the side, leaving the seeps and springs intact as hydrologic features. These seeps and springs could be labeled and identified as part of the interpretative program. Water level, water and air temperature, and conductivity data acquired at Blue Lake (see the Technical and Interpretative Reports) could be worked up into an in-cave display that illustrates (1) cave meteorology, and (2) the hydrology and chemistry of Blue Lake and Blue Lake Springs.

Additional modifications of the Mystery II trail system may be necessary. The hydraulics of the entrance area are a problem. During recharge events, water sprays out of the retaining walls, runs a short distance down the tourist trail, and erodes a small sinkhole in the trail. This pit is a hazard to anyone entering the Mystery II entrance. We recommend that engineering solutions to this problem be investigated.

About 80 ft west of 17 Layer Rock in 5th Avenue of Mystery II there is a side passage that leads toward a surface valley. During major recharge events, a small stream flows down the passage and spreads out over the trail of 5th Avenue. At times, the water forms one or more pools up to five inches deep. The pools can cover the entire width of the passage, as occurred during the wet summer of 1993. The pools impede tours. We recommend that engineering solutions to the problem be investigated.

Activities on the Surface above Mystery Cave

Groundwater in the upper parts of Mystery Cave, including all of the tourist trails, flows primarily downward to the horizontal streams in the lower levels of the cave. These lower level streams locally represent the top of the water table and mark the transition from predominantly vertical to horizontal groundwater flow. Horizontal movements of groundwater in the upper portions of Mystery Cave certainly exist but are limited by the major vertical joints. Water flowing horizontally may be diverted down smaller joints, but cannot flow far without intersecting a major joint. The major joints are spaced about every 30 to 100 meters. This spacing is evident in the cave itself and is visible in local limestone quarries. Examples illustrating downward vertical flow in the upper levels can be seen at Enigma Pit, the Smoking Chamber, Frozen Falls, and at the waterfall in Old Mystery Cave. The primary management implication of this downward flow pattern is that *the land surface directly above the cave is the source of most of the water in the upper parts of the cave*. The major exception to this is water flowing on the surface for some distance before sinking over the cave. Most of the land over Mystery is not owned by the State of Minnesota or managed by the Department of Natural Resources and Forestville State Park. This limits the management options available to protect the water quality in Mystery Cave.

Forestville State Park does manage the critical surface areas around both entrances to the cave. Human activities in these areas directly affect water quality in the cave. Management policies adopted by Forestville Park will, by example, set an upper limit on practices the DNR may hope the surface landowners will adopt. We will make recommendations mainly on the policies that the DNR can adopt for its own property over the cave. We hope these will illustrate the principles that should guide the DNR managers in their negotiations with the other surface land owners.

A major potential source of water pollution in the cave is from human sewage generated by visitors at the cave. Although perhaps not the most aesthetically pleasing solution, the current use of self-contained "port-a-potties" is an excellent solution to the problem and may be the most economically viable approach for the foreseeable future. The important hydrogeologic characteristic of these facilities is that no waste water is injected into the subsurface over the cave. We recommend that sewage treatment at any new visitor or management facilities at Mystery Cave or as a replacement for the existing "port-a-potties" should not involve any type of drain fields or technology over the cave that will inject effluent into the subsurface. Such injected water may be in the cave on a time-scale of minutes and will almost certainly be in the cave in hours to days. A closed system that is periodically pumped and transported or a sewer system that moves the waste to a treatment facility hydraulically downstream from the cave is necessary.

Use of the previously existing cesspool outhouses were very correctly abandoned as soon as Forestville Park began to manage the cave. However, those old cesspools remain in at least three locations over the cave. They may develop into a source of groundwater pollution as the geochemical changes in the wastes progress. We recommend that the feasibility of excavating and removing those old cesspools be investigated.

Dye tracing has documented that the septic system at the DNR residence at Mystery I impacts the water quality in some lower stream passages of Mystery I. About 1% of the effluent going into the drain field reaches the lower stream levels as fast as does the water which sinks in the river in front of the cave. There is little documentation of the construction of that drain field. We recommend that the existing drain field be replaced with some type of closed system. The trailer dump facility at the campground in Forestville Park is well downstream from the cave and does not threaten water quality in the cave. That facility is one possible place to treat waste from the residence over the cave.

The DNR does not maintain any animals or agricultural activities in their land over Mystery. One management practice that might arise is the use of herbicides to control plant growth around the cave entrances or over the cave. Any such practice is not recommended and if necessary should be monitored very carefully. If the cave area is tied into the trail system of Forestville Park and those trails are to be used by horses, the stable areas and hitching areas should not be over or upstream of the cave.

Parking lots for visitors are an ongoing challenge. To the maximum extent possible, such facilities should not be over the cave. The water quality associated with runoff from parking lots contains hydrocarbons, heavy metals, antifreeze, etc. Parking lot runoff is not a desirable addition to the cave's waters. Many National Parks that manage caves are currently struggling with this problem. Off-site parking is the ultimate goal. Roads over the cave should in general be viewed as a necessary evil and whenever possible should be routed away from the cave.

