Kentucky Section-AIPG Professional Development Conference

Karst Hydrogeology and Geotechnical Applications in Kentucky

Hamilton Valley Research Station (Western KY University Cave Research Foundation)
321 Hamilton Valley Road, Cave City, KY 42127
Friday, April 29, 2016

Technical Session Schedule and Presentations

8:00 a.m. - 8:30 a.m.	**Registration and Check-in**
8:30 a.m. - 8:40 a.m.	**Welcome and Acknowledgements** Dr. Donnie Lumm, ECSI, LLC, Lexington, KY
8:40 a.m. – 9:20 a.m.	**All Caves are Not Created Equal** Dr. Pat Kambesis, Western KY University, Bowling Green, KY
9:20 a.m. – 10:00 a.m.	**Lineaments, Fracture Traces, and Fluid Flow Enhancement- An Overview of Applications!** Dr. James Howard, Consulting Geologist, Owensboro, KY
10:00 a.m. – 10:20 a.m.	***Break***
10:20 a.m. – 11:00 a.m.	**Karst and the Development of Appropriate Investigation, Monitoring, Cleanup, and Remediation Plans** Mr. David Jackson, Kentucky Division of Water, Frankfort, KY
11:00 a.m. – 11:40 a.m.	**Modern Geophysical Methods for Buried Karst and Geologic Hazard Evaluations** Mr. Bernd Rendermann, GHD Environmental, Franklin, TN
11:40 a.m. – 12:40 p.m.	***Lunch***
12:40 p.m. – 1:20 p.m.	**Pitfalls of Void Detection in Karst** Dr. Thomas Brackman, Western KY University, Bowling Green, KY
1:20 p.m. – 2:00 p.m.	**Geologic Hazards Common in Karst Areas** Mr. James Currens, Kentucky Geological Survey, Lexington, KY
2:00 p.m. – 2:20 p.m.	***Break***
2:20 p.m. – 2:50 p.m.	**Discovering Relationships Between Surface and Groundwater Velocities Through Dye Tracing in Fayette County, Kentucky** Ms. Laura Norris, Ms. Cassie Simpson, and Dr. Trent Garrison, Eastern KY University, Richmond, KY
2:50 p.m. – 3:30 p.m.	**Hydrogeology and Geomorphology of the South central Kentucky Karst: Why is the World's Longest Cave Here?** Dr. Christopher Groves, Western KY University, Bowling Green, KY
3:30 p.m. – 3:40 p.m.	**Summary Remarks** Mr. Mark Sweet, Shield Environmental Associates, Lexington, KY

All Caves are Not Created Equal

Kambesis, Pat. A, Hoffman Environmental Research Institute, Western Kentucky University, 1906 College Heights Blvd., #31066, Bowling Green, KY, 42101; pat.kambesis@wku.edu

This presentation will address the diversity (epigene, hypogene, and coastal) of cave/karst types in terms of morphology and speleogenesis. Epigene caves and karst form from recharge directly from the surface. Hypogene karst forms by water in which the aggressiveness has been produced at depth beneath the surface, independent of surface or soil CO_2 or other near-surface acid sources. Coastal karst forms by processes that are associated with sea level and coastal hydrology and dissolution. Pseudokarst will also be briefly reviewed since morphologies displayed by pseudokarst processes can be confused with karst features. The use of GIS to differentiate karst types will also be discussed.

Lineaments, Fracture Traces and Fluid Flow Enhancement – An Overview of Applications!

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Although photolineament and fracture trace analysis was first developed as a tool in petroleum exploration in the 1950's (Blanchet, 1957), application of the technology as an investigative tool for identifying groundwater anisotropies was pioneered by Lattman and Parizek (1964). Since that early work, the technology has proved valuable in numerous areas of geologic investigation. While most recent emphasis in the field has been placed on the glamorous, high-tech results from Landsat, SLAR and Multi-spectral imagery, in my personal experience, some of the most useful field applications have resulted from the use of low-level, 1:24,000 scale, high-contrast, black and white imagery widely available from the U.S. Geological Survey and U.S. Soils Conservation Service files.

This presentation is based on the results of over 40 years of personal experience and field research into the origins, geophysical and geomorphological characteristics of fracture traces and assessment of the effects and limitations of fracture traces on fluid flow. The presentation will discuss surface morphology and geophysical methods of ground-truthing fracture traces. Discussions on effectiveness and limitations of fracture trace technology are based on case histories in problem-solving in various groundwater, petroleum, mining and contaminant transport projects.

Although fracture traces are very useful in selection of drilling sites that maximize fluid extraction, the features also act as preferred pathways for contaminant migration, both laterally and vertically. They are often overlooked in site location evaluations for hazardous or waste materials disposal or storage. Vertical hydraulic connection greater than three hundred feet and lateral migration pathways greater than one mile have been identified for soluble and gaseous NAPL and DNAPL contaminants in bedrock settings impacted by fracture traces.

