Proceedings of the 22nd National Cave and Karst Management Symposium

16 – 20 October 2017, Eureka Springs, Arkansas

Editors
Matthew L. Niemiller
Michael E. Slay
Charles J. Bitting

NATIONAL CAVE AND KARST MANAGEMENT SYMPOSIUM

PROCEEDINGS OF THE TWENTY-SECOND SYMPOSIUM

NCKMS: AN ANCIENT LAND WITH MODERN PROBLEMS

16 – 20 October 2017
Eureka Springs, Arkansas

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Cover Photo: Silhouetted researchers pause before entering a Newton County, Arkansas, cave to enjoy a mild autumn day in the Ozarks. Photo by Michael E. Slay.

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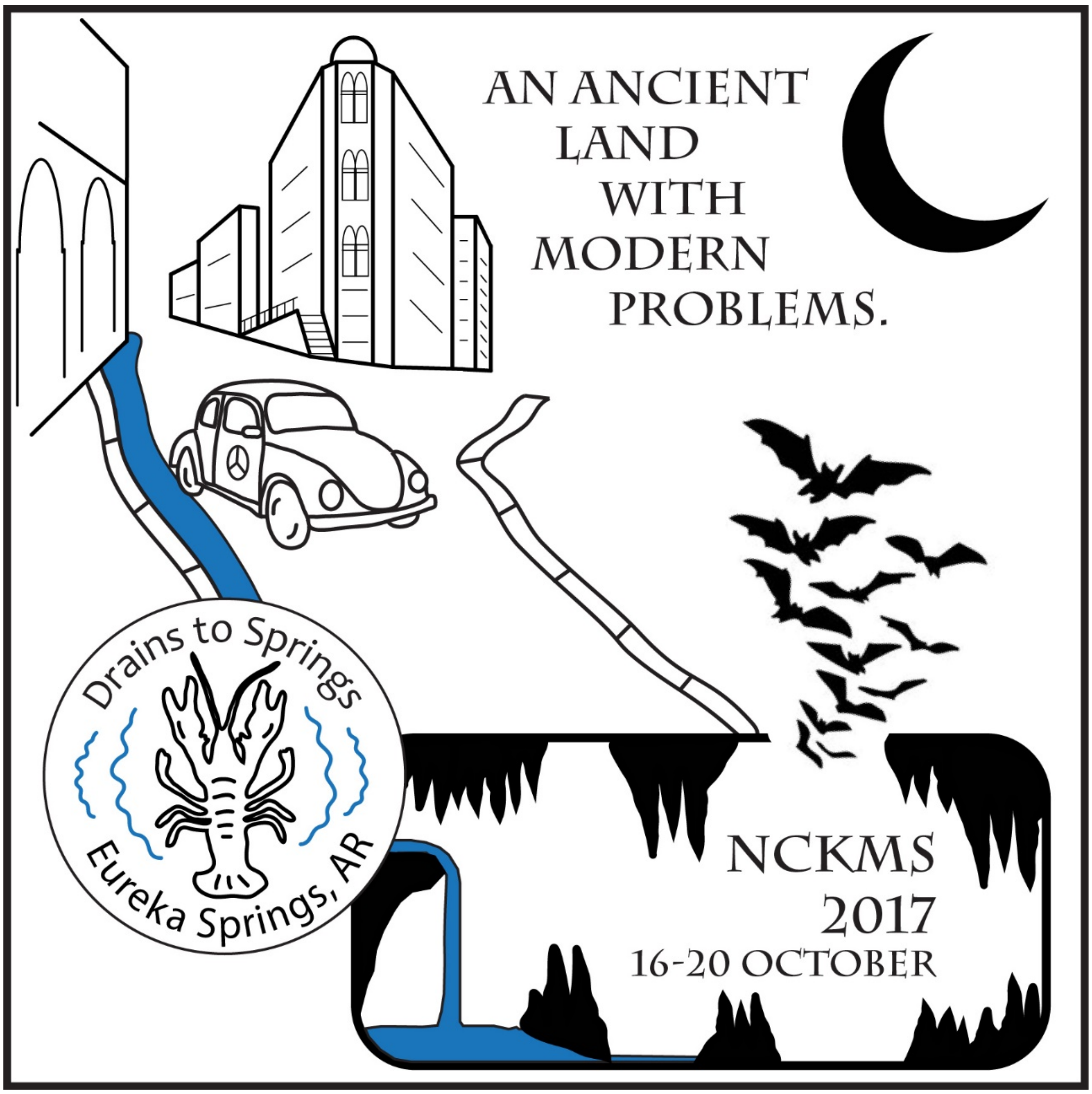
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Drains to Springs
Eureka Springs, AR
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2017
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- Thomas Aley, Ozark Underground Laboratory, Protem, MO, USA

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FOREWORD

The 22nd National Cave and Karst Management Symposium was held in downtown Eureka Springs, Arkansas, in October 2017. It was the second time the meeting has occurred in Arkansas; the first NCKMS being held in 1976 in Mountain View. While advances in methodology and techniques have allowed karst conservation practitioners additional options for managing cave and karst resources, many of the issues remain similar to problems discussed 41 years ago. Our banquet speaker, Tom Aley, was involved in organizing the 1976 meeting, and he provided some valuable context and history concerning the protection of karst resources and outlined future considerations.

The theme for the meeting was "An ancient land with modern problems," and presentations addressed a range of topics related to this theme. Papers presented over the course of the week were grouped into three categories: Biology, Geology and Hydrology, and Conservation, Management & Techniques. A similar format is followed here in the Proceedings. In addition to presentations, attendees participated in workshops on bat identification and acoustics, dye tracing, unpaved road sediment management, and database creation and management. Attendees also had an opportunity to participate in one of three field trips that highlighted local and regional karst locations, their problems, and their conservation successes. The Buffalo River canoe trip highlighted karst features and the local geology of the Buffalo River and discussed groundwater contamination issues in the watershed. The cave trip to Tumbling Creek Cave gave participants an opportunity to see examples of landscape level collaborative management strategies that enhance surface and subsurface habitats and their corresponding species. The walking tour of the caves and springs of Eureka Springs provided attendees a local example of living on karst and all the associated benefits and problems. Additional activities during the week included a White-nose Syndrome session that provided updates and discussion on research related to this deadly bat disease and an opportunity for attendees to test their "Cave Softly" skills by crawling through CaveSim's artificial cave simulator. Finally, what is NCKMS without evenings filled with spirited and entertaining discussions over a favorite libation? Perhaps some of those discussions will result in new topics presented at future NCKMS.

Lastly, we are grateful to the sponsors that supported this meeting, and we are especially grateful to the George N. Huppert Scholarship Program that provided travel and registration funds for 13 of the attendees. We also thank members of the 2017 NCKMS Planning Committee for helping see this meeting to fruition. Your hard work made this year's Symposium a success.

See you at the next one!

Mike Slay
Matthew Niemiller
Chuck Bitting

PLENARY SPEAKER

WATERSHED MANAGEMENT IN A KARST DOMINATED LANDSCAPE: PERSPECTIVES FROM A WATERKEEPER

Jessie J. Green[1]

[1] *White River Waterkeeper, Harrison, AR, USA*

Waterkeepers serve as the eyes, ears, and voices of the waterbodies they protect to ensure fishable, swimmable, and drinkable water for all. White River Waterkeeper advocates on behalf of the entire 27,798 mi^2 White River watershed, of which over 70% falls within the karst dominated landscape of the Ozark Highland and Boston Mountain ecoregions in Arkansas and Missouri. Insufficient federal and state laws and regulations will be discussed with special regard to the Clean Water Act and protections of water quality in karst landscapes. Experiences with evaluating special studies to determine water quality impacts will be provided to discuss failed assumptions of common study designs due to complexities related to fate and transport of pollutants.

KEYNOTE ADDRESS

SIXTY YEARS OF CAVE AND KARST MANAGEMENT AND CHALLENGES AHEAD

Tom Aley[1]

[1] *Ozark Underground Laboratory, Protem, MO, USA*

Local Examples of Karst Management

In a multi-million dollar purchase a fellow bought a "house" constructed in a cave in northwestern Arkansas. The ceiling of the five-bedroom, five-bathroom house was native cave surfaces of limestone and stalactites that had been coated with an epoxy in an effort to prevent what water periodically did naturally (specifically, drip into the cave). The system worked adequately during dry weather (when the sale was made). However, in wet weather water would build up above the epoxy layer and stretch it until some coefficient of elasticity was exceeded and then produce a new drippage zone. In an incomplete enumeration, I counted 189 drippage zones in the house include those above the sofa and the grand piano in the great room. Some drippage zones discharged up to a gallon of water per hour, and the young fellow hired to dump the array of buckets said he was extremely busy when it rained.

And then there was the wine cellar deeper into the cave. The buyer reportedly purchased $10,000 worth of wine ranging from bottles in my price range up to those probably costing over $100 (well out of my price range). The wine cellar idea did not give consideration to the cave fauna, and cave crickets, in particular. No respectable cave cricket would walk all the way out of the cave to feed until a new in-cave food source had been consumed. Wine labels to us are nothing but convenient cellulose to cave crickets. The owner soon found that he had two kinds of wine: red and white. I once shared a bottle of red with him and it was very nice.

A lawsuit in federal court revolved around the legal issue of "implied warranty of inhabitability," since the property was sold as a house and one should perhaps expect a very expensive house to be inhabitable. Would it be inhabitable if the annual amount of ceiling drippage would equal two feet of water depth throughout the house? In my view, caves in the Ozarks don't make very good houses.

Green Forest is a small town 20 miles east of Eureka Springs. They built a sewage treatment plant to serve the town and the engineer, who had apparently never attended a cave and karst management symposium, located the plant where it would discharge to Dry Creek. Streams in karst areas that lose especially large portions of their flow to karst groundwater systems often have names such as Dry Creek or Dry Fork. Once Green Forest had a sewage treatment plant, they were able to attract an industry; being Arkansas, that industry was a chicken processing plant. Poultry wastes vastly overloaded the capacity of the treatment plant and fowl water discharged to Dry Creek where it routinely entered the groundwater system within a mile of the plant. Dye tracing showed that groundwater beneath about 60 mi^2 of neighboring land was contaminated by discharges from the sewer plant. It was necessary to extend rural water district lines to serve people living in the surrounding hills and hollows who had lost the utility of their wells to Green Forest sewage.

At one affected home the resident told me that his family had "chicken fat" in their well water and invited me into the house to see for myself. He lifted the top of the toilet tank and, as reported, there was an obvious layer of fat floating on top of the water. He said that they had to dip the fat off about once a week. When I asked why, he said that if they didn't the fat would overflow the tank and make the seat slippery. It is worth remembering that sewage discharges to dry creeks can produce slippery toilet seats. This might make a good bumper sticker.

During my expert witness testimony in federal court, I said that my calculations showed that, on an annual basis, about 6% of the water in the groundwater system within the 60 mi^2 affected area had discharged from the sewer plant. For comparison I put fluorescein dye in my toilet bowl, flushed the toilet, and let the bowl refill. An analysis of dye concentrations showed that my toilet bowl had about 0.6% as much dye in it after one flush as it had before the flush. From that I concluded that the groundwater system affected by the sewer plant had an average of about 10 times more sewage in it than did my toilet bowl after one flush and that I didn't believe that people should drink out of toilet bowls after one flush, or for that matter after two or three flushes, although I had a cat that did. The judge declared a recess for lunch. I skipped the chicken special.

So much for bad decisions. Arkansas is also a state with great examples of sound karst management. There is a large bend in Interstate Highway 59 west of Springdale. The bend placed the highway outside of those portions of the recharge area for Cave Springs where highway runoff or vehicle accidents would pose significant risks to water quality in Cave Springs Cave. That cave is a very important habitat site for Ozark Cavefish and Gray Bats.

The Northwest Arkansas Regional Airport is west of Cave Springs. Part of the airport property is within the recharge area for another population of Ozark Cavefish. Major efforts were taken in the design and construction of facilities at the airport to ensure the protection of groundwater quality, and one local official claims that protecting the cavefish cost ten million dollars. I suspect that estimate is inflated, but the important point is that northwest Arkansas now has a good airport and concurrently is protecting federally listed cave fauna. Good job, Arkansas. That's the kind of deal we need to see more often.

Evolving U.S. Cave and Karst Management

This discussion is focused on cave and karst management, not research on caves and karst. It is skewed in favor of my experience and knowledge of the topic. That's OK, I'm the banquet speaker and get to do those things. In considering the evolving nature of cave and karst management I have relied heavily on the topics of papers published in the proceedings of the Cave and Karst Management Symposiums. They are important references in my professional library. I have attended at least 8 of these symposiums beginning with the first one in Albuquerque, New Mexico in 1975. What I will do is give a snapshot of conditions at about 10- (or in one case 15-) year intervals.

Vintage 1960. The term then was cave conservation, not cave management. There were two dramatically different approaches in the U.S. Approach 1 was secrecy, and it was the approach with which I was aligned. It was prominent in the West where most of the caves were on public lands. There were "no caves to speak of" in Arizona. No caving equipment was visible in cars and certainly no bat stickers on windows or bumpers. Frost Creek Cave in California was so-named because there was no Frost Creek anywhere near it. In contrast, Approach 2 presumed that cave lists with locations and descriptions represented a public good. Around 1960 there were at least 11 states with book titles such as "Caves of Missouri." Such books exist for Washington, California, Montana, Wyoming, Colorado, Missouri, Illinois, Indiana, Tennessee, West Virginia, and Virginia; I possibly missed a state or two. The books attracted people to caves. I once saw a copy of “Caves of California” on the front seat of a jeep parked near the entrance to a cave. The jeep also contained broken speleothems. The poor little nearby cave was destined for an even worse fate; it was inundated by the New Melones Dam, a project of the Bureau of Reclamation on the Stanislaus River.

Vintage 1965 to 1970. There was almost certainly earlier concern with cave protection during the 1930s when the Civilian Conservation Corps was involved with show cave development at a number of caves in the United States. In the 1940s and perhaps into the 1950s, Dr. E.R. Pohl of Kentucky was involved with cave management issues for the National Park Service, but I have only very sketchy details on this. However, the period 1965 to 1970 saw the beginning of important projects focused on practical cave and karst management. Three examples illustrate the start of such projects during this period.

In early 1966, I bought a cave and 126 acres of land to create the Ozark Underground Laboratory. It was generally perceived as a naive idea that would fail, but it was my money and observers were tolerant. My premise was that ignorance was a major cave and karst management problem, and the solution was education. I established field programs focused on characterizing surface and subsurface interactions in cave and karst regions. Over the years, about 40,000 people have attended our field programs, and one of the field trips for this year’s symposium visited our facilities. We focused major attention on the protection of cave fauna and karst hydrology, plus pioneered recharge area delineations and vulnerability assessments associated with important caves and springs. It has been an incredibly wonderful career for a cave guy.

In 1965, the U.S. Forest Service established a barometer watershed program that planned for about 23 study watersheds across the United States. Each was to be a type example study for demonstrating the hydrologic benefits of Forest Service land management in different hydrologic settings. Hurricane Creek in south-central Missouri, a surface tributary to the Eleven Point River and a groundwater tributary to the Current River, was designated as the barometer watershed for karst areas. The Forest Service had everything needed except someone to direct the study when I, an unemployed karst hydrologist who was broke from buying a cave, blundered into the relevant Forest Service office.

I directed the Hurricane Creek Barometer Watershed for 7 ½ years. The project focused on groundwater contamination problems and karst management. Dye tracing using activated carbon samplers became a major focus of the Hurricane Creek studies. Presumptions that it took decades to centuries for water to move 10 to 40 miles or so to major Ozark springs fell under the assault of actual tracing data. Straight-line underground travel rates were often shown to be one to three miles per day. Many of our dye traces moved from the Eleven Point River basin to Big Spring, a tributary to Current River.

In the late 1960s in the Missouri Ozarks, many “fortunate” towns had community dumps located in sinkholes. These included the towns of Alton, West Plains, and Dora. West Plains, with a population of about 5,000 in that period, asked the Forest Service for a new sinkhole to use since their current one (in the recharge area for Mammoth Spring, Arkansas) was almost full. Because of the Hurricane Creek studies the request was denied. Dye traces we conducted from the Alton and Dora dumps to important springs led to closures of those dumps.

The Dora sinkhole was, among multiple insults, a dumping point for a local septic tank pumper. We traced fluorescein dye and stained *Lycopodium* (club moss) spores from the Dora sinkhole dump to Hodgson Mill Spring where the water was used without treatment in a little café. Information and pictures about our trace covered most of the front page of the West Plains Quill newspaper. Dumping subsequently ended at the sinkhole, not by an edict but instead by information on how the system functioned. But everything goes somewhere, and trash formerly destined for the sinkhole dump appeared in local losing stream channels. “Sanitary” landfills, which routinely functioned like teabags in karst landscapes (the water goes in the top and the flavor goes out through the sides and bottom) replaced sinkhole dumps. In the Ozarks new proposed landfills now generally avoid karst settings.

In the late 1960s and early 1970s, the U.S. Soil Conservation Service was pushing “headwaters impoundments” as a way to reduce flooding on major rivers. Plans sprouted for lots of impoundments in karst areas including in the Ozarks and the Lost River Country of Indiana. Most impoundments in karst areas didn’t hold water and some induced large sinkhole collapses. Using techniques developed on Hurricane Creek I began assessing the impoundments. I received an award for saving the Forest Service a lot of money on a planned recreational impoundment in southern Indiana that would never have held water. By removing the anticipated benefits from a lake that would not have held water, a simple dye trace unraveled a project that included 15 to 20 impoundments and was a pet project of somebody with political power. I received an “official letter of reprimand” for comments critical of a sister agency (SCS). It was a compromise and better than the alternative of being fired. I framed it next to my award and ordered more dye. No good deed goes unpunished.

A couple of years after the start of the Hurricane Creek project, Jim Quinlan began working for the National Park Service at Mammoth Cave. He did an incredible amount of groundwater tracing work, with many of the traces beginning outside of the National Park and terminating at springs within the Park. His work was critical to efforts by the Caveland Sanitation Authority to establish regional sewage treatment for the towns of Cave City and Horse Cave south of the Park. Jim’s work was of great benefit to both the National Park and communities surrounding the Park.

Jim Quinlan integrated his groundwater tracing work with expanded and very detailed cave exploration and mapping. Mammoth Cave became a great training ground for many people concerned with the protection of caves and karst management. Jim also did important problem-solving work for other National Park units, and he and I worked together on several projects including two here in Arkansas.

Vintage 1975. The first National Cave Management Symposium was held in Albuquerque, New Mexico. Most of the organization of the symposium was by federal employees, although there was good representation by cavers and those associated with private and non-federal groups. The term “karst” did not appear in the title of any of the papers at the first symposium; the meeting was clearly defined by the inside surfaces of cave walls. Thirty-one percent of the papers presented were on visitor management, and only nine percent were on resource management. Cave management of the period was primarily managing people, not caves. In my opinion, the greatest benefit of the first symposium was that it began important dialogs and was productive enough to result in many more symposiums.

Vintage 1985. The 1984 cave management symposium had one paper on visitor management and 24 papers on resource management. This was a dramatic reversal in emphasis in nine years. We were no longer simply managing cave entrances and those who passed through them.

Vintage 1995. This was a period when the scope of the symposiums was in flux, but was generally growing broader. In 1995, the title was National Cave Management Symposium. In 1997, it was National Karst and Cave Management Symposium with a strong focus on Alaska and British Columbia karst management. In 1999 the pendulum swung back at bit and the title was National Cave and Karst Management Symposium, and that name has been applied continuously since that time.

Vintage 2005. Interest in and concern for cave faunas was a major thrust of the symposium in 2005. Thirty percent of the papers dealt with cave faunas and threats to them. Concern for cave faunas was illustrated by the fact that Missouri had a state cave biologist, Dr. Bill Elliott who did a tremendous amount of very important work. Unfortunately, when Bill retired from the Missouri Department of Conservation his position was not refilled, although Missouri does still have a bat biologist.

Vintage 2017. Things are not going very well. Caves and karst are threatened by the current political climate and results of the 2016 election. White-Nose Syndrome (WNS) has been devastating to bats in eastern North America. The Endangered Species Act is itself either threatened or in danger of extinction. Trichloroethylene (TCE), an industrial solvent extensively used in the past, is present in the air of many caves. I will spend the rest of this talk giving my perspective on WNS, the Endangered Species Act, and TCE in underground air.

White Nose Syndrome (WNS). An exotic fungus native to Europe and perhaps parts of Asia has arrived in North America and attacks multiple species of bats that use caves and abandoned mines. It has been responsible for the deaths of millions of bats and, as of 2017, has spread from an initial invasion site in New York south to southern Mississippi, west to eastern Oklahoma and Nebraska, and north into the Maritime Providences, southern Ontario, and southern Quebec in Canada. There is no reason to not expect it to continue to spread. A strategy advocated by the U.S. Fish and Wildlife Service (USFWS) for 12 years has been to try and contain the outbreak by: 1) blaming cavers for spreading the fungus, and 2) encouraging the closure of public-owned caves to the public. Show caves are excluded from the closure.

The containment strategy may seem reasonable to people lacking a background in the biological sciences. WNS is spread from an infected bat to other bats by direct contact, and colonial bats (in particular) have a lot of direct contact. This has clearly been proven. One can look at the readily available map of the spread of WNS and see that the margins of the area where infected bats have been found radiates further outward each year from the initial site. That is fully consistent with bats spreading the disease and inconsistent with cavers being the spreading agent. Within the infected zone more infected sites appear in subsequent years as the “dead body counters” visit additional sites and as there are more infected bats spreading the disease. If cavers, or people in general, were transporting the spores and subsequently infecting bats the distribution pattern would be dramatically different. For example, we would expect little epicenters around annual National Speleological Society (NSS) convention sites. This clearly is not the case.

The containment strategy was tried and failed in New York. As the epidemic expanded containment has continually failed when applied to increasingly larger areas. It has not worked and clearly will not work. It is yet another example of the adage in government that if something doesn’t work you do more of it.

The “close the caves and blame the cavers strategy” is not harmless and the argument that “maybe it might do a little bit of good” is specious. First, caves on public land belong to the American public. It is improper to exclude us from our caves without a credible and valid reason, and time has clearly shown that there is no credible and valid reason. Second, the “close the caves and blame the cavers strategy” demeans cavers and criminalizes a legitimate activity. An editorial in the NSS News (Schindel 2017) noted that membership in that organization has decreased by about 20% in the last 7 years. While there are multiple possible explanations for this decline, the demeaning and criminalization of caving has likely been an important factor.

So what? Caves, bats, America's public lands, and the agencies that administer these lands need supporters. Agencies that have adopted cave closure policies in lock step with the USFWS bureaucrats have harmed their own credibility as science-based resource managers and lost public support that our natural resources need and deserve. If the USFWS and the other agencies wish to be perceived as science-based entities they should end the farce of cave closures and quit blaming cavers for spreading WNS. Finally, if the biologists and bureaucrats making WNS funding decisions are the same individuals backing the "cave closures and blame the cavers strategy", I frankly question their competence in making the kind of science-based decisions needed to allocate limited research funds. On a personal basis, I will continue to support research efforts on WNS. However, we must all recognize that even under the best of circumstances it is very unlikely that: 1) WNS will be controlled, or 2) significantly impacted bat populations will recover. Very sad, yet clearly the almost certain outcome.

The loss of millions of bats will have substantial impacts on both cave and surface ecosystems and little attention is being paid to this issue. Bat guano is a major energy source for some cave ecosystems and for the associated cave faunas. Will the loss of the bat guano push some of our cave invertebrates into extinction? Can we offset the loss of guano by importing an alternate detritus food source such as wood into impacted caves where the bats have been lost? If so, how much and what species of wood should be used? I suspect that maple and hickory would be good, but that walnut and cherry would be undesirable, but this needs to be evaluated. If we are to import an alternate detritus source into caves, who will do it? Will the resource management agencies that have demeaned and criminalized cavers now need their help? And on the surface of the land, how might we offset the ecological and economic services provided by the bats that have died from WNS? Should some of the funding now focused on bats and WNS be shifted to offsetting the resulting impacts on other ecosystems? I'm reminded of the old adage: "Lord, help me to understand the things I can fix, the things I can't fix, and the difference between the two." Are we spending our research money on an unfixable problem while financially starving actions that are potentially very valuable?

Threats to the Endangered Species Act (ESA). The ESA is a target of special interest and anti-government groups and some politicians who argue that it poses threats to private property rights. I own about 2,500 acres of land in Missouri that provides habitat for three federally endangered species and one federally threatened species. Their presence certainly does not bring the wrath of government down on my head as ESA opponents claim. These species are among the major assets of my property; they are not problems or liabilities.

The ESA is very important in protecting many caves and springs. There are eleven cave and karst species that are federally listed under the ESA in the Ozarks and there are at least 155 habitat sites for these species. That's a lot of protected sites. If the ESA is appreciably weakened or abolished then cave management in much of the United States has lost one of its strongest cave protection tools. We must not let this happen, but in my view there are serious threats to the ESA in the current political climate. We need to increase recognition of the benefits of the ESA and increase public support for this important law.

Culver et al. (2000) report that there are 927 obligate cave species and subspecies in the lower 48 states. They further report that about 50% of animal species listed by The Nature Conservancy (TNC) as vulnerable or imperiled are cave species, but that less than 4% of them are federally listed as threatened or endangered. Clearly many cave species are highly vulnerable to extinction yet currently have no federal-level protection. They deserve and should receive special management attention. In the absence of effective management attention it may be appropriate to list many of these species under the provisions of ESA. Effective management attention and/or ESA listing require good conservation data on the species. In the case of aquatic species recharge area delineations of their habitats are essential so that we know what areas are critical to their survival and where surface activities could adversely impact them. Preventing extinctions requires good data and habitat conservation. Cave states need state cave biologists focused on these sensitive ecosystems. We need to manage our threatened and endangered species as assets, not problems or liabilities. Among those concerned with cave and karst management we need an increased recognition that ESA must be protected and that it is a critical cave and karst protection tool.

Trichloroethylene (TCE) in Cave Air. TCE is an industrial solvent that has been in use for decades and has been largely replaced for modern use by other solvents that are of lower environmental and health concern. Because of past use and its great mobility in the subsurface TCE is present in groundwater beneath thousands of sites in the United States.

TCE is moderately soluble in water (1,100 mg/l at 20°C), so it can be readily transported as a dissolved contaminant in karst groundwater. It is about 46% heavier than water so it can sink as a free product to above a sloping impermeable rock layer and move along that geologic contact in directions different from the groundwater gradient. It is a volatile compound and can move from water into air or the reverse. Its volatile nature poses substantial problems in karst systems with well-developed epikarst and/or numerous sinkholes and/or other cavernous features. In such karst systems there are few barriers to long distance and multi-directional movement of TCE vapors in underground air within the bedrock. Additionally, much of the TCE lost into the subsurface in karst area decades ago is still present, and in some cases in Missouri has migrated for miles from the initial discharge site.

TCE in workplace air is federally regulated by the Occupational Safety and Health Administration (OSHA). The maximum allowable exposure on a time-weighted 8-hr average is 100 parts per million which is equivalent to about 540,000 micrograms per cubic meter (µg/m^3). Average workplace exposure where TCE is routinely used is about 30% of the maximum allowable concentration. EPA's target concentration for TCE in air at sites impacted by a spill or discharge great enough to come under the purview of CERCLA (Superfund) is 6 µg/m^3. No, this is not a misprint. Two federal agencies have concentration limits presumably intended to protect human health (one a standard and the other a target) that differ by a factor of 90,000. A further inconsistency in targets is that EPA enforces their 6 µg/m^3 limit only in some states. Finally, the minimum discharge of TCE that brings a site under the provisions of CERCLA is 100 pounds, and this is so small that most sites that have used TCE are likely to come under EPA regulation and the 6 µg/m^3 target concentration in air. This applies not only to the site where TCE was used or discharged, but also to all properties to which the TCE has now migrated.