The land over the cave that is in private ownership is a major challenge. The atrazine, nitrates, chlorides, and coliform bacteria observed in water from the upper levels of Mystery Cave probably came in large part from the agricultural and domestic activities over the cave. Several private homes over the cave have septic systems that probably impact the cave. The nutrients and agricultural chemicals applied to the fields are impacting the cave's waters. The animal wastes

from barn yards, feed lots and manure applications to the fields are impacting the cave's waters. We can only recommend that the DNR work creatively and innovatively with the local landowners to limit these inputs.

Activities in the Surface and Groundwater Basin of the Root River

Water quality in the lower stream levels of Mystery Cave is largely determined by the water quality in the South Branch of the Root River which sinks at the cave and forms the lower level streams. That water resurges at the Rise of the South Branch of the Root River in Crayfish, Seven, and Saxifrage Springs. The water from the South Branch that sinks north of Mystery Cave resurges at Moth and Grabau Springs. Moth and Grabau springs are the headwaters of North Branch or Forestville Creek, which flows for most of its length in Forestville State Park. The water quality in the South Branch upstream from Mystery Cave, therefore, directly affects the water quality in major parts of the cave and park. Elevated levels of nitrate, coliform bacteria, and atrazine are ubiquitous in the river water and the lower level streams in Mystery Cave. We recommend that the DNR examine its regional management policies to look for ways to improve the water quality in the South Branch upstream of Mystery Cave. We recommend that the classification of this stretch of the South Branch be upgraded to reflect its impact on Mystery Cave and the trout streams in Forestville State Park.

The summer of 1993 proved to be exceptionally wet. The South Branch of the Root River covered all of the flood plain at the ticket building at Mystery I and flooded parts of the Mystery I tourist trail twice. Major log jams formed on the upstream side of the new bridge to the Mystery I picnic area. The log jams partially blocked flow, causing ponding upstream. This may have exacerbated the flooding of Mystery I. We recommend that the impact of these recurring log jams on the local flooding be investigated and necessary corrective measures be developed.

Routine practices that can impact the water quality in the South Branch include the agricultural and domestic activities of everyone who lives, works, plays, or visits the basin. The City of Ostrander is in the basin. The Ironwood Sanitary Landfill with its industrial waste pollution is in the basin. The American Oil Company pipeline crosses the South Branch of the Root River's basin about a mile upstream from Mystery. This is an old pipeline. Spills and leakage have occurred as close as the Amoco tank farm just east of Spring Valley. A variety of hazardous materials are transported on the roads in the basin and are stored on farms, businesses, and residences.

Scenarios for the impact of events in the surface basin on the cave range from minimal up to life threatening. A gasoline spill, for example from a tank truck or the pipeline, would move down the South Branch and flow into the lower stream levels of Mystery. The turbulence of the cave streams would vaporize part of the gasoline. Explosive mixtures of gasoline vapors could then rise from the lower levels into the tourist portions of the cave. If this occurred during the summer tour season, an entire tour group might be lost to an underground explosion. We hasten to add that this is a worst-case scenario. However, explosions and fires from fuel spills have occurred in caves, sewers, and houses in karst areas, under circumstances in which the spilled materials originated outside the explosion sites. We recommend that the DNR cave management coordinate with all local, county (Fillmore *and* Mower), regional, and state emergency response authorities. Notification of the cave management of any report of a spill or release of pollutants anywhere in the basin of the South Branch of the Root River should be a high priority. We recommend that contingency plans be created to deal with such an emergency.

RECOMMENDATIONS FOR EDUCATION

Mystery is the largest and most accessible cave in the state. Minnesota has invested millions of dollars in upgrading the tourist access in Mystery I. The new, state-of-the-art Mystery I facilities are outstanding and a testament to the vision, skills, dedication, and hard work of the Park staff. Mystery Cave has an immense educational potential. We recommend that the educational use of Mystery Cave be significantly upgraded and expanded.

Public Education

Forestville Park staff has made a concerted effort to include preliminary results of this project and all other available scientific into the visitor experience during summer tours. This public educational effort is already excellent and should be strengthened and expanded. The Park has a strong program of training of the summer interpretive staff. This project will supply much additional material to enhance the training and information available to the staff. Many of the summer visitors spend a significant amount of time waiting for their cave tour. We recommend that audio-visual material which gives background information on the cave and the cave tour be developed. Such material could simultaneously enhance the experience for the visitor and simplify the task of the interpretive staff on the tours.

K-12 Education

Mystery Cave historically had a strong component of K-12 educational visits before and after the summer tourist season. The other commercial caves in the region continue such programs and their experience indicates a strong interest in, and demand for, such educational opportunities. We recommend that Forestville State Park develop a program, including pre- and post-visit curricular materials, to encourage various grade levels of school groups to visit the cave. The opportunity to begin educating K-12 students about karst hydrogeology is unsurpassed. Such an effort will require significant new resources but is directly in line with the current LCMR priorities. K-12 visitation of Mystery will increase the use of the cave during the off season.

College and University Classes, Professional Education

Individual faculty members at regional colleges and universities routinely include visits to the cave as part of field trips in various earth and environmental science courses. Visits to Mystery are also routinely included in field trips associated with professional and scientific meetings and short courses. The staff of Forestville State Park have encouraged and facilitated such usage. Such visits, however, are largely at the initiative of the individual faculty or meeting staff and are not coordinated. Other faculty and meeting staff may not realize that such visits are possible. Various educational materials have been generated in connection with these field trips, but little of it has been accessible to or used by the Park staff. This usage should be encouraged as part of the educational effort. The educational materials generated for these field trips should be assembled and coordinated. We recommend that policies designed to encourage and facilitate such educational usage be developed.