Zones of high-density fracturing in carbonate terrain are especially effective in enhancing solution and consequent groundwater production. Effectiveness of the feature is often modified by tectonic relationship/orientation, lithologic character of the carbonate body and long-term formation water chemistry modifications during production.

Karst and the Development of Appropriate Investigation, Monitoring, Cleanup, and Remediation Plans: Observations of a State Regulator

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Developing appropriate investigation, monitoring, cleanup and remediation plans in karst terrains requires thorough field investigations in order to meet the environmental performance standards, site requirements and design criteria of Kentucky's regulatory programs. Often plans which are submitted for these activities are wholly insufficient due to a lack of understanding of karst systems.

Regulatory requirements for major programs, such as Solid Waste, Hazardous Waste, Underground Storage Tanks, and Environmental Response, were developed based on granular flow models and are often imperfect for characterizing and monitoring karst systems. This leads to plans being developed that will inherently fail because the plans are based on the minimal design and monitoring requirements of the regulations.

Designing appropriate investigation, monitoring, cleanup and remediation plans for karst systems requires the consultant, the field investigator, and the regulator all to have a working knowledge of karst systems if design plans, investigations, monitoring, cleanup and remediation are to be successful and protective of human health, safety, and the environment. Thorough field reconnaissance utilizing karst inventory methods, and dye trace studies form the backbone for understanding karst systems. Utilizing spring discharge conditions to determine the type of karst system being characterized, seepage versus quick flow can assist with monitoring and remediation designs. Recently, the use of surface geophysics, borehole geophysics, and discrete fracture sampling has begun to be utilized to ensure that karst systems are being adequately characterized to ensure that monitoring, cleanup and remediation plans are designed to be successful when dealing with karst terrains.

Modern Geophysical Methods for Buried Karst and Geologic Hazard Evaluations

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During the past decade, advances in high speed computer aided data processing has allowed consultants to provide cost-effective geophysical data collection services, that in combination with subsurface exploration, has been instrumental in the identification and delineation of buried karst topography and the potential for sinkhole activity based on statutory definitions in the homeowners insurance industry. Mainly in Florida, where thick layers of homogeneous sands overlie clay that is “draped” over limestone, ground penetrating radar (GPR) has traditionally been the most reliable resource for the identification of buried karst topography. In northern states, including Tennessee and Kentucky, where alluvial clays predominate at the ground surface, electrical resistivity imaging (ERI) and multi-channel analysis of surface waves (MASW) have proven effective in the identification of geologic hazards where GPR has lost its usefulness.

This presentation discusses the uses and applications of ERI and MASW from a consultant’s standpoint who is focused on rapid data collection to expedite the project for additional subsurface exploration and reporting. Specifically, we will demonstrate common electrode and/or geophone array layouts employed around residential structures, graphically present data acquisition parameters, and discuss the benefits and limitations of each method based on site specific conditions.

Pitfalls of Void Detection in Karst

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The methods of near surface geophysics measure geophysical properties of the subsurface. Electrical properties of geological materials found in nature and especially in karst terrains can vary widely, and dissimilar materials may show the same resistive signature. A dry competent limestone will be very resistive while an air filled dry cave void will also have a high resistivity. The geophysical properties from a single method can result in a non-unique representation of the geological model. The use of multiple methods to determine additional properties to construct a unique model may be required. Working in concert with geologist, the geophysicist can aid in constructing a robust investigation plan to provide sufficient data to construct a geological model of the site. This presentation will examine case studies on non-uniqueness and propose multiple applications to acquire proper information to construct geological models.

Geologic Hazards Common in Karst Areas

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In Kentucky, about 55 percent of the state is underlain by rock with potential to develop karst, 38 percent of the state has sinkholes mapped on topographic maps, and 25 percent has highly developed karst. Sixty-seven percent of Kentucky residents live on karst. Karst-related geologic hazards include sinkhole flooding, sudden development of cover-collapse sinkholes, groundwater pollution, and radon accumulation in homes. Karst geohazards cost the Kentucky economy an estimated $20 to $130 million per year.

Sinkhole flooding affects private residences the most. Unlike a surface stream channel, the conduit draining a karst valley has a fixed cross-sectional area. An increase in flow requires a much greater increase in the stage (head) than an open channel would. A second cause is back flooding from a river or lake. Conduits can also become partially blocked by rock fall and flood debris. The Kentucky Department of Emergency Services estimates that the March 1997 flood cost more than $1 million in mitigation costs alone for a few counties in the central and western karst areas.

Cover-collapse is the sudden and unpredictable collapse of the unconsolidated material overlying karstic limestone. Cover-collapse damages buildings, roads, utility lines, and farm equipment. It has killed livestock, including thoroughbred horses, and has injured people. The development mechanisms of cover collapse have been understood for years, but predicting the precise location and timing of future collapse remains enigmatic.