Missouri is one of the states where EPA has been enforcing the 6 µg/m^3 target concentration. This forced Meramec Caverns, one of the most heavily visited show-caves in America, to recently close for several months until two large-diameter ventilation shafts were drilled into the cave, forced ventilation was started by using a fan on top of a ventilation shaft, internal airflow control doors were installed, and the natural microclimate of the cave was substantially altered. TCE has never been used at Meramec Caverns. The source for TCE in the cave was former industrial activity in the town of Sullivan, five miles from the cave.

Fantastic Caverns, another heavily visited Missouri show-cave impacted by EPA's 6 µg/m^3 TCE target concentration, has been forced to artificially ventilate the cave with a large exhaust fan set at the top of a newly constructed 22-inch diameter shaft into the cave. The rated capacity of the fan is sufficient to move the entire volume of air in the toured portion of the cave in less than an hour and a half. TCE has never been used at Fantastic Caverns; the obvious source area is an uncontrolled waste site over three miles from the cave. That site is regulated by the Missouri Department of Natural Resources. TCE concentrations in cave air in the lower level of the cave, but within 100 feet of toured passages, have been as high as 2,400 µg/m^3. That is 400 times greater than the EPA target concentration.

As most cavers know, there can be substantial underground movement of air in cave systems. In some cases, such as Wind Cave National Park in South Dakota, the direction and volume of air movement is largely governed by differences in barometric pressure between cave passages and the surface. More commonly, the direction and magnitude of underground air movement is due to differences in surface elevations between cave entrances; this is sometimes called the chimney effect or convective air flow. Underground convective airflow in karst landscapes does not require cave entrances; sinkholes and other discrete groundwater recharge areas are routinely points where surface and subsurface air either enters or leaves the subsurface. One result, seen clearly at Fantastic Caverns, is that an extensive mass of air contaminated with TCE seasonally oscillates around TCE source areas in karst landscapes. Air contaminated with TCE discharges to the surface in higher elevation areas under cold weather conditions and at lower elevation areas under warm weather conditions.

Because of surface and subsurface air exchanges a substantial amount of TCE-contaminated air discharges annually to the surface and sometimes into buildings. Millions of dollars have been spent in the US in controlling TCE vapor intrusion into buildings. Unless substantial efforts are undertaken the total volume of TCE in underground air typically does not substantially diminish with time because it is replenished by TCE that volatilizes out of contaminated groundwater which in turn is replenished by TCE derived from the free product remaining in the subsurface.

There are over 32 mi^2 of karstlands located closer to the TCE source area than the point in Fantastic Caverns where the values 400 times the target concentration have been detected. In this area are thousands of homes, probably at least 100 businesses, plus schools, churches, and day-care facilities. How much of this area has TCE concentrations in underground air that exceed the EPA target concentration has not been assessed. How much further from the source area the TCE vapors have spread has also not been assessed.

The EPA target value of 6 µg/m^3 has not been subject to public review and the quality of the data on which is it based is limited and in my view very questionable. As a result, the target value may not be a credible limit for the protection of human health. Hundreds of thousands of people have been exposed for years to TCE concentrations in workplace air that are over four orders of magnitude larger than the EPA target. If the target were credible, I would expect a large collection of “bodies” and for even low concentrations of TCE in workplace air to be a well-recognized health hazard. Perhaps I just haven’t found the data.

If the EPA target is anywhere close to being credible, then it poses a major problem for karst regions that are cavernous, and/or have well-developed epikarst with appreciable inter-connected void space, and/or have sinkholes and other discrete recharge zones. That is a lot of America’s karstlands. There are hundreds, and probably thousands, of TCE contaminated sites in karst where underground air at concentrations likely to be similar to those at the two Missouri caves must be expected and needs to be assessed. Ultimately, the source areas need to be effectively remediated. That will not be a simple undertaking.

I leave you with a final comment. The two most common elements in karst landscapes seem to be calcium and stupidity. Thank you.

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BIOLOGY

CAVE SPRINGS AREA KARST CONSERVATION STUDY: A SUCCESS STORY IN KARST RESOURCE MANAGEMENT AND URBAN DEVELOPMENT

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Cave Springs Cave in northwestern Arkansas is the largest population for the Ozark Cavefish (*Troglichthys rosae*), a federally-listed threatened species that is found in the Springfield Plateau of the Ozark Highlands in Missouri, Arkansas, and Oklahoma. As northwestern Arkansas continues to grow, the recharge area for Cave Springs Cave continues to be converted from a rural agricultural setting to suburban development. This ongoing development has resulted in an increasing threat to water quality and the Ozark Cavefish at Cave Springs Cave. The Cave Springs Area Karst Conservation Study was developed in response to this ongoing situation. This study is composed of three integrated components. The first component included the development of a science-based understanding of the location and hydrologic functioning of the recharge area for Cave Springs Cave. The second component was designing karst-appropriate Best Management Practices (BMPs) based on relative land vulnerability within the recharge area that will concurrently protect Ozark Cavefish and permit continued suburban land development. The third component is developing and enacting ordinances to implement appropriate BMPs to guide further land development in the recharge area. The execution, integration, and implementation of these three components of the study will be presented.

HOW THE MADISON CAVE ISOPOD, *ANTROLANA LIRA* (CIROLANIDAE), CAN SAVE THE PHREATIC AQUIFER

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The Madison Cave Isopod, *Antrolana lira* Bowman 1964, is a free-swimming troglobiotic cirolanid isopod known to occur only within the carbonate-saturated waters of the phreatic karst aquifer of the Shenandoah Valley. The type of locality was originally limited to two pools in Madison Cave and a small pool in an adjacent cave named Steger's Fissure in Augusta County, Virginia. Because *A. lira* was threatened by human visitation to its only known habitat and by mercury pollution of the nearby South River, the taxon's status as a threatened species was finalized in a rule issued by the U.S. Fish and Wildlife Service (USFWS) on 4 October 1982. Since that time, the range of *A. lira* has been extended through much of the Shenandoah Valley in Virginia and West Virginia. In 2009, GeoConcepts Engineering was contracted by The Conservation Fund to perform a karst survey of the 76-mile alignment of the Columbia Gas Transmission Pipeline through the Shenandoah Valley. The findings of this survey were among those used to develop the NiSource/Columbia Gas Multi-Species Habitat Conservation Plan. Included in the plan were a series of avoidance and minimization measures (AMMs) and best management practices (BMPs) designed to minimize impact to the taxon's habitat, which were developed in teamwork with the USFWS. The primary goal of these measures was to prevent and/or minimize the incursion of sediment- and contaminant-laden water into the epikarst through surface features, eventually finding its way into the deep phreatic aquifer. The majority of reliable wells and perennial springs in karst-lands are dependent on the phreatic aquifer for much of their source water. Therefore, we suggest that the same AMMs and BMPs used to protect *A. lira* should be invoked even in places where the taxon does not occur in order to protect vital drinking water resources.

Lighting and Substrate Effects on Lampenflora Microbial Communities in Carlsbad Cavern

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Artificial lighting in show caves can stimulate the unnatural growth of algae and cyanobacteria, termed "lampenflora," which has been shown to negatively impact cave resources. Carlsbad Caverns National Park recently modernized the lighting in Carlsbad Cavern replacing the sodium halide, incandescent, and fluorescent lights with an LED system that has the capacity to adjust color temperature and intensity of individual lights. To assess the influence of LED color temperature (2700°K vs. 3500°K) as well as substrate type (sediment, porous limestone, and dense limestone/calcite) and light intensity (<100 to >500 lux) on the proliferation of lampenflora, we have been monitoring growth at five sites in the Big Room of the cavern. Growth of phototrophic biofilms is being measured using reflected light spectrophotometry, and characterization of the microbial communities has been performed by DNA extraction and high-throughput amplicon sequencing of 16S and 18S rRNA genes for bacteria, archaea, and Eukarya. Resulting sequences show a diversity of microbes in the biofilms, from photosynthetic green algae, Chlorophyta; golden-brown algae, Ochrophyta; and several different types of cyanobacteria. In addition, there is a diversity of heterotrophic archaea, Eukarya, and bacteria that supports the concept of diverse and well-established biofilms at the experimental sites in the caverns. Our portable reflected light spectrophotometer has been demonstrated to effectively quantify the amount of photosynthetic biomass in a non-destructive way, and tracking over time shows changes to the biofilms within the cavern at the different light levels. This presentation represents data from nearly a full year of study, which has been funded by Carlsbad Caverns National Park in hopes of identifying optimum color temperature and intensity settings to discourage lampenflora growth.

INDIANA BAT HABITAT RESTORATION PROJECT ON THE SYLAMORE RANGER DISTRICT OF THE OZARK-ST. FRANCIS NATIONAL FORESTS

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The Sylamore Ranger District of the Ozark-St. Francis National Forests began implementing the Indiana Bat Habitat Restoration Project in 2014. Funding for the project was received through a Joint Chiefs' grant with the Natural Resources Conservation Service (NRCS). The project was aimed at treating approximately 67,151 acres of national forest system land over a period of 12 years. Activities in the project area included protection of Indiana Bat hibernacula through cave gating, interpretation and education, commercial timber harvest, prescribed burning, mechanical treatments, monitoring, etc. The overall goals of the project were to create conditions more likely to provide continual roost trees for Indiana Bats, protect Indiana Bat hibernacula from human disturbance, reduce and maintain canopy closure across primary and secondary bat conservation zones, and promote regeneration of oak, hickory, and shortleaf pine for a continual supply of available roost trees.

MONITORING CAVE AQUATIC BIOTA AT SELECTED NATIONAL PARKS IN THE CUMBERLAND PIEDMONT NETWORK

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Threats to cave stream communities located inside national park boundaries include chemical and thermal contamination from surface water flow due to land use inside and outside park boundaries. Runoff from large-scale agriculture and septic leachate increases the nutrient load and *Escherichia coli* in water flowing into subsurface streams and may alter the structure of stygobiont communities adapted to nutrient-poor conditions (Simon and Buikema, 1997; Graening and Brown, 2003; Lewis et al., 2015). Weather and climate change are expected to significantly alter hydrologic regimes across the Southeast (Monahan and Fisichelli, 2014). Increasingly intense, frequent flood pulses moving through cave streams or backflooding of surface water with temperatures significantly outside cave normal range may significantly modify the cave aquatic habitat and structure of cave aquatic communities (Holsinger and Culver, 1988; Trimboli et al., 2016). Collecting systematic, long-term data to explain the abundance and distribution of cave aquatic biota (CAB) metapopulations will provide resource managers with the necessary data to make informed decisions regarding resource management and which habitats they should prioritize for protection.

Monitoring objectives addressed by the Cumberland Piedmont Network's (CUPN) long-term monitoring protocol for CAB at Cumberland Gap National Historical Park, Mammoth Cave National Park, and Russell Cave National Monument include:

1. For common target CAB, estimate status and long-term trends in abundance within monitored cave stream reaches in three parks in the CUPN.

2. For uncommon target CAB, determine status and long-term trends in the probability of occupancy and proportion of reaches occupied within monitored cave stream reaches in three parks in the CUPN.

3. Sample selected cave stream habitat characteristics and water-quality and water-quantity parameters we hypothesize are relevant to gaining an understanding of CAB abundance, occupancy, or detectability within monitored cave stream reaches in three parks in the CUPN.

This monitoring protocol is focused on monitoring a suite of cave aquatic biota that regularly inhabit seven selected caves within the three national parks. We identified these cave streams as conducive to visual survey for CAB while walking, wading, or snorkeling. Due to logistical constraints, all three parks cannot be visited during a single sampling season so they are divided into two separate panels. The sampling season occurs during the dry season from July–October since the probability of detecting cave aquatic biota during sampling events is highest due to low water levels and low turbidity.

Sampling events, consisting of two independent surveys of each cave stream on two nonconsecutive dates, will be

Table 1. Estimated abundance (λ) and occupancy (ψ) and associated detection probabilities (p) obtained from January 2015 pilot efforts. All parameters are reported with associated standard errors. Dashes denote models that did not converge.

	Abundance (N-mixture)				Occupancy			
Species	$\boldsymbol{\lambda}$	se($\boldsymbol{\lambda}$)	**p**	se(**p**)	$\boldsymbol{\psi}$	se($\boldsymbol{\psi}$)	**p**	se(**p**)
Caecidotea stygia	4.85	0.56	0.73	0.05	0.46	0.11	0.88	0.09
Cambarus tenebrosus	--	--	--	--	--	--	--	--
Copepod	--	--	--	--	1.00	0.28	0.05	0.04
Orconectes pellucidus	18.99	3.67	0.39	0.09	0.90	0.07	0.97	0.03
Stygobromus vitreus	0.98	0.49	0.41	0.20	0.63	0.29	0.40	0.20
Typhlichthys subterraneus	5.28	1.78	0.36	0.12	0.94	0.11	0.69	0.10

conducted at one panel per sampling season such that, conditions permitting, all cave streams in both panels will be surveyed four times every two years. A single sampling event consists of two teams, one observer and one recorder each collecting data on water quality and quantity and conducting staggered, independent visual surveys for CAB in a given number of noncontiguous, 40- meter transects while also collecting data on their habitat characteristics. One set of water-quality and water-quantity data are collected (objective 3), upstream of the transects to be surveyed, using opportunistic grab sampling and water level and temperature data loggers, respectively. Visual surveys for CAB (Objectives 1 and 2) typically involve the observer moving slowly and quietly upstream and, using a powerful headlamp or dive light, conducting a timed count in each transect. Each CAB detected are called out to the data recorder along with a size estimate and any noticeable characteristics (e.g., damage). Finally, field personnel collect limited qualitative data on habitat characteristics (Objective 3) such as habitat type (e.g., riffle, pool, or glide) and percent substrate composition (e.g., gravel or pebbles). Sampling techniques differ depending on whether the cave stream being sampled is wadeable or nonwadeable. Wadeable cave streams or pools are generally shallow and so transects can be surveyed while walking along the bank. Cave streams with a majority of nonwadeable habitat must be surveyed by snorkeling observers, with recorders paddling inflatable kayaks behind.

The primary goals of this protocol are to identify changes in CAB abundance and occupancy for resource managers at Cumberland Gap NHP, Mammoth Cave NP, and Russell Cave NM. To meet this goal, we must account for the variation in detectability over time and space to provide reliable data for effective resource management. Hierarchical models are a flexible framework in which a complex system may be modeled using multiple submodels. We believe the flexibility inherent in the modular nature of HMs will be useful for the reliable estimation of occupancy and abundance of imperfectly detected cave aquatic biota. Further, with our selected covariates we will attempt to account for variation in abundance among reaches. There is precedent for using these modeling techniques in the estimation of abundance and occupancy of both surface and subsurface aquatic organisms (Krecja and Weckerly 2007, Collier and Fenolio

2009, Schneider et al. 2009, Peterman et al. 2013, Coleman et al. 2016, Mollenhauer and Brewer 2017). This framework is particularly suited to inference about abundance, occupancy, species richness, and demographic characteristics because it can accommodate multiple data sets, sources of variability, scales of measurement, and varying data quality inherent in the kinds of data we will collect.

In January 2015 we conducted two pilot sampling events at a Mammoth Cave National Park cave stream reach where we obtained count data on commonly observed cave aquatic biota. During each event, two separate teams, consisting of an observer and recorder; made timed, independent counts of cave aquatic biota in 20 non-contiguous 20-meter transects. We used the R package 'unmarked' to fit N-mixture and occupancy models to the count data to estimate the occupancy and abundance of detected CAB (Table 1). Only four out of six CAB species were detected frequently enough for analysis: two small (i.e., 2–15 millimeter) cave crustaceans, a large (i.e., 1–8 centimeters) cavefish, and a large (i.e., 1–8 centimeters) cave crustacean (i.e., *Stygobromus vitreus, Caecidotea stygia, T. subterraneus*, and *Orconectes pellucidus*, respectively). Estimates of CAB detectability for occupancy at the reach level made intuitive sense in that they were likely correlated with size and pigmentation: *S. vitreus* is small and transparent whereas the other CAB are much larger and white or pink. Curiously, estimates of CAB detectability for abundance (detectability per individual) were low and inversely correlated with size (Table 1). However, with more abundant CAB there are multiple chances to see at least one individual among multiple transects which makes for more robust occupancy modeling. CAB not detected during the 2015 pilot (e.g., *Palaemonias ganteri* and *Amblyopsis spelaea*), which we nonetheless plan to monitor, are at least as abundant and detectable as those we detected.

We conducted simulations testing the feasibility of using HMs to estimate status and temporal trends in CAB abundance and the uncertainty associated with combinations of parameter values we considered for this sampling design (e.g., transect length, number of sampling sites, number of sampling visits). Generally, these simulations indicated our sampling design's ability to detect a 50% population decline at both 5% and 10% decline per year, even with the moderate year to year fluctuations built into the simulation, has greater than 80% power to detect declines in abundance or occupancy except for CAB with low abundances or detectability. We intend to investigate or develop the use of environmental DNA (Niemiller et al. 2017) to increase detection probabilities used to estimate CAB abundance and occupancy.

Data handling procedures will be in place to ensure data collected under this protocol are of an acceptable quality and are available for current and future data users. Data recorded on field data sheets or collected by data loggers will be entered and stored in several databases. Water-quality and water-quantity data will be stored in NPSTORET and AQUARIUS databases, respectively, and CAB detection/nondetection data will be store in a Microsoft® Access database to be developed by the CUPN in cooperation with National Park Service contractors. Data verification and validation will be conducted before electronic data sets are archived. Queries and reports in the database will be used to retrieve data for analysis and to generate Summary Reports and Trend Analysis Reports for park management. Through the use of this protocol, we intend to ensure that a scientifically credible story regarding the ecological condition of CAB metapopulations, their responses to park management actions, land use changes, and other stressors can be told to park visitors and managers alike.

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BATCAVER – CITIZEN SCIENCE TO IDENTIFY CRITICAL BAT HABITAT IN WESTERN CANADA

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Wildlife Conservation Society Canada's BatCaver program (www.batcaver.org) is a collaborative initiative between biologists and cavers to locate and describe hibernation habitat for bats in western Canada. Up to 14 species of bats may hibernate in western Canada during the winter. Focus is on habitat use by bats in winter, as it is during this time of year when a deadly fungal disease, White-Nose Syndrome (WNS), kills bats. WNS is devastating some bat populations in eastern North America, and was discovered in Washington state in 2016, its first occurrence in western North America. Research on potential treatments of WNS is ongoing with much focus in the east on potential treatments of hibernating bats. BatCaver has focused on trying to locate bat hibernacula and collect data that can be used to determine to what extent western bat species are at risk from WNS die-back, and evaluate potential mitigation, management and treatment strategies.

***Background*.** BatCaver was inspired by a successful collaboration in Montana that saw Montana's Northern Rocky Mountain Grotto (NRMG), Big Fork High School Caving Club, Montana Natural Heritage Program (MNHP), and other state and federal agencies conduct surveys, bat counts and mapping of caves and starting in 2011. In 2013, WCS Canada's Dr, Cori Lausen, inspired by the success of the Montana initiative, began attending meetings of the Alberta Speleological Society (ASS) and British Columbia Speleological Federation (BCSF), receiving support in both groups for this type of program; even before funding was secured, BatCaver came into being thanks to enthusiastic volunteer cavers from both provinces.

In December 2014, the Government of Canada added three species of bats to the List of Wildlife Species at Risk in Canada (also known as Schedule I of the Species at Risk Act). Two of these three bats species occur in western Canada - the Little Brown Myotis (*Myotis lucifugus*) and the Northern Myotis (*M. septentrionalis*)—both listed as Endangered due to the threat of WNS. A 2015 draft federal recovery strategy for these species listed a schedule of studies to identify critical habitat (hibernacula). Two of the listed studies are directly aligned with BatCaver: 1) conduct surveys in areas where hibernacula are suspected but not confirmed 2) refine biophysical attributes for hibernacula (Environment Canada 2015). In 2015, Environment Canada became one of BatCaver's major funders, in addition to 10 other funders. Numerous provincial government departments, speleological organizations and academic institutions also support this program (see list of sponsors and partners in the Acknowledgements).

Program Structure-- BatCaver is led by three cavers: program coordinator, Martin Davis, a long time very experienced caver and bat researcher living on Vancouver Island, oversees the program and field logistics for most of British Columbia; Dave Critchley and Greg Horne, Alberta cavers, oversee Alberta, Northwest Territories and SE British Columbia regions of BatCaver. The three coordinators and Lausen use their personal cave/mine knowledge, networks of cavers (both club-affiliated and not), government biologists, universities, geologists and consultants to tap into as much knowledge as possible regarding where and when bats are using mines and caves.

A compilation of all known lists and databases of caves and abandoned mines in Alberta and British Columbia on public lands served as the starting point for BatCaver, with valuable information from BCSF, ASS and Parks Canada. Approximately 1,370 potential sites were assembled in a database. Ranking and prioritization of sites is based largely on background information from the coordinators' network of contacts and their personal knowledge including: past bat observations, evidence of bats (guano, bones, carcasses), size of cave/mine (total or estimated length), access (time, effort, hazards & cost) and reliable/accurate directions to entrance. The ability of BatCaver to obtain the necessary provincial or federal research permits also has greatly influenced where monitoring has occurred.

BatCaver relies on volunteer field help (cavers, geologists, naturalists, etc.) although some services are contracted, especially for deploying and/or recovering monitoring equipment (see below) at high priority sites that would not otherwise be visited by volunteers. Consideration for recovery of the monitoring equipment (see below) is critical. Participants are matched with sites based on skills/experience and they generally provide their own caving equipment, meals and transportation, with some expenses reimbursed as requested ahead of time. Expenses are often reimbursed to cavers in return for deployment and a plan to retrieve monitoring equipment. Helicopter flights may be subsidized, as determined on a case by case basis for high priority sites. Volunteers can donate their claimable allowances back to WCS Canada. Participants sign a waiver and in some cases may be covered under WCS Canada worker's compensation insurance.

Monitoring Plan**.** Monitoring equipment includes an Anabat® Roost Logger (http://www.titley-scientific.com/us/the-anabatr-roost-logger.html) ideally placed deep enough into a cave or mine where a stable climate for hibernation exists (for western Canada in the range of 1-10C, >95% RH). Temperature & relative humidity loggers (iButton, https://www.thermochron.com/product/ds1923-hygrochron/ or Hobo, http://www.onsetcomp.com/products/data-loggers/u23-001) are deployed if a site used for roosting bats, or potentially used, can be identified. There is limited data on the general cave climates available for bat hibernation in western Canada. Even less is known about the specific microclimates bat chose. The

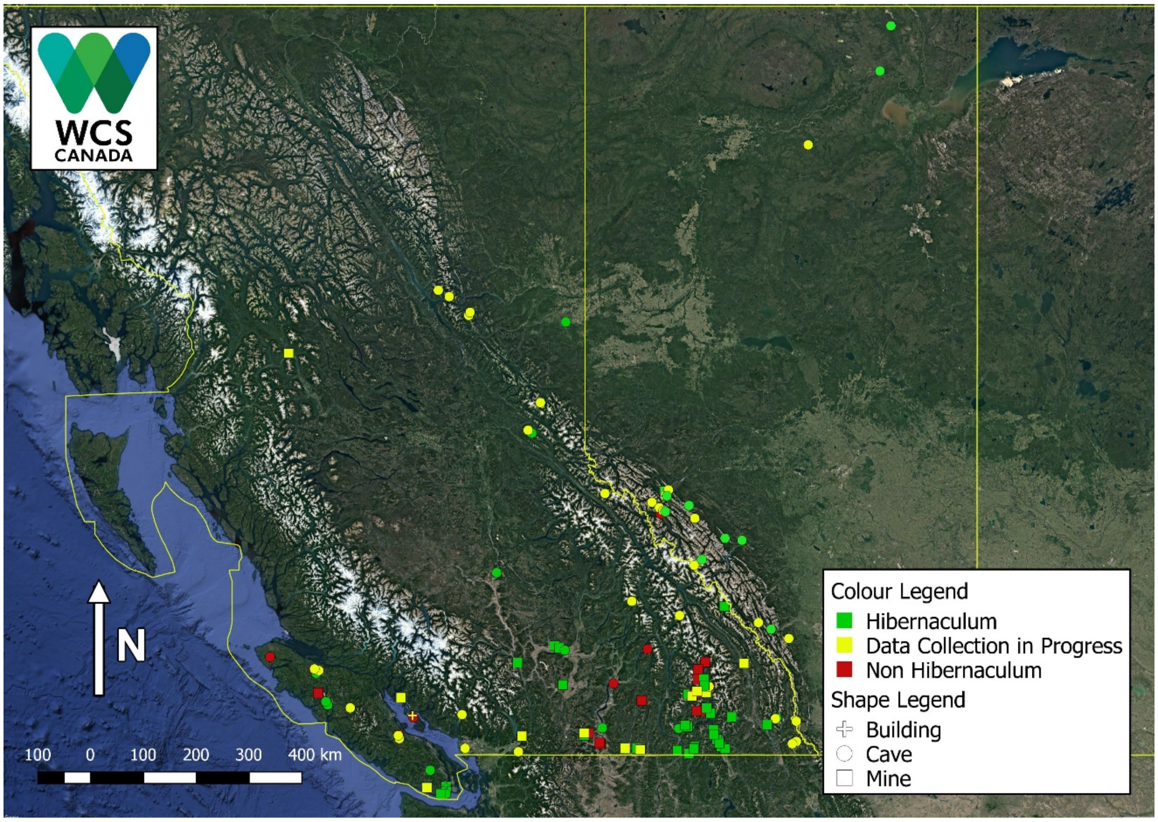

Figure 1. Map depicting the preliminary categories of sites investigated by BatCaver and their hibernaculum status in western Canada.

gathering of this climate data by BatCaver may help with a predictive model to assist with the search for hibernacula and development of WNS survivorship models.

Roost loggers allow for long term monitoring, more than a year if programmed to subsample. The ideal deployment occurs in late summer with pick up early the following summer, permitting two bat activity periods to be sampled—autumn insurgence and spring emergence. Bats may also be detected on roost loggers during the winter hibernation period because they are likely to fly periodically during hibernation.

Cavers are asked to make a detailed site investigation looking for and documenting evidence of bats: digital photos of roosting bats, bat bones, guano and carcasses, and collection of guano/skulls if permitted. All cavers follow Canadian WNS decontamination protocols.

Results. A total of 256 sites have been monitored as part of BatCaver since 2014. One hundred and fifteen have been identified as hibernacula with another 50 sites currently being investigated (**Table 1; Figure 1**). Some of the 115 hibernacula were previously known but are being further monitored by BatCaver to expand site knowledge. Site follow-up has included installation of educational signs at hibernacula and discussions with landowners and stakeholders.

Future planning to search for and monitor potential hibernacula will extend field work to at least summer 2019.

Table 1. Summary results of jurisdiction and category of site investigated by BatCaver from 2014 to 2017.

	Building	Cave	Mine	Category Total
Alberta				
Non Hibernacula		6	1	**7**
Hibernacula		8	1	**9**
Data Collection in Progress		10		**10**
Total Alberta Sites		**24**	**2**	**26**
British Columbia				
Non Hibernacula		71	13	**84**
Hibernacula	2	51	51	**104**
Data Collection in Progress		20	11	**31**
Total BC Sites	**2**	**142**	**75**	**219**
Northwest Territories				
Hibernacula		2		**2**
Data Collection in Progress		9		**9**
Total NWT Sites		**11**		**11**
Grand Total	**2**	**177**	**77**	**256**

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Partners: Alberta Speleological Society, British Columbia Speleological Federation, British Columbia Ministry of Agriculture, British Columbia Ministry of Environment, British Columbia Ministry of Forests Lands and Natural Resource Operations, Canadian Cave Conservancy, NAIT (Northern Alberta Institute of Technology), Thompson Rivers University.