RECOMMENDATIONS FOR FURTHER STUDY

The research in this program has demonstrated that Mystery Cave is indeed a world class cave. The assembled information base should form the basis for a whole series of ongoing research efforts. New and additional information generated in such work will only enhance the stature and value of the cave and will assist in the ongoing management challenges. We recommend that management policies explicitly encourage the use of Mystery Cave for scientific

research.

A particularly new and exciting development in paleoclimatology is the recent discovery of annual banding in speleothems. This discovery, coupled with new advances in the precision of speleothem dating and isotope geochemistry, raises the possibility that the speleothems and sediments in Mystery contain a unique record of climate change in the upper midwest for the last 150,000 years. We recommend that carefully selected speleothem and sediment materials be available for such research.

Much work has been done on zinc leaching from galvanized steel and other building materials. Zinc initially weathers rapidly, forming zinc carbonate and other surface coatings that tend to protect the lower layers of zinc as well as the steel. Later weathering can be slower, but varies greatly according to the environment. Weathering environments that allow zinc coatings to dry tend to have lower leaching rates, but many factors are involved. Knowledge of long-term zinc leaching rates in a variety of surface environments has allowed engineers to predict the expected lifetimes of galvanized steel structures on the surface, out of doors as well as indoors in such settings as chemical factories. We cannot at present predict expected lifetimes of the galvanization of Mystery Cave bridges. We do not have useful long-term data on leaching in cave environments, nor is it clear what effects local environmental and chemical factors will exert in Mystery Cave. The cave is humid, and most bridges and railings are never fully dry in Mystery I, so leaching rates could be high. At some locations, the galvanization could be protected, if waters supersaturated with respect to calcite deposit calcite crusts directly onto the metal. Because the railings and bridges are essential to operation of the cave tours, we recommend additional work directed at estimations of zinc leaching rates. If those rates turn out to be high, zinc concentrations of waters, sediments, or organisms might rise to unacceptable levels. Mystery Cave provides an excellent opportunity to investigate zinc removal from galvanized steel and its possible accumulation within the subsurface. Such an opportunity should be seized, if for no other reason than that galvanized steel definitely does have a limited useful lifetime. When the time (hopefully many years from now) eventually does come to replace or upgrade the bridges, it will be helpful to know as much as possible about the performance of the existing materials.

Mystery Cave is one of the best possible locations for long-term monitoring of water quality trends in southeastern Minnesota's karst region. Management of the cave will require some level of routine water-quality monitoring. There are several programs within Minnesota State environmental management efforts that monitor Minnesota's ambient groundwater quality. We recommend that the DNR work to include some of the waters in Mystery Cave and Forestville Park in these ongoing groundwater-quality monitoring efforts. There is a real opportunity to avoid duplication and to conserve financial resources here.

We recommend that specific research and monitoring of the cumulative impact of various types of visitation on the cave and its waters be initiated. Does the cave have carrying capacities for specific types of visitations? The water-quality data generated in this project will serve as the baseline for such future work.

JAN 13 1994

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Department of Natural Resources
Parks and Recreation

State of Minnesota
Office Memorandum

DATE: January 12, 1994

TO: John Velin and Susan Thornton

FROM: Warren Netherton
Cave Specialist, Forestville/Mystery Cave State Park

PHONE: 507-937-3251

SUBJECT: Mystery Cave Resource Evaluation Report

Enclosed is a report generated from the hydrology study of the Mystery Cave Resource Evaluation. It is actually an extension of the study funded by the Division of Parks and Recreation. The information from this extension has clarified data collected from the two year LCMR effort markedly.

July 1, 1993
LCMR Final Status Report - Summary - Research
LCMR WORK PROGRAM 1991

I. **Mystery Cave Resource Evaluation**

Warren Netherton
Forestville State Park
Rt. 2, Box 128
Preston, MN 55965
Department of Natural Resources
507 937-3251

A. M. L.92 Ch. 254 Article 1 Sec. 14 Subd:3(1)
Appropriation: $150,000
Balance: $ 3,130

Mystery Cave Resource Evaluation:
This appropriation is to the commissioner of natural resources to perform a resource inventory and study of Mystery Cave to include groundwater, cave meteorology, geology, and biology as part of the park plan.

B. Compatible Data - During the biennium ending June 30, 1993, the data collected by projects funded under this section that have common value for natural resource planning and management must conform to information architecture as defined in guidelines and standards adopted by the Information Policy Office. In addition, the data must be provided to and integrated with the Minnesota Land Management Information Center's geographic data bases with the integration costs born by the activity receiving funding under this section.

C. Match Requirement - not applicable

II. Narrative

A. Statement of the Problem: Mystery Cave was acquired by the State of Minnesota and made a part of Forestville State Park in 1988. It is one of the primary resources of the park and the only show cave in the outdoor recreation system. Although some prior research has involved the cave, major gaps in understanding the groundwater, geology and mineralogy, meteorology, and biology of the cave place limitations on the ability to develop interpretive programs and make sound management decisions.