Groundwater in karst aquifers is highly vulnerable to pollution because of direct and unfiltered recharge at swallow holes. The flow though conduits does little to settle or filter out dissolved or microorganism-size contaminants. Contaminants entrained in the flow travel much more rapidly than in a porous-media aquifer, which allows little time to plan a response to a spill. Mapping karst groundwater basins is vital for protecting the quality of water discharged from springs because it can help identify the area from which the contaminant came.

Discovering Relationships Between Surface and Groundwater Velocities Through Dye Tracing in Lexington, Fayette County, Kentucky

Norris, Laura A., Simpson, Cassie E., and Trent Garrison, Department of Geosciences, Eastern Kentucky University, 521 Lancaster Ave., Roark Building 103, Richmond, KY 40475; laura_norris5@mymail.eku.edu

In mature karst regions, water may flow through sizeable subsurface conduits, expediting flow to surficial karst springs. The Middle Ordovician karst of Lexington, Fayette County, Kentucky is an example of this type of environment, providing opportunities for geologists to study water flow.

We performed a dye trace in a single karst drainage basin in southwest Lexington, the primary objective of which was to compare surface-water velocities to groundwater velocities. Important locations within the study area include (1) the Campbell House sinkhole, (2) McConnell Springs, and (3) Preston's Cave Spring.

Data were collected using activated charcoal dye receptors (CDRs) and water grab samples. Eosine (Acid Red 87) was injected into the Campbell House sinkhole during high-flow conditions on September 30, 2015. CDRs and grab samples were collected downstream at McConnell Springs (1.9 km) and Preston's Cave Spring (3.2 km) over a period of two weeks. Sampling intervals for grab samples were every three hours the first day, and were gradually reduced to one sample per day. CDR samples were taken once per day and gradually reduced to every other day.

Dye appeared on October 1, 2015 (six hours after injection) at McConnell Springs, and peaked three hours later. Calculated conduit velocity between the Campbell House sinkhole and McConnell Springs was 5.95 cm/sec (0.133 mph), compared to 76 cm/sec (1.7 mph) for surface-water flow at McConnell Springs, making surface-water velocity approximately 13-times faster than conduit velocity. Although surface-water flow is faster than conduit flow, it is well-understood in karst geology that water flowing through karst conduits is often orders of magnitude faster than water flowing through granular material. This study is a contributory step in understanding conduit-flow velocities in the Lexington area during high-flow conditions.

Hydrogeology and Geomorphology of the South central Kentucky Karst: Why is the World's Longest Cave Here?

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There is a set of elements that must conspire together to form a karst landscape/aquifer system. An analysis of how these elements are expressed in a particular region can be used as a framework to understand why that system—at the surface and in the subsurface—has the characteristics that it does.

One of the world's classic karst landscapes lies between the Green and Barren Rivers of south central Kentucky. Here, a proverbial "perfect storm" of these elements has come together to form a great range of surface and subsurface landforms that include more mapped cave passages than any similar sized place on earth. The star of this is the Mammoth Cave System, which alone is more than 650 km in length and still being explored. The world's 9th and 54th longest caves are also here. Global significance has been codified with the designation of the area as a U.S. National Park and by the United Nations as both a World Heritage Site and International Biosphere Reserve.

What are these landscape forming elements and how are they expressed here? There are:

1. The ***lithologic*** element. Especially soluble rocks must be present, and here the Mississippian-aged Girkin, Ste. Genevieve, and upper St. Limestone formations consist of relatively pure calcium carbonate. The Big Clifty Sandstone and other non-carbonate rock layers overlie these, influencing both the hydrogeology and geomorphology.

2. The ***climatic*** element. There must be a solvent, and the area receives approximately 1,300 mm (51.2 in) of rain per year with a climate that supports abundant vegetation as a source of carbon dioxide.

3. The ***structural*** element. There must be a system of fractures that allows the solvent to get into, move through, and remove dissolved limestone from the aquifer framework. Here, the limestone dips gently to the northwest on the flank of the Cincinnati Arch, and bedding planes provide extensive proto-flow paths for subsurface karst development to have been established.

4. The ***topographic*** element. Water flows downhill, so the water getting into the karst system must do so at an elevation higher than where it will ultimately drain out of it. Thus, there must be relief in the landscape. Although the details depend on local conditions, most recharge enters the extensive sinkhole plain of the Pennyroyal Plateau, flows beneath the Mammoth Cave Plateau, and emerges at springs along a gorge of the Green River that has been cut into the plateau.

5. The ***historic*** element. Once these other requirements are satisfied, karst landscapes do not suddenly "pop out." It takes time for this to happen, and knowing the span of this time tells us what events have occurred during that period to shape the landscape's evolution. Mammoth Cave records a 3.5 million-year history that preserves records of biological, climatic, and human activities that have shaped south central Kentucky.