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THE LEE COUNTY CAVE ISOPOD (*LIRCEUS USDAGALUN*) DEBACLE: AN ENDANGERED SPECIES DISCOVERED NOT TO BE A SPECIES

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Hubricht and Mackin (1949) published a revision of the isopod genus *Lirceus* in which eight new species were described and five extant ones were re-described. Departing from conventional description of the genital pleopods that allow identification of asellid isopods, they instead returned to the 19th century practice reliant on color patterns and non-genital appendages. This approach resulted in an assemblage of 13 unidentifiable species. Subsequently, two rare species were eloquently described from caves in southwestern Virginia: *L. usdagalun* Holsinger & Bowman, 1973 and *L. culveri* Estes & Holsinger, 1976. *Lirceus usdagalun,* termed the Lee County Cave Isopod, was listed as an endangered species in 1992 following extirpation of one of two known populations.

In 2015 the senior author commenced a revision of the genus *Lirceus*. The goal was description of the genital pleopods of all species and incorporation of molecular genetic data, with the intended outcome being that all species could be identified by anyone familiar with isopods. Ironically, this revision was viewed as a mostly academic pursuit that would be of little interest outside of those interested in asellid isopods. That view was about to change.

February 2016 was spent at the Smithsonian Museum Support Center where Hubricht and Mackin had deposited their type specimens of *Lirceus.* The plan was to redescribe all species of the genus, either using the types if they could be located (Hubricht's collections were uncatalogued among tens of thousands of specimens of *Lirceus*) or topotypic specimens. The assumption was that *L. usdagalun* and *L. culveri* were well-described and needed no further attention. The evaluation was uneventful until examination of specimens of *L. hargeri*, an epigean species known from springs in Lee County, Virginia and adjacent northeastern Tennessee: the genital pleopods of *L. hargeri* were identical to those of *L. usdagalun*! The realization dawned that *L. usdagalun* was conspecific with the epigean *L. hargeri*. It was apparent that not even Dr. John Holsinger, the co-author on the description of *L. usdagalun*, could separate it from *L. hargeri*. Specimens with eyes and pigmentation from Flanary Bridge Spring (Lee Co., Virginia) were identified by him as *L. usdagalun,* although clearly *L. hargeri*. Under different circumstances the two species would be synonymized—depigmentation in itself is not valuable in separating species of asellids. Many spring-dwelling asellids in North America have depigmented cavernicolous populations, analogous to the European species *Asellus aquaticus*, with troglomorphic populations recognized as subspecies (Hargeby et al., 2005).

This was a taxonomic blunder of significant proportions. Decades of conservation work had been expended by the Virginia Natural Heritage Program (VNHP) and large amounts of land had been acquired in Lee Co., Virginia to protect the caves inhabited by the endangered *L. usdagalun*. After returning from the Smithsonian, the news was shared with

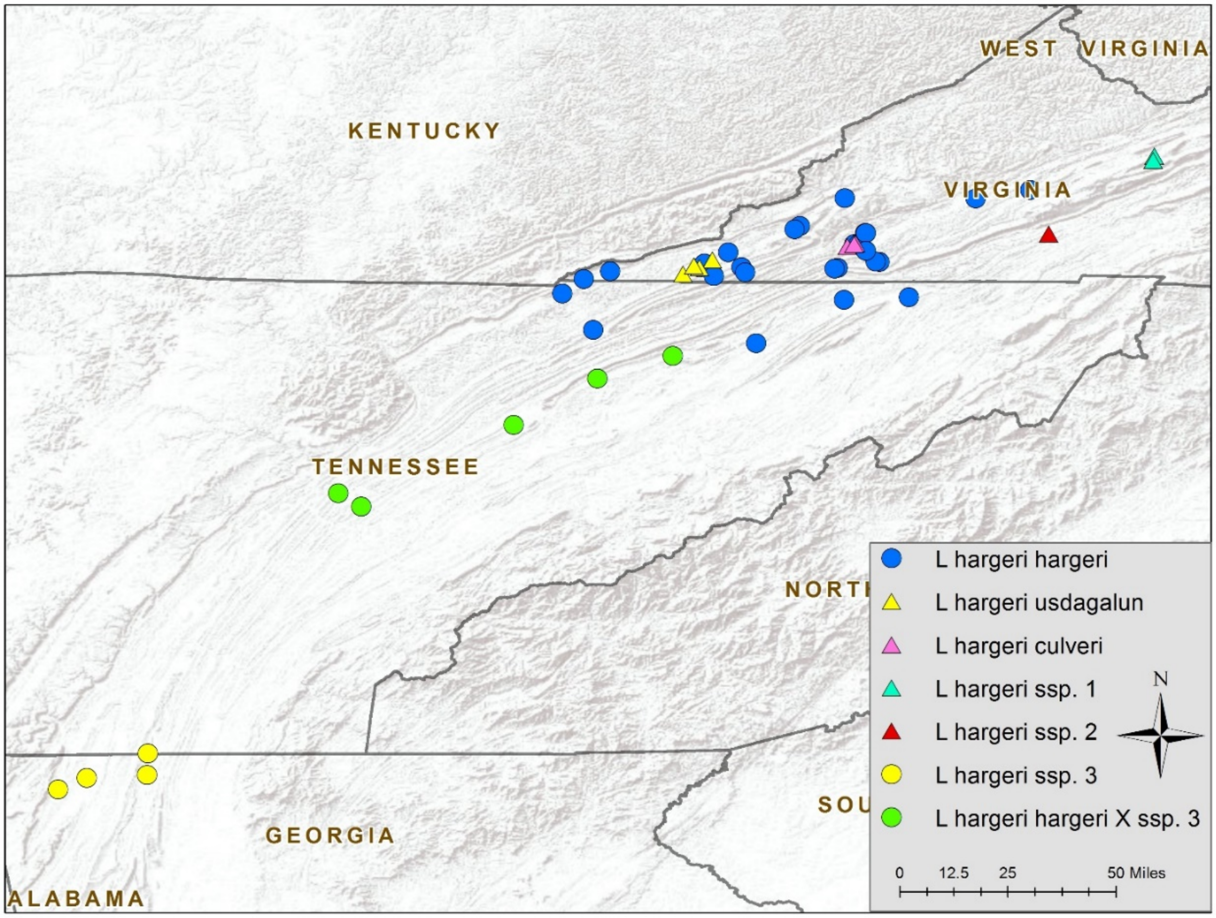

Figure 1. Distribution of proposed subspecies of *Lirceus hargeri.*

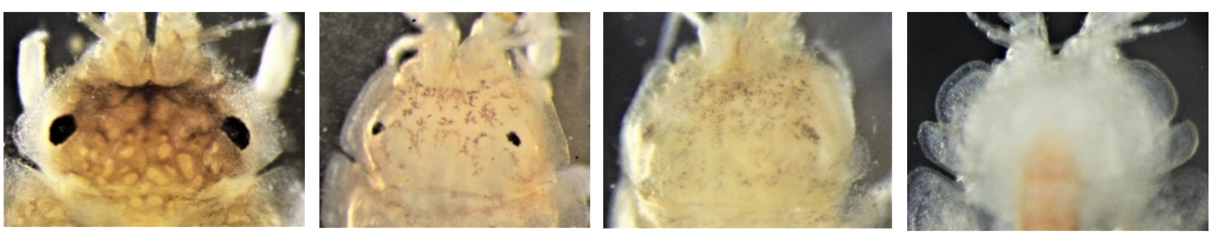

Figure 2. *Lirceus hargeri* morphs (left to right, all from Virginia): *hargeri*-Lee County; new subspecies-Tazewell County; new subspecies-Washington County; *usdagalun*, Lee County.

VNHP and U.S. Fish and Wildlife Service. While awaiting the allocation of funds for re-evaluation of the status of *L. usdagalun*, a reconnaissance visit was made to Lee County to collect new specimens for sequencing, and to have a fresh look at the geographic situation as well.

Later in 2016, another visit to the Smithsonian was made to examine and identify thousands of Appalachian *Lirceus* specimens. Examination of an additional 2,371 specimens revealed six identifiable *L. hargeri* morphs, all with identical genital pleopods. This was followed by a field evaluation of Appalachian *Lirceus*, with specimens collected from 31 caves and springs from New York to Georgia for morphological and genetic analysis.

When published, *L. hargeri* will be considered a polymorphic species distributed from southern Virginia to Georgia (**Figure 1**) with six proposed subspecies (Lewis, 2017) encompassing intergrades from pigmented to unpigmented (**Figure 2**): (1) *hargeri* –epigean, Virginia and Tennessee; (2) *usdagalun* –Lee County, Virginia; (3) *culveri*—Scott County, Virginia; (4) new subspecies – stygobiont, Tazewell County, Virginia; (5) new subspecies– previously unknown stygobiont, Washington County, Virginia; (6) new subspecies-- epigean, Tennessee, Georgia.

We concur with the evolutionary scenario of Estes and Holsinger (1976) that the subterranean *Lirceus* populations were the result of groundwater invasions by epigean ancestors. The evidence suggests that an ancestral epigean species dispersed through the upper Tennessee River Valley, with invasion of caves in Virginia's inter-mountain karst belts resulting in troglomorphic populations. A gap in the range of *Lirceus* occurs between Tazewell and Rockbridge counties, Virginia where one finds the southern end of the range of *L. brachyurus*, the sister species of *L. hargeri*. Preliminary molecular analysis of nine *Lirceus* species reveals genetic inferences affirming the morphological deductions.

In this scenario the Lee County Cave Isopod can retain endangered status as a subspecies. The other three troglomorphic populations of *Lirceus hargeri* endemic to Scott, Washington, and Tazewell counties will become formally recognized and described, paving the way to new conservation status for them as well. This is likely to be welcome, as two visits to Singleton Cave, the only known locality for the proposed Washington County subspecies, have failed to find the isopods. Thus, this new subspecies, known only from a 1967 collection, likely has been extirpated prior to recognition of its existence.

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Partial cave closures for study of microbiome in Grand Canyon Caverns, a sulfuric hypogene dry cave in north central Arizona, revealed a biotechnologically relevant community and had no deleterious economic impact

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Microbial and elemental analyses were conducted at Grand Canyon Caverns, a privately-owned, commercial, sulfuric hypogene dry cave in north-central Arizona. Sampling was conducted on multi-colored rock formations with the consistency of fine powder within the cave spanning the distance of 1–3 m^2. The owner agreed to limit access to newly discovered sites within the cave in order to preserve the microbial community. Microbial community analysis was conducted by collecting 14 samples from various multi-colored formations. DNA was extracted from samples followed by amplicon sequencing of the V4 region of the 16S rDNA with the 515f/806r barcode primers in triplicate. Amplifications were pooled and sequenced on an Illumina MiSeq. OTUs were filtered using QIIME and taxonomy was assigned against the Greengenes database. Digested dry rock samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Ticket sales were tracked before and during times of limited access to areas of the cave to assess the economic impacts. Analysis of the cave microbiome revealed ~900 distinct genera of bacteria and archaea. Presence of genera varied across 14 sampling locations and included *Arcobacter* (1.0 ± 0.7%), *Amycolatopsis* (1.6 ± 2.3%), *Bacteroides* (2.6 ± 1.8%), *Phormidium* (1.1 ± 1.1%), *Pseudonocardia* (15.7 ± 17.3%), *Streptococcus* (0.7 ± 0.6%), *Streptomyces* (2.4 ± 3.1%), and unclassified (1.3 ± 1.1%). ICP-MS indicated that elemental composition varied and contained primarily iron (6.2 ± 3.5 g/l) and calcium (1.1 ± 1.1 g/l). Ticket sales did not decrease due to limited access to areas of the cave. This study demonstrates that cave conservation and scientific discovery have limited negative economic impacts on cave recreation and reveals the opportunity to discover microorganisms that may be beneficial for the development of novel industrial biotechnologies and medicines.

CURRENT STATUS UPDATES OF 17 RARE CAVE BEETLES OF THE GENUS *PSEUDANOPHTHALMUS* IN VIRGINIA

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Beetles are one of the most diverse groups of insects in the caves of Virginia (Holsinger *et al.,* 1988). In Virginia, beetles of the genus *Pseudanophthalmus* are all cave-limited troglobionts. Virginia is home to 31 described *Pseudanophthalmus* species (Holsinger *et al*., 2013) and 16 or more undescribed species. Under a cooperative agreement with the U.S. Fish and Wildlife Service (USFWS), Virginia Department of Conservation and Recreation (DCR) staff are performing status assessments of 17 of Virginia's rarest cave beetles that were listed in the Center for Biodiversity's 2010 multispecies listing petition. Before this study, eight species were known from only a single cave, and no species from more than three caves. Eighty-eight sampling events were performed, including 44 to caves where the target species was previously known. At least one visit was made to 26 of 30 caves where a target species was known, including at least one for each species. For 15 of these 17 species, *Pseudanophthalmus* sp. have been verified in at least one of the previously known sites. Of these, 14 have been verified to target species. Up to 15 new localities for eight of the species were identified. Of these, 10 have been confirmed to species level, three are females of the appropriate group with the remainder pending taxonomic confirmation. *Pseudanophthalmus* sp. were collected from 59 different caves over the course of this project. Once determinations are complete, a clearer picture of the distribution and rarity of these species will emerge. Although bait stations were set, beetles were found at most sites by hand collections in suitable habitat, typically near flowing or standing water. Hydrologic conditions influenced sampling success. Beetles were more abundant in the Valley and Ridge Province, especially to the south, and less abundant in the Shenandoah Valley. Based on current inventory data, of the target species, seven are secure, eight are vulnerable, and two are at risk of extinction and merit further investigation to see if listing under the U.S. Endangered Species Act is warranted.

On 20 April, 2010 the Center for Biological Diversity submitted to the United States Secretary of the Interior a "Petition to list 404 Aquatic, Riparian, and Wetland Species from the Southeastern United States as Threatened or Endangered under the Endangered Species Act." Included in this petition were 17 rare cave-limited beetles of the genus *Pseudanophthalmus.* Before this study, eight species were known from only a single cave, and no species from more than three caves. All of these cave beetles have very restricted geographic ranges (Barr 2004) located in the karst regions of western Virginia. One or more of these species were known to occur in a total of only thirty caves in Virginia. In January 2015, the USFWS Virginia Field Office entered into a cooperative agreement with the Virginia DCR Natural Heritage Program in order to evaluate the conservation status of these species in Virginia. Most of the beetles listed in this petition have not been seen or collected in a substantial amount of time from their previously known localities. The 17 cave beetles of the genus

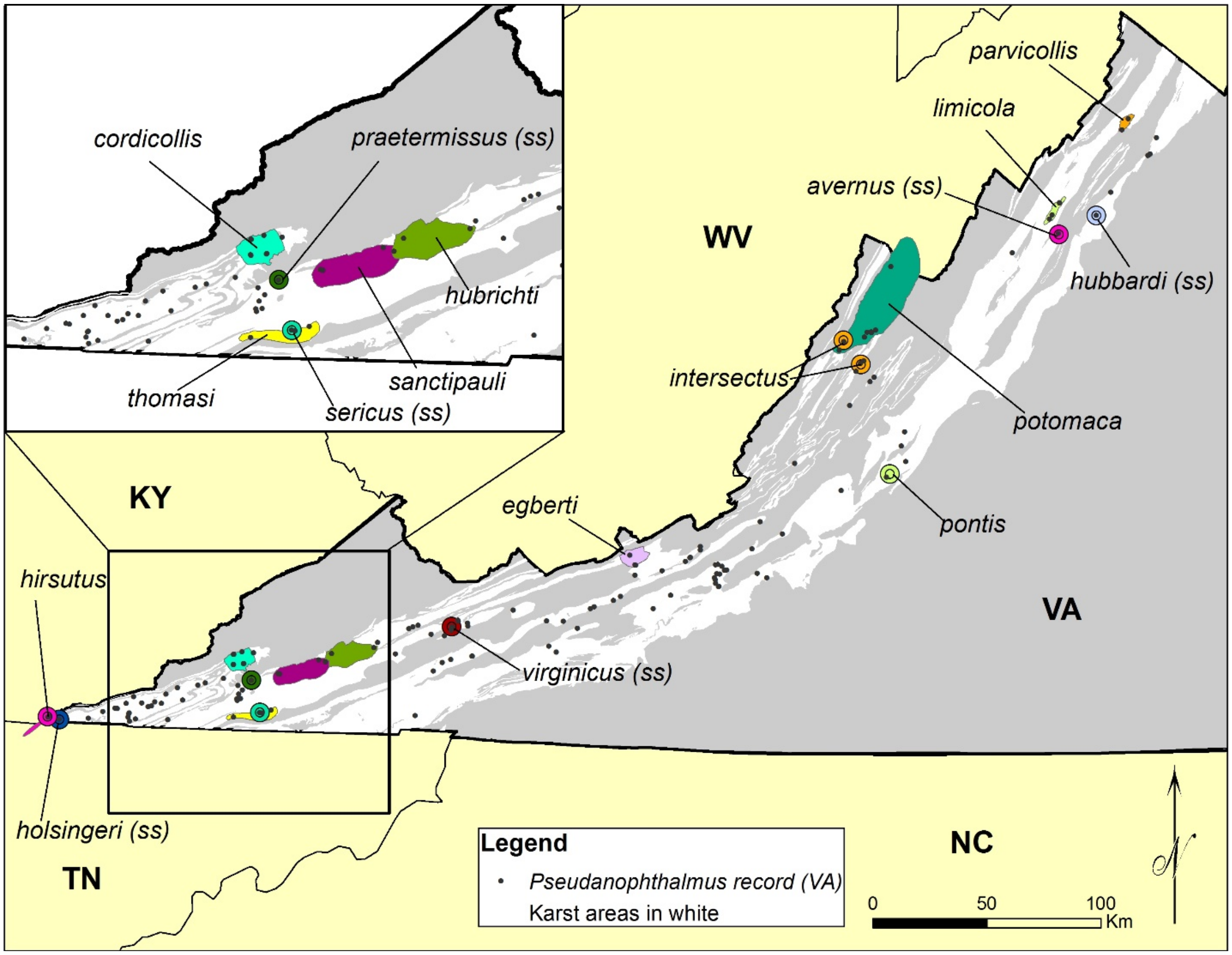
Table 1. Summary of *Pseudanophthalmus* cave beetle survey efforts to date (! - likely extant, * - females of group identified at sites within known range of species).

Species	Previously Known VA Cave Sites					New Sites		All known VA Sites				
	Number	Visited	Found	Not Found	Pending	Confirmed	Pending	Total Known	Found	Not Found	*Pending*	*Not visited*
P. avernus	1	1	1					1	1			
P. cordicollis	3	2	2			3		6	5			1
P. egberti	2	2	1		1	1		3	2		1	
P. hirsutus !	2	1		1				2		1		1
P. holsingeri	1	1	1					1	1			
P. hubbardi !	1	1		1				1		1		
P. hubrichti	1	1	1			1	1	2	2		1	
P. intersectus	2	2	2			1	3*	3	3		3*	
P. limicola	4	2	1	1				4	1	1		2
P. parvicollis	2	2	1	1				2	1	1		
P. pontis	1	1	1			1		2	2			
P. potomaca	3	3	1	2		2		5	3	2		
P. praetermissus !	1	1		1				1		1		
P. sanctipauli	2	2	1	1			1	2	1	1		
P. sericus	1	1	1					1	1			
P. thomasi	2	2	2			1		3	3			
P. virginicus	1	1	1					1	1			

Pseudanophthalmus that were named in Virginia are: Avernus Cave Beetle *(P. avernus* Valentine 1945*),* Little Kennedy Cave Beetle *(P. cordicollis* Barr 1981*),* New River Valley Cave Beetle *(P. egberti* Barr 1965), Cumberland Gap Cave Beetle *(P. hirsutus* Valentine 1931)*,* Holsinger's Cave Beetle *(P. holsingeri Barr 1965),* Hubbard's Cave Beetle *(P. hubbardi* Barber 1928), Hubricht's Cave Beetle *(P. hubrichti* Valentine 1948), Crossroads Cave Beetle *(P. intersectus* Barr 1965)*,* Maddens Cave Beetle *(P. limicola* Jeannel 1931), Hupps Hill Cave Beetle *(P. parvicollis* Jeannel 1931)*,* Natural Bridge Cave Beetle *(P. pontis* Barr 1965)*,* South Branch Valley Cave Beetle *(P. potomaca* Valentine 1932)*,* Overlooked Cave Beetle *(P. praetermissus* Barr 1981)*,* Saint Paul Cave Beetle *(P. sanctipauli* Barr 1981), Silken Cave Beetle *(P. sericus* Barr 1981), Thomas' Cave Beetle *(P. thomasi* Barr 1981) and Maiden Spring Cave Beetle (*P. virginicus* Barr 1960)*.*

Caves that were known to have had previous records for target beetles were focused on for collections. Additional caves that were located in the assumed ranges of the 17 species based on geologic setting were also targeted to be surveyed with the hope of identifying new localities for the species of concern. In addition, when time allowed efforts were made to collect *Pseudanophthalmus* sp. beetle from any additional caves that were entered while conducting work on other projects within the time frame of this project. In total, 100 cave visits have been included in this study, and beetles of the genus *Pseudanophthalmus* have been collected from 59 different caves

Figure 1. Distribution of target *Pseudanophthalmus* species in Virginia (ss indicates a single site endemic).



in Virginia over the course of this project. During the agreement performance period, 26 of the 30 caves determined to have existing records for the beetles of concern specified in the agreement were visited one or more times and one cave was not able to be located in the field. **Table 1** summarizes the results of *Pseudanophthalmus* cave beetle survey efforts to date. For the caves listed in the work plan 44 sampling events have been performed to date comprised of 55 total cave visits. At least one cave has been visited for each of the 17 rare cave beetle species. For 15 of these 17 species, beetles of the genus *Pseudanophthalmus* have been verified to be present in at least one of the previously known sites. Of these, 14 have been verified to target species level and one contained beetles of another *Pseudanophthalmus* species. Three species have not been captured (*P. hirsutus, P. hubbardi, P. praetermissus*) but are likely extant. Additional collection efforts are needed to confirm this. In addition, up to 15 new localities for eight of the species have been identified. Of these 10 have been confirmed to species level. Two of the remaining are pending taxonomic confirmation and three are females that have been narrowed down to group but will not provide positive identification from traditional taxonomic methodology. The identification of new additional sites and the updates at previously known sites allow us to have a better understanding of the ranges (**Figure 1**) of these 17 cave beetles within the state of Virginia.

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MAKING CAVE CRICKETS FAMOUS: MANAGING KARST LANDSCAPES AND CONSERVATION MESSAGES

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In Austin, Texas, residents voted to fund the purchase of over 40,000 acres of land for the protection of endangered species habitat and recharge to the Edwards Aquifer starting in 1996. In addition to two species of neotropical birds, six endangered karst invertebrates benefit from this protection as well as twenty-five percent of the aquifer's recharge zone and seven percent of the contributing zone. Twenty years later, this karst landscape now finds itself at odds with one of the fastest developing areas in the United States, attracting many new residents who didn't participate in the sometimes heated discussions that led to this significant conservation of sensitive lands. The City's Wildland Conservation Division staff work not only to manage the land, but also the public messaging about why cave conservation matters for endangered species, water resources, and people. In addition to training educational cave trip leaders and hike guides each year, Wildland Conservation staff, along with local partner organizations, seek to build tangible connections to the karst landscape through off-site strategies including YouTube documentaries about land management, animations of macro invertebrates through augmented reality games and apps, and local art exhibits that connect people with plants, crickets, and ultimately the underground conduits of karst ecosystems.

NEW TECHNIQUES FOR DETERMINING OCCURRENCE AND DEMOGRAPHICS OF CAVE CRAYFISH

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Many species of cave crayfishes are of conservation concern due to narrow distributions and threats to groundwater quality. To protect stygobiotic organisms, we need to adopt innovative techniques for studying their populations. For example, environmental DNA (eDNA) is a new technique that can be used to detect presence of organisms via DNA shed in the environment. In addition to knowing where stygobionts occur, we need to better understand their life history. Recent work has demonstrated that lobsters and crayfishes can be aged via their gastric mill instead of relying on indirect techniques, such as length-frequency histograms. Our objectives were to assess the use of eDNA for detection of cave crayfishes and determine if using hard structures for aging cave crayfishes could be used for demographic analysis. For eDNA analysis, we collected 2-L water samples from groundwater throughout the Ozark Highlands ecoregion. DNA was extracted using a modified phenol-chloroform method. DNA was amplified using quantitative polymerase chain reaction (qPCR) with a primer/probe combination to increase specificity. We collected 50 *Faxonius neglectus* and two *Cambarus setosus* to test the use of hard structures for aging crayfish. Preliminary results show amplification of *C. setosus* DNA. Age estimates of *F. neglectus* via gastric mills match estimates from length-frequency histograms until year 5. Gastric mills of cave crayfishes display rings that appear similar to rings found in surface species. Future work will focus on amplifying DNA from groundwater samples where other species of cave crayfishes and cavefishes occur. Also, we will raise crayfish in the lab and confirm that the rings visualized on hard structures correspond to yearly rings. Results of our study demonstrate that two new techniques may advance the way we study stygobiotic populations.

Rediscovery and conservation status of short-range endemic *Pseudanophthalmus* cave beetles (Carabidae: Trechini) in Tennessee, Alabama, and Georgia

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The North American endemic cave beetle genus *Pseudanophthalmus* is exceptionally diverse, with >150 described taxa in karst regions of the eastern United States. Eighty-seven percent of taxa, however, are at risk of extinction due to small, restricted distributions, low abundance, and several potential anthropogenic threats to their habitats. Several species in TAG (Tennessee, Alabama, and Georgia) are exceedingly rare with some taxa considered candidates for listing under the U.S. Endangered Species Act. Each of these species are extreme short-range endemics, and some of which have not been observed in several decades. Between July 2013 and August 2017, we search >200 caves through the Appalachians and Interior Low Plateau karst regions of TAG to determine if populations were still extant, to search for new populations, and to estimate relative abundance. We confirmed the continued existence of several species, including *P. fowlerae*, *P. insularis*, *P. paulus*, and *P. tiresias*, which had not been observed in 52, 60, 50, and 42 years, respectively. Although U.S. Fish and Wildlife Service ruled that six species do not warrant federal listing, all species continue to have restricted ranges and remain at an elevated risk of extinction.

USING ENVIRONMENTAL DNA TO DETECT AND MONITOR RARE AND ENDANGERED GROUNDWATER FAUNA: A CASE STUDY

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Effective conservation and management of biodiversity is limited by a lack of critical knowledge on species' distributions and abundances. This problem is particularly exacerbated for species living in habitats that are exceptionally difficult to access or survey, such as groundwater habitats. Environmental DNA (eDNA) represents a rapid, noninvasive, and potentially cost-effective new tool for detection and monitoring of biodiversity that occur in such habitats. We investigated the utility of eDNA in detecting the federally endangered Hay's Spring Amphipod *Stygobromus hayi* and a co-occurring common congener *S. tenuis potomacus* from unique groundwater associated habitats in the Washington, DC metro area. We developed taxon-specific primers and probes for each species to amplify *Stygobromus* DNA using qPCR. In silico and in vitro validation demonstrated specificity of each designed assay. Assays were then used to screen water samples collected from ten seepage springs. *Stygobromus hayi* was detected at four seepage springs, including one potential new locality, while *S. t. potomacus* was detected at four springs, two of which were new localities. This study is the first to our knowledge to successfully employ an eDNA approach to detect rare or threatened invertebrates from subterranean ecosystems. Our study highlights challenges of employing an eDNA approach for the detection and monitoring of invertebrates in groundwater habitats that are difficult to study, including accounting for PCR inhibition and the potential for cryptic genetic diversity.