B. Importance: The cave is one of the 100 longest caves in the world and the longest in Minnesota. It has the classic characteristics found in many caves and also somewhat unusual cave features. Mystery Cave has been an important facet of southeastern Minnesota tourism for fifty years. It is a natural laboratory for the intimate study and understanding of karst and groundwater flow which is of regional and national importance.

C. Extent of the Problem: No systematic examinations of Mystery Cave have integrated the major environmental components of groundwater, meteorology, mineralogy, and biology. Existing information on the cave is limited. The present information used for public tours, educational tours and management decisions is piecemeal with a significant portion being generic, extrapolated from studies in other caves.

III. OBJECTIVES

A. **Inventory present water chemistry and water quality throughout the cave system, attempt to identify the sources and sinks of the various cave waters, measure the response of various cave waters to seasonal precipitation events and to human activities.**

A.1. Narrative: Management of the unique and fragile Mystery Cave karst hydrologic system requires a detailed inventory of the drip, pool and stream waters of the cave and an understanding of how those waters respond to natural and human-induced changes on the surface. The focus of this objective is to inventory the cave's groundwater resources and to evaluate how those waters respond, in quantity and quality, to surface events.

A.2. Procedures: Water samples will be collected periodically from a variety of accessible cave drips, pools, and streams throughout the cave system. The

samples will be analyzed for a variety of chemical parameters. In most cases the parameter list will include field determinations of pH, conductivity, and temperature, and laboratory analysis of common and trace cations and pesticides, and anions. Analytical techniques will include direct current plasma/atomic emission spectroscopy, immuno assay and ion chromatography. Selected samples will be analyzed for VOCs, pesticides, and bacterial parameters. The results of these analyses will define the current state of the water quality in the cave, seasonal variability and be used to look for evidence of human impact on the cave hydrology. If evidence of the human impact is found, the water quality will be correlated with overlying and adjacent land uses.
One digital data acquisition system will be installed on the surface above the cave and at least one system will be installed in the cave. The surface station will acquire continuous measurements of air temperature, precipitation, wind speed and direction, relative humidity, barometric pressure and river stage and water temperature. Additional parameters may be measured if feasible. The in cave station will acquire continuous measurements of water levels in a cave pool, drip rates in a cave drip, temperature, conductivity and other appropriate parameters. The comparison of the continuous data records from the surface and cave stations along with periodic sampling throughout the cave system will be used to determine the links between the surface events and the cave hydrology. The external and internal meteorologic stations will be developed and installed cooperatively with objective B below.

A.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$62,000	$15,000
b. Expended:	$62,000	$15,000
c. Balance:	$ 0	$ 0

A.4. Timeline, Products/Tasks:

	July91	Jan92	June92	Jan93	June93
Coordination with other objectives	.....				
Design and installation of data acquisition systems	.....				
Collection and analysis of water samples		.....			
Data analysis and interpretation		.....			
Quarterly reports		..	..	..	
Preparation of Technical final report and layman's report			.....		

A.5. Status: Water samples were taken from waterfalls, streams, pools, stalactite drips, flowstone flows and drips, bedrock drops, and in cave springs in Mystery Cave. The samples were analyzed for a variety of parameters.

Mystery Cave and associated waters exhibit a diverse water chemistry and water quality that varies with season and with the magnitude of recharge and discharge.

Water levels were monitored inside the cave at a lake, stream, and various drip points. The data from these locations were examined with surface meteorologic events. The waters flowing through Mystery Cave respond rapidly to precipitation events on the surface, particularly to flows originating from leakage through sediment-filled fractures in the Root River.

The researchers shared their cave expertise with the Forestville State Park interpretive staff by providing a field and classroom training session.

Material gleaned from this study has and is being shared with the public on a daily basis at park interpretive programs in the summer. The findings from this work assisted researchers of the geology and mineralogy section (C) in interpreting facets of their work. The study has provided a baseline of hydrologic data from which to compare with anytime in the future. One of the great strengths of this study is the continuous hydrologic readings gathered with periodic water samples. The Division of Parks and Recreation has recognized the value of continued water monitoring of this study and in order to gain a better understanding of the hydrologic system is funding a one year

downscaled continuation of the study.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

A.6. Benefits: Determining the water chemistry, flow paths and underground effects of surface precipitation will have direct and immediate benefits in the form of public education on cave tours and other interpretive activities in Forestville State Park. The focus of this objective will answer a multitude of fundamental and specific groundwater questions frequently asked by the public about Mystery Cave. It will also provide invaluable baseline data which will help gauge hydrologic changes resulting from human activity or natural occurrences.

B. **Cave Meteorology: Investigate the cave meteorology in Mystery Cave and study its relationship to radon environment and air exchange and assess the impact of cave renovation on the cave meteorologic system.**

B.1. Narrative: Elevated radon concentrations in Mystery Cave make it necessary to monitor the exposure of persons spending long periods in the cave. Radon levels, which are controlled in part by meteorologic conditions outside and inside the cave have not been systematically studied, making it difficult to accurately monitor employee or other exposures. Present direction and rate of air movement through the cave is unknown. This objective is intended to gather baseline data by continuously monitoring radon and meteorologic conditions within selected parts of the cave system over a two year period. It will seek to determine air flow relating to seasonal and daily weather events. It will also compile existing radon data (from the cave) to assist with developing the measurement system. An examination of the ventilation and air flow in Mystery Cave, both as they relate to radon levels and to changes that might result from cave renovations, will be performed. An attempt to correlate temperature and humidity levels with air movement will be made.