Characteristics of Bats at a Cave in Eastern Oklahoma: Spring Emergence and Fall Swarming

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Data presented here represent four sampling periods (two fall swarming and two spring staging) that will be used to estimate changes in the overwintering populations of Northern Long-eared Bats (MYSE), Tri-colored Bats (PESU), and Gray Bats (MYGR) in a single cave system in the Ozark Plateau National Wildlife Refuge (OPNWR) in Adair County, Oklahoma. This cave system has 11 known entrances, three of which are the areas of interest for this survey. The cave system was negative for *P. destructans* in winters 2013–2016, but positive in spring 2016. Data from bats at the hibernaculum were compared to data collected on the landscape during the July 2013 Bat Blitz from the same general area. Bats were captured at three cave entrances in the OPNWR during the nights of 29 & 30 September 2015, 5 & 6 April 2016, 28 & 29 September 2016, and 20 & 21 March 2017, using harp traps at cave entrances and mist-nets strategically placed around those same cave entrances. All equipment, traps, poles, nets, cloth bat bags, and processing gear were new or decontaminated following USFWS protocols. MYSE and MYGR were banded with uniquely numbered forearm bands. Previous winter surveys of this cave system counted <50 MYSE. Although we captured over 1,500 individuals, many individuals were seen inside and around the cave entrances and we stopped the surveys each night long before the bats stopped their activity. We estimated >1,000 individuals of MYSE during each survey period. A cold front passed through on the second night of the fall 2015 survey, and the activity of PESU increased to a point that we took down the nets and traps. A small number of MYGR are known to use the cave during the summer and it is likely that these MYGR leave this cave for other hibernacula. There were significant differences in mass between summer and fall and between spring and fall for both MYSE and PESU as they emerge from or prepare for hibernation, but no significant differences were observed in MYGR. This may occur as fall bats are in transit or have not departed for their hibernacula and future mass increases. At this time, we do not know if the sex ratio for MYSE in the spring 2016 and 2017 survey (>95% male) represents the hibernating population or if the females departed prior to our survey. Low numbers of MYSE captured in spring 2017, are likely weather related and due to unseasonably warm weather and not related to WNS.

GEOSPATIAL ASSESSMENT OF LANDSCAPE THREATS EFFECTING OKLAHOMA KARST SPECIES

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The Ozarks contain an underground wilderness of caves, springs and aquifers that over the millennia have formed in the carbonate bedrock of the region. The porous and fractured nature of karst terrain makes it susceptible to pollution caused by incompatible land use, and these same landscape alterations may reduce the availability of high quality foraging and roost habitats for cave-dwelling bats. More generally, human visitation and vandalism likely threaten all karst species. To understand these impacts, a Geographic Information System (GIS)-based index model was developed that assessed site-specific threats associated with 28 Oklahoma karst species (4 bat species, 8 terrestrial cave species, and 16 aquatic cave species) using threat indicators derived from 25 geospatially available datasets. Threats were assessed for 94 karst habitats (caves, springs, or seeps). In addition, a groundwater vulnerability model was developed for northeastern Oklahoma using a modification of the Environmental Protection Agency's DRASTIC model. Nearly all sites are experiencing some level of threat. Karst sites experiencing a high level of modelled threat are distributed across northeastern Oklahoma, but many highly threatened sites are concentrated near or north of the U.S. Highway 412 corridor. In addition to identifying highly threatened individual sites, the model characterizes threat at species and community levels. In Oklahoma, the threat model is being used to evaluate conservation priorities at all three of these levels, and it is being used to reassess and update a 2003 Ozark Ecoregional Conservation Assessment Plan developed by The Nature Conservancy.

ANTHROPOGENIC THREATS TO THE RIVER CAVE AND HA HA TONKA SPRING KARST SYSTEMS AT HA HA TONKA STATE PARK, CAMDEN COUNTY, MISSOURI

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In 2007, the Missouri Department of Conservation ranked River Cave as the 5th most biodiverse cave in Missouri. Known for its significant colony of federally endangered Gray Bats, Indiana Bats, four salamander species, cavefish and a suite of aquatic invertebrates, River Cave remains protected as part of the 70-acre Karst Natural Area. With increasing occurrences of flash flood events since the 1990s, the losing stream that traverses the cave and flows to Ha Ha Tonka Spring through a natural sump has become choked with increasing amounts of road gravel and fines. The stream, Dry Hollow, exists parallel to a gravel road that has witnessed increased urbanization at the park's border. On the 1.6 mi. of gravel road frontage, culvert systems and ditching projects have occurred, resulting in massive gravel loading in the stream. As Dry Hollow enters the cave's back sinkhole, the cave, and ultimately Ha Ha Tonka Spring—Missouri's 12th largest and part of the natural area—significant amounts of road gravel continue to accrue following heavy rain events. This karst system, nominated for National Natural Landmark status in 1979 and 2011, is increasingly threatened, with cave and spring biota populations notably declining. The massive gravel accretion from Dry Hollow Road as a direct result of continuous road improvement and ditching projects has resulted in rapid declines in amphipod and salamander populations, in the complete blockage of ancillary cave passages, and, today, islands of gravel filling in the spring branch. In September 2017, the park applied for funding for a multi-tiered project to mitigate this issue including paving the road, creating a catch basin for the remaining gravel, removing gravel from the sinkhole to prevent entry into the cave, and dredging the spring. It was recommended that the park seeks external partnerships to fund this important project.

CONSERVATION, MANAGEMENT, & TECHNIQUES

FROM MAYAN TO MODERN: THE CONTINUED RELIANCE AND CURRENT EXPLOITATION OF CAVES IN MEXICO

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Formed entirely from limestone, the Yucatán Peninsula, Mexico is riddled with sinkholes and caves. These systems range from shallow caves to incredibly extensive systems. Systems Ox Bel Ha and Sac Actun, for example, rank among the top longest caves in the world with over 300 miles of passage combined (QRSS). A shallow aquifer underlies the expanse of the peninsula, filling caves with small pools or completely submerged passages. High permeability and conductivity of the bedrock promotes groundwater flow to the ocean. However, the porous karst landscape does not allow for the formation of surface water bodies. Without rivers or lakes, humans, both ancient and modern, look to the subterranean for resources. The Mayans used caves for their primary water supply as well as for shelter. It is common to find evidence of this ancient civilization in the form of tools, pots, altars, and sculptures. Large cities, such as Chichen Itza, were established close to cenotes, the local name for openings in the bedrock that provide direct access to the groundwater.

In addition to the fascinating archeology and history, caves here are home to unique, endemic, and endangered terrestrial and aquatic organisms. In dry areas, scorpions, pseudoscorpions, amblypygi, spiders, beetles, and other arthropods dominate

Figure 1. Cavers admiring a small pool and beautiful formations in a cave in Quintana Roo. Mexico. Credit: Sean Lewis.

Figure 2. A cave-adapted fish and eel. Credit: Rachel E. Adams.

(Reddell 1977). Sixty of the 134 bat species in Mexico roost in caves (Arita 1993). In submerged passages, due to the saltwater intrusion under the peninsula, both fresh and saltwater species are found in the form of fishes, crustaceans, and other invertebrates (Iliffe 1992).

Unfortunately, today, caves, both dry and water-filled are being contaminated, exploited, and destroyed. Waste water is pumped into the saltwater layer of the aquifer with the intension of it draining to the ocean. Two thirds of the water is not treated before being injected (Bauer-Gottwein et al. 2011). It has been found that the saltwater layer responds to tidal patterns, promoting the spread of untreated waste water further inland before moving towards the coast (Beddows et al. 2002). Expanding urbanization increases quantity of waste as well as increasing the amount of freshwater being pumped from the aquifer. Simultaneously removing clean water and adding contaminated water is narrowing the range of drinkable water under the peninsula (Bauer-Gottwein et al. 2011). This has significant impact on the human population as well as organisms that inhabit caves. Increased nutrients and chemicals in the aquifer can decimate both fresh and saltwater stygobionts and troglobionts.

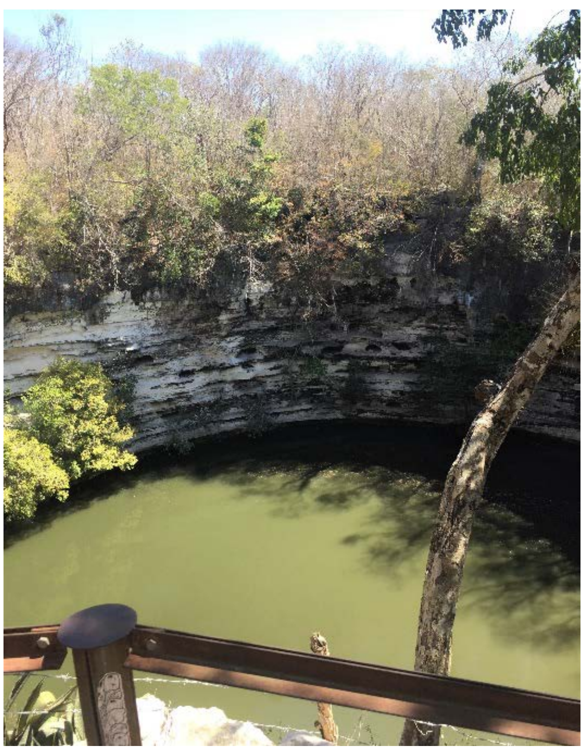

Figure 3. Murky green water in Sacred Cenote at Chichen Itza. Credit: Rachel E. Adams.

Caves and cenotes are commonly developed for tourism. Large-scale operations have the capacity to significantly alter the above and below ground environment through commercialization efforts. These include constructing walking paths, installing artificial lights, widening or making new entrances, and damaging speleothems. All of these activities disrupt the natural ecosystem and impact the abundance and distribution of native organisms. Outside of the cave, the forest is cleared for buildings and roads to host tourists. While some caves are being exploited for tourism, others are being completely destroyed. In expanding urban areas, caves are filled in with rocks and cement in order to avoid sinkholes in the future. As limestone exports and concrete production are prominent industries in Mexico, quarries can destroy entire cave systems. While there is increased pressure to promote and sustain the quality of groundwater in Mexico (Holliday et al. 2007), there is no formal agency or organization that supports the protection and conservation of caves, both dry and water-filled. Therefore, caves have been exploited and destroyed for development without regulation. Many more will be subject to the same fate.

Throughout the course of my graduate studies, I have had the opportunity to visit caves across the Yucatán Peninsula. My dissertation research focuses on trees that utilize the water in caves and their influence on the ecosystems in the cave and on the surface. Thin soils encourage trees to root into the bedrock in search of water and can even root directly into caves

Figure 4. Tree roots in a submerged cave passage: Credit: Petra Kovač-Konrad (left); Dead tree and cleared landscape around a cenote. Credit: Rachel E. Adams (right).

(Estrada-Medina et al. 2013). Tree roots provide habitats and potential food sources for the cave fauna. However, particularly at tourist locations, roots are cut to prevent injury. Without groundwater access, trees die and no longer supply valuable roots to the cave system. Deforestation of large areas further disconnects the surface vegetation and the subterranean. In the midst of my research in Mexico, I have witnessed the human impacts on the underground world. These caves and cenotes here are the some of the final frontiers, leaving much to discover and understand. It is disheartening that so many caves are exploited even though they are a precious resource for knowledge of ancient cultures, water, and incredible biological diversity.

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ENHANCEMENTS TO A BAT-FRIENDLY CAVE GATE DESIGN FOR INCREASED SECURITY

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Bear Hollow Cave, located in Bella Vista, Arkansas, has been managed by The Nature Conservancy since its donation to the organization by Pat and John Cooper, Jr., and Cooper Communities in 1998. The cave has about 2000 feet of passage with a significant stream; however, there are dry habitats as well. Tri-Colored Bats (*Perimyotis subflavus*), Big Brown Bats (*Eptesicus fuscus*), and various salamanders are commonly found in this cave. The most notable species is the endangered Benton County Cave Crayfish (*Cambarus aculabrum*). Bear Hollow Cave is one of only four caves in world which this species is found. The Nature Conservancy has actively documented the population of the crayfish as well as the bats within this system for many years.

Unfortunately, Bear Hollow Cave has also been the location for illegal dumping, vandalism, and trespassing. Because of this, a steel pipe gate was installed by Arkansas Game and Fish Commission in 1994 to protect the cave and its fauna. Over the years, the gate frequently suffered damage via broken locks and cut bars. Individuals have even attempted to remove the gate using heavy machinery, bending the steel pipes. Despite the presence of the gate, these events resulted in continued vandalism and destruction of the cave environment and fauna. During past routine visits to the cave, Conservancy staff observed organisms intentionally killed by trespassers. Bats were knocked down from the ceiling and endangered cave crayfish were stepped on. While repairs were made after each break-in, the gate remained an easy target for vandalism. In addition, the gate was designed and installed prior to the development of the Agency Guide to Cave and Mine Gates that provides guidance and

Figure 1. Original gate (dimensions: 8 by 12.5ft) (top); Trash removal event prior to 2009 (bottom).

Figure 2. R.C. Schroeder welds one of the reinforced horizontal beams (top left). A pair of enhanced stiffeners inside the large angle iron (bottom left). The backside of the lock box with the dummy lock on the bottom and true lock on the top (right).

specifications on constructing bat-friendly gates. Therefore, the design desperately needed to be updated to accommodate the resident bats as well as deter future vandalism.

In July 2015, we deconstructed the 22-year-old gate and installed a bat-friendly version. The new gate features fewer vertical bars for the bats to fly between as well as several layers of protection due to the prior heavy vandalism. After removing the old gate, soil and rocks were displaced from the entrance in order to create a flat area to lay metal mesh. The mesh extends six feet on either side of the gate to prevent digging. A flat piece of metal was welded to the mesh and covered with soil and rocks, establishing the base of the gate. Each horizontal bar was constructed from 4 by 4-inch angle iron. The larger angle iron was reinforced with two 1.5 by 1.5-inch angle iron stiffeners. For each pair of stiffeners, one was filled with gravel and concrete, while a freely spinning stainless steel rod was enclosed in the other. During attempts to cut horizontal bars, the internal rod will spin against a saw and the concrete-gravel mixture will dull the cutting blade. The stiffeners were welded into the larger angle iron, constructing sturdy triangular horizontal beams. Finally, the door was designed to be more discreet with the addition of a dummy lock. Due to past tampering of the lock either by drilling, cutting, and on one occasion, being filled with glue, the lock box was redesigned to include a fake lock. The functional lock was placed above the decoy so potential trespassers would locate the fake lock first

Figure 3. New bat-friendly gate with increased security at Bear Hollow Cave.

and reduce potential damage to the true lock.

Since construction, monthly visits have been conducted to check for vandalism. A few attempts to dig under the cave gate were observed but were thwarted. The first documented attempt was just two weeks after the completion of the gate. Conservancy staff are continuing population counts of the bats and cave crayfish, hoping to see an increase in both groups. The improved design has proven successful at preventing vandalism and unapproved access, ensuring the safety of the fragile cave organisms and environment.

Acknowledgments. We want to thank the Roenfeldt family who generously donated the funds in order to complete this project. We also thank Sheilah Roenfeldt, Harvey Williams, Vincent Adams and Bridget Frost who all volunteered their time and energy to construct this gate.

MANAGING ENDANGERED SPECIES ON PRIVATE PROPERTY AS ASSETS, NOT LIABILITIES OR PROBLEMS

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This is a case history of 51 years of successful land and cave fauna management at the privately-owned Tumbling Creek Cave, in Taney County, Missouri. This cave has the most diverse cave fauna (with 116 species) of any cave in the United States west of the Mississippi River. The cave provides habitat for three federally endangered and one federally threatened species plus other species of conservation concern. These are Gray bat (*Myotis grisescens*), Indiana bat (*Myotis sodalist*), Northern long-eared bat (*Myotis septentrionalis*), and the Tumbling Creek Cavesnail (*Antrobia culveri*). The Cavesnail is endemic to Tumbling Creek Cave.

Tumbling Creek Cave (TCC) is located at the Ozark Underground Laboratory (OUL). The OUL is owned by Tom and Cathy Aley and much of the cave underlies land owned by the Aleys. The remainder of the cave underlies land owned by the Tumbling Creek Cave Foundation (TCCF), a 501 (c)(3) not-for-profit operating foundation. The Aleys and TCCF own about 2,900 acres and lease an additional 640 acres with most of this land being above the cave or within the delineated recharge area for the cave. The total recharge area for the cave is 9.02 square miles. The Aleys, OUL, and TCCF work cooperatively in the management of the cave, its fauna, and the recharge area. Numerous federal, state, and private partners have been involved with the conservation and recovery of the Tumbling Creek Cavesnail for over 20 years.

This paper is intended to encourage landowners and those who advise them to manage threatened or endangered species (federally listed species) as valuable property assets. Our experience demonstrates that such a management approach is beneficial to the species, landowners, and the environment. This approach is contrary to a popular misconception that the presence of such species on private property limits landowner rights and opportunities. In reality, federally listed species can enhance, rather than limit, landowner opportunities by providing alternate sources of funding or income not usually available to private landowners.

Private landowners are generally affected by the federal Endangered Species Act (ESA) only if a federally listed species occurs on their property and some federal action or federal money is involved. Taking a federally listed species is illegal as is shooting a white-tailed deer out of season or manufacturing illicit drugs. Federally listed species at the OUL are wildlife, and public agencies hold wildlife in trust for the American people. On private land public agencies are responsible for the animals, but not for their habitats. It is landowners whose responsibility is to ensure there is adequate habitat and that it is properly maintained for federally listed species. Without the proper management of suitable habitat, it will be difficult to recover federally listed species and prevent possible extinction. Loss of sufficient habitat of adequate quality is probably the single-most important factor in causing species to become listed under the provisions of the ESA. There is limited suitable habitat for many cave-adaptive species, and the need for proper maintenance of suitable habitat creates unique environmental and economic opportunities for cave owners.

While the environmental benefits for landowners who provide habitat for federally listed species are obvious, landowners often fail to recognize the potential for economic opportunities. There are various grant opportunities and other funding sources that are available to landowners in providing habitat for federally listed species. Many of the management practices add value to the landowner's property while also benefitting federally listed species, species of conservation concern, and other plants and wildlife. While the landowner or some other partner will often need to provide a cost share in the funding, the economic benefits to the landowner routinely exceed the value of their contribution. For example, in 50 years about $1.5 million has been obtained to help in the protection, maintenance, and management of Tumbling Creek Cave, its fauna, and its environment.

We have used 6 important and overlapping strategies or attributes in managing federally listed species as assets and we provide examples of each in the following paragraphs.

Strategy 1. Demonstrate that the landowner has appropriate resource management expertise to be an effective partner in conservation efforts. Success in managing federally listed species as a property asset is greatly enhanced if the landowner can work cooperatively with state and federal resource management agencies. To be most effective the landowner needs to either possess or acquire resource management expertise applicable to the site and to the species involved and then implement sound management on lands he controls. Consultants or advisors can fill in gaps in the expertise, but building a track record of sound land management actions is an important asset in any environmental partnership. Funding is generally more readily awarded if you have demonstrated on a smaller scale the implementation of conservation actions that have benefited federally listed species.

Both Tom and Cathy Aley have strong and highly relevant academic backgrounds and both serve as members of the U.S. Fish and Wildlife Service's (USFWS) Tumbling Creek Cavesnail Workgroup and Partnership. Similar to USFWS approved Recovery Teams, state workgroups consist of technical experts who outline actions that can contribute to the conservation and recovery of federally listed species. While landowners are not routinely members of workgroups or Recovery Teams, their involvement with other conservation members can be very beneficial, especially in cases where they own a significant habitat site. Landowners should recognize that workgroup members and Recovery Teams are critical in outlining management actions to benefit listed species and in securing financial support for recovery actions. Serving as workgroup or team members and being a main contact with species experts and other agency partners is obviously beneficial to the species and all parties involved.

Strategy 2. Use protection of listed species as a fundamental part of your operation. A substantial portion of educational field trips at the OUL focus on its management efforts to benefit federally listed species. Additionally, the OUL has initiated several project to benefit the Cavesnail and then sought funding to expand and continue those projects. For example, the OUL started a project with their own funds to locate trash dumps within the recharge area for Tumbling Creek Cave and assess the severity of potential problems these sites created. The dumping of trash in karst sinkholes and losing stream channels was historically a common practice in rural areas of the Ozarks. This analysis enabled the OUL to ultimately receive funds from several sources to manage the project, pay employees to clean up 32 dump sites, and properly dispose of over 100 tons of wastes. The OUL recycled as much as possible and sent the remainder to proper disposal sites. The end result of these efforts is that the Tumbling Creek Cave recharge area is now free of dumps. These management actions have improved underground water quality which is critical to aquatic cave organisms and humans as well.

Strategy 3. Repeatedly emphasize (and demonstrate to the public) that it is a species that is endangered, not the landowner. The number of Cavesnails in Tumbling Creek Cave was about 15,000 in the mid-1970s. By 2001 when the Cavesnail was emergency listed as an Endangered Species the population had declined to less than 150 (USFWS 2001). One of the factors believed responsible for causing this dramatic decline was sewage from on-site sewage systems in the recharge area for the cave. The OUL raised about $15,000 for improved sewage treatment and disposal on their land. Additionally, along with other partners, they assisted the local country school in raising $89,000 for a major upgrade of the school's failed sewage system. This system is directly connected to the stream in Tumbling Creek Cave. Without the OUL involvement and the potential adverse impacts to a federally endangered aquatic organism, this problem would not have been resolved and the school would have been forced to close. With another grant TCCF pumped out about half of the septic tank systems in the recharge area of Tumbling Creek Cave and paid for professional inspection of the systems and some repairs and upgrades at no cost to any landowner. This was all possible because the Cavesnail is an endangered species and we manage it as an asset. It was the Cavesnail that is endangered, not local landowners. The OUL, our rural community, and the Cavesnail and other cave organisms all benefitted from the collaborative efforts of multiple partners.

Strategy 4. Gain recognition for the significance of your site and your conservation efforts; seek help to do more. The Tumbling Creek Cavesnail is an endemic found only in Tumbling Creek Cave. The OUL assisted the snail taxonomist in his essential work in describing the Cavesnail as a species new to science. You cannot have a listed species unless that plant or animal has a scientific name. Because of the nationally significant cave fauna Tumbling Creek Cave was designated as a National Natural Landmark by the U.S. Department of the Interior in 1981. Obtaining this designation required substantial effort and input from the OUL. When the National Geographic Society was planning an hour-long TV documentary entitled "Strange Creatures of the Night" the OUL provided technical and logistical support for filming in the cave. When Time-Life Books published "The Ozarks" in their American Wilderness Series there was a 12-page photo essay on Tumbling Creek Cave. The OUL spent a week transporting photographers and gear into remote parts of the cave. Conservation efforts implemented by the Aleys (or OUL) have been featured in major articles in "Sports Illustrated", "On Earth", and "Missouri Conservationist"; on the editorial page of the "St. Louis Post Dispatch" and on the front page of the "Los Angeles Times"; and on National Public Radio's "Morning Edition" and "All Things Considered." The OUL has provided annual cave and karst educational tours that have been attended by federal and state personnel, college professors, and their students. These efforts have had long-term benefits and Tumbling Creek Cave, and actions implemented to protect it, have gained major public respect and support as well as national recognition. Respect ultimately results in help and cooperation from a multitude of sources.

Strategy 5. Work cooperatively with agencies and key people. In most cases the agency employees dealing with federally listed species are dedicated people who are committed to preventing extinction and facilitating recovery of federally listed species. Unfortunately, many landowners that agency employees encounter are likely to be fearful that having a federally listed species on their property will be a problem. Many agency officials have commented over the years how refreshing it is to meet private land owners who are committed to conservation of Missouri's rich biological diversity and advocate a strong environmental ethic. Landowners who want to improve habitat they own will find helpful and cooperative agency people who are likely to know of programs (i.e., both federal and state incentive programs) that can benefit both the species of concern and the landowner.

A landowner who has established his managerial credibility can greatly influence what improvements receive funding on his or her property. In the Recovery Plan for the Tumbling Creek Cavesnail (USFWS 2003), sediment deposition in the cave stream was identified as one of the major problems adversely impacting the Cavesnail. The Aleys received funding to plant about 75,000 trees along losing stream corridors on recently acquired eroding lands and to repair about 13,000 feet of eroding gullies and stream channels. Additionally, the Aleys receive annual payments to maintain the newly reforested corridors. These successful efforts have improved water quality in the cave, enhanced conditions for the Tumbling Creek Cavesnail, and increased the value of the Aleys property and their enjoyment of it.

Establishing and maintaining cooperation with a variety of partners including species experts is extremely important. In our society hardly anybody who makes significant accomplishments does it alone. One of the long-term key people in our conservation efforts has been Dr. Dave Ashley, a biology professor at Missouri Western State University. He has conducted population census work on the Cavesnail for over 20 years and his survey efforts were critical in providing baseline data that was instrumental in the Cavesnail being federally listed as an endangered species by the USFWS. Along with the USFWS, there are over 30 representatives of federal, state, and private entities who have been committed to the conservation of the Cavesnail and Tumbling Creek Cave for over 20 years. It is through the collective efforts of this cooperative partnership that the Tumbling Creek Cavesnail and its habitat will be recovered and enjoyed by future generations.

There are a number of things that a landowner can do that an agency cannot. For example, when the Cavesnail was proposed for federally listing as an endangered species the Aleys contacted local, state, and federal elected officials and asked them to support the listing on their property. A result was that there was no governmental opposition to the listing of the Tumbling Creek Cavesnail as an endangered species. On the other hand there are things that only agencies can do such as conduct environmental reviews under Section 7(a) (2) of the ESA that is undertaken by the USFWS. In the final analysis, establishing and maintaining cooperative resource management efforts involving agencies, landowners, species experts and other key partners and entities is clearly a critically important strategy.

Strategy 6. Manage what you have, target what you want, and creatively imagine what can be accomplished. The OUL has over 50 years of management history at Tumbling Creek Cave focused on protecting the cave and its environment. OUL cave conservation started with initial management actions that were of limited scale and relatively inexpensive. For example, to minimize unnatural airflow patterns in the cave, a system of airlock doors was constructed at and near the artificial entrance. If you do not do a good job of managing what you already control you will have limited credibility and opportunity to receive funding for conducting larger scale efforts.

One of the Aleys long-term priority goals was to ultimately own all land overlying the cave as well as key properties within the recharge area for Tumbling Creek Cave. In rural America much real estate comes on the market only once a generation, and sometimes not even that often. Commonly, the only time to buy a key tract of land is when it is for sale, and the window of opportunity is often very short. The timing is often difficult for a private land owner or a not-for-profit trying to acquire critical properties for protecting a cave and its fauna. Initially Tumbling Creek Cave was beneath three different properties. It took 35 years before all three overlying properties could be purchased.

Protecting caves and preventing extinctions requires flexibility in adapting to short-term opportunities and changing conditions plus a long-term view of likely characteristics of future conditions and resource management needs. Sound management today must give attention to creatively imagining the nature and role of sites like Tumbling Creek Cave in the future. A key part of protecting listed species into the future is managing them as valuable assets today. We urge landowners with habitat for listed species to adopt this management approach.

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The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

DEVELOPING MULTIDISCIPLINARY CAVE MANAGEMENT PLANS AT GREAT BASIN NATIONAL PARK, NEVADA

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Great Basin National Park contains 40 known caves, including Lehman Caves, with more than 30,000 visitors a year. Other caves in the park range from stream caves, vertical caves, high elevation caves with perennial ice, and caves with endemic biota. Federal land managers who manage cave and karst resources are tasked with developing management plans. At Great Basin National Park, upper management has directed resource management staff to develop two cave management plans: one for Lehman Caves and one for wild caves and karst. These plans are near completion.

Lehman Caves has been open for visitation since 1885. Three trail types have been built on top of one another and through cave pools; several lighting systems have been installed and abandoned in place; and over a million people have traveled through the cave, each leaving bits of lint or debris behind. The overall impacts of visitation is a cave with altered geology, impacts on cave biota, changes in natural air flow, impediments to natural water flow, and a decrease in the beauty of the cave.

Multidisciplinary meetings have been held for over a year with maintenance, interpretation, visitor and resource protection, administration, cultural resource, natural resource specialists, and tribal representatives. The primary goal of the Lehman Caves Management Plan is to manage the cave in a manner that will preserve and protect cave resources and processes while allowing for respectful recreation and scientific use.