B.2 Procedures: A comprehensive system of radon and radon daughter product monitoring will be deployed along sections of the commercial (tour) routes in Mystery Cave. This will include at least 4 continuous radon monitors, 2 weather stations recording barometric pressure, relative humidity and temperature in separate parts of the cave, and a possible third station outside recording barometric pressure, relative humidity, temperature, wind speed and direction and rainfall. Two locations will also continuously record radon daughter product concentrations. The radon monitors, radon daughter monitors and weather stations will be located on the tour routes. Grab sample radon and radon daughter measurements will be collected throughout the undeveloped portions of the cave system. Seasonal measurements of air movement and exchange within the cave will be carried out using PET (tagged perflurocarbon tracer) gasses. Quarterly measurements of aerosols, which affect the distribution of radon daughter products will also be made, as will emanation rates of radon from the various rock types within the cave. Data reduction will include time series analysis of the continuous radon and radon daughter record and correlation with the various meteorologic parameters, aerosol and air exchange measurements. Data from the radon and air flow measurements will be used to assess the effects of renovation on the air system. Other characteristics of the cave air such as carbon dioxide levels will be measured as time and budget permit.

B.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$43,000	$0
b. Expended:	$43,000	
c. Balance:	$ 0	$0

B.4. Timeline for Products/Tasks:

	July 91	Jan 92	June 92	Jan 93	June 93
Analyze existing radon data	. . . .				
Design monitoring program	. .				
Implement monitoring program	.....	.....			
Analysis of data	.....	.....			
Quarterly reports	..	..	..		
Final report					.....

B.5 Status: The cave meteorology results from the radon measurements indicate that the annual average radon concentration in the cave is about 200 pCi/L. For comparison, the Environmental Protection Agency guidelines for radon in buildings is 4 pCi/L. Daily changes in radon concentration can be as much as a factor of 60 in the winter and less than two in the summer. Radon was less sensitive to changes in barometric pressure in summer than winter. Outside temperature was observed to correlate with some variations in radon concentration.

Both the results from the radon measurements and the meteorologic measurements, particularly temperature and barometric pressure indicate that air-flow within the cave is connected to outside meteorologic conditions.

General air motion in the cave is from west to east with occasional flow from east to west.

Aerosol monitoring results indicate that the cave is relatively free of aerosols greater than 0.3 microns in diameter. A typical home may have 10,000 particles per cubic centimeter, while the cave has less than 0.01 particles per cubic centimeter.

The researcher shared his cave expertise with the Forestville State Park interpretive staff by providing a classroom training session.

Baseline data was collected during the study that shows trends which were unknown previously. Variations in radiation levels recorded, although not directly comparable to records kept for safety purposes, will assist in cave operation planning efforts that consider radiation exposure of personnel.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

B.6. Benefits: This objective develops and implements a program of basic research that will provide baseline data on environmental conditions within Mystery Cave. The data can be used to help guide policy decisions on cave renovations, improve radon exposure information for employees and help guide policy on exposure limits. Both the radon and meteorologic environments in the cave are sensitive issues, in terms of long-term health risk and alteration of the physical and biological cave environment through public use and/or management, that require adequate information which to base decisions.

C. **Narrative: Geologic mapping of Mystery Cave, and determination of mineral types, their distribution, geochemical stability, and origin.**

C.2. Procedures: A leveling survey through the main passages of the cave system (with hand level and engineer's level, using the existing map of the cave for horizontal control;) will be run. Elevations of cave ceilings and floors, geologic contacts, sediment levels, water levels (past and present) and mineral locations will be measured. From the leveling data a geologic map will be constructed. Mineral and mineral types, shall be analyzed using in-cave observation and lab analysis of broken specimens (leaving no visible impact on the cave). Analytical techniques will include X-ray diffraction, scanning electron and light-transmission microscopy, and chemical tests. Geochemical analysis of pool and drip waters in which the cave minerals occur will be performed cooperatively with objective A. to evaluate mineral stability. Mapping and interpretation of sedimentary deposits and flow indicators such as solutional scallops shall be performed. On the basis of mineral types and their range of stability, management strategies will be determined. A report will be compiled on the geologic history setting of the cave that can be used for interpretive purposes by park staff will be assembled.

C.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$39,500	$0
b. Expended:	$39,500	
c. Balance: (12/24/92)	$ 0	$0

C.4. Timeline for Tasks/Procedures:

	July91	Jan92	June92	Jan93	Jun93
Geologic mapping mineral ident	.....		...		
Analyze rock, mineral samples		.....		.....	
Prepare interim reports		...	...	..	
Quarterly reports		..	..	..	
Final report & map					.....

C.5. This research mapping has resulted in the most detailed geologic mapping of any cave to date. This stratigraphic work is an important facet to explaining the history and evolution of the cave. It has demonstrated the favorable beds for cave system development, structural changes in the middle of the cave and the relation between predominate cave development and jointing patterns.

Lab analysis of pool deposits has shown very unusual formation; the type of which is generally only found in southwestern U.S. caves such as Carlsbad Caverns and Lechuguilla Cave.

A much clearer understanding of the environment during deposition of the rock layers is also a result of this study. Analysis has discerned much on the geologic background of dolomite/limestone. Such information may benefit future geology researchers.

The researchers have shared their cave expertise with the park interpretive staff by presenting classroom and field training sessions on Mystery Cave, caves and their research. The researchers fielded questions on a multitude of speleology concerns of the staff and also provided lengthy written narratives of each topic.

This study has elucidated the geologic history of the cave. It relates the cave origin and evolution to the way features look underground today. It has identified highly unusual cave deposits that should be preserved, explained the significance of other formations in the world of caves, and addressed concerns for cave conservation. The result of this project is site-specific knowledge of the cave resources that is related to the public every day on cave tours. A good understanding of the importance of Mystery Cave in relation to the surrounding area and other caves of the region and world was made.

The Division of Parks and Recreation has recognized the value of integrating the results of all the studies of the Mystery Cave Resource Evaluation into an expanded more holistic final version of the research efforts and is providing funding an additional year.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

C.6. Benefits: Knowledge of the minerals in the cave, their origin, stability, and significance will provide management guidelines for their protection. The geologic mapping and interpretation will provide interpretive information for use by Park personnel in presenting the cave to the public. The cave origin and surrounding area, geologic history, regional significance, and comparison to other caves will be fully discussed in this report.

D. **To determine the occurrence and distribution of aquatic invertebrates in Mystery Cave.**

D.1. Narrative: The aquatic microinvertebrates within cave systems have recently begun to receive more attention from biologists, and a number of endemic species have been found in various caves. The kinds and distribution of aquatic invertebrates in Mystery Cave remains relatively unknown. The information collected will provide a basis for integrating biological resources and water quality and be used in developing cave interpretive programs and other management activities.

D.2. Procedures: Aquatic invertebrates will be quantitatively and qualitatively sampled in various waters throughout the cave. Over 800 meters of underground river corridors in four separate locations and eight pools or lakes will be examined. Sampling methodology may include the use of core samples from sediments, drift nets, activity traps, plankton net tows, or qualitatively picking of substrate. Due to the unique physical constraints of the habitat, sampling will be modified as necessary.

D.3. Budget:

	LCMR Funds	Matching Funds
a. Amount Budgeted:	$5500	$0
b. Expended:	$2370	
c. Balance:	$3130	$0

D.4. Timeline:

	July91	Jan92	June92	Jan93	June93
Refine collecting and initiate sampling techniques	.....				
Taxonomic lab work		.....	.....		
Quarterly reports		..	..	..	
Compile data and write reports			.....	.....	

D.5. Status: The aquatic invertebrates were qualitatively sampled from six sites within Mystery Cave. Both, macro and microinvertebrates were collected. This effort represents the first methodical and published survey of invertebrates sampling from Mystery Cave.

Nine micro-crustaceans, three rotifers, and 25 insect taxa were collected from the cave sites. Two species of Collembola not previously reported from Minnesota were collected from pools along a tour route. Both are reported as cave forms.

Additionally, fish were collected from two cave stream locations and in the South Branch Root River proximal to major cave stream inflow. Although a fish survey was not intended at the implementation of this aquatic work, it was convenient to do at no additional cost. Seven species of fish were collected. None of the fish collected are cave adapted.

This study has answered one of the commonest questions from the public about the cave - Does anything live here?

Recommendations have been made to continue regular systematic sampling in search of species missed. Also, recommendations are given for underground and surface management considerations in order to maintain the cave aquatic community.

Technical, interpretive and management reports generated by this discipline of the study are being filed in the Legislative Reference Library.

D.6. Benefits: This study will identify what lives in the cave waters; fundamental resource information that may also help define the range of species found in other caves. It will be used to determine limits of recreational caving and integrate surface land management with underground management to assure adequate protection to the invertebrate fauna. This inventory will function as a baseline data barometer for future surveys.

IV EVALUATION

The cave resource evaluation can be assessed by its ability to:

1) determine the chemistry of the cave water, where it arises from, and how it moves through the cave system.

2) identify the overriding influences of cave air movement and radon levels and how they are affected by these influences.

3) provide interpretive staff information to address frequently asked questions from the public concerning the cave's meteorology, groundwater, minerals, geology and aquatic invertebrates.

4) identify what minerals and aquatic invertebrates exist in Mystery Cave and their distribution.

5) provide reports that can assist managers in making sound resource management decisions.

6) provide a starting point of base line data from which possible future changes to the cave environment may be gauged.

environment may be gauged.

V CONTEXT; RELATED CURRENT AND PREVIOUS WORK

A. This project begins to answer fundamental questions about what minerals and organisms exist in Mystery Cave. A preliminary survey has identified only a portion of the aquatic invertebrates. Such a basic inventory has not been accomplished before. Although previous studies have examined water flow through the cave, the results provide a partial view of hydrologic connections. A current water chemistry study is providing important limited preliminary data, but it does not begin to provide the picture of groundwater conditions in the cave system which this project addresses. Existing park data hints at cave meteorological occurrences that require an on site study to understand.

B. To date, studies at Mystery Cave have focused on a)clastic sediments (including radiometric dating of speleothems), b)major hydrologic flow paths, c)limited water chemistry, d)bat censuses. The research conducted in a, b, and c provides valuable initial information from which to launch this integrated study. These earlier accomplishments reflect a logical progression of important preliminary studies that will save field time for this project.