The objectives of the plan are:

1. Provide high quality visitor experience including education and outreach.
2. Regulate or prohibit uses that would cause resource damage to cave systems.
3. Protect and preserve biodiversity.
4. Manage the cultural resources and cultural landscape.
5. Prioritize safety.
6. Design and utilize infrastructure that reduces maintenance, enhances longevity, and has minimal impact on the cave. Remove and repair past infrastructure damage.
7. Encourage, facilitate, and conduct high-quality scientific study of cave and karst resources.
8. Use partnerships and volunteer resources.

The multidisciplinary team developed desired future conditions for the cave. These include a cleaner cave with less lint; upgraded infrastructure that has less impact on the cave; additional interpretive opportunities such as a wild and virtual cave tours and distance learning; and more study and monitoring of the natural and cultural resources in the cave.

The park has applied for Southern Nevada Public Lands Management Act (SNPLMA) funding to accomplish many of these goals. It appears that funding is likely, which will allow the park to update the lighting system in the cave, to reduce the amount of non-native vegetation (algae) and enhance endemic cave biota populations. Improved lighting will also increase safety and enhance the visitor experience. Debris and lint coming into the cave will be reduced by installing grates and blowers outside the cave. Installing lint curbs in the cave will contain approximately 80% of the lint brought into the cave on the trail, making it easier to clean and reducing impacts to the cave. The park will also remove sections of the old trail and replace it with an elevated trail, allowing water to flow freely from pool to pool. Wildlife conservation will include bat monitoring and education, pre- and post-project invertebrate surveys, and climate studies. Improvements to the cave will help conserve cave resources and allow for sustainability over the next 50 years.

Figure 2. Lint is one of the biggest management concerns in Lehman Caves, as it can affect geologic, biologic, and aesthetic resources.

For the other 39 caves in the park, the Wild Caves and Karst Management Plan collates all known information about the caves

Caves are found in various locations throughout Great Basin National Park. Lengths of the caves vary from 30 ft. to about 11,000 ft. (Lehman Caves), the longest cave in the state of Nevada. The depth of the caves varies from 7 ft. (T-Cave) to 436 ft. (Long Cold), the deepest cave in the state of Nevada. Elevation of the caves varies from 6,736 ft. (Little Muddy) to High Pit (11,552 ft.), the highest cave in the state of Nevada. These caves are varied, with some intricately decorated (e.g., Lehman, Lehman Annex, Snake Creek), while some have practically no speleothems (e.g., Model, T Cave). About one-third of the caves require ropes for access. Several caves have water in them, while some are extremely dry, and some caves have both dusty areas and wet areas (e.g., Snake Creek).

The primary goal of the Wild Caves and Karst Management Plan is to manage the caves in a manner that will preserve and protect cave resources and processes while allowing for respectful scientific use and recreation in selected caves. More specifically, the intent of this plan is to manage wild caves in GRBA to maintain their geological, scenic, educational, cultural, biological, hydrological, paleontological, and recreational resources in accordance with applicable laws, regulations, and current guidelines.

The plan identifies data gaps, such as maps, biological, geological, cultural and paleontological inventories. It also recommends some management actions like better protecting caves with pictographs with interpretive components and incorporating a no-retardant drop area near caves with sensitive biota. A funding request to SNPLMA will be developed to accomplish these tasks.

The management plans have been useful to the park to take a step back and assess what is in place and what the desired future condition is. Using multidisciplinary teams helps improve buy in and creates a good environment to see the caves from many angles and be creative in solving the management challenges they face.

COOPERATIVE CAVE AND KARST MANAGEMENT AT BUFFALO NATIONAL RIVER, ARKANSAS DURING A PERIOD OF SHRINKING FEDERAL BUDGETS AND STAFFING

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Funding to federal land management agencies has been shrinking over the past 20 years. Simultaneously, the population of the United States and visitation to these protected areas has increased significantly. Emerging or accelerating threats to the viability of biological systems such as White-Nose Syndrome, and physical processes such as global climate change, increase the severity of the already tenuous situation for federal land managers. A very effective and efficient partnership between the National Park Service (NPS) and the Cave Research Foundation (CRF) has been evolving at Buffalo National River over the past 15 years. For the past 4 years, NPS and CRF have worked together through a Cooperative Agreement which allows NPS to provide seed money to accelerate work at the national river by CRF in cave and karst management assistance. Nearly 150 new caves have been documented by CRF during this brief period, a large percentage of the previously documented caves have received renewed documentation in the form of biological and cartographic surveys, and a group of strong cavers has coalesced around the project. This citizen science effort has vastly improved the ability of NPS to manage the cave and karst resources. This effort has provided cavers an opportunity to actively participate in their government by constructively improving the management of our public natural resources.

THE WILDERNESS UNDERGROUND OF BUFFALO NATIONAL RIVER

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The Buffalo National River contains approximately 500 documented caves. About 25% of these caves are within the Buffalo National River Wilderness. Wilderness designation and Wilderness boundaries are somewhat arbitrary and artificial in nature in that they are manmade contrivances over portions of the Earth. Caves, on the other hand, nearly always contain features and landscapes which intrinsically exhibit wilderness character. The extent of caves is difficult to define, their boundaries continue to change over time as new passages are discovered, entrances open or close naturally, and the waters feeding their hydrologic systems vary with hydrologic and atmospheric conditions. Cave wilderness designation at Buffalo National River has the potential to be used as a management tool, limiting land managers underground activities with little impact to non-wilderness surface activities where wilderness non-conforming activities can continue to be practiced, but with an eye toward conserving the wilderness character of the cave resources and values.

A COMPARISON OF LOW-COST 3D SCANNING TECHNIQUES APPLIED TO THE CAVE ENVIRONMENT

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The standard tool for characterizing cave passage position and morphology is the cave map, created using a line survey and hand-drawn sketch of cave walls and features. However, 3D scanning, often conducted with terrestrial laser scanners, is becoming increasingly common for applications in both cave management and cave science. The cost, size, and fragility of standard laser scanners limit the use of these devices to relatively well-funded projects within large and accessible cave passages. However, a variety of low-cost scanning techniques are also available, and these techniques are seeing rapid development by the computer science and robotics community. We argue that these low-cost techniques may have broader applicability within the cave environment, and may ultimately lead to a revolution in cave mapping. We review emerging technologies and algorithms and explicitly compare two of the most promising options: 1) Structure-from-motion photogrammetry, and 2) structured light sensors (RGB-D). Both technologies enable 3D scanning of cave passages using equipment that has costs comparable to standard cave survey equipment. These techniques are already sufficiently mature that they are being applied in studies of cave passage morphology and the processes of speleogenesis. Though substantial hurdles need to be overcome before these methods could provide a practical means of mapping caves, it is possible to envision a future where you map a cave by strapping a small device to your helmet and simply going caving.

Ecology-based cave and karst forest management recommendations and best management practices for working forests

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In 2016 The Tennessee Chapter of The Nature Conservancy (TNC) initiated a forest management project, Working Woodlands, targeting large (3000+ acres) privately owned tracts in Tennessee. The Working Woodlands project is designed to increase sustainable forestry in the region by employing preferred conservation-based silviculture techniques on these lands. This project enables landowners to offset the cost of potentially reduced forestry revenues by enrolling in the private carbon market.

Much of Tennessee consists of a significant karst landscape. Tennessee is known regionally as the cave state, containing over 10,000 known caves according to the Tennessee Cave Survey. With caves come other karst features such as sinkholes, sinking streams, swallets, springs, etc. The Tennessee Chapter of The Nature Conservancy performed an international review of forest management plans with karst considerations and found very limited consistency within those plans and almost no documentation of evidence to support management prescriptions and guidance.

Plans are written with a variety of circumstances, objectives, and resources in mind, so variability in plans is certainly expected and acceptable. However, without stated supporting evidence of guidance rationale and reasoning, implementers and future planners are likely to experience reduced acceptance and long-term implementation may suffer. Certainly, by including evidence-based rationale, planners will give significant resonance and increased buy-in to any plan.

With that being said, the landscape of research and literature specific to forestry conservation practices and techniques associated with karst features is limited. Through this project, TNC identified what is likely a well-known research gap, specifically in reducing erosion and sediment loss on karst as a result of forest management. There is considerable research, comparatively, on bat responses to silviculture, and some evidence of trogloxene foraging ranges significant to cave and karst ecology, as well as other evidence to support conservation of karst features. TNC used what supporting evidence it could find, along with existing karst-based forestry plans, to create forestry management recommendation on karst landscapes for the Working Woodlands Program.

The following guidance is designed to be part of a larger forest management plan, so a lot of generalized language and some definitions will be noticeably absent, as they are covered in the general forest management plan. This plan does provide supporting evidence when possible, but some recommendations for which we could not find sufficient evidence are inspired by other forest management plans, notably those created for the United States Forest Service-AZ (2015), British Columbia-Canada (2003), and Tasmania (2002). This

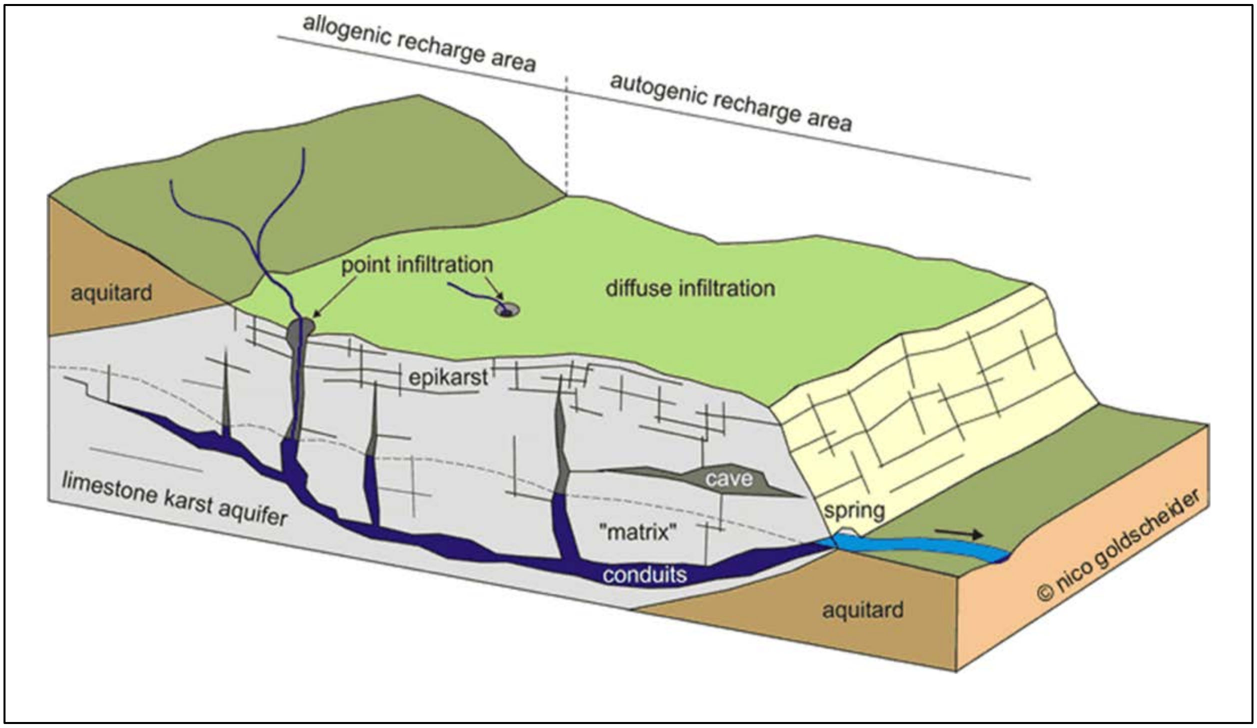

Figure 1. Typical features found with karst landscapes (Goldscheider and Drew, 2007).

document will be continually updated as new research and information become available and supported in scientific literature. TNC's Working Woodlands karst recommendations are presented here to support and provide evidence for conservation forestry recommendations on karst, and to raise awareness of the value of evidence-based management, and the leverage provided by documenting rationale within resource management plans.

Forest management considerations and best management practices on karst landscapes

Karst landscape/aquifer systems are formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum. Karst topography is characterized by underground drainage systems with sinkholes, caves, underground rivers, and large springs (**Figure 1**). Karst aquifers are often cavernous and can have very high permeability, resulting in groundwater that is, typically, highly vulnerable to contamination. This comes from high groundwater velocities, reduced opportunity for contaminants to be filtered, and the fact that sediment can be carried into and through the subsurface. Karst areas contain what are among the most environmentally sensitive of terrains and ecosystems, and among the most complex and least understood hydrologic and geomorphic systems (Veni, 1999). They therefore require specialized management considerations.

Karst systems are often typified by an overall reduction in surface water and a suite of topographic and geologic features specific to surface and groundwater interactions. These features include caves, sinkholes, sinking streams, swallets, and springs. The presence of these features on a landscape are often indicative of karst terrain and indicators of complex surface and groundwater relationships. Groundwater can move very rapidly through karst terrain, carrying contaminants and sediment with it.

Surface aquatic resource protection and erosional processes on non-karst terrains are generally well understood with existing guidance and acceptance from forestry professionals, such as widely implemented state Best Management Practices (BMPs). Karst terrains complicate water protection and erosion inhibition as water does not generally flow across the surface landscape following topography and creating surface drainage features. Karst terrains can be extremely variable and complex, but in general surface water travels underground having entered the subsurface either through diffuse infiltration or very often through discreet points where surface streams, often intermittent, sink into sinkholes and swallets. In contrast to most other groundwater, once water goes underground within karst terrains there less opportunity for filtering or other amelioration of contaminants; therefore, it is necessary to take extra precaution to prevent hazardous contamination and sediment loss in the first place.

Key objectives while conducting active forest management on karst landscapes include efforts to:

- Maintain the ability of karst landscapes to regenerate healthy and productive forests after harvesting
- Maintain the quality of surface and subsurface habitats of karst ecosystems to ensure biodiversity
- Maintain the natural flows and water quality of the impacted karst hydrologic systems
- Reduce soil erosion around karst features and into the subsurface
- Provide/maintain quality roosting habitat for bats
- Maintain the natural rates of air exchange between surface and subsurface atmospheres
- Manage and protect significant surface karst features (e.g., sinkholes, sinking streams, springs, and cave entrances) and subsurface karst resources (e.g., caves, underground streams, and subterranean fauna); and
- Provide recreational opportunities where appropriate.

Prominent Karst Features

As mentioned, there are a variety of features associated with karst landscapes and aquifers, each with unique considerations and risks for active management operations. The primary, and most frequently impacted features include:

- caves
- sinkholes
- swallets: where surface streams sink underground

A **cave** is generally considered any underground space large enough for a human to fit into. The National Speleological Society does not specify size limits for cave classifications. Caves can be horizontal or vertical in nature and even blind pits from the surface are considered caves.

Caves are incredibly unique habitats and can be home to a myriad of organisms. These can range from surface dwellers that exploit the cave climate to fully adapted animals who survive just fine in complete darkness and generally live nowhere else. Ecologically, caves are void of sunlight and are largely allelopathic, or dependent on external energy sources (Poulson and Culver, 1969). Those energy inputs come from sources including dissolved organic carbon seeping in through porous rocks, sinkholes and sinking streams washing in organic material, and trogloxenic organisms—or “part time” cave utilizers—such as bats and crickets foraging outside caves and bringing energy in.

Most North American caves do not have large populations of bats, however cave crickets are a reliable source of energy through guano deposition, eggs, and carcasses (Mohr and Poulson, 1966; Barr, 1967). Cave crickets are considered a keystone species for caves as they maintain cricket guano communities, egg predators, and provide dispersed energy inputs that increase biological diversity in caves (Lavoie et al., 2007). Cave crickets are vulnerable to changes within their foraging radius (Lavoie, 2007; Taylor et al., 2007) and impacts to crickets will have direct

Figure 2. River sinking into a karst aquifer at a swallet. In this case significant quantities of sediments, fecal bacteria and agricultural chemicals are being washed into the aquifer with little filtering or other attenuation. Photo by Chris Groves.

effects on cave ecology. Crickets are known to forage regularly within a 105m radius of cave entrances (Taylor et al., 2005). They are also extremely sensitive to changes in vegetation and microclimate (Studier and Lavoie, 1990), especially warming and decreases in relative humidity.

In addition, many caves do provide habitat for bats. There are 45 species of bats in The United States (Hammerson et al., 2017). These bats are among the most imperiled terrestrial vertebrates on the continent (Hammerson et al., 2017). 21 species of North American bats utilize caves as roost sites and many North American bats breed in the forested areas immediately surrounding cave entrances in the fall (Barbour and Davis, 1989; Dalton, 1985, 1987; Furey and Racy, 2015). Forest management considerations for bats should not be limited to caves and karst features, and should be addressed more generally in any forest management plan in a landscape with rare, threatened, or endangered bat species.

Sinkholes are natural, closed depressions found on the surface in karst landscapes. They are often semicircular in shape and are extremely variable in dimensions. Sinkhole sides range from gently sloping to vertical, and their overall form can range from saucer-shaped to conical or even cylindrical. Sinkholes are extremely variable in size ranging in area from just a few square feet to over 5 square miles in North America.

A **swallet** is a distinct area or hole into which a surface stream sinks into the karst aquifer (**Figure 2**). Swallets can be discrete features, within closed depressions, or beneath alluvial streambeds where water sinks incrementally through the sediment into fractures in the rock below as the stream flows along the channel. Swallets can be within sinkholes and are distinguished by being a much smaller point feature on the landscape, often, but not always, with a visible open space where water flows underground.

Sinkholes and swallets are considered significant components of a hydrologic system as they harbor great potential as contaminant and sediment loss zones. Surface water is generally captured within these features and once underground there is little to no process for filtration or other contaminant attenuation processes. Within

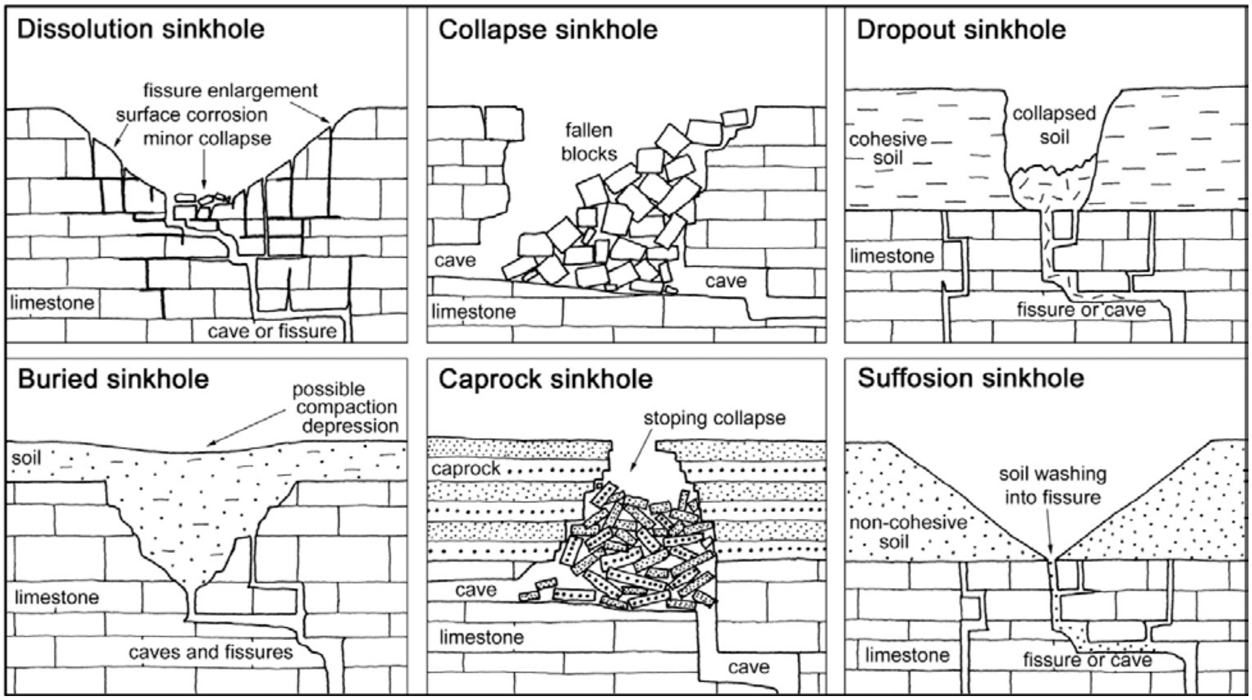

Figure 3. Sinkhole types from Waltham and Fookes (2003).

karst terrains, sinkholes and swallets are therefore critical points for aquatic resource protection. They are the interface where surface water becomes groundwater and are critical points for watershed protection.

Karst terrains also contain considerable "bonus" habitats that generally don't occur elsewhere. Sinkholes, swallets, and cave entrances are often refugia for a myriad of organisms seeking specific microclimate conditions provided by karst features (Batori et al 2012). These karst features often create habitat islands for remnant species. These same habitat islands and refugia may well provide added landscape resiliency in the face of changing climate conditions where the overall trend is increased temperature and/or decreased humidity (Batori et al 2014). In addition, the epikarst, caves, and myriad of underground spaces within a karst terrain provide additional habitat for a wealth of organisms specially adapted to these environments (Culver and Pipan 2009).

Waltham and Fookes (2003) along with many others have created classifications of sinkholes, generally based on geologic processional origin of the feature (**Figure 3**).

For the purposes of sustainable forest management operations, geologic derivation of the feature is less important and the concern is more with natural resource protection; specifically, potential for exacerbated erosion and functional ability to maintain natural karst feature microclimates. The following guidelines and best management practices should apply to all karst features to some extent but are primarily targeted at those with the highest environmental risk associated with forestry activities: caves, sinkholes, and swallets.

Best management practice recommendations for forest management on karst landscapes

Given the sensitive and unique nature of karst landscapes, appropriate, specialized Best Management Practices should be implemented. Analogous to Streamside Management Zones (SMZs) as part of common water quality BMPs, it is recommended that Karst Management Zones (KMZs) with additional surface protections be established where applicable. Below is a collection of non-regulatory karst BMPs designed to supplement current water quality BMPs in areas of karst topography. These recommended BMPs are designed to protect karst systems and limit impacts caused by surface disturbances.

General best practices for karst landscapes

The following practices are generally recommended when operating on karst landscapes and are designed to limit negative impacts resulting from forest management operations:

- Ensure that the activities of forest management do not result in observable siltation of karst features
- Minimize exposing mineral soil as much as possible and the potential for erosion of any exposed soil should be minimized through appropriate mitigation measures including seeding, mulching, and/or covering with slash
- Ensure that roads, skid trails, landings, and other similar silviculturally disturbed areas are constructed outside of KMZs
- Keep the wheels or tracks of equipment at least 25-feet from the slope breaks of karst features. If not possible, keep wheels or tracks parallel to the edge of features
- Soil erosion and siltation is a primary concern therefore mitigation measures such as placement of soil barriers, traps, dips, slash distribution, and others to reduce disturbance and siltation should be implemented. Take additional measures as necessary to correct inadvertent water diversions to prevent sediment transfer into subsurface environments
- Fell and transport timber away from karst features and drainages
- Restrict harvesting to periods when the likelihood of heavy rains and high runoff are low
- Avoid locating roads over sinking streams, noting that some of these may only be active during rain events or snow runoff
- Remove any slash and debris that falls in or around a karst feature, provided removal does not cause further soil or feature disturbance
- Leave understory vegetation along buffer boundaries and live trees in and around harvest areas to help maintain interior microclimatic conditions and inhibit the encroachment of edge species into the buffer
- Retain non-merchantable trees, snags, advanced regeneration, wildlife trees, and other native vegetation within the KMZs
- If previously unidentified karst features are encountered, modify or cease operations until the features or values can be assessed and risks mitigated
- Locate storage areas for fuel and other hazardous materials off karst terrain or at least on low vulnerability areas and in appropriate containers
- Avoid fueling or servicing machinery near surface karst features and take appropriate measures should a spill occur
- Take measures to ensure human waste, petroleum products, herbicides, litter, and other pollutants do not contaminate karst landscapes by following proper storage and transport procedures
- Invasive and exotic species can be managed within KMZs
    - Invasive tree cuttings, trees should be felled away from karst feature
    - Chemical applications should be a last resort and applied with extreme care

Measures for specific karst features

For well-developed karst features, such as those described above, additional mitigation measures specific to karst systems are recommended. Management guidelines are minimum recommendations and forest managers are encouraged to go beyond these when appropriate, especially in low karst density project areas. In well-developed karst landscapes, sinkholes can be so large that they are not easy to identify as karst features in the field. Topographic maps, digital elevation models, remote sensing, and LiDAR technologies can be very useful in defining sinkhole boundaries.

Sometimes landscape features may align with multiple management recommendations. Default management action should always be to the highest level of minimum protection recommended when a feature falls into more than one definable resource protection category. For example, if a swallet is within a small Class 1 sinkhole, with classes defined in Table 1 below, there will be management recommendations for both the swallet and the sinkhole. The swallet management recommendations may be more protective and will therefore supersede the Class 1 sinkhole management recommendations.

Caves. Given the overall significance of caves and cave entrances, the following minimum protection recommendations are prescribed:

- Maintain a minimum no-cut buffer extending 200 feet from cave entrances
  For buffers around entrances of caves known to contain significant bat hibernacula or maternity colonies, or threatened or endangered species, contact local U.S. Fish and Wildlife Service biologists for potential species-specific criteria for that micro-site

Sinkholes. Sinkholes can be extremely variable in nearly all aspects, thereby making definition of management considerations challenging. Additionally, karst development, sometimes measured by sinkhole density, varies greatly, often within a forest management unit. Indeed, above some well-developed karst aquifers there may be little or no surface expression. To find the right balance between appropriate resource protection and minimizing managed acreage loss the incorporated sinkhole classification system and associated management guidelines for sinkholes is recommended. This is designed to give the greatest specificity for landscapes with very high karst development, but can also be simplified for regions with lower sinkhole density or less sinkhole diversity. All karst landscapes should be treated with additional care and be considered as sensitive areas, as described in local forestry BMPs guidelines.

In order to classify sinkholes, it is necessary to calculate their depth to area or diameter to depth ratio. This is conducted to determine a relationship between the area of the sinkhole and its depth as an indicator of sinkhole characteristics and the sink's erosional vulnerability and micro-climate refugia status. Sinkholes with a depth to area greater than 33% (or <3:1 diameter to depth) are expected to be more vulnerable to erosion and more likely to create a micro-climate that serves as habitat refugia.

Table 1 below describes the three classes of sinkholes, with each having different management recommendations. Diameters are estimated as an average for the sinkhole opening measured from the discernable rim. Depths are to be estimated from the lowest point of the sinkhole "rim" to the lowest point of the sink. The rim of a sinkhole is not always a watershed divide, especially on well-developed karst on steep slopes. The rim is often an observable boundary defined by an obvious change in slope, surface expression or soil/rock stability. A sinkhole rim may be vertically separated, especially when a sinkhole is on

Table 1. Sinkhole class definitions.

Class	Description	Example
Class 1	• Traditional closed depression sinkhole of any shape • Less than 10 acres • Diameter to depth ratio >3	Diameter: 100' Depth: 32' Ratio: 3.1:1 or 3.1 (100/32) Therefore CLASS 1
Class 2	• Traditional closed depression sinkhole of any shape • Less than 10 acres Diameter to depth ration <u><</u>3	Diameter: 100' Depth: 34' Ratio: 2.9:1 or 2.9 (100/34), Therefore CLASS 2
Class 3	• Traditional closed depression sinkhole of any shape greater than 10 acres • Class 3 sinkholes often contain recognizable ephemeral stream courses ending in swallets	Larger than 10 acres Therefore CLASS 3

an extreme slope, or adjacent to a bluff or outcrop.

Like streamside management zones, karst management zones will often have Inner and Outer management zones with varying levels of activity allowed within each zone. The inner KMZ for Class 1 and Class 2 sinkholes extends 25 feet <u>from the rim of the sinkhole</u> in all directions. To maintain the integrity of the sinkhole, no harvesting is allowed in the Inner KMZs. The Inner margin of the sinkhole buffer should be located at the drainage divide, outside of which run-off will no longer flow into the sinkhole. That may not be practical for all projects, in which case the innermost boundary of the KMZ can be placed where the inflowing slope is 5 degrees or less.

An additional outer KMZ will be designated on CLASS 2 sinkholes. Harvesting in outer KMZs should be limited to single-tree and group selection, while maintaining at least 50 percent of the overstory. Roads, skid trails, landings, and other similar silviculturally disturbed areas are constructed outside of the outer KMZ, except when placement of disturbance-prone activities outside of the KMZ would result in more environmental disturbance than placing such activities within the outer KMZ. Outer KMZ's begin where inner KMZ's end. Inner and Outer KMZ minimum recommendations can be found in Table 2. Slope calculations in Table 2 for Outer KMZ widths <u>only apply upslope of the sinkhole being considered</u>. Erosional and microclimate risk associated downslope from the sinkhole rim is considered to be negligible.

Due to their larger size, Class 3 sinkholes have high potential for greater sediment loss and erosion. The highest level of consideration should be paid to road construction, ditch and stream crossings, skid trail erosion, log landings, closeouts, concentrated flow paths, etc. Chemicals such as hydraulic oil and/or herbicides should not be stored within Class 3 sinkholes unless sinkhole size and parcel dynamics prohibit storage elsewhere (Class 3 sinkholes can be hundreds of acres in size).

Class 3 sinkholes often contain swallets at their lowest elevation and the Class 3 KMZ recommendations will supersede swallet KMZ recommendations. Class 3 sinkholes should have a minimum Inner KMZ of 300' measured from the lowest elevation of the sinkhole in which harvesting should not occur. This may be one discrete point or it could be a larger area of relatively even elevation at the bottom of the sinkhole. Class 3 sinkholes do not require an outer KMZ if all other recommendations are met.

All recognizable ephemeral stream courses within, and leading to a Class three sinkhole should have SMZ's applied consistent with perennial streams for the region.

Swallets. Because swallets can be located within sinkholes, within stream courses, or as standalone features on the landscape, they will be managed for separately and in combination with other karst features. Care should be taken not to artificially direct runoff into a swallet. If a swallet is located within a sinkhole, whichever recommendation has the highest level of minimum protection recommended should be applied. Swallets should have an Inner KMZ of 50' and any recognizable stream course leading to a swallet should be treated as a perennial SMZ upstream of the swallet.

Karst features described should be buffered as summarized in **Table 2** below. Note, Class 2 buffer widths correspond with FSC Appalachian Region guidance for SMZ buffer widths.

Conclusion

The above management recommendations are designed as minimum thresholds for adequate resource protection specific to karst. Where possible, the included management recommendations are created from supporting literature. Where specific published evidence could not be found, this guidance is inspired by existing forest management plans specific to karst landscapes: notably Apache-Sitgreaves National Forest - Cave and Karst Management Guide (2015), Forest Sinkhole Manual (2002), and the Karst Management Handbook for British Columbia (2003). Overall, the collective literature available relating to karst features and karst landscapes provides ample evidence of the environmental vulnerability of karst compared to non-karst landscapes. Each surface karst feature is a portal that represents an imaginary line between surface water and groundwater and the surface and subsurface habitats. This interaction represents the simplest perception of karst vulnerability and reasoning for increased resource protection. Karst landscapes are inherently complex and associated hydrology can be extremely hard to define. These management recommendations are generalized conservation minimum practices for any karst landscape. In landscapes with less karst development and/or fewer karst features, implementers are encouraged to expand these recommendations.

Table 2. Karst management zone buffers. Measurements are from the lowest point or elevation.

Karst Management Zones – Minimum Buffers						
Feature	Inner KMZ	Outer KMZ (<10% slope)	Outer KMZ (<20% slope)	Outer KMZ (<30% slope)	Outer KMZ (<40% slope)	Outer KMZ (>40% slope)
Cave	200'	N/A	N/A	N/A	N/A	N/A
Class 1 Sinkhole	25'	N/A	N/A	N/A	N/A	N/A
Class 2 Sinkhole	25'	55'	75'	105'	110'	140'
Class 3 Sinkhole	300'	N/A	N/A	N/A	N/A	N/A
Swallet	50'	Perennial SMZ	Perennial SMZ	Perennial SMZ	Perennial SMZ	Perennial SMZ

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THE DESIGN CONCEPT BEHIND THE NEW LED LIGHTING SYSTEM AT CARLSBAD CAVERN, NEW MEXICO

Rodney D. Horrocks[1]

[1] *Carlsbad Caverns National Park, Carlsbad, NM, USA*

The new LED lighting system at Carlsbad Cavern was designed to highlight individual features, a different concept from the previous 1975 Ray Grenald design. His design used warm and cool lights to accentuate depth with much of the cave dimly lit in order to stimulate the imagination of the visitors. This gave visitors' eyes time to relax and generate anticipation for a handful of more brightly lit features. With the new design, the cave was divided into 145 named scenes, with a scene defined as a feature that was easily separated from adjacent scenes. Light was used to accentuate and dramatize an already spectacular cave in an artistic rendition, a process known as "painting with light." By using texture, color, shadow, and contrast, features were highlighted for which the cave is famous: huge chambers, large formations, profuse decorations, and complex mazes. A sense of mystery was intentionally evoked by creating black holes in numerous side passages and pits. Many highlighted features (30%) were not lit in the previous lighting system. In order to maintain one foot candle of ambient light on the trail, some features in the vicinity of the trail were lit. However, in order to protect delicate cave resources, other features within reach of the trail were intentionally not lit. Additionally, the "crazy" lights in the cave were all eliminated: those lights that had to be accessed by rope, long ladders, or exposed traverses. It is now possible to adjust the intensity of each LED light from 0-100% and the color temperature from 1800-4000 K from the comfort and safety of the trail through a radio controller and ruggedized laptop. The color temperature used most often in the new system, especially in wet areas, is between 2600-2700 K, which has been found to discourage, but not eliminate, algae growth.

DEVELOPING CAMOUFLAGING TECHNIQUES FOR THE NEW CAVE LIGHTING SYSTEM AT CARLSBAD CAVERN

Rodney D. Horrocks[1]

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In 2016, a new LED cave lighting system was installed in Carlsbad Cavern. Prior to any work being done, a camouflaging plan was developed to disguise the cables and fixtures in this new system. The black cables contrasted against the lightly-colored cave surfaces and artificial straight lines attracted visitors' attention to those cables. Although colored mortar was successfully used to hide the cables in the previous lighting system, that technique caused unacceptable impact to cave resources and was not even considered as an alternative for the new system. The new camouflaging techniques use local sediment, loose rock, or previously broken formations in order to not introduce foreign materials to the cave ecosystem. Techniques developed include: painting cables located further from the trail with a local sediment slurry, burying cables where possible, using blast rubble along rock walls, using broken formations or loose rocks to cover cables, and in some cases rerouting cables to more effectively use shadows and cracks. Because there is no single camouflaging technique that worked in every situation, multiple techniques were used on most cable runs. In addition to disguising the cables, the camouflaging project also placed fixtures in dimly lit areas to reduce visual impact. Specially fabricated shrouds were placed in the snoot of each fixture to reduce visibility glare, with the goal of visitors' eyes being naturally drawn to the highlighted features and not distracted by being able to see into the lights. If visitors wonder where the light comes from, upon searching they will be able to find the unobtrusive fixtures in ambient low-light conditions. The success of the on-going camouflaging work is directly attributable to Lois Manno and her volunteer work groups from the Sandia Grotto of the National Speleological Society.

BRANDENBARK™, A MANAGEMENT TOOL FOR BARK ROOSTING BATS

Gregg Janos[1], Zachary Baer[1], Mark Gumbert[1], Joshua Adams[1], Piper Roby[1], Price Sewell[1], Richard Borthwick[1], Lois K. Baer[1], and Michael Brandenburg[2]

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Multiple imperiled bat species utilize cave and karst features during the winter months as hibernacula; however, during the summer months these bats leave their hibernacula and utilize tree bark roosts. As a result, summer habitat enhancement can prove to be an important tool in assisting populations of bark roosting bat species, especially those with low population numbers and/or those impacted by White-nose Syndrome. BrandenBark™ is an artificial roost structure developed to mimic the natural summer habitat of bark roosting bats. BrandenBark™ structures have documented use by six bat species, including the federally endangered Indiana Bat. Within a study site at Fort Knox, Kentucky, BrandenBark™ structures were used to supplement degrading habitat used by Indiana Bats. Subsequent monitoring efforts at Fort Knox have documented bats regularly utilizing BrandenBark™ structures with 77.2% of roost visits confirming bat presence and 72.7% of the structures having confirmed use within three months of installation. BrandenBark™ average emergence counts compare favorably with the United States Fish and Wildlife Service's average adult maternity colony size estimates in natural roosts. The second highest Indiana bat maternity emergence count has been recorded from BrandenBark™ (n=451), compared to the highest known natural roost exit count of 475. Overall, Indiana Bat use of 13 BrandenBark™ structures has resulted in a total of 248 bat days. Temperature stability tests show the temperature difference between ambient air and real bark was not different than the temperature difference between ambient air and BrandenBark™ ($F_{1,5}$ = 0.0489, P = 0.8338). BrandenBark™ has been deployed as a mitigation/habitat enhancement tool by federal and state agencies as well as private organizations to provide immediate, long-lasting roosting habitat for imperiled bark roosting bats that rely on karst features in winter. To date, 181 BrandenBark™ structures have been installed in eight states and one Canadian province.

ONLINE PERMITTING OF CAVE PRESERVE VISITORS TO ENHANCE VISITOR EXPERIENCE, MANAGE RISK AND INFORM CONSERVATION EFFORTS

Ray Knott[1]

[1] *Southeastern Cave Conservancy, Chattanooga, TN, USA*

The Southeastern Cave Conservancy, Inc. manages 31 cave preserves in six southeast states. All but two of these preserves are open for recreational caving. Prior to the implementation of the online permit system, it was difficult to 1) quantify the number of preserve visitors to each preserve, 2) fully utilize liability releases as part of an overall risk management strategy, and 3) understand the impacts of visitation on sensitive sites. Visitation numbers were anecdotally reported via volunteer preserve management teams and liability releases, if completed, were stored in electronic and hard-copy formats in various locations. Additionally, the organization did not have contact information for preserve visitors beyond the permit holder. With input from stewardship volunteers, staff began designing an online permit system which would formalize permitting on all preserves managed by the Southeastern Cave Conservancy, Inc. Using a database application designer and open source tools, the online permit system was completed and tested on two preserves over a three-month period in the Fall of 2016. The online permit system went live system-wide on 1 January 2017. Since implementation, the online permit system has issued 1,813 permits for 7,361 preserve visitors. The organization now has visitation data to compare to observed changes on preserves and in caves. These data will help guide stewardship decisions based on visitation levels at individual sites. The system allows for each preserve or site to have custom visitation parameters and approval procedures. Individual preserve management plans can be adjusted to ensure visitation does not cause undue harm to sensitive sites while maintaining a mission-driven objective to provide for recreational caving in a responsible manner. In addition to obtaining stewardship goals, the online permit system has allowed the organization to collect liability releases from all preserve visitors and to increase its audience for mission-based communications and donor solicitations.

KARST CONSIDERATIONS IN THE SITING OF INTERSTATE UTILITY CORRIDORS: EXAMPLES FROM TWO MAJOR NATURAL GAS TRANSMISSION PIPELINES PROPOSED TO CROSS WESTERN VIRGINIA

William D. Orndorff[1], Thomas E. Malabad[1], and Katarina Kosič Ficco[1]

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In 2014, companies proposed the construction of 42” diameter pipelines, the Dominion Energy Atlantic Coast Pipeline (ACP) and the Mountain Valley Pipeline, LLC (MVP), to move natural gas at pressures up to 1440 psi from production wells tapping the Marcellus and Utica shales beneath the Allegheny Plateau to the US eastern seaboard, crossing karst regions of Virginia and West Virginia on the way. Karst quickly emerged for both geotechnical and environmental reasons as

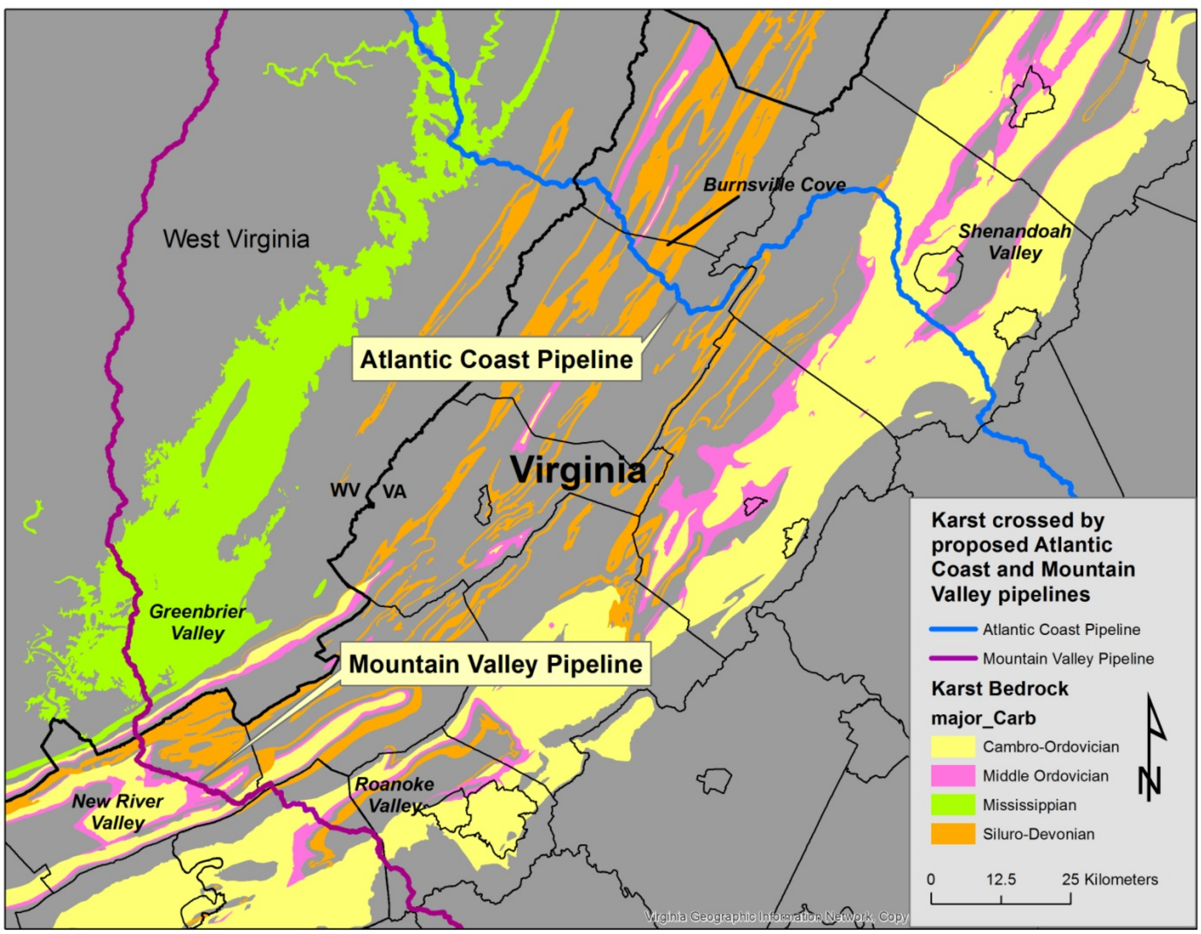

Figure 3. Gas transmission lines proposed to cross karst topography in the Virginias (Weary and Doctor, 2014)

a serious concern to both projects during the National Environmental Policy Act (NEPA) process and development of the Environmental Impact Statement (EIS) by the Federal Energy Regulatory Commission (FERC). Efforts by the companies and state and federal regulators have focused on avoidance and mitigation measures, including emergency response planning. **Figure 1** shows the two pipeline corridors where they intersect karst areas. In Virginia, the ACP crosses karst developed in Siluro-Devonian and, to a lesser extent, middle Ordovician limestones in Highland and Bath counties, and in the karst of the Cambro-Ordovician carbonate strata of the Shenandoah Valley. MVP crosses karst developed in middle Ordovician limestones in Giles County and in a broader sequence of Cambro-Ordovician carbonates in Montgomery County. Both pipelines cross karst areas developed in Mississippian, Siluro-Devonian, and/or middle Ordovician limestone in West Virginia.

Review for potential impact to karst resources at the state level in Virginia was coordinated by the Department of Conservation and Recreation Natural Heritage Program, which worked in conjunction with the Cave Board, a governor appointed board established by the Virginia Cave Protection Act of 1979, and the Virginia Speleological Survey, an internal organization of the National Speleological Society that manages Virginia's cave data. Specific emphasis was placed on limiting impacts to caves designated as State Significant under the Cave Protection Act, caves known to host populations of rare cave invertebrates, and caves associated with legally protected species, including bats. All areas where land disturbance could reasonably be expected to impact such caves are incorporated into conservation sites, which function both as red flags for proposed development projects and as a focus of conservation efforts.

Concerns over more general potential impacts to karst from the pipelines raised by the Cave Board and DCR focused mainly on the construction and maintenance components of the projects. Specific areas of concern identified were:

1) Erosion and sediment control. The primary concern was erosion of karst features and discharge of sediment to karst systems along and receiving runoff from the pipeline corridor.
2) Hazardous material spills discharged to karst. The potential for fuel and other chemical spills to enter karst systems are a concern with any construction project on karst terrain. Contamination in 2015 of a karst spring serving as a public water supply to Peterstown, WV was attributed to the release of diesel fuel to a sinkhole on Peters Mountain during construction of an industrial natural gas supply line.
3) Horizontal direction drilling. Horizontal directional drilling beneath the New River during construction of the Duke Energy Patriot Pipeline resulted in loss of drilling fluid that rose to the surface both within the bed of the New River and in the floodplain in New River Trail State Park.
4) Disposal of hydrostatic test waters on karst. Construction of temporary basins to contain hydrostatic test waters induced significant subsidence on a farm in Wythe County, VA during construction of the Patriot Pipeline.
5) Intersection of buried karst features and associated subsidence within or adjacent to the pipeline trench. Construction of the East Tennessee Natural Gas Company's Jewell Ridge Pipeline in 2006 in Tazewell County, VA, intersected an approximately 50' deep pit within a conservation site with globally significant biodiversity due to cave fauna.

The Virginia Cave Board was established under the Virginia Cave Protection Act of 1979 and tasked with the responsibility of advising state agencies and other stakeholders on cave and karst related issues. The Board (Virginia Cave Board, 2015) produced a Frequently Asked Questions (FAQ) document and posted it on their website to help address citizen concerns over the proposed projects potential impacts to karst. The Board met in spring of 2015 with representatives from Dominion Energy to advise them on karst issues and to learn from Dominion more about the construction and operation of natural gas pipelines, as well as the complicated process of selecting a route and obtaining appropriate permits and authorizations.

Geoconcepts Engineering (Ashburton, VA) was contracted by ACP and Draper Aden Associates (Blacksburg, VA) by MVP to address karst issues, both companies possessing significant expertise and experience in karst. The primary strategy for each project was the identification and avoidance of sensitive karst features and more broadly DCR Natural Heritage conservation sites associated with karst resources. Each company used a similar approach to screen for and evaluate karst features:

1) Desktop review for documented cave and karst features within ¼ mile of the project corridor centerline and areas intersecting or receiving runoff from temporary work spaces, including access roads and ancillary work space (e.g. laydown yards for temporary staging of materials and equipment.) This review included coordination with state cave surveys in addition to published sources and a variety of geospatial and remote sensing data.
2) Field surveys within 300' wide construction corridor and temporary work spaces.
    a. Verification and characterization of features identified during desktop review.
    b. Documentation and characterization of previously unknown karst features.
3) Performance of geophysical surveys to characterize karst in the shallow subsurface. Electrical resistivity surveys were performed along the centerline for the ACP wherever it crosses karst, and for selected areas of intense karst development along MVP.
4) Sensitivity ranking of features identified in steps 1 and 2 to facilitate prioritization of avoidance and mitigation measures.

The methodology is described in detail in the "Karst Terrain Assessment Construction , Monitoring, and Mitigation Plan" for ACP (Geoconcepts Engineering, 2017a) and the "Karst Mitigation Plan" for MVP (Draper Aden Associates, 2017a.) Results of the desktop and field surveys were compiled in the "Karst Survey Report" for ACP (Geoconcepts Engineering, 2017b) and the "Karst Hazards Assessment" for MVP (Draper Aden Associates, 2017b.). Each of these documents went through multiple iterations as proposed routes changed and methodologies were refined, are on file with the Federal Regulatory Commission. The most recent versions are available upon request from the author. The karst mitigation plans also address circumstances in which avoidance of conservation sites or karst features was not possible due to other routing constraints.

For ACP, Geoconcepts Engineering divided karst features in those with high potential impacts to groundwater (including caves, open throat sinkholes, and sinking streams) and those without (flat-bottomed or stable sinkholes, karst springs.) Draper Aden Associates assigned karst features along the MVP corridor ranks of minor, moderate, or major potential for environmental impacts. No clear criteria for these risk ranks were defined. However, they appear to be similar to those used by Geoconcepts on ACP, and adjustments were made so that the final MVP route intersects no features deemed to have a major potential for impact. Throughout the process, consultants for both pipelines maintained close contact with and provided information on surveys to VA DCR and the state cave surveys.

Recognizing that undocumented karst features are likely to be uncovered during construction, karst mitigation plans for each pipeline include explicit procedures for addressing any such features, including coordination with VA DCR. Mitigation plans for sinkholes formed within the project limits of disturbance during construction and operation involve a combination of characterization and stabilization using some variation of an inverted filter design. Furthermore, procedures for preventing discharge of sediment or chemicals from project corridors to new or existing features are outlined in the respective karst mitigation, erosion and sediment control, and spill prevention, control, and countermeasure (SPCC) plans.

In the three years from project inception until issuance of the Environmental Impact Statements by FERC, both pipelines explored multiple potential corridors in search of routes that would be approved through the NEPA process. MVP has gone through six major corridor revisions, while DCR has seen at least ten variations for the ACP route. Karst was but one of many environmental, cultural, and political issues that were involved in route selection and review. However, both major and minor corridor adjustments were made at least in part to concerns raised over impacts to significant cave and karst resources. Early proposed routes for MVP were modified to avoid the Clover Hollow and Pig Hole Conservation Sites. Access roads proposed to cross the Burnsville Cove Conservation Site were moved to avoid potential discharge from ACP to the Butler-Sinking Creek and Chestnut Ridge cave systems. Numerous minor route adjustments were made on both projects to reduce potential impacts to a karst area in cases where total avoidance was not possible. For example, in Giles County the MVP corridor was rerouted around both state significant Canoe Cave and the newly discovered Eight Second Cave. Within the Slussers Chapel Conservation Site, the corridor was revised multiple times to reduce impacts to karst resources. For the ACP, detailed geophysical and dye trace studies were performed in the Cochrans Cave Conservation site resulting in route modifications to minimize potential impacts. Dominion made other reroutes for ACP in Bath and Highland counties in an effort to further reduce potential impacts to karst. In several cases on each pipeline project, the potential for reroutes was severely constrained by non-karst factors.

While both projects did an exceptional job in documenting, avoiding, and protecting karst features along the proposed corridors, there remains room for improvement. Sinking streams crossed by corridors upstream of their sinkpoints were not always recognized. In addition, there was difficulty in documentation of flow paths within karst systems receiving contaminants should protective measures fail, information critical for emergency response and spill recovery planning. Existing dye tracing data was considered in emergency response planning, but, with the exception of Cochrans Cave, no new dye tracing was performed during the NEPA process. This situation was a result of both the incomplete nature of the state's karst hydrology database and the provisions of Virginia law (COV 56 – 49.01,) which provides right of entry to properties under consideration for natural gas infrastructure installation, but not to offsite down-gradient areas where springs, wells, and cave streams necessary for dye trace studies would be found. Both VA DCR and the Department of Environmental Quality raised the issue of inadequate hydrological delineation through the state environmental review process. However, the Final Environmental Impact Statement (FEIS) issued to each project in summer 2017 by FERC granting conditional approval did not require any additional dye traces.

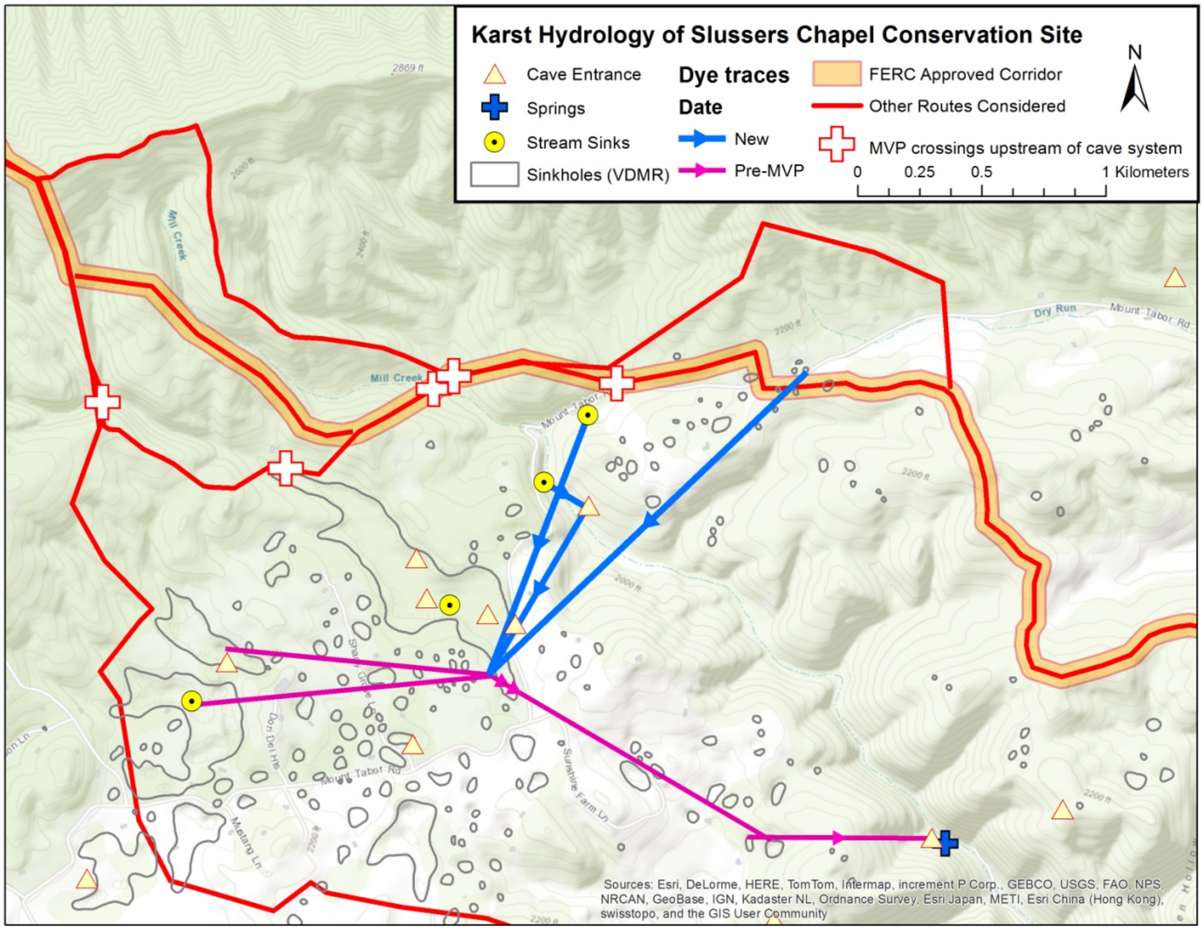

Figure 4. Karst hydrology map of Slussers Chapel Conservation Site showing various iterations of MVP corridor (Pre-MVP traces from Fagan and Orndorff, 2008.).