C. No funding from LCMR has been provided for Mystery Cave studies previously. The biological component of this project is very limited and does not include bats or terrestrial invertebrates that use the cave. It is anticipated that LCMR funding beyond the fiscal year 92 - 93 biennium will be sought.

D. Not applicable.

E. Biennial Budget System Program Title and Budget: Not available at this time.

VI QUALIFICATIONS

1. Program Manager

Warren Netherton

Cave Specialist
Forestville State Park-Minnesota Department of Natural Resources

B.A. Field Biology, 1978, Evergreen State College, Olympia, Washington

The program manager has been involved with cave surveys and exploration in the United States and Mexico since 1972. He performed field cave evaluations for the Illinois Natural Areas Inventory and was formerly employed at Wind Cave National Park in a cave management position. Since 1988 Mr. Netherton has worked in his present capacity, charged with the resource management and interpretation of Mystery Cave. Mr. Netherton's primary role will be coordination of team efforts of objective A, B, C, D and provide limited on site assistance for objectives A, B and C.

Netherton, W. N., Where the Sun Doesn't Shine: A Developing Cave Interpretation Program. Proceedings of the 1989 National Interpreters Workshop, St. Paul, MN pp 292-294.

Netherton, W. N., Mystery Cave Trails: Past, Present and Future. 1989 National Cave Management Symposium Proceedings, New Braunfels, TX, in press.

2. Cooperators/other investigators:

A. Dr. E. Calvin Alexander, Jr.
Professor, Department of Geology and Geophysics, University of Minnesota

Ph.D. Chemistry, University of Missouri at Rolla, 1970
B.S. Chemistry, Oklahoma State University, 1966

Dr. Alexander has conducted research on the groundwater pollution problems of southeastern Minnesota karst for fourteen years. He has been engaged in research in Mystery Cave throughout this period. Dr. Alexander is responsible for the production of the current maps of the cave, for what is know of the flow systems involving the cave, and the initial water quality information form the cave. His primary role will be in the acquisition of the groundwater quality and quantity data in and

around the cave, listed under objective A. Selected from a long list of Dr. Calvin Alexander, Jr.'s karst related publications are five titles below.

Milske, J.A., Alexander, E. C. Jr. and Lively, R. S., 1983, Clastic sediments in Mystery Cave, southeastern Minnesota. NSS Bull., v. 45, pp. 55-75

Wheeler, Betty J., Alexander, E. Calvin Jr., Adams, Russell, S., Jr. and Huppert, George N., 1989, Agricultural land use and ground water quality in the Coldwater Cave groundwater basin, Upper Iowa River karst region, U. S. A. Part II in Gillieson, D. and Ingle Smith, D. (eds.) Resource Management in Limestone Landscapes: International Perspectives. Spec. Pub. #2, Univ. College, Aus. Def. Force Acad., Canberra, Australia, 11pp.

B. Richard Lively
Scientist, Minnesota Geological Survey

M. S. Isotope Geology, Michigan State University, 1977

Mr. Richard Lively has been studying the occurrence of natural environmental isotopes since arriving at the Minnesota Geological Survey in 1977. Studies have included U-series dating of speleothems in caves in the Upper Midwest, including Mystery Cave, studies of radon in Mystery Cave, radioactive isotopes in ground water, radon in soil gas and indoor radon as it relates to local geology. Mr. Lively has authored papers in peer reviewed journals, refereed publications and proposals and presented papers at national meetings. His primary role will be radon data analysis and interpretation of objective B.

Milske, J. A., Alexander, E. C., Jr. and Lively, R. S., 1983, Clastic sediments in Mystery Cave, southeastern Minnesota. NSS Bull., v. 45, pp. 55-75.

Lively R. S. and Morey G. B., 1982 Hydrogeochemical distribution of uranium and radon in east central Minnesota, in Isotope Studies of Hydrologic Process (edited by E. C. Perry Jr. and C. W. Montgomery), pp. 91-107 (DeKalb, Il: Northern Illinois University Press).

Lively, R. S., 1983, - Late Quaternary U-Series Speleothem Growth Record from Southeastern Minnesota; Geology II; 265-262.

Lively, R. S., Bettis III, E. A., Hallberg, G. R. and Hobbs, H., Exposure of the Songamon Soil in southeastern Minnesota, Proceed of Iowa Academy of Science, Vol 94, No. 4, pp. 111-115, 1987.

Lively, R. S. and Ney, E. P., Surface radioactivity resulting from the disposition of radon 222 daughter products, Health Physics, Vol. 52, No. 4, pp. 411-415, 1987.

C. Dr. Brian Krafthefer
Staff Engineer, Honeywell, Inc.
Working on Ph.D., University of Minnesota
M. S. University of Minnesota, 1985

Mr. Brian Krafthefer has expertise and more than eight years experience in environmental measurements, measurement systems and has conducted research on indoor air movements, environmental air pollutants indoors and indoor radon. Mr. Krafthefer has authored publications and presented papers on indoor air environments at national and international meetings. His primary role will be design and set-up of instrumentation and data analysis of objective B.

Krafthefer, B. C., and Janssen, J. E., Control of Radon Decay Products, Proceedings of the Second International congress on Building Energy Management, IA, 30 May 3-June 1983.