A case in point is where MVP crosses the Slussers Chapel Conservation site in Montgomery County. Early versions of the project passed through the western side of the Conservation Site, which included two blind valleys that prior dye traces (Figure 2) had shown connected to the two state significant caves in the conservation site, Slussers Chapel Cave owned by the Cave Conservancy of the Virginias and Mill Creek Cave owned by the Nature Conservancy. In part to avoid these blind valleys, the route was moved to the eastern side of the conservation site. Because water flow in the caves exceeded that from the aforementioned blind valleys, DCR suspected significant water contribution from the eastern portion of the conservation site as well. Supported by a grant from the Cave Conservancy of the Virginias to the New River Land Trust, DCR dye traced two previously undocumented sinking streams, a newly discovered cave, and a sinkhole along the MVP corridor to the Slussers Chapel-Mill Creek system (Figure 2.) Note that the modified routes cross multiple stream crossing just upstream of sinkpoints, and pass over sinkholes draining into the system. The initial reroute proposed included five stream crossing upstream of such sinkpoints. An additional modification eliminated two of these crossings from the FERC approved corridor.

As part of the Clean Water Act Section 401 Permit process, Virginia DEQ requested that the companies conduct further dye trace studies along sections of the corridors where existing data is insufficient. Geoconcepts is performing these traces for ACP, while MVP has funded VA DCR to perform traces along its corridor. Preliminary investigations by DCR in karst areas crossed by the MVP corridor have identified previously undocumented springs and sinking streams, further underscoring how the lack of pre-existing karst hydrological data makes it difficult to predict and reduce environmental impacts when siting utility corridors.

Karst issues emerged as a major concern to stakeholders expressing concerns over the pipeline projects, including conservation groups, local governments, and citizen stakeholders. The word "karst" appears at least once in 718 individual documents file with FERC in relation to the MVP pipeline, and in 679 documents related to ACP. A detailed review of these documents is beyond the scope of this article, but interested readers may access them online at the FERC Docket search website: https://elibrary.ferc.gov/IDMWS/search/fercgensearch.asp. Docket numbers are PF 15-6 and CP 15-554 for the Atlantic Coast Pipeline and CP16-10-000 for the Mountain Valley Pipeline.

A majority of these documents cite karst as one of the main reasons the pipelines cannot be built across the Appalachian Valley and Ridge. Over two thousand miles of natural gas transmission pipelines already cross karst landscapes in KY, TN, WV, and VA alone, yet it is difficult to find documentation of karst-related failures or environmental impacts. However, some filings with FERC pointed out that relatively few of these existing lines cross the Valley and Ridge, where the combination of topography and karst may render portions of the proposed corridors particularly problematic (Kastning,). Finally, ACP and MVP are both larger diameter and higher pressure than the vast majority of existing gas lines on karst in the region, and any catastrophic line failure could be expected to produce proportionally greater impacts.

Relative to other utility corridor projects in Virginia, unprecedented attention has been given to karst issues associated with the Atlantic Coast Pipeline and Mountain Valley Pipeline during federal (NEPA) and state (VA-DEQ) permitting processes. The karst mitigation plans and surveys performed for these projects have established a new standard to which future projects in the state should be held. The difficulty in planning caused by a lack of karst hydrological data in much of the project area would be best addressed through the allocation of resources necessary for proactive hydrological delineation of karst systems in western Virginia.

Acknowledgements

DCR acknowledges the generous financial support of the Cave Conservancy of the Virginias and the New River Land Trust in performance of dye trace studies to delineate groundwater basins in the vicinity of the MVP pipeline.

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Cave Research Foundation: Cave and Karst Management in the Buffalo National River

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The Buffalo National River flows freely from west to east for roughly 135 miles and is one of the few remaining undammed rivers in the lower 48 states. The river was brought into the National Park System in 1978, providing over 94,000 acres and offers floating, hiking, camping, and other outdoor activities for people of all ages. The Buffalo National River is home to over 500 cave and karst features, including lengthy caves, small shelters, pits, and more. The Cave Research Foundation (CRF) has worked for decades in the Buffalo National River under a scientific research and collecting permit. The purpose of the CRF work in the Buffalo National River is to provide baseline data on caves and other karst features within the park boundaries. Included in this task are the location of caves, cartographic surveys, and baseline biological monitoring, with a special emphasis on monitoring for White Nose Syndrome. In order to maintain easily accessible and searchable records of the many cave and karst features contained by the Buffalo National River, a sophisticated, yet broadly comprehensible database was created initially populated by existing, historic records and files. It is regularly updated with new and enhanced information. This poster details the ongoing work by the CRF in the Buffalo National River and provides details for salient discussions among conference-goers.

THE EXCAVATION OF CAVES FOR EDUCATION

Drew R. Thompson[1]

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In 2013 Dr. Nico Hauwert of the City of Austin's Watershed Protection Department created a team of seven cave specialists to oversee and coordinate the restoration and studies of the city's caves and karst lands. Among many other duties, the cave team excavated and restored caves and other karst features to create underground classrooms for the Watershed Protection Department's Education Outreach Program. Historically, the majority of caves and sinkholes in Austin and surrounding areas were filled in by landowners and developers to dispose of trash and debris, reduce public trespassing, and to protect livestock. By removing the trash and fill from the caves and features, it gave us the opportunity to improve recharge and educate the public about the ecosystem and the function of the aquifer and what we can do to protect it. Now the caves are being utilized by many educators to expose more than 3,000 patrons a year to this sensitive and complex natural resource. With the reopening of these caves, we now face the challenges of preservation and management.

PLUGGING THE MANAGEMENT HOLES IN KARST ENVIRONMENTS

Teresa A. Turk[1]

[1] *Teresa Turk Enterprises, Fayetteville, AR, USA*

In 2012, a large swine Confined Animal Feeding Operation (CAFO) was approved for a Regulation 6, NPDES permit by the Arkansas Department of Environmental Quality (ADEQ) located six miles upstream of the Buffalo National River (BNR) at Carver. The facility called C&H generates almost 3 million gallons of untreated swine waste annually that is spread on many fields adjacent to Big Creek, the fifth largest tributary of the BNR. Currently ADEQ did not renew the Regulation 6 permit but is now considering granting a Regulation 5 state permit. During the public comment period, ADEQ received over 20,000 comments by citizens heavily in favor of not granting the permit. The presentation will roll back time to 2012 prior to C&H's regulation 6 permit approval and proved recommendations to ADEQ for a revised permit approval process. Many of the recommendations are current requirements and procedures used by other states and will be focused on rural areas with karst geology.

SHARING GIS DATA LAYERS DEVELOPED FOR UNITED STATES GEOLOGICAL SURVEY REGIONAL WATER-AVAILABILITY STUDIES

Drew A. Westerman[1]

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The U.S. Geological Survey (USGS) Water Availability and Use Program is conducting an assessment of water availability throughout the United States to gain a better understanding of the status of our water resources and how changes in water use and climate may affect those resources. Through this effort, multiple layers of Geographic Information System (GIS) data are created to aid in the development of surface-water and groundwater models that represent a resource of interest. The produced GIS data are standalone products and can be used in other projects and to help guide resource-management decisions. Examples of GIS data include the hydrogeologic framework that contains the altitude and thickness of units within regional aquifer systems, county-level water-use data, geophysical profiles of soil conductivity, and potentiometric surfaces of wells screened in an aquifer. The USGS can quickly disseminate the GIS data using customized web applications or the USGS ScienceBase platform.

How to upgrade to an LED cave lighting system for under $40,000

Michael E. Wiles[1]

[1] *Jewel Cave National Monument, Custer, SD, USA*

The lighting system of Jewel Cave's half-mile Scenic Tour route has remained virtually the same since the first tour in May 1972. In recent years, technology has matured to the point that an upgrade to LED lights can be accomplished without major renovation, or replacement of the system. Beginning in 2014, the park's maintenance staff began upgrading switches, wiring, and fixtures. This year, most of the 129 incandescent bulbs were replaced with comparable LED screw-in bulbs. The remaining bulbs and 6 mercury vapor lamps will be replaced this winter. The project is being conducted with the goal of keeping things simple, so that the lighting system will be as "bomb proof" as possible. Thus, it does not include high-end bulbs or remote computer control. It will reduce energy consumption and heat input by 80%, and reduce the frequency of changing bulbs. When completed, the upgrade will cost around $35,000 including all labor and materials.

POLICY COMMUNICATION AND THE IMPACT OF AGRICULTURAL COMMUNITIES ON KARST LANDSCAPES: AN EXAMPLE FROM PHONG NHA-KẺ BÀNG NATIONAL PARK, VIETNAM

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Karst landscapes are vulnerable to human influence, especially agricultural development. Interconnectedness between surface activities and subsurface environments make karst landscapes especially susceptible to soil erosion and water contamination. The likelihood of these two phenomena happening increases when agricultural intensification, irrigation, or fertilizer application occurs. In order to mitigate the negative consequences of agriculture on karst landscapes, increased implementation of policy to regulate human activities and increased communication of these policies is needed. This study occurred in Phong Nha-Kẻ Bàng National Park, Vietnam, a UNESCO World Heritage site dominated by the oldest karst landscapes in East Asia, extensive agricultural communities, and mediocre success in protecting its karst terrain. Interviews, observation, and GPS analysis were used to analyze the effectiveness of policy communication and karst protection in the Park. It was found that karst protection policy in the region is minimally communicated and, when communicated, often delivered in the wrong way to the wrong individuals. Despite the known harm agriculture causes to karst landscapes, intensification, irrigation, and the use of fertilizers still occurs frequently and is often supported by government officials. Policy and karst landscape information is concentrated among park officials and rarely presented in an informal setting, leaving those in most frequent contact with the karst landscape—the farmers—without any information on the vulnerability of karst terrain to agriculture and the subsequent impacts on human and biological health. In analyzing the situation in Phong Nha-Kè Bàng, general conclusions on policy to protect karst terrain in agricultural regions can be drawn. The communication of karst science and the implementation of policy to protect the landscape must be presented both formally to governing officials and local representatives and then passed down through informal networks to general citizens. Through these means, karst protection can successfully be implemented.

GEOLOGY AND HYDROLOGY

CASTING PEARLS BEFORE SWINE 2017: HOW PUBLIC REVIEW AND ANALYSIS OF AN INDUSTRIAL HOG FARM'S PERMIT WILL PROTECT THE WATERS OF AMERICA'S FIRST NATIONAL RIVER

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The citizens of Arkansas and the United States have spoken loudly and forcefully to the Arkansas Department of Environmental Quality (ADEQ) about their efforts to perpetuate a poorly designed and implemented permit for a Large Confined Animal Feeding Operation (CAFO) near the Buffalo National River. The initial permit was issued in December 2012 with the facility starting operation in June 2013. The phosphorus content of the facility's waste stream is equivalent to that of a town of 28,000 people. The waste is initially stored in earthen ponds lying upon mantled karst. It is then spread, untreated, on a series of fields, almost all of which are developed on thin soils over karst. The karst under the ponds and fields drains to the Buffalo National River. Buffalo National River is managed by the National Park Service. The Buffalo National River is intensively used by fishermen, swimmers, canoers, kayakers, and hikers from all over the U.S., and many foreign countries. The initial permit and all subsequent modifications display numerous weaknesses. The public has been quite vocal on this issue, and has raised numerous complaints, filed administrative appeals, and filed lawsuits. The latest iteration of the permit has been held up in the administrative process at ADEQ for six months, and will likely be held up for another six months. Meanwhile, the facility is being allowed to operate on a permit which expired in October 2016. This is a case study showing how citizen engagement can counteract, at least partially, lax agency regulatory efforts, misguided political lobbying, and poor environmental implementation to protect a national treasure.

MORPHOLOGICAL INVESTIGATIONS OF CAVERNOUS HYDROTHERMAL FEATURES WITH AN EMPHASIS ON YELLOWSTONE NATIONAL PARK, WYOMING

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Morphological investigations of hydrothermal features were performed throughout the western United States where tectonic and volcanic activity have affected groundwater circulation by geothermal convection. The fluid geochemistry and hydrogeology of most inspected features have resulted in an integrated mass-transfer system with permeability structures dominated by caverns and conduits, and self-organized to facilitate the movement of ascending thermal waters as a process known as hypogene speleogenesis. The greatest numbers of these features are found in Yellowstone National Park, where caverns have developed in mostly siliceous material from the dissolution of quartz by thermal fluids. Caverns in calcareous material are most common outside the park and formed as thermal fluids cooled. Due to limitations of boiling thermal fluids, most of the cavernous hydrothermal features inspected were shallow and limited to the terraces of sinter deposits. However, a few cooler features were examined by visual and electronic inspection through cave diving and submersible cameras, which revealed caves extending beneath the sinter deposits into the underlying rocks. Classic hypogenic cave morphologies are obvious within these features. The development of nearly all features inspected during this study is attributable to hypogene speleogenesis, but the morphologies of cavernous openings into the thermal features may be affected by multiple processes acting synchronously with hypogene speleogenesis. Many of the caverns appear to have formed as framework caves by the accumulation of material around vents, while others have formed by erosional processes such as hydrothermal explosion or collapse within the sinter deposits to reveal cavities below. This understanding of hydrothermal features as hypogenic karst groundwater systems presents new insights into the development and function of geysers and hot springs, as well as the need for management approaches that borrow from those of more typical karst systems.

NASH DRAW GROUNDWATER TRACE: PHASE ONE IMPLEMENTATION

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Abstract. Nash Draw is a karst valley approximately 29 kilometers east of Carlsbad, New Mexico, U.S.A. This 27 km long valley trends northeast from its low point in a salt playa. The primary karst rock type there is the Permian age Rustler formation resting conformably upon the Salado salt beds. The Rustler contains five distinct members alternating between gypsum and dolomite. The two dolomite members are aquifers. A third brine aquifer runs at the base of the Rustler formation on top of the Salado salt formation. During the early Pleistocene solutional processes began developing the karst valley known as Nash Draw. The apparent regional base level is the Pecos River which is separated from the lower end of Nash Draw by a narrow strip of land.

The earliest human use of Nash Draw was during the late Pleistocene, approximately ten thousand years ago. It is thought the area was popular because of the salt that could be harvested from naturally salty lake (Laguna Grande de la Sal) at the lower end of the karst valley.

Potash was discovered in the area in 1927 and mining began in 1931. Three mines began operation on the flanks of Nash Draw. The mine tailings discharge, which consists of salt (NaCl) and clay, has been dumped in the bottom of the karst valley. Since the mining operations began, the accumulation of salt on the surface is substantial. The tailings piles have covered numerous sinkholes.

The management question is whether salt from the tailings discharge ponds is entering the Pecos River. To answer this question and advance the further understanding of the groundwater flow in Nash Draw a ground water trace is being conduct. The trace is being initiated in phases. This presentation covers the first phase, which is tracing the tailings pond discharge.

Introduction. The karst processes occurring in Nash Draw were first described by Willis T. Lee in 1925. He referred to a process of solution and fill where by the bedrock composed of alternating gypsums and dolomites underlain by salt was dissolved and collapsed into the resulting voids (Lee 1925). The karst valley described is 29 kilometers east of Carlsbad, New Mexico (see Figure 1) and extends approximately 27 kilometers from north to south ranging from 5 to 19 kilometers wide. The playa exhibits approximately 200 feet of vertical relief. The primary geologic unit is the Permian aged Rustler Formation, which is composed of five members. At the top is the Forty Niner gypsum member followed by the Magenta dolomite. Below that lies the Tamarisk gypsum followed by the Culebra dolomite. The bottom member is the Los Medanos, which rests conformably on top of the Salado salt formation. There are three karst aquifers in Nash Draw. They are in the Magenta and Culebra dolomites and a brine aquifer at the base of the Los Medanos running on top of the Salado salt formation. At the lower end of Nash Draw are a series of lakes. Historically these were dry, with the exception of a pool in the largest playa called Laguna Grande de la Sal. It is generally accepted that the playas now contain the discharge from the potash refining. A narrow strip of land called Scoggin Flat separates the lower end of Nash Draw from the Pecos River.

Potash was discovered in the Nash Draw area in 1927 and mining began in 1931. Three of the potash mines have their operations in Nash Draw. The tailings consists of salt (NaCl) and clay, and have been disposed of on top of numerous sinkholes. Throughout the history of geologic and hydrologic studies in Nash Draw (Lee 1925, Robinson and Lang 1938, Hale, et al. 1954, Hendrickson and Jones 1952, Vine 1963, Geohydrology Associates, 1978, Bachman 1981, Powers, et al. 2006) there has been no definitive work which conclusively answers the question: Where does the water go? Literature disagrees as to whether the water from the lower lakes in Nash Draw enters the Pecos River. Water samples taken at Malaga Bend over a period of decades beginning in 1923 indicate that the river water is getting saltier. There is no information describing the sampling or analysis methods so the information can only be considered as a possible trend.

To test the hypothesis that water travels from Laguna Grande de la Sal to the Pecos River a groundwater trace has been initiated. The trace is being conducted in phases to better isolate the various parts of the Nash Draw hydrologic system. The overall goal is to begin assembling hydrologic data that will guide the development of a groundwater management strategy for Nash Draw.

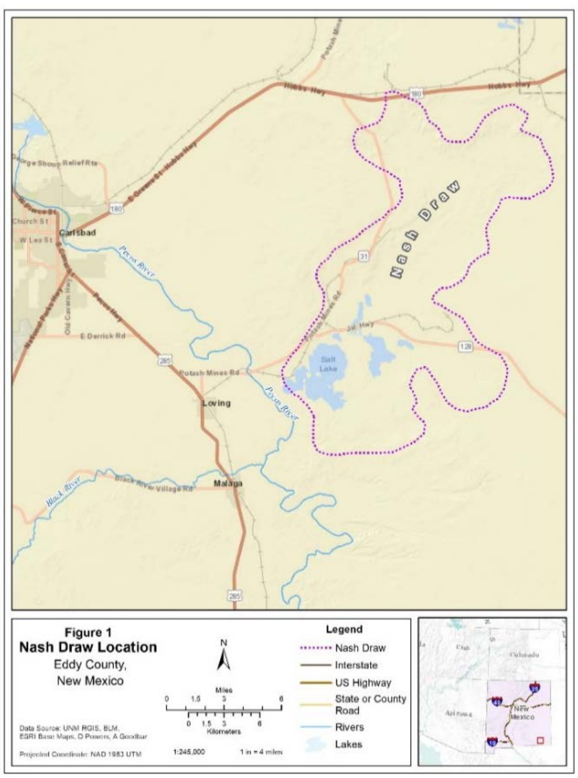

Figure 1
Nash Draw Location
Eddy County,
New Mexico

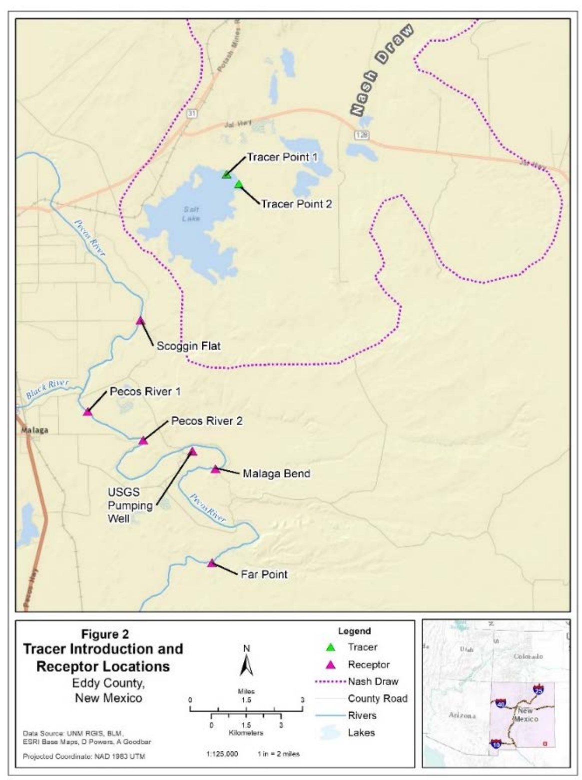

Figure 2
Tracer Introduction and
Receptor Locations
Eddy County,
New Mexico

The first phase is tracing the waters that feed into Laguna Grande de la Sal. Four of the seven lakes have been channelized to flow into Laguna Grande de la Sal, which lies closest to the Pecos River. The tracer was introduced into Laguna Grande de la Sal on August 18th, 2017. Later traces will move up gradient to determine what other flow paths may be present.

Environmental Factors. There are several environmental factors in the study area that may affect the tracer experiment. One of these factors is the pH of the water. Low or high pH can enhance sorption of the tracer onto mineral surfaces and make it less detectable. (Zhu 2005 Reference?) Some tracers have strong affinity to be adsorbed onto clay minerals, a potential problem in this area because most of the tailings from processing potash are salt and clay. Tracer behavior under exposure to Ultra Violet (UV) radiation is important because many florescent dyes are highly degradable in UV light, and the initial phase of the trace involves introducing the tracer to surface impoundments subject to high insolation. The salt content of the water is also an important factor because fluorescent intensities are reduced in high salinity solutions (Magal, et al. 2008). Much of the water in the Nash Draw study area is naturally salty. Naturally occurring salt in the brine aquifer is associated with the dissolution of the Salado at the base of the Rustler formation. Robinson and Lang (1938) place chloride levels near Malaga Bend at 154,800 ppm chloride, and 145,700 in Nash Draw at the southeast end of Laguna Grande de Sal. It is speculated that additional salt enters the system as runoff from the potash tailings and discharge from the processing of the ore (Goodbar and Goodbar 2014).

The Tracer. The tracer determined to be applicable in the Nash Draw environment is Sodium Naphthionate (Magal et al. 2008). This tracer can tolerate the harsh environmental conditions of the study area. The tracer is more precisely, 1 Naththylamine-4-sulfonic acid sodium salt hydrate, CAS Number 123333-48-2, Linear Formula $H_2NC_{10}H_6SO_3Na \cdot xH_2O$. The powdered dye is mixed at one pound per gallon of water. The lowest detection limit in water is 10 ppb with a positive detection limit of 50 ppb. A pH below 9 is needed for the optimal detection of Sodium Naphthionate (Bledsoe, Crawford Hydrology Lab., personal com. 2017). The pH was measured at the two introduction points prior to tracer introduction using a YSI data logger that had been calibrated at the factory before use. The pH at introduction point 1 was 7.3 and the pH for introduction point 2 was 7.48. Eighteen pounds of Sodium Naphthionate was introduced at two points in Laguna Grande de la Sal. One is where the decanted discharge from the Mosaic tailings pond is piped into the lagoon and the second is where the waters from four of the other lagoons have been channelized to flow into Laguna Grande de la Sal. (See Figure 2)

Tracer Receptors and Analysis. The tracer receptors are a combination of activated coconut charcoal and cotton sewn into nylon mesh tubes approximately 1 inch by 3 inches, (Figure 3). Sample analysis will be conducted by the Western Kentucky University (WKU), Crawford Hydrology Laboratory. The lab is capable of detecting levels of down to 10 ppb for Sodium Naphthionate.

Figure 3. Activated charcoal/cotton tracer receptor

Obtaining a Baseline. Six locations along the Pecos River were selected for pick-up points. Background receptors were left in place for two months then retrieved and sent to the Crawford Hydrology Lab and analyzed for Sodium Naphthionate, fluorescein, and rhodamine WT to check for the presence of the tracers to be used. The lab results for these background receptors showed none of the tracers tested for in the samples. A sampling frequency of one month is being used for the first six months then moving to every other month to allow the maximum amount of time for the experiment to run and for the tracer to accumulate in the receptors. The flow rates and residence times in the aquifers are unknown so the project duration is thought to allow an appropriate time for the tracer to reach the receptors.

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LIVING ON CRUMBLING KARST, 1879–2017, EUREKA SPRINGS, ARKANSAS

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Eureka Springs is sited upon a forested upland karst in the headwaters of East Leatherwood Creek in the southern Ozarks. The topography is rugged with ridges, deep ravines, and a Mississippian limestone scarp localizing numerous springs. The whole city is a recharge area divided into many patches with small springs. It is a crumbling karst characterized by shallow bedrock, patchy thick regolith, rockslides, colluvium/scree filled fans and hollows, losing streams, small caves, few sinkholes, small recharge areas, and many small or seasonal springs and seeps. Extensive cave systems and large springs are absent and deemed to be located at depths below the Devonian Chattanooga Shale aquitard and below the regional water table. The Springs Reservations, created in the late 1880s, wisely set buffer zones at the largest springs. The beauty of our town is inescapable, but the maintenance of yards, streets, and sewer and waterworks has a history of emergencies. The city has a population of 2,073, (down from 10,000 in 1890) but this may triple during tourism events and weekends. Therefore, the financial demands on infrastructure are high, as are the noted environmental challenges. Contamination of springs remains common due to the flashy hydrology in storm events and the aging wastewater infrastructure dating back to the 1880s. Steep slopes and steep streets, and losing steep hollows limit retention of runoff by the wonderful stone walls constructed to stabilize slopes. So, the small lot sizes and steep slopes make it difficult to maintain slope stability or install sufficient retention structures to mitigate storm events. An unprecedented grassroots coalition was awarded an EPA grant in 1979 for an exfiltration study to determine the sources and magnitude of contamination of springs. Despite this knowledge and some improvements, the city still requires renewed vision and better infrastructure management than is recognized or affordable.

BLANCHARD SPRINGS CAVERNS AND A BILLION POINTS OF LIGHT

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The Center for Advanced Spatial Technologies (CAST) and the Ozark-St. Francis National Forests entered into a cooperative agreement to do a complete 3D point cloud survey scan of all the visitor facilities and cave tour. Because the infrastructure of the Blanchard Visitor Information Center and Caverns was developed in the late 60's and early 70's, there is a need to look at infrastructure updates that look at safety, energy conservation, protection of geologic features, protection of threatened and endangered species, and the preservation of heritage sites. New technology available today allows for detailed mapping of the visitor center and the caverns so that appropriate updates can be planned. This mapping also helps resource professionals with research and modeling that will help with the preservation of this very unique site that is the home of threatened, endangered, and sensitive species.

ANALYZING THE RISK OF BEDROCK COLLAPSE SINKHOLES IN BOWLING GREEN, KENTUCKY

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Sinkholes occur throughout the state of Kentucky and particularly in the southcentral part, as indicated by the occurrence of the highest density of sinkholes in the state. The most common sinkhole-type in southcentral Kentucky is the cover collapse, which occurs in the soil or other loose material overlying soluble bedrock. Bedrock sinkhole collapses, which are considered rare, occur when the ceiling of a cave collapses, exposing the cave passage to the surface. On geologic time scales of cave formation and degradation, bedrock collapses are much more common as indicated by the 350 cave entrances in Warren County, Kentucky. However, Bowling Green, Kentucky, has seen two major bedrock collapse sinkholes within the past 16 years, as well as smaller bedrock collapses that have not received the same attention. In both cases, the bedrock collapses are associated with the development of human infrastructure. The purpose of this study was to determine the risk of bedrock collapse sinkholes as anthropogenically-induced geohazards in Bowling Green, Kentucky. Methods and data utilized included remote-sensing, cave and karst mapping, local geologic mapping, isopach mapping of overburden, and hydrogeologic information and data, all incorporated into a GIS. The results of the study showed that all recent bedrock collapses were associated with human infrastructure development. The GIS highlights areas that have the potential for bedrock collapses that would result in damage and loss of infrastructure.

KARST AQUIFERS PROTECTION: A SCIENTIFIC AND LEGISLATIVE CONUNDRUM

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[4] Professor Emeritus, University of Arkansas, Department of Geosciences, Fayetteville, AR, USA
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[6] AECOM, Warrenville, IL, USA
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The need for enhanced protection of karst aquifers is increasing on a yearly basis, because these valuable water resources face deterioration and over-exploitation worldwide. From the scientific perspective, enhancing karst aquifer protection through legislative mechanisms seems to be an unequivocal part of the solution, and this is often inhibited by financial restrictions. However, the challenges can extend beyond financial barriers. The example of vulnerability mapping of an area within the Big Creek basin in Newton County, Arkansas will help present the obstacles that policy makers could face while trying to develop a framework for protection and management of karst aquifers.

ATRAZINE TRANSPORT THROUGH A SOIL-EPIKARST SYSTEM

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Introduction. Agricultural production has impacted the land use and water quality of the highly-developed karst landscape/aquifer systems within Kentucky's Western Pennyroyal Region (WPR) (Figure 1). Gently dipping limestones of the Mississippian-aged Ste. Genevieve and St. Louis Formations have been modified through dissolution by flowing groundwater and the resulting high permeability aquifers allow contaminants to enter groundwater with relatively little attenuation. Within the WPR, land use associated with row crop and livestock production has contaminated groundwater with fecal bacteria, pesticides and nutrients (Currens 2002). Typical of many karst systems, surface drainage is almost wholly lacking within the plateau, as most precipitation directly infiltrates, moving

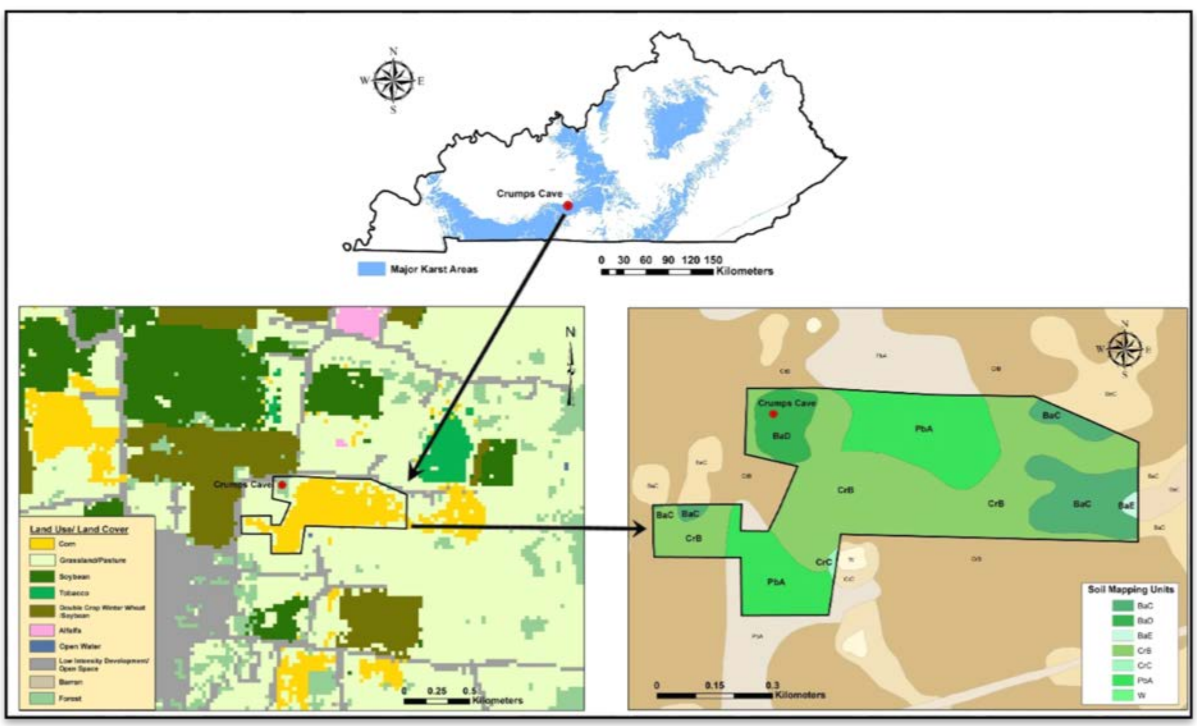

Figure 5. Map of Kentucky and the Western Pennyroyal Region, showing major karst areas, land-use/land cover near Crumps Cave, and soil series within the adjacent corn field and surrounding the cave.

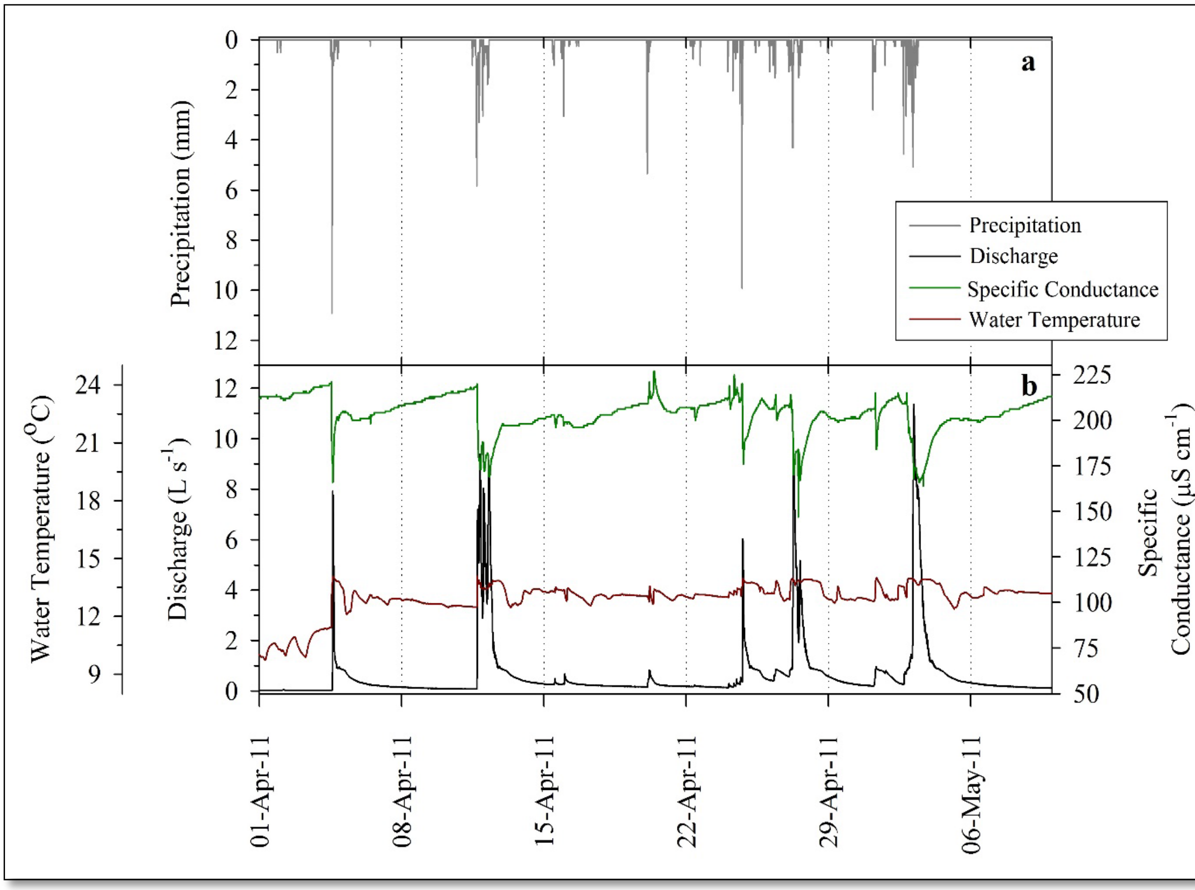

Figure 2 Instantaneous precipitation measured at Crumps Cave (a), and instantaneous discharge, specific conductance, and water temperature measured at WF-1 (b) from April 1 to May 15, 2011. All measurements were made at 10-minute intervals.

through the soil to the epikarst (soil-bedrock boundary) and then into the highly permeable limestone aquifer.

In this study, we investigated the transport of atrazine from field application to the epikarstic drainage system beneath a field with active row-crop farming. The primary objective was to use discharge and water chemistry in combination with concentrations of atrazine and two metabolites (DEA and DIA) to interpret herbicide transport through the soil column and into the epikarst drains. This research was designed to utilize the unique Crumps Cave field site to evaluate the fate and transport of atrazine within the soil and epikarst system beneath an actively farmed field. This site allowed for detailed observation of the subsurface behavior of atrazine directly tied to a single application.

Materials and Methods. The study site was Crumps Cave, a shallow autogenic drainage system with a recharge area of ~1 ha that contains two epikarst drains (WF-1 and WF-2). Crumps Cave is formed within the upper St Louis limestone located in Warren County Kentucky (37.0620833 N; 86.1977667 W). Water movement from the atrazine treated field travels laterally for ~200 m and vertically about 25 m below the land surface to reach the waterfall sampling sites within the cave. Land cover immediately above the cave is deciduous forest and grasses with the row crop field immediately to the south and east of the cave (Figure 1). Surface weather conditions adjacent to the field and above the cave were recorded every 10 minutes. Major soil series within the cropped field include the

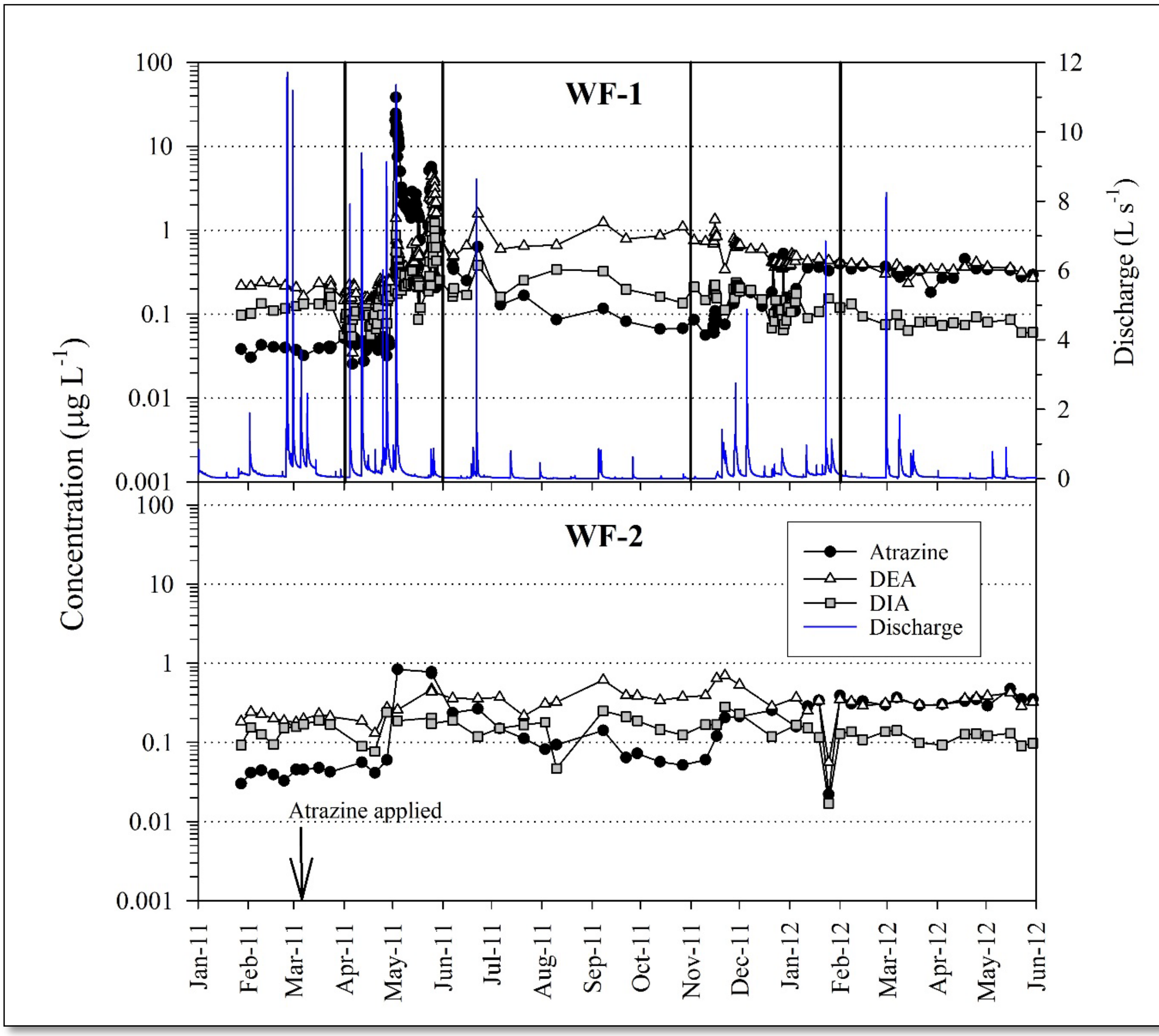

Figure 3. Concentrations of atrazine, DEA, and DIA at the WF-1 and WF-2 sites from January 2011 to May 2012. Vertical bars indicate dynamic transport time periods at WF-1.

Crider (2-6% slope) and Pembroke (0-2% slope) silt loams. These soils were formed from clayey residuum and occur on ridges in this karst upland setting. Soils extend to at least 2 m depth and are classified as well drained. Clay mineralogy is mixed and restrictive soil layers that impede root growth or vertical water movement are absent. Based on observation, atrazine was applied to the field on March 4, 2011.

Two epikarst drains within Crumps Cave were monitored for the presence of atrazine, DEA, and DIA from Jan 2011 to May 2012. A combination of grab and event-based samples were collected at the WF-1 site, while weekly grab samples were collected at the WF-2 site. Water stage, pH, specific conductance (SpC), and water temperature were measured every 10 minutes at WF-1 and discharge computed from the stage data. A total of 185 samples were collected at WF-1 and 51 samples at WF-2. Analysis of atrazine, DEA, and DIA in water was performed by C_{18} solid-phase extraction (SPE) followed by quantification with gas chromatography- mass spectrometry (GC/MS) using external calibration. Method detection limits were 0.002 µg L^{-1} for atrazine and DEA and 0.013 µg L^{-1} for DIA. Additional details about the analysis parameters and quality assurance samples were described by Lerch et al. (2015).

Using the atrazine and metabolite concentrations, the dealkylated metabolite to parent ratio (DMAR) was computed as, DMAR = ([DEA]+[DIA])/[Atrazine], where [DEA], [DIA], and [Atrazine] represent concentration (nmol L^{-1}). The DMAR provides a means of assessing movement of atrazine through soil and into groundwater (Adams and Thurman 1991). The underlying concept is that DMAR values >1 represent sufficient residence time of atrazine within the unsaturated soil zone where soil microbial activity converts it to DEA and DIA. Conversely, low DMAR values represent short or no residence time within the unsaturated zone and rapid transport of atrazine to groundwater aquifers.

Results and Discussion. Discharge, specific conductance, and water temperature at WF-1 all showed rapid responses to precipitation inputs (Figure 2). These data were typical of the quick response of discharge and water chemistry at WF-1 following precipitation events and indicated that transport of water from the surface through the soil profile and into the epikarst was extremely fast and very sensitive to precipitation inputs.

From Jan 2011 through May 2012, atrazine, DEA, and DIA were detected in 100% of the samples collected at WF-1 and WF-2 sites. Median atrazine concentrations were 0.181 µg L^{-1} at WF-1 and 0.153 µg L^{-1} at WF-2, but the maximum concentration at WF-1 was 38.5 µg L^{-1} while it was only 0.834 µg L^{-1} at WF-2. Atrazine concentrations at WF-1 exceeded the MCL in 12% of samples, but the maximum 60-d running average of 1.97 µg L^{-1} was below the recently proposed aquatic standard of 3.4 µg L^{-1} (USEPA 2016). At both sites, median DEA concentrations were greater than that of atrazine, and median DIA concentrations were nearly the same as atrazine. These data indicated that herbicide application on nearby cropped fields had a similar impact on the epikarst groundwater quality of both sites, but peak concentrations were attenuated at WF-2 compared to WF-1.

Atrazine, DEA, and DIA concentrations varied greatly over time, especially at WF-1, and the data reflected the transport of previously and recently applied atrazine (Figure 3). Newly applied atrazine did not appear in the epikarst drains until an event on May 2 2011, 58 days after application (Figure 3) when concentrations at WF-1 abruptly increased from 0.043 µg L^{-1} on April 29 to >20.0 µg L^{-1} on May 2 and peaked at 38.5 µg L^{-1} on May 3. From the application date to the early May event, 4 major discharge events occurred and over 2.2 million L of discharge were measured at WF-1, indicating relatively slow transport of atrazine through the soil profile. From Jun through Oct 2011, atrazine concentrations steadily declined while metabolite concentrations increased and were present at consistently greater levels than atrazine (Figure 3). From Nov 2011 until Jan 2012, atrazine concentrations progressively increased while metabolite concentrations decreased. All three compounds showed slow zero-order kinetic decreases in concentrations from Jan to May 2012. At the observed rates, it would take from 180 to 760 d before the compounds reached concentrations equal to their limits of detection. The WF-2 site showed the same general time trends as WF-1, but with greatly constrained peak concentrations of all three compounds (Figure 3).

Mass balance calculations indicated that the total load at WF-1 accounted for 0.7 to 1.7% of the atrazine applied within the recharge area. This relative atrazine load was within the range reported for edge-of-field studies (Ghidey et al. 2010; Capel et al. 2001) and for watershed-scale estimates (Lerch and Blanchard 2003; Lerch et al. 2011) in which the primary means of transport was by surface runoff. Thus, transport of atrazine and its metabolites to the epikarst drains was of a similar magnitude to that occurring by surface runoff in other agricultural areas of the Corn Belt. Except in May 2011, metabolites were the majority of the total load (i.e., atrazine plus metabolites) at WF-1, contributing 54 to 94% of the monthly loads. This was consistent with the DMAR data at both sites (average of 5.4 at WF-1 and 5.3 at WF-2), demonstrating that the metabolites were generally present in water at greater concentrations than the parent. The DMARs and the concentration data supported the hypothesis of atrazine slowly leaching through the soil column such that significant sorption and degradation occurred as opposed to fast atrazine transport to the epikarst aquifer and subsequent storage before eventual breakthrough to the cave.

Large areas of karst topography with intensive row cropping and high atrazine usage exist within portions of Kentucky, Illinois, Indiana, and Missouri. Results of this study suggest that atrazine loads to karst aquifers in these areas would be comparable to surface runoff losses that occur in other portions of the Corn Belt. In contrast to runoff, transport of atrazine and metabolites to epikarst drains occurs over years, resulting in consistent, long-term inputs to the groundwater aquifer. For karst aquifer systems, approaches that reduce herbicide inputs, such as use of low rate and less toxic herbicides and implementation of production systems with diverse crop rotations and cover crops, could immediately reduce the magnitude of offsite transport.

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EXAMINING THE HYDROGEOLOGY OF THE UNIQUE FENSTER-TYPE KARST IN THE WESTERN GREAT SMOKY MOUNTAINS, TENNESSEE

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In the western Great Smoky Mountains, the Ordovician Knox Group, a sequence of dolomite and limestone, is exposed in several carbonate fensters in the overlying Pre-Cambrian sandstones and phylllite. The fensters facilitate allogenic recharge, where streamflow from the surrounding insoluble strata sinks at the contact with the underlying Knox Group and results in karst development. Though the karst is limited in area and the overall number of caves is low, the resources are significant; Bull Cave is the deepest cave in Tennessee at 281 meters deep, two caves are major bat hibernacula, and Cades Cove, one of the most-visited sites in the National Park Service, is a large-scale karst feature. Recent work by the U.S. Geological Survey, beginning in 2017, seeks to improve understanding of the hydrologic behavior of the karst areas through hydrologic and geochemical monitoring, seepage runs, and dye tracing. Instrumentation was placed in the main stream in the lower portion of Bull Cave, a sump in White Oak Blowhole, and a karst wetland in Cades Cove. Additionally, a stream gage was installed along Abrams Creek, the main stream flowing through Cades Cove. Dye injections were conducted in Bull Cave, White Oak Blowhole, Rainbow Cave, and Kelly Ridge Cave, following equipment installation in the caves. Traces were performed to determine the flow paths of the cave streams and aid in delineating recharge areas for the springs located below the caves. From this work, at least four different spring basins are now known in Tuckaleechee Cove, the resurgence point for the caves in the study. The karst of the Smokies presents challenges due to the difficult nature of the caves, accessibility of the terrain, and complexities of the geologic setting. The study is being conducted in cooperation with Tennessee Wildlife Resources Agency, Great Smoky Mountain National Park, and the Tallassee Fund.

KARST HYDROLOGY AND GEOMORPHOLOGY OF THE UPPER-MISSISSIPPIAN PENNINGTON FORMATION IN SAVAGE GULF STATE NATURAL AREA, TENNESSEE

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Mississippian aged carbonates underlie the fluviokarst landscape of central Tennessee, where river incision has long been linked with the development of solutional caves on the Cumberland Plateau escarpment. Relatively little attention has been given to discontinuous karstification in the uppermost Mississippian unit, the Pennington Formation, wherein pockets of carbonate rock occur irregularly in a matrix of insoluble shale and sandstone. This research takes a geomorphological approach towards understanding speleogenesis and controls on drainage in the Pennington Formation, using Savage Gulf State Natural Area in Tennessee as a case study. Pennington caves, swallets, and karst springs in the upper reaches of Big Creek and its tributary, Firescald Creek, were surveyed and fluorescent dye tracer tests were conducted to establish connectivity between active parts of the hydrologic system. Discharge and saturation index of sinking and resurging waters were determined where possible. Data were digitized for spatial analysis in a GIS, which helps to visualize and contextualize the dynamic nature of drainage through the Pennington Formation. Karst processes in the Pennington Formation have implications not only for Cumberland Plateau geomorphology, but also for local ecology and biodiversity, water quality, and land management.

Preliminary analysis of water chemistry for select Northwest Arkansas caves

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In March 2017, the Northwest Arkansas Council predicted that within three years Northwest Arkansas will be one of the nation's 100 largest metropolitan statistical areas. Per day population growth as increased annually over the last five years. Growth from 2015 to 2016 increased by 1.7 person/day from 30.3 to 31.7 people/day, respectively. Effects from consistent urban growth on surface water and groundwater in Northwest Arkansas have been documented for the last three decades. Objectives of this study are to develop baseline water chemistry conditions for minimally developed cave systems as well as utilize historical data to evaluate changes through time in highly developed systems. Study sites were selected by ranking occurrence of Species of Greatest Conservation Need (SGCN) and accessibility. One year of monthly monitoring is complete for five sites in Benton County (Bear Hollow Cave, Blowing Springs Cave, Civil War Cave, Cave Springs Cave, Logan Cave), two sites in Madison County (Withrow Springs, War Eagle Creek Cave), and one site in Washington County (Elm Springs). At each site, nutrients and ions (chlorides, sulfates, total dissolved solids, and specific conductance) were analyzed monthly, while metals (total and suspended) were analyzed every other month. Average total phosphorus concentrations ranged from 0.03 mg/L at four of the eight sites to 0.11mg/L at Civil War Cave. Civil War Cave also has the highest average ion concentrations. Water temperature was higher at more urban sites (Cave Springs Cave and Civil War Cave), and water temperature at Cave Springs Cave is roughly 1 degree warmer than temperatures reported 15 years ago. Land use differences within recharge areas may explain some observed differences in water chemistry, and we will explore how land use changes may be influencing water quality changes over time.

ESTIMATING THE TRUE ELEVATION OF CAVE LAKES WITH SURFACE AND SUBSURFACE GEOLOGY AT JEWEL CAVE, SOUTH DAKOTA

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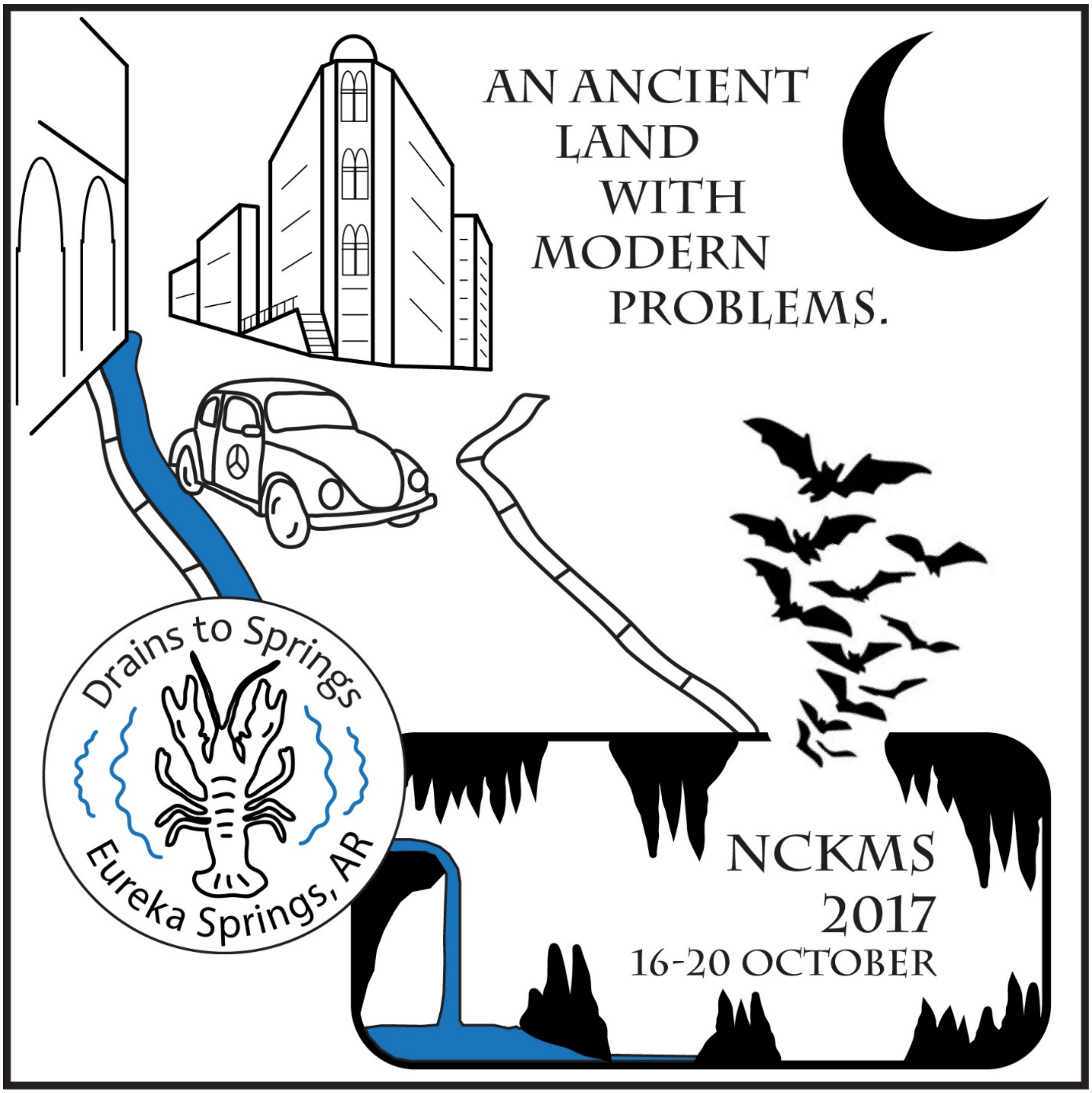
In 2014, volunteer cave explorers discovered the first underground “lakes” in Jewel Cave, located in the southern Black Hills of South Dakota. The lakes occur where cave passages intersect the regionally important Madison aquifer. These discoveries provide a unique opportunity to monitor variations in water level within the aquifer, which is especially important because Madison wells are quite sparse in the southern Hills. This new source of information can significantly improve USGS modeling of the aquifer, and establish natural trends within the system. However, the cave survey is not adequate for establishing the true elevation of the lakes. Even though internal loop closures and over 30 radiolocations have been used to control lateral errors, there is no way to confidently control vertical errors. There are thousands of stations between the lakes and the nearest certain vertical control. Therefore, the park is using the known thicknesses of geologic strata and cave levels to estimate the lake levels to within 20 feet (6 m). Although this is an approximation, it provides the best possible estimate, short of an actual observation well, and has shown that the cave survey has drifted more than 50 feet (15 m) lower than the actual depth.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