Krafthefer, B. C., et at., On the Life and Performance of Zr02 Based Oxygen Sensors, Second International Conference eon the Science and Technology of Zirconia, Stuttgart, W. Germany, June 21-23, 1983.

Woods, J. E. and Krafthefer, B. C., Filtration as a Method for Air Quality Control in Occupied Spaces, Fluid Filtration: Gas, Volume 1, ASTP STP 975, R. R. Raber, Ed., American Society for Testing and Materials, Philadelphia, 1986.

Krafthefer, B. C., Filtration or Ventilation for Indoor Air Quality Control, First Congress on Housing Technology, St. Paul, MN April 13, 1987, pp.15.

Krafthefer, B. C., Effect of Filtration on Particle Size Distribution, ASHRAE Transactions, V. 94, Pt. 2, 1988.

D. Dr. Arthur N. Palmer, Ph.D.
Professor of Geology, Director of Water Resources Program, State University of New York College at Oneonta, NY Ph.D. in Hydrogeology, Indiana University, 1969
M. A. in Geology, Indiana University, 1965
Dr. Palmer has thirty years experience in the study of cave geology and origin throughout the world. He has performed geologic mapping and interpretation of such caves as Mammoth Cave - Kentucky, Wind Cave and Jewel Cave - South Dakota, Lechuguilla Cave - New Mexico, and Blue Spring Cave - Indiana. He has written interpretive guidebooks for the first three caves listed above, plus approximately 30 journal articles, book chapters, and published reports on cave geology and origin, a sampling is listed below. He is also the author of computer software used in geochemical analysis of mineral stability. Dr. Palmer's primary role will field and lab work designed to accomplish objective C.

Palmer, A. N., 1984, Geomorphic interpretation of karst features, in LaFleur, R. G. (ed.), Groundwater as a geomorphic agent: Boston, Allen and Unwin, pp. 173-209.

Palmer, A. N., 1989, (1) Stratigraphic and structural control of cave development and groundwater flow in the Mammoth Cave region; and (2) Geomorphic history of the Mammoth Cave System, in White, W. B., and White, E. L. (eds.), Karst hydrology: concepts from the Mammoth Cave area: New York Van Nostrand Reinhold, pp. 293-316, 317-337.

Palmer, A. N., 1983, Karst research in North America: Karstologia (France), v. 1, pp. 39-46.

Palmer, A. N., 1987, Cave levels and their Interpretation: Natl. Speleol. Soc. Bulletin, V. 49, pp. 50-66.

Davis, D. G., M. V. Palmer, and A. N. Palmer, in press, Extraordinary Subaqueous speleothems in Lechuguilla Cave, New Mexico: Natl. Speleol. Soc. Bulletin.

E. Margaret U. Palmer
Geologic consultant in Carbonate Petrology

M. A. in Geology
State university of New York, Oneonta, 1976

Ms. Palmer has 25 years of experience in geologic studies of caves, including those listed for A. N. Palmer. She has extensive laboratory experience in the analysis of cave minerals. co-author of several journal articles, book chapters, and guidebooks on the geology, mineralogy, and origin of caves.

Palmer, M. V., and Palmer, A. N. 1989, Palekarst of the United States, in Bosak, P., ed., Paleokarst: Prague, Academies/Elsevier, 337-363.

Palmer, M. V., in press, Geologic history of caves in the Black Hills, South Dakota: Natl. Speleol. Soc. Bulletin, v. 52.

Palmer, M. V. and Palmer, A. N., 1975, Landscape development in the Mitchell Plain of southern Indiana: Zeits. Geomorph., v. 29, no. 1, pp. 1-39.

Dakalowicz, J. J., D. C. Ford, T. E. Miller, A. M. Palmer, M. V. Palmer, 1987, Thermal genesis of dissolution caves in the Black Hills, South Dakota: Geol. Soc. Amer. Bulletin, V. 99, pp. 729-738.

Davis, D. G., M. V. Palmer, and A. N. Palmer, in press,

Lechuguilla Cave New Mexico: Natl. Speleol. Soc. Bulletin.

F. Gary Montz
Invertebrate Specialist
Ecological Services - Department of Natural Resources

M. S. Fisheries Aquatic Biology, 1986
Thesis title: The Littoral Benthos of the Apostle Islands National Lakeshore.

Mr. Montz is the DNR's main liaison for mosquito and black fly control programs in the metro area. He is developing a program to address the infiltration of zebra mussels. Mr. Montz performs field sampling and laboratory work in river surveys throughout the state and has done preliminary surveys of aquatic invertebrates found in Mystery Cave in 1989.

Montz, G., The Occurrence of Ripistes parasita (Oligocheeta:Naididae) in Minnesota and its implications for benthic sampling., Jour. of the North Am. Benth. Soc. Vol. 7 (2): 160-162, 1988.

Montz, G., Biological Survey of the St. Croix River - Invertebrates Special Publication, Minnesota Department of Natural Resources, in press.

Montz, G., Geological Survey of the Rainy River - Invertebrates Special Publication, Minnesota Department of Natural Resources, in press.

VII REPORTING REQUIREMENTS

Semiannual status reports will be submitted not later than January 1, 1992, July 1, 1992, January 1, 1993, and a final status report by June 30, 1